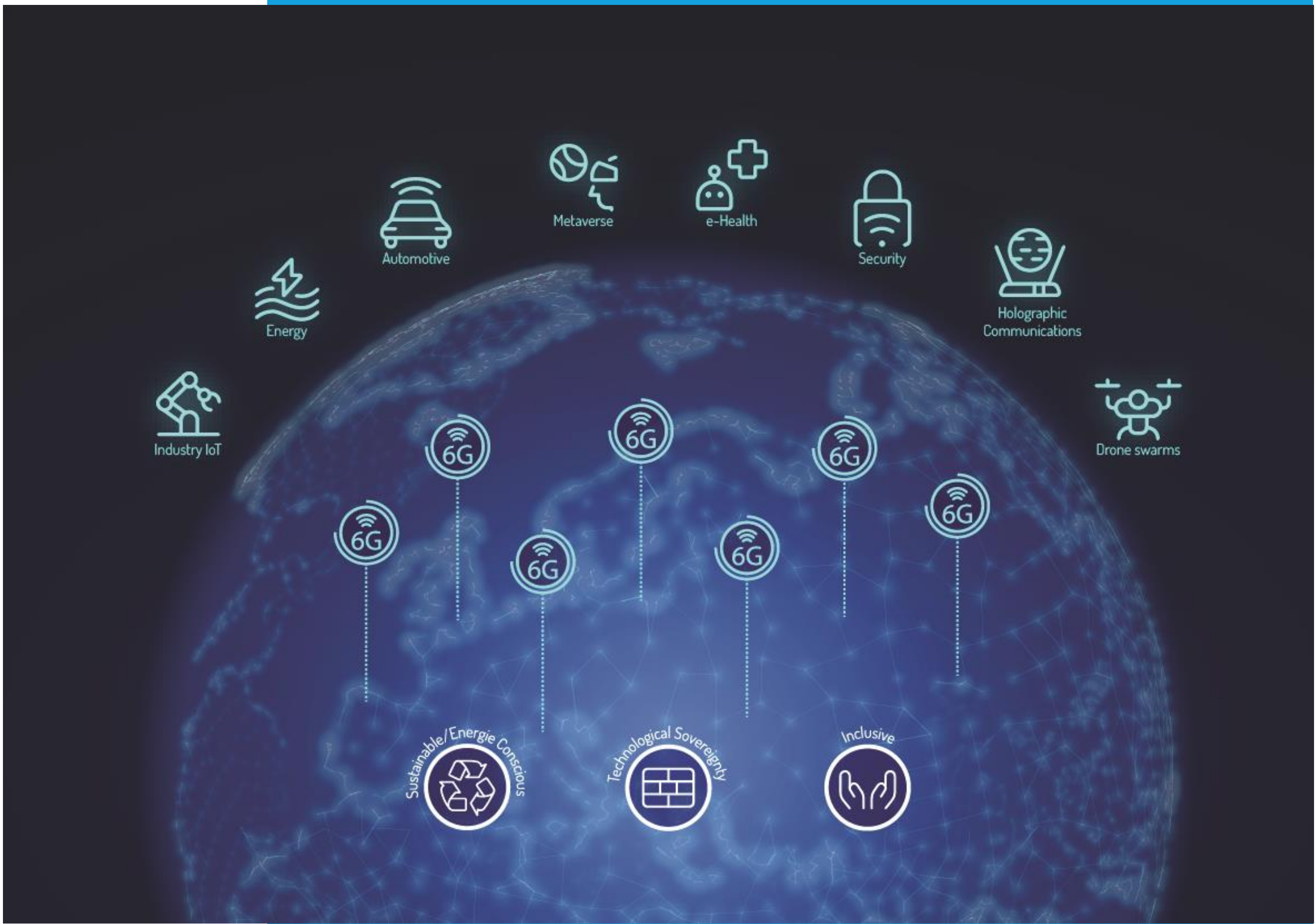
Smart Networks and Services Joint Undertaking (SNS JU)
Test Measurement and Validation Working Group (TMV WG)



Version 1.0

January 2025

WHITE PAPER

6G KPIS –DEFINITIONS AND TARGET VALUES

DOI: 10.5281/zenodo.14621168
URL: https://doi.org/10.5281/zenodo.14621168

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EXECUTIVE SUMMARY

The Test, Measurement, and KPIs Validation (TMV) Working Group (WG) of SNS JU focuses on developing and sharing best practices for 6G testing, monitoring, and analytics. The TMV WG aims to promote common methodologies across projects, support 6G trial Use Cases (UCs), and ensure a unified European vision for the 6G network lifecycle. A key objective is the definition and validation of performance KPIs. This white paper consolidates 6G KPIs from SNS JU projects, providing definitions, target values, and context to shape the 6G vision. Furthermore, the TMV WG promotes common collection procedures, validation methodologies, and analysis of KPI metrics. Various SNS JU projects provided the KPIs, which drive their technical developments.

Europe, through the SNS initiative, goes beyond pure performance indicators and considers a vision based on European values and societal needs as the drivers of 6G system design, which are described by Key Value Indicators (KVIs). Nevertheless, the focus on KPIs in this white paper aims to support global alignment and avoid fragmented standards.

To align with the ITU-R IMT2030 approach, the main KPI categories were classified into KPI families. Some ITU-R KPI categories were merged for readability, and additional KPI families were introduced. The identified KPI families are (i) Data rate and Capacity, (ii) Latency, (iii) Reliability and Availability, (iv) Mobility, (v) Compute, (vi) Sensing, (vii) AI-related Capabilities (viii) Electromagnetic Fields (EMF) aspects), (ix) Positioning and Localisation, as well as (x) Energy Efficiency (xi) Coverage -related and (xii) Other KPIs.

Concerning date rate and capacity the analysis covers various segments ranging from infrastructure to application and includes KPIs such as user experienced-, peak user-, Max. achievable- data rates and peak data rates at system level. Furthermore, area traffic density, connections density and elements capacity are discussed. Concerning latency, the analysis includes KPIs related to transmission time in mobile networks, focusing on E2E latency. Further considerations discuss jitter, as well as timing-related KPIs in the context of orchestration, provisioning, and control procedures. The importance of stable and predictable latency is emphasized. Reliability and availability focus on measuring network performance and operability. KPIs include latency as a performance constraint and availability as the readiness of the network to provide communication services with an assured level of quality. Mobility-related performance metrics essential for seamless and reliable connectivity across a variety of 6G UCs and align with IMT 2030 and 3GPP benchmarks, incorporating new requirements for emerging use cases (UCs) like XR (Extended Reality), real-time Digital Twins (DTs), and network-assisted mobility.

Concerning computation platforms, a set of KPIs refers to resource utilization at the system infrastructure level, including servers, hosts, and data centres. Sensing focuses on KPIs related to localization, motion detection, and environmental context awareness, with a focus on accuracy, latency and coverage area for sensing-oriented services. AI-related capabilities have been formulated to support network optimization, enhanced mobility, security, privacy, and performance KPIs. Key points of attention are resource consumption and processing time for AI-related functions. EMF considerations for 6G networks focus on increased exposure due to more devices, safety guidelines by ICNIRP and ITU, challenges in measuring higher frequencies, ongoing health impact research, and real-time monitoring for compliance. Positioning and localisation KPIs address GNSS coverage limitations in urban and indoor environments. B5G/6G networks can assist or substitute GNSS, exploiting parameters like absolute and relative positioning, accuracy, latency of service and integrity. In the other family of KPIs, energy efficiency is the dominant topic.

New use cases (UCs) introduced in 6G call for new and updated KPIs. Therefore, we must revisit KPI definitions, emphasize contextual KPIs (i.e. in the context of specific UCs), integrate cross-domain metrics, prioritize sustainability, support testing and validation, ultimately harmonising global standards.

To facilitate accurate KPIs measurement and validation we recommend to improve the tools and methodologies to support E2E performance evaluation, multi-layer and cross-domain measurements, introduce AI-assisted tools, solidify testbeds and simulation platforms for dynamic environments and, last but not least, introduce sustainability metrics.

In order to ensure consistency across regions, we recommend to standardize tools and metrics and integrate with pre-standardisation efforts in order to align with emerging standards.

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LIST OF TABLES

ABBREVIATIONS AND ACRONYMS

Abbreviation	Meaning
3GPP	3rd Generation Partnership Project
5G PPP	5G Infrastructure Public Private Partnership
ADAS	Advanced driver-assistance system
AGV	Automated Guided Vehicle
AI / ML	Artificial Intelligence / Machine Learning
AR	Augmented Reality
BLER	Block Error Rate
BS	Base Station
CU	Central Unit
CP	Control Plane
DL	Downlink or Downstream
DT	Digital Twin
E2E	End-to-end
EMF	Electromagnetic Fields
GNSS	Global Navigation Satellite System
ICNIRP	International Commission on Non-Ionizing Radiation Protection
IEC	International Electrotechnical Commission
IMT-2030	International Mobile Telecommunications 2030
IP	Internet Protocol
ITU	International Telecommunication Union
JCAS	Joint Communication and Sensing
KPI	Key Performance Indicator
KVI	Key Value Indicator
L3	Layer 3
LCM	Life-cycle Management
LCS	Location-Based Services
LDCP	Low Density Parity Check

M2M	Machine-to-Machine
MCS	Mission Critical Communications
MIMO	Multiple Input Multiple Output
mMTC	Massive-Machine Type Communication
Mngmt	Management
MNO	Mobile Network Operator
NaN	Not a Number
NF	Network Function
O-RAN	Open Radio Access Network
OWC	Optical Wireless Communication
OWD	One-way Delay
PDCP	Packet Data Convergence Protocol
PDU	Packet Data Unit
PoC	Proof of Concept
QoS	Quality of Service
R&D	Research and Development
R&I	Research and Innovation
RAN	Radio Access Network
RIS	Reconfigurable Intelligent Surface
RMS	Root Mean Square
RMSE	Root Mean Squared Error
RSRP	Reference-Signal Received Power
RSRQ	Reference-Signal Received Quality
RSSI	Received Signal Strength Indicator
RTT	Round-Trip Time
RU	Radio Unit
SAR	Specific Absorption Rate
SDO	Standards Development Organization
SDU	Service Data Unit
SINR	Signal-to-Interference-and-Noise Ratio
SISO	Single Input Single Output

SLA	Service Level Agreement
SLAM	Simultaneous Localization and Mapping
SNS JU	Smart Networks and Services Joint Undertaking
SRIA	Strategic Research and Innovation Agenda
(S)RIT	(Set of) Radio Interface Technology(ies)
srsRAN	Opensource Ran project (https://www.srslte.com/)
T&M	Testing & Monitoring
TCP	Transmission Control Protocol
TDD	Time Division Duplex
TMV WG	Test Measurement & KPIs Validation Working Group
TRxP	Transceiver
TSN	Time-Sensitive Networking
UC	Use Case
UE	User Equipment
UL	Uplink or Upstream
UP	User Plane
UPF	User Plane Function
V2I	Vehicle to Infrastructure
V2V	Vehicle to Vehicle
VR	Virtual Reality
WHO	World Health Organization
WG	Working Group
XR	Extended Reality

1. INTRODUCTION

During the last years, as 5G networks are in the phase of commercial rollout across all continents, European and global research efforts are totally concentrated on the specification and development of the 6th generation (6G) of networks. To optimize research resources and foster Europe's technology sovereignty in 6G, the Smart Networks and Services Joint Undertaking (SNS JU) was established in November 2021, as a follow up of 5G PPP. The Test, Measurement and Validation Working Group (SNS JU - TMV WG) has been established as a follow up of 5G PPP TMV WG activities and is one of four SNS JU WGs that were formed with the goal to ensure a unique European vision on aspects spanning the entire lifecycle of 6G network evolution, ranging from R&D to actual deployed environments. The TMV WG focuses on allowing experts to exchange best practices developed and results obtained within the SNS JU funded projects and on promoting commonalities across SNS projects that have strong interest in Testing & Measurement (T&M) methodologies.

The work of the SNS JU - TMV WG leverages on the working methods and best practices used in the 5G PPP TMV group as well as its closing works ([19],[20]) and is progressing the discussion on formalization and validation of 6G KPIs/KVIs, as well as on harmonization and re-usability of testing and measurement methods and procedures.

This document is the first White Paper of the SNS JU TMV WG and aims to provide a consolidated report on the 6G KPIs definitions and target values as currently defined in the context of R&D projects funded under the SNS JU Phase I and Phase II. It provides the view of the contributing SNS JU projects on the KPIs considering the KPIs categories identified in the current version of the Recommendation ITU-R M.2160, (11/2023) "ITU-R: Framework and overall objectives of the future development of IMT for 2030 and beyond" [3], along with initial target values. It also addresses the gaps in the definitions of the new IMT-2030 (currently only defined as targets for research and innovation) by proposing how they can be technically interpreted and evaluated.

1.1. OBJECTIVES & MOTIVATION

The objectives of the TMV encompass testing, validation, and measurement of technological solutions in the context of 6G trials and use cases (UCs). To this end, KPIs definition, sources, collection procedures, and validation methodologies are in the focus of the TMV WG activities. The work of the WG includes also KVIs validation methodologies and analysis, testing frameworks (requirements, environment, scenarios, expectations, limitations, and tools), along with testing methodologies and procedures. At the next 6G development phases, the work will focus on the testing lifecycle, encompassing execution, monitoring, evaluation, and reporting, and will conclude with the analysis of trial results and the generation of insights.

Addressing first main objective of the TMV WG, SNS-JU Phase I and Phase II projects were asked to provide the 6G KPIs that they have identified -and which have been used to drive the projects' technical developments-, along with target values and other supportive information. The invitation was well accepted by a significant number of projects, which contributed with input and discussions, provided useful insights and further worked on the analysis of the information[1].

This White Paper provides a consolidated report on the SNS-JU projects' 6G KPIs definitions, target values, Context/UCs/Trials where these are defined, and (where relevant) comments on the relation of these KPIs to existing standards. These projects are either (Phase I projects) in the phase of development thus have already concluded the initial work on KPIs definition or have (a few Phase II projects) just concluded the phase of initial KPIs definition. Even though the focus of projects is various -depending on their envisioned 6G UCs and deployment scenarios- the KPIs definitions cannot be completely harmonized, and their reported target values cannot be directly compared, this work can provide significant insights on clarifying the vision of 6G systems capabilities, usage scenarios, and new capabilities, and identifying early the evaluation criteria and methods with which 6G systems will be assessed (by market/ stakeholders/ users, even if not standardized). The dissemination of this part of the projects' work also aims to assist next phase projects to exploit and leverage on expertise gained and knowledge created by early phase.

The remainder of this paper is structured as follows:

- Section 2 provides an overview of the current views on 6G networks KPIs and target values by Standardisation Organisations and by Global Activities.
- Section 3 reports on the projects' views on 6G KPIs, their target values and the context where these are set; using as baseline the KPIs categories and new capabilities defined (until the time of the White Paper publication) for IMT-2030 by ITU-R.
- Section 4 provides an analysis of the collected material, along with aggregate insights on 6G networks performance and capabilities.
- Finally, Section 5 concludes this white paper.

1 Input was gathered by Hexa-X-II [24], TRIALSNET [25], CENTRIC [26], 6G-SANDBOX [27], 6G-SENSES [28], ENVELOPE [29], ACROSS [30], 6G-EWOC [31], ImagineB5G [32], BeGREEN [33], DESIRE6G [34], PREDICT-6G [35], 6GXR [36], 6GTandem [37], ECO-eNET [38], 6G-PATH [39], FIDAL [40], while representers of other projects also contributed to the analysis of the data and the generation of this document.

2. OVERVIEW OF KPIS – STANDARDISATION ORGANISATIONS & GLOBAL ACTIVITIES

Europe has been on the front line of the 6G development process, pushing forward a concrete vision for 6G networks via the Smart Networks and Services Joint Undertaking (SNS JU), that is currently funding approximately 80 Research & Innovation projects. The SNS JU vision is significantly based on the EU values and societal needs as well as the vision of its private sector represented by the 6G Smart Networks and Services Industry Association (6G-IA) [4] and a detailed Strategic Research and Innovation Agenda (SRIA) produced by NetworldEurope [2].

Similar activities take place at global level. As in the previous generations of cellular networks, North America, Japan, South Korea, China, India, Taiwan, etc., are very active in the design of the future 6G system. One key objective between all these regions is to avoid fragmented 6G standards that will obstruct the broad adoption of networks and services and underachieve the desired economies of scale, endangering the success of 6G.

To achieve pre-standardization consensus among the different regions, global alignment is pursued in terms of the main targeted usage scenarios (or UCs), enabling technologies that will comprise the building blocks of 6G and of course the targeted Key Performance Indicators (KPIs). As such, it becomes critically important to contribute to this process from SNS-JU and to be aware of the global 6G research landscape, the goals and targets set by key stakeholders around the world and the vision that the global 6G community is working towards.

For a couple of years now, the various global stakeholders have been publishing white papers and positioning papers, promoting their respective vision for 6G networks, analysing the societal needs that drive their technological developments and setting ambitious targets that 6G should fulfil to make it a technological and market success. Such publications help shape the global vision of 6G and enhance the understanding of the different needs around the globe that 6G should meet.

A cornerstone in the development process of 6G (and all previous generations before it) is the publication by the International Telecommunication Union (ITU) of the IMT 2030 Recommendations [3], which are considered the common baseline for the future development of 6G features and technologies around the world. Within this recommendations document, the ITU establishes (among other aspects) i) the high-level **Usage scenarios** and overarching aspects for 6G and ii) the targeted capabilities / **KPIs for 6G** – so far as targets for research and innovation, which are not yet finally agreed.

