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D2.6 Final report on programme progress and KPIs

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Abstract

This deliverable highlights the known developments from the 5G PPP towards the 5G PPP KPIs in the second year of the 5G PPP. The assessments include:

- Refinements of the 5G KPI definitions considering the worldwide context on 5G
- Progress on reference test cases and measurement tools able to monitor the developments towards the performance KPI targets, to quantify the progress achieved, as a reference point for phase 2.
- Analysis of the progress towards the business KPIs, with some conclusions presented

Overall the work shows that the 5G PPP is performing well on nearly all KPIs as far as they can be assessed at this point in time, and is even over-performing on the private investments leveraging factor.

Document revision history

Version	Date	Description of change	List of contributor(s)
v0.1	02/10/2017	First complete draft version	D. Kennedy
v0.2	10/10/2017	Review and revision	U. Herzog

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

EXECUTIVE SUMMARY

In this deliverable we have again considered the 4 performance-, 3 business- and 5 societal KPIs defined in 5G PPP. The performance-related KPIs show significant development and understanding in the second year of the programme. Some work to analyse the progress towards the business KPIs has been done and some conclusions can also be presented for those. However, the progress towards societal KPIs remain challenging to determine as the 5G infrastructure, services and applications are not yet in commercial service.

This deliverable has, for the sake of readability, concentrated on the changes and developments that took place since Euro-5G's intermediate report on programme and KPI progress was released in Deliverable D2.4. Nevertheless, important baseline information has been included again with smaller updates as necessary. The main part of Deliverable D2.6 focuses on the performance-related work and progress achieved by the 5G PPP Phase 1 projects.

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Abbreviations

3GPP	Third Generation Partnership Project
5G PPP	5G Public Private Partnership
AIV	Air interface variant
BF	Beamforming
BMS	Broadcast Multicast Service
BS	Base station
CP	Control plane
CRAN	Centralized RAN
D2D	Device-to-device
DC	Dual connectivity
DL	Downlink
DRAN	Distributed RAN
E2E	End–to-end
eMBB	Enhanced mobile broadband
ETSI	European Telecommunication Standards Institute
FY	Financial Year
HARQ	Hybrid automatic repeat request
HetNet	Heterogeneous network
HO	Handover
HW	Hardware
IEEE	Institute of Electrical and Electronic Engineers
IETF	Internet Engineering Task Force
IMT-A	International Mobile Telecommunication-Advanced
InH	Indoor hotspot
IoT	Internet of things
IRTF	Internet Research Task Force
ISD	Inter-site distance
ITS	Intelligent Transport System
ITU	International Telecommunication Union
KPI	Key performance indicator
LoS	Line-of-sight
LTE	Long Term Evolution
LTE-A	LTE-Advanced
MBB	Mobile broadband
MCS	Modulation and coding scheme

MIMO	Multiple input multiple output
mMIMO	Massive MIMO
mMTC	Massive machine type communications
mmW	Millimetre wave
MTC	Machine-type communication
MU-MIMO	Multi user-MIMO
MWC	Mobile World Congress
NGMN	Next Generation Mobile Networks
NLoS	Non line-of-sight
NR	New Radio
PDU	Protocol Data Unit
PER	Packet error rate
QoE	Quality of experience
QoS	Quality of service
RACH	Random access channel
RAN	Radio access network
RAT	Radio access technology
RMa	Rural macro
RRM	Radio resource management
RTT	Round trip time
RX	Receiver
SINR	Signal to interference and noise ratio
SOTA	State-of-the-art
TCO	Total cost of ownership
TRxP	Transmission reception point
TTI	Transmission time interval
TX	Transmitter
UC	Use case
UDN	Ultra-dense network
UE	User equipment
UL	Uplink
uMTC	Ultra-reliable MTC
UP	User plane
URLLC	Ultra-reliable and low-latency communications
V2X	Vehicle-to-anything
xMBB	Extreme MBB

1 Introduction

D2.6 “Final report on programme progress and KPIs” is the year 2 report on 5G PPP programme progress overseeing and KPIs monitoring activities performed by Euro-5G.

Following Euro-5G objectives, this deliverable aims at:

- Refinements of the 5G PPP KPIs definition considering the worldwide context of 5G
- Progress on reference test cases and measurement tools able to monitor the developments towards the KPI targets
- To quantify the progress achieved, especially on performance KPIs, as a reference point for phase 2.

It is composed of 7 sections:

- Section 1 is an introduction;
- Section 2 briefly repeats the requirements and performance targets that have been defined globally for 5G technologies or services with a focus on ITU and 3GPP
- Section 3 reasserts the definition of KPIs in 5G PPP and proposes some proxies to monitor in an easier manner some KPIs which cannot be measured before 2020
- Section 4 presents the results of the coordination done between projects on use cases and test scenarios towards a common performance progress measurement plan
- Section 5 details the achievements of 5G PPP Phase 1 projects regarding performance-related KPIs
- Section 6 details the Euro-5G analysis regarding business-related KPIs
- Section 7 summarises the conclusions.

2 What are the worldwide 5G targets?

The objective of this section is to give an overview of the evolution of 5G targets in the world.

2.1 What is really 5G?

There is a worldwide effort on the further characterization of 5G use cases and related requirements (e.g. ITU, 3GPP, NGMN...) which has accelerated in 2015.

In early 2015, operators have kick started this activity with a vision paper from NGMN[2] which identified the following vision for 5G:

"5G is an end-to-end ecosystem to enable a fully mobile and connected society. It empowers value creation towards customers and partners, through existing and emerging use cases, delivered with consistent experience, and enabled by sustainable business models."

and the following 8 use case families in early 2015:

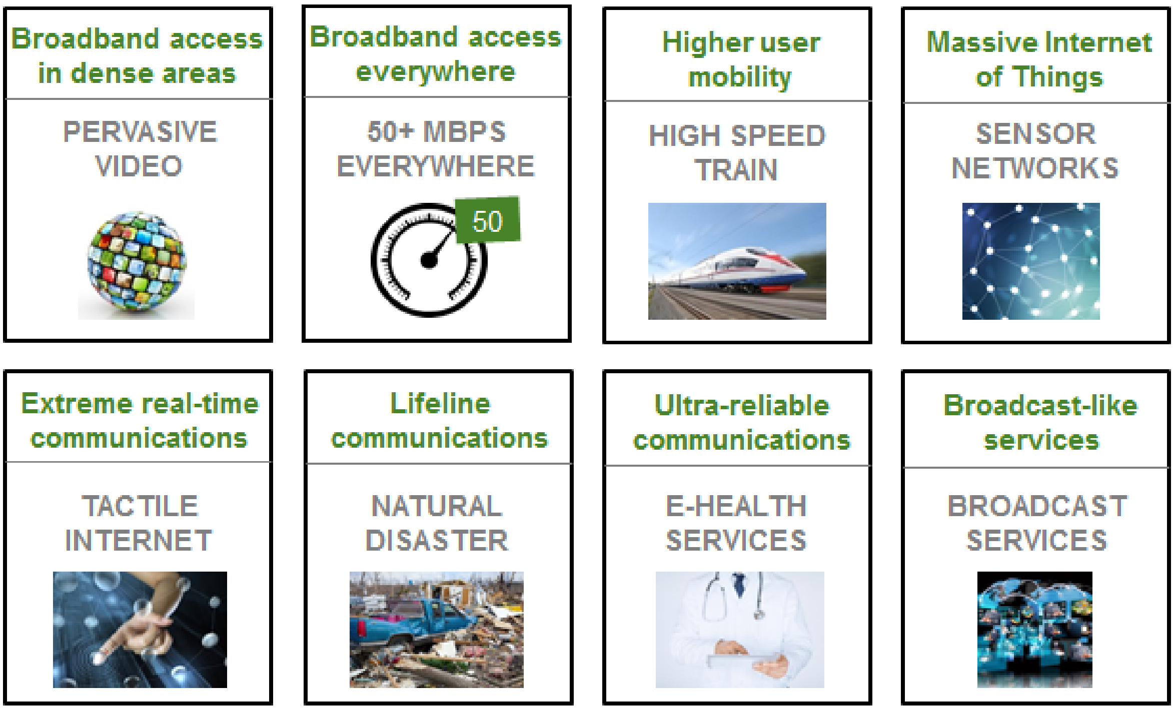

Figure 1: 5G use cases families

This definition is still valid and can keep being considered as a reference.

