Service performance measurement methods over 5G experimental networks

White paper – ICT-19 performance KPIs

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Executive summary

This white paper analyses vertical use cases of various domains for their performance KPIs and their mapping to 5G network KPIs. The scope is to identify (based on architectural elements analysis, information flow, etc.) the potential impact on the service performance and user perceived quality. The challenge is to understand the relative influence of 5G network performance indicators to the vertical services. The KPIs mapping methodology includes three steps:

- Research on definitions and information derived from the respective 5G-PPP projects, standardisation bodies and respective alliances e.g. ITU, NGMN etc., as well as definition of use cases from 5G-PPP projects' respective.
- Identification of relevant key service KPIs and their definitions that are of importance to the respective industry.
- Mapping of selected services KPIs on the respective network KPIs that impact the operation of the architectural elements that participate in the service provision process.

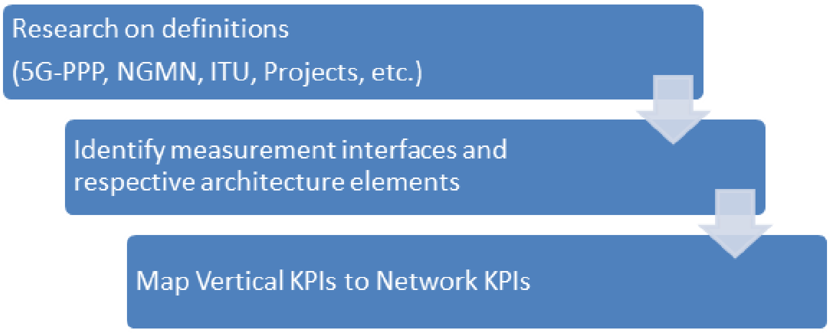

Figure 1 KPI mapping process

1 Scope

1.1 Business motivation

The scope of this document is to provide a detailed analysis of the mapping of performance KPIs to 5G network KPIs as well as insights of the target KPIs values for specific use cases and services analysed, setting the benchmarking basis for the collection and evaluation of performance measurements in similar cases.

The first important step is the definition of the methodology, followed by the performance evaluation, the identification of the use cases, the architectures and the relative KPIs. This white paper defines in a clear and solid way the KPIs mapping and their target values in order to prove and validate that the 5G technology can provide prominent industry verticals with ubiquitous access to a wide range of forward-looking services with orders of magnitude of improvement over 4G.

The white paper analyses use cases in the following industry domains: *i)* Industry 4.0 (**IN**), *ii)* Smart Cities & Utilities (**SC**), *iii)* Transportation (**TR**), *iv)* Automotive (**AU**), *v)* Media & Entertainment (**ME**), *vi)* Agriculture & Agri-food (**AG**), *vii)* Smart (Air)ports (**SP**), *viii)* Energy (**EN**) and *ix)* E-health & Wellness (**HW**)

Currently, Vertical industries address their connectivity and communication requirements with dedicated specific solutions. 5G technology principles such as slicing and virtualization will provide a common base that delivers an open, cost-efficient and interoperable eco-system enabling a solution platform for the different verticals. 5G must also cater in an economical way the diverse requirements and business needs of a multitude of verticals. In addition, 5G infrastructure and architecture will integrate heterogeneous technologies and enable network slicing, so that the multiple concurrent execution of vertical operational services is performed regardless of their diverse requirements.

1.2 Service performance

5G System is expected to quickly address a multiplicity and diversity of services coming from various vertical sectors. 3GPP and ITU have mapped in a similar way the vertical industries to large service categories called service classes by ITU-T [1], allowing for the design of a more 5G user-centric platform dictated by service types for specific uses cases with optimised networks with different characteristics and behaviours determined by key performance requirements.

The concept of a “Service” as well as some additional terminologies around it used throughout the paper relate to the verticals.

First the “**vertical domain**” or sector (see 3GPPP and ITU mapping above), is an industry or group of enterprises in which similar products or services are developed, produced, and provided [2].

As for the “**vertical**”is the stakeholder belonging to an industrial sector and consuming services.

A “**vertical service**” then, from a business perspective, is a service focused on a specific industry or group of customers with specialized needs (e.g., automotive services, entertainment services, e-health services, industry 4.0).