Figure 1 depicts the usage scenarios promoted within the ITU-R IMT 2030 Recommendations and their evolution from the 5G era (IMT 2020). These high-level scenarios are the first attempt to bring into scope the specific services and UCs that 6G will have to address. Under their umbrella, a number of specific UCs have been targeted by key stakeholders from Europe [4], USA [5], India [6], Japan ([7],[8]), South Korea ([9],[10]), China ([11],[12]), Taiwan [13] and the operators association (NGMN -[14],[15]) including Holographic Communications, Cyber-Physical Systems, Digital Twin, Manufacturing, Multi-Sensory XR, Gaming / Entertainment, Tactile / Haptic Communications, Medical/ Health Vertical, Telesurgery, Cooperative Operation among a Group of Service Robots / drones, Imaging and Sensing, Transportation UCs (automotive, logistics, aerial, marine, etc.) and more.

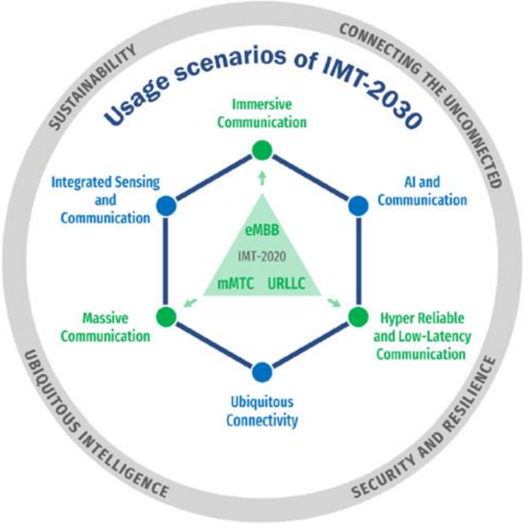

Figure 1: Usage Scenarios of IMT 2030 by ITU-R

In addition to promoting their targeted use cases, the regional associations discussed their priorities for the technologies, features, and enablers that should form the building blocks of 6G. These elements are expected to ensure the future network delivers the required performance and flexibility needed to meet the stringent KPIs of all envisioned use cases. These so called '6G Drivers' are considered the necessary technological advancements, strategic decisions and novel features that will realize the vision of 6G. Throughout an extensive survey of more than twelve white & positioning papers from the largest global stakeholders [4]-[15], several of these drivers are mentioned as important, depending also on the specific socio-economic landscape and needs of each region. However, seven features / technologies seem to aggregate the global consensus that they will comprise the cornerstone of 6G networks. Figure 2 depicts the seven 6G drivers that are globally regarded to be the key elements of 6G networks, aggregating support from all (or almost all) of the aforementioned regions.

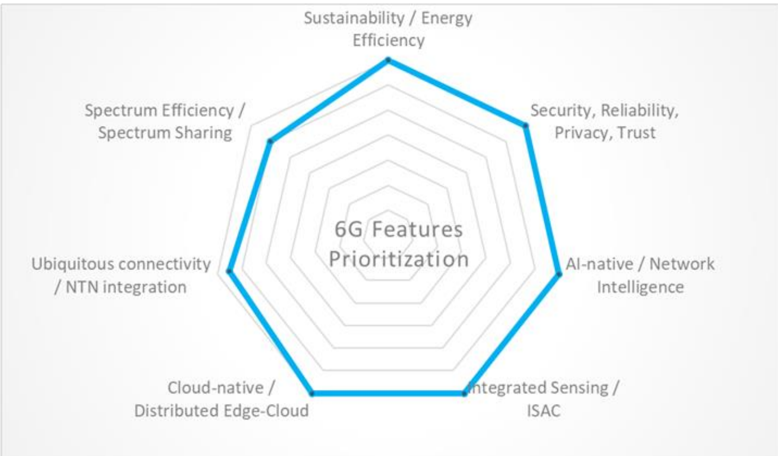

Figure 2: 6G Key enabling factors for 6G UCs across the globe

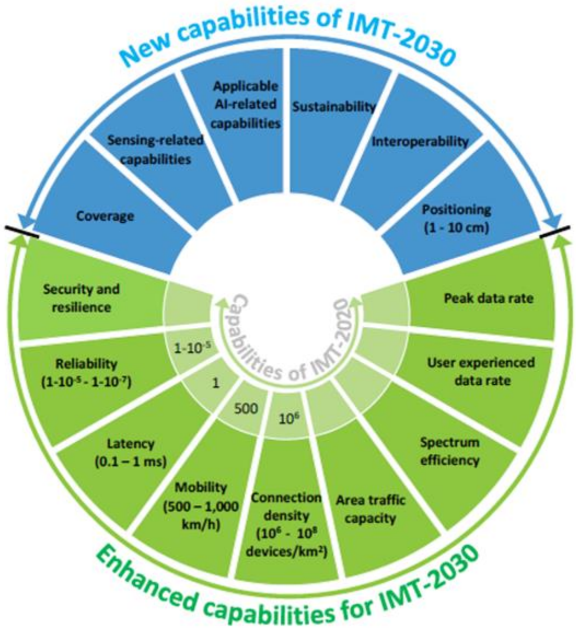

Figure 3: Enhanced and New Capabilities of IMT20230 by ITU-R

Perhaps the most interesting part of the ITU-R IMT 2030 Recommendations document is the clear definition of the Enhanced capabilities (evolved from previous generations) and the new capabilities that 6G networks should bring and their respective targeted KPIs (depicted in Figure 3). These capabilities comprise the first list of target KPIs and objectives initially for 6G research and innovation and upon agreement (expected by mid 2026) for next generation of networks, in order to qualify as 6G, and are based on a consensus drawn from the analysis of the regional visions, needs and targets of 6G, as expressed by global stakeholders.

In order to understand the commonalities and differences between the diverse global regions as well as the socio-economic needs driving their respective technological vision and developments, it is interesting to analyse the targeted KPIs of each region (as expressed in their various publications) and how they compare to the targeted KPIs eventually adopted by ITU. Table 1 provides an overview of the global regional KPI targets based on key global stakeholders' vision documents ([4]-[13]) and the eventual values adopted by the ITU recommendations. It is interesting to observe that in most cases, a good alignment is observed between the regional targets and the eventually adopted ITU targets (*density, reliability, latency, mobility, positioning*), while there are also cases where the ITU has adopted more modest targets than the ones expressed by the majority of global stakeholders, as is the case for the Peak and Average user data rates.

The analysis presented in Table 1 shows that in general there is good alignment among the global stakeholders for what concerns the high-level targets that should be achieved, which is an encouraging sign for the way forward towards a commonly adopted 6G standard. As the R&I activities around the world progress, it becomes more and more interesting to monitor the evolution of the various technologies and how close to these KPI targets the various researchers can achieve.

This White paper from the TMV WG of the SNS JU, attempts to provide a first overview of the actual targeted KPIs within each R&I project, not just based on the 6G vision, but based on the actual UC requirements that will be implemented. The following analysis of KPI definitions and targets, relevant network layer and KPI evaluation methodology, will assist in the better understanding of the projects' work and will shed some light into the methodologies, targets and way of working within the SNS JU.

Table 1: Aggregation of regional targeted KPIs [4]-[13] and comparison with IMT 2030 KPIs

KPIs	Networld Europe SRIA 2022	Next G Alliance (USA)	IMT-2030 PG (China)	B5G Consortium (Japan)	TSDSI (India)	TAICS (Taiwan)	ITU IMT-2030
Peak Data Rate	1 Tbps	0.5-1 Tbps	1 Tbps	100-200 Gbps	0.5-1 Tbps	100 GBps -1 Tbps	50-200 Gbps
User Experienced Data Rate	10 Gbps	DL: up to 1 Gbps UL: up to 1 Gbps	10-100 Gbps	10-100 Gbps	DL: up to 10 Gbps UL: up to 5 Gbps	1Gbps	300-500 Mbps
Density	10^6 dev/km^2	10^6 dev/km^2	10^6 dev/km^2	10^6 dev/km^2	10^6 dev/km^2	10^6 dev/km^2	$10^6 – 10^8$ dev/km^2
Reliability [BLER]	>1-10^{-8}	>1-10^{-8}	>1-10^{-7}	>1-10^{-7}	>1-10^{-7}	~1-10^{-5}	~1-10^{-5} - 1-10^{-7}
U-Plane Latency	<0.1 ms	0.1-1 ms	0.1 ms	0.1-1 ms	0.1-1 ms	0.1 ms	0.1-1 ms
Energy Efficiency (Network/ Terminal)	>100% gain vs IMT-2020	Extremely low power / never charging devices	Network: 100x w.r.t 5G Device: 20 years battery	Network: 100x w.r.t 5G	Battery lifetime up to 20 years	10% of 5G Device: 20 years battery	n/a
Mobility	<1000 Km/h	> 500 km/h	n/a	Up to 1000 km/h	Up to 1000 km/h	Up to 1000 km/h	500 - 1000 km/h
Positioning accuracy	<1 cm	1 mm - 10 cm Six degrees of motion: (x,y,z)	Outdoor: 50 cm Indoor: 1 cm	1-2 cm	< 1 cm	Indoor: 10 cm	1-10 cm

3. KPIS – FAMILIES AND DEFINITIONS

Consistent with commonly adopted project development practices, the majority of SNS-JU projects focus on the definition of scenarios and UCs that the system under development will support, followed by identifying the requirements and KPIs that must be achieved. The scope of the projects, the envisioned UCs and the associated usage scenarios/ services/ applications influence significantly the definitions and the quantification of the KPIs and the relevant targets to be achieved. While several network KPIs are common across network generations -thus also inherited in 6G networks specifications- new capabilities are envisioned that need to be evaluated qualitatively and quantitatively. Non-standardized technical capabilities are particularly vulnerable to multiple interpretations as technological specifications and to varying definitions of evaluation criteria, such as KPIs and target values. As mentioned earlier, the objective of the TMV WG is to identify and promote the SNS-JU project's concepts and vision on '6G KPI definition, sources, collection procedures, validation methodologies, and analysis.' It also aims to ensure a formalized—and, at later stages of 6G development, harmonized—perspective on 6G KPIs across projects, which can be leveraged by ongoing and future efforts of the EU research community.

This work leverages previous 5G PPP work on KPIs (published in [19] and [20]), by updating the list of KPI definitions and targets, and by especially focusing on providing insights and shaping a harmonised view on the IMT-2030 new capabilities that are currently ambiguous or undefined.

To this end the TMV WG followed a three-step methodology (adhering to the 5G PPP TMV WG practices). As first step, the TMV defined the information to be collected, related to the KPIs names and definitions, the network layer/ segment/ etc where they refer, the target values, the context (UC, Usage Scenario, Trial) where the KPIs refer, and any additional information related to existing definitions from standards. At second step, the input by projects was collected; and at third step, the input was classified in KPIs categories/ families and analysed by TMV WG members.

To align with the ITU-R IMT2030 approach, the main KPI categories of the ITU-R KPIs wheel diagram was considered as baseline for the classification of the projects' input. For analysis purposes, in this White Paper, some ITU-R KPIs categories were merged into one family -i.e. user experienced datarate, peak datarate, device density and area capacity were all included in the Datarate/ Capacity Family #1 (however analysed separately) – while some additional KPIs families have been included – i.e. Compute, EMF and Others -including Security, Privacy, Spectral efficiency etc. In overall, the identified KPIs Families are the following:

- Family #1 – Data rate and Capacity
- Family #2 – Latency
- Family #3 – Reliability and Availability
- Family #4 – Mobility
- Family #5 – Sensing
- Family #6 - Electromagnetic Fields (EMF) aspects
- Family #7 – AI-related Capabilities
- Family #8 – Positioning and Localisation

- Family #9 – Energy Efficiency
- Family #10 – Coverage
- Family #11 – Compute
- Family #12 - Other KPIs

3.1. FAMILY #1 – DATA RATE/ CAPACITY

The first KPIs Family (#1) – Data rate/ Capacity includes a set of KPIs sub-categories that are used to evaluate the amount of network resources that are either provided to end-users or are available for provisioning to users, as well as to evaluate the available system/ element resources. Depending on the nature of the SNS projects providing the information, KPIs range from capacity KPIs at segment/ stratum/ infrastructure layer -which derive from the relevant 6G technologies capabilities- up to application/ service level KPIs -which derive from the user/ vertical service requirements. This family comprises four KPIs from the IMT-2030 wheel, i.e. user experienced data rate, peak data rate (separated into peak user data rate and peak system data rate), connection density, and area traffic capacity. It also includes metrics for evaluating the capacity of 6G network elements.

In general, the projects that have contributed to this sub-category have a harmonised view on the KPIs definitions as they adopt the existing ITU-R M.2410-0 definitions for IMT -2020. However, the endpoints or network layer to which the reported target values referred range from the user level down to the infrastructure and technology levels. In particular:

User Experienced data rate, is commonly defined as the achievable data rate that is available to a mobile device a certain probability across the cell area. To this end, the exact wording selected by projects to define this KPI (see Table 2)as well as the target values vary between projects in terms of considering:

- the coverage area and any range aspects (i.e. some projects define User experienced data rate at cell edge, at specific range, ubiquitously over the network coverage area etc.)
- the sustainability of the data rates over time/ session
- whether it refers to DL or UL traffic
- statistical properties of the variation of data rate i.e. specific percentile of the cumulative distribution function of the user data rates, average data rates etc.

However, despite highlighting such aspects in the definitions most projects ultimately adopt, to some extent, the definition of User Experienced Data rate provided in ITU-R M.2410-0 (11/2017) [1], which is the following:

"User experienced data rate is the 5% point of the cumulative distribution function (CDF) of the user throughput. User throughput (during active time) is defined as the number of correctly received bits, i.e. the number of bits contained in the Service Data Units s (SDUs) delivered to L3, 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 equation (x).

Let W denote the channel bandwidth and SEuser denote the 5th percentile user spectral efficiency. Then the user experienced data rate, Ruser is given by:

Ruser = W × SEuser (x)"

Which can be generalised as follows: "User experienced data rate is the average achievable data rate that is available to the user equipment with a certain probability over the coverage area."

This definition also includes the M.2160-0 (11/2023) [3] definition of this KPI as "the achievable data rate that is available ubiquitously across the coverage area to a mobile device."

As aforementioned the target values reported for this KPI differ depending on the context where they refer. In general, target values range from a few Mbps to hundreds of Mbps up to the order of 1Gbps in the DL and up to 100Mbps in the UL, exceeding the IMT-2020 targets.

Peak User data rate, is commonly defined by the Max. achievable data rate for serving a single user. To this end, the exact wording selected by projects (see Table 3) to define this KPI vary between projects in terms of considering:

- the coverage area and radio conditions (i.e. some projects refer to this KPI and the target values to "under ideal conditions", under "error-free transmission", etc.)
- the channel configuration (i.e. few projects refer to this KPI and target values "at Max. available channel bandwidth and peak spectral efficiency", "summed over multiple bands if applicable").
- whether it refers to DL or UL.

However, despite highlighting such aspects in the definitions, in overall projects inherit at some point the definition of Peak Data rate provided in ITU-R M.2410-0 (11/2017) [1], which is the following:

"Peak data rate is the Max. achievable data rate under ideal conditions (in bit/s), which is the received data bits assuming error-free conditions assignable to a single mobile station, when all assignable 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 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 SEp denote the peak spectral efficiency in that band. Then the user peak data rate Rp is given by:

Rp = W × SEp   (1)

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

$$R=\sum_{i=1}^{Q} W_i \times SEp_i \qquad (2)$$

where Wi and SEpi (i = 1,...Q) are the component bandwidths and spectral efficiencies respectively.

In general, target values range from more than 1Gbps up to 1Tbps in the DL and up to >500 Mbps in the UL. Practical target values are still below IMT-2030 recommendations (ITU-R M.2160) as KPI validation is performed from the point of view of the project UCs using currently available technologies in the test facilities. Moreover, given the versatility of reported target Peak user data rates at different distances, in order to extract useful equipment specifications, target values need to be normalised on a distance/ range basis.

It shall be noted that in some cases, in order to overcome this ambiguity, projects define the peak data rate per network node/ element. To this end, we came across projects defining the target of 1Tbps per RAN node, while one has set the RIS capacity enhancement to “1Gbps within the shadow region”. In the forthcoming period we expect that data rate KPIs will be elicited for specific RAN technologies i.e. cell-free Access Points, RIS, Sensing radios etc.

Area Traffic Density is commonly defined as the traffic demand/ throughput per unit of surface/ geographical area. In some more detailed definitions Area Traffic Density also considers the success probability of achieving the target throughput per unit area for specific bandwidth and transmit power configurations. In general, the definitions adhere to ITU-R M.2410-0 (11/2017)[1], which is the following:

“Area traffic capacity is the total traffic throughput served per geographic area.”

“This can be derived for a particular UC (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.”

“In case bandwidth is aggregated across multiple bands, the area traffic capacity will be summed over the bands.”

In general, target values range from more than 250Mbps/m^2 up to 1-10Gbps/m^3 (in the DL) clearly exceeding the IMT-2020 targets, even those currently proposed in IMT-2030 recommendations (ITU-R M.2160) [3]. At this point we observe that (see Table 5), similar to the peak user data rate, area traffic density target values need to be normalised on a per surface unit basis to extract comparable results. Moreover, network planning and deployment in 3 dimensions (3D) comes up in the 6G networks discussions. In any case, such targets can only be evaluated and achieved at network planning and network deployment phases, while KPI definition and targets will need to refer to a common deployment scenario for comparison purposes.

Connection Density is defined by SNS-JU projects (see Table 4) as the total (possible) number of connected and/or accessible devices per unit area. This definition is in line with the currently provided definition by IMT-2030 recommendations (ITU-R M.2160). The target values set by SNS JU projects range between 0.1 to 10 devices/m^2 which is lower than the 1-100 devices/m^2 target of [3].

Complementarily, spectral efficiency (see Table 6) is defined in the context of a few projects. 6G-SENSES uses Spectral Efficiency as a measure of data rate normalized by channel bandwidth, distinguishing between Peak Spectral Efficiency (Max. data rate under ideal conditions per unit bandwidth) and Average Spectral Efficiency (aggregate throughput of all users divided by channel bandwidth and number of TRxPs) for its experimentations platforms. As far as the target value for the two concrete PoCs, the Cell-Free mMIMO with JCAS capabilities is expected to showcase a 5x improvement in 95%-likely per-user throughput over small-cell systems (under uncorrelated shadow fading conditions), while the experimentation platform is expected to achieve a 2x improvement comparing with the 5G performance.