The 5G Infrastructure Public Private Partnership (PPP) has also progressed on the identification of uses cases and requirements with a clear effort on verticals markets, e.g. the five white papers addressing Factories, Automotive, eHealth, Energy as well as Media and Entertainment[3].

We will detail further in the following subsections the visions which were developed by ITU and 3GPP, the main standardisation bodies for 5G.

[2] https://www.ngmn.org/uploads/media/NGMN_5G_White_Paper_V1_0.pdf

[3] These whitepapers on vertical industries are available on 5G PPP website here: https://5g-ppp.eu/white-papers/.

2.2 KPIs at the ITU level

Recommendation ITU-R M.2083 defines eight key “Capabilities for IMT-2020”, which form a basis for the 13 technical performance requirements released by ITU WP 5D in February 2017 in their DRAFT NEW REPORT ITU-R M. [IMT-2020.TECH PERF REQ] “Minimum requirements related to technical performance for IMT-2020 radio interface(s)”[4].

The key minimum technical performance requirements defined in that document are for the purpose of consistent definition, specification, and evaluation of the candidate IMT-2020 radio interface technologies (RITs)/Set of radio interface technologies (SRIT) in conjunction with the development of ITU-R Recommendations and Reports, such as the detailed specifications of IMT-2020. The intent of these requirements is to ensure that IMT-2020 technologies are able to fulfil the objectives of IMT-2020 and to set a specific level of performance that each proposed RIT/SRIT needs to achieve in order to be considered by ITU-R for IMT-2020.

Type of performance requirement	Evaluation planned for usage scenario	KPI (minimum requirement)
Peak data rate	eMBB	Downlink peak data rate: 20 Gbit/s. Uplink peak data rate: 10 Gbit/s.
Peak spectral efficiency	eMBB	Downlink peak spectral efficiency: 30 bit/s/Hz. Uplink peak spectral efficiency: 15 bit/s/Hz.
User experienced data rate	eMBB	Downlink user experienced data rate: 100 Mbit/s. Uplink user experienced data rate: 50 Mbit/s.
5th percentile user spectral efficiency	eMBB	Indoor hotspot: DL: 0.3 / UL: 0.21 Dense Urban: DL: 0.225 / UL: 0.15 Rural: DL: 0.12 / UL: 0.045 (all figures in bit/s/Hz)
Average spectral efficiency	eMBB	Indoor hotspot: DL: 9 / UL: 6.75 Dense Urban: DL: 7.8 / UL: 5.4 Rural: DL: 3.3 / UL: 1.6 (all figures in bit/s/Hz/TRxP)
Area traffic capacity	eMBB	Downlink: 10 Mbit/s/m^2 in the Indoor Hotspot – eMBB test environment.
User plane latency	eMBB and URLLC	4 ms for eMBB 1 ms for URLLC
Control plane latency	eMBB and URLLC	20 ms (10 ms encouraged)

[4] https://www.itu.int/md/R15-SG05-C-0040/en

Connection density	mMTC	1 000 000 devices per km^2
Energy efficiency	eMBB	a) Efficient data transmission in a loaded case: demonstrated by the average spectral efficiency b) Low energy consumption when there is no data: should support a high sleep ratio and long sleep duration
Reliability	URLLC	1-10^{-5} success probability of transmitting a layer 2 PDU of 32 bytes within 1 ms in channel quality of coverage edge for Urban Macro-URLLC test environment, assuming small application data
Mobility	eMBB	Indoor hotspot: Stationary, Pedestrian* Dense Urban: Stationary, Pedestrian, Vehicular (up to 30 km/h)* Rural: Pedestrian, Vehicular, High speed vehicular (up to 500 km/h)* **Traffic channel link data rates normalized by bandwidth are also defined but not included here*
Mobility interruption time	eMBB and URLLC	0 ms
(maximum aggregated system) Bandwidth	IMT-2020	at least 100 MHz up to 1 GHz for operation in higher frequency bands (e.g. above 6 GHz).

Table 1: 5G performance requirements of ITU

2.3 KPIs at the 3GPP level

A study has been done at 3GPP SA level about 5G service requirements. The objective was to develop high-level use cases and identify the related high-level potential requirements to enable 3GPP network operators to support the needs of new services and markets.

74 Use Cases have been identified in the study on New Services and Markets Technology Enablers (FS_SMARTER) [TR 22.891].

4 families of use cases have been identified – still valid at the time of preparing this Deliverable:

- eMBB - Enhance mobile broadband which can be decomposed in 5 categories,
  - High Data Rates : This family focuses on identifying key scenarios from which eMBB primary data rate requirements for peak, experienced, downlink, uplink, etc. data rates can be derived, as well as associated requirements pertaining to latency when applicable with UEs relative speed to ground up to 10 km/h (pedestrian).
  - Higher Density: This family covers scenarios with system requirement for the transport of high volume of data traffic per area (traffic density) or transport of data

for high number of connections (devices density or connection density) with UEs relative speed to ground up to 60 km/h (pedestrian or users moving on urban vehicle).

  - Deployment and Coverage: This family covers scenarios with system requirement considering the deployment and coverage scenario e.g. indoor/outdoor, local area connectivity, wide area connectivity, with UEs relative speed to ground up to [120] km/h.
  - Higher User Mobility: This family focuses on identifying key scenarios from which eMBB mobility requirements can be derived, with UEs relative speed to ground up to 1000 km/h.
  - Devices with highly variable data rates: This family focuses on identifying key scenarios from which eMBB requirements can be derived, for UEs having multiple applications which exchange small amount of data and large amount of data.

- CC - Critical communication which can be decomposed in 6 categories,
  - Very low latency: Characterized by a very high system requirement for latency. It is essential to carry the messages very quickly between the sender and receiver (e.g. tactile internet).
  - Mission critical services: Communications that are critical and need a higher priority over other communications in the networks.
  - Higher reliability and lower latency: Characterized by a high system requirement for reliability and latency. In most cases the data rates are moderate, and what matters most is that the messages are transmitted quickly and reliably (Industrial control systems, Mobile Health Care, Real time control of vehicles, road traffic, accident prevention, Wide area monitoring and control systems for smart grids, Speech, audio and video in virtual and augmented reality…).
  - Higher availability: One typical area where this type of communication is needed is when the traditional cellular network is congested or damaged, or when its coverage is not wide enough.
  - Higher reliability, higher availability and lower latency: Characterized by a high system requirement for reliability, availability, and latency. In most cases the data rates are moderate, and what matters most is that the messages are transmitted quickly and reliably, and that the coverage is sufficiently wide.
  - Higher accuracy positioning: High positioning accuracy includes requirements that the location information is acquired quickly, is reliable, and is available.
- mIoT - Massive Internet of Things which covers the following aspects,
  - Operational aspects (lightweight device configuration, variable data size, Internet of Things security, farm machinery and leasing, one user with multiple devices, one device with multiple users, connection support by service provider, communication between devices with multi-vendors).
  - Connectivity aspects (device in direct 3GPP connection mode, in indirect 3GPP connection mode, in indirect 3GPP connection mode in the roaming case, in direct device connection mode, service continuity).
  - Resource efficiency aspects (mobility management, variable data size, discovery mechanisms…).
- NO - Network operation which covers flexibility in terms of mobility and performance envelope, scalability, network slicing, network capability exposure, broadcast, efficient content delivery, self-backhauling, multiple access support, migration, interworking and security.