In this context, **service performance** shall refer to the evaluation of the overall behaviour of the high layer service with the targeted values of the relevant key performance indicators dictated by the actual service provided to the end user (could also be referred to as application level KPIs) and not only by the network performance results. it is also important to note that when it comes to the measurements of such service KPIs, it may not be directly measurable hence the need for an analysis on possible aggregation/correlation between different KPI levels.

With this in mind, the mapping between vertical KPIs and network KPIs should include any contributor participating in the end-to-end network service provisioning: network infrastructures or functions. For instance, it may need to consider the physical deployment and the technical properties of the system elements that the application interacts with as well as the computation or caching required.

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2 Methodology for mapping service to network KPIs

Service/Vertical and network/core KPIs might have a relationship that can be different from a one-to-one mapping. Indeed, a service might imply the elaboration of information that is not only handled by network functions only but also by instruments (e.g., hypervisors) that are virtualising resources. In particular, if network functions are virtualised the end-to-end delay is impacted by the data packet propagation time but also by the load of the computing resource where the functions elaborating the packet are virtualised. In addition, Service KPIs might not be directly measurable, and this is the reason why a mapping between Network/Core 5G KPIs and Service/Vertical KPIs is needed. In this way, combining different Core 5G KPIs (completely transparent to the verticals), specific Service KPIs can be evaluated, which allow verticals to determine whether the use cases deployed using the 5G technology and the utilized resource fulfil the expected performance and functional requirements.

A possible method for mapping the service KPIs to the network KPIs adopted in 5Growth project is the one represented in Figure 2. In this figure Core KPIs are referring to network KPIs. Then a mapping is performed between Core KPIs and Service KPIs, independent from the specific Proof of Concept (PoC).

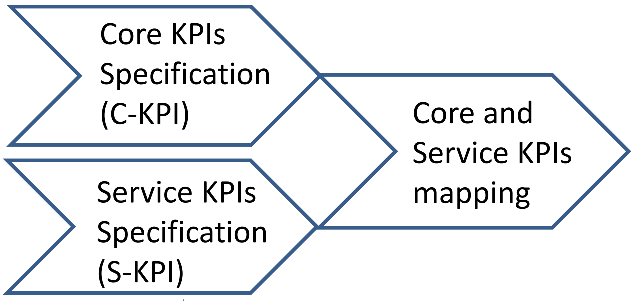

Figure 2 Procedure for mapping service KPIs to network KPIs

3 Verticals and Use Cases

3.1 Industry 4.0

Industry 4.0 is signalling a change in the traditional manufacturing landscape. Also known as the Fourth Industrial Revolution, Industry 4.0 encompasses three technological trends driving this transformation: connectivity, intelligence, and flexible automation. The Industry 4.0 use cases presented below fall in the category of smart factories. Industry 4.0 use cases are related to remote support and time-critical process control in the factories. These use cases demonstrate the performance of a 5G communication network serving industrial applications where strict requirements of reliability and latency are mandatory to keep the connection stable and to avoid emergency stops and safety issues. In IN_UC4 industry 4.0 use case, Connected Worker Remote Operation of Quality Equipment, it is explored how 5G technologies can be used to enable remote access to M3BOX, an edge device used to control the Coordinate Measuring Machine (CMM), to perform setup and configuration operations that nowadays require an expert to travel to the customer's premises. The IN_UC5 use case, depicted in Figure 3, Connected Worker Augmented Zero Defect Manufacturing Decision Support System, involves the development of a Machine to Machine (M2M) collaboration system using 5G technologies that will improve the flexibility and productivity of the CMM.

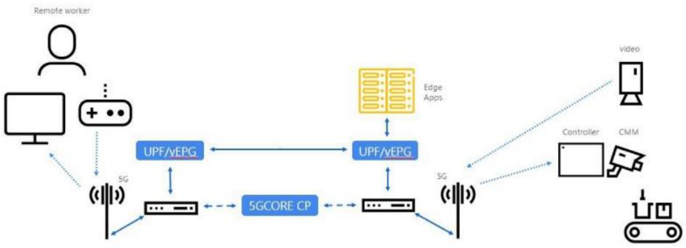

Figure 3 Connected Worker Remote Operation of Quality Equipment

3.2 Smart Cities & Utilities

The vision of a smart city "incorporates the six "s", i.e. a shared, secure and scalable infrastructure that enables human possibilities in a manner that is smart, safe and sustainable. This vision is achieved by a smart network connecting sensors, machines and citizens to cloud based internet of things (IoT) applications".

The Use Cases selected for this white paper are being validated as part the 5G-SOLUTIONS [3] project, below is a brief summary of their objectives along with an illustration of an architecture combining both UCs covered showing that real-time images from a camera mounted on a pole (can be street light):

Use Case SC_UC1: Intelligent street lighting

The primary objective is to accelerate the use of intelligent lighting in smart cities and increase the environmental, financial, safety and security benefits that societies can have.

Use Case SC_UC2: Smart parking

The primary objective is to allow drivers to look for inter-city parking spaces so as to easily spot the most convenient and available parking places.

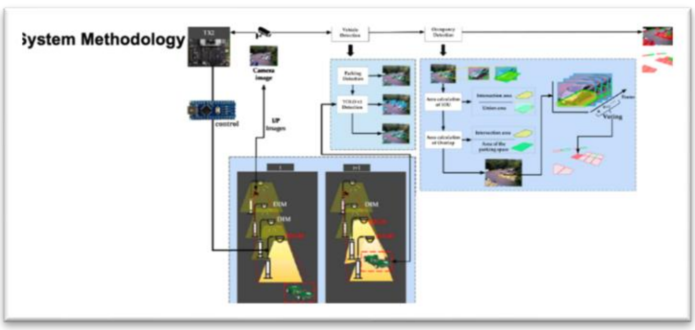

Figure 4 Smart Parking - Intelligent Street Lighting System

3.3 Transportation

Representative use case of the transportation vertical industry is the provisioning of Future Railway Mobile Communication System (FRMCS) services to various end-users and stakeholders engaged in the railway industry, over a single, technology neutral, 5G network deployment as examined in the context of 5G-VICTORI Project. For this purpose, as basis for the analysis, they are used representative vertical applications of all FRMCS service categories, namely from (as in [25]) :

1. "Business services", that is, services supporting the railway business operation in general that are usually provided to passengers requiring communication services and broadband connectivity when embarking, travelling and disembarking from the trains daily. Wireless internet/data, Infotainment services, streaming video services (of eMBB type) are used as an example.
2. "Performance services", that is, non-critical services related to train operation. In general, these can be sub-grouped into four main categories: i) passenger information services, ii) advisory services, iii) telemetry services and iv) infrastructure monitoring and maintenance services; the use case focuses on CCTV services for supervision of the rail tracks quality and provision maintenance when needed. Cameras mounted on the front and rear part of the train capturing images that are forwarded in real time to the Operations Center (of the railway facilities) are used indicatively.
3. "Critical services", related to train operation/movement, railway automation systems (Automatic Train Control - ATC, Automatic Train Operation (ATO)), trackside maintenance, emergency and safety services, and so on. Information generated in this type of services must be shared between different stakeholders, e.g. infrastructure operators and several railway operators. Mission Critical Push to Talk (e.g. between the controller(s) of the train/ operations centre and the driver/ on-train staff etc.) is used as indicative application of this type.

3.4 Automotive

The vision of cooperative, connected and automated mobility (CCAM) across Europe can only be realized when harmonized solutions that support cross-border traffic exist. The possibility of providing CCAM services along different countries when vehicles drive across various national borders has a huge innovative business potential. However, the seamless provision of connectivity and the uninterrupted delivery of services along borders also poses interesting technical, administrative and regulatory challenges. Such an environment offers exceptional innovation potential given the multi-country, multi-operator, multi-telco-vendor, and multi-car-manufacturer scenario of any cross-border layout.

The automotive vertical sector presents a wide range of use cases / applications with often diverse performance requirements. 3GPP has defined the following five areas for vehicle-to-everything (V2X) application scenarios [9]:

1. Advanced Driving
2. Platooning
3. Extended Sensors
4. Remote Driving
5. Vehicle quality of service Support

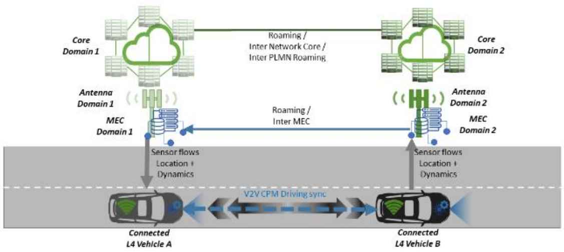

Figure 5 Advanced Driving UC: Cooperative Collision

3.5 Media & Entertainment

Use Case: Ultra-High-Fidelity media

Rapid progress in display and capture technologies is enabling a new, highly immersive production and viewing experience with ultra-crisp, wide-view pictures with deep contrast and multi-channel sound. Both linear and non-linear content will be used for testing the Ultra High-Fidelity Media (UHFM) experience. In order to guarantee a high quality of experience for UHFM, 5G network should be able to support efficient network management, fair resource allocation, high speed transport capabilities and strategies, e.g. by means of local and network caching of content. UC involves media streaming to devices using a variety of applications supported by the partners under different network configurations.

One aspect to be proved is the possibility to scale delivery for large audiences. 3GPP has prioritized the work around unicast use cases since the first release of 5G, Rel'15, and hence 5G point-to-multipoint (PTM) would only be addressed starting from Rel'17. The lack of PTM characteristics may lead to an inefficient service provisioning and utilization of the network and spectrum resources when distributing the same data to multiple users and devices (e.g., live and linear content with very large audiences or mass software updates). However, whether 5G unicast is already able to withstand massive media consumption needs to be investigated.

3.6 Agriculture & Agri-food

Use Case: Aquaculture Use Case: Remote Monitoring of Water and Fish Quality

Aquaculture production is strongly characterized by a requirement for continuous monitoring and management of the site with the goal of optimising production and fish welfare. These requirements are often difficult to meet in the harsh marine environment within which fish production occurs and manual intervention is difficult to avoid. However, there is an increasing trend for continuously including new technologies to cover these needs, including multi-sensor monitoring of water quality as well as image/video footage to monitor the infrastructure and the fish stocks themselves for extracting information that traditionally comes from manual observations.

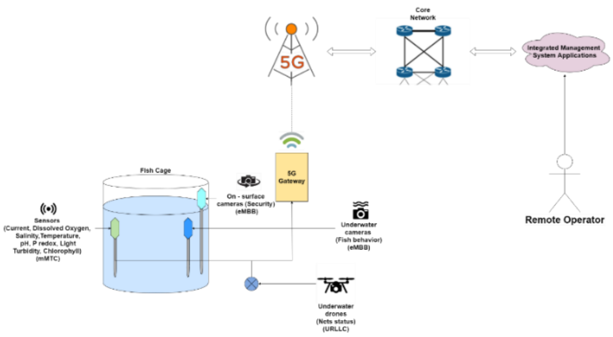

Figure 6 Aquaculture Scenario Architecture

3.7 Smart (Air)ports

SP_UC1: Autonomous assets and logistics for smart port

The purpose of this use case is to demonstrate the capabilities of 5G technology to support real-time operation and integration support for autonomous assets in a logistics hub. The autonomous test site includes the smart port, the logistics solution used in the cargo loading area as well as a dedicated autonomous vessel with autonomous land-based cargo handling assets. This UC will explore the enhanced service offering enabled by 5G technology.

SP_UC2: Port safety – Monitor & detect irregular sounds

Safety and security within a port are of great importance thus they are a significant part of a smart port design. Through this use case, emphasis is given on the irregular noise and sound detection technology to assist in the security and safety measures. The deployment of such detection systems (e.g. sensitive microphones and UHD+ 360o CCTV (closed-circuit television) cameras) through the use of a reliable 5G network, transmitting real-time audio-visual information on events to the ports operations centre, is of utmost importance to port authorities by allowing them to act immediately and find out the exact location of the incident.

3.8 E-health & Wellness

The eHealth and wellness use cases are shown below:

- Use case **HW_UC1 – "Remote interventional support"** that explores the use of advanced, rich media communications in the context of remote monitoring, education and robotics in patient diagnostics and treatment.
- Use case **HW_UC2 – "Remote polyp detection performed by AI in real-time"**, which aims to test real-time transmission with feedback control of a pill camera (capsule video endoscopy), in order to improve diagnosis of cancer or precancerous pathology.
- Use case **HW_UC3 – "Vital-sign patches with advanced geo-localisation"**, whose objective is to explore direct-to-cloud disposable vital-sign patches to enable continuous monitoring of ambulatory patients, anytime and anywhere.

4 Service and Network KPIs Mapping

In this section, Indicative primary Service KPIs for each vertical Industry's use cases and the respective mapping to Core 5G network KPIs (CKPIs) are addressed. Their association being that the Core 5G KPIs constitute the very technical performance parameters related to the network and system components, which contribute to the 5G service KPIs.

4.1 Industry4.0

SKPI-1: Service Setup Time - Time elapsed since the vertical requests a specific service until the service is completely operational. This time comprises the provisioning and configuration of the resources needed for a vertical. **Mapping to CKPI**. Deriving the service setup time from a vertical service can be achieved by measuring two Core KPIs: Slice Creation/Adaptation Time and Availability. Slice Creation/Adaptation Time is defined as the time elapsed since the creation/reconfiguration of a slice is triggered until the slice is fully operational. Availability is defined as the percentage of time during which a specific component of the use case (application, server, network function, etc.) is responding to the requests received with the expected QoS requirements. That is, it is the ratio between the up-time of a specific component over the total time the component has been deployed. **Motivation-** The Slice creation or adaptation time impacts directly the Service KPI, as the service setup time depends on the creation or adaptation of the slice where the vertical service will be accommodated. Secondly, once the slice where the vertical service is deployed, instantiated, or adapted, the time the vertical service takes in deploying its components is measured with the Availability Core KPI.

SKPI-2: Synchronization between Communication Components - Synchronization between components evaluates the ordered and timely execution of operations requested among components. Out-of-order operation requests must be near zero in real-time communications among the involved components. **Mapping to CKPI.** Inferring the Synchronization capability between communicating components in a vertical service can be achieved by measuring two Core KPIs for each of the communication links: **End-to-end latency** and **Packet loss**. End-to-end latency is defined as the aggregation of one-way time delays measured between specific components of the logical architecture of the vertical service. Packet loss is defined as the number of packets that fail to reach their destination, measured in specific interfaces of the vertical service logical architecture. **Motivation**. End-to-end latency is measured across the whole communication path to assure that the delay in the traffic flow is always lower to the maximum end-to-end latency required for a correct synchronization. Moreover, to maintain the desired synchronization, the Packet loss Core KPI shall be also measured to avoid exceeding the defined packet loss tolerance since the synchronization protocols automatically downgrade the transmission speed when packet loss increases. This, in turn, directly impacts the synchronization time.

SKPI-3: Device Mobility - Capacity of the mobile devices of a given use case to move within the area of applicability of the service without degrading its performance, independently of the devices speed. **Mapping to CKPI.** Deriving the device mobility capability of a vertical service can be achieved by measuring three different Core KPIs, namely, Packet Loss, Guaranteed Data Rate, and Availability. Packet loss and availability are defined as above. The guaranteed data rate is the minimum expected data rate for the vertical service to function correctly. **Motivation.** Packet Loss and Guaranteed Data Rate directly affects the Mobility as the end-user devices can only move inside areas with acceptable network service, i.e., those with a minimum level of packet loss and data rate. Additionally, the availability of the networks traversed can also impact the device mobility. Specific network services demand different availability requirements, limiting their operation to areas where their minimum availability can be guaranteed.

SKPI-4: High-resolution Real-time Video Quality - Specific use cases are supported by a real-time video streaming service whose high-quality resolution is critical for the correct operation of the vertical service. This SKPI evaluates the QoE of the users consuming the video feed that supports a given use case. E.g., in a IN4.0 context, the high-resolution video service is needed to perform accurate measurements of industrial pieces remotely and in real-time. **Mapping to CKPI**. Inferring high-resolution real-time video quality for a vertical service can be achieved by measuring four different Core KPIs: Packet Loss, Guaranteed Data Rate, Data Volume, and Jitter. Packet Loss and Guaranteed Data Rate are defined as above. Data volume is the total quantity of information transferred over a given interface during specific use case operations, measured in bits. Jitter is the Variation of the end-to-end latency for the communications between specific components of the vertical service. **Motivation.** Real-time video requires monitoring the packet-loss, the minimum guaranteed data rate, the available data volume, and the jitter. Specifically, real-time video is limited by the minimum data rate necessary for the video transmission at a certain quality. The minimum data rate is defined to avoid possible queuing or dropping of video frames which degrade the quality of the video transmitted. Moreover, the jitter and the packet loss can also directly affect the quality of the real-time video, as the variation between frame latency and retransmissions caused by packet loss. This typically results in video discontinuity. Additionally, the volume of data available to the application can also impact the quality of the real-time video, as the available data volume is essential to determine at which quality a video can be streamed.

4.2 Smart Cities & Utilities

Primary Service KPIs Mapping for the *Intelligent Street Lighting Use Case*:

SKPI-1: Total number of Active lights - Checking the number of active sensors, helping in the definition of streetlights turned on and consuming energy.