Table 2: User-Experienced Data rate KPI

Project	Target Value	PoC/ UC where this KPI is evaluated
6GTandem	< 380 Mbps	Remote surgery, enabled by VR telepresence
6GTandem	< 10 Mbps	AR-enriched events (future everyday XR)
6GTandem	< 100 Mbps	DT (DT) in Industrial Environments
6GXR	DL: 560 Mbps, UL: 150 Mbps	Evaluated in 6G-XR UCs related to collaborative 3D DTs and E2E energy efficiency (UC4-5) with Max.load in a single cell.
6GXR	DL: 4.1 Gbps, UL: 570 Mbps	Evaluated in 6G-XR XR UCs related to collaborative 3D DTs and E2E energy efficiency (UC4-5) with Max.load in a single cell.
6GXR	DL: 100 Mbps, UL: 50 Mbps	Evaluated in 6G-XR UCs related to holographic communications, collaborative 3D DTs and E2E energy efficiency (UC1-5) with normal load generated by the UC applications in a single cell.
TRIALSNET	200-500 Mbps (UC1), 12-25Mbps (UC10), 10-40Mbps (UC12)	UC1 "Smart Crowd Monitoring", UC10 "Immersive fan engagement", UC12 "City parks in the metaverse", UC13 "Extended XR museum experience"
TRIALSNET	20-100 Mbps (UC1), 100-300 Mbps (UC10), 10-40 Mbps (UC12)	UC1 "Smart Crowd Monitoring", UC10 "Immersive fan engagement", UC12 "City parks in the metaverse"
TRIALSNET	100 Mbps (UC5), 40 Mbps (UC12), 8 Mbps (UC13), 50 Mbps (UC13)	UC5 "Control Room in Metaverse", UC10 "Immersive fan engagement", UC12 "City Parks in the Metaverse", UC13 "Extended XR Museum Experience"
TRIALSNET	111 Mbps (UC1), 14 Mbps (UC4), 100 Mbps (UC5), 40 Mbps (UC12), 2 Mbps (UC13)	UC1 "Smart Crowd Monitoring", UC4 "Smart traffic management", UC5 "Control Room in Metaverse", UC10 "Immersive fan engagement", UC12 "City Parks in the Metaverse", UC13 "Extended XR Museum Experience"
TRIALSNET	150 Mbps (UC2,UC3), 50 Mbps (UC7, UC8)	UC2 "Public Infrastructure Assets Management", UC3 "Autonomous APRON", UC7 "Remote proctoring", UC8 "Smart Ambulance", UC11 "Service Robots for enhanced passengers' experience"
TRIALSNET	30 Mbps (UC2, UC3)	UC2 "Public Infrastructure Assets Management", UC3 "Autonomous APRON", UC11 "Service Robots for enhanced passengers' experience"
Hexa-X-II	< 250 Mbps	Seamless Immersive Reality (Immersive Experience)
Hexa-X-II	< 10 Mbps	Cooperating Mobile Robots (Collaborative Robots); Data rate between robot and campus network. Can be significantly higher locally in a subnetwork where raw sensor data and/or AI/ML traffic is exchanged.
Hexa-X-II	< 100 Mbps	Network Assisted Mobility (Physical Awareness)
Hexa-X-II	< 100 Mbps	Realtime DTs (DTs)
Hexa-X-II	DL: 0.1 - 25 Mbps | UL: 2 Mbps	Ubiquitous Network (Fully Connected World)
6G-EWOC	V2V data rate of >100 Mb/s	For short-range (>100 m) head/rear-lamp Optical Wireless Communication (OWC) channel
6G-EWOC	User data rate of >1 Gb/s	For long-range (>200 m) V2I OWC channel.
6G-EWOC	User data rate of 10+ Gb/s	OWC channel by Focal Plane Array (FPA) antenna
DESIRE6G	50-100 Mbps UL, 130-960 Mbps DL	AR/VR app (UC1, demo1)
DESIRE6G	1-1000 Mbps	DT (UC2, demo2)
DESIRE6G	10-50 Mbps	Image Monitoring (UC3)
DESIRE6G	1 Mbps-few Gbps	Robot Control (UC4)
DESIRE6G	10 Mbps-150 Mbps	Cloud Gaming (UC5)
ImagineB5G	>160 Mbps DL / >40 Mbps UL	Situational Awareness Framework Enabling Robust Emergency Response for Urban Flood Warnings (SAFER-FLOW)
ImagineB5G	>10-20 Mbps (UL/DL)	Edge Platform for Dynamic XR Applications (DEMOCRATS)
ImagineB5G	50 Mbps	Leveraging Edge Optical Sensing for Emergency Diagnostics (LEOSED)
ImagineB5G	At least 10 Mbps (base tier - 1080p), at least 25 Mbps (top tier - 4K)	Drone Care Angel (DCA): Mobile health monitoring as a service enabled by beyond 5G
ImagineB5G	5 Mbps * number of cameras	Ultra-Low Latency M2M communications for 5G enabled Fabrication Systems (ULTRA-FAB5G)

Project	Target Value	PoC/ UC where this KPI is evaluated
ImagineB5G	0.5 Mbps (UL/DL)	5G-enabled AI gloves as Industry 4.0 IoT sensor of human activity ALMA (Ai gLoves huMan Activity) (ALMA)
ImagineB5G	100 Mbps (DL) 20 Mbps (UL)	Artificial Intelligence for Forestry Applications (AI4FS)
ImagineB5G	Remote Renderer – Hololens 2: >10-20 Mbps DL-user, high priority; iPhone – Object Detection: >10-20 Mbps UL-user, high priority	Bidirectional education system based on holographic cabins through 5G Networks (BiNetHol)
ImagineB5G	~40 Mbps DL and ~15 Mbps UL	srsRAN Platform Extension
ImagineB5G	DL 500 Mbps, UL 100 Mbps	Extension of the IMAGINEB5G French platform (F-EXTENSION)
ImagineB5G	>= 80 Mbps	Advanced Drone-Assisted Port Technology with Augmented Reality and 5G Communications (ADAPT-AR5G)
6G-SANDBOX	<1 Gbps	User Experienced Data rate defined as in ITU-R M.2410.
6G-SANDBOX	1 Tbps	To be evaluated in experimentation platforms
6G-PATH	>20 Mbps	Live video transmission for remote emergency responder training. (UC-EDU-3) Drone high quality video transmission in farming scenario. (UC-FARM-1)
ENVELOPE	Up to 100 Mbps both in UL and DL	It-UC1 "Advanced In-Service Reporting for Automated Driving Vehicles", It-UC2 "Dynamic Collaborative Mapping for Automated Driving"
ENVELOPE	>= 16 Mbps UL	Dt-UC3 "Periodic vehicle data collection for improving DT", Dt-UC4 "Vehicle testing with mixed reality", Dt-UC5 "Tele-operated driving aided by DT"
ENVELOPE	DL: 100 Mbps, UL: 50 Mbps	Gr-UC6 "MEC service handover between multiple MNOs"
FIDAL	DL: 23.2 Mbps/user	UC6.1: "Cloud-native XR PPDR application for first-aid responders"
FIDAL	UL: 81 Mbps/user	UC6.2: "Cloud-native AR PPDR Application for Law Enforcement Agents"
FIDAL	UL: 14.2 Mbps/stream	UC2 : " Digital Twin for first responders"
FIDAL	DL_< 0,1 Mbps; UL<1 Mbps	Outgoing MCPTT call

Table 3: Peak Data rate KPI

Project	Target Value	Definition	PoC/ UC/ System where this KPI is evaluated
TRIALSNET	150 Mbps (UC1, UC4)	UL cell capacity: Max. amount of data (number of bits contained in the SDUs delivered to L3) that can be transferred from all devices in a specific cell to the network over a certain period of time.	UC1 "Smart Crowd Monitoring", UC4 "Smart traffic management".
TRIALSNET	1.5 Gbps (UC1, UC4)	DL cell capacity: Max. amount of data (number of bits contained in the SDUs delivered to L3) that can be transferred from the network to all devices in a specific cell (a geographic area covered by a single cell) over a certain period of time.	UC1 "Smart Crowd Monitoring", UC4 "Smart traffic management".
CENTRIC		Max. aggregated system bandwidth that is supported by single or multiple radio frequency carriers.	
CENTRIC		Number of transmitted bits per unit time	ALML based MIMO precoding; Joint sensing and communication; ML-enabled symbol modulation; Emerging multiple-access protocols for specialized services; Task-oriented cognitive wireless scheduling; ML-based sub-band selection; Probabilistic Time Series Conformal Risk Prediction
6G-SANDBOX	>1 Tbps	Node Capacity: Max. number of users or the amount of data a network node can handle simultaneously.	RAN node
6G-PATH	>3 Gbps	Data throughput rate.	Automated logistics with AGVs (UC-CITIES-2) MCX in security coordination scenarios (UC-CITIES-3)
6G-PATH	>1 Mbps	Min. throughput needed to transmit control commands and telemetry.	Automated decision-making process for irrigation in avocado farm (UC-FARM-1)

Project	Target Value	Definition	PoC/ UC/ System where this KPI is evaluated
ENVELOPE	Up to 200 Mbps both in UL and DL	Peak data rate: Max. achievable data rate at the highest theoretical speed under ideal conditions that an end user can experience considering DL and UL traffic	It-UC1 "Advanced In-Service Reporting for Automated Driving Vehicles", It-UC2 "Dynamic Collaborative Mapping for Automated Driving"
FIDAL	DL: 800Mbps, UL 150Mbps	Max cell capacity measured during testbed evaluation. (UoP/pNet). .	FIDAL dry run testing (WP4)

Table 4: Connection Density KPI

Project	Target Value	PoC/ UC/ System where this KPI is evaluated
6GTandem	>4 devices/m^2	AR-enriched events (future everyday XR)
6GTandem	< 0.2 devices/m^2	DT (DT) in Industrial Environments
Hexa-X-II	< 0.1 devices/m^2	Cooperating Mobile Robots (Collaborative Robots)
Hexa-X-II	1-10 devices/m^2	Realtime DTs (DTs)
Hexa-X-II	10^4 devices/km^2	Network Assisted Mobility (Physical Awareness)
Hexa-X-II	0,1 devices/m^2	Ubiquitous Network (Fully Connected World)
Hexa-X-II	1-10 devices/m^2 indoor | <0.001 outdoor	Human-centric Network (Trusted Environment)
6G-SENSES	>20% increase in connection density	CF-mMIMO with JCAS capabilities. Intelligent connectivity density to achieve >20% increase in connection density compared to existing systems.
DESIRE6G	Drones per service: 1-10; Users per service: 100	AR/VR app (UC1, demo1)
DESIRE6G	1-50 nodes	DT (UC2, demo2)
DESIRE6G	1-50 nodes	Image Monitoring (UC3)
DESIRE6G	1-50 robot arms	Robot Control (UC4)
DESIRE6G	1-100 users	Cloud Gaming (UC5)
6G-SANDBOX	2 to 5 million devices/km^2	Experimentation Platforms/ Following ITU-R M.2410-0 definition: Total number of devices fulfilling a specific QoS per unit area (per km2).
ImagineB5G	364 devices/km^2	Ultra-Low Latency M2M communications for 5G enabled Fabrication Systems (ULTRA-FAB5G)
6G-PATH	1.000.000 devices/Km^2	Total number of connected devices per unit area in MCX scenarios. (UC-CITIES-3)

Table 5: Additional Capacity KPIs

Project	KPI Name	Definition	Target Value	PoC/ UC where this KPI is evaluated
Hexa-X-II	Area traffic capacity	As defined in IMT-2030 (total traffic throughput served per area)	< 250 Mbps/m2 Indoors, per floor; < 20 Mbps/m2 wide area/ outdoors	Seamless Immersive Reality (Immersive Experience); E2E perspective
ENVELOPE	Area Traffic Capacity	Area traffic capacity: Total traffic throughput served per geographic area (in Mbps/m2). The throughput is the number of correctly received bits, i.e. the number of bits contained in the SDUs delivered to L3, over a certain period of time.	Up to 5 kbps/m²	It-UC1 "Advanced In-Service Reporting for Automated Driving Vehicles", It-UC2 "Dynamic Collaborative Mapping for Automated Driving"
ECO-eNET	Area Traffic Capacity	Area capacity provided by a set of AP nodes	>1Gbps	Immersive Communication (indoor/ short range)
6G-SANDBOX	Area Traffic Capacity	The total number of devices fulfilling a specific QoS (QoS) per unit area (per km²). It considers the delivery of a message of a certain size within a certain time and success probability, for a limited bandwidth and number of TRxPs.	~1-10 Gbps/m3	Experimentation Platforms; Infrastructure Layer
6G-SANDBOX	RIS - Capacity enhancement	The total traffic throughput served per geographic area, measured in Mbps/m². It is derived from the average spectral efficiency, network deployment density, and bandwidth, summed over multiple bands if applicable.	>1Gbps within shadow region	Experimentation Platforms; Infrastructure Layer

Table 6: Spectral Efficiency-related KPIs

Project	Definition of KPI	Target Value	PoC/ UC
6G-SENSES	Spectral Efficiency related KPI: Improvement in 95%-likely per-user throughput over small-cell systems (under uncorrelated shadow fading conditions)	5x improvement	CF-mMIMO with JCAS capabilities
6G-SANDBOX	Spectral Efficiency: The measure of data rate normalized by channel bandwidth, distinguishing between Peak Spectral Efficiency (Max.data rate under ideal conditions per unit bandwidth) and Average Spectral Efficiency (aggregate throughput of all users divided by channel bandwidth and number of TRxPs).	60b/s/Hz (5G: 30b/s/Hz)	Experimentation Platforms

3.2. FAMILY #2 – LATENCY

The Latency KPIs family includes all KPIs related to the the delay introduced by the network and applications, due to either transmission, processing, queueing, propagation etc. across the various network segments and layers (Radio Access, Transmission, Core, Application). In general, the KPIs definitions are harmonised across the SNS JU projects (see Table 7) that have contributed to this part, as they focus on the end-2-end (one-way) latency. In general, when E2E or application latency is defined, definitions follow that of ITU-R M.2410-0, that is: "UP latency is the contribution of the radio network to the time from when the source sends a packet to when the destination receives it. It is defined as the one-way time it takes to successfully deliver an application layer packet/message from the radio protocol layer 2/3 SDU ingress point to the radio protocol layer 2/3 SDU egress point of the radio interface in either UL or DL in the network for a given service in unloaded conditions, assuming the mobile station is in the active state."

However, the different understanding of the endpoints and layer where E2E refers to, the difference in the architecture, and above all the diversity of applications/ services that are considered, derives in a very different targets set by projects. To this end, there is a long list of UCs with latency targets even looser than the IMT-2020 targets, however projects considering robotic UCs and sensing-based services have identified < 1ms targets. These targets are essentially considering end-points close to the RAN and are in line with IMT-2030.M2610 targets (referring to the air interface).

Jitter - Going beyond the ITU-R M.2410-0 KPIs definitions, some projects (see

Table 8) focus on the variability of the latency – jitter- with two definitions: jitter between consecutive packets and definitions based on the distribution of latency. These KPIs show the raising importance of the stability of the Latency KPI and the importance of the predictability in future 6G UCs. To this end, the identified jitter target values range significantly between ~1μs – 100ms.

Other latency components - Furthermore, some projects (see Table 9) focus on the latency components at the different network segments/ layers explicitly i.e. Radio Interface, Transmission and Application, which indicates the importance of these KPIs in all levels. Also, beyond IMT-2020 targets and KPIs definitions, SNS JU projects address other time-related KPIs associated with orchestration, provisioning and control procedures of services (e.g. Service or Slice setup time) or of network elements (e.g. RIS Update Rate, Cell-Free MIMO Access Points), which indicates the importance of the control plane in 6G networks.

In general, the family of Latency KPIs is in the focus of the SNS projects, under a collective understanding of the importance of E2E latency and the impact in 6G UCs. At the same time, the contribution of latency components in the E2E latency is examined and relevant targets are set, while some projects delve into complementary latency metrics as the variability of latency, jitter etc. highlighting the importance of stable wireless connectivity comparable to that of wired networks.

