FUDGE-5G

FUlly DisinteGrated private nEtworks
for 5G verticals

Deliverable 4.1

Interim Technical Validation of 5G Components with Vertical Trials

Version 1.0

Work Package 4

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Abstract

This document describes the first efforts towards the validation of 5G components with vertical trials. After describing a common validation methodology, the document goes into detail for each use case: UC1 - Concurrent Media Delivery, UC2 - Public Protection and Public Relief (PPDR), UC3 - 5G Virtual Office for Hospitals, UC4 - Industry 4.0 and UC5 - Interconnected NPNs.

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Executive Summary

FUDGE-5G aims to perform field trials for the validation of its platform in five vertical use cases, which should target a Technology Readiness Level (TRL) of 7 or above, i.e., system prototype demonstrations in an operational environment. After deliverable D1.1 defining in detail each use case and following the integration work reported in deliverable D3.1, this deliverable (D4.1) aims to report on the interim technical validation efforts of FUDGE-5G components in the field, which aim to fulfil FUDGE-5G Objective through the realisation of trials.

Each use case organizes trials that involve prominent stakeholders and are set to obtain tangible results. Hence, for each trial, the methodology involves the collection of KPIs from all the 5G components and obtaining relevant feedback from the stakeholders, which combined provide both means for the technical validation of the 5G infrastructure and to conduct a gap analysis between the 5G measured performance and the technical requirements and KPIs stemming from the vertical use cases (use case validation). Moreover, potential improvements and new features can be derived from the results of each trial, and those also play an important role in the overall outcome of the FUDGE-5G project.

At this stage only some of the first trials were organized, mainly due to the difficulties caused by the ongoing COVID-19 pandemic and the necessity of running trials with physical presence of the involved people. However, this document is an interim release of the validation work to be performed for the use cases, which is an ongoing process and lasts until the last month of the project. Hence, a second and final version will be released at the end of the project when the consortium expects that all trials will have happened.

Abbreviations

5G	5^{th} Generation of mobile communications
5GC	5G Core
AF	Application Function
AMF	Access and mobility Management Function
API	Application Programming Interface
AUSF	Authentication Server Function
eBPF	extended Berkeley Packet Filter
DNS	Domain Name Service
DNN	Data Network Name
E2E	End to End
GUI	Graphical User Interface
LAN	Local Area Network
MAC	Medium Access Control
NEF	Network Exposure Function
NF	Network Function
NFV	Network Function Virtualization
NOW	Network on Wheels
NPN	Non-Public Network
NR	New Radio
O&M	Operation and Management
PFD	Packet Flow Description
PLMN	Public Land Mobile Network

PNI-NPN	Public Network Integrated-NPN
PTT	Push To Talk
PPDR	Public Protection and Disaster Relief
RAN	Radio Access Network
RHCOS	Red Hat Enterprise Linux CoreOS
RHEL7	Red Hat Enterprise Linux 7
SBC	Session Border Controller
SCP	Service Communication Proxy
SEPP	Security Edge Protection Proxy
SFV	Service Function Virtualization
SMF	Session Management Function
SA	Stand-Alone
SH	Service Host
TRL	Technology Readiness Level
TSN	Time Sensitive Networking
UC	Use Case
UDM	Unified Data Management
UE	User Equipment
UPF	User Plane Function
VA	Vertical Application
VM	Virtual Machine

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1. Introduction

FUDGE-5G is split into 5 vertical Use Cases (UCs), which aim to validate the technology innovations brought by the FUDGE-5G platform. These use cases follow a realization methodology, which is depicted in Figure 1.

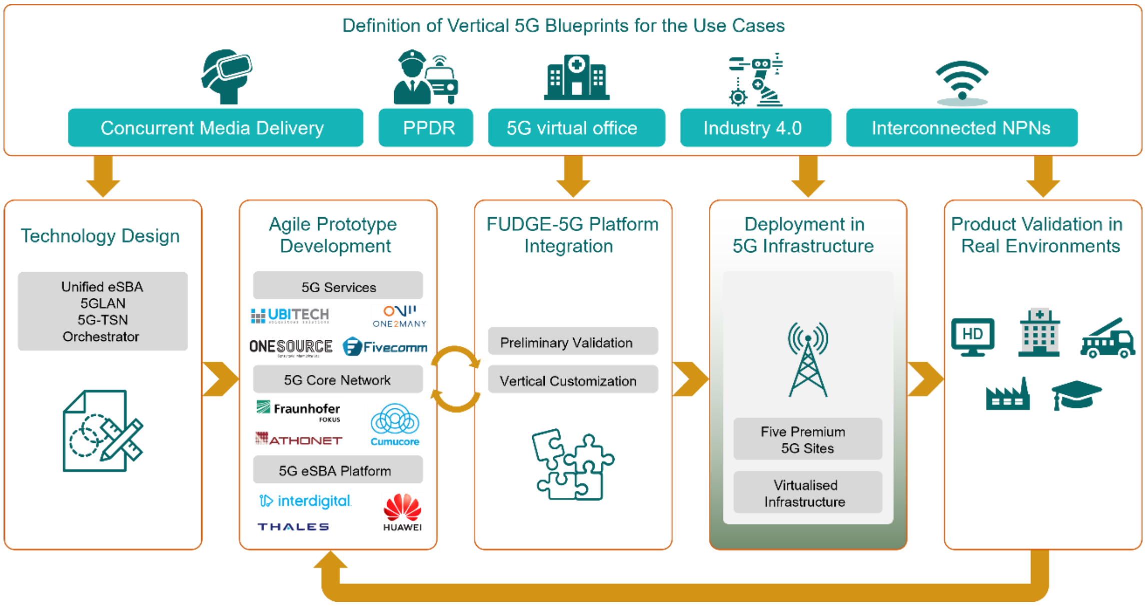


Figure 1: FUDGE-5G use case validation methodology

This deliverable focuses on the last step of the realization methodology, which is the product validation in real environments, i.e., trials. These trials are set to occur in two different phases: phase 1, aimed at individual validation of the components and phase 2, targeting an integrated evaluation of all the 5G components. For each phase, trials are scheduled to run for each UC, and this deliverable reports on the status, methodology, outcomes, and tangible results for each of those trials.

2. Technical Validation Methodology

The validation framework to support the work of FUDGE-5G is focused on getting validation of functional and non-functional requirements of each use case, which by itself provides the means for UCs to perform gap analysis, get stakeholder satisfaction feedback and assess overall success of the project's objectives.

The methodology behind the framework is split into four inclusive components: 1) its overall description for concise definition of the architecture; 2) requirement specification and validation; 3) KPI definition, measurement, and validation tools; 4) the definition of mechanisms for stakeholder feedback, which includes questionnaires and focus groups.

Concerning the component of questionnaires and focus groups, the approach is common to all use cases. We will administer evaluation questionnaires to the participant to trials to extract meaningful responses. In general, a psychometric scale composed of a set of questions answered through a Likert scale will be used to assess each identified metric. The complete set of questions addressing all metrics will be contained in a questionnaire provided to participants, adhering to the common, unified measurement methodology presented in here. Questionnaires will be typically answered before and after the trial execution. When possible, objectively measured KPIs will serve as a complement to the questionnaire results.

The respondent will answer to each questions/statement through a 5-point Likert Scale ("Strongly Disagree -> Strongly Agree"). The use of multiple questions per construct allows for a stronger internal validity and reliability of the scale.

Exemplary questions:

- I think that I would like to use the system frequently
- I found the system unnecessary complex to use
- I thought the system was easy to use
- I think I would need the support of a technical person to be able to use the system
- I found the various functions in the system to be well integrated
- I thought there was too much inconsistency in the system
- I think many users will learn to use the system quickly
- I found the system very cumbersome to use
- I felt very confident using the system
- I needed to learn a lot of things before being able to use the system

The validation framework of FUDGE-5G also establishes a generic architecture that is followed by all use cases but leaves to each use case the specification of a more concrete and well-defined architecture that better fits their needs. Below, the generic architecture for the framework is highlighted with greater detail.

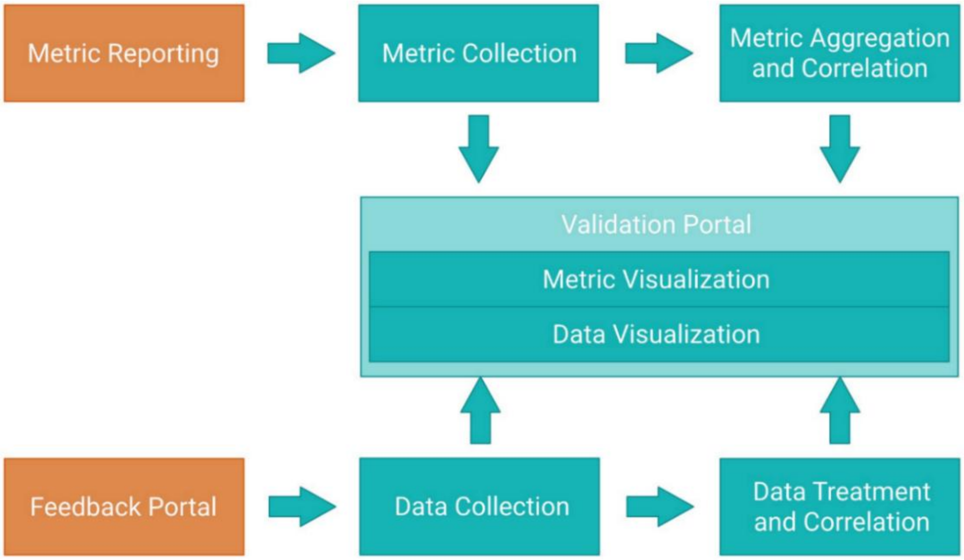


Figure 2: FUDGE-5G Validation Framework Architecture

The FUDGE-5G validation framework architecture, depicted in Figure 2, is purposely generic for flexibility of the FUDGE-5G use cases. In fact, due to the specifics of each use case, each use case defines their own validation framework with the generic architecture as a template. Despite the flexibility, a set of requirements is defined:

- It must include reporting, collection, aggregation, correlation, and visualization of all the technical and functional metrics.
- It must include reporting, collection, treatment, correlation, and visualization of all the non-technical and non-functional metrics.
- All data sources should follow a standardized interface.
- Ideally, visualization tools should be common to all use cases.

3. FUDGE-5G Platform

Across all use cases, the FUDGE-5G platform offers unified routing, orchestration and telemetry for Enterprise Services, such as 5G Cores and Vertical Applications. The validation framework presented in [1] already describes the KPIs for routing and orchestration, which are not repeated in this section. Moreover, the routing and orchestration functionalities directly compete with standard IP routing and container orchestration frameworks, such as Kubernetes, respectively, and the unique KPIs available in both technologies cannot be directly compared with the current de-facto industry standard, as dedicated experiments must be conducted to do so. Thus, the advances of FUDGE-5G's platform capabilities are validated using Key Value Indicators, based on the opportunities the technologies provide over de-facto industry standards. The KVIs described in this document predominantly evaluate and validate the advances of an SBA platform that offers a unified routing, orchestration and telemetry to Enterprise Services.

3.1. Routing

This section presents the KVIs identified to be of importance for the validation of the FUDGE-5G platform across all use cases. The KVIs are entirely based on the KPIs listed and described in [1, p. 79].

Table 1: KVIs for Validation of FUDGE-5G's Routing Platform Component

KVI	Description
Programmable SCP	Programmability through well-defined APIs is key towards a unified platform that is positioned as a Platform-as-a-Service offering. The routing component under trial in FUDGE-5G is one of the three deployment examples described in 3GPP's 23.501 and offers programmable APIs to register FQDN-based Service Function Endpoints (NF instances) against the routing layer (SCP). The key value in this can be formulated around a routing component that comes with a programmable API for registration and routing policy control allowing Enterprise Services or orchestrators to freely define which instances are serving requests for a specific FQDN, without any changes required on the endpoints themselves. Such value is key for the telco world where control and manageability requirements come along with functionality.
NRF-independent SCP	From a system architecture perspective, the NRF – as part of the 5GC – is partially moved into the platform layer of the FUDGE-5G system, as the SCP available to Enterprise Services implements a policy-based routing engine. This is however fully decoupled from the 5GC which does not interact with the available SCP apart from issuing the respective HTTP-based control plane transactions. From 3GPP's specification, this is described as Model D for the SCP where the NRF is co-located with the SCP and no additional signalling is required by consumers or producers before sending their HTTP-based control plane packets. The key difference is though that in FUDGE-5G, all 5GCs orchestrated over the FUDGE-5G platform come

	with their own NRF and any decision by the NRF to use a specific instance of a producer to handle consumer requests will not have any effect on the SCP's policy-based routing decision. The key value in this behaviour can be seen in the clear separation of the logic implemented by Enterprise Services, and what logic must be fully "out-sourced" to components outside of the Service layer. The proposition to have an NRF-independent SCP follows the Cloud-Native paradigm, complemented by the 12-factor app software design principles. This fosters multi-vendor deployments of 5GCs, where each producer can ultimately communicate the routing policy that should apply to them, independently from the requirement from other producers in the same 5GC. This allows each 5GC to program the SCP to their needs and how their Network Function performs best.
Transparent NF Instance Switching	The ability of the FUDGE-5G routing layer allows the transparent switching of HTTP sessions to a new Service Function Endpoint (aka producer instance). Both the consumer and producers involved in the HTTP sessions see any of the SCP procedures to achieve that; hence, the characteristic of being "transparent". The key value in this technology is the ability to freely lifecycle manage producer instances based on any monitoring policy that can be implemented through data points reported by Enterprise Services.
Policy-based Routing	The routing layer of the FUDGE-5G platform offers a dedicated policy engine that allows to program the desired routing decision for HTTP-based communication. Any change in policy can be enforced within milliseconds and does not break any on-going HTTP transactions. The key value in this technology is the programmability of routing policies in-line with the proposition of SBA and the work in FUDGE-5G to put SBA under trial. With SDN concepts not in the forefront of any standardisation of the 5G control plane, this technology shall contribute for the next steps of SBA within the Beyond-5G R&D efforts across organisations and fora.

3.2. Orchestration

This section presents the KVIs for the orchestration component of the FUDGE-5G platform. The KVIs herein are based on the validation framework presented in D1.1 [1, p. 82]

Table 2: KVIs for Validation of FUDGE-5G's Routing Platform Component

KVI	Description
Location-Aware SF Provisioning	The Service Function Virtualisation Orchestrator (SFVO) follows an information model which allows the provisioning of Service Functions (aka Network Functions) in a location-aware manner where each compute host can be selected in a resource descriptor. The key value in such capability is a native inclusion of location awareness as a key proposition of edge scenarios in the telco domain. With frameworks such as OpenStack or Kubernetes, location is not natively supported given their data

	centre-centric scope of deployment. The ability to offer location-aware SF provisioning allows the design of logic, outside of the SFVO, to determine which locations an SF should be placed for optimal QoS or energy efficiency purposes.
Location-Aware Lifecycle Control	The Service Function Virtualisation Orchestrator (SFVO) allows the lifecycle control of Service Functions per location. The set of Service Function Endpoint (instance of a Network Function) states offered by the SFVO are NON_PLACED, PLACED, BOOTED and CONNECTED. The key value in offering location-aware lifecycle control lies in the ability for advanced algorithms to control the exact number of instances in specific states for optimal QoS or energy efficiency.
Constraint-Based SF Description	SFV allows Service Hosts (compute hosts that register against SFVO) to communicate their capabilities such as supported kernel modules, their versions and networking interface types. For instance, if a UPF requires is provisioned as a container and requires OpenvSwitch in Version 2.3, the SFVO can assure that this UPF is only provisioned to a Service Host which offers this specific requirement – or requests the installation of this kernel module. Also, when provisioning Service Functions, the descriptor allows to define the needed capabilities of a Service Hosts. Besides kernel modules, SFV also allows the reporting of network interface types, e.g. 3gpp/n3 or 3ggp/n4 abstracted fashion from actual interface names which are rather meaningless, e.g. eth0 or enp3s0. The key value in such workflow and abstraction is the unique differentiation from cloud-centric frameworks for containers, e.g. Kubernetes, or Virtual Machines, e.g. OpenStack, allowing SFV (or simply its concepts) to see adoption across the telco community to drive the acceptance of cloud-native, while respecting the telcos' needs.
Virtualisation Technology-Independent	SFV supports a range of container and virtualisation technologies such as KVM, LXC and Docker. Furthermore, the SFV specification allows the entire framework and specific to be agnostic to the Service Function Package and even supports Android APKs or plain executables such as EXE (if desired). All it requires is an update to the list of accepted instance manager acronyms (on top of kvm, lxc and docker) and the implementation on the Service Host side on how to import and start such instance. The key value in such approach is the support of diversity in the telco domain when it comes to the choice of virtualisation technology and the realisation that technology will see other emerging virtualisation technologies, which ultimately will appear in the telco domain.

4. Concurrent Media Delivery Vertical Trials

UC1, Concurrent Media Delivery, is composed by two sub-scenarios: Remote Production, and Media Showroom. Each sub-scenario follows their own trial roadmap and validation path and will converge in the Concurrent Media Delivery at the last part of the project.

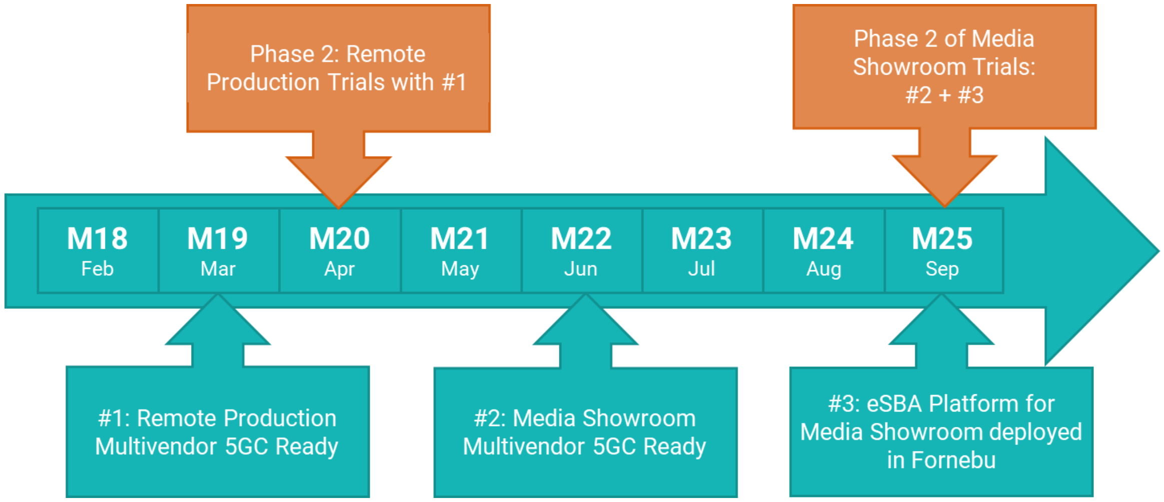


Figure 3: UC1 Concurrent Media Delivery time plan

4.1. Test Cases

The tests cases mentioned are tests carried out during or before the trials with the vertical stakeholders. However, for the Phase-1 trials, the focus was put into realizing the viability of 5G to serve as Remote Production enabling technology rather than evaluating the capabilities of the consortium components. The test cases are planned to be carried out in the Phase-2 trials, part of them beforehand, in laboratory environments, while others being evaluated during the trials themselves. More details can be found in [1].

4.1.1. Remote Production

Table 3 contains the Test Cases that need to be evaluated before the Phase-2 trials for Remote Production. Some of them will be retested during the trials themselves to ensure the functionality in a commercial environment. Note that the FUDGE-5G Platform won't be used to manage the NFs and 5G components so there are no Platform specific Test Cases.

Table 3: UC1 Remote Production Test Cases

Title	Description
E2E connectivity	The professional video cameras can send their captured stream and also receive data from the media production endpoint using 5G. The quality of the link is maintained and stable for every case.
E2E connectivity in Multivendor	The professional video cameras can send their captured stream into the media production endpoint using 5G. The 5G network consists of Network Functions provided of several manufacturers and still offer the same features
Static IP mapping	For the vertical stakeholder, the ability to have Static IP mapping for the different capture devices in Remote Production is a must-have feature. The different devices involved in the production of the content should be assigned always the same IP from the 5G network.
Detection of backhaul failure	The 5G network will automatically route the data into a redundant production chain hosted locally or in the cloud in case of failure.

Media Showroom

Table 4 contains the Test Cases that need to be evaluated for Media Showroom. This Use Case realization will make use of the FUDGE-5G Platform and its Service Routing capabilities. Some of the test cases will be validated beforehand the trials.

Table 4: UC1 Media Showroom Test Cases

Title	Description
Delivery of ultra-high-quality video	The high-quality display is able to stably reproduce live content coming from the private network.
Provision of immersive content	A tactile device (smartphone or tablet) interacts with the high-quality display.
Low RTT time	The link to the tactile features a latency low enough to the sensation of immersiveness can be experienced.
Low-latency + high bandwidth service separation	Both the delivery of ultra-high-quality video and the immersiveness are able to be served concurrently while preserving the quality for both.

Concurrent Media Delivery

Table 5 contains the Test Cases that need to be evaluated for the Concurrent Media Delivery. This Use Case combines both the Remote Production and Media Showroom test cases, and their evaluation methodology will be similar.

Table 5: UC1 Concurrent Media Delivery Test Cases

Title	Description
E2E connectivity	The professional video cameras can send their captured stream and also receive data from the media production endpoint using 5G.
Static IP mapping	For the vertical stakeholder, the ability to have Static IP mapping for the different capture devices in Remote Production is a must-have feature. The different devices involved in the production of the content should be assigned always the same IP from the 5G network.
Detection of backhaul failure	The 5G network will automatically route the data into a redundant production chain hosted locally or in the cloud in case of failure.
Delivery of UHD video	The high-quality display is able to stably reproduce live content coming from the private network.
Service Separation	Both the delivery of ultra-high-quality video and the immersiveness are able to be served concurrently while preserving the quality for both.

4.2. Tools

The validation tools used in the Concurrent Media Delivery Use Case are a mix of SW and HW tools. They are used to evaluate the test cases, both during laboratory and preliminary testing, and also during the trials themselves.

On the one hand, the SW-based validation tools are comprised by existing open-source tools, bandwidth analysis websites (e.g., Speedtest, M-lab). The components used in the trials are a mixture of the 5G modules provided by the consortium, integrated with commercial equipment (e.g., professional video encoders for the production cameras). The commercial equipment features their own monitoring tools, like the one shown in Figure 4, that provide an insight into the status of the connection from device up to the application, which may reside in the same premise as the 5G Private Network or in the cloud.

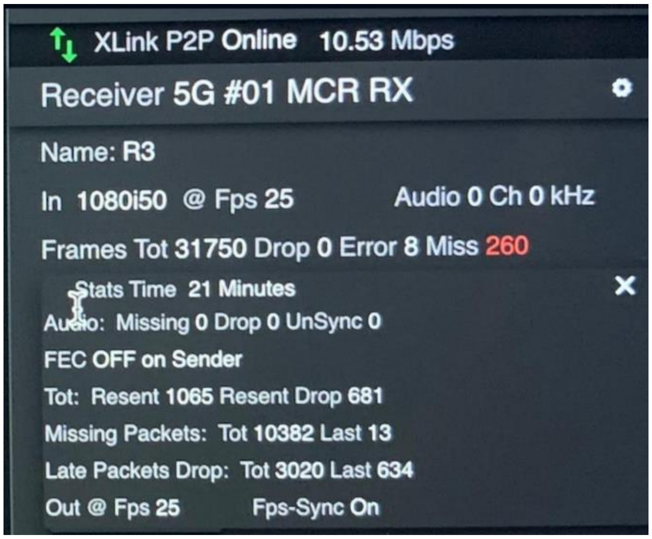


Figure 4: Capture of the Video XLink Monitoring screen, showing the connection status between the production application and a production camera

On the other hand, HW-based field spectrum analysers and drive test equipment is used to evaluate the coverage signal in outdoors environments. Subjective questionnaires are also used as a validation tool and to gather feedback from the stakeholders. A different questionnaire will be forward to the 5G Component providers, to evaluate the features of the FUDGE-5G platform in the Phase 2 trials of the project.

Another product to highlight is ClearView video generator and software suite from Video Clarity[1]. Featuring a plethora of video formats, resolutions and modes, it is used in NRK and Telenor premises to evaluate the performance of multimedia transmission/reception in the 5G Networks. The software interface can output metrics such as the perceived video quality, perceived audio quality, Pseudo-SNR, and artefact detection.

4.3. KPIs

The KPIs are detailed in the two next subsections, also split by the sub-scenario involved. They are divided into Application and Service, depending on which part of the network they affect.

4.3.1. Application KPIs

The Application KPIs are described in Table 6.

[1] VideoClarity, "Video Quality Analysis Systems," 2022. [Online]. Available: https://videoclarity.com/videoqualitymeasurement/.

Table 6: Application KPIs for Concurrent Media Delivery use case

Sub-scenario	KPI name	Description	Objective
Remote Production	Glass-to-glass latency	The time from the moment that an event is being captured by the camera until the video stream reaches the production	**< 100 ms**
	Reliability	The number of errors at the input of the video decoder. Notwithstanding faulty equipment, the transport network is assumed to be error free and capable of delivering 100% of the radio packets to the 5GC. Target KPI for reliability is Quasi Error Free (QEF)	**1 uncorrected error event per hour**
	Throughput	The output bitrate by the production cameras that the air interface and transport network should be able to absorb, multiplied by number of equipment.	**100 Mbps 1080@50** **200 Mbps 4K@25**
	Coverage Area	Area where the coverage of the 5G connection is adequate to ensure the stability of the service.	**5000 m^2**
	Number of devices	The maximum number of production devices capturing content	**5 cameras**
Media Showroom	Throughput	The bitrate of the immersive services delivered, depending on the type of display targeted	**5 Mbps Portable TV** **8 Mbps HDTV Stationary TV** **50 Mbps VR Headsets**
	Latency	This value includes the time when the client has sent off the request for a DASH segment until the HTTP response has arrived with the DASH segment.	**< 10 s**
	Coverage area	Indoor coverage where the displays can be placed and still receive enough 5G signal to receive the service properly	**100 m^2**
	Mean Opinion Score	The subjective score of the media showroom, not only based on the image quality itself but on the responsiveness and overall immersive feeling of the system	**4 or higher**

4.3.2. Service KPIs

The Service KPIs are described in Table 7.

Table 7: Platform KPIs for Concurrent Media Delivery use case

KPI name	Description	Objective
Management framework footprint	The HW requirements for all the management and stakeholder applications to run properly. A high amount of storage is expected to save and handle the almost error-less production streams.	**CPUs** **GB of RAM** **TB of storage (SSD)**
Number of slices	The maximum number of slices concurrently supported by the system, in order to differentiate traffic types in the network	**> 8**
Transparent Access Network Connectivity	The Platform should be able to provide a data pipe between stakeholder applications and the devices. The stakeholder applications should not be aware that the devices are under a fiber, WiFi or New Radio access.	**2 or more access network supported**

4.4. Trials

The trials during Phase 1 were focused on Remote Production and a preliminary assessment of FUDGE-5G components over bare-metal integration, while the platform is being prepared to orchestrate the components and improve the service. The Network on Wheels (NoW) has been equipped with FUDGE-5G consortium products in order to enable a portable 5G S-NPN, for outdoor trials.

The overall goal of the three trials was to showcase the viability of 5G state-of-the-art equipment towards the Stakeholder (NRK, for the Media use case), and to evaluate the incorporation of 5G in the Remote Production vertical.

4.4.1. Objectives

These objectives are the goal of the Phase-2 trials:

- Validate the 5G SA platform setup and components at the Network on Wheels
- Showcase the potential of 5G for Remote Production, and the ability to perform Network Slicing between public mobile operators and private enterprises to prioritize backhaul traffic.
- Coverage of remote events using professional video cameras via 5G
- Backhaul recovery, if the main link to the cloud servers is lost, alternative paths are automatically selected by the network.

- Deployment flexibility. The NoW can move inside the area of interest and provide service as long as the cameras receive 5G coverage. The number of cameras can be changed more dynamically compared to previous wired setups.

4.4.2. Deployment Topology

As part of Phase-1, three trials have been carried out. All of them have make use of the NoW. More details of the integration can be found in [2].

Elverum:

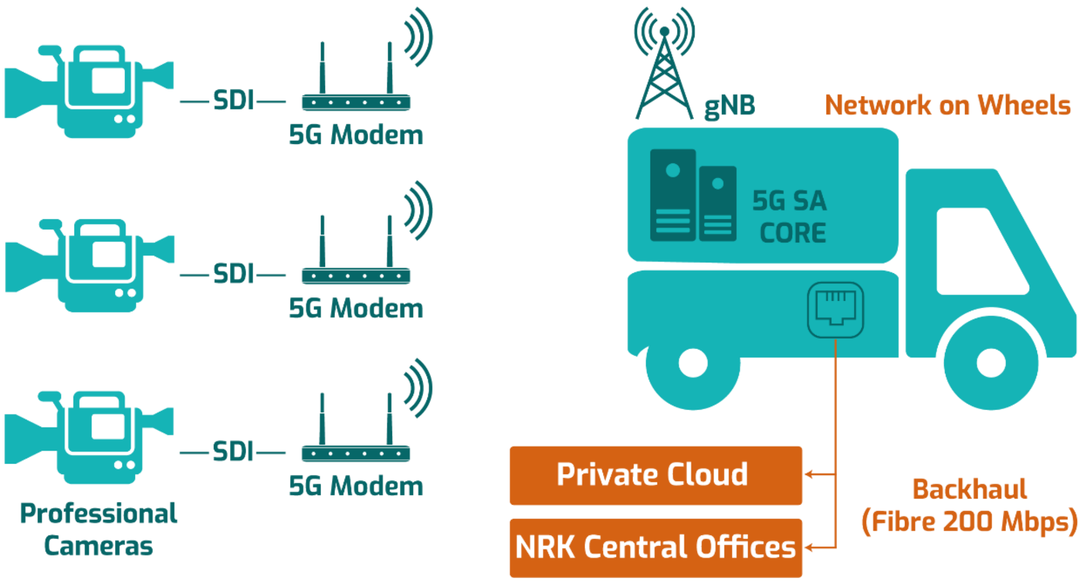


Figure 5: Elverum deployment topology, including the NoW and the cameras connected to 5G

Midstuen:

Figure 6: Midstuen deployment topology (right) and the map of the location (left), including the position of the NoW and the cameras

Sjusjøen:

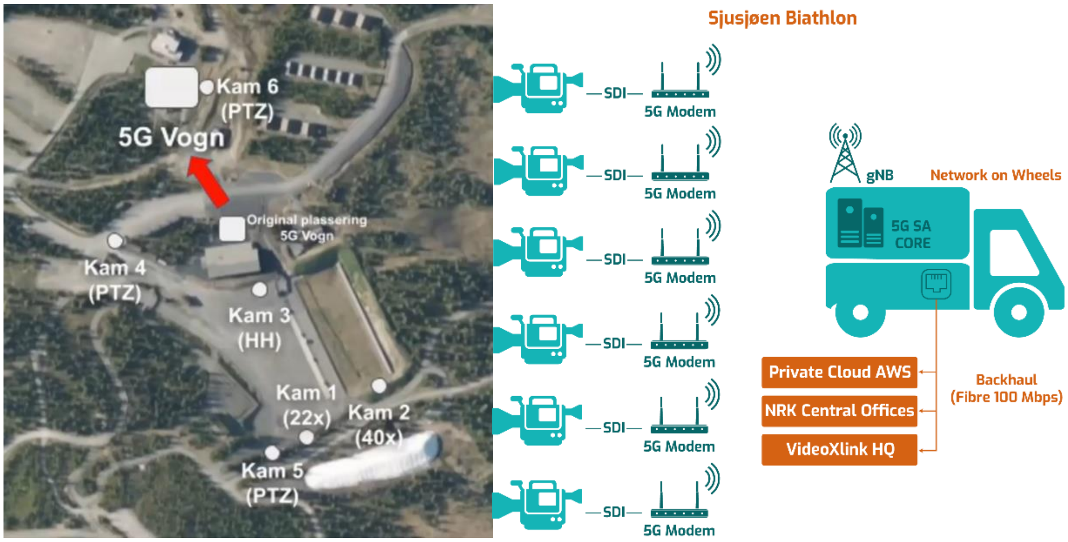


Figure 7: Sjusjøen deployment topology (right) and the map of the location (left), including the position of the NoW and the cameras

4.5. Results

Elverum:

The goal was to perform preliminary trials, ensuring the end-to-end connection in an outdoor environment between the cameras, the 5G SA on the NoW, and the backhaul link to the public cloud. The Standalone Non-Public Network was concepted to be totally independent of the backhaul link used and its termination, and in case of backhaul link loss, to still be able to store content in lesser quality, be produced offline or be sent as files in other technology (e.g., 4G Channel Bonding based connections).

Network Device Interface (NDI) protocol was used between the captured content and the public cloud applications, but the first test cases showed that it could not handle the use of backhaul links towards public cloud without compromising frames or quality. For this reason, the Remote Production has settled with videoXLink, a proprietary protocol that incorporated error recovery mechanisms to send the frames over public internet.

Midstuen:

Real coverage of a ski event in Midstuen. 3 cameras (from 9 total) were connected using 5G to the NoW. The cameras used videoXlink encoders, and the NoW featured a 200Mbps fiber backhaul connection to reach NRK main Master Control Room (MCR). NRK could not really appreciate differences from the 5G or wired cameras.

Sjusjøen:

Coverage of another event that usually requires 20 cameras. NRK challenged themselves to cover them with 6 Pan-Tilt-Zoom (PTZ) cameras. The NoW had to be moved 500 meters inside the event premises due to lack of permissions at the original parking, but had no problems doing so thanks to all the equipment being connected wirelessly. The backhaul requirement still exists, but NRK team was able to get internet connection from a nearby cafeteria.

4.5.1. Measured KPIs

The Table 8 the preliminary KPIs measured on the field trials, using the metrics given by the video encoding performance tools. The number of devices is a qualitative measure.

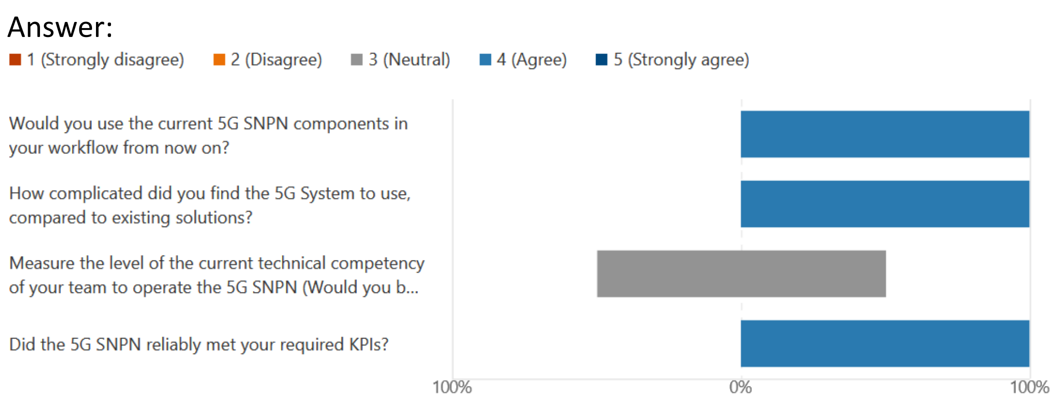
Table 8: Concurrent Media Delivery trials measured KPIs

#	KPI Name	Brief Description	Target	Result
1	**Uplink Throughput**	The output bitrate by the production cameras that the air interface and transport network should be able to absorb, multiplied by amount of equipment.	100 Mbps per 1080i@50 fps	10 Mbps uplink bandwidth
2	**Glass-to-glass latency**	Time measured from the cameras to the production application. Most of the time added is due to UDP Retransmissions.	<100 ms	130 ms
3	**Number of Devices**	The maximum number of production devices capturing content. Bandwidth is reused thanks to Multiuser MIMO.	up to 5	3 tested

4.5.2. Post-trial surveys

The NRK R&D team, which was directly involved in designing and executing the 5G production, filled a survey after the trials were done. The survey was hosted via Microsoft Forms and covers several topics regarding the SNPN, such as performance, operability, and level of satisfaction. The survey and results are detailed below:

- Answer the questions based on your level of satisfaction, from 1 to 5, regarding the Remote Production SNPN trials:



- What is, in your opinion, the most challenging issue to overcome by the 5G SNPN?

  Answer:

  1. Nomadic 5G: Need for dedicated frequencies on short notice at unknown locations. Without nationwide regulations that ensure spectrum for private 5G networks, this may be a logistic problem.

  2. Backhaul in remote locations (satellite and point to point wireless links might help, as well as available internet connections. IP gives us great flexibility).

  3. Support for more granular radio frame structures, like 3/2, allowing a higher uplink speed (preferable on beamforming antenna).

  4. Rugged equipment tailored for Outside Broadcast.

  5. Low latency encoding and robust transport on IP.

- Would you recommend other companies in the industry to incorporate 5G into their Remote Production ecosystem?

  Answer: Yes, very much so! We have tested 5G SNPN in real life remote productions on air, even with several control-rooms and a cloud-based vision mixer. The flexibility when avoiding cables and the potential for more efficient workflows on IP really points the way forward for us!

4.6. Analysis

- The latency is an issue, since there is a public internet segment that connects into the cloud production application. Future iterations of NDI protocol may reduce the latency into acceptable levels. Other possibilities imply the migration of cloud apps into an edge on-boarded on the NoW.
- The Air Interface seems capable to provide the necessary bandwidth for the cameras, for 1080@50 quality. 4K content may not be possible without advanced uplink techniques such as Supplementary Uplink.
- Standards such as ST2110/JPEGXS are not feasible for the trials at the moment. JPEGXS provides very low latency but has very high bandwidth requirements, while ST2110 requires a very precise synchronization source available over 5G to the cameras (e.g., TSN/PTP).
- The flexibility in physically moving the NoW position inside an area of interest or adding/removing cameras is appreciated by NRK. It was a very costly process when everything was wired.
- The operability of the 5G SNPN is a challenge to overcome. The stakeholder doesn’t feel fully capable to operate the 5G SA network on their own, and relies with help from the operator (TNOR in this case).

4.7. Pain Points and Risks

The two parts composing the Concurrent Media Delivery have their own time plan. The first risk that this use case is the progress misalignment done between Remote Production against Media Showroom. While Remote Production trials have been carried out in 2021 thanks to the Network on Wheels and early, bare metal version of the components are available, the Media Showroom is dependent on the implementation of the FUDGE-5G Platform. Media Showroom is still at the integration phase, and a delay in the development, on-boarding and trialing could derive in an overall delay of the development of the Concurrent Media Delivery, programmed by the last months of the project.

Regarding the Remote Production trials, the initial goal was to illustrate to the stakeholder, NRK, the performance and ease of deployment that 5G can provide compared with existing technology enablers, for professional content production. Due to this, no extensive measures were logged; so the S-NPN component validation alongside the TRL validation is not yet completed in the Phase-1 of the trials. This issue has been acknowledged by the partners and NRK. In consequence, the focus and methodology for the next Phase of the trials will be changed and the partners involve in the Media use case are evaluating how to carry and verify the test cases. Additionally, the trials will depend on the availability of a suitable outdoors event that NRK is interested to cover, which imposes a restriction in the trials schedule.

Table 9 contains more info on the risks and pain points for the Concurrent Media Delivery.

Table 9: Summary of risks and mitigation measures

Risk Description	Likelihood (L / M / H)	Severity (L / M / H)	Mitigation measure
Media Showroom trials execution experience delay, bottlenecking the Concurrent Media Delivery development	M	L	Media Showroom is still on the integration phase, and a delay in the development, on-boarding and trialling could derive in an overall delay of the development of the Concurrent Media Delivery. In case of extreme delays, the overall Use Case will be downscaled to focus into full 5G Remote Production with a small component of Content Distribution
Remote Production trials execution do not compile sufficient metrics to validate components	M	H	This issue has been acknowledged by the partners and NRK. In consequence, the focus and methodology for the next Phase of the trials will be changed and the partners involve in the Media use case are evaluating how to carry and verify the test cases. Additionally, the trials will depend on the availability of a suitable outdoors event that NRK is interested

			to cover, which imposes a restriction in the trials schedule.
E2E 5G SNPN capabilities not enough for 5G Full Scale Remote Production	M	M	If the use of the FUDGE-5G components cannot meet Remote Production requirements; advanced and optimized studies of the whole component chains will be explored. On the radio side, New Radio techniques such as Bandwidth Parts and Supplementary Uplink will be tested and measured.
Devices for mmWave 5G are not stable	M	L	In case stable mmWave devices are not available for Concurrent Media Delivery trials, sub-6 GHz equipment and bands will be used.

5. PPDR Vertical Trials

UC2, PPDR, is composed by three scenarios:

1. Standalone Network on Wheel (NoW).
2. Interconnection to a remote cloud.
3. Coexistence of public and non-public networks.

The first period of the project has focused on the integration and validation activities of Scenario 1. Figure 8 proposes the roadmap for the validation activities and the trial extension to the other two scenarios.

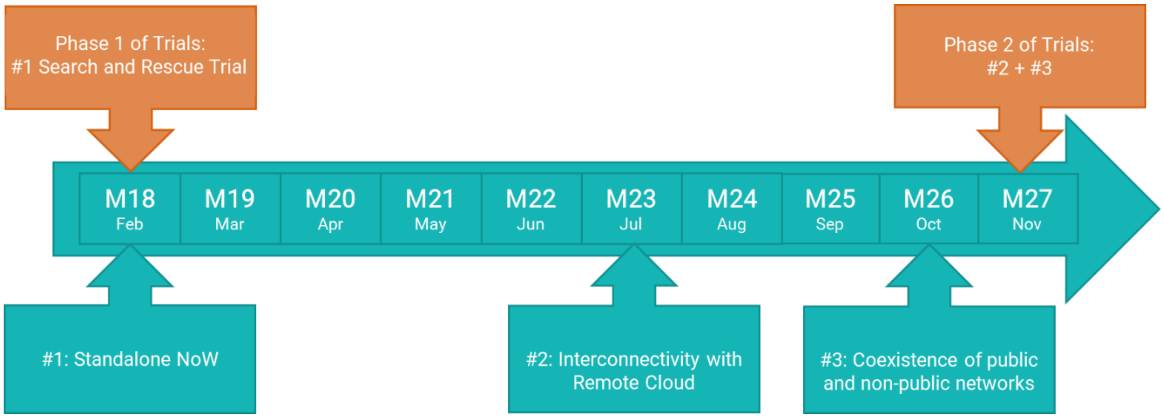


Figure 8: UC2 PPDR time plan

5.1. Test Cases

The use case involves three test cases, one for each scenario of the PPDR use case. Consistent with the Concurrent Media Delivery trial, Phase-1 trials for PPDR focused more on validating the feasibility of scenario 1: “Standalone Network on Wheel (NoW)” and the related test cases rather than on the overall evaluation of related KPIs. Phase-2 trials, which will follow the timeline in Figure 8, will instead cover the functional validation and evaluation of both the test cases and the KPIs for scenarios 2 and 3.

5.1.1. Standalone Network-on-Wheels

The test cases for the “Standalone Network-on-Wheels” scenario are described in Table 10. These test cases are geared towards validating the Fudge-5G NoW capabilities to support a standalone 5G network bubble oriented to specific PPDR operations. This is why both basic but also multimedia types of communications are tested to support the work done in the field by first responders.

Table 10: PPDR standalone Network-on-Wheels test cases

Title	Description
Basic 5G connectivity available	5G devices in the proximity of the NoW can associate with the 5G network provided by the NoW. From the device it is possible to ping a local edge server deployed on the NoW, then to realize a speed test to evaluate the raw available bandwidth.
Push-to-talk (PTT) between a group of devices	A group of 5G devices connected to the NoW can exchange voice PTT communications over the 5G network provided by the NoW. The PTT server is deployed locally on the NoW.
Group video conference between deployed forces and a C2 operator	A 5G device associated to the NoW can stream a video from the field to the other members of the group and back to an operator sitting inside the NoW via a C2 application. The C2 application is deployed locally on the NoW.
Group chat with BFT and situational awareness update	A group of 5G devices connected to the NoW can exchange textual messages and situation awareness data (photo, video, audio files and GPS positioning) in order to help reconstruct the hostile environment. The situation awareness server is deployed locally on the NoW.
Live tracking of health data	5G sensors are connected with the NoW. An operator sitting inside the NoW is able to subscribe to alerts from sensor readings and to evaluate the status of each sensor. The situation awareness server is deployed locally on the NoW.
Streaming Videos from HD situational awareness	Multiple video streams from multiple sources, such as drones and bodycams are streamed concurrently toward the operator in the NoW. The situation awareness server is deployed locally on the NoW.
Broadcast warning messages to all end-devices in coverage	An operator sitting inside the NoW can broadcast a warning message (textual) to all devices in the radio coverage of the NoW. The message is received also by devices not associated with the network provided by the NoW. The broadcast server is deployed locally on the NoW.

5.1.2. Interconnectivity with Remote Cloud

The test cases for the "Interconnectivity with Remote Cloud" scenario are described in Table 11. These test cases aim at extending the previous ones, by validating the interconnectivity of the NoW with a remotely available cloud datacentre by means of the use of an opportunistic backhaul link (e.g., a satellite link, or an aggregation of commercial 4G/5G networks). Apart from mere connectivity, these test cases require making use of the advanced capabilities of the FUDGE-5G platform for handling service routing between the edge and the cloud, and for managing the lifecycle of vertical applications.

Table 11: PPDR interconnectivity with remote cloud test cases

Title	Description
Basic 5G connectivity available	A 5G device in the proximity of the NoW can associate with the 5G network provided by the NoW. From the device, it is possible to ping both a local endpoint deployed in the NoW and a remote endpoint deployed in a distant cloud. It is possible to realize a speed test to evaluate the available raw bandwidth with both endpoints.
Push-to-talk (PTT) between a group of devices	A group of devices connected to the NoW can exchange voice PTT communications over the 5G network provided by the NoW. The PTT server is deployed on the remote cloud.
Group video conference between deployed forces and a C2 operator	A 5G device associated to the NoW can stream a video from the field to the other members of the group and back to an operator sitting inside the NoW via a C2 application. The C2 application is deployed on the remote cloud.
Group chat with BFT and situational awareness update	A group of 5G devices connected to the NoW can exchange textual messages and situation awareness data (photo, video, audio files and GPS positioning) in order to help reconstructing the hostile environment. The situation awareness server is deployed on the remote cloud.
Live tracking of health data	5G sensors are connected with the NoW. An operator sitting inside the NoW is able to subscribe to alerts from sensor readings and to evaluate the status of each sensor. The situation awareness server is deployed on the remote cloud
Broadcast warning messages to all end-devices in coverage	An operator sitting inside the NoW can broadcast a warning message (textual) to all devices in the radio coverage of the NoW. The message is received also by devices not associated with the network provided by the NoW. The broadcast server is deployed on the remote Cloud.
Crowd-sourced gun-detection system	5G devices serves as gunshot detection probes to discover the orientation and position of a gunshot. The devices continuously overhear and use a gunshot detection server to discover the position and the type of weapon. The gunshot detection server is on the remote Cloud.
Intermittent connectivity with remote cloud	Any of the vertical applications (e.g., gunshot detection or messaging server) from the previous test cases is instantiated locally at the NoW. Once backhaul connectivity with a remote cloud is activated, an instance of the vertical application is launched on the remote cloud and application traffic is rerouted there. In case of disconnection, local traffic is brought back to the autonomous edge instance.

5.1.3. Coexistence of public and non-public networks

The test case for the "Coexistence of public and non-public networks" scenario is described in Table 12. This test case complements the previous ones by adding the capability to steer traffic over different 5G slices provided by different networks (e.g., a PPDR-specific and a public network) dependent on the type of application.

Table 12: PPDR Coexistence of public and non-public networks test cases

Title	Description
Simultaneous use of NPN and PLMN	A 5G device is capable of exchanging data with a mission-critical service provided via the NoW (e.g., MC-PTT communications), but also a non-critical service provided over a PLMN (e.g., web browsing, map application).

5.2. Tools

The testing tools for validating the PPDR Use Case are mainly software. They are employed for the evaluation of the test cases, both during the laboratory tests and during the trials themselves, but also as a means to troubleshoot issues during the integration phases.

Validation tools comprise of iPerf3 client and Servers, nmap, OpenSpeedTest and Cisco Trex, tcpdump and Wireshark to capture network traces. A suite of testing and troubleshooting tools, namely iPerf, VLC, and DNS (Domain Name Service) servers – are deployed as VM instance on the NoW compute infrastructure and can be launched from the mobile terminals to assess performance.

Mean opinion scores are employed to evaluate multimedia streams via subjective quality evaluation tests administered to participants. In addition to those, questionnaires and focus group for getting both technical and exploitation-related feedback from key stakeholders and participants to the trials (more details are provided in Section 5.6.2).

5.3. KPIs

The target KPIs listed below are the minimum required to ensure that the functionalities proposed on the test cases are successfully delivered. KPIs are divided in two categories, namely Application KPIs and Service KPIs.

Application KPIs refer to application-related indicators that involve the interaction with end-users (e.g., characterising the user plane). Service KPIs mainly refer to platform setup and configuration (e.g., characterising the management and control planes).

5.3.1. Application KPIs

The application KPIs are described in Table 13.

Table 13: Application KPIs for PPDR use case

Application	KPI name	Description	Objective
Voice	Mouth-to-ear latency	The time between an utterance by the transmitting user, and the playback of the utterance at the receiving user's speaker (both for PTT and group calls)	**< 350 ms**
	Late call entry time	The time to enter an ongoing group call measured from the time that a user decides to monitor such a group call, to the time when the UE's speaker starts to play the audio	**< 350 ms**
	Access time	The time between when a PTT user request to speak and when this user gets a signal to start speaking.	**< 300 ms**
	Concurrent calls	The maximum number of concurrent person-to-person and PTT calls that the system can handle	**>10 concurrent calls**
	Users in a group call	The maximum number of users in a PTT group call	**> 25 users**
Video	Throughput	The measured average data rate to support H265 (4K)	**DL: >25 Mbps** **UL: >25 Mbps**
	Latency	The time between when a video stream is captured and when the user receive the stream	**500 ms**
	Late stream entry time	The time to enter an ongoing MC-Video stream measured from the time that a user decides to monitor such a MC-Video stream, to the time when the UE's scree, starts to play the video	**350 ms**
	Concurrent streams	The maximum number of concurrent H265 streams that the system can handle	**> 10 concurrent video stream**
	Mean Opinion Score	The subjective score of video streaming, based on the overall subjective feeling of the respondent	**> 4**
Messaging / Facsimile	Latency of distribution	The time required to distribute a message to all members of a distribution group	**< 1000 ms**

	Delivery failure	The percentage of messages that were not delivered after the delivery deadline	**< 0.1%**
Location	Localization latency	The time between the localization reading by a user device and the visualization over a remote C2 screen	**< 2000 ms**
Public warning broadcast	Coverage	The maximum distance where a device can receive the public warning message	**> 1500 m** **@ 43 dBm**
	Initialization time	The time to setup the public warning message network service before it being operational	**< 5min**
	Public warning latency	The time required to distribute a public warning message to the last device receiving it	**< 1000 ms**
Vital signs monitoring / telemetry	Monitoring latency	The time between the vital signs readings by a user device and the visualization over a remote C2 screen	**< 1000 ms**
Data	Data Rate	The maximum speed at which data is transferred between the source and its destination device	**> 100 Mbps**

5.3.2. Service KPIs

The service KPIs are described in Table 14.

Table 14: Service KPIs for PPDR use case

KPI name	Description	Objective
NoW installation time	The time to provision and setup the required software components to make the NoW fully functional, including the onboarding of FUDGE-5G platform, the 5G core, and vertical applications artefacts, but excluding service-specific deployment and configurations.	**< 0.5 days**
Management framework footprint	The minimum (recommended) HW requirements for all the management (VIM, orchestrators) to run properly	**CPUs** **GB of RAM** **GB of storage**

Service establishment time	The elapsed time to deploy and configure a vertical application, including 5G-specific slice parameters, before it being fully operational (from the deployment command)	**< 5 min**
Number of slices	The maximum number of slices concurrently supported by the system	**8**

5.4. Trials

The trials during Phase 1 focused exclusively on the validation of the *Standalone NoW* (Scenario 1), with the objective of validating the capabilities of a 5G network embedded in a mobile edge, offering broadband communication capabilities to first responders and Special Forces even in the case of remote deployments. Integration activities realized for the Standalone NoW are reported in [2].

The stakeholders involved in validation activities along the FUDGE-5G consortium partners for this use case are the Norwegian Defence Material Agency (NDMA) and the Norsk Luftambulanse.

It is important to note that the initial ability to validate Scenario 1 represents a key milestone for the PPDR Use Case, as the *Standalone NoW* represents the basis for further evolutions, to cover also the scenarios *Interconnectivity with remote cloud* (Scenario 2) and the *Coexistence of public and non-public networks* (Scenario 3).

5.5. Narrative

A natural catastrophe (e.g., flooding, avalanche, land slide) has hit a small village situated in the Norwegian mountain ranges (around 30 miles northeast of Oslo). The catastrophe has destroyed multiple buildings, and several people are still missing. In the aftermath, public authorities have ordered the evacuation of the village, and launched a rescue mission supervised by the military, including Norsk Luftambulanse aerial drones and the Red Cross to save missing people. When first responders arrive on the site, they report that public telecommunication infrastructure (both fixed and mobile) is severely damaged, practically inhibiting their use for first responders needs.

The FUDGE-5G NoW is employed to provide communication supporting the communications of first responder teams and serving as mobile C3 (Command, Control & Communications) hub. The NoW can be moved close to the area of operations, easily set up to provide 5G connectivity and computing capabilities. In particular, the use of remotely piloted drones and aerial photography is instrumental to provide aerial support. The teams operating on the field are monitored as well to ensure their safety and they provide real-time video from the field to enhance the situational awareness at the C3.

On the terrain, the enhanced situational awareness is instrumental to improve local decision making at the C3. Teams in the field and external support teams can access the situational awareness platform via their smartphones and monitor drone video and teams' location to improve their activities or support others.

5.5.1. Objectives

1. Validate the integration of 5G SA components at the NoW.
2. Validate the compatibility of 5G SA end devices from OneSource with the 5G SA network provided by the NoW.
3. Validate the use of vertical applications (namely Triangula gunshot detection, OneSource Mobitrust situational awareness platform and video distribution app) within the NoW.
4. Showcase the potential and the ability of a standalone private 5G network to allow broad band capabilities to first responders and special forces.
5. Evaluate the simplicity to setup and operate of such solution for non-technical operators.
6. Evaluate the reliability and stability of the solution.
7. Evaluate the flexibility of the deployment.

5.5.2. Deployment Topology

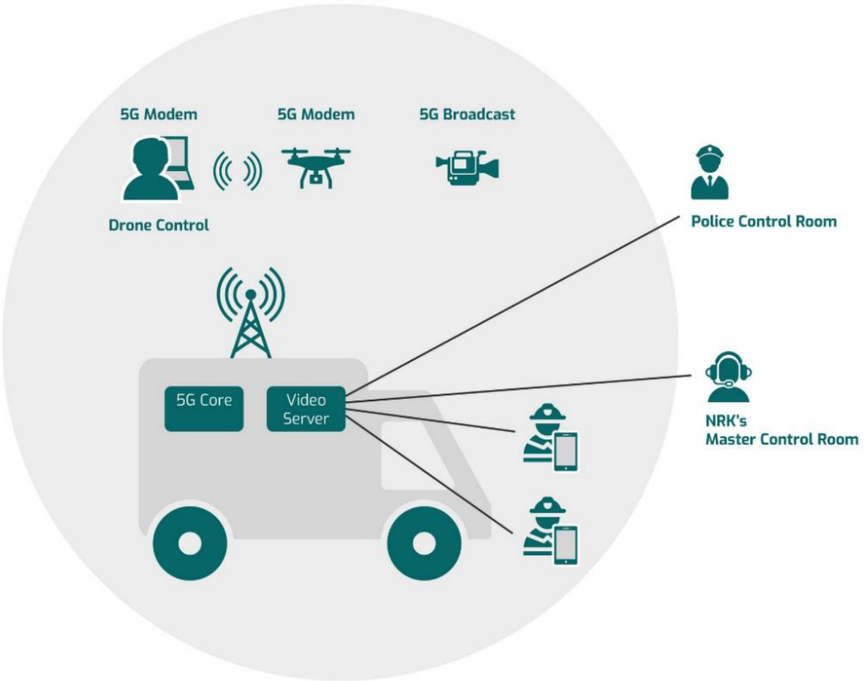


Figure 9: High-level architecture for the Standalone NoW trials

Figure 9 presents a high-level view of the technical architecture deployed during the "**Search and Rescue trial" held on December 2021 at the Rygge Airport in Oslo, Norway**. The trial mimics a typical deployment for a Search and Rescue (SAR) operation where it is possible to identify dismounted operators with cameras and flying drones with HD camera. The objective of the trial was to validate a subset of the objectives introduced before and, in particular, demonstrate the capability to stream multiple video flows from HD cameras, carried by dismounted operators or the drones, towards a video server hosted at the NoW (taking the role of C3).

5.5.3. Trial Progress

As part of Phase-1, four trials have been carried out. In addition to the Search and Rescue trial held in December 2021, the NoW was employed in other 3 demonstration activities with external stakeholders. All of them have make use of the NoW.

1. Participation to the NDMA Tech Day, held on 1st September 2021;
2. Testing of interference between 5G and Radar communications (stakeholder Norwegian Communications Authority - Nkom), held on October 2021;
3. Search and Rescue (SAR) Trial (stakeholder NDMA and Norsk Luftambulanse) held on December 2021 at the Rygge Military airbase;
4. Test of 5G radio interference on helicopters altimeter (stakeholder Norwegian Communications Authority - Nkom), held on January 2022.

5.6. Results

This section contains the results gathered at the trials.

5.6.1. KPIs

Several KPIs were logged during the execution of trials.

Table 15: KPIs of PPDR use case

KPI name	Description	Target	Result
Throughput	The measured average data rate to support H265 (4K)	**UL: >25 Mbps** **DL:>25 Mbps**	**UL: 12 Mbps**
Data Rate	The maximum speed at which data is transferred between the source and its destination device	**> 100 Mbps**	**UL+ DL: 130 Mbps**
Concurrent streams	The maximum number of concurrent H265 streams that the system can handle	**> 10 concurrent video stream**	**4**

5.6.2. Questionnaires

Participants to the Search and Rescue trial performed in December 2021 were given evaluation questionnaires to understand both their pre-trail expectations and post-trial overall satisfaction. The Microsoft Forms tool was used to design and collect data anonymously.

In total, we received 8 responses that allowed us to extract several interesting insights.

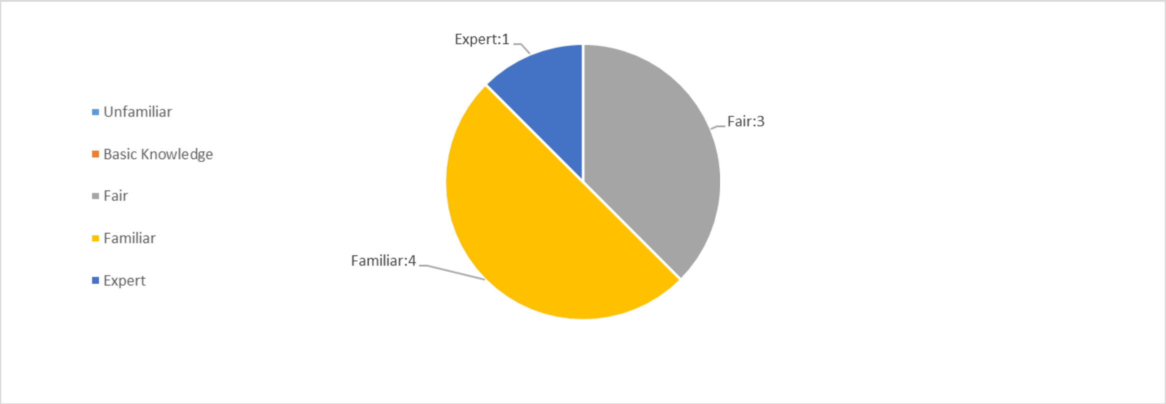
Pre-Trial

The pre-trial questionnaire focused on the expectations from of the stakeholders that assisted to trials.

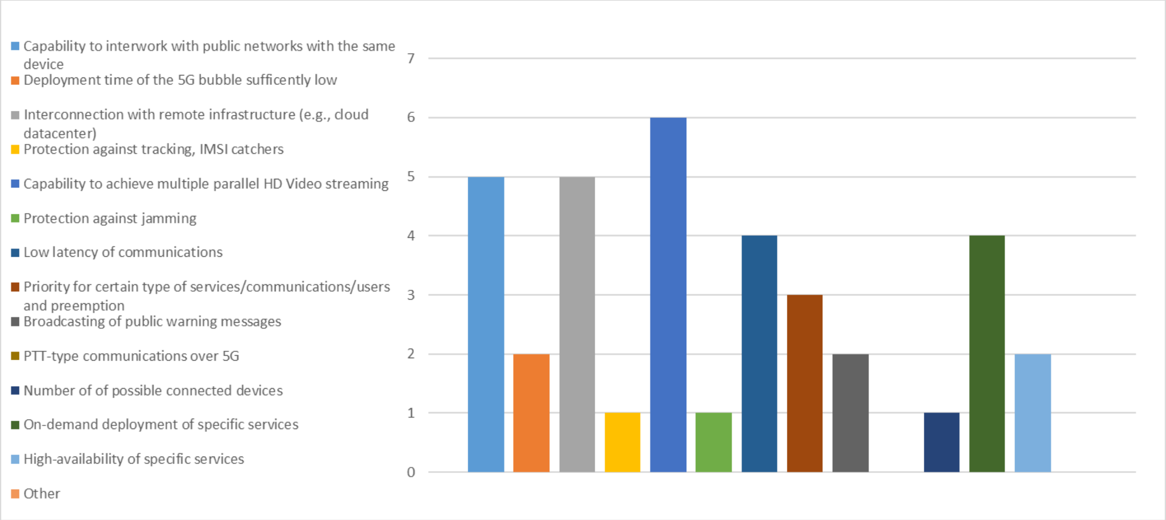
Q1: What is your role in your organization?

#	Answer
1	Technical Roadmap Project management Procurement
2	Technical director
3	Security Ambassador in Telenor Business
4	Team manager Broadcast&Media services
5	Product Manager
6	Sales and business development
7	R&D
8	Partner development and innovation

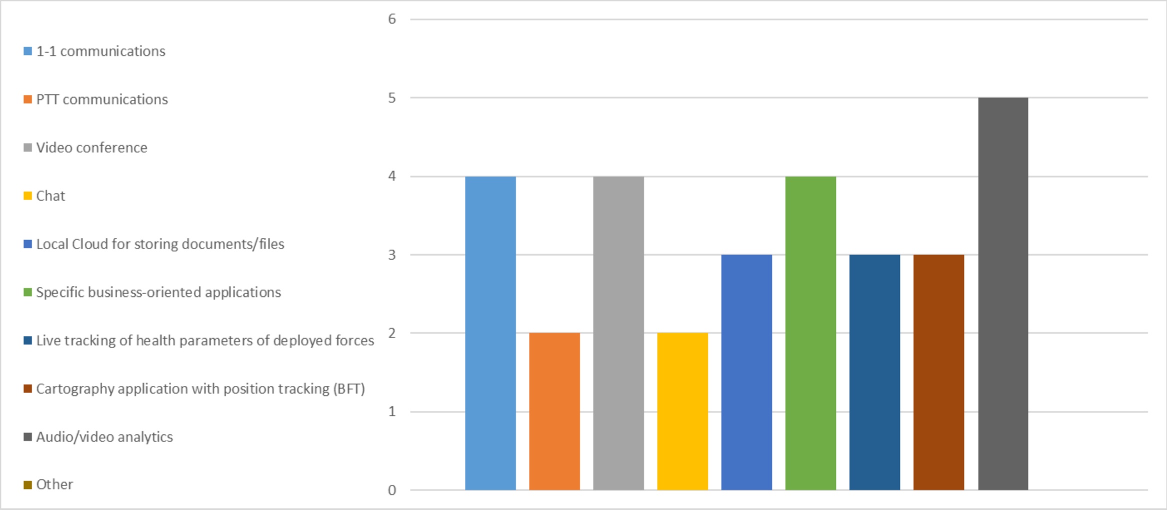
Q2: Self-rate your familiarity with 5G technology



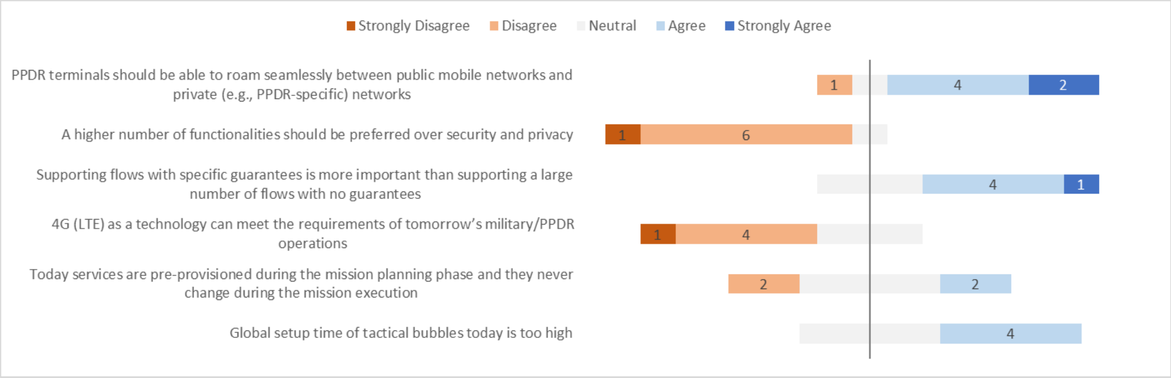
Q3: What are the most interesting aspects that should be validated in FUDGE-5G trials for PPDR/military deployment?



Q4: What are the applications/services that you would expect in a standalone PPDR/military deployment after 5G is validated?



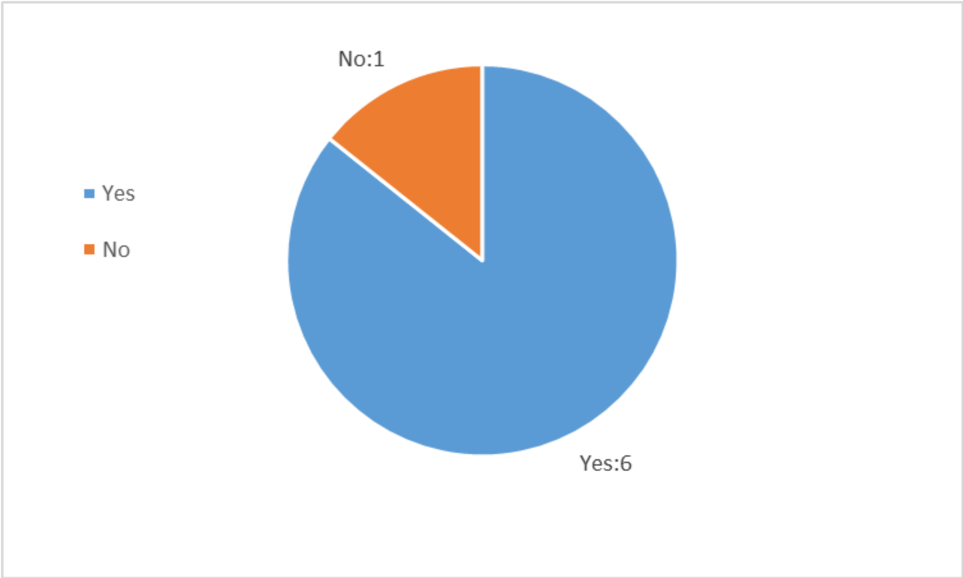
Q5: Please provide your agreement on the following questions



Post-Trial

Post-trials questionnaire focused on the satisfaction of the stakeholder that assisted to trials.

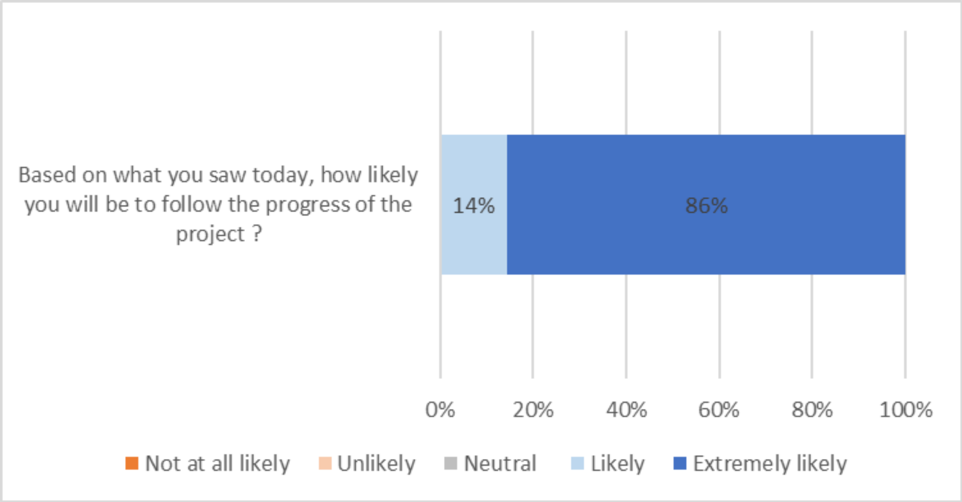
Q1: Before today, were you aware of the FUDGE-5G project?



Q2: Based on what you saw today, what is the single most important benefit that a private 5G could bring to a military/PPDR deployment?

#	Answer
1	Mobility with 5G coverage anywhere you want
2	Secure, low latency, high quality
3	Flexibility- based on location and functionality
4	A mobile VPN anywhere anytime multivendor multi service - and the ability to add your vpn to any dedicated network (like a 5g area network , or a nodnett) or any public network (like telenor) and any remote or public cloud service (like nrk on prem dc for analysis and broadcast , and or AWS for storage and AI)
5	Utilize the 3GPP ecosystem with “off the shelf” modems/smartphones
6	Private and secure network
7	Ultra reliability low latency

Q3: Based on what you saw today, how likely you will be to follow the progress of the project?



5.7. Analysis

- The focus of the first trials has been to demonstrate the integration of the different components into the NoW. The objective is already achieved as the NoW has been assembled and is currently working. This is demonstrated by the trial and demonstration activities that have been carried out in Q4 2021 and Q1 2022.
- The trials have demonstrated the stability of the FUDGE-5G NoW, which has been reliably working without major inconvenient during all the trialing activities. This is one of the main requirements requested by the PPDR stakeholders. This demonstrates as well the current TRL 6 achieved by the components integrated in the NoW. The TRL is expected to increase to 7 by the end of the project.
- Another requirement is represented by the deployment simplicity of the solution. In general, it takes less than 10 minutes from a cold start for having a 5G system fully functional. This represents as well one of the main requirements requested by the PPDR stakeholders.
- Currently, three vertical applications have been integrated and tested, namely Triangula (Gunshot detection), Mobitrust situational awareness platform, and a video distribution app from NLA.
- The aggregate bitrate of outbound flows from the 5G Core is currently capped at around 130 Mbps, although the RAN, the edge routers, and the Ethernet interface are all able of reaching 1 Gbps speed. This represents an unacceptable limitation that is in the process of being resolved. In fact, early investigations on the problem ruled out problems in the 5G Core implementation and pointed towards a limitation of the hardware hosting the core functions. The HW solution will be upgraded to a powerful machine to solve the issue.
- While we initially set a throughput requirement of 25 Mbps on the uplink, the cameras and drones employed during the trials have never required more than 13 Mbps to transmit their HD stream. This is likely due to very efficient compression algorithms and represent an interesting dimensioning parameter for MC-video slices.

- Voice performance have not yet been tested due to the ongoing delays of the integration of 5G-compliant MCPTT services.
- In general, the responses to the evaluation questionnaires reveal a great interest of the stakeholders in the proposed solution, and a marked satisfaction with the work carried out so far.

6. 5G Virtual Office Vertical Trials

6.1. Test Cases

There are three test cases, one for each sub-scenario of the 5G Virtual Office use case. The multiple steps of each test case are detailed in the subsections below.

6.1.1. Ward Remote Monitoring

The test cases for the "Ward Remote Monitoring" sub-scenario are described in the Table 16.

Table 16: 5G Virtual Office Ward Remote Monitoring test cases

Title	Description
The doctor connects a UE to the video camera, microphone and sensors	The doctor in the office has direct access to the hardware located at the patient's room at the ward, so it is able to monitor the patient's condition remotely.
Doctor subscribes to alerts from sensors attached to a patient	All the sensors on the patient's room at the ward are connected to the hospital network, so it is possible to subscribe to alerts from sensor readings. A doctor that is responsible for a patient receives these alerts on his/her UE, regardless of his/her location.
Sensor levels move outside typical ranges, or an abnormal pattern is detected, so the doctor receives an alert	Examples: if the SpO2 level drops under the threshold, the system raises an alarm and places an alert to the responsible doctor's UE; if an abnormal ECG pattern is detected by machine learning, an alarm is raised, and an alert is sent to the responsible doctor's UE for further analysis.
Remote medical procedure support	A patient at the ward requires a medical procedure that needs supervision of a specialized doctor. The doctor, connects his/her UE to the patient sensors, camera and microphone and guides the staff, located in the ward, on the steps to perform the necessary procedure.

6.1.2. Intra-Hospital Patient Transport Monitoring

The test cases for the "Intra-Hospital Patient Transport Monitoring" sub-scenario are described in the Table 17.

Table 17: 5G Virtual Office Intra-Hospital Patient Transport Monitoring test cases

Title	Description
A patient needs to be transported from the ward to the radiology department	A doctor, in office, connects the UE to the sensors, camera and microphone on the patient to be transported.
The doctor monitors remotely the patient state during the transport	A doctor, at his office, connects his UE to the sensors, camera and microphone on the patient to be transported.
Patient transport starts	The staff starts moving the patient towards the Radiology department. The sensors remain connected and roam from microcell to microcell without any disruption in connectivity.
Supervised medical procedure required	The doctor, monitoring remotely, receives an alert that the patient blood pressure is dropping. Immediately, the doctor request that the appropriated medication is applied and supervises the procedure.
The patient undergoes radiology exam and then is returned to his room at the ward	During the exam and when returning to the room, the doctor can monitor the patient from office, without any connectivity loss. Also, machine learning algorithms always keep processing sensor’s data in real time.

6.1.3. Ambulance Emergency Response

The test cases for the “Ambulance Emergency Response” sub-scenario are described in the Table 18.

Table 18: 5G Virtual Office Ambulance Emergency Response test cases

Title	Description
An ambulance is notified of the new call (patient’s address, possible status)	An ambulance on its way back to the headquarters receives a notification from the central that an emergency is happening. The crew gets the patient’s address and the status report.
Paramedics retrieve patient’s electronic health records from the hospital (simulated)	The ambulance, on its way to the emergency location, connects to the hospital database and retrieves the patient’s electronic health records.
The ambulance arrives at the patient´s address, the doctor is notified	The notification is generated automatically when the Vertical Applications detects that the ambulance arrived at the patient’s location. It is based on Geofencing to select the group of doctors to

	receive the notification and to understand the location of the paramedics.
The doctor connects his UE to the ambulance's video camera, microphone and sensors	The doctor connects to the ambulance's video camera, microphone, and sensors. As the paramedic enters the patient's house, the doctor gets a live FPV video feed.
The doctor assesses the patient situation and countermeasures are performed by the paramedics	The doctor and the paramedic assess the patient's state and the paramedic deploys the countermeasures requested by the doctor. The paramedic can perform some simple procedures with the supervision of the doctor at the hospital.
Paramedics update electronic health records	As soon as the patient is stable, the paramedic updates the patient's electronic health records from the ambulance. The updated file is instantly accessible at the hospital.
The on-site staff gets notified of the imminent arrival of the ambulance (patient id)	The staff on the hospital are notified and can monitor time left before the arrival of the ambulance. At the same time, they prepare the room with the required equipment according to the information received from the scene.

6.2. Validation Tools

The 5G Virtual Office use case adopts the generic validation framework architecture of FUDGE-5G, further specifying it for its needs. In Figure 10, this architecture is depicted in detail. It includes three sources for metrics: the 5G infrastructure and platform and the Kubernetes Cluster (functional metrics), as well as the stakeholders (non-functional metrics). For functional metrics, the process can follow different paths depending on how they are collected, aggregated, and correlated: they can come already as metrics, or they may require pre-processing if obtained through logging systems. Once these metrics and processed, they are visualised in the portal provided by Grafana. In the same portal, a different interface is used for non-functional metrics through the capabilities of Google Forms, aiming at collecting, processing and visualize feedback from stakeholders in the form of questionnaires.

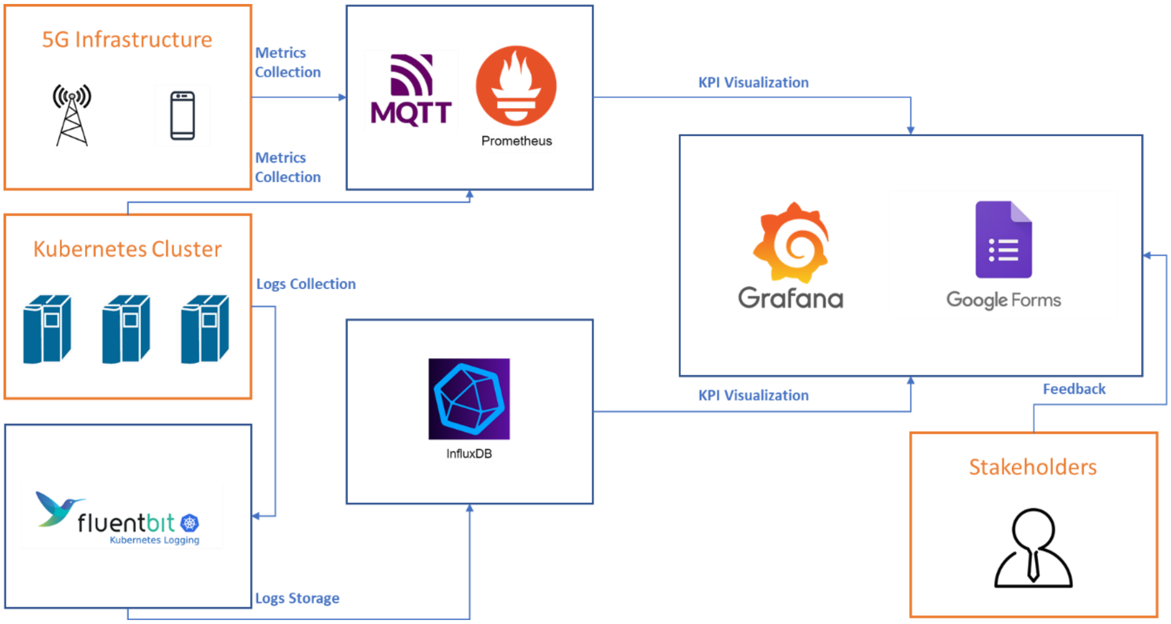


Figure 10: Validation Framework Architecture for 5G Virtual Office

6.3. Validation KPIs

This section describes the multiple validation KPIs to be used in the trials of the use case.

6.3.1. Service KPIs

Table 19 lists the KPIs for the platform on the 5G Virtual Office UC, as well as its target values. The targets listed are the minimum required to ensure that the functionalities proposed on the use case are successfully delivered.

Table 19: Platform KPIs for 5G Virtual Office

Profile	Distance	Resolution	Frame Rate	E2E Latency	Packet error Rate	Date Rate UL	Date Rate DL
Live Video from patient´s room	up to 500m	3840 x 2160 4K	60 fps	400 ms	10^{-10} UL 10^{-7} DL	50 Mbps	20 Mbps
Live Video from ambulance	< 1 km	3840 x 2160 4K	60 fps	450 ms	10^{-10} UL 10^{-7} DL	50 Mbps	20 Mbps
	< 10 km		60 fps	600 ms	10^{-10} UL 10^{-7} DL		

	< 50 km		60 fps	1.5 s	10^{-10} UL 10^{-7} DL		
Remote Monitoring of Vital Signs from ambulance	< 1 km	n.d.	n.d.	10 ms	10^{-10} UL 10^{-7} DL	250 kbps	500 kbps
	< 10 km	n.d.	n.d.	20 ms	10^{-10} UL 10^{-7} DL	250 kbps	500 kbps
	< 50 km	n.d.	n.d.	50 ms	10^{-10} UL 10^{-7} DL	250 kbps	500 kbps
Remote Monitoring of Vital Signs within Hospital	up to 1 km	n.d.	n.d.	10 ms	10^{-10} UL 10^{-7} DL	250 kbps	500 kbps

6.3.2. Application KPIs

The application KPIs are described in Table 20.

Table 20: Application KPIs for 5G Virtual Office

KPI ID	Description	Measurement procedure
UC3-K1	Incident Notification Time (INT) is the elapsed time from the moment the incident is identified (TS1) until the moment the users receive the notification (TS2). INT should not exceed 1000 ms.	The identification, the content of the message and TS1 and TS2 timestamps will be logged into a KPI pool.
UC3-K2	End-to-End HD Multimedia Latency (HML) is the elapsed time from the moment HD Multimedia is requested (TS1) by the operator until the multimedia is displayed at the operator screen (TS2). HML should not exceed 600ms.	The identification, the content of the message and TS1 and TS2 timestamps will be logged into a KPI pool.
UC3-K3	HD Multimedia Quality of Experience (QoE) represents the user satisfaction feedback by evaluating the responses to the question "How satisfied are you with multimedia experience" on a 0 a 5 scale (Very dissatisfied, Dissatisfied, Neutral, Satisfied, Very satisfied). 80% of users are expected to provide a "Very satisfied" feedback.	The identification, HD Multimedia QoE type, and response to the satisfaction inquiry will be logged into a KPI pool.

UC3-K4	Incident Response Action Time (IRT) is the elapsed time from the moment the incident was identified (TS1) until the moment the response action is initiated (TS2). IRT should not exceed 1000 ms.	The identification, the content of the message and TS1 and TS2 timestamps will be logged into a KPI pool.
UC3-K5	End-to-End SD Multimedia Latency (SML) is the elapsed time from the moment the device starts sending SD Multimedia (TS1) until it is displayed at the operator screen (TS2). SML should not exceed 400 ms.	The identification, the content of the message and TS1 and TS2 timestamps will be logged into a KPI pool.
UC3-K6	Mobitrust Platform QoE represents the user satisfaction feedback by evaluating the responses to the question "How satisfied are you with MOBITRUST platform" in a 0 a 5 scale (Very dissatisfied, Dissatisfied, Neutral, Satisfied, Very satisfied). It is expected that, at least, 80% of the users providing a "Very satisfied" feedback.	The identification, platform QoE type, and response to the satisfaction inquiry will be logged into a KPI pool.
UC3-K7	Sensor Data Latency (SDL) is the elapsed time between the timestamps of the messages since they are delivered from the device (TS1) until the moment they are received by the operator (TS2). SDL should not exceed 10 ms.	The identification, the content of the message and TS1 and TS2 timestamps will be logged into a KPI pool.
UC3-K8	Device Authentication Time (DAT) is the elapsed time from the moment the device is turned on (TS1) until the moment it receives the acknowledgement (TS2). DAT should not exceed 1000 ms.	The identification, the content of the message and TS1 and TS2 timestamps will be logged into a KPI pool.
UC3-K9	Device battery life should last 4 hours while delivering sensor data to the CCC, since they are turned on (TS1) until the moment they are shut down (TS2).	TS1 and TS2 for BK Devices are logged into a KPI pool.
UC3-K10	Device should run without restarts.	Connection log messages will help to identify the number of device restarts since they are turned on.
UC4-K11	Device communication should be available 99% of the time.	Device communication downtime (DT) will be retrieved from device logs. This KPI will consider the total running time (RT) to compute the formula (DT/RT)*100.

6.4. Trials

The current planning of trials for this use case, depicted in Figure 11, spans from M18 to M25, i.e., February 2022 to September 2022. It includes all the trials of the first phase, which follows an incremental roadmap and aligns with the availability of the FUDGE-5G platform components as well as with the availability of additional hardware to validate the multiple scenarios of the use case. It also includes the second phase of trials, which is bound to start in September 2022 and will have all the components and all the scenarios from the very first day, including improvements stemming from the gap analysis to be performed with phase 1 trials.

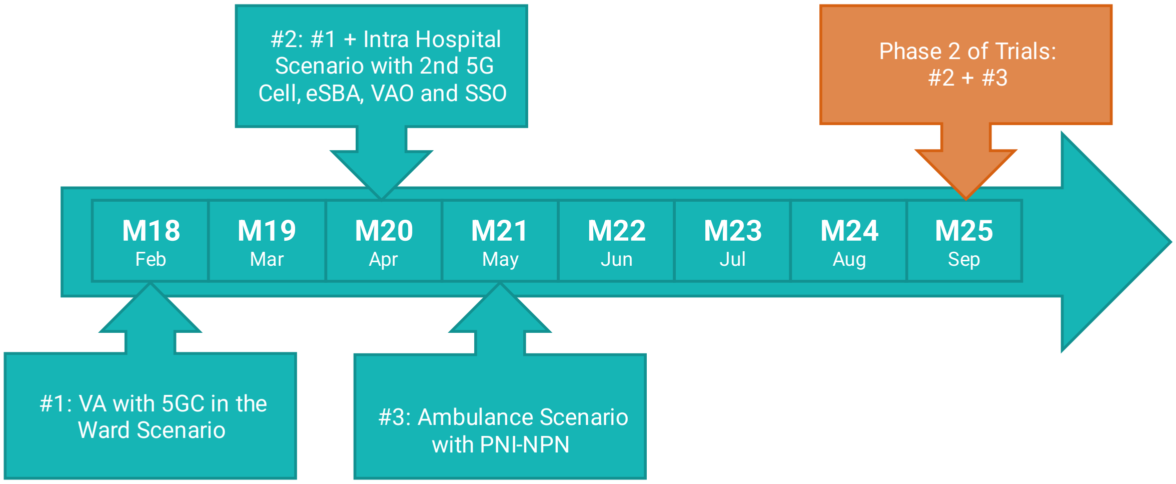


Figure 11: 5G Virtual Office Trials Roadmap

6.5. Results

Until today there were no trials for this UC. Hence, no results can be presented, and this information will be updated in the next version of this document.

6.6. Analysis

Until today there were no trials for this UC. Hence, no results can be analysed, and this information will be updated in the next version of this document.

6.7. Pain Points and Risks

The execution of trials and their validation is expected to face some pain points. The key pain points are detailed below:

- Time-sensitive alerts (very low SpO2 level or blood pressure drop) require reliable and deterministic latencies. State-of-the-art networks are not able to offer low enough latency to assure that alerts get to the destination fast enough and that decisions (via video/audio) on a patient can be performed in a safe way.
- Non-public networks need to be accessed transparently and securely, even when supported on public networks. This requires isolation from the rest of the network and the capability to execute NF instances within the provider premises securely.
- It is not always possible to have a health professional in front of a health monitoring computer terminal or next to the patient, so most times diagnosis and treatment are delayed until that can happen. An S-NPN 5G network that removes the location factor

could help to mitigate this issue, while satisfying privacy concerns due to its internal management and isolation.

7. Industry 4.0 Vertical Trials

7.1. Test Cases

Use Case 4 has been basically divided into four different test applications. We detail in the following tables all the different test cases and steps for each application. Information about the target KPIs, requirements and assumptions are also highlighted.

7.1.1. Remote Monitoring-as-a-Service

The test cases for the "Remote Monitoring-as-a-Service" sub-scenario are described in the Table 21.

Table 21: Test cases for application 1: Remote monitoring as a service

Test case	Description	Target KPIs	Assumption
1	Video streaming of remote assets and processes – no image processing.	UL throughput, DL throughput, E2E latency	8 streams of 4K-quality. *UL throughput ideal requirement*: 200 Mbps
2	Video streaming of remote assets and processes – image processing at the edge node.	UL throughput, DL throughput, E2E latency	8 streams of 4K-quality. *UL throughput ideal requirement*: 200 Mbps
3	Network orchestration – dynamic resources allocation	Network load	-
4	Data traffic handling – seamless handling of traffic with varying priority levels. Traffic with high priority is prioritized	Throughput, Reliability	-
5	Network throughput handling with distance and mobility	Throughput vs static distance, Throughput vs. moving object	Moving object speed of up to 20-80 cm/s
6	Coverage of NPN with multiple gNB's and smooth handling of client handover from one gNB to another.	Availability, Latency	-

7.1.2. Remote Control-as-a-Service with Real-Time Feedback

The test cases for the "Remote Control-as-a-Service with Real-Time Feedback" sub-scenario are described in the Table 22.

Table 22: Test cases for application 2: Remote control-as-a-Service with real-time feedback

Test case	Description	Target KPIs	Assumption
1	Video streaming of remote assets and processes with equipment control running in parallel over the same network	UL throughput, DL throughput, E2E latency	8 streams of 4K-quality. *UL throughput requirement*: 200 Mbps *Control requirement*: max. 10ms latency.
2	TSN support with 5G NPN	TSN for IP traffic, TSN for non-IP traffic	-
3	Time sync functionality evaluation	Timing accuracy	-
4	Data traffic handling – seamless handling of traffic with varying priority levels. Traffic with high priority is prioritized	Throughput, Reliability	8 types of traffic will be simulated
5	Network throughput handling with distance and mobility	Throughput vs static distance, Throughput vs. moving object.	Moving object speed of up to 20-80 cm/s
6	Coverage of NPN with multiple gNB and smooth handling of client handover from one gNB to other	Availability, Latency	-
7	Localization service over 5G	Position accuracy	-

7.1.3. 5G Adaptability in Industrial Environments

The test cases for the "5G Adaptability in Industrial Environments" sub-scenario are described in Table 23.

Table 23: Test cases for application 3: 5G adaptability in industrial environments

Test case	Description	Target KPIs
1	Transmission power level control for safe operations in hazardous areas	UL throughput, DL throughput, E2E latency, Reliability
2	Coverage in dense environments with heavy metal and concrete construction – onshore/offshore. Small cell coverage and options to connect repeaters.	Coverage
3	Interoperability and hardware independency of 5G core &f RAN from different vendors.	Reliability
4	Impact of 5G spectrum on NPN.	Frequency bands to be tested in Norway
5	5G devices and network provisioning	Software as a service test, Whitelisting

7.1.4. Process Control over 5G

The test cases for the "Process Control over 5G" sub-scenario are described in the Table 24.

Table 24: Test cases for application 4: Process control over 5G

Test case	Description	Target KPIs
1	PID over 5G – simulated process.	Quality of Control (QoC)
2	PID over 5G – optional (test bed).	QoC
3	Control functionality with physical controller.	QoC
4	Control functionality with soft/virtual controller.	QoC

7.2. Tools

A set of tools will be used to test the performance and user experience of the use case's platform. These will provide both quantitative and qualitative analysis regarding the execution of the use case and how its objectives are fulfilled.

Test equipment will be industrial devices and host systems will be actual process control software. Use case partners shall meet the application requirements transparently without having host system intervention. In addition, ABB expects to be provided with adequate software and tools to design, provision, commission and operate 5G NPN with connected devices. The tools being referred here are the software packages needed to configure/control the 5G NPN. The test applications in end devices and host systems will be designed assuming that the network provides the services within the acceptable level of target KPIs.

7.3. KPIs

The table below lists the ideal minimum required application and network KPIs to ensure that the functionalities proposed on the use case are successfully delivered, as well as the expected achievable values for these KPIs with the hardware available in the project.

In the factory, a controller will interact with many sensor and actuator devices located within a small area (up to 100 m^2). These applications have high performance requirements such as low latency, high reliability, and deterministic delivery of messages. The following validation KPIs and performance requirements are expected to be met.

7.3.1. Application KPIs

Table 25: Application KPIs for Industry 4.0 use case

KPI name	Description	Achievable requirements	Ideal requirements
End-to-end latency	Latency is measured as the time delay from message generated at source until its arrival at the end node.	Depends on the application	10 ms
NPN 5G latency	Considered as part of the end-to-end latency. Delay introduced by the 5G NPN network	10 ms	1-2 ms
DL throughput	Average data rate in the DL. In typical 5G consumer use cases, DL throughput is of utmost importance. Condition monitoring, optimization, VR, AR, and CCTV applications require significant throughputs	900 Mbps	4 Gbps

UL throughput	Average data rate in the UL. Note that in in industrial use cases UL throughput is also important	80 Mbps	200 Mbps
Power consumption	Controlling energy levels is key in this use case, because of the need to reduce production costs.	-	-
Transmission power	Transmission power levels in the gNB must be kept to a lower value to ensure that it is safe to operate the equipment when deployed in a hazardous area in the considered frequency range.	EIRP ~ 2-10 W	EIRP ~ 2-10 W
5G coverage	The maximum distance where a device can receive the public warning message. gNB transmission power levels should be enough to provide coverage and support the required communication in the industrial environment. This will be supported for the considered frequencies.	Related to consumption	Related to consumption
Reliability	Quality of a system of being trustworthy or of performing consistently well.	99.9%	99.9%
Availability	This value will vary depending on the outage time permitted in a year, that is, the period of time when the system is unavailable.	TBD	99.8% for 17h 31m 53s 99.9% for 8h 45m 56s 99.999% for 5m 15s 99.999999% for 0.3s
Mobility	Maximum speed tolerated for guaranteeing a minimum reliability specified.	80-100 cm/s	20-80 cm/s
QoS	Overall performance of a service experienced by the users of the network.	-	-
Position accuracy	The difference in location between a measured value to a standard or known value.	< 1 m	< 1 m

QoC	Process that ensures that product quality is maintained or improved.	-	-

7.4. Trials

The trials have been divided into two phases. The first phase of integration consists of a standalone NPN to be used within a controlled environment in ABB premises. In this initial phase, all components are demonstrated on premises, with a bare metal 5GC deployed at ABB. It spans from the beginning of the project, i.e., M1, to M20, where the first trial is planned. This first integration will not include TSN and 5G-LAN functionalities, which will be demonstrated in the second phase. Note that the first phase has been delayed because ABB, the main stakeholder of this use case, moved to another building in Fornebu and some administration processes, as well as planning of the activities, needed to be reformulated.

The second integration phase will go from M21 to M30 and will expand the functionalities integrated in Phase 1 and demonstrate TSN and 5GLAN as main innovations. Another main achievement in this phase is the validation of the FUDGE-5G platform, which will be used to orchestrate the 5GC. The location for the final trial will be also ABB premises, although in this case the 5GC will be placed in a cloud-hosted environment. The following figure shows an updated version of the trial planning showed in D3.1 [2] for Phase 2.

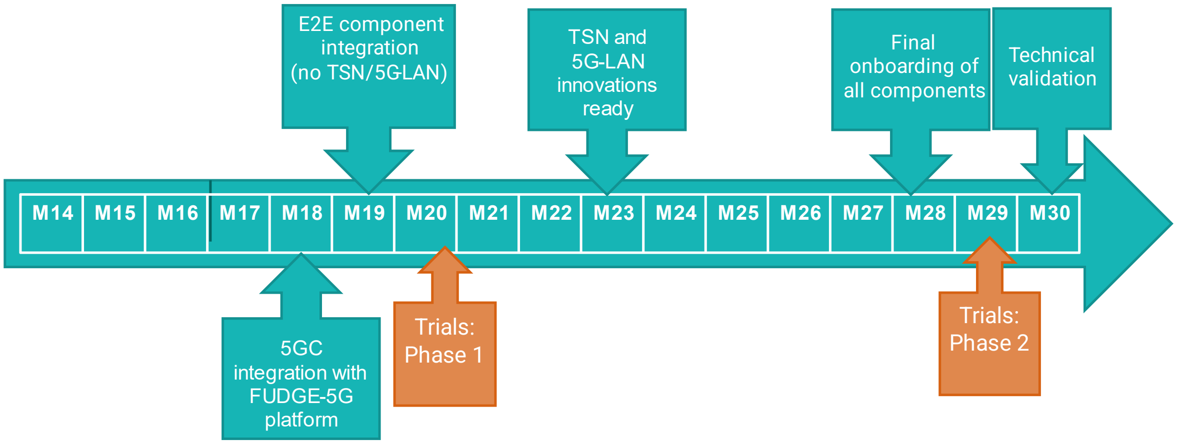


Figure 12: Use case 4 timeline and milestones for trials

7.5. Results

Until today there were no trials for this UC. Hence, no results can be presented, and this information will be updated in the next version of this document.

[2] FUDGE-5G Consortium, "D3.1 Test-bed Continuous Technology Integration," 2021.

7.6. Analysis

Until today there were no trials for this UC. Hence, no results can be analysed, and this information will be updated in the next version of this document.

7.7. Pain Points and Risks

Although the execution of trials and their validation has not started yet at the point of writing, it is expected to face some pain points and risks along the way:

- The first pain point in the Industry 4.0 use case is related to the integration of 5G components. Although this step is part of WP3, any potential delay in the development and integration of a particular component affects the entire ecosystem, causing delays and therefore affecting the dates of the planned trial. The integration of the RAN and the 5GC is, for instance, a key milestone whose delay would affect the rest of components.
- Another potential risk is the low coverage in the considered scenario. To solve this problem, a proper coverage planning, including visits to the factory, is being done at the moment.
- The current solution for phase-1 will is based on bare metal versions of the network components. Partners may experience some delays when moving these components to a cloud-hosted environment using the FUDGE-5G platform.
- There is a potential risk that the maturity level of the developed TSN and 5GLAN solutions may be low for final trials in a real industrial environment. This specially affects TSN, which complete specification will come with 3GPP Rel-16. Partners are working on implementing TSN over Rel-15 solutions and will implement Rel-16 at the end of the project.
- Non-public networks need to be accessed transparently and securely. This is key in an industrial environment where there are not only robots but also workers involved, and their safety is of utmost importance.

The COVID-19 pandemic may cause delays or small modifications in the plans, since the physical presence of some partners will be essential for running trials.

8. Interconnected NPNs Vertical Trials

The use case Interconnected NPNs showcases two scenarios of roaming between private networks:

- Local breakout - where the UE is authenticated by the home network and can utilise the services of the visited network.
- Home routed roaming - where the UE is authenticated by the home network and can utilise the services of both visited network and home network.

The following subsections will discuss how these scenarios will be validated in the trials.

8.1. Test Cases

There are four test cases, depending on the scenarios covered by the Interconnected NPNs use case. The multiple steps of each test case are detailed in the subsections below.

8.1.1. Interconnection of the NPNs

The test cases for the "Process Control over 5G" sub-scenario are described in the **Error! Reference source not found.**.

Table 26: Interconnected NPNs connectivity between NPNs test case

Title	Description
Establishment of connectivity between Visited and Home Network	Visited network initiates connection to the home network, if there is visited subscriber which needs to be authenticated by the home network.
Termination of connectivity between Visited and Home Network	The visited and the home network should terminate their interconnection in case there is no visited subscriber connected.

8.1.2. Home Subscriber Authentication

The test cases for the "Home Subscriber Authentication" sub-scenario are described in the Table 27.

Table 27: Interconnected NPNs home subscriber authentication test case

Title	Description
Home subscriber connects to the home network	Home subscriber is within the coverage of home network, it initiates registration procedure by sending the registration request to the local AMF through the local RAN.
Home subscriber authenticated by the home network	After receiving the registration request, the home subscriber gets authorized by the home network.

8.1.3. Visited Subscriber Authentication

The test cases for the "Visited Subscriber Authentication" sub-scenario are described in the Table 28.

Table 28: Interconnected NPNs visited subscriber authentication test case

Title	Description
Visited subscriber connects to the visited network	Visited subscriber is within the coverage range of a potential visited NPN, it initiates registration procedure by sending the registration request to the local AMF through the local RAN.
Identity check for the visited subscriber	The local AMF in the visited network will determine the identity provided by the visited subscriber belongs to the local domain or an external one. In case of external domain AMF will forward the request to local SBC.
Discovering home network and establishing connectivity	Visited networks should discover dynamically home networks for the visited subscribers and initiate a secure connection towards the home network.
Forwarding message to the home network for the visited subscriber	Once the connection is established the SBC in visited network will forward the authentication request for the visited subscriber to the home network SBC.
Visited subscriber authenticated by the home network	After receiving the authentication request, the visited subscriber gets authorized by the home network and the response is sent to the visited network to complete the registration procedure.

8.1.4. Access to Network Services

The test cases for the "Access to Network Services" sub-scenario are described in Table 29.

Table 29: Interconnected NPNs access to local and remote network services test case

Title	Description
Access to local network services	Both Home and Visited subscriber will have access to the local network services and local offload.
Access to home network services	Subscribers connected to the home network will have access to home network services. Subscribers connected to the visited network will have access to home network services in case of home routed roaming, not for local breakout.

8.2. Validation Tools

The following set of tools is planned to be used to test the scenarios and validate the performance of the platform. These will provide both quantitative and qualitative analysis regarding the execution of the use case and how its objectives are fulfilled.

- Emulated UEs and gNodeBs within the Open5GCore testbed will be used to validate the authorization framework.
- Devices with different PLMNs will be connected to the 5G cores through a 5G RAN. The interoperability testing will be performed and devices for which the PLMNs belong to another domain will be authenticated by the remote domain.
- The Open5GCore integrated Benchmarking Tool (BT) (https://www.open5gcore.org/) will be used to validate the capacity and performance of the system. The variation of procedure duration will be validated for both home and visited subscribers.

8.3. KPIs

8.3.1. Service KPIs

As this use case interconnects three distinct networks using a third-party backhaul. The backhaul is over the internet (a "best-effort" network) which is not under the control of the experiments. Because of this, all the specific KPIs are dependent on the backhaul characteristics (e.g., the delay of the best effort network should be added to the procedures delay, etc.).

The KPI performance values presented into the next table are done without including the impact of the backhaul. This will be computed during the actual execution of the measurements.

Table 30: Performance KPIs for the Interconnected NPNs use case

KPI ID	Type of UE	Description	Measurement procedure	Measurement
UC5-K0	N/A	Control KPI to determine the "best-effort"	Parallel control during the other measurements of backhaul RTT and capacity with ICMP measurements and iPerf capacity and jitter measurement.	Depending on the best-effort network.
UC5-K1	Home Network UE	Time taken by the UE for completing the registration procedure with the core network as defined by 3GPP in the specifications.	To measure this parameter, a UE from Benchmarking tool will be registered to calculate the time for completing the procedure.	60 ms
UC5-K2		Time taken by the UE for completing the PDU session establishment procedure with the given data network.	To measure this parameter, PDU session establishment procedure will be triggered for a UE from Benchmarking tool to calculate the time for completing the procedure.	40 ms
UC5-K3		Time taken by the UE for completing the de-registration procedure with the core network as defined by 3GPP in the specifications.	To measure this parameter, a UE from Benchmarking tool will be de-registered to calculate the time for completing the procedure.	20 ms
UC5-K4		RTT for data path to home network.	To measure this parameter, ping will be executed to home network DNN.	15 ms
UC5-K5	Visited Network UE	Time taken by the UE for completing the registration procedure with the core network as defined by 3GPP in the specifications.	To measure this parameter, a UE from Benchmarking tool will be registered to calculate the time for completing the procedure.	60 ms + 8 * Backahul RTT.
UC5-K6		Time taken by the UE for completing the PDU session establishment procedure with the given data network.	To measure this parameter, PDU session establishment procedure will be triggered for a UE from Benchmarking tool to calculate	40 ms + 4 * Backhaul RTT

			the time for completing the procedure.	
UC5-K7		Time taken by the UE for completing the de-registration procedure with the core network as defined by 3GPP in the specifications.	To measure this parameter, a UE from Benchmarking tool will be de-registered to calculate the time for completing the procedure.	20 ms + 2 * Backhaul RTT
UC5-K8		RTT for data path to home network.	To measure this parameter, ping will be executed to home network DNN.	15 ms + 2 * Backhaul RTT
UC5-K9		RTT for data path to visited network.	To measure this parameter, ping will be executed to visited network DNN.	15 ms

For the network capacity, there is a direct dependency on the backhaul capacity to the home network. The following KPIs will be measured:

Table 31: Performance KPIs for the Interconnected NPNs use case

KPI ID	Type of UE	Description	Measurement procedure	Measurement
UC5-K10	Visited Network UE	Data path capacity in the local network	Fill up the local RAN connection	Mbps
UC5-K11		Effective data path capacity in the local network	Fill up the local RAN connection	Effective capacity (Mbps) / Momentary Outbound Capacity (Mbps)
UC5-K12		Data path capacity over the best effort backhaul	Fill up the local RAN connection	Effective capacity (Mbps) / Momentary Backhaul Capacity (Mbps)

8.4. Trials

The planning for the trial of this use case is shown using Figure 13. The time span of the roadmap is from M18 to M30. In the first phase of the trial, the use case is validated more on the functionalities. Local breakout scenario for roaming was tested between UPV and FOKUS NPNs. In the next phase, the trials will be performed between the three NPNs deployed at FOKUS, UPV and TNOR campus. The integration of the FUDGE platform and connectivity between the three NPNs will be important to validate different scenarios of the use case. Functionalities to perform home routed roaming will be onboarded in this phase. The second phase will validate the use case based on the functionalities it is aiming to achieve and based on the KPIs collected throughout the trials. Phase 2 trials is planned from M26 to M29.

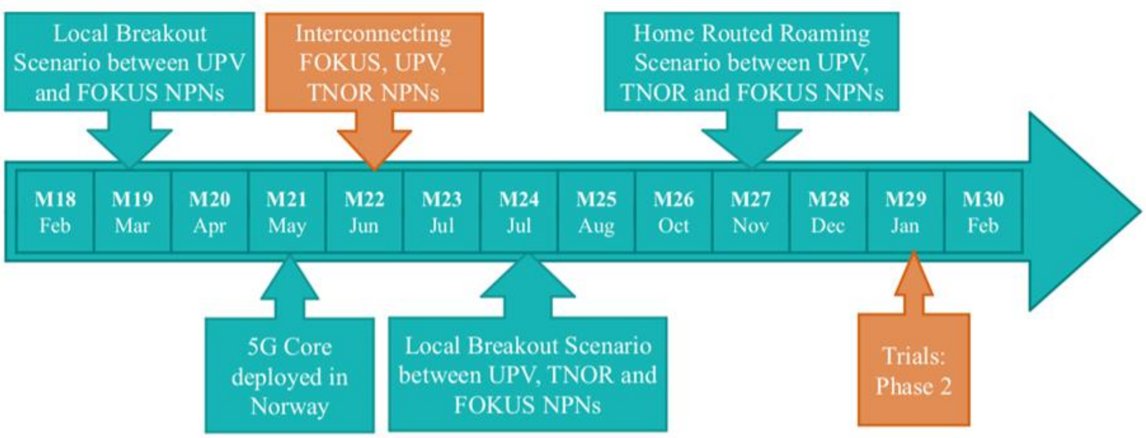


Figure 13: Interconnected NPNs Trials Roadmap

8.5. Results

For this use case till now only functional validation have been performed for local breakout roaming. For the trials planned later measures will be collected and will be documented in the next version of the document.

For the functional validation, NPNs were deployed in UPV and FOKUS campuses. Both the sites were connected through a VPN tunnel for improving security. ZTE modem and Amarisoft RAN was used at UPV to validate the roaming functionality. ZTE modem which was in the coverage of UPV campus could register itself to the home network deployed in FOKUS. This functional test verified that the roaming works with a real UE between UPV and FOKUS campuses.

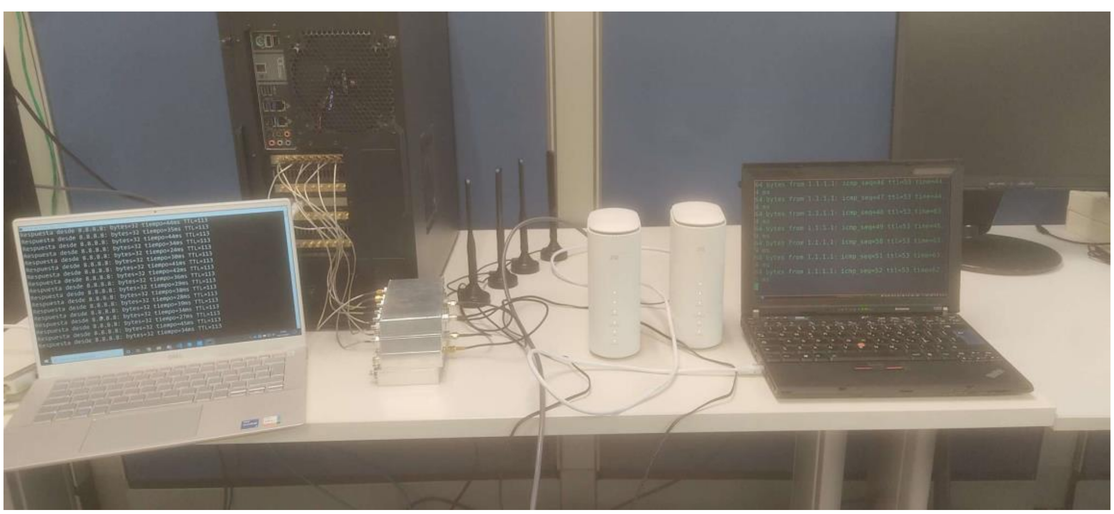


Figure 14: Setup at UPV

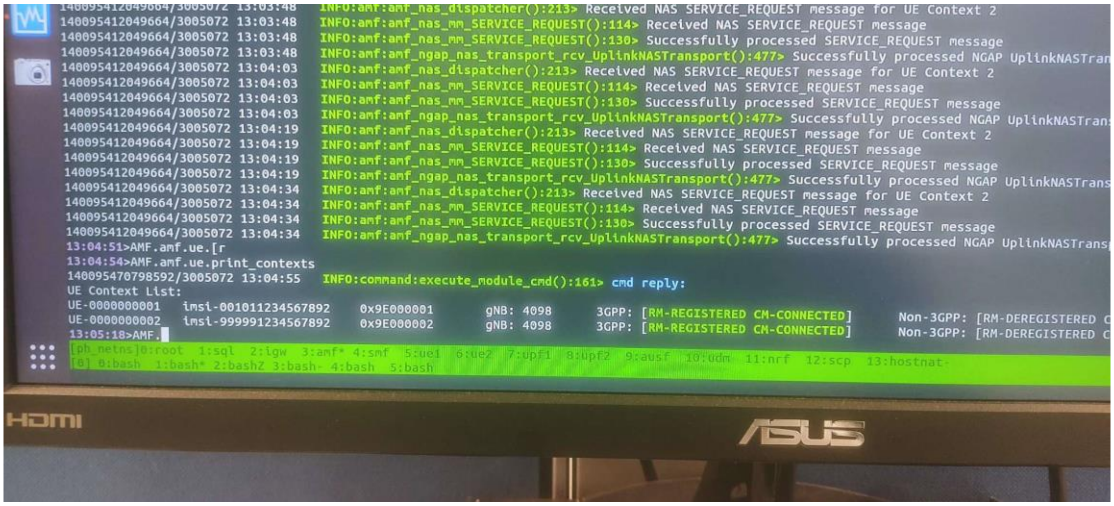


Figure 15: Both Home and Visited subscriber registered at AMF

8.6. Analysis

For this use case, only functional validation can be analysed. For the trials planned later results can be analysed and will be documented in the next version of the document.

From the validation, it was seen that the local breakout roaming functionality worked fine. The visited subscribers were able to get registered with the core network and had access to the internet. In the later phase when measures will be collected more analysis could be done based on the KPIs defined.

8.7. Pain Points and Risks

The pain points and risks associated with this use case are listed in the table below.

Description	Mitigation
Failure to create secure connectivity between three domains	Partners will have to create the setup for three domains with different PLMN locally
Connection failure to the remote networks	Need to take backup of the subscriber details in a central server
Failure in SBC can lead to single point of failure can occur in the networks	The SBC is stateless in the core network. Auto-restart the SBC, in case it is down. If the SBC is in a hang state it should be manually restarted
Latency of message exchange between two domains may result in failure in core	The interconnection between the domains should be revisited and should be restarted if the link fails. The procedures should wait until the link is up

Registration time depends on the backhaul	Best effort network should be selected as the backhaul to minimize the latency between the domains
Interoperability issue with the RAN and the 5G Core	Use of emulated gNodeB from the Open5GCore platform
Lack of Devices having SIM with different PLMNs	Use emulated UE from the Open5GCore platform

9. Conclusions

This deliverable provided a report on the progress of validating the FUDGE-5G components with vertical trials. Although some use cases are more advanced than others in terms of trial execution, that is expected as the schedule's plan was exactly to split execution in time to avoid running multiple trials in parallel. However, severe delays have conditioned the execution of some trials and the consortium is currently making additional efforts to recover from those delays.

Throughout the previous sections, and for each use case, the document highlighted how the validation work is being done, what is being collected, where and how the trials are being executed, what were the results and outcomes of those trials and, finally, the plan for the next months of work to be done in WP4. In the end, the results and outcomes of the work that was already carried out are satisfactory and have attracted interest from stakeholders beyond the internal reach of the project, which validate the potential and innovation brought by FUDGE-5G.

10. References

[1] FUDGE-5G, "D1.1 v2 Technical Blueprint for Vertical Use Cases and Validation Framework".

[2] FUDGE-5G Consortium, “D3.1 Test-bed Continuous Technology Integration,” 2021.