FIDAL WHITE PAPER

FIDAL Use Cases : Trial and validation results

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List of acronyms and abbreviations

Abbreviation	Description
5G	5^{TH} Generation
5QI	5G Quality indicator
AI	Artificial Intelligence
AR	Augmented Reality
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
HLS	HTTP Live Streaming
JRC	European Commission Joint Research Centre
KPI	Key Performance Indicator
KVI	Key Value Indicator
LCS	Location Services
LST	Large Scale Trials
MCX	Mission Critical Services
nApp	Network Application
PPDR	Public Protection and Disaster Relief
PTP	Precision Time Protocol
PhyS	Physics Service
PUGC	Professional User-Generated Content
RRS	Remote Rendering Service
RTT	Round-trip time
UEA	User Equipment Application
UGC	User-Generated Content
UHD	Ultra-high-definition
UMA	University of Malaga
UoP	University of Patras
VR	Virtual Reality
XR	Extended Reality

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Executive summary

This whitepaper presents the results and lessons from FIDAL Work Package #6 on large-scale trials across public-safety communication and user media Use Cases (UC), showing how emerging Beyond 5G acapabilities can support immersive interaction, mission-critical communications, remote expertise, edge-assisted XR/AR, live media production, networked music performance, and multi-site community engagement. The trials collectively demonstrate that Beyond 5G can enable meaningful new services when combined with network applications, edge/cloud resources, slicing, and application-specific media handling.

Across the Public Protection and Disaster Relief (PPDR) oriented use cases, the white paper documents strong feasibility and operational value. UC1 validated synchronized multi-user haptic delivery over 5G after architectural improvements, UC2 demonstrated an automatic fire detection and Digital Twin platform for wildfire response, UC3 confirmed the suitability of public 5G infrastructure and slicing for mission-critical voice/video communications, UC6.1 validated distributed XR-assisted emergency medical guidance with remote rendering, and UC6.2 demonstrated real-time AR annotations for public-safety situational awareness using AI processing at the edge.

The user media and community-oriented use cases confirm both the promise and the difficulty of low-latency live media over 5G. UC4 showed that prioritized 5G slicing significantly improves uplink video quality under congestion, UC5 proved that musicians could complete a performance across distant sites but remained close to the latency limits of comfortable co-performance, and UC7 evolved from smart village engagement into a broader concept of multi-site live telecommunication for cultural, educational, civic, and community participation.

A consistent finding across the trials is that nominal throughput is necessary but not sufficient. User experience and service viability depend strongly on latency, jitter, packet ordering, framerate stability, radio conditions, uplink capacity, orchestration robustness, endpoint energy efficiency, timing support, and the ability to protect demanding traffic through slicing or equivalent service profiles.

The Key Value Indicator (KVI) results indicate that the tested solutions are not only technically relevant but also perceived as valuable by users and stakeholders. Across use cases, participants recognized benefits such as improved situational awareness, safety, training value, trustworthiness, energy efficiency, cultural connection, flexibility, and reduced need for travel. However, the evidence also points to the need for broader validation, larger and representative participant samples, stronger confidence in future stability and reliability across varied conditions over time, and clearer operational readiness before wider adoption.

Overall, the white paper concludes that FIDAL has generated practical evidence for how 5G-enabled platforms can support future PPDR, media, and community services. The main recommendation is to move from individual successful demonstrations toward reusable, hardened service capabilities: predictable low-latency connectivity, application-aware slicing, edge processing, precise timing, robust orchestration, stronger radio planning, and user-friendly deployment packages suitable for future Beyond 5G and 6G-oriented trials.

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Introduction

The transition from 5G towards Beyond 5G and future 6G networks is creating new opportunities for services that demand high performance, low latency, edge computing, network slicing, and intelligent network exposure. The FIDAL project has explored these opportunities through a series of Large-Scale Trials (LST) across PPDR public protection and disaster relief, media, immersive communications, and community engagement scenarios. The objective has been not only to validate technical performance, but also to understand the value such capabilities can create for users, organizations, and society.

This white paper presents the key findings, experiences, and lessons learned from seven FIDAL use cases covering Internet of Senses applications, Digital Twins for first responders, mission-critical communications, XR- and AR-assisted public-safety services, advanced media production, networked music performance, and multi-site live telecommunication. Together, these trials provide practical evidence of how advanced mobile networks, edge/cloud resources, and network applications can enable new forms of interaction, collaboration, and situational awareness across geographically distributed users and environments. Beyond technical results, the white paper highlights user feedback, Key Value Indicators (KVIs), operational insights, and recommendations for future deployments.

The white paper first presents the FIDAL trial environments, including FIDAL's structured methodology for validating Beyond-5G solutions through a phased experimentation process that includes laboratory testing, dry-runs, LSTs, and open-call activities. It describes the common trial lifecycle, workflows, and KPI/KVI evaluation framework used across all use cases and testbeds to ensure consistent design, execution, and assessment of experimental results.