An overview of the corresponding requirements can be found below.

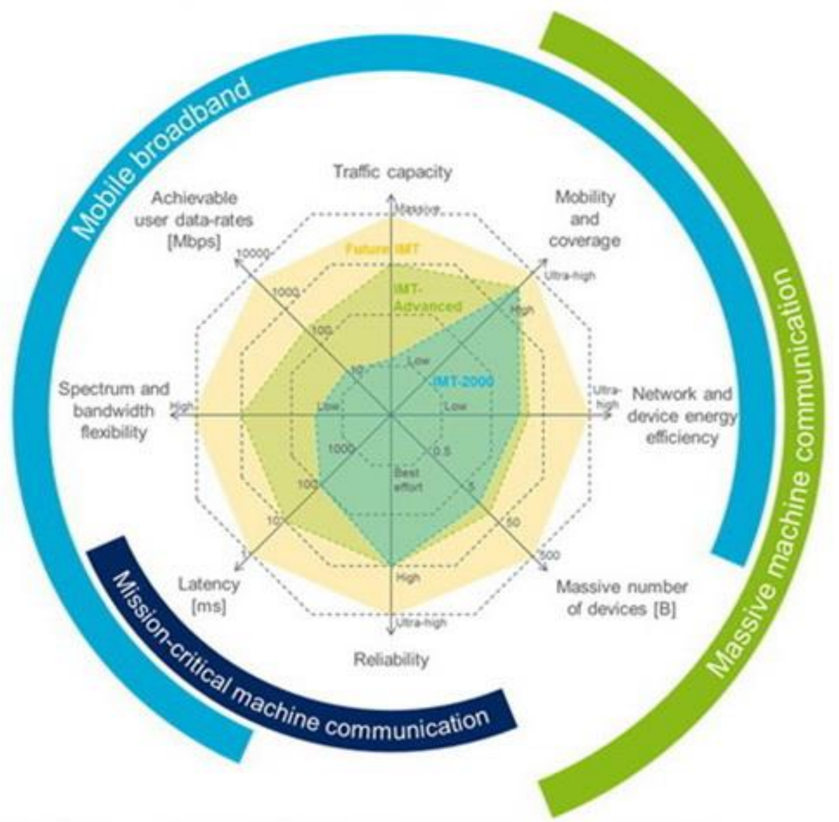

Figure 2: 3GPP SA requirements spider diagram

2.4 Conclusion

There is globally a large convergence on 5G targets in the world. There are divergences on the actual figures of the KPIs to be reached but globally the order of magnitude is the same.

However, the energy efficiency KPI is not so well defined. ITU, originally recommending an improvement of x100, has not defined a clear minimum requirement. Instead, it only refers to the *average spectral efficiency* criteria to represent energy efficiency in the active state, while a *Low energy consumption when there is no data* is stated as the target and recommending to support a high sleep ratio and long sleep duration. Likewise, 3GPP is very vague too (from middle to ultra-high efficiency).

Resilience, security and privacy are seen as important by all stakeholders but there is no real description of the way to measure them. ITU has defined a criteria at least for *Reliability*.

In the same vain, end-to-end services aspects such as creation time, scale-up, scale-down, capabilities exposure and so forth are explored only very superficially by the different 5G fora.

3 5G PPP Key Performance Indicators description

The objective of this section is to refine the 5G PPP KPIs definition.

3.1 KPIs in the PPP contract

There are 3 KPIs related to business aspects:

- B1. Leverage effect of EU research and innovation funding in terms of private investment in R&D for 5G systems in the order of 5 to 10 times;
- B2. Target SME participation under this initiative commensurate with an allocation of 20% of the total public funding;
- B3. Reach a global market share for 5G equipment & services delivered by European headquartered ICT companies at, or above, the reported 2011 level of 43% global market share in communication infrastructure.

There are 5 KPIs related to societal aspects:

- S1. Enabling advanced user controlled privacy
- S2. Reduction of energy consumption per service up to 90% (as compared to 2010)
- S3. European availability of a competitive industrial offer for 5G systems and technologies
- S4. Stimulation of new economically-viable services of high societal value like U-HDTV and M2M applications
- S5. Establishment and availability of 5G skills development curricula (in partnership with the EIT)

There are 4 performance KPIs:

- P1. Providing 1000 times higher wireless area capacity and more varied service capabilities compared to 2010
- P2. Reducing the average service creation time cycle from 90 hours to 90 minutes
- P3. Facilitating very dense deployments of wireless communication links to connect over 7 trillion wireless devices serving over 7 billion people
- P4. Creating a secure, reliable and dependable internet with a "zero perceived" downtime for services provision

3.2 Refinement of KPIs definition

3.2.1 Business related KPIs

- B1. Leverage effect of EU research and innovation funding in terms of private investment in R&D for 5G systems in the order of 5 to 10 times

This KPI is rather difficult to assess. The first comment that we can make is that the refection on this KPI covers a couple of years. Indeed, investment in collaborative research now can be leveraged in very high investment in telecom infrastructures to support 5G services in 5 to 10 years from now. Indeed, telecom technology adoption follows the famous S curve with limited investment at the beginning and a faster pace when the first cities are covered by the new technology.

The methodology we propose to measure and monitor this KPI is based upon gathering the published public figures from annual reports for worldwide R&D expenses in the ICT sector. Then we need to define which proportion of the R&D spends of the ICT industry is 5G related. The easiest way to proceed to define this value is to issue a poll among industry players (including: equipment manufacturers, mobile network operators, test equipment manufacturers and device manufacturers, and chipset manufacturers). The proportions of 5G versus the total telecom R&D expenses will increase as 5G moves into full standardisation, development and production over the next few years. In order to identify an investment value specific for Europe, Euro-5G used a representative set of European key ICT players (Ericsson, Nokia, Huawei, Samsung, DT, Orange, TIM, Telefonica, Telenor, Intel, Sequans) which are contributing to 5G PPP programme. We propose to use the same set of players for further iterations.

- B2. Target SME participation under this initiative commensurate with an allocation of 20% of the total public funding

The measurement of this KPI is rather straightforward and is a direct output of the selections of projects made by the European Commission for 5G PPP calls. One has to consider that it is probable that we will increase the participation of SMEs as we are approaching to market products. Indeed, it is difficult for many SMEs to support multiple year research programmes without any revenue stream except public funding.

- B3. Reach a global market share for 5G equipment & services delivered by European headquartered ICT companies at, or above, the reported 2011 level of 43% global market share in communication infrastructure

This KPI is very difficult to measure and monitor before 2020 when the market for 5G equipment will really start. As an indirect measurement, we could use the share of European manufacturers in 5G trials planned in 2018 in order to monitor progress before 2020. We could also count the number of proof of concepts developed and disseminated by 5G PPP projects.

Another indirect measurement for this KPI is the importance of joint contributions to standardisation bodies. Indeed, these contributions are direct outputs of 5G PPP projects and are helping the private side to coordinate on the products and services to invest in and to position their technologies and know-how in the worldwide landscape. This importance can be looked at in terms of patent portfolio for European players and number of joint contributions in standardisation bodies.

3.2.2 Societal KPIs

- S1. Enabling advanced user controlled privacy

Two projects are particularly focused on this KPI in 5G PPP Phase 1: 5G-ENSURE and CHARISMA. They have defined three main categories of enablers which need to be delivered to fulfil this very important KPI:

- anonymization and un-trackability services to avoid the unwanted propagation of mobile network, device or localization identifiers
- privacy policy compliance engines working also at the application and device layer
- tenant isolation mechanisms to fully benefit from network slices without opening any security backdoor

We propose to monitor the existence and richness of these enablers to follow up on this KPI.