Table 7: User Plane / Application Level Latency KPIs

Project	KPI Name	Definition of the KPI	Network Layer / segments	Target Value	PoC/ UC where this KPI is evaluated
CENTRIC	E2E Latency	Time elapsed between the beginning and the end of the air interface functionality	Air Interface		Model Predictive Control
6GTandem	E2E L.	Time taken by the E2E system for a packet, of a specified size, to travel from the source to the destination.		12 ms	Remote surgery enabled by VR telepresence
6GTandem	E2E L.			20 ms	AR-enriched events (future everyday XR)
6GTandem	E2E L.			0.1 - 100 ms	DT (DT) in Industrial Environments
6G-XR	E2E L.	Time between when the source application/node sends a data packet to when the destination application/node receives it in ms.	1.Infrastructure/ app. 2.RAN,core, edge 3.UE - core/edge	50 ms	Video Processing Service in 6G-XR UC related to holographic communications (UC3) using a network edge service deployment
6G-XR	E2E L.		1.Infrastructure/ app. 2.RAN,core, edge 3.UE - core/edge	50 ms	Video Processing Service in 6G-XR UC related to holographic communications (UC1-2) with application data processing at the network edge.
6G-XR	E2E L.		1.Infrastructure/ app. 2.RAN,core, cloud 3.UE-core/cloud	200 ms	Video Processing Service, in 6G-XR UC related to holographic communications (UC1-2) with application data processing in the cloud.
6G-XR	E2E L.	Guaranteed latency between when the source node sends a control data packet to when the destination node receives it (ms). Measurement performed at L3.	1.Infrastructure 2.RAN, core, edge 3.UE - edge	10 ms	Mission Critical Service, in 6G-XR UC related to collaborative 3D DTs (UC4) with remote control of a robotic arm.
6G-XR	E2E L.	Time between when the source node sends a user data packet to when the destination node receives it (ms). Measurement performed at L3.	1.Infrastructure 2. RAN, edge 3. UE - edge	DL: 7 ms UL: 9 ms	UC related to collaborative 3D-DT (UC4). Targets are below IMT-2030 rec. as KPI validation is performed using currently available technologies in the test facilities.
Hexa-X-II	E2E L.	Time taken by the E2E system for a packet, of a specified size, to travel from the source to the destination. (i.e., different from IMT2030 for it mostly focuses on the air interface, whereas Hexa takes the whole system into account).	E2E	< 10 ms for split rendering < 50 ms for voice < 150 ms for collaboration	Seamless Immersive Reality (Immersive Experience)
Hexa-X-II	E2E L.		E2E	< 0.8 ms	Cooperating Mobile Robots (Collaborative Robots)
Hexa-X-II	E2E L.		E2E	20 ms	Network Assisted Mobility (Physical Awareness)
Hexa-X-II	E2E L.		E2E	Order of ms	Realtime DTs (DTs)
Hexa-X-II	E2E L.		E2E	10-100 ms	Ubiquitous Network (Fully Connected World)
Hexa-X-II	E2E L.		E2E	< 250 ms for AGV & care robots < 1000 ms for initiating an intervention	Human-centric Network (Trusted Environment)
Predict-6G	Deter-ministic	Time required by a deterministic network to deliver an application packet when performing a specific E2E communication service.	End point(s): Border (TSN-Detnet) Bridges/routers:1.	1-10 ms, depending on the UC architecture	Deterministic Networks, Smart factory, Multi-Domain factory, Deterministic services for critical communications

Project	KPI Name	Definition of the KPI	Network Layer / segments	Target Value	PoC/ UC where this KPI is evaluated
	Network latency		Bridges connected to end-stations. 2.Bridges connected to other TSN system (per domain KPI)		**Method of measurement:** The Service Latency is measured at the border bridges, and it is obtained as the difference between the time a packet exits a multi-domain deterministic network and that it entered. It can be mapped as combination of: -Domain OWD: Time required for transmitting the packet through a deterministic network. -RTT: Time to receive a packet that contains the answer to a previous packet request. It is highly dependent on the UC and comprises not only network latency, but also application/protocol elaboration times.
TRIALSNET	App. one way latency	Amount of time it takes at application level from the source to the destination application	App. layer, from UE to edge cloud	UC1 (Madrid, Iasi) < 100ms, UC2 800ms, UC3 80ms, UC4 < 100ms, UC9 10-15ms (03/2023)	UC1, UC2 "Public Infrastructure Assets Management", UC3 "Autonomous APRON", UC4 "Smart traffic management", UC9 "Adaptive Contro of Hannes Prosthetic Device", UC11 "Service Robots for enhanced passengers' experience", UC12, UC13
TRIALSNET	E2E L.	Amount of time it takes for the application to receive a response or output after sending a request or input to a server or network	App. layer, from UE to edge cloud	UC1 (Madrid) < 100ms, UC1 (Iasi) < 50ms, UC2 10-100ms, UC3 10-100ms, UC4 < 50ms, UC5 < 100ms, UC7 20ms, UC8 20ms, UC11 800ms, UC13 15ms	UC1 (Madrid) UC1 (Iasi) "Smart Crowd Monitoring"
ACROSS	E2E L.	The delay before a transfer of data begins following an instruction for its transfer		< 10ms	TC3.5: Heavy Hitters detection and implementation of appropriate actions to mitigate its effects promptly
6G-SENSES	E2E L.			E2E latency reduction towards the 0.1 – 1 ms target	
DESIRE6G	E2E L.		App. & network (RAN, edge)	5ms for the network, <20ms total (ideal), <50ms total (tolerated)	AR/ VR application (UC1, demo1)
DESIRE6G	E2E L.		App. & network (RAN, edge)	1-100ms for the network	DT (UC2, demo2)
DESIRE6G	E2E L.		App. & network (RAN, edge)	2ms-20ms for the network	Image Monitoring (UC3)
DESIRE6G	E2E L.		App. & network (RAN, edge)	0.5ms-10ms	Robot control (UC4)

Project	KPI Name	Definition of the KPI	Network Layer / segments	Target Value	PoC/ UC where this KPI is evaluated
DESIRE6G	E2E L.		App. & network (RAN+edge)	20-30ms for the network, <120ms total	Cloud Gaming (UC5) Note that RTT less than 150ms results in acceptable gaming experience, however good user experience requires <120ms
ImagineB5G	E2E L.	Elapsed time between the timestamps since a sensor data request is sent from one component to the UE until the moment the response is received	E2E	<=30 ms	Situational Awareness Framework Enabling Robust Emergency Response for Urban Flood Warnings (SAFER-FLOW)
ImagineB5G	E2E L.	Latency from an action performed on the capture set until it is visualized/heard on the holographic display or HDM	E2E	Between Remote Renderer and Hololens 2: <100-200ms in static settings, <60 ms in dynamic setting Between Simulation Server and clients: <10 ms.	Edge Platform for Dynamic XR Applications (DEMOCRATS)
ImagineB5G	E2E L.	Low latency are essential for the use case, high latency in critical communications can be fatal, and can cause nausea to doctors that are supporting an emergency.	E2E	<= 100 ms	Drone Care Angel (DCA): Mobile health monitoring as a service enabled by beyond 5G
ImagineB5G	E2E L.	The M2M communication will synchronize machines, so latency is critical, as late packets are no longer useful.	E2E	< 20 ms	Ultra-Low Latency M2M communications for 5G enabled Fabrication Systems (ULTRA-FAB5G). The M2M communication will synchronize machines, so latency is critical, as late packets are no longer useful.
ImagineB5G	E2E L.	Latency and jitter must stay within the given bound to permit the Mimetik application running on the edge server to predict poses and actions in real-time.	E2E	100 ms	5G-enabled AI gloves as Industry 4.0 IoT sensor of human activity ALMA (Ai gLoves huMan Activity) (ALMA)
ImagineB5G	E2E L.	For ultra-low latency communication, network latency target for the UC is having RTT latencies <100ms for the CP and <200ms for UP, for video transmission via drones.	E2E	200 ms (video streaming to edge) 50 ms (ground sensors to edge)	Artificial Intelligence for Forestry Applications (AI4FS)
ImagineB5G	E2E L.	Latency from an action performed on the capture set until it is visualized/ heard on the holographic display or HDM	App.	50ms unidirectional/ 100ms bidirectional	Bidirectional education system based on holographic cabins through 5G Networks (BiNetHol)
ImgineB5G	E2E L.	Elapsed time from the moment multimedia is requested by the operator until the multimedia is displayed at the operator screen	App.	<2ms	Situational Awareness Framework Enabling Robust Emergency Response for Urban Flood Warnings (SAFER-FLOW)
ImgineB5G	E2E L.	Round-trip delay for data transmission	E2E	<= 20 ms	Advanced Drone-Assisted Port Technology with Augmented Reality and 5G Communications (ADAPT-AR5G)
6G-SANDBOX	Network latency	Time taken for a packet to travel from the source to the destination in the UP, measured as the one-way time to successfully deliver an app. layer packet from	Infrastructure Layer	0.1 to 1ms round trip time	Experimentation Platforms; based on TS 22.261

Project	KPI Name	Definition of the KPI	Network Layer / segments	Target Value	PoC/ UC where this KPI is evaluated
		the radio protocol L2/3 SDU ingress point to the corresponding ingress point in either UL or DL, under unloaded conditions.			
6G-PATH	E2E L.	Max. latency in transmitting data from sensors and drones to the processing servers over the 5G/B5G network.	E2E	20-30ms	Drone high quality video transmission in farming scenario. (UC-FARM-1)
6G-PATH	E2E L.	Max. latency in XR Enabled interactions.	App.	<3ms	XR classroom. (UC-EDU-1)
6G-PATH	E2E L.	Max. latency in XR Enabled interactions.	App. network (RAN+edge)	< 20 ms, extended to 50 ms if object detection is done at the Edge and head movement is tracked at the HMDs. 30 - 50 ms for the manikin feedback.	XR remote emergency responder training scenario. (UC-EDU-3)
6G-PATH	E2E L.	Max. latency in AGV remote control.	E2E	<5ms	Automated logistics with AGVs (UC-CITIES-2)
ENVELOPE	UP L.	UP latency: time employed by a packet to travel from the UE to the edge server that represents the Data Network instance.	App.	<30ms	It-UC1 “Advanced In-Service Reporting for Automated Driving Vehicles”, It-UC2 Dynamic Collaborative Mapping for Automated Driving
ENVELOPE	E2E/ App. L.	Calculation of the time difference between data transmission at the application sender (e.g., client) and reception by the receiver (e.g., service)	App.	Up to 200 ms	It-UC1 “Advanced In-Service Reporting for Automated Driving Vehicles”, It-UC2 Dynamic Collaborative Mapping for Automated Driving
ENVELOPE	UP L.	UP latency is the contribution of the overall B5G system to the time from when the source sends a packet to when the destination receives it (in ms). It is defined as the one-way time it takes to successfully deliver a UP packet between the UE and the egress port of the UPF of the B5G core.	Network	<= 150ms, <=100ms, <=75ms	Dt-UC3 “Periodic vehicle data collection for improving DT”, Dt-UC4 “Vehicle testing with mixed reality”, Dt-UC5 “Tele-operated driving aided by DT”
ENVELOPE	One Way Delay	E2E delay or OWD refers to the time taken for a packet to be transmitted across a network from source to destination. It is a common term in IP network monitoring and differs from RTT in that only path in the one direction from source to destination is measured.	App.	<= 150ms, <=100ms, <=75ms	Dt-UC3 “Periodic vehicle data collection for improving DT”, Dt-UC4 “Vehicle testing with mixed reality”, Dt-UC5 “Tele-operated driving aided by DT”
ENVELOPE	E2E App. L.	Calculation of time difference between data transmission at the application sender (e.g., client) and reception by the receiver (e.g., service)	App.	between 100-2000ms	Gr-UC6 MEC service handover between multiple MNOs
FIDAL	RTT	RTT (Round Trip Time)	App & E2E	< 30 ms	Measured during a MCPTT call (MCX use case)

Project	KPI Name	Definition of the KPI	Network Layer / segments	Target Value	PoC/ UC where this KPI is evaluated
FIDAL	E2E App. L.	Latency measured by the network application	App	60.5ms (average)	UC6.1: "Cloud-native XR PPDR application for first-aid responders"
FIDAL	E2E App. L.	Latency measured by the network application	App	34ms (average)	UC6.2: "Cloud-native AR PPDR Application for Law Enforcement Agents"
FIDAL	E2E App. L.	Latency measured by the network application	App	62.5ms(average)	UC2 : " Digital Twin for first responders"

Table 8: Jitter KPIs

Project	Definition of the Jitter KPI	Network Layer / segments	Target Value	PoC/ UC where this KPI is evaluated
6G-XR	Relative latency variance between two consecutive successfully delivered data packets in percentage. The latency measurement is performed at L3.	1.Infrastructure/ app. 2.RAN, core, edge 3.UE - core/edge	DL: 10 % UL: 25 %	Evaluated in 6G-XR UC related to collaborative 3D DTs (UC4) using the baseline test facility configuration.
Predict-6G	Difference in ms between the 0 quantile (min.) and the 1-10-3 quantile of the delay variation. Method of measurement: (IP) delay variation is the difference between the OWD of two sequential packets in a flow. E2E jitter: the OWD difference between the border bridges of a multi-domain deterministic network.	End point(s): Border (TSN-Detnet) bridges/routers: -Bridges connected to end-stations. -Bridges conn. to other TSN (per domain KPI)	1 ms	Smart factory Multi-Domain factory Deterministic services for critical communications. Based on [18]. Jitter is calculated by measuring the difference between the Min. delay variation and the 1-10-3 quantile of the delay variation distribution.
ImagineB5G	Since a solution relies on long term sensing sessions jitter can affect quality. This depends to the type of data transfer used to forward the data stream to the sensing module.	E2E	<20 ms	Leveraging Edge Optical Sensing for Emergency Diagnostics (LEOSED). Since a solution relies on long term sensing sessions jitter can affect quality. It depends on the type of data transfer used to forward the data stream to the sensing module.
ImagineB5G		E2E	<= 20 ms	Drone Care Angel (DCA): Mobile health monitoring as a service enabled by beyond 5G. Low jitter needed in video streaming – to avoid nausea to doctors that are supporting an emergency.
ImagineB5G		E2E	20-100 ms	AI gloves as Industry 4.0 sensor of human activity ALMA (Ai gLoves huMan Activity). Jitter must stay within the given bound to permit the Mimetik app. At edge server to predict poses and actions in real-time.
ImagineB5G	Measures the variability in packet arrival times, affecting the stability of the connection	E2E	100 ms (video streaming to edge) 20 ms (ground sensors to edge)	Artificial Intelligence for Forestry Applications (AI4FS)
ImagineB5G	Jitter for a single radio site with a 20MHz SISO cell with a single user and a 7/2 TDD pattern considering non-ideal channel conditions.	5G UP	~10 ms (depending on SR allocation & other RAN params)	srsRAN Platform Extension

Project	Definition of the Jitter KPI	Network Layer / segments	Target Value	PoC/ UC where this KPI is evaluated
6G-SANDBOX	The short-term variations in packet arrival times of UP packets, quantified by metrics such as RMS or peak-to-peak displacement of the delay variation in packet arrival times, as defined by ITU-T.	Infrastructure Layer	Low delay jitter (order of 1µs)	Experimentation Platforms
FIDAL	Jitter		App & E23	< 5 ms

Table 9: Other Latency Components as KPIs

Project	KPI Name	Definition of the KPI	Network Layer / segments	Target Value	PoC/ UC where this KPI is evaluated
ImagineB5G	Service deployment time	Time required to deploy the orchestrator at the edge	App.	< 2 min	Enabling Proximity Services: A Server-based practical deployment (ProSe-Serv)
ImagineB5G	Service deployment time	Tracks the time required to set up and activate the service in the operational environment	App.	< 30 sec	Artificial Intelligence for Forestry Applications (AI4FS)
ImagineB5G	Latency	Critical for the quickness of patient diagnostics, it is important to measure it at two scales: on app. level (incl. sensing processing delay), and network level. Due to the longer measurement taking – in the order of several decaseconds – some latency can be tolerated. While a latency of less than 100ms is expected, the end-to-end app.-level latency should <1s.	App. & E2E	100-1000 ms	Leveraging Edge Optical Sensing for Emergency Diagnostics (LEOSED).
ImagineB5G	Latency	PDU session establishment time (from RRC setup request over security setup, UE capability exchange to PDU session establishment request)	5G CP	250 ms	srsRAN Platform Extension
ImagineB5G	Latency	Ping latency	5G UP	20-30 ms	srsRAN Platform Extension
ImagineB5G	Average processing delay	Average multimedia processing delay	App.	<0.2 ms	Situational Awareness Framework Enabling Robust Emergency Response for Urban Flood Warnings (SAFER-FLOW)
6G-SANDBOX	C-Plane Latency (network)	CP latency refers to the transition time from a most "battery efficient" state to the start of continuous data transfer.	3GPP NF	2 ms RTT	Experimentation Platforms; based on TS 22.261
6G-SANDBOX	RIS Update Rate	Time required for a RIS to update the state of all control elements in a single RIS panel, which may involve multiple updates to optimize the path between the RIS, BS, and UE.	Infrastructure Layer	<1 µS	Experimentation Platforms
6G-SANDBOX	Service Provisioning Time	Total time from submitting a request to create a containerized service or function to the actual deployment of that service/function and its provisioning to the target user.	3GPP NF	-	Experimentation Platforms; based on TS 22.261

Project	KPI Name	Definition of the KPI	Network Layer / segments	Target Value	PoC/ UC where this KPI is evaluated
6G-SANDBOX	Slice Provisioning Time	Total time from submitting a request to create a network slice to the actual deployment of that slice and its provisioning to the target user.	3GPP NF	-	Experimentation Platforms; based on TS 22.261
BeGREEN	LDPC processing time	The LDPC and the sphere decoder will be implemented on both the CPU and the GPU. The scenarios that will be tested on the in-lab POC will be run twice: Once with the CPU implementation and once with the GPU implementation. The utilization and processing time will be compared between the two configurations	Infrastructure - RAN		In-Lab emulation
BeGREEN	Cell on/off latency	Cell on/off scheme by xApp based in geolocation information	Infrastructure - RAN		In-Lab, and testbed evaluation
ACROSS	Reaction time	The time it takes for a system to detect a heavy hitter and take mitigation measures	Network		Simulation tests of DDoS attacks and large transfers
ACROSS	Setup Time	The time required for the initial setup of the system	Infra-structure	<15 min.	Use of AI for the prevention of network congestion
ACROSS	DT Network delay	The delay from the moment a packet ingress a network until the moment it leaves	Network	<10 ms	Use digital twin network
6G-PATH	Mouth to ear latency	The one-way delay from speech entering the microphone to emanating from the recipient's speaker.	PTT	<200 ms	MCX enabled Security coordination scenarios. (UC-CITIES-3)
6G-PATH	Edge connectivity	Establishment of the connectivity between the Edge and the central network over third party backhauls.	Infrastructure Layer	<5 s for transport network	Remote 3D hydrogel patch printing. (UC-HEALTH-1) Remote elderly monitoring. (UC-HEALTH-2)
6G-PATH	E2E connectivity establishment	Establishment of the connectivity for the UEs	Infrastructure - Radio Access	<2 s	Remote 3D hydrogel patch printing. (UC-HEALTH-1) Remote elderly monitoring. (UC-HEALTH-2)
6G-PATH	Latency	E2E data path	Infrastructure Layer	<200 ms	Remote 3D hydrogel patch printing. (UC-HEALTH-1) Remote elderly monitoring. (UC-HEALTH-2)
ENVELOPE	Service Setup Delay	The required time to setup a new service. It is measured as the time difference between when a new service is initiated, and the service setup is complete.	Mngmt & Orchestration Layer	< 120 s	It-UC1 "Advanced In-Service Reporting for Automated Driving Vehicles", It-UC2 "Dynamic Collaborative Mapping for Automated Driving"
ENVELOPE	Slice Setup Delay	Time elapsed between the request for a new 5G slice activation with traffic redirection and the actual moment in which the targeted users' traffic flows over the new slice.	Mngmt & Orche-stration Layer	< 180 s	It-UC1 "Advanced In-Service Reporting for Automated Driving Vehicles", It-UC2 "Dynamic Collaborative Mapping for Automated Driving"
ECO-eNET	AP activation time	Time needed for the activation of an AP of a Cell-Free MIMO cluster	Mngmt & Orch. Layer	<1 s	
ECO-eNET	AP re-configuration time	Time needed for the (re-)configuration of an AP to attach it to a Cell-Free MIMO cluster	Mngmt & Orch. Layer	<1 s	

Project	KPI Name	Definition of the KPI	Network Layer / segments	Target Value	PoC/ UC where this KPI is evaluated
FIDAL	MCPTT access time	MCPTT access time is defined as the time between when an MCPTT User requests to speak and when this user gets a signal to start speaking and it does not include confirmations from receiving users, as defined by the 3GPP Technical Specification (TS 122 179).	App & E2E	<160 ms	MCX use case
FIDAL	Mouth-to-ear latency	Mouth-to-ear (M2E) latency describes the time it takes speech input in a voice communication transmit device to be output from a receiving device (TS 122 179)	App & E2E	< 200 ms	MCS use case

3.3. FAMILY #3 – RELIABILITY & AVAILABILITY

The Reliability and Availability KPIs family comprises a set of KPIs focused on measuring the stability of performance (in terms of overall QoS) and the operability of the networks against expected performance.

Considering ***Reliability***, in defining KPIs from this family (see Table 10) projects have a harmonized understanding (even expressed under similar terms e.g. outage probability), which is directly related with the definition of Reliability in ITU-R M.2410-0. In particular, the generic definition of Reliability as a measure of "the ability of the system to successfully transmit a predefined amount of data within a pre-determined time duration with a specified probability of success" is adopted. Beyond this, several projects attempt to evaluate this KPI under measurable metrics, thus detail on the "amount of data", on the "pre-determined time duration", and set target values on the "probability of success" or the complementing "probability of failure". To this end, projects define KPIs such as packet loss and frame errors under this family, highlighting the need to integrate those KPIs into the Reliability and Availability family (also considering the relevant definitions in 3GPP specifications).

Regarding the targets declared for each project, there is a direct dependency with the UC they are analysing, and the targets range from 99% to beyond 99.9999%. It is important to highlight that some projects are aligned with IMT-2030 in the need of hyper-reliable networks, not only with a target beyond the six nines, but also stressing the performance constraints of the communication services.

Regarding ***Availability***, the contributing projects (see Table 11) have the same level of harmonization as they focus on the readiness of the network to provide communication services with certain level of quality (SLA, expected QoS). Definitions of Availability relate to the time during which the network fulfils the SLAs for all the deterministic communications compared to the non-expected downtime. Apparently this KPI is mostly relevant to operational environments and assurance of SLAs. Being however included as a service KPI in a considerable number of projects, we can acknowledge the increasing importance of deterministic service performance in a considerable number of 6G UCs, and thus the need to put in focus of 6G research technologies for evaluating and assuring availability.

Table 10: Reliability-related KPIs

Project	KPI Name	Definition	Layer / segment	Target Value	PoC/ UC where this KPI is evaluated
6GTandem	Reliability	Ability of the system to successfully transmit a predefined amount of data within a pre-determined time duration with a specified probability of success.		99%	Remote surgery, enabled by VR telepresence
6GTandem	Reliability			99.999 %	Digital Twin (DT) in Industrial Environments. Network layer packet reliability target value depends on the service. Lower reliability for process and asset monitoring and higher reliability for motion control and alarms. Five nines for process automation. [21]
6GTandem	Reliability	Ability of the system to successfully transmit a predefined amount of data within a pre-determined time duration with a specified probability of success, at the service level		97%	AR-enriched events (future everyday XR)
6GXR	XR UE satisfaction	XR UE is declared satisfied if more than X% of application data packets are successfully transmitted within a given latency constraint.	1.Infr/re 2.RAN, edge 3.UE - edge	95 %	Evaluated in 6G-XR UC related to holographic communications (UC1-2) (Latency constraint: 10 ms) The measurement is performed at L3. (3GPP TR 38.838)
CENTRIC	Reliability	Capability of transmitting a specific amount of traffic within a predetermined time duration with high success probability. (Following Hexa-X & IMT-2030)	Air Interface		Model predictive control. (Target Values not defined yet.)
CENTRIC	Outage probability	Probability that an outage will occur during a time period (ref. IMT-2030)			
CENTRIC	Bit error rate	Number of bits in error relative to the total number transmitted bits	Air Interface		ML-enabled symbol modulation
CENTRIC	Block error rate	Probability that an entire block of transmitted data contains at least one error	Air Interface		AI/ML aided Beam management; JCAS; Multi-user MIMO; Neural Receiver
PREDICT-6G	Category Packet Loss Packet Error Rate @ network layer	Percentage of the packets lost during a period of time (Following 3GPP specifications).	**End point(s)** Border (TSN-Detnet) bridges/ routers: · Bridges conn. to end-stations. · Bridges connected to other TSN system (per domain KPI)	Almost 0. Current target is 10^{-5}	Smart factory, Multi-Domain factory, Deterministic services for critical communications **Method of measurement:** The ratio between the numbers of lost packets regarding the total of packets during a period. Lost packets also include the packets that arrive late or out-of-order, so this KPI can refer to a latency requirement. Per-domain packet loss can be calculated using local metrics. Global packet loss must consider multiple paths using different segments for aggregating the availability. An E2E measurement is recommended.
PREDICT-6G	Category Packet Loss KPI name: Packet ordering	Percentage of the packets in-sequence versus the total of packets in a deterministic network. (Adapted part of [17]. Following [17] for packet order classification.)		99,9999%	Smart factory, Multi-Domain factory, Deterministic services for critical communications **Method of measurement:** For measuring the packet order, each packet has to include a sequence number (when packets belong to a stream or are marked). Depending on the sequence number,

Project	KPI Name	Definition	Layer / segment	Target Value	PoC/ UC where this KPI is evaluated
					packets can be in-sequence, out-of-order or duplicate [8]. An in-sequence packet is “A received packet with the expected Test Sequence number.” [8] An out-of-order packet is “A received packet with a sequence number less than the sequence number of any previously arriving packet.” [8] A duplicate packet is “A received packet with a Test Sequence number matching a previously received packet.” [8]
PREDICT-6G	Service reliability	Reliability is the success probability of performing a deterministic E2E communication service within a given time interval in the context of a defined SLA. (Ref. in [16]. Adhered to IETF RAW for this definition)		99,9999%	Smart factory, Multi-Domain factory, Deterministic services for critical communications **Method of measurement:** The probability is measured for layer 2 or L3 packets with the application PDU. The SLA is defined per UC and can involve any of the other KPIs defined in the project, so Reliability KPI shall aggregate other KPI measurements. E2E reliability includes the global measurement of all network segments involved in the communication. Per-domain reliability is measured in each domain or segment. Probability calculation may include scenarios that stress network resiliency: e.g., when one network segment is not available.
TRIALSNET	Service reliability	Period of time for which the service satisfies the required performance constraints (DL/UL capacity, E2E latency) (as from [20]])	App. layer, UE - edge cloud	100%	UC1 "Smart Crowd Monitoring", UC2 "Public Infrastructure Assets Mgmnt", UC3 "Autonomous APRON", UC4 "Smart traffic Mgmnt ", UC6, UC7, UC8, UC9 "Adaptive Control of Hannes Prosthetic Device", UC11 "Service Robots for enhanced passengers experience"
TRIALSNET	Reliability	Period of time for which the service satisfies the required performance constraints (DL/UL capacity, E2E latency) (as from [20]])			
Hexa-X-II	Reliability	Ability of the system to successfully transmit a predefined amount of data within a pre-determined time duration with a specified probability of success, at the service level.	E2E	99.9 - 99.999 %	Seamless Immersive Reality (Immersive Experience)
Hexa-X-II	Reliability		E2E	99.99999 %	Realtime DTs (DTs)
Hexa-X-II	Reliability		E2E	99.99 - 99.999 %	Human-centric Network (Trusted Environment)
Hexa-X-II	Reliability		E2E	99.999-99.99999 %	Cooperating Mobile Robots (Collaborative Robots)
Hexa-X-II	Reliability	Fraction of packets within latency bound E2E	E2E	99.99 %	Network Assisted Mobility (Physical Awareness)
ACROSS	Packet Loss	Packet loss during transmission		< 0.01%	TC3.5
DESIRE6G	Reliability			99%	AR/VR app (UC1, demo1)
DESIRE6G	Reliability			99.999%	DT (UC2, demo2)
DESIRE6G	Reliability			98-99%	Image Monitoring (UC3)
DESIRE6G	Reliability			99.999%	Robot Control (UC4)

Project	KPI Name	Definition	Layer / segment	Target Value	PoC/ UC where this KPI is evaluated
DESIRE6G	Reliability			command: 99.999%; video:98%	Cloud Gaming (UC5)
6G-SANDBOX	Operational Network Reliability	A measure of network reliability as in 3GPP TS 22.104 and TS 22.261, quantified using metrics such as mean time between failures or the probability of no failure within a specified period. In the context of network layer packet transmissions, it is expressed as the percentage of successfully delivered network layer packets to a system entity within the required time constraint, divided by the total number of sent packets.	3GPP Network Layer	Up to the order of 10^{-9}	Experimentation Platforms; measured at the end-user level
6G-SANDBOX	Session Reliability (Frame Error Rate)	The ratio of erroneous packets or frames to the total number of sent packets or frames, indicating the reliability of session transmissions. (Following [21])	3GPP Network Layer	Up to the order of 10^{-9}	Experimentation Platforms; measured at the end-user level
6G-SANDBOX	Packet Loss Rate	The ratio of lost packets to the total number of sent packets within specified timing constraints, reflecting the effectiveness of packet delivery in the network. (Following 3GPP TS 22.261)	3GPP Network Layer	<<0.1%	Experimentation Platforms
6G-SANDBOX	Frame Loss Rate	The ratio of lost frames to the total number of sent frames within specified timing constraints, similar to the packet loss rate but focused on frames. (Following 3GPP [21])	3GPP Network Layer	<<0.1%	Experimentation Platforms
ImagineB5G	Success of communication establishment	Success rate of direct communications following a setup instruction	E2E	>= 75%	Enabling Proximity Services: A Server-based practical deployment (ProSe-Serv)
ImagineB5G	Success of content sharing via established connection	Transmission success rate when communication is established	E2E	>= 80%	Enabling Proximity Services: A Server-based practical deployment (ProSe-Serv)
ImagineB5G	Detection of available opportunities	Rate of detection of situations favorable to data exchange via real-time direct communications	E2E	>= 90%	Enabling Proximity Services: A Server-based practical deployment (ProSe-Serv)
ImagineB5G	Reliability	Service needs to be almost always available since several seconds can affect a person's decision, and that in many medical situations can be the difference between life and death.	Network	99%	Drone Care Angel (DCA): Mobile health monitoring. Several seconds of unavailability can affect a person's decision, and that in many medical situations it is critical.
ImagineB5G	Reliability	Communication services cannot fail, since a packet lost can affect machines and lead to defects not being	Network	99%	URLLC M2M communications for 5G enabled Fabrication Systems (ULTRA-FAB5G). A packet lost can affect machines and lead to

Project	KPI Name	Definition	Layer / segment	Target Value	PoC/ UC where this KPI is evaluated
		detected in the materials not yet glazed during the production phase. This can increase the cost of production since more raw material is needed.			defects not being detected in the materials not yet glazed during the production phase. This can increase the cost of production since more raw material is needed.
ImagineB5G	Reliability	The system is supposed to monitor progress in real-time. Uptime is therefore critical.	E2E	99%	5G-enabled AI gloves as Industry 4.0 IoT sensor of human activity ALMA (Ai gLoves huMan Activity).The system is supposed to monitor progress in real-time. Uptime is therefore critical.
ImagineB5G	Reliability	Percentage of Successful API Calls/Requests; Maintain a Max. success rate	App. layer	>90%	CAMARA-API: Extending IMAGINEB5G framework & facilities
ImagineB5G	Reliability	API Data Error Rate; Keep the Min.rate of error rate	App. layer	<10%	
ImagineB5G	Reliability	Percentage of Authenticated API Requests; Achieve 100% authenticated requests	App. layer	>95%	
ImagineB5G	Reliability	Number of Unauthorized Access Attempts Blocked; percentage of blocked unauthorized access attempts	App. layer	100%	
ImagineB5G	Reliability	Platform extensibility	Appl. layer	>=4 additional endpoints	
ImagineB5G	Reliability	FR2 BLER (Block Error Rate)	Network, RAN	<5%	Extension of the IMAGINEB5G French platform (F-EXTENSION)
ImagineB5G	Reliability	Reliability		99,90%	Extension of the IMAGINEB5G French platform (F-EXTENSION)
6G-PATH	Packet loss rate	Loss of data packets during XR transmissions.	App. layer	<0.01%	XR classroom. (UC-EDU-1)
6G-PATH	Packet loss rate	Loss of data packets during video transmission.	App. layer	<1%	XR remote emergency responder training scenario. (UC-EDU-3)
6G-PATH	Reliability	Capability of transmitting a given amount of traffic within a pre-determined time duration with a high success probability.		>99%	Automated logistics with AGVs (UC-CITIES-2) MCX enabled Security coordination scenarios. (UC-CITIES-3)
ENVELOPE	Packet Loss Rate	The ratio of packets dropped to packets transmitted between two endpoints over a period of time.	App. Layer	<1%	It-UC1 “Advanced In-Service Reporting for Automated Driving Vehicles”, It-UC2 “Dynamic Collaborative Mapping for Automated Driving”
ENVELOPE	Packet Loss Rate	The ratio of packets dropped to packets transmitted between two endpoints over a period of time.	App.	<=max. threshold ratio (e.g., 0.05%)	Dt-UC3 “Periodic vehicle data collection for improving DT”, Dt-UC4 “Vehicle testing with mixed reality”, Dt-UC5 “Tele-operated driving aided by DT”
ENVELOPE	App. Service Reliability	Reliability is Max.tolerable packet loss rate at the application layer within the Max.tolerable E2E latency for that application.	App.	99%	Gr-UC6 “MEC service handover between multiple MNOs”

Table 11: Availability-related KPIs

Project	Definition of the KPI	Network Layer / segments	Target Value	PoC/ UC where this KPI is evaluated
PREDICT-6G	Percentage of time in which deterministic networks successfully operate in the context of a defined SLA. (Based on [16]. Adhering also to IETF RAW for this definition)	**End point(s):** -Border (TSN-Detnet) bridges/routers: -Bridges connected to end-stations. -Bridges connected to other TSN system (per domain KPI)	99,9999%	Smart factory, Multi-Domain factory, Deterministic services for critical communications **Method of measurement**: Measured as the result of the (uptime) / (uptime + downtime). uptime is the time during the network fulfils the SLAs for all the deterministic communications. downtime includes not only outage of service but also degradation. Per-domain Availability can be calculated using local metrics. Global Availability must consider multiple paths using different segments for aggregating the availability. An E2E measurement is recommended. **Units:** %
TRIALSNET	Ratio between the amount of time during which a specific component of the UC (app., server, NF, etc.) is responding to the received requests, and the total amount of time that the component has been deployed. [62]	App. layer, from UE to edge cloud	100%	UC1 "Smart Crowd Monitoring", UC2 "Public Infrastructure Assets Management", UC3 "Autonomous APRON", UC4 "Smart traffic management", UC6, UC7, UC8, UC9, UC11 "Service Robots for enhanced passengers' experience"
Hexa-X-II	Probability to get communication service (as defined with E2E latency) within service space when requested	E2E	99.99 %	Network Assisted Mobility (Physical Awareness)
Hexa-X-II	Percentage of time the service can be delivered	E2E	98.5 %	Ubiquitous Network (Fully Connected World)
ACROSS	Percentage of time during which the system is working correctly and meeting the expected QoS.		0,99	TC3.2
ACROSS	Recovery time after failure		< 30 s	TC3.2
DESIRE6G			5nines-8nines	DT (UC2, demo2)
DESIRE6G			99,9999%	Image Monitoring (UC3)
DESIRE6G			99,9999%	Robot Control (UC4)
ImagineB5G	Service needs to be almost always available as several secs can affect a person's decision, in many medical situations making the difference between life and death.	E2E	99%	Drone Care Angel (DCA): Mobile health monitoring as a service enabled by beyond 5G
ImagineB5G	Communication services needs to be available all the time, to ensure the proper function of the production line.	E2E	99%	Ultra-Low Latency M2M communications for 5G enabled Fabrication Systems (ULTRA-FAB5G). Communication services need to be available all the time, to ensure the proper function of the production line.
ImagineB5G	Quality control requires a high service availability; otherwise leading to missing the quality issues. Depending on user requirements, availability can vary 99% - 99.999%	E2E	99,999%	5G-enabled AI gloves as Industry 4.0 IoT sensor of human activity ALMA (Ai gLoves huMan Activity) (ALMA)
ImagineB5G	Percentage Uptime of CAMARA API; Availability	App. layer	99,90%	CAMARA-API: Extending IMAGINEB5G framework & facilities
ImagineB5G	Availability	E2E	99,9%	Extension of the IMAGINEB5G French platform (F-EXTENSION)
ImagineB5G	Device number of restarts during an extended period of time	Devices	0	Situational Awareness Framework Enabling Robust Emergency Response for Urban Flood Warnings (SAFER-FLOW)
6G-PATH			>99%	Automated logistics with AGVs (UC-CITIES-2)
ENVELOPE	Measured as a ratio between up-time and down-time.	App.	> 95%	Gr-UC6 "MEC service handover between multiple MNOs"

3.4. FAMILY #4 – MOBILITY

This KPI family focuses on mobility-related performance metrics which are essential for enabling seamless and reliable connectivity across the envisioned 6G UCs. IMT2030 identified Mobility as Max. speed, at which a "defined QoS and seamless transfer between radio nodes which may belong to different layers and/or radio access technologies (multi-layer/multi-RAT) can be achieved.".

From a standardization perspective, IMT-2030 defines mobility requirement with "The research target of mobility" that could reach 500 – 1000 km/h. Similarly, 3GPP TS 22.261 provide foundational definitions upon which one can categorize mobility scenarios, ranging from pedestrian to ultra-high-speed environments. SNS JU projects align with these benchmarks but extend the discussion by incorporating new requirements for emerging UCs, such as XR, real-time DTs, and network-assisted mobility.

As seen from the SNS projects' input in Table 12, the KPI values and use-case contexts vary across projects but remain comparable. One key finding is that the term "mobility" is frequently used not only for defining user body moving (from one position to another), but also to define user parts movement i.e. gestures, hand movement etc. To this end, relatively low-speed scenarios, targeting <2 m/s for body motion and <6 m/s for handheld devices in applications like remote surgery and AR-enriched events have been identified. Slightly higher mobility thresholds (up to 10 m/s) are set for industrial DT UC. The project's findings highlights the unique challenges in XR UCs, where even small movements—like a tilt of the head or hand—specifically at millimeter Wave (mmWave) frequencies, can severely impact connectivity stability. Even lower mobility targets (up to 1 m/s) are considered for proximity-based services and sensors in industry 4.0 IoT applications, showing its focus on localized, precision-driven scenarios. Other projects consider broader mobility ranges, targeting speeds up to 83 m/s for vehicular applications and slower speeds for pedestrian-centric environments. The collection of these target values illustrates a spectrum of mobility needs shaped by diverse application contexts identified by the presented SNS JU projects. Unlike in [3], higher values considering super fast trains and LEO satellites are not reported currently by SNS-JU projects.

Table 12: Mobility KPIs

Project	Target Value	PoC/ UC where this KPI is evaluated
6GTandem	<2 m/s for body, <6 m/s for hand Peak <180 °/s, median <50 °/s	Remote surgery, enabled by VR telepresence
6GTandem	<2 m/s for body, <6 m/s for hand Peak <180 °/s, median <50 °/s	AR-enriched events (future everyday XR)
6GTandem	< 10m/s	DT in Industrial Environments
Hexa-X-II	Seamless Handover for Pedestrian, up-to vehicular speeds	Seamless Immersive Reality (Immersive Experience)
Hexa-X-II	<5.5 m/s	Cooperating Mobile Robots (Collaborative Robots)
Hexa-X-II	up to 83 m/s seamless handover	Network Assisted Mobility (Physical Awareness)
Hexa-X-II	< 28 m/s	Realtime DTs
Hexa-X-II	up to 33 m/s seamless handover	Ubiquitous Network (Fully Connected World)
Hexa-X-II	slow vehicular, pedestrian	Human-centric Network (Trusted Environment)
6G-SENSES	28m/s (city) – 83 m/s (railway)	Exploiting sensing info to improve communication services

Project	Target Value	PoC/ UC where this KPI is evaluated
ImagineB5G	<3,6 km/h (human walking speed)	Proximity Services, Server-based deployment (ProSe-Serv)
ImagineB5G	4 km/h	5G-enabled AI gloves as Industry 4.0 IoT sensor of human activity ALMA (Ai gLoves huMan Activity)

3.5. FAMILY #5 – SENSING

This KPI family corresponds to the New IMT-2030 KPIs Category "Sensing Capabilities", related to various aspects of sensing of the environment, including localization, motion detection, and environmental context sensing, thus these KPIs are not yet defined/ standardized. As generic definition, IMT-2030 – ITU-R M.2160 defines that "Sensing-related capabilities refer to the ability to provide functionalities in the radio interface including range/velocity/angle estimation, object detection, localization, imaging, mapping, etc. These capabilities could be measured in terms of accuracy, resolution, detection rate, false alarm rate, etc."

The current definition lacks in specifying measurable, quantitative (even qualitative) criteria. Even though this KPIs Family is not widely addressed in SNS-JU projects, specific projects that focus on JCAS and other network sensing aspects elaborate heavily on the definition of the relevant measurable/quantitative KPIs in an attempt to bridge this gap. Given that, this KPI family is still undefined in standards, the projects that have answered have diverse views on the KPIs definitions. In such projects, sensing-related capabilities involve estimating distance, angle, velocity, and shape of objects. To this end (see Table 13),

- Sensing Accuracy
- Sensing Resolution
- Sensing Timing (Latency/ Times/ Rates)
- Sensing Coverage area

have been identified as quantitative criteria validating "Sensing Capabilities" functionalities and assessing their performance. The associated KPIs targets and evaluation criteria are diverse depending on the UCs where they are assessed, such as DT in Industrial Environments, Seamless Immersive Reality, Cooperating Mobile Robots, and Network Assisted Mobility.

Complementarily, it shall be mentioned network sensing is considered in the context of other (than the access) network segments i.e., at transport level; both from the network management and the environment sensing perspective.

In overall, although views on this KPIs family are still not harmonised, we can identify a strong interest from the SNS JU projects on these capabilities, and their adoption in versatile contexts.

Table 13: Sensing-related KPIs

Project	KPI Name	KPI Definition	Target Value	PoC/ UC where this KPI is evaluated
6GTandem	Sensing-related capabilities	Involves the estimation of distance and angle to an object (localization) and the estimation of velocity and shape	Required	DT in Industrial Environments
Hexa-X-II	Sensing-related capabilities	Involves the estimation of distance and angle to an object (localization) and the estimation of velocity and shape	Required	Seamless Immersive Reality (Immersive Experience); requires the human sensory system to receive realistic stimuli from a mixed or VR. Some scenarios may use joint communication and sensing (JCAS) or may apply sensor fusion of network and sensor data of connected sensors.
Hexa-X-II	Sensing-related capabilities	Involves the estimation of distance and angle to an object (localization) and the estimation of velocity and shape	Required	Cooperating Mobile Robots (Collaborative Robots); Robots and cobots depend on capturing the environmental context. Network-integrated sensing may complement or replace dedicated onboard sensors. Efficient transport of data/information from connected external sensors is likely needed.
Hexa-X-II	Sensing-related capabilities	Involves the estimation of distance and angle to an object (localization) and the estimation of velocity and shape	Required	Network Assisted Mobility (Physical Awareness) Object detection probability, Object location accuracy/ resolution, Object velocity accuracy/ resolution, Object size accuracy/ resolution
Hexa-X-II	Sensing-related capabilities	Involves the estimation of distance and angle to an object (localization) and the estimation of velocity and shape	Required	Realtime DTs Network-sensing: accuracy, resolution, and range to enrich the DT model
Hexa-X-II	Sensing-related capabilities	Involves the estimation of distance and angle to an object (localization) and the estimation of velocity and shape	Required	Human-centric Network (Trusted Environment)
6G-SENSES	Range resolution	level of detail sensed at distance		Exploiting sensing information to improve communication services
6G-SENSES	Orientation accuracy			Exploiting sensing information to improve communication services
6G-SENSES	Motion rate accuracy			Exploiting sensing information to improve communication services
6G-SENSES	Angular Resolution			Exploiting sensing information to improve communication services
6G-SENSES	Sensing Latency	Time to obtain sensing information from ISAC - measured from initiation of request	< 10 ms stipulated by O-RAN	Exploiting sensing information to improve communication services
6G-SENSES	Sensing Bandwidth	Bandwidth needed for transmitting sensing information	in the order of MB/s	Exploiting sensing information to improve communication services
6G-SENSES	Sensing update rate	Time between two different samples of sensed data		Exploiting sensing information to improve communication services
6G-SENSES	Active Sensing- Sensing accuracy of motion detection	Full duplex operation on active sensing with self-interference mitigation enables detection of human movement	within 2 m from the sensor	Exploiting WiFi sensing information for XR apps
6G-SENSES	Active Sensing -Sensing accuracy of motion detection	Hand Motion Doppler detection distance	at < 50 cm	Exploiting WiFi sensing information for XR apps

Project	KPI Name	KPI Definition	Target Value	PoC/ UC where this KPI is evaluated
6G-SENSES	Passive Sensing - Sensing accuracy of motion detection	Detection of human movement	<4 m from the sensor (human walking/ crossing the line between Wi-Fi APs).	Exploiting WiFi sensing information for XR apps
6G-SENSES	Sensing area Coverage	Percentage of Radio Covered area where network sensing (ISAC) is available	Optimally 100% of coverage area; >50% of radio coverage area	Exploiting sensing information to improve communication services
6G-EWOC	Sensing-related Capabilities	Connected radar, showing simultaneously detection and communication capabilities	for a range of <200 m and between 0.5 and 1 Gbps	Exploiting joint communication and sensing (JCAS) for Crowdsourced SLAM data fusion for Safe and Efficient ADAS Driving.
ECO-eNET	Fiber Sensing Accuracy	Fiber Fault detection accuracy	>95%	Capturing fiber sensing information for transport network fault detection in order to increase availability/ reliability.
ECO-eNET	Fiber Sensing distance (latency)	Max.sensing distance for latency-critical applications is determined by latency constraints from the application and the sensing technology		
ECO-eNET	Fiber Sensing timeliness	Sensing timeliness (time to sense) is the intrinsic sample collection rate, incl. the selected sensing data output interval from the devices and the processing speed by the ML-based algorithms		Shall be sufficient to enable timely service reconfiguration of the services for achieving availability up to 99.999%
ECO-eNET	Fiber Sensing data capacity/ data rate	The collected sensing data rate (req. capacity)		Shall be kept to Min.to reduce transmission and processing costs within the accuracy limits of the sensing application
ECO-eNET	Wireless Sensing Service Latency	Time needed to sense an object	100-500ms	Sensing involves acquiring information of the environment and/or objects within the environment, such as the distance (range), angle, or instantaneous linear velocity of objects,
ImagineB5G	Sensing precision loss	The goal of this newly introduced KPI is to reflect the potential impact of throughput optimization on sensing quality. If the entire data stream is forwarded from the camera to the sensing module the precision loss should be 0%. However, to lower the throughput and latency some precision loss can be tolerated and the KPI will be considered as fulfilled if the precision loss is lower than 2%.	<2%	Leveraging Edge Optical Sensing for Emergency Diagnostics (LEOSED).

3.6. FAMILY #6 – ELECTROMAGNETIC FIELD ASPECTS (EMF)

Electromagnetic Fields (EMF) are a necessary consideration in the development of 6G next-generation mobile networks and contribute to a major extent to the acceptability of the technology by regulators and the general public. Several areas need attention. With the deployment of 6G, the number of devices and infrastructure will increase, leading to denser networks thus more complexity and effort at system and deployment design phases to ensure that legal radiation limits and maximum EMF exposure are respected cumulatively.

This being a critical aspect in mobile and wireless networks deployment, Standards and Regulations are developed by SDOs to address EMF aspects. The main bodies that publish guidelines and standards concerning EMF are the International Commission on Non-Ionizing Radiation Protection (ICNIRP) and the International Telecommunication Union (ITU). The objective is to ensure safety.

Considering the technological challenges, 6G will operate at higher frequencies, and will use several bands, which will pose new challenges for EMF measurement and management. The challenge is to maintain network performance, while ensuring compliance with EMF exposure limits. To align with Health and Safety considerations, ongoing research aims to understand the potential health impacts of EMF exposure from next generation networks. It is essential to assess whether these findings can also be applied to the 6G era especially if new frequency bands are used.

Accurate measurement of EMF exposure is essential in deployment environments to assess and ensure compliance with standards. To this end, new methods and technologies are being developed to monitor and assess EMF levels in real-time to ensure compliance with established safety standards.

The main reference work for EMF consideration in the European 5G/6G community (as seen from Table 14) has been published by the 5G PPP TMV WG in July 2023 titled "Beyond 5G/6G EMF Considerations" [23]. In ITU-R M.2160-0 - "Framework and overall objectives of the future development of IMT for 2030 and beyond", are not specified EMF related capabilities or target values given that radiation limits are defined in ICNIRP Guidelines up to 300 GHz.

Given the broadness of the EMF topic, this section of this document serves as a reference to this work rather than covering EMF aspects in detail.

Table 14: EMF-related KPIs

Project	KPI name	Definition	Target value	PoC/ UC where this KPI is evaluated
CENTRIC	Specific Absorption Rate (SAR, W/kg)	Power absorbed per mass unit and measure for the absorption of electromagnetic fields in materials (as defined by TMV WG ICNIRP)	Not specified	EMF reduction via AI-enabled cell-free networking
CENTRIC	Absorbed power density (Sab, W/m2)	Power absorbed in tissue that closely approximates the superficial temperature rise (as defined by TMV WG ICNIRP)	Not specified	EMF reduction via AI-enabled cell-free networking
CENTRIC	Electrical field strength (E, V/m)	Unperturbed RMS (rms) values of the incident electric field strength (by TMV WG ICNIRP)	Not specified	EMF reduction via AI-enabled cell-free networking
CENTRIC	Magnetic field strength (H, A/m):	Unperturbed RMS (rms) values of the incident magnetic field strength (as defined by TMV WG ICNIRP)	Not specified	EMF reduction via AI-enabled cell-free networking
CENTRIC	Power density (S, W/m2):	Power per unit area normal to the direction of propagation (as defined by TMV WG ICNIRP)	Not specified	EMF reduction via AI-enabled cell-free networking
6G-SANDBOX	Self EMF exposure	The assessment of specific absorption rate of human exposure to radio frequency fields from handheld and body-worn wireless communication devices, as defined by IEC 62209. (by 5G PPP, SDO, IEC (IEC 62209))	Not specified	Experimentation Platforms
6G-SANDBOX	Inter EMF exposure	The evaluation of RF field strength, power density, and specific absorption rate (SAR) in the vicinity of radiocommunication base stations to assess human exposure, as defined by IEC 62232. (as defined by 5G PPP, SDO, IEC (IEC 62232))	WHO norm or more strigent national norms	Experimentation Platforms

3.7. FAMILY #7 –AI-RELATED CAPABILITIES

Artificial Intelligence (AI) and Machine Learning (ML) will play an intrinsic role in 6G mobile communications. AI/ML will be utilized in various areas, such as network optimization, mobility enhancement, security and privacy, the radio interface and performance KPIs (e.g., latency, energy efficiency, reliability, throughput, and scalability). In addition, AI is increasingly be applied in services and applications.

Recommendation ITU-R M.2160-0 - "Framework and overall objectives of the future development of IMT for 2030 and beyond", describes applicable AI-related capabilities but does not give precise definitions of target values. Applicable AI-related capabilities refer to the ability to provide certain functionalities throughout IMT-2030 to support AI enabled applications. These functionalities include distributed data processing, distributed learning, AI computing, AI model execution and AI model inference, etc.

However, AI/ML itself is subject to the achievement of its KPIs, e.g. with respect to resource consumption, effectiveness, processing time, etc. In view that no KPIs have yet been defined by SDOs, certain SNS JU project have come up with AI-related KPIs (as seem in Table 15).

Table 15: AI/ML-related KPIs

Project	KPI Name	Definition of KPI	Target value	PoC/ UC where this KPI is evaluated
CENTRIC	Training complexity	Number of real-valued of operations needed for training an AI model until convergence (assuming fixed input data distribution).		In-context learning AIML-enabled CSI compression ALML based MIMO precoding Joint sensing and communication Multi-user MIMO Neural Receiver ML-enabled symbol modulation AIML aided Beam management
CENTRIC	Inference complexity	Number of real-valued of operations needed for pre-, post-processing, and inference of in an AI model. Can also be characterized as the number of real-valued model parameters.		Model predictive control In-context learning AIML-enabled CSI compression AIML based MIMO precoding Joint sensing and communication Multi-user MIMO Neural Receiver ML-enabled symbol modulation AI/ML aided Beam management Emerging multiple-access protocols for specialized services
CENTRIC	Storage and computation for LCM	Quantification of storage and computation needed for: training data collection, model update, model monitoring, activation, deactivation, selection, switching, etc.		
CENTRIC	Model generalization capability	A model's ability to perform under unseen scenarios / data distributions.		Model predictive control In-context learning AI/ML-enabled CSI compression AI/ML based MIMO precoding Multi-user MIMO Neural Receiver ML-enabled symbol modulation AI/ML aided Beam management
CENTRIC	Over-the-air overhead	Overhead incurred for assistance information, data collection, model delivery/transfer, and other required signalling.		
CENTRIC	Simulation-to-real fidelity	The accuracy of a virtual model of a communication network as a function of the computational resources available at the virtual system.		Model predictive control In-context learning
CENTRIC	Inference speed	Latency incurred in the computation of an AI model in inference mode		DCI compression Task-oriented cognitive wireless scheduling
CENTRIC	Training loss	Value achieved on the model's loss function after training convergence is achieved.		ML-based sub-band selection
Hexa-X-II	AI/ML-related capabilities	Whether it considers "AI- Native", "Embedded AI", or "AI/ML provided by the network" capabilities	Required	Seamless Immersive Reality (Immersive Experience)
Hexa-X-II	AI/ML-related capabilities	Whether it considers "AI-Native", "Embedded AI", or "AI/ML provided by the network" capabilities	Required	Cooperating Mobile Robots (Collaborative Robots)

Project	KPI Name	Definition of KPI	Target value	PoC/ UC where this KPI is evaluated
Hexa-X-II	AI/ML-related capabilities	Whether it considers "AI-Native", "Embedded AI", or "AI/ML provided by the network" capabilities	Required	Network Assisted Mobility (Physical Awareness)
Hexa-X-II	AI/ML-related capabilities	Whether it considers "AI-Native", "Embedded AI", or "AI/ML provided by the network" capabilities	Required	Realtime DTs
Hexa-X-II	AI/ML-related capabilities	Whether it considers "AI-Native", "Embedded AI", or "AI/ML provided by the network" capabilities	Required	Human-centric Network (Trusted Environment)
ImagineB5G	Accuracy	Percentage of correct classifications made by the AI models	Improve by 20%	Situational Awareness Framework Enabling Robust Emergency Response for Urban Flood Warnings (SAFER-FLOW)
ImagineB5G	Inference speed	Assess the time it takes for the AI models to make predictions or decisions during deployment	Improve by 20%	
6G-SANDBOX	AI/ML accuracy (MSE, RMSE, etc)	Metrics to assess the performance of regression models by calculating the distance between predicted values and ground truth. Common metrics: Mean Absolute Error (MAE), Mean Squared Error (MSE), and RMSE (RMSE), with MSE the most commonly applied statistic.	>0.95	
6G-SANDBOX	AI/ML Precision (Type-I errors)	A measure of the accuracy of a classification model, specifically the ratio of true positives to the sum of true positives and false positives. Type-I errors refer to incorrectly identifying a negative instance as positive.	Not a Number (NaN)	
6G-SANDBOX	AI/ML training time	The total time taken to train a machine learning model, which can vary based on the complexity of the model and the size of the training dataset.	NaN	
6G-SANDBOX	AI/ML training effectiveness	A measure of how well a machine learning model performs on unseen data after training, often assessed through validation metrics such as accuracy, precision, recall, or F1 score.	NaN	
6G-SANDBOX	AI/ML processing times	The time taken to process input data and generate predictions or outputs from a trained machine learning model.	<0.15ms	
6G-SANDBOX	AI/ML processing resources	The computational resources (CPU, GPU, memory) utilized during the processing of data and execution of machine learning models.	NaN	
6G-PATH	Inferencing accuracy and interpretability	Prediction of the correct irrigation decisions with the usage of explainable AI techniques.	Improve >5% compared with 5G	Automated decision-making process for irrigation in avocado farm. (UC-FARM-1)
ACROSS	Level of Automation	Degree of Automation achieved	>80%	Evaluation of tasks performed automatically versus manual ones
ACROSS	ML accuracy	Accuracy of ML classification model	>0.9	Measure obtained using formula on labeled data and predictions.
ACROSS	ML precision	Precision of ML classification model	>0.9	Measure obtained using formula on labeled data and predictions.
ACROSS	Recall ML	Recall of ML classification model	>0.9	Measure obtained using formula on labeled data and predictions.
ACROSS	Mean absolute error of ML	Mean Absolute Error of ML regression model	< 10	Measure obtained using formula on labeled data and predictions.

3.8. FAMILY #8 – POSITIONING - LOCALISATION

This KPI Family addresses positioning as an enabler for 6G Usage Scenarios and applications. Traditionally, services requiring positioning base their algorithms on information obtained by the own terminal, which is generally originated locally from GNSS. This presents limitations like time to acquire location, operation in urban and indoor environments, accuracy and availability. GNSS information can be substituted by or assisted with positioning information obtained from networks as 5G. Support for Location Based Services (LCS) has been introduced in 5G. Although positioning was not addressed in IMT-2020 KPIs, the raising significance of this network capability in 6G usage scenarios and UCs led to its being included in the suggested new capabilities of IMT-2030. The given definition has been provided in [3]: "Positioning is the ability to calculate the approximate position of connected devices. Positioning accuracy is defined as the difference between the calculated horizontal/vertical position and the actual horizontal/vertical position of a device."

This KPI has been addressed in the previous network generations by 3GPP. In particular, 3GPP, in TS 22.261 [21], identifies requirements that apply to 5G when providing that support, including a section on 'High-accuracy positioning', defining seven 'Positioning service levels', according to the following parameters:

1. Absolute vs Relative (between two UEs) positioning
2. Horizontal (0.2 m to 10 m) and Vertical (0.2 m to 3 m) accuracy (defined as "95% confidence level")
3. Service availability (95% to 99.9%)
4. Service latency (10 ms to 1 s)
5. Service area (indoor/outdoor) and velocity (up to 30 km/s in indoor; between 60 and 500 km/s in outdoor)

Additionally, Time-To-First-Fix (TTFF) and UE's heading are also considered, as is the service model: on request, periodically (0.1 s to 1 month) or event triggered.

Following existing work (esp.by 3GPP), SNS JU projects have a harmonised view of the metrics/KPIs to evaluate positioning. The identified KPIs fall inside the ones set by 3GPP, being:

1. Positioning accuracy, latency and integrity
2. Direction/orientation accuracy

Still, there are some differences between 3GPP definitions and the projects' definitions and requirements, specifically in the way accuracy is measured. While projects define "accuracy" as the "difference between the calculated horizontal/vertical position and the actual horizontal/vertical position of a device" and specific accuracy target values between 1cm and 10m, 3GPP provides no information on that. For almost all projects, position accuracy is a relevant KPI. Required values stand below 1 meter with some mentioning the need for less than a 1 cm. The time required to obtain the positioning measurements is less important. Direction accuracy is also mentioned. Details are provided in Table 16 and Table 17.

Table 16: Positioning- Localisation KPIs

Project	KPI name	Definition	Target value	PoC/ UC where this KPI is evaluated
6GTandem	Positioning Accuracy	Difference between the calculated horizontal/vertical position and the actual horizontal/vertical position of a device.	< 5cm, <5°	Remote surgery, enabled by VR telepresence
6GTandem			< 1m, <5°	AR-enriched events (future everyday XR)
6GTandem			<= 1 cm & <10 degrees	DT (DT) in Industrial Environments
Hexa-X-II	Positioning Accuracy	Difference between the calculated horizontal/vertical position and the actual horizontal/vertical position of a device.	<= 10 cm, horizontal & vertical	Seamless Immersive Reality (Immersive Experience)
Hexa-X-II			< 0.1 m fine, <1m coarse	Cooperating Mobile Robots (Collaborative Robots)
Hexa-X-II			<= 10 cm	Realtime DTs (DTs)
Hexa-X-II			< 10 location accuracy | <0.3 - <1 positioning accuracy | <0.1 relative positioning accuracy	Human-centric Network (Trusted Environment)
Hexa-X-II			1 meter (3D) precision with 99.9% reliability within 99.9% of service space (0.1)	Network Assisted Mobility (Physical Awareness)
CENTRIC	Positioning Accuracy	Position estimation accuracy. (3GPP, TS 2.261)		UC10 "immersive Fan Engagement"
6G-Senses	Positioning Latency	Time to acquire objects' position	< 10 ms to comply with E2E service latency of <1 – 10 ms.	Exploiting sensing information to improve communication services
6G-Senses	Positioning Accuracy			Exploiting sensing information to improve communication services
6G-EWOC	Localisation accuracy	Incremental reconstruction of scenes from multiple ego-poses and discrimination of dynamic elements with range precision better than 0.5 m and ACC > 60%. (ETSI TS 103 324 V2.1.1 (2023-06))	Range precision < 0.5 m. Accuracy as mean deviation between the estimated positions and the actual ground truth positions of vehicles and other road users > 60%	Exploiting EWOC's V2V and V2I communication KPIs to provide ACC > 60%
6G-EWOC	Direction/ Orientation accuracy	Demonstration of a data fusion sensor suite with low parallax error based on connected Lidar/radars. (ISO/IEC 17025, as measurement uncertainty)	Less than 10% of the measured value	Exploiting EWOC's JCAS connected Radar and Lidar to provide low parallax error
ImagineB5G	Positioning Accuracy	Accuracy of the device's geolocation positioning	Improve 20%	Situational Awareness Framework Enabling Robust Emergency Response for Urban Flood Warnings (SAFER-FLOW)
6G-PATH	Positioning/ Localisation	Position/localisation accuracy	< 1m (6G-1cm in 3D representation)	MCX enabled Security coordination scenarios. (UC-CITIES-3)

Table 17: Localisation- specific KPIs

Project	KPI name	Definition	Target value
CENTRIC	Localisation accuracy	Accuracy in the positioning of the device obtained through the 5G network	
6G-SANDBOX	Localization accuracy	A measure of the difference between the actual location of an entity and its estimated location, which can be expressed in horizontal (XY) and vertical (Z) coordinates. Common statistics include MSE, RMSE, and the 99% localization error in meters. (acc. [21])	<1cm in 3D
6G-SANDBOX	Direction accuracy	A measure of the difference between the actual location of an entity and its estimated location, which can be expressed in horizontal (XY) and vertical (Z) coordinates. Common statistics include MSE, RMSE , and the 99% localization error in meters. (acc. [21])	
6G-SANDBOX	Localization related delays	Metrics for Reliability, availability and localization delays and services, include: (1) First-time-to-fix: Time until the first location estimate is provided. (2) Localization latency: Time between a request for positioning information and the availability of that position. (3) Update rate: Time between successive position estimates., (4) Availability: Mean-time between failures (MTBF) or the duration of service availability. (5) Reliability: Ratio of erroneous positioning estimates to the total number of positioning estimates. (acc. 3GPP, TS 22.261)	
6G-SANDBOX	Localization integrity (error)		

3.9. FAMILY #9 – ENERGY EFFICIENCY

Energy Efficiency is one of the core and emerging categories of the 6G KPIs, directly linked with the sustainability of both the 6G networks and the connected devices, within all ecosystems and UCs. More specifically, SNS projects utilise two categories for energy efficiency a) related with the Network [1] and b) in NFV ([21][22]). As a result, this family comprises the KPIs which are related to both the network level and applications/devices level.

The standard definition on the network energy efficiency is the capability of a RIT/SRIT to minimize the radio access network energy consumption in relation to the traffic capacity provided. The definition considers two main aspects: a) Efficient data transmission in a loaded case; b) Low energy consumption when there is no data (sleep ratio).

As far as the recent findings are coming up from the SNS projects (see Table 18), energy KPIs and methodological approaches depend highly on the nature of the projects and the UCs designed for different verticals. The definitions for the energy efficiency in SNS projects are well defined, given the prioritisation in achieving high "green", meaning environmental and sustainability impact, based on the reduction of energy consumption. The KPIs are well defined based on the definitions used by SDOs, such as the IMT-2020 and the updates in IMT-2030, the outcomes of the flagship project Hexa-X I and the proposed framework and measuring methodology, for the great majority of the projects.

The definitions capture from the projects follow the standards, while the KPIs are expressed in terms of percentage (%) reduction in energy in comparison to 5G, ranging from >20% to 50%. The great difference among the target values depends on the heterogeneity of the UCs and PoCs implied, with specific target values determined numerically. Another definition given is the network and devices energy consumption as a multiplier of reduction in comparison with the 5G networks. Complementarily, another important aspect identified is the impact of the AI/ML enabled adaptive modulation and the energy needs for AI/ML training.

In overall, many projects address energy efficiency as a measure of (environmental) sustainability, although the KPIs definitions vary in terms of target values and baseline references. In any case, the fact that the focus is given in the field of energy promise that well-defined KPIs and target values will be shaped for the upcoming 6G experimentations and UCs.

Table 18: Energy-related KPIs

Project	KPI Name	Definition of KPI	Target Value	PoC/ UC where this KPI is evaluated
6G-SANDBOX	Network Energy Efficiency	The capability of a Radio Interface Technology (RIT) or Set of Radio Interface Technologies (SRIT) to minimise energy consumption in relation to the traffic capacity provided. It includes efficient data transmission during loaded conditions and low energy consumption when idle, measured by metrics such as average spectral efficiency and sleep ratio.	10x comp. to 5G	
6G-SANDBOX	Device Energy Efficiency	The capability of the RIT/SRIT to minimise the power consumed by the device modem in relation to traffic characteristics. Similar to network energy efficiency, it focuses on efficient data transmission and low energy consumption during idle periods.	10x comp. to 5G	
CENTRIC	Network Energy Efficiency	Number of information bits that are transmitted per unit energy consumed (bits per Joule)		Model predictive control ML-enabled symbol modulation
BeGREEN	Base Station Energy Efficiency	BS Energy Consumption used in Energy consumption model for 5G/B5G base-stations		Simulation
BeGREEN	Area energy Efficiency	Network energy consumption per area over time		Simulation
BeGREEN	MIMO Processing (LDPC and sphere decoding Energy Efficiency	Energy efficiency of optimized, accelerated implementation of MIMO LDPC and sphere decoder	≥15%	Emulation (in the lab)
BeGREEN	Radio Unit Energy Efficiency	RU Power amplifier blanking, when there is no data to transmit	≥ 40%	Simulation, Emulation (in the lab), and evaluation on the Outdoor Testbed
BeGREEN	UPF, CU-UP Energy Efficiency	Bare metal server energy consumption reduction at low load with respect to bare metal server energy consumption at peak load, without noticeable impact on UP traffic performance.	≥ 20%	HW Emulation (in the lab)
BeGREEN	Edge AI Service Energy Efficiency	Energy consumption reduction on the server that runs the edge AI service AI service power consumption	≥ 20%	Emulation (in the lab)
BeGREEN	CU Energy Efficiency	Energy consumption reduction on running CU on ARM and HW accelerating PDCP of CU-UP	≥ 20%	HW Emulation (in the lab)
BeGREEN	Near-Real-Time RIC Power Efficiency	Power consumption reduction on running Near-RT RIC on ARM and HW accelerating xApp	≥ 20%	HW Emulation (in the lab)
6G-EWOC	Energy Efficiency	Provisioning of traffic flows achieving 50% reduction of the energy consumption	≥ 50%	Autonomous driving for connected vehicles for efficient transportation

3.10. FAMILY #10 – COVERAGE -RELATED KPIS

Coverage refers to the ability to provide access to communication services and applications for users, within a desired service area. 6G networks are expected to support enriched and potential immersive experience, enhanced ubiquitous coverage, and enable new forms of collaboration. In the current IMT-2030 work, coverage is defined as the cell edge distance of a single cell through link budget analysis, essentially referring to "link budget" or "cell range", without touching upon the statistical behaviour of the radio channel or the outage probability.

In the context of the contributing SNS projects (see Table 19), coverage KPIs include either link budget metrics following the IMT-2020 and current IMT-2030 definitions or percentage metrics, e.g. of a target area under study covered with the required network performance to support specific usage scenarios. Latter definitions are better linked with the term ubiquitous, which is part of the ITU-R and 6G-IA vision.

In the first case coverage KPIs follow the definitions of 3GPP specifications, including metrics like Reference-Signal Received Power (RSRP)/Signal-to-Interference-and-Noise Ratio (SINR)/ and Reference-Signal Received Quality (RSRQ) for measuring the network's signal level and quality (e.g. in the context of for PPDR and Situational Awareness UCs).

In the second case (coverage as percentage), definitions refer more to KPIs evaluated at operational environments, where target values are converging to the level >99% (of a specific target area under study). More specifically, projects reported a target value of >99% for their for UCs that include "Smart Crowd Monitoring", Network Assisted Mobility (Physical Awareness), Realtime DTs and Ubiquitous Network (Fully Connected World).

Table 19: Coverage -related KPIs

Project	KPI Name	Definition of KPI	Target Value	PoC/ UC where this KPI is evaluated
TRIALSNET	Coverage	Geographic area where a network signal can be received and used by a device	99%	UC1 "Smart Crowd Monitoring"
Hexa-X-II	Coverage	Fraction of defined service space (in 3D) within latency bound.	99.99 %	Network Assisted Mobility (Physical Awareness)
Hexa-X-II	Coverage	Ability of the network to provide access to communication services for users in a desired service area | Both indoor & outdoor	99.99 %	Realtime DTs (DTs)
Hexa-X-II	Coverage	Ability of the network to provide access to communication services for users in a desired service area.	Up to 10-15 kms range (cell radius) | 99.9% area coverage with integrated networks	Ubiquitous Network (Fully Connected World)
ImagineB5G	RSSI	RSSI UE measurements	>= -85 dBm	Situational Awareness Framework Enabling Robust Emergency Response for Urban Flood Warnings (SAFER-FLOW)
ImagineB5G	RSRP	RSRP UE measurements	>= -70 dBm	SAFER-FLOW
ImagineB5G	RSRQ	RSRQ UE measurements	>= -15 dBm	SAFER-FLOW

3.11. FAMILY #11 – COMPUTE

This type of KPIs refer to the ones which are related to the infrastructure elements, which can either be hardware or software. They are measurable quantities that constitute the computing power of PCs and/or servers that are allocated and consumed for computing activities. The main elements of the compute resources are the central processing unit (CPU) whose measurement is the clock frequency in GHz. Today's processors come in packages with multiple cores, each one having its own processing capabilities, which allows instructions to be processed simultaneously. Another compute resource is the memory which is measured in bytes. The speed at which data can be read or written in RAM is measured in gigahertz (GHz).

Nowadays, given the increased cloudification of applications and network functions and their distribution across the edge-cloud continuum, a lot of attention is paid on the allocation of cloud/edge compute resources and the joint optimisation of compute and network performance. Given that compute infrastructures constitute a separate (huge) technology domain (per se) there is no harmonised view across SNS projects on the key factors thus metrics (of this category) to be used in view of 6G networks performance evaluation. Neither can one find indicative KPIs related to this infrastructure aspect in networking related standards.

In general, as can be seen from Table 20, in overall compute KPIs refer to resource utilisation and scalability aspects especially considering the edge, or/ and to assessing the optimisation of resource allocation/ utilisation mechanisms/ algorithms.

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Table 20: Compute-related KPIs

6GXR	KPI Name	KPI Definition	Target Value	PoC/ UC where this KPI is evaluated
6GXR	Edge computational resource usage	Edge resource utilization per app/VNF in terms of CPU, RAM, GPU		Scalability enabler, edge continuum enabler
6GXR	OPEX @edge	Operation expenditure @edge		
6GXR	Delta in network Mngmt decision	Delta in network management decision		
6GXR	Availability	Availability		UC2 - Routing to the best Edge
6GXR	Resource utilization	Resource utilization		
6GXR	Scale-out latency	Resource utilization		
6GXR	Computing resource utilization	Computing resource utilization		
TRIALSNET	Precision	How often the algorithm is correct when it predicts a positive outcome	0.8	UC2 "Public Infrastructure Assets Management", UC3 "Autonomous APRON", UC11 "Service Robots for enhanced passengers' experience"
TRIALSNET	Recall	How often the algorithm correctly predicts a positive outcome out of all the actual positive outcomes.	0.6	UC2 "Public Infrastructure Assets Management", UC3 "Autonomous APRON", UC11 "Service Robots for enhanced passengers' experience"
TRIALSNET	F1 score	Harmonic mean of precision	0.68	UC11 "Service Robots for enhanced passengers' experience"
ACROSS	Scalability	System capacity to handle increased users	60 nodes	TC3.2
6G-SANDBOX	Computational resource utilization/ optimization	Metrics (Average, Peak, Mean) representing the cumulative usage percentage of total computational resources across hosts and data centers used for 6G service provisioning, reflecting the efficiency of resource utilization.	~40% reduction/optimization of computation versus 5G	Experimentation Platforms
6G-SANDBOX	Optimization periodicity	A set of KPIs that define the targets for triggering optimization functionalities, which can be based on predefined periodicity parameters or utilization thresholds.	<1% with hour periodicity	Experimentation Platforms
ImagineB5G	Resource utilization	Resource utilization in terms of computing, storage, and networking, of the hosts and data centers across the network domains	~40% reduction/ optimization of computation vs. 5G	
ImagineB5G	Scale-out Latency	The time it takes from submitting the order of creating (or scaling-out) a containerized function to the actual deployment of such function	<1% with hour periodicity	

3.12. FAMILY #12 – OTHER KPIS

Finally, Table 21 provides some other KPIs provided by the projects, that do not belong to the other families. These are related to qualitative measurements for both the networks and the end-services, such as the level of automation and the quality of the monitoring, the level of security conformance, and privacy, the service quality and safety, as well as other metrics used for the PoC/UC evaluation.

Table 21: Other KPIs

Project	KPI Name	Definition of KPI	Target Value	PoC/ UC where this KPI is evaluated
6G-SANDBOX	Anomaly detection precision	A measure of the accuracy of an anomaly detection system, calculated as the ratio of true positives (TP) to the sum of true positives and false positives (FP). It indicates the proportion of correctly identified anomalies relative to the total instances identified as anomalies, with values ranging from 0 to 1.		Experimentation Platforms
6G-SANDBOX	Security Conforma-nce	The process of evaluating and verifying whether security controls, protocols, configurations, and implementations within a network align with specified security standards and guidelines. It assesses the effectiveness of security measures against established criteria, including access controls, encryption, authentication, and intrusion detection systems.	Pass all test vectors & robust against fuzzing	Experimentation Platforms
6G-SANDBOX	Tenant data privacy	Metrics used to measure and enhance the effectiveness and maturity of tenant data privacy programs, focusing on customer trust, risk mitigation, and business enablement. It includes compliance metrics (e.g., data subject requests) and advanced metrics (e.g., privacy breaches, customer satisfaction) to track performance and demonstrate accountability.	Pass all test vectors & robust against fuzzing	Experimentation Platforms
6G-SANDBOX	Service, safety, integrity and maintain-ability	The property of being accessible and usable upon demand by an authorized entity, expressed as the percentage of time QoS targets are met. It is calculated as Availability = (1 – (MTTR/MTBF)) x 100%, where MTTR is the mean time to repair and MTBF is the mean time between failures.	99.999% Towards 99.9999 %	Experimentation Platforms
ENVELOPE	Compliance with Security & Privacy Standards	The percentage of the system that complies with security and privacy standards or regulations (e.g., GDPR, Data Act, etc).	> 90%	It-UC1 "Advanced In-Service Reporting for Automated Driving Vehicles", It-UC2 "Dynamic Collaborative Mapping for Automated Driving"
ACROSS	User Service Security Extension Time	Time for an orchestrator to augment a deployed user service with an additional security component placed between the traffic source and the service for filtering.	sec	Time for an orchestrator to add a security component to a deployed user service for traffic filtering.
ACROSS	End-user telemetry provisioning Time	Time it takes for an orchestrator to provision telemetry for an end user's service atop existing compute and 5G resources.	< 5sec	Time taken by an orchestrator to provision telemetry services for an end-user service, utilizing already provisioned compute & 5G resources.

ACROSS	Amount of blocked traffic over total traffic	Average amount of traffic blocked through the access control (ACL), layer over the total amount of traffic.	< x%	Proportion of traffic blocked by the ACL compared to total traffic volume.

4. INSIGHTS FROM KPIS DEFINITIONS AND MEASUREMENT ASPECTS

IMT-2020 and 3GPP standardized 5G KPIs definitions detailed on traditional KPIs, which were primarily focused on data rate, latency, and reliability to address the requirements of 5G vertical services/ service classes (i.e. eMBB, URLLC, mMTC). Going beyond the 5G vertical services, and service classes the 6G networks vision introduces innovative UCs, such as holographic communications, DTs, multisensory extended reality (XR), and collaborative robotics. These applications demand a redefinition and expansion of traditional KPIs). As 6G integrates advanced technologies like joint communication and sensing (JCAS), edge computing, and AI-driven optimization and applications, new KPIs emerge, emphasizing precision, intelligence, and environmental sustainability. UCs like holographic telepresence and XR require ultra-low latency (below 0.1 ms) and high reliability to deliver immersive experiences. DTs in industrial and urban environments extend the scope of KPIs to include sensing accuracy, network-assisted mobility, and compute-resource utilization. Furthermore, autonomous robotics and vehicular communications demand mobility KPIs capable of supporting seamless handovers at high speeds. These shifts highlight the importance of dynamic and context-aware KPIs and thresholds (i.e. tailored to specific scenarios) that adapt to diverse and evolving operational environments. This has been visible from the definitions of new KPIs and the wide range of target values specified by the SNS-JU projects. Vice versa, KPIs definitions and target values shall be considered along with the context where these are defined.

Furthermore, in line with the preliminary IMT-2030 vision, KPI Definitions need to be revisited in order to account for new dimensions, such as network intelligence, energy efficiency, and sensing, alongside traditional metrics. This includes integrating KPIs for AI/ML capabilities (such as predictive network management and real-time optimization), for energy consumption as primary means to quantify sustainability (that are quantitative, measurable and comparable across platforms/ networks like). To this end, at some point, Cross-Domain metrics would be necessary to evaluate UCs like DTs requiring cross-domain coordination, by incorporating KPIs that measure interactions between sensing, communication, and compute layers.

From another perspective, accurate measurement and validation of KPIs in 6G networks are critical to ensure that the ambitious targets for performance, reliability, and sustainability are met. As too few SNS JU projects have reached the phase of testing and validation at present, KPIs assessment aspects are still not completely shaped. Future efforts on KPIs will need to focus more on defining enhanced and common methodologies for testing and KPIs validation. To this end, given the complexity and diversity of 6G UCs, measurement methodologies must evolve beyond the traditional frameworks used in 5G to accommodate multi-dimensional and context-specific KPIs.

With view to the SNS -JU KPIs definitions and preliminary work on measurement aspects, we outlined below are some critical insights for the KPIs evaluation:

- E2E measurement methodologies are essential for assessing KPIs across various ends of the entire network stack, from the user equipment to the edge, core, cloud end-points. This includes the evaluation of KPIs in dynamic network deployment and configuration scenarios. Tools like real-time traffic generators and network emulators will play a significant role in simulating diverse traffic flows and patterns and in stress-testing system performance.
- Multi-Layer and Cross-Domain Measurements. 6G KPIs (especially in the context of UCs evaluation) often span multiple domains and include diverse streams and components for sensing, communication, and computing. Measurement frameworks should capture interactions across these domains. For instance, evaluating KPIs for DTs requires synchronized measurements of sensing precision, data processing latency, and communication reliability. Cross-layer monitoring tools that integrate data from sensors, network nodes, and computational resources will provide the granularity needed for such assessments.
- AI-Assisted Measurement Tools. AI and machine learning (ML) will be integral to 6G KPI measurement. These technologies can predict performance trends, identify anomalies, and be used as means to optimize various KPIs. In future, AI-driven tools can also automate data collection and analysis, providing insights into complex metrics such as network intelligence, energy efficiency, and contextual reliability.
- Testbeds and Simulation Platforms. Advanced testbeds are critical for validating 6G KPIs under "6G conditions" (i.e. data traffic conditions created/influenced by 6G services rather than by 5G ones). These platforms should be able to replicate diverse 6G environments. Hybrid testbeds that combine physical infrastructure with DTs of network components will allow for scalable and flexible KPI validation.
- Dynamic and Adaptive Measurement Frameworks. As 6G networks are expected to support highly dynamic UCs, measurement methodologies should be adaptive. Real-time monitoring systems will be essential for capturing transient behaviours and maintaining service quality.

Last but not least, with view to the KPIs definitions, it becomes apparent that harmonization across regions and standardization bodies is critical to achieve consensus on KPI frameworks for 6G networks performance and capabilities evaluation. Harmonized metrics and testing methodologies will further facilitate global deployment and compatibility across 6G networks.

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5. SUMMARY AND NEXT STEPS

The SNS JU fosters research collaboration and promotes a harmonized European vision for 6G evolution, spanning research, development, and deployment. A key pillar of this initiative is the TMV WG, which builds on the methodologies and achievements of the 5G PPP TMV working group. Its focus is on formalizing 6G KPIs, harmonizing testing and measurement procedures, and fostering reusability across projects.

To support its objectives, the TMV WG has gathered input from SNS JU-funded projects on KPIs which have been identified and used to guide their technical developments. A number of SNS JU-funded projects contributed to the report, providing perspectives shaped by their diverse UCs and deployment scenarios. Although KPI definitions and target values vary across projects due to referring to diverse contexts (i.e. use cases, network deployments, layer etc.), this work provides critical insights into the envisioned capabilities and evaluation criteria of future 6G networks/ platforms.

This document constitutes the first white paper by the SNS JU TMV WG and consolidates the insights captured from SNS JU Phase I and II projects on defining 6G KPIs, their target values, and their contexts in trials and use cases (UCs). The motivation behind the document is to address gaps in the current definitions of 6G capabilities, offering technical interpretations and evaluation methods for emerging metrics not yet standardized. To this end, projects' input have been classified in families following existing classifications from global research efforts and SDOs.

The key findings of this work can be summarized as follows:

- Traditional network KPIs (e.g. User Experienced/ Peak Data rate, capacity, latency, mobility, spectral efficiency. etc.) will still be used for the basic evaluation of future 6G networks/ platforms, as basic, comparable, measurable metrics of performance. The reported target values are very diverse following the diversity of the use cases/ services/ network deployments where they refer, and the immaturity of application services implementing the use cases. In general, the optimal target values of these KPIs will be further enhanced (compared to 5G), while evaluation shall be performed in a context-aware framework. Further work shall focus on analysing and validating/ harmonizing the target values in a contextual basis.
- Besides the traditional KPIs, the envisioned 6G networks will enable innovative use cases, such as holographic communications, DTs, multisensory XR, collaborative robotics etc., based on new capabilities like, network intelligence, energy efficiency, and sensing capabilities. These will demand redefinition and expansion of traditional KPIs, and the multi-factor evaluation of 6G platforms/ networks/ services. Currently, a gap exists between the definition of new 6G capabilities by SDOs and the definition of KPIs and metrics that are Specific, Measurable, Achievable and Relevant to these capabilities. To this end, this white paper provides a listing of KPIs defined by SNS-JU projects addressing these new capabilities. Further work shall focus on analysing and validating/ harmonizing these KPIs and further bridging gap between the high-level capabilities and KPIs definition. Even further, cross-domain metrics will also be

necessary to evaluate complex UCs like DTs, which require coordination across sensing, communication, and computing layers.

- Considering the KPIs evaluation, most SNS JU projects are still in early phases, and KPI assessment methodologies remain under development. In more mature phases (especially at network deployment and operational phases) harmonized measurement and validation methodologies of 6G KPIs will be required for contextual and replicable 6G platforms comparative evaluation. Future efforts would need to focus on these aspects. Furthermore, considering the aforementioned need for cross-domain metrics to evaluate complex 6G use cases and services, cross-layer/ cross-domain monitoring tools will be vital for capturing and evaluating performance aspects.
- Advanced testbeds and simulation platforms will be needed to validate KPIs under 6G-specific conditions, replicating diverse environments influenced by 6G services rather than 5G ones. Hybrid testbeds that combine physical infrastructure with digital twins of network components will allow scalable and flexible validation.
- Harmonization of KPI definitions and testing methodologies across regions and standardization bodies is critical to ensuring global deployment and compatibility of 6G networks. Unified metrics and frameworks will facilitate collaboration, promote interoperability, and streamline the development of 6G systems worldwide.

Overall, this white paper provides a collective reading of 6G KPIs captured by SNS JU projects. It aims to consolidate views coming from the research community on 6G networks performance targets, and to contribute to bridging the gap between the envisioned new 6G capabilities and the definitions of Specific, Measurable, Achievable and Relevant metrics to evaluate them. Given the fact that 6G research is at initial phases, it shall be considered as an initiation of an iterative process to reach these goals.

Future work within the TMV WG will put emphasis on further analysing, refining, specifying definitions especially for the new capabilities and contextual KPIs as well as on harmonising and contextualising the corresponding targets. Efforts will also focus on defining and cross-validating relevant measurement methodologies for these KPIs.

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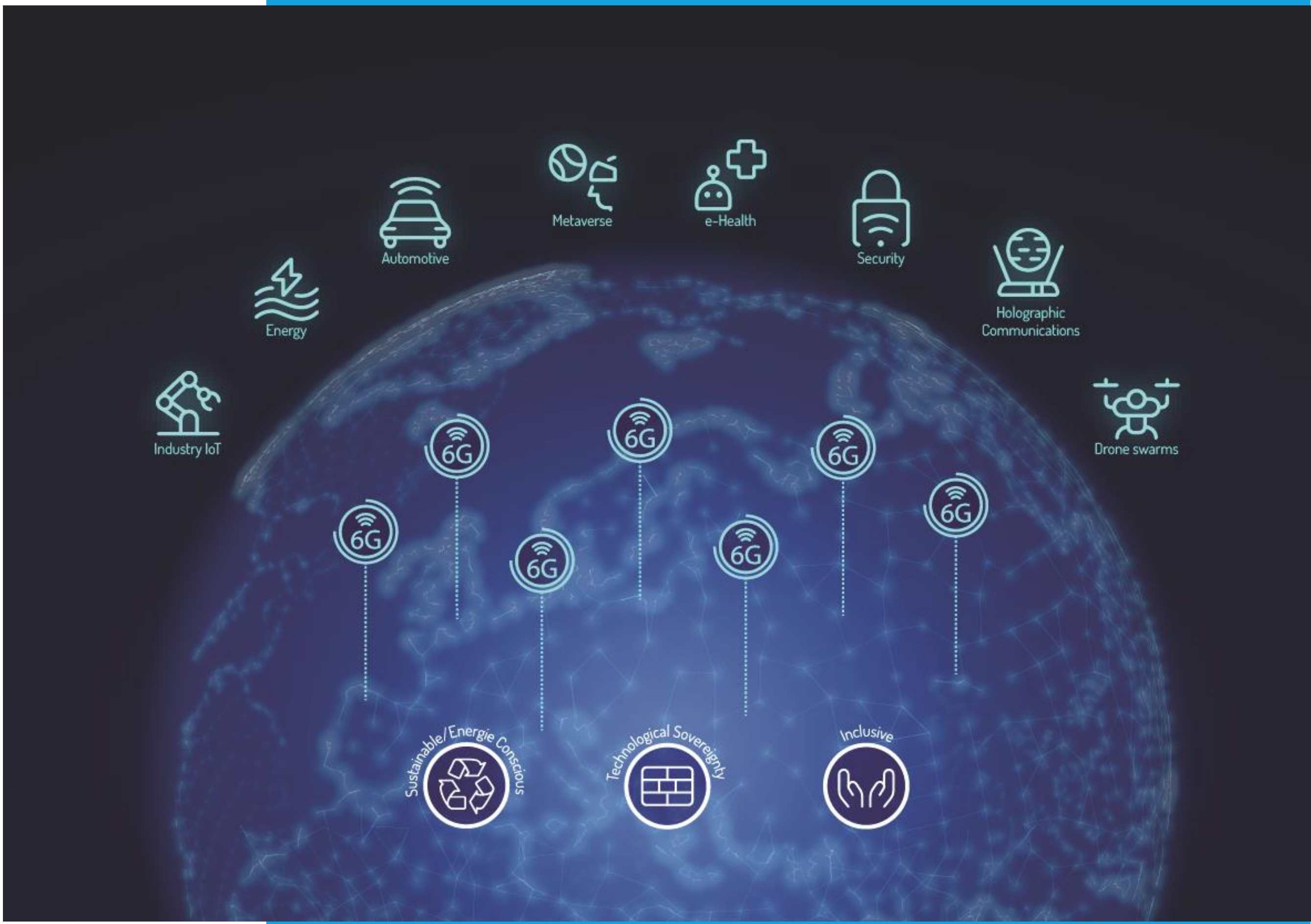
The SNS JU projects have received funding from the Smart Networks and Services Joint Undertaking (SNS JU) under the European Union's Horizon Europe research and innovation programme.



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