SKPI-2: Total number of active movements - Checking the movement in the city, helping in the predictive analysis.

SKPI-3: Total Average illuminance - Calculating the luminance from the lights and number of active lights, helping in making sure a safe environment is possible for the citizens.

Mapping to CKPI: Edge-to-edge Latency (Target <100ms), Reliability (>99%), Coverage (>99%) and Device Density (1 dev/m^2)

Primary Service KPIs Mapping for the *Smart Parking Use Case*:

SKPI-1: Vehicle detection processing time- Time consumed to detect a vehicle.

SKPI-2: Parking Availability - What is the current parking availability.

SKPI-3: Parking Occupancy - How many vehicles in the parking lot.

Mapping to CKPI: Positioning accuracy (Target <1ms), Reliability (>99.9%), Coverage (>99.9%) and Data Rate (> 1000Mbps per cell)

4.3 Transportation

SKPI-1: Service Setup Time - Time elapsed since the vertical requests a specific service until the service is completely operational. This time comprises the provisioning and configuration of the resources needed for the use case. **Mapping to CKPI:** End-to-end Latency

SKPI-2: High-resolution Real-time Video/Audio Quality - Specific use cases are supported by a real-time video/audio service whose high-quality resolution is critical for the correct operation of the vertical service. This SKPI evaluates the QoE of the users consuming the video feed that supports a given use case. **Mapping to CKPI:** Packet Loss, Guaranteed Data Rate and Jitter

SKPI-3: Device Mobility - Capacity of the mobile devices of a given use case to move within the area of applicability of the service without degrading its performance, independently of the devices speed. **Mapping to CKPI:** Coverage (m^2), Availability, Mobility / Speed (Km/h), Handover Time

SKPI-4: Service Area - Geographical area of the service applicability. This SKPI determines the area in which a network service needs to be provided. **Mapping to CKPI:** Packet Loss, Guaranteed Data Rate, Coverage, Availability and Reliability

SKPI-5: Area Traffic Density - Total traffic throughput that can be served over a specifically defined geographic area. **Mapping to CKPI:** Availability, Connection Density and Area Network Capacity

Application Key Service KPIs:

SKPI-A: Channel/ Stream Switching time – Time between the moment that channel switching is triggered on the device up to the moment that the new channel is presented on device screen. Mapping to CKPI: End-to-end Latency, Availability

SKPI-B: Total Wagon Traffic Density - Total traffic offered, thus the access network capacity required in a highly occupied wagon or train. Mapping to CKPI: Availability, Connection Density and Area Network Capacity

SKPI-C: Total Traffic transferred from trains CCTV cameras to monitoring/ operations' center Mapping - time between the moment that the CCTV service switching on is triggered on the device up to the moment that it is setup. Mapping to CKPI: Availability, Connection Density and Area Network Capacity

SKPI-D: Bulk transfer of infrastructure monitoring data (e.g. CCTV archives, engine performance measurement archives etc.), collected over time. Mapping to CKPI: Coverage, Availability, Area Network Capacity

SKPI-E: Voice Quality of MCPTT session. Mapping to CKPI: Jitter, End-to-end Latency, Packet Loss, Guaranteed Data Rate, Coverage, Availability

SKPI-F: Setup time of a communication session. Mapping to CKPI: End-to-end Latency, Availability

SKPI-G: Talker assignment time - The time between a talker request and the permission to talk applicable to group communication, after the group has been established. Mapping to CKPI: End-to-end Latency, Availability

SKPI-H: Session Loss Rate - Number of sessions released due to failure over a specific time window. Mapping to CKPI: Availability, Reliability.

4.4 Automotive

SKPI-1: Local Perception metrics - Object classification capability (true positive)- TPR refers to the number of objects correctly classified to the right classification. **Mapping to CKPI:** Latency, User plane Latency, Reliability

SKPI-2: Augmented Perception metrics - Recognition of (non-)communicating objects: Evaluates the capacity of the system in correctly recognizing (non-)communicating objects. This reflects to the capability of data fusion between the received CAMs, CPMs and the output of the local perception. **Mapping to CKPI:** Latency, User plane Latency, Reliability

SKPI-3: Risk analysis metrics:

Time to collision: The time remaining before the rear-end accident if the course and speed of vehicles are maintained. **Mapping to CKPI:** Latency, User plane Latency, Reliability

Number of Platooning Messages Loss: Number of platooning messages that have been lost and cannot be used for platooning control. **Mapping to CKPI:** Latency, Control plane Latency, User plane Latency, NG-RAN Handover Success Rate, Application-Level Handover Success Rate, Mobility interruption time

Remote driving session outage: The amount of time in which the remote driving session is lost or degraded. **Mapping to CKPI:** Latency, Control plane Latency, User plane Latency, Position accuracy, NG-RAN Handover Success Rate, Application-Level Handover Success Rate, Mobility interruption time

Control action delay: Delay between control command message and manouevre execution of remote vehicle. **Mapping to CKPI:** User experienced data rate, Throughput, Latency, Control plane Latency, User plane Latency, Position accuracy, NG-RAN Handover Success Rate, Application-Level Handover Success Rate, Mobility interruption time

4.5 Media & Entertainment

SKPI-1: the server accessibility (application accessibility). **Mapping to CKPI:** End-to-end, Latency Coverage, Availability, Slice Creation Time, Connection Density, Area Network Capacity, Mobility / Speed, Handover time.

SKPI-2: the waiting time (time to first picture). **Mapping to CKPI:** End-to-end Latency, Coverage, Availability, Slice Creation Time, Connection Density, Area Network Capacity, Mobility / Speed, Handover time.

SKPI-3: user defined timeout (emulates the user's patience) leads to a ""failure"". **Mapping to CKPI:** End-to-end Latency, Packet Loss, Coverage, Availability, Slice Creation Time, Connection Density, Area Network Capacity, Handover time, Reliability

SKPI-4: very importantly the picture quality (MOS for each 10s interval of a video, and certainly as the average MOS for the whole video). **Mapping to CKPI:** End-to-end Latency, Packet Loss, Guaranteed Data Rate, Data Volume, Jitter, Area Network Capacity, Mobility / Speed, Handover time, Reliability

SKPI-5: freezing / stalling of the video in % and **SKPI-6:** lost streams (constant freezing). **Mapping to CKPI:** Packet Loss, Coverage, Availability, Connection Density, Jitter, Mobility / Speed, Handover time, Reliability.

SKPI-7: jerkiness in % (if frame rate is not high enough, e.g., < 20 fps, the video is not perceived as fluent). **Mapping to CKPI:** Packet Loss, Coverage, Availability, Connection Density, Jitter, Mobility / Speed, Handover time, Reliability.

4.6 Agriculture & Agri-food

SKPI-1: Space/Area Dependent Interactivity - This user requirement, is a measure of the spatial distribution of the end-users/devices. It indicates the ability to issue commands (or even send data/video) and requests and receive acknowledgement of execution and/or reaction (that can be in the form of data/video) within a very short period of time (in the msec order of magnitude) from a large number of "collocated" end user/devices etc. (example is gaming and or guidance for emergency evacuation, transaction stock/financial markets or the more common request for a Web Page). **Mapping to CKPI:** End-to-end Latency, Connection (device) density, Interactivity (num. of transactions over time) and Area Traffic Capacity

SKPI-2: Fast Response - The time between issuing a request (i.e., change direction) or transmitting a piece of information (i.e., an alarm happened), and receiving a response should be as short as possible. Technology-wise this is the end-to-end Latency of a Telecommunication Network also referred to as round-trip-delay. A simple measurement of this is done via the ICMP protocol with the “ping” command. **Mapping to CKPI:** End-to-end Latency (Service_E2E-L = 5G-Core_L + Transport _L + Edge_L + 5G-Radio_L)

SKPI-3: Data/Video transmission - Video Transmission (UL): Indicates the user need to transmit video information of different formats and definitions/resolutions and frame rates. Data Transmission (UL): Indicated the need to transmit different types of data (Upload) from the user end device to the network and/or other users. **Mapping to CKPI:** Uplink Throughput, Broadband connectivity / Peak data rate, Reliability, end-to-end latency and Mobility

4.7 Smart (Air)ports

SKPI-1: Mobility Service KPI - To ensure accurate and on-time operations, the various components of a smart port must stay connected at any time and in any conditions. In order to support the port autonomy, mobility is a crucial aspect that must be ensured. Service availability must be guaranteed at any time and in any location within the smart port logistics perimeter while elements are moving without degrading the performance and providing the agreed QoS. **Mapping to CKPI**: Network Availability, Coverage, radio signal quality and buffer occupancy.

SKPI-2: Latency Service KPI - Latency on the Ues can occur from the transmission interface while transmitting the data, the microphones while receiving the actual noise, the actuator of the vehicles until they translate the signal to an action. **Mapping to CKPI**: End-to-end Latency

4.8 E-health & Wellness

SKPI-1: Real-time control data - In a bilateral network-based teleoperation system, depending on the architecture, the control loop or part of the control loop of the system passes through the communication link. Sensory information such as forces, torques and velocities should transmit over the real-time control data channel with low jitter and with the delay being below an allowed maximum. It means that hard-real time and reliability requirements must be met in this link.

SKPI-2: Medical video streaming - The ultrasound video is vital for the cardiologist, and therefore this video must be sent over a high priority link.

SKPI-3: Ambient video streaming - In a remote tele-operation setting, it is important for the cardiologist to be able to communicate with the patient. Therefore, a video conference link is needed between the sites.

5 Conclusions

This white paper summarized the progress and several key findings produced by 5G PPP projects on the methods to measure the Service performance for Verical Industries over 5G experimental networks, in order to prove and validate that the 5G technology can provide prominent industry verticals with ubiquitous access to a wide range of forward-looking services. Thescope of this work is to better understand the correlation and formal associations of the core 5G KPIs with respect to technical service KPIs, for a plethora of Vertical Indusrties.

5G PPP has the capability to demonstrate the feasibility for Vertical Industries to develop and deploy 5G innovative solutions in vertical markets. This will eventually allow an increasing number of Verticals to follow a similar path, ultimately increasing the European market share on a global scale. This will strengthen the prospects for European Vertical Industries to achieve sustainable growth and become key players in the new business environment created by the 5G paradigm, considering that "the rising demand from various (vertical) applications has been recognized as the major drivers for the 5G infrastructure market growth."

SKPIs identify the business and operational-oriented benchmarks and figures of merit that must be met in order to certify that the vertical services, once implemented, are fully functional (i.e., they work as expected to satisfy the demanded vertical requirements and agreed SLAs). In a nutshell, the SKPIs are the promises that the underlying management institutions make to the verticals. Each service's set of SKPIs is a list of observable, measurable, and quantifiable parameters that are only important and meaningful for that service. As a result, even if both coexist and are carried out over a similar (computing and network) infrastructure, the collection of SKPIs for a given service may not be relevant to other vertical services.

The latter then creates a collection of CKPIs that are connected to the computing and networking resources which will be allocated to support the vertical service. Remember that CKPIs are measurable performance parameters associated with the network and computing infrastructure that supports the vertical service's functions, applications, connectivity, etc. As a result, an indisputable relationship is established between a vertical service's SKPI and its determined set of CKPIs. These CKPIs can be measured, collected, and analyzed through a range of locations (e.g., edge DC, terminal, etc.), data and control interfaces, functions, systems, and devices that are all part of the deployed vertical service.

Abbreviations and Acronyms

3GPP	3rd Generation Partnership Project
5G PPP	5G Public Private Partnership
AF	Application Function
ATO	Automatic Train Operation
CMM	Coordinate-Measuring Machine
CCTV	Closed-Circuit Television
CDN	Content delivery network
CKPI	5G Core Key Point Indicator
CPE	Customer Premises Equipment
eMBB	enhanced Mobile Broadband
FR	Functional Requirements
FRMCS	Future Railway Mobile Communication System
GIS	Geographic Information System
GPS	Global Positioning System
GSM-R	Global System for Mobile Communications – Railway
HL	High-Level
HTTP	Hypertext Transfer Protocol
IoT	Internet of Things
ITU	International Telecommunication Union
KPI	Key Performance Indicator
M2M	Machine-to-Machine
MCPTT	Mission Critical Push to Talk
MCM	Manoeuvre Coordination Messages
mMTC	massive Machine Type Communications
NB-IoT	NarrowBand IoT

NR	New Radio
PoC	Proof of Concept
QoS	Quality of Service
QoE	Quality of Experience
RAN	Radio Access Network
RSU	Road Side Units
RTT	Round trip TIme
SKPI	Service KPI
TCO	Total Cost of Ownership
UC	Use Case
UE	User Equipment
URLLC	Ultra-reliable low-latency communication
V2I	Vehicle-to-Infrastructure
V2V	Vehicle-to-Vehicle
V2X	Vehicle-to-everything
VNF	Virtual Network Function
VOU	Vehicular Onboard Unit
ZDM	Zero Defect Manufacturing

Contributing 5GPPP Projects

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