- S2. Reduction of energy consumption per service up to 90% (as compared to 2010)

From section 2, we can clearly see that this KPI is the most controversial in the world with different targets depending on the standardization bodies and measurement processes. Despite our efforts, we have not been able to converge on a single way to measure energy consumption in the various projects nor to find a proper reference for 2010 energy consumption. The CSA has proposed to reuse the tool machinery developed by GreenTouch (https://s3-us-west-2.amazonaws.com/belllabs-microsite-greentouch/index.html) consortium but we have not seen a frank adoption of this methodology by 5G PPP projects. As a result, for the moment we will ensure a monitoring of this KPI through various proxies: spectrum efficiency, mechanisms to activate cells only when necessary, specific protocols to decrease the consumption of connected objects, and hardware components consumption reduction.

- S3. European availability of a competitive industrial offer for 5G systems and technologies

This KPI is very close to B3 so we can reuse the proposed approach for B3 to monitor this KPI.

In addition, we could add in the monitoring process for this KPI aspects related to the existence and large coverage of a European infrastructure to deliver 5G services. From that perspective we could start from a very accurate knowledge on 5G technologies (realistic and quantified assessments of the maturity and performances of the different technological components) so as to estimate the total cost of ownership and rollout for different coverage targets for operators. Depending on the result, we could estimate the possible scenarios based on the perspective on revenue streams and regulatory evolutions in Europe.

Another important aspect for operators is to ensure that 5G technologies will serve the services ambitions of European operators in terms of capabilities. Indeed, the interests might be different depending on the regions in the world. European operators need to find business growth in the B2B market segment and in particular with partners in the vertical industries which are very strong in Europe (industry, energy…).

- S4. Stimulation of new economically-viable services of high societal value like U-HDTV and M2M applications

Compared to the beginning of the cPPP, the vision on future services has largely evolved and has been disseminated thanks to the Vision & Societal Challenges Working Group[5]. As a result, UHDTV and M2M maybe not the best services for 5G target. So we should reorient this KPI towards the stimulation of services for vertical industries in Europe. In particular, we should estimate the impact of 5G enabled services on efficiency and worldwide competitiveness in vertical industries (e.g. cost of renewables compared to traditional energy sources for energy…).

- S5. Establishment and availability of 5G skills development curricula (in partnership with the EIT)

We have not managed to engage with the EIT on this aspect. So we propose to focus our target on the establishment of curricula dedicated to 5G in Europe in order to increase skills in the domain. We propose to monitor this KPI by counting the number of available master degrees and other curricula in European universities as well as summer schools.

3.2.3 Performance KPIs

- P1. Providing 1000 times higher wireless area capacity and more varied service capabilities compared to 2010

We propose to translate this generic KPI in 2 distinct KPIs inspired from ITU, 3GPP and projects reflexions:

- absorb 1 TB/s of traffic in a smart office or high speed train (corresponding to 10 TB/s/km² of wireless area capacity)
- reach a peak user data rate between 1 and 10 GB/s for specific deployment scenarios and use cases

- P2. Reducing the average service creation time cycle from 90 hours to 90 minutes

This KPI is rather difficult to measure since service creation time vary a lot already today depending on required services. For example, a SIM card activation can take a few hours allowing a new consumer to connect to the Internet very rapidly. On the opposite side, a corporate VPN can take several weeks to be fully activated because some fibres and physical equipment need to be installed on customer premises or within local exchanges.

As a result, we propose to monitor the following parameters:

- level of automation of service related processes (service fulfilment, service assurance, service negotiations …)

[5] https://5g-ppp.eu/wp-content/uploads/2016/02/BROCHURE_5PPP_BAT2_PL.pdf

  - existence and range of an autonomic network management framework including the capability to reallocate resources very rapidly between services and users
  - usage of Open Source, SDKs and DevOps to facilitate and speed up service developments

- P3. Facilitating very dense deployments of wireless communication links to connect over 7 trillion wireless devices serving over 7 billion people

We propose to translate this generic KPI in 2 distinct KPIs inspired from ITU, 3GPP and projects reflexions:

  - handle between 10.000 and 1.000.000 devices per km² for specific deployment scenarios and use cases
  - facilitate (technically and economically) the deployment and operation of a big number of small cells (tens of sites per km²)

- P4. Creating a secure, reliable and dependable internet with a "zero perceived" downtime for services provision

We propose to translate this generic KPI in 3 distinct KPIs inspired from ITU, 3GPP and projects reflexions:

  - provide a latency between 1 and 10 ms depending on deployment scenarios and use cases (1 ms being for the air interface link)
  - reach a reliability > 99% (meaning that a packet reaches the destination in the allowed latency budget in 99% of the cases) and even close to 99,999% for specific deployment scenarios and use cases
  - reach an availability rate > 99% (meaning that the user equipment is covered by a 5G service more than 99% of the time of usages) for specific deployment scenarios and use cases

The security and privacy aspects are not easy to quantify so we will provide a qualitative monitoring of these aspects.

4 What are the tests which will show the achievement of 5G PPP performance KPIs?

This section will present reference test cases able to demonstrate the fulfilment of the KPI targets. It is based on METIS II cross project deliverable entitled "5G PPP use cases and performance evaluation models". We focus here only on the 3 of the performance KPIs (P1, P3 and P4) plus the energy efficiency KPI and we do not consider other societal KPIs or business KPIs.

In order to quantify how certain technical solutions would affect 5G PPP KPIs, specific evaluation metrics are needed. This section provides basic info on how to evaluate them through inspection, analysis or simulation.

- In case of evaluation through inspection the evaluation is based on statements
- In case of analytical procedure, the evaluation is to be based on calculations using the technical information provided by the technology component owner (methodology, algorithm, module or protocol that enables features of the 5G system is a technology component or enabler)
- Evaluations through simulations contain both system level simulations and link level simulations although it is expected that majority of solutions will be assessed using system level evaluation.

During the first year of 5G PPP programme, METIS II organized a joint activity between 5GPPP Phase 1 projects to share use cases, requirements, deployment scenarios and performance assessment methodologies between projects. The following table details some 5G characteristics and their assessment method as defined by this cross project activity:

Inspection (yes/no):	Analysis (calculation)	Simulations:
• Bandwidth and channel bandwidth scalability • Deployment in IMT bands • Operations above 6 GHz • Spectrum flexibility • Inter-system handover • Support for wide range of services	• Control plane latency • User plane latency • mMTC device energy consumption • Inter-system HO interruption time • Mobility interruption time • Peak data rate	• Experienced user throughput (bursty traffic) • Traffic volume density (bursty traffic) • Capacity (full buffer) • E2E latency • Reliability • mMTC device density • RAN energy efficiency • Supported velocity

Table 2: Assessment methodologies

For analysis, the cross project deliverable details the required steps which need to be taken into account for each quantity. For example, for user plane latency, 5 steps have been defined:

- Transmitter processing delay
- Frame alignment
- Synchronization
- Number of TTIs used for data packet transmission (includes UE scheduling request and access grant reception)
- HARQ retransmission
- Receiver processing delay

METIS II cross project activity went a step further on the performance assessment by simulations. This activity defined 4 synthetic deployment scenarios for 5G:

- indoor hotspot
- urban macro
- outdoor small cells
- rural macro and long distance

For each of these synthetic deployment scenarios, range of configurations covering all 5G PPP use cases were described for base station layout (hexagonal…), inter-site distance, antenna height, number of antennas elements & ports, antenna gain, transmit power, frequencies, and carrier bandwidth.

All use cases from 5G PPP Phase 1 projects were also reviewed to classify them along these 4 synthetic deployment scenarios and to define the following test parameters: number of user equipment per area, number of user equipment antenna elements and RF chains, user equipment height and antenna gain, maximum power, minimum distance between user equipment and base station, indoor / outdoor ratio, channel model, traffic and mobility models.

With this full set of parameters, each use case can be tested in similar conditions by different projects or with different technology settings to measure the impact of various architectural concepts or technology components developed within 5G PPP Phase 1 programme. These simulations and measurements will be conducted during the second year of the programme.

Point of Concern: The METIS-II continuation proposal for Phase 2 was not successful and, as this deliverable is being prepared, it is not clear which project will take over this activity if any. The To-Euro-5G project will consider how this work can be continued in phase 2.

5 KPI progress achieved so far

This section is based on the collaborative document produced by the projects through the Technology Board. It provides an overview of the use cases and models that were developed for an early evaluation of different 5G radio access network concepts originating from various 5G Public-Private Partnership (5G PPP) phase 1 projects. It covers 5G scenarios, definitions of key performance indicators (KPIs) and models (e.g., of wireless channel, traffic or user's mobility), as well as corresponding assessment results. Developed use case families are mapped to a corresponding business cases identified in vertical industries. Additionally, performance evaluation approaches are compared with the latest version of performance evaluation framework proposed in Third Generation Partnership Project (3GPP).

The creation of this work was facilitated by the Euro-5G project and it assembles the inputs received from the phase 1 5G PPP projects with a strong focus on the progress on the KPIs in the radio access domain. As such it contains:

- An overview on deployment and operational use cases being considered
- Renewal of key performance indicators and performance evaluation models based on the latest agreements in 5G PPP
- Addition of exemplary evaluation results, giving insight into potential 5G performance

This section is structured as follows: Section 5.1 contains basic time line information on the upcoming events and milestones, relevant from the perspective of 5G use cases and their performance assessment. Section 5.2 provides an overview on the 5G use cases developed by 5G PPP projects involved in creation of this document. It also maps proposed use cases to corresponding business cases identified in various vertical industries. Section 5.3 focuses on definitions of KPIs relevant for 5G, while Section 5.4 outlines exemplary evaluation results showing potential performance of 5G in selected use cases.

5.1 Time frame for IMT-2020/5G evaluation framework

Similarly as in the International Mobile Telecommunication-Advanced (IMT-A)/4th generation (4G), IMT-2020/5G will be subject to an evaluation process issued by the Radiocommunication Sector of International Telecommunication Union (ITU-R). Following meeting dates of Working Party 5D (WP5D) responsible in ITU-R for the overall radio aspects of IMT systems, are considered as key milestones for this process.

- WP5D meeting #24 (June 2016): approval of the IMT-2020 process. Agree on key parameter names and definitions
- WP5D meeting #26 (February 2017): the performance requirements are approved. Report ITU-R M.[IMT-2020. TECH PERF REQ] finalized in this meeting. Finalize requirements
- WP5D meeting #27 (June 2017): finalization of Report ITU-R M.[IMT-2020.EVAL] and Report ITU-R M.[IMT-2020.SUBMISSIONS]
- WP5D meeting #32 (June 2019): initial technology submission (high-level description)
- WP5D meeting #36 (October 2020): detailed specification submission (stage-3 specifications)

In the context of direct contributions to the standard bodies, 3rd Generation Partnership Project (3GPP) is a clear candidate. Initial considerations on 5G scenarios, KPIs and requirements are captured in [3GPP17-38913]. Additionally, TSG RAN#75 approved Self Evaluation Study Item [RP-170526] aiming at providing assessment of 3GPP technology for IMT-2020 based on evaluation criteria following Report ITU-R M.[IMT-2020.EVAL].

3GPP should submit the final specs at the 5D meeting in February 2020, based on functionally frozen specs by December 2019 [3GPPSP-150149].

5.2 5G use cases and vertical industries

Even if different 5G PPP projects have defined their own use cases, an in-depth analysis of these latter reveals similarities between them. This is because all 5G PPP projects agree on the three 5G services:

- extreme mobile broadband (xMBB)
- ultra-reliable machine-type communication (uMTC), and
- massive machine-type communication (mMTC) [6]

and started their use case definition from the results of METIS project, NGMN, ITU and other fora.

Use cases of 5G PPP projects can thus be classified into six families, as detailed in the table below. The following ranges have been considered for the KPIs used for clustering the use cases:

Device density:	High: ⩾ 10.000 devices per km^2 Medium: 1.000 – 10000 devices per km^2 Low: < 1.000 devices per km^2
Mobility:	No: static users Low: pedestrians (0-3 km/h) Medium: slow moving vehicles (3 – 50 km/h) High: fast moving vehicles, e.g. cars and trains (> 50 km/h)
Infrastructure:	Limited: no infrastructure available or only macro cell coverage Medium density: Small number of small cells Highly available infrastructure: Big number of small cells available
Traffic type:	Continuous Bursty Event driven Periodic All types
User data rate:	Very high data rate: ⩾ 1 Gbps High: 100 Mbps – 1 Gbps Medium: 50 – 100 Mbps Low: < 50 Mbps
Latency:	High: > 50 ms Medium: 10 – 50 ms Low: 1 – 10 ms
Reliability:	Low: < 95% Medium: 95 – 99% High: > 99%
Availability (coverage)	Low: < 95% Medium: 95 – 99% High: > 99%

5G service type, comprising:

xMBB, where the mobile broadband is the key service requirement of the use case
uMTC, where the reliability is the key service requirement of the use case.
mMTC, where the massive connectivity is the key service requirement of the use case.

[6] These three 5G services are equivalent to the ones defined in 3GPP: extreme mobile broadband (eMBB), ultra-reliable low-latency communication (URLLC) and mMTC

In addition to these KPIs, localization and security requirements are important KPIs for vertical industries.

5.3 Key Performance Indicators Evaluation

In order to quantify how certain technical solutions would affect a quality of experience (QoE) of end users or what would be the 5G system performance in a desired used case, specific evaluation metrics are needed. This section gives definitions of 5G main characteristics and KPIs, like the ones defined in [ITUR15-M2083], and provides basic info on how to evaluate them through inspection, analysis or simulation:

- In case of evaluation through *inspection* the evaluation is based on statements
- In case of *analytical procedure*, the evaluation is to be based on calculations using the technical information provided by the technology component owner (methodology, algorithm, module or protocol that enables features of the 5G system is a technology component or enabler)
- Evaluations through *simulations* contain both system level simulations and link level simulations although it is expected that majority of solutions will be assessed using system level evaluation.

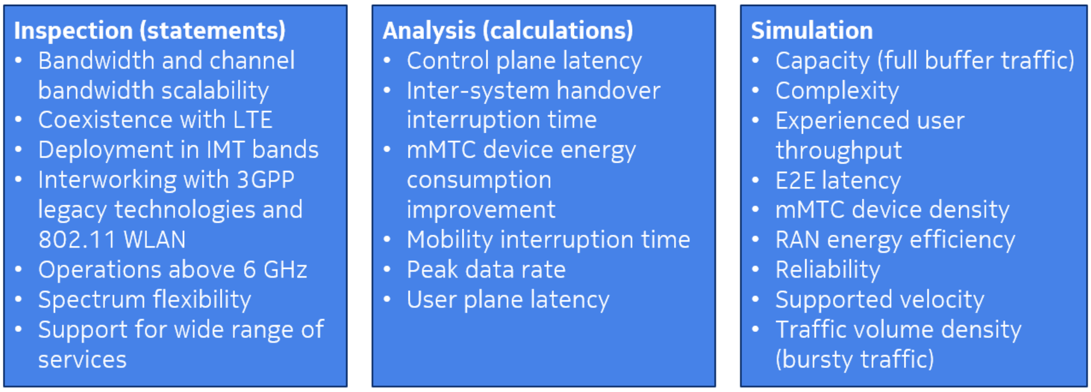

Figure 3: 5G KPIs and their assessment method

5.3.1 Inspection methods

Inspection methods are applied to 5G KPIs that are design-dependent and can be assessed by looking into general system design information. Despite the fact that these KPIs require only simple yes/no answer for assessment, it should be highlighted that all KPIs that are listed in this section will play a fundamental role in 5G and are basis for high performing wireless system.

Bandwidth and channel bandwidth scalability

Scalable bandwidth is the ability of the 5G system to operate with different bandwidth allocations. This bandwidth may be supported by single or multiple radio frequency carriers.

The 5G system shall support a scalable bandwidth of at least 1 GHz. Proponents of proposed 5G system solution are encouraged to consider extensions to support operation in wider bandwidths (e.g. up to 2 GHz).

Coexistence with LTE

The new 5G Air Interface[7] (AI) must be able to coexist with Long Term Evolution (LTE) from Release 8 and onward. This coexistence refers to the ability of the 5G access technology to share resources with a LTE technology operating in the same block of spectrum with possible bandwidth overlap. In this sense, the new AI must be able to support flexible allocation of resources both in frequency and in time domain.

Deployment in IMT bands

Deployment of the 5G system must be possible in at least one of the identified IMT bands. Proponents are encouraged to clarify the preferred bands for the proposed candidate(s).

Interworking with 3GPP legacy technologies and 802.11 Wireless Local Area Network (WLAN)

Interworking refers to the capability of the 5G AI terminals to switch multimode terminals to another technology depending on the coverage and achievable Quality of Service (QoS).

Operation above 6 GHz

The candidate air interface shall be able to operate in centimetre wave and/or mmW bands with one or several Air Interference Variants[8] (AIVs) especially suited to these bands.

Spectrum flexibility

The ability of the access technology to be adapted to suit different DL/UL traffic patterns and capacity needs for both paired and unpaired frequency bands [3GPP15-152129].

Support for wide range of services

The ability of the access technology to meet the connectivity requirements of a range of existing and future (as yet unknown) services to be operable on a single continuous block of spectrum in an efficient manner [3GPP15-152129].

Note that hybrid services including xMBB, mMTC and uMTC may be supported in the same band.

5.3.2 Analysis method

Analysis methods are applied for 5G KPIs that can be assessed using elementary calculations. Although some input parameters for such KPIs depend on e.g., network load, and can be specified using simple simulations, in general their value is repetitive or static during regular network operations.

Control plane latency

The following steps should be detailed, included their need and, if appropriate, the time required for each step:

- Step 0: User Equipment (UE) wakeup time
- Step 1: DL scanning and synchronization + acquisition of broadcast channel
- Step 2: Random access procedure
- Step 3: UL synchronization
- Step 4: Capability negotiation + hybrid automatic repeat request (HARQ) retransmission
- Step 5: Authorization and authentication/ key exchange + HARQ retransmission
- Step 6: Registration with the Base Station (BS) + HARQ retransmission
- Step 7: Radio Resource Control (RRC) connection establishment/ resume + HARQ retransmission

Total latency must be provided together with the latencies of all intermediate steps, if any. Note that

[7] An AI is here defined as the RAN protocol stack and all related functionalities describing the interaction between infrastructure and device and covering all services, bands, cell types etc. that are expected to characterize the overall 5G system.

[8] An AIV is defined in the same way as an air interface, but covers only a subset of services, bands, cell types expected to characterize the overall system.

the full set of steps represents the idle to active state transition. However, the proponent must clarify intermediate states that could be included in the AIV, like a connected-inactive state, and the latencies associated with each intermediate state.

User plane latency

UP latency is defined as the one-way transmission time of a packet between the transmitter and the availability of this packet in the receiver. The measurement reference is the MAC layer in both transmitter and receiver side. Analysis must distinguish between UP latency in infrastructure-based communications and in a direct device-to-device (D2D) communication. Following steps should be evaluated.

- Step 0: Transmitter processing delay at BS (or UE in D2D communication)
- Step 1: Frame alignment
- Step 2: Synchronization
- Step 3: Number of Transmission Time Intervals (TTIs) used for data packet transmission (unloaded condition is assumed)
- Step 4: HARQ retransmission (assuming 10% error probability)
- Step 5: Receiver processing delay in UE

mMTC device energy consumption improvement

mMTC device energy consumption improvement is defined as the relative enhancement of energy consumption of 5G devices over LTE-A ones, under the assumption that device is stationary and uploads a 125 B message every second. If not mentioned explicitly, energy consumption in RRC idle state is assumed the same for LTE-A and 5G devices. Following steps should be evaluated.

- Step 0: Synchronization
- Step 1: Transmit scheduling request
- Step 2: Receive grant
- Step 3: Transmit 125 B data
- Step 4: HARQ retransmission

Inter-system handover interruption time

The time duration during which a UE cannot exchange UP packets with any BS during transitions between 5G new AIVs and another legacy technology, like LTE-A which is of mandatory study. Other AIVs, including non-3GPP ones, are for future studies (FFS) [3GPP15-152129].

Mobility interruption time

Mobility interruption time is defined as the time span during which a UE cannot exchange UP packets with any BS during transitions [3GPP15-152129]. It can be regarded as intra-system handover interruption time.

Note that in 5G system, handover between adjacent BS may no longer exist due to solutions based on multi-connectivity and CP / UP decoupling.

Peak data rate

The peak data rate is the highest theoretical single user data rate, i.e., assuming error-free transmission conditions, when all available radio resources for the corresponding link direction are utilized (i.e., excluding radio resources that are used for physical layer synchronization, reference signals or pilots, guard bands and guard times). Peak data rate calculation shall include the details on the assumed MIMO configuration and bandwidth.

5.3.3 Simulation method

Simulation methods are applied for 5G KPIs that are heavily dependent on the instantaneous network conditions, such as available infrastructure and related radio resources, number of users, radio conditions, etc. Precise assessment of these KPIs is impossible without system level simulations.

Experienced user throughput

Experienced user throughput refers to an instantaneous data rate between Layer 2 and Layer 3. It is evaluated through system level simulations in respective deployment scenarios proposed in Annex A, according to simulation assumptions from Annex A and using bursty traffic models. Note that experienced user throughput depends on the system bandwidth, and therefore this parameter shall be clearly identified in the simulation analysis. Experienced user throughput is calculated as:

$$\boldsymbol{U_{Tput}} = \frac{\boldsymbol{S}}{\boldsymbol{T}},$$

where $\boldsymbol{S}$ is the transmitted packet size and $\boldsymbol{T}$ is the packet transmission duration calculated as the difference between the time when the entire packet is correctly received at the destination and the time when packet is available for transmission. Experienced user throughput is calculated separately for DL (transmission from source radio points to UE), UL (transmission from UE to destination radio points) and (potentially) for D2D (transmission directly between involved UEs).

Experienced user throughput is linked with availability and retainability.

Traffic volume density

Traffic volume density is defined as the aggregated number of correctly transferred bits received by all destination UEs from source radio points (DL traffic) or sent from all source UEs to destination radio points (UL traffic), over the active time of the network to the area size covered by the radio points belonging to the RAN(s) where UEs can be deployed. Here active time of the network is the duration in which at least one session in any radio point of RAN is activated. Traffic volume density can have the following units: [Gbps/m^2] or [Gbps/km^2].

Traffic volume density is evaluated through system level simulations, in respective deployment scenarios and assumptions proposed in Annex A.

Note that D2D traffic should be evaluated independently from the cellular one. Besides, the link between source and destination may cover multiple hops especially when non-ideal backhaul is taken into consideration. Again, system bandwidth assumption must be clearly identified.

E2E latency

Different types of latency are relevant for different applications. E2E latency, or one trip time (OTT) latency, refers to the time it takes from when a data packet is sent from the transmitting end to when it is received at the receiving entity, e.g., internet server or another device. Another latency measure is the round-trip time (RTT) latency which refers to the time from when a data packet is sent from the transmitting end until acknowledgements are received from the receiving entity. The measurement reference in both cases is the interface between Layer 2 and 3.

Reliability

Refers to the continuity in the time domain of correct service and is associate with a maximum latency requirement. More specifically, reliability accounts for the percentage of packets properly received within the given maximum E2E latency (OTT or RTT depending on the service). For its evaluation dynamic simulations are needed, and realistic traffic models are encouraged.

More specifically, reliability for uMTC is evaluated through the packet reception ratio (PRR), following the 3GPP definition [3GPP15-36885]. PRR is calculated for each transmitted packet as X/Y, where Y is the number of UEs/vehicles located in the range of up to 150 m from the transmitter, and X is the number of UEs/vehicles with successful reception among Y. Distance intervals of 20 m from the transmitter are assumed. Reliability of uMTC at specific level is achieved when a given PRR (equal to the reliability) can be guaranteed at a specific distance, for the messages successfully received within a specific time interval.

In general reliability is linked with availability and retainability.

Availability

The availability in percentage is defined as the number of places (related to a predefined area unit or pixel size) where the QoE level requested by the end-user is achieved divided by the total coverage area of a single radio cell or multi-cell area (equal to the total number of pixels) times 100.

Note: FANTASTIC-5G defines availability as equal to (1 – service blocking probability), where service blocking probability is due to lack of enough resources to access, grant and provide the service, even in case of adequate coverage.

Retainability

Retainability is defined as the percentage of time where transmissions meet the target experienced user throughput or reliability.

mMTC device density

Given mMTC device density is achieved when radio network infrastructure specified in Annex A can correctly receive a specific percentage of messages (equal to availability) transmitted by mMTC devices deployed according to models given in Annex A.

RAN energy efficiency

Energy efficient network operation is one of the key design objectives for 5G. It is defined as the overall energy consumption of 5G infrastructure in the RAN comparing to a performance of legacy infrastructure. In order to prove expected energy savings both spatial (entire network) and temporal (24 hours) variations need to be taken into account, therefore direct evaluation in proposed UCs is inaccurate.

Supported velocity

Following steps should be taken to evaluate the high velocity support:

- Step 0: Run system level simulations with parameters as defined RMa deployment scenario with setting the speed to a given value and using full buffer traffic model to collect the overall statistics for downlink cumulative distribution function (CDF) of pilot signal power.
- Step 1: Use the CDF of this received power to collect the given CDF percentile value required by desired availability (e.g., for availability of 95% a 5th %-ile value should be chosen).
- Step 2: Run the downlink link-level simulations for RMa settings and given velocity for both LoS and NLoS conditions to obtain link data rate and bit error rate as a function of the pilot signal power.
- Step 3: Proposal support desired velocity requirement if obtained link data rate is equal or greater than required value and required bit error rate. It is sufficient if one of the spectral efficiency values of either LoS or NLoS channel conditions fulfils the threshold.

Complexity

Even if many attempts have been made, complexity is, in general, difficult to measure. Under the complexity KPI a wide variety of technical aspects can be considered. For example, in the analogue hardware domain, complexity is often characterized by the integration level (size, footprint) of the device/component, whereas in the digital baseband and software domains, complexity is often described in terms of algorithmic complexity. Thus, it seems clear that different parts of the mobile communication networks will use different KPIs to measure this complexity. Consequently, they cannot be compared directly. In these cases, the most meaningful metric for complexity comparison is based on cost. The cost KPI is defined as the expenditure of resources, such as time, materials or labour, for the attainment of a certain objective (be it the execution of a function or the production of a HW component).

Nonetheless, whenever the complexity of a technical component needs to be assessed compared to a given reference of its same kind, it is always preferable to use a magnitude for complexity that is natural given the specific nature of the components to be compared. For example, as stated previously:

- Analogue HW device/component: use the KPI related to the HW footprint like size/volume.
- Digital baseband and software domain: use the computational complexity KPI expressed as the scaling order of the number of operations required to execute a given function in terms of certain input parameters (like number of antennas, samples, subcarriers, etc.)

5.4 Performance Evaluation Results

5.4.1 Inspection

All inspection KPIs from Section 5.3 were evaluated positively, as captured in the deliverables of phase 1 project METIS-II. Exemplary evaluation for KPI of *Operations above 6 GHz* could be summarized as: 5G PPP addresses this KPI through spectrum-related activities in METIS-II, e.g. analysis of coexistence with fixed service links operating on mmW, or feasibility studies for outdoor-to-indoor deployment at higher frequencies) as well as through appropriate UP and CP design.

5.4.2 Analysis

Summary of analysis evaluation is captured in Table 3.

KPI	Requirement	Performance	Key contributor
CP latency	< 10 ms	7.125 ms	RRC Connected Inactive, reduction of processing time in BS and UE
UP latency	< 1ms	0.763 ms	Shortening of TTI, reduction of processing time in BS and UE
mMTC energy efficiency	> 10 years on a 5 Wh battery	> 10 years on a 5 Wh battery	Extension of DRX, C-Plane latency reduction, deep sleep energy conservation features
Peak data rates	> 20/10 Gbps for DL/UL	21.7/12.4 Gbps for DL/UL	MIMO spatial multiplexing (for lower frequencies), exploitation of mmW bands
Mobility interruption	0 ms	0 ms	Multi-connectivity + make-before-brake

Table 3: KPI evaluation through analysis, results

Detailed evaluation for each analytical KPI given above can be found in METIS-II. Exemplary evaluation for peak data rate is as follows:

The analysis assumes a 100 MHz component carrier bandwidth channel in TDD mode, but with flexible UL/DL allocation which allows a full allocation of bandwidth in the peak data rate analysis. Two simultaneously used bands are assumed, one centred in the 3.5 GHz with 100 MHz allocated (one single component carrier), and another at 28 GHz with 500 MHz available (five aggregated component carriers). At 3.5 GHz 16 spatial parallel flows are transmitted, whereas at 28 GHz only 8 spatial flows are possible. A 64 QAM modulation (6 bits per symbol) and error-free channel (channel coding rate is 1) are assumed. Additionally:

- Subcarrier spacing is set to 60 kHz.
- 100 MHz bandwidth per component carrier encompasses 1650 subcarriers and thus 110 Resource Blocks in frequency domain, each with 15 subcarriers. In fact, these 1650

carriers cover only 99 MHz with remaining 1 MHz used as a guard band for the purpose of calculation.

- Cyclic prefix is set to 1.17 µs, resulting in an OFDM symbol duration of 17.84 µs.
- A total of 56064 OFDM symbols are transmitted per second, reserving 10% of symbols for signalling purposes and 20% of subcarriers for channel reference signals.
- Peak data rate per component carrier results in 56064*1650*(0.7)*6*16 = 6216376320 bps, i.e. about 6.2 Gbps for below 6 GHz band, and in 56064*1650*(0.7)*6*8 = 3108188160 bps, i.e. about 3.1 Gbps for above 6 GHz band.

In the aggregation case for the DL, 5 component carriers (500 MHz) at above 6 GHz and 1 at below 6 GHz (100 MHz) will result in a total peak data rate of 21.7 Gbps. In the UL, 2 component carriers at 28 GHz and 1 component carrier at 3.5 GHz will result in a total peak data rate of 12.4 Gbps. The ratio of 3 to 6 component carriers between UL and DL is due to the power limitations existing in handheld devices.

5.4.3 Simulations

5G PPP evaluated several 5G UCs. The remaining part of this section gives examples of theses evaluations, which are detailed in Deliverables of several Phase 1 projects.

For the "Wide area coverage (FANTASTIC-5G)" use case, a mMIMO configuration is adopted in macro-cellular environments (UMa/RMa) to provide MBB services to multiple users. Simulations assume a rectangular antenna array with two-stage precoding [ANA+13] (regularized zero-forcing on top of a grid-of-beams). An optional inter-cell Coordinated beamforming (BF) scheme is applied on top of mMIMO. For comparison purposes, a baseline LTE-A system (using 8x8 single-user MIMO) is also evaluated.

Results are reported for three deployment environments: rural (inter-site distance (ISD) = 1000 m, 100 users/km²), suburban (ISD = 600 m, 400 users/km²), and urban (ISD = 200 m, 2500 users/km²). The target value for the average user data rate in this use case is 50 Mbps. While the LTE-A baseline cannot reach this objective alone, the proposed mMIMO technique can provide at least twice as much as the target. Additionally, the mMIMO with Coordinated BF boosts the user data rate from 9.16% (in the rural scenario) up to 19.5 % (in the suburban scenario) comparing to basic mMIMO operations.

Supported traffic density is also greatly increased comparing to LTE-A. With Coordinated BF technique provides an additional gain of 18.0% (in the urban scenario) to 20.8 % (in the suburban scenario) comparing to mMIMO.

Finally, the availability is calculated as the percentage of the target throughput achieved by each user, or 100% if higher. While LTE-A is in the 25%-50% range, mMIMO reaches more than 94%. With the additional coordinated BF, results exceed 97%.

6 Business KPIs

As a support to the 5G PPP and the 5G-IA, Euro-5G updated its assessment of the level of industrial investment in 5G PPP research in proportion to the EU investment in 5G PPP.

6.1 Assessment methodology used

Our methodology is based upon gathering the published public figures from annual reports for worldwide R&D expenses.

The main challenge is then to assess the declared R&D figures of a representative set of Key ICT players and deduce which proportion of their R&D spend is 5G related. We also discussed if the 5G spend in Europe could be identified or at least assessed.

So we made conservative assumptions on what the 5G activities share of their worldwide R&D was – usually in the order of 10% and then we further reduced that to reflect what European share of the 5G activities as part of the total R&D expenses could be – typically we ended up with a figure of about 5% of global R&D. To further eliminate over-assessment risks and to give us a very conservative figure we also considered the European 5G as 2% of Global R&D. These proportions of 5G research of total research expenses will increase as 5G moves into full standardisation, development and production over the next few years and future iterations of these assessments will take account of this.

Our first release dated July 2016 was based on publicly available figures for FY2015. The second edition uses FY2016 figures. We do not modify the shares we applied last year as we consider the full standardisation phase has not begun yet. In our view, 2018 will be a transition year from standardisation to trials.

For direct evaluation purposes, we took into account a representative set of players active in the 5G PPP. For a second reference figure we have considered a wider set of players in different aspects of the ICT sector, including equipment manufacturers, mobile network operators, test equipment manufacturers, device manufacturers and chipset manufacturers.

6.2 Main biases from the methodology and declared figures

There are significant methodology biases that we have to be aware of.

First, R&D figures are often considered as sensitive by companies. As such, data on trends are not always consistent and public figures can be misleading. Some companies disclose information on Capital Expenditures, other on “innovation”. Innovation appears as a portmanteau word that leaves much space for interpretation. Others prefer to use the term “R&D expenses”, without one knowing the method actually used of what is counted.

Second, the assumptions we made on what the 5G activities share of the worldwide figures collected was is based on our expertise, but could significantly vary depending on companies. We tried to lower the uncertainty in this field as much as possible and correct misperceptions.

Third, we selected a wide set of players involved in the 5G field but could not gather information from *all* companies. Information could remain fragmentary in some areas. However, we consider our sample of 13 organisations as sufficiently reliable for our estimation.

6.3 Assessment of leverage ratio for 2016

Redoing the same exercise as in 2016, Euro-5G has prepared below table based on publicly available figures and estimates:

all figures in million EUR	**2016 R&D**	**5G as 10% of global R&D**	**5G as 5% of Global R&D**	**5G as 2% of Global R&D**
Ericsson	3 378	338	169	68
Nokia (incl. ALU)	4 904	490	245	98
Huawei	11 060	1 106	553	221
Samsung	11 247	1 125	562	225
Deutsche Telekom	4 900	490	245	98
Orange	780	78	39	16
TIM	1 900	190	95	38
Telefonica	906	91	45	18
Telenor	67	7	3	1
Keysight Technologies	384	38	19	8
Rohde & Schwarz	288	29	14	6
Intel	11 517	1 152	576	230
Sequans	24	2	1	0
TOTAL	**51 355**	**5 136**	**2 568**	**1 027**

Table 4: 5G R&D expenses 2016

It now can be seen from the table that the most conservative assessment of 2% of the Global R&D spend being invested in 5G would increase in **a leverage factor of 15 to 34** depending on whether one considers the whole 5G PPP phase one investment or an annualised figure (70m or 30m p.a.).

Results are quite similar to those disclosed last year based on 2015 publicly available figures for R&D investments.

The 5G PPP funding for phase 1 projects was about 70 mEUR for bigger industry, which facilitated projects with a value of around 30 MEUR per year – allowing for projects with different durations (between 24 to 26 months). The total funding budget for 5G PPP Call 1 was 125 MEUR.

6.4 Conclusion on Leverage ratio for 2016

From the above exercise, even allowing for the assumptions and generalisations, we can confidently state that the European ICT sector is achieving, and most probably exceeding, the planned level of investment leverage expected in the 5G PPP Contractual Arrangement.

7 Summary

This document refers to the work done in 5G PPP on KPIs and how use cases considered for 5G in different 5G PPP projects contribute to the evaluation of those KPIs.

7.1 Performance KPIs

5G evolution will require a re-assessment of the performance metrics that can be used for a meaningful assessment of new use cases. The KPIs and corresponding evaluation procedures proposed in the collaborative work so far can be used to harmonize evaluation results coming from different sources and therefore facilitate a fair assessment and comparability of the different technical concepts considered for 5G.

The **analytical evaluation** of the radio KPIs concluded the ability that 5G RAN can deliver peak data rates at the order of 21 Gbps in DL and 12 Gbps in UL. Compared to 4G operations, 5G will also enable a significant reduction of UP and CP latencies, down to 0.763 ms and 7.125 ms, respectively. In UP, the reduction of the sub-frame length to 0.125 ms is of paramount importance. It was also proven that for mMTC operations a single battery life time exceeding 10 years is possible for devices that sporadically upload data to the network.

Simulation-based evaluations carried out in 5G PPP prove that proposed 5G solutions can cater for >100 Mbps experienced user data rates in rural deployments. In dense urban deployments the HetNet deployments are capable of > 300 Mbps data rates and enable high energy efficient RAN operations. Reliability of 99.999% is achievable for URLLC services.

Conducted simulations proved also that dual connectivity deployments of 5G and LTE-A provide superior performance over standalone operations. This improvement is clearly noticeable for users (higher data rates) and network operators (lower energy consumption of infrastructure).

7.2 Business KPIs

While it is too early in the program to accurately assess the financial return on the work of phase 1, it is clear that the industrial investment figures are substantially ahead of the projections made in the 5G PPP contract.

The evaluation of economic aspects of future network suggests that centralized RAN deployments reduce the total costs of running 5G networks. Especially in edge cloud operations, when edge cloud provisioning of base station processing is beyond 30 macro sites its optimal price point is reached.

7.3 Societal KPIs

As the 5G services have not yet been introduced to the market it is too early to report on the societal impact.

7.4 Next Steps

The To-Euro-5G project, together with the TB and the phase 2 projects must find a way where the cross project collaboration on *5G PPP use cases and performance evaluation*, previously led by METIS-II, may continue and produce further versions of their reports. This will be particularly important as we move into phase 3 and larger scale experiments start. Performance metrics must be part of phase 3 projects from the start.

[end of document]