Next, the main body of the whitepaper is the presentation of the use case trials, organized into two main domains: PPDR and Media. For each use case, the whitepaper describes the use case and value proposition, the trial setup, key technical results (KPIs), user feedback and KVIs, lessons learned, as well as future perspectives and recommendations. The individual UCs have their specific context, objectives, and target, so the detailed presentation structure is adapted accordingly.

The white paper concludes by synthesizing the common findings across all trials, highlighting reusable network capabilities, user value, operational insights, and recommendations for future Beyond 5G and 6G services, architectures, and large-scale deployments.

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Testbeds and trials in FIDAL

FIDAL adopts a structured and repeatable experimentation methodology that is applied consistently across the use cases, while adapting to specificities of the testbeds. UC2, UC4, UC6.1 and UC6.2 were performed in the testbed in Greece (Patras and Athens, by PNET and University of Patras- UoP-). UC1 and UC3 were performed in the testbed of Malaga, Spain (by UMA – University of Malaga- and Telefonica), while UC5 and UC7 were performed in the testbed in Norway (Fornebu / Oslo, and Trondheim, by Telenor). The approach is designed to ensure that experimental results are comparable, reproducible, and evidence-based, while accommodating the diversity of vertical domains, technologies, and deployment environments involved in the project. By using a common framework for planning, execution, monitoring, and evaluation, FIDAL enables all stakeholders to assess innovation outcomes in a consistent manner and consolidate lessons learned across the entire project portfolio.

At the core of FIDAL's methodology is a common trial lifecycle and workflow that guides each use case from experiment design and laboratory validation through integration testing, trial execution, and post-trial assessment. Each trial defines objectives, hypotheses, success criteria, and measurable indicators before validating solutions in controlled environments, performing dry-runs, deploying them in large-scale operational trials, collecting and validating measurement data, and documenting outcomes in a structured way. This harmonized process reduces methodological differences between testbeds, supports comparison and aggregation of evidence across use cases, and provides a coherent basis for assessing the performance and value of the technologies under investigation.

A key aspect of the framework is the combined use of Key Performance Indicators (KPIs) and Key Value Indicators (KVIs). KPIs capture the technical performance of the networked solutions, such as latency, throughput, reliability, availability, and scalability, while KVIs assess the broader impact on users, businesses, operations, sustainability, and society. By evaluating both technical performance and value creation within a single assessment framework by considering such dimensions as trustworthiness, inclusivity, safety, and culture connection FIDAL ensures that experimentation extends beyond technology validation and demonstrates the real-world benefits and adoption potential of Beyond-5G capabilities. This dual KPI/KVI perspective provides a comprehensive basis for assessing the effectiveness and relevance of the experimental outcomes.

FIDAL's KVI assessment followed a mixed-methods approach. It combined user surveys, objective technical measurements, demographic comparison against external population baselines, documentary evidence review, and qualitative feedback from trial participants. Most participant surveys used a five-point Likert scale with a few open-ended questions to provide context. Results across all dimensions were classified into three directional outcomes, Negative, Mixed, or Positive, to reflect whether evidence pointed toward the intended value outcome.

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FIDAL use case trials in PPDR

1.1 Use Case 1: Internet of Senses and Haptic Sensing

1.1.1 Introduction & Value Proposition

Immersive entertainment and remote interaction are entering a phase where sight and sound are no longer sufficient. The next leap, increasingly referred to as the Internet of Senses, requires touch to be transported across the network with the same fidelity and timing that 5G already provides for video. UC 1 tackles exactly this gap: delivering real-time haptic sensations from a content application to a wearable actuator on a remote user, end-to-end over a 5G slice, and doing so in a way that scales multiple concurrent participants in shared scenarios.

The UC is led by OWO, contributing the OWO haptic vest and the associated content and device stack, in partnership with the University of Málaga (UMA) and Telefónica, who provide the 5G infrastructure and operational support. The end-to-end network application chain integrates a VR application with the OWO API as the sensation source, the FIDAL Network Application (nApp) deployed on the UMA 5G testbed, secure exposure through CAPIF, the MyOWO companion app on the participant's mobile device, and BLE forwarding to the wearable vest. Together these components turn the 5G network into a delivery fabric for low-bitrate, latency-sensitive haptic traffic alongside conventional flows.

Although the trial population and content were drawn from the consumer gaming domain, the same delivery chain is directly relevant to PPPDR: synchronized haptic cues over a network slice can support immersive training of first responders, silent tactile alerts in noisy or low visibility environments, and remote guidance where visual and audio channels are saturated. UC1 therefore provides the network level evidence on which such PPDR applications can build.

Shared sensation under network control unlocks new categories of immersive gaming, remote training, and co-located physical experiences in venues where wired solutions are not viable. It also stresses the network on a dimension that conventional KPIs do not capture well, many small, time-critical messages that need synchronous delivery to many devices at once, which is precisely the regime that 5G and future 6G networks claim to enable.

1.1.2 Trial Setup and Targets

UC1 ran two LST campaigns. The first (LST 1, UMA Cultural Week, 21 March 2025) exercised the end-to-end chain under controlled university-campus conditions with groups of 1–6 concurrent participants. The second (LST 2) was split across two venues: a live public demonstration at the Transfiere innovation event in Málaga (25 February 2026), operating on a portable 5G network deployed by UMA and Telefónica at the venue, and a structured multi-user session at Polo Digital (2 March 2026) using the UMA 5G infrastructure with up to seven concurrent users. All participants received an information sheet and gave informed consent for data collection before taking part.

In every session the platform integrated the same components: a VR game with the OWO API as the sensation generator, the nApp exposed through CAPIF for secure session registration and PIN assignment, the 5G network as the transport, the MyOWO mobile app as the device-side endpoint, and the OWO vest as the haptic actuator over BLE. LST 1 used a first-person Virtual Reality (VR)

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scenario to drive sensations at two different rates, a Normal profile (≈1 message/s, matching natural gameplay) and a Bandwidth profile (≈10 messages/s, used to stress the per-user delivery rate). LST 2 reused this chain to validate the architectural changes introduced after LST 1: (i) phones registering their real IP with the nApp bypass NAT-induced UDP loss, and (ii) a single message carrying an array of target PINs being fanned out internally by the nApp instead of one message per target.

The objectives of the trial campaign were to demonstrate (a) end-to-end haptic delivery over a 5G slice with latency suitable for multi-user immersive scenarios, (b) stable operation across both controlled and live-event venues with consistent QoE, (c) graceful scaling of the nApp under increasing concurrent users and message rates, and (d) a quantified Key Value Indicator (KVI) baseline across the eight dimensions defined for UC1: Cultural Connection, Digital Inclusivity, Privacy, Trustworthy, Energy Efficiency, Waste Management (Repair & Upgrade), Representative, and Flexibility. Figure 1illustrates the high-level architecture of the UC1 deployment.

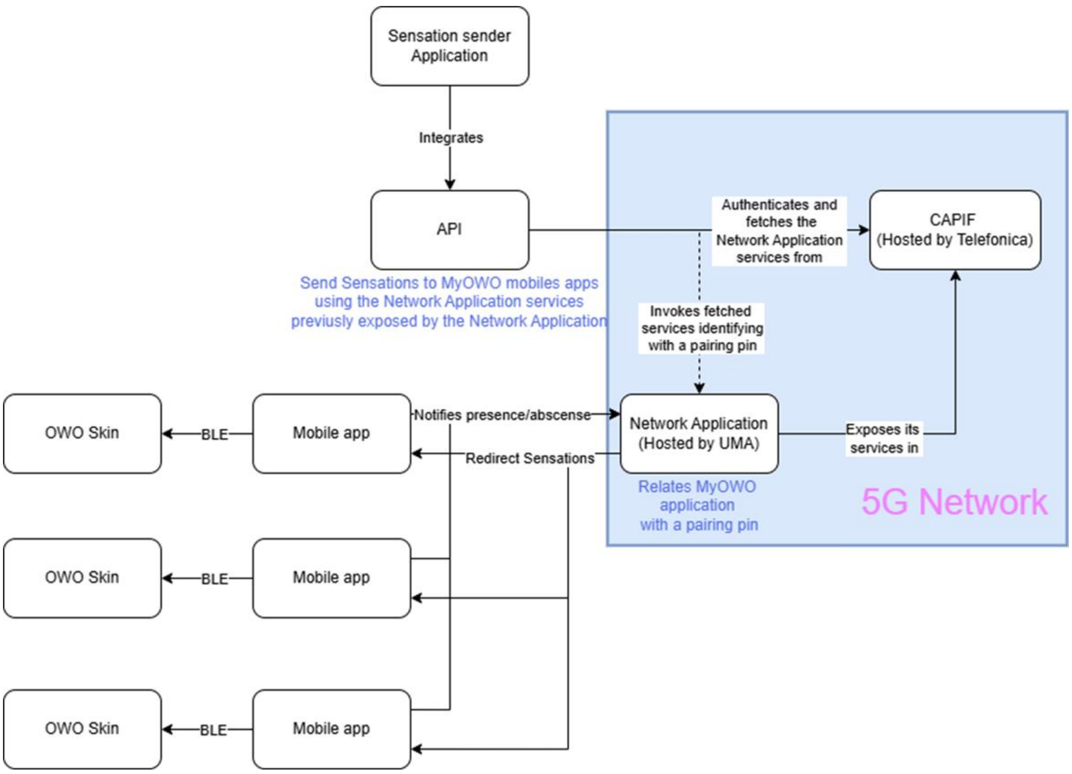

Figure 1: UC1 High-level Architecture

The platform and infrastructure were evaluated against the following KPIs: end-to-end haptic latency from sensation generation to vest actuation; per-user and aggregate message throughput on the haptic stream; multi-user scaling under both Normal and Bandwidth profiles; nApp registration and service deployment time via CAPIF; portability of the 5G deployment between fixed and portable infrastructures; and end-device energy efficiency (lab versus field battery drain on both the wearable and the companion app).

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Figure 3: OWO Haptic Vest used in UC1

Figure 2: UC1 Mult-user haptic demonstration session

1.1.3 Key findings and results

Technical Results

Relative to the Target KPIs, the campaign closed all evaluation lines defined for UC1. LST 1 served as the architectural stress test of the end-to-end chain and surfaced a NAT-induced UDP path issue that was fully resolved before LST 2 via real-IP registration at the nApp and array-based PIN distribution. With these corrections in place, LST 2 delivered synchronized multi-user haptic operation at both the live-event venue (Transfiere, portable 5G) and the controlled multi-user session (Polo Digital, up to seven concurrent users). Service-deployment, portability, and end-device energy-efficiency targets were met in all sessions, confirming a stable and reproducible UC1 baseline over 5G. Table 1 summarizes the key experimental results and the main findings obtained during the evaluation campaigns.

KPI	Experimental Results	Assessment
End-to-end haptic latency	LST 1 measured approximately 180 ms due to NAT-related UDP routing issues. Following architectural corrections, LST 2 achieved qualitative multi-user synchronization across all participants, although no quantitative latency measurement was repeated.	Synchronized haptic delivery was successfully demonstrated during the final trials.
Multi-user scalability	Several experiments were performed in LST 1 with groups of one to six users. LST 2 (Polo Digital) successfully supported up to seven concurrent synchronized users using the optimized PIN-array distribution mechanism.	Multi-user operation successfully validated.
Uplink throughput (haptic	Stable transmission of low-bitrate UDP haptic commands was maintained under both the Normal (~1 message/s) and Bandwidth (~10 messages/s) profiles.	Reliable low-latency message delivery demonstrated.

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command stream)		
Service deployment time	The nApp was successfully registered and exposed through CAPIF during all deployment sessions within the target window.	Automated service deployment successfully validated.
Deployment portability	The complete solution was demonstrated both on the UMA campus and on a portable 5G network deployed by UMA and Telefónica during the Transfiere event.	Portability across laboratory and field environments successfully demonstrated.
End-device battery efficiency	Vest: 0 percentage point (pp) difference; companion app: 1 pp difference over a 15-min session. Lowest possible lab-vs-field drain	Lowest possible lab-vs-field drain. No measurable impact from deployment environment.

Table 1: UC1 Highlighted KPI Results

User feedback and KVI Results

UC1 evaluated all eight Key Value Indicator (KVI) dimensions defined in the FIDAL Internet of Senses framework. The collected user feedback indicates that immersive haptic delivery over 5G is perceived as a meaningful enhancement to shared cultural and social experiences while demonstrating broad applicability across different usage scenarios. Acceptance was strong across the participants , drawn primarily from OWO's core gaming demographic. Notably, 100% considered the technology applicable beyond gaming, including training, healthcare, and education, while the customizability and within-scenario adaptability dimensions received average scores of 4.92/5 and 4.85/5, respectively. Table 2 summarized the outcomes of the KVI evaluation across all assessed dimensions for UC1.

KVI dimension	Outcome
Cultural Connection	Users expect that immersive haptics could add value to shared cultural and gaming experiences over 5G. Current sense of community connection is modest (40%), with stronger expectations for the future (60%).
Digital Inclusivity	Strong scores on customization (4.92/5) and within-scenario adaptability (4.85/5); body-type adaptability rated 4.69/5.
Privacy	93% of participants preferred anonymisation even at the cost of personalization; 53% identified a risk of haptic data being used to infer health or emotional information.
Trustworthy	Confidence in the platform built from a stable communication chain (VR – CAPIF – nApp - MyOWO - Vest) across two distinct venues.
Energy Efficiency	Minimal lab-vs-field battery drain delta on both wearable (0 pp) and companion app (1 pp); 5G link is not the dominant energy cost.

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Waste Management — Repair & Upgrade	European Commission Joint Research Centre (JRC) criteria answered end-to-end; OWO vest scored against the framework with reinterpretation notes for connected wearables.
Representative	N=13 demographic responses (LST 1 + Polo Digital); deviation versus OWO's target audience documented per category.
Flexibility	100% of respondents see applicability beyond gaming; system tested across single-user, multi-user, controlled and live-event contexts.

Table 2: UC1 KVI Outcomes

The evaluation further demonstrated consistent user experience across both deployment environments, namely a portable 5G network operating at a busy public exhibition and a controlled multi-user laboratory session. Participants reported consistent perceived synchronization in both settings. Moreover, the negligible difference in battery consumption between laboratory and field deployments indicates that the 5G communication link is not the dominant contributor to the overall energy consumption of the end-to-end haptic system.

Results Summary

The UC1 LST campaign successfully demonstrated end-to-end haptic delivery over a 5G network, with secure service exposure through CAPIF and stable operation across both controlled and live-event environments. Following the architectural improvements introduced after LST 1, namely real-IP registration and array-based PIN distribution at the nApp, LST 2 validated synchronized multi-user operation with up to seven concurrent participants.

The KVI evaluation covered all eight dimensions defined for UC1 and showed strong user acceptance, particularly with respect to adaptability, customisation, privacy awareness, and the perceived applicability of the solution beyond gaming. Together, the KPI and KVI evaluations demonstrate that the proposed architecture satisfies the objectives of the UC1 trial campaign.

Overall, the trial confirms the feasibility of using 5G to support immersive multi-user haptic applications and provides practical evidence for Internet of Senses services within the FIDAL framework.

1.1.4 Future potentials and recommendations

UC1 has consolidated a viable architecture for transporting touch over 5G, and the LST phase is complete. Looking beyond FIDAL, the most interesting directions are evolutionary: applying 6G-relevant primitives, ultra-low-latency URLLC slices, deterministic-time delivery and network-exposed synchronization services, to multi-user haptic scenarios, where the value of a millisecond-class transport is already qualitatively visible in user feedback. The validated UC1 stack provides a credible starting point for that next generation of immersive-sensation services.

Subsequent campaigns, beyond the scope of this trial, could broaden the demographic and venue mix, for example a deployment in a non-Spanish, non-urban setting with explicit inclusion of users with disabilities and a wider age band, to reinforce the Representative and Digital Inclusivity dimensions already validated here. The European Commission Joint Research Centre (JRC) Repair-and-Upgrade

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framework was also applied in full to the OWO vest, with observations recorded on how connectivity-era criteria (BLE health, companion-app/OS compatibility, nApp/CAPIF-side faults) could be incorporated in any future revision of the indicator.

On the application side, future trials could integrate richer content, beyond first-person shooter scenarios, and validate adjacent verticals such as immersive training, healthcare simulation, esports and co-located shared experiences in public venues. From a network-application standpoint, exposing additional control surfaces to the nApp (e.g. per-user QoS hints, dynamic group reconfiguration, energy-aware scheduling of haptic frames) would let the system trade off latency, throughput and energy explicitly per scenario. Taken together, these directions provide a strong basis for evolving UC1 from a successful FIDAL trial into a reference architecture for sensation delivery in 5G/6G networks.

1.2 UC2 - Digital Twin for first responders

1.2.1 Introduction & Value Proposition

Forest fires are among the most devastating natural disasters, posing significant threats to human life, property, and the environment. Early detection, together with rapid and coordinated emergency response, is essential to mitigate these risks. However, unpredictable fire behaviour, difficult terrain, and limited situational awareness often reduce the effectiveness and safety of firefighting operations. These challenges highlight the need for advanced technologies that improve operational awareness, support decision-making, and enable more efficient deployment of emergency resources.

UC2 addresses these challenges by integrating Digital Twin technology with 5G connectivity to support wildfire response operations. The solution combines real-time monitoring, automated fire detection, and enhanced communication capabilities to provide first responders and emergency operators with an accurate and continuously updated view of the evolving incident.

A Digital Twin is a virtual representation of a physical environment that is continuously synchronized using real-time data from multiple sources. In UC2, the Digital Twin integrates live video streams from fixed surveillance cameras, drone-mounted cameras, and mobile devices carried by first responders, together with the location of personnel and operational assets. Beyond providing real-time situational awareness, the platform enables predictive analysis to anticipate fire evolution, optimize resource allocation, and improve responder safety.

The capabilities of the Digital Twin are enhanced through 5G communications, which provide the low latency, high bandwidth, and reliability required to transport live video streams and operational data with minimal delay. This enables continuous synchronization between field assets and the Command Centre, allowing emergency operators to make timely and informed decisions throughout the incident lifecycle.

1.2.2 Trial Setup and Targets

UC2 demonstrates an Automatic Fire Detection and Situational Awareness Platform operating entirely over a 5G network to support wildfire emergency response. The platform combines automatic fire and smoke detection, Digital Twin visualization, and real-time communications to enable early incident identification, improve situational awareness, and enhance coordination between the Command Centre and field responders.

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The deployed solution integrates multiple heterogeneous data sources, including fixed surveillance cameras, a tethered drone, mobile responder devices, fire detection analytics, and Digital Twin visualization services into a unified operational environment. Live video streams are continuously analysed to detect fire and smoke events, generating alerts that are immediately transmitted to the Command Centre. Operators can monitor incidents through the Digital Twin interface, coordinate drone deployment for enhanced situational awareness, and maintain bidirectional communication with responders operating in the affected area. Mobile devices provide responders with continuous access to operational updates, geospatial information, live video streams, and situational intelligence throughout the intervention. Figure 4 illustrates the high-level architecture of UC2.

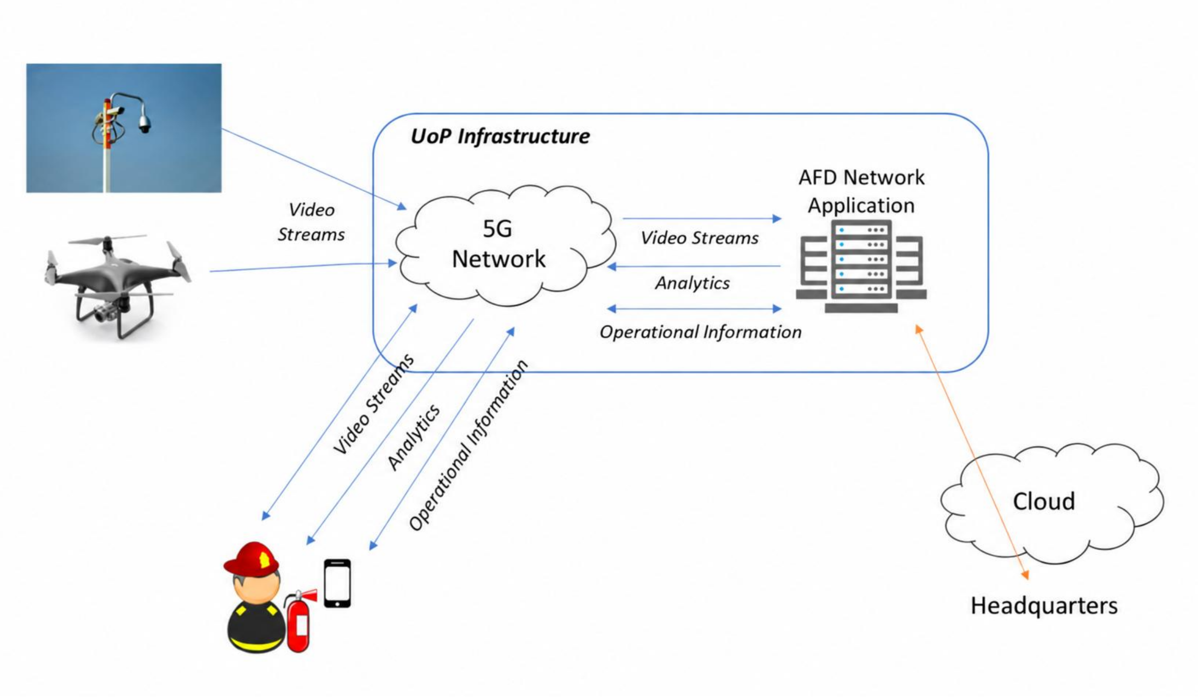

Figure 4: UC2 High-level Architecture

The trial infrastructure consisted of four surveillance cameras, a tethered drone providing aerial monitoring, a Command Centre workstation, and mobile devices used by field responders. All components communicated exclusively through the available 5G network, enabling real-time video transmission, automated alert dissemination, and continuous synchronization between field operations and the Command Centre.

The trial pursued four primary objectives:

- Validate the performance and reliability of the 5G communication infrastructure.
- Improve situational awareness through Digital Twin visualization.
- Demonstrate low-latency emergency communications over 5G.
- Enhance coordination between the Command Centre and field responders during wildfire response operations.

The performance of both the platform and the supporting 5G infrastructure was evaluated using the following KPIs:

- Uplink and downlink throughput

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- Application latency
- Positioning accuracy
- Supported user density
- Video stream resolution and frame rate
- Service deployment time
- Network application deployment time

The trial successfully demonstrated the feasibility of integrating automatic fire detection, Digital Twin technologies, and 5G communications into a unified operational platform for wildfire response. The results confirm that the proposed architecture supports timely situational awareness, reliable information exchange, and coordinated emergency response under realistic deployment conditions. Figure 5 illustrates the UC2 trial deployment during the LST at the University of Patras and PNET infrastructure, including the controlled fire scenario and the tethered drone used to provide aerial situational awareness.

Figure 5: UC2 Large Scale Trial at Patras Testbed

1.2.3 Key findings and results

Technical Results

The UC2 Large Scale Trial successfully validated the proposed Automatic Fire Detection and Digital Twin platform operating over a 5G network. The evaluation demonstrated reliable end-to-end operation under realistic deployment conditions, with stable video transmission, rapid service deployment, and effective support for situational awareness and emergency response coordination. Overall, the trial confirmed that the platform satisfied the technical objectives defined for UC2 and

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demonstrated the suitability of 5G communications for supporting Digital Twin-enabled wildfire response operations. Table 3 summarizes the key experimental results and the main findings obtained during the evaluation campaigns for UC2.

KPI	Experimental Results	Assessment
Peak Throughput	Uplink throughput reached 121 Mbps, while downlink throughput reached 54 Mbps with the complete platform operating simultaneously.	Sufficient network capacity demonstrated to support concurrent video streaming and operational data exchange.
Application Latency	Live video streams were delivered with no perceptible delay during the trial, enabling real-time monitoring and response.	Low-latency communications successfully demonstrated for emergency operations.
Positioning Accuracy	Continuous positioning of field assets and responders was successfully maintained throughout the trial.	Digital Twin localization capabilities successfully validated.
Supported User Density	The platform supported the intended number of concurrent users and operational components without service degradation.	Multi-user operation successfully validated.
Video Stream Resolution	Live video streams were delivered at 1440p resolution and 60 fps.	High-quality real-time video transmission successfully demonstrated.
Application Service Creation	Application service creation was completed in approximately 1 minute.	Rapid service provisioning successfully demonstrated.
Network Application Deployment Time	Network application deployment completed in less than 2 minutes.	Fast deployment of network applications successfully validated.

Table 3: UC2 Highlighted KPI Results

User feedback and KVI Results

The UC2 KVI evaluation focused on the perceived value of the Automatic Fire Detection and Digital Twin platform during emergency response operations. User feedback indicated strong confidence in the platform's reliability, transparency, and operational effectiveness, with participants highlighting its contribution to improved situational awareness, faster decision-making, and more effective coordination between the Command Centre and field responders. The evaluation also demonstrated that the platform maintained its core operational capabilities under varying network conditions while

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supporting efficient continuous monitoring through the 5G infrastructure. Table 4 summarizes the outcomes of the KVI evaluation across all assessed dimensions for Use Case 2.

KVI dimension	Outcome
Representative	Participants closely matched target demographics on gender. Limited representation from peri-urban and coordination roles.
Trustworthy	Users expressed high confidence in the platform, with very few disconnections recorded across all devices and strong ratings for alert transparency and confidence in achieving operational goals.
Safety	Users considered detection accuracy excellent, showing confidence in the platform's contribution to safety enhancement and emergency decision-making.
Resilience Economy	Core functionality was maintained on a public network, with advanced features benefiting most from strong 5G connectivity
Digital Inclusivity	Users saw potential for the tool to serve all regions equally, but were less confident it would perform as well in areas with weaker network infrastructure
Waste Management	Product longevity and repairability were strong points, which could be increased even further with additional training and support.
Protection of Humans	The platform improved situational awareness and response efficiency for responders, though its role in protecting the broader public is an area for further development.
Security	The system showed solid security practices, with clear training, transparency about its dependencies, and controls tailored to the emergency response context.
Energy Efficiency	The use of the 5G infrastructure contributed to efficient continuous monitoring while maintaining low operational energy consumption, showing consistent savings over 4G.

Table 4: UC2 KVI Outcomes

The KVI evaluation demonstrates that the proposed platform provides tangible operational value beyond its technical performance. In addition to supporting reliable communications, the integration of automatic fire detection, Digital Twin visualization, and 5G connectivity enhanced users' ability to understand evolving incidents, coordinate response activities, and make timely operational decisions. Overall, the results confirm the potential of the platform to support safer, more efficient, and better coordinated wildfire response operations.

Results Summary

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The UC2 Large Scale Trial successfully demonstrated the feasibility and operational value of the Automatic Fire Detection Platform operating exclusively over 5G connectivity. The platform achieved reliable real-time fire detection, efficient alert dissemination, and continuous situational awareness through the integration of analytics, live video streaming, Digital Twin visualization, and mobile responder communication.

The trial results confirmed that the system can effectively support coordination between the Command Centre and field responders while maintaining stable operation under varying network conditions. Both KPI and KVI evaluations highlighted strong system performance, high user confidence, improved operational safety, and enhanced emergency response capabilities.

Overall, the trial validated the potential of combining fire detection and 5G communications to support faster, safer, and more coordinated wildfire response operations.

1.2.4 Future potentials and recommendations

The UC2 platform demonstrates strong potential for future large-scale deployment in wildfire monitoring and emergency response operations. The combination of fire detection, Digital Twin technologies, and 5G-enabled communications can significantly improve early incident detection, situational awareness, and coordination between operational teams in time-critical scenarios.

Future developments should focus on expanding the platform to larger operational environments and integrating additional sensing and monitoring assets, including next-generation aerial platforms with native 5G support. Further enhancement of Digital Twin capabilities and AI analytics could also strengthen decision-support functionalities and improve operational efficiency during complex emergency situations.

In addition, broader validation under different environmental and connectivity conditions, and with a wider range of participant roles, would support the assessment of scalability, robustness, and interoperability with existing emergency response infrastructures. Overall, the platform provides a strong foundation for the development of advanced, resilient, and fully connected wildfire response ecosystems.

1.3 UC3 - City security event or incident

1.3.1 Introduction & Value Proposition

Ensuring secure and reliable communications for public safety organizations is a critical requirement, particularly during large public events where network congestion, high user density, and rapidly evolving situations can challenge conventional communication systems. The evolution of 5G technologies and Mission Critical Services (MCx) offers new opportunities to enhance operational effectiveness by providing high-performance, resilient, and prioritized communications for first responders and control room operators.

To address these challenges, a large-scale mission-critical communication scenario has been developed in collaboration with the Malaga Police. The scenario encompasses the complete operational chain, from first responders on field to command-and-control officer located in the control room. Its primary objective is to support the police in managing large crowds during major events by enabling reliable voice and video communications within operational groups, thereby improving situational awareness, coordination, and response capabilities.

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1.3.2 Trial Setup and Targets

The trial implements a complete mission-critical communication system involving the Malaga Police, from first responders deployed on field to operators located in the municipal Emergency Control Centre. The objective is to evaluate the ability of 5G-enabled Mission Critical Services (MCx) to support public safety operations during large-scale public events where communication reliability is essential.

The scenario focuses on group-based voice and video communications, real-time location sharing, and coordination between first responders on field and command-and-control operators. While the operational scenario remained largely unchanged throughout the various Large-Scale Trial (LST) sessions, continuous improvements in the integration of MCx services over Telefónica's public 5G network resulted in progressively enhanced technical and operational performance.

Particular attention was given to the implementation of 5G network slicing, enabling mission-critical communications to benefit from dedicated network resources, improved prioritization, reduced latency, enhanced reliability, and increased resilience under heavy traffic conditions. Figure 6 below, illustrates the high-level architecture of the UC3 deployment.

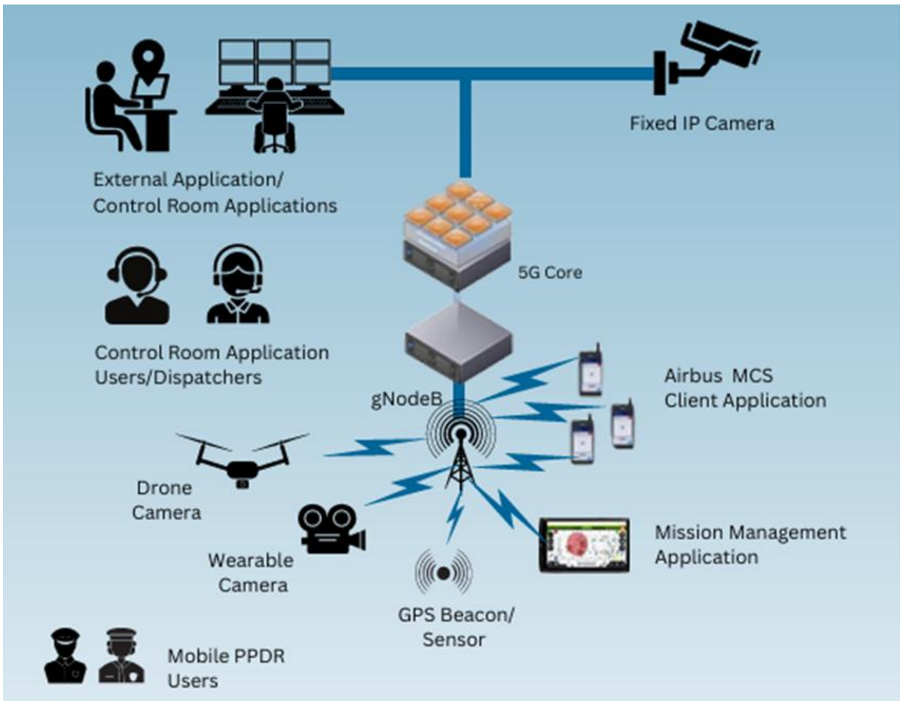

Figure 6: UC3 High-level Architecture

The main objectives of the trial were:

- Validate the end-to-end operation of Mission Critical Push-to-Talk (MCPTT), video, messaging, and location services over a public 5G network.
- Assess the reliability and quality of mission-critical communications during large-scale events generating significant network loads.

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- Evaluate the benefits of 5G network slicing for prioritizing public safety communications during periods of network congestion.
- Measure communication performance between first responder on field and command-and-control officer.
- Verify service continuity and operational effectiveness when the network approaches its capacity limits.
- Collect feedback from end users and public safety stakeholders regarding usability and operational value.

The use case assessed 6 KPIs:

- Peak Throughput
- Application latency focused on audio and video streams
- User density
- Video resolution
- Application service creation
- Network Applications deployment time

1.3.3 Key findings and results

Technical Results

Relative to the target KPIs, the UC3 trials successfully validated the performance of the mission-critical communication platform under realistic operational conditions. The evaluation assessed mission-critical voice and video performance, network throughput, user density, and service deployment capabilities during large-scale public events. The results confirmed that the platform maintained low latency, high reliability, and rapid service provisioning while leveraging 5G network slicing to preserve service quality under network congestion. **Error! Reference source not found.** summarizes the key experimental results and the main findings obtained during the evaluation campaigns.

KPI	Experimental Results	Assessment
MCPTT latency	Access time < 70 ms; mouth-to-ear latency < 130 ms	Exceeded mission-critical voice requirements (300 ms).
Video performance	End-to-end latency < 70 ms; 4K video at 30 fps	High-quality real-time video successfully demonstrated.
Peak throughput	Uplink 101 Mbps; Downlink 30 Mbps	Sufficient bandwidth for mission-critical voice and video services.
User density	0.0225 devices/m² during large public events	Stable operation maintained under high user density.

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Application service creation	< 1 minute	Rapid service provisioning successfully demonstrated.
Network application deployment	< 2 minutes	Fast deployment met operational requirements.

Table 5: UC3 Highlighted KPI Results

User feedback and KVI Results

The KVI assessment indicates strong perceived overall value of the UC3 platform for mission-critical public safety operations. The Safety dimension achieved a high score of 4.46/5, with particularly strong ratings for situational awareness and 5G-enabled coordination (both 4.7/5), confirming the platform's ability to support effective emergency response. Digital Inclusivity scored 3.77/5, reflecting good scalability and user acceptance while identifying network reliability under varying conditions as the primary area for future improvement. The Security assessment indicated a high level of organizational maturity, supported by formal governance processes, dedicated security teams, and well-established operational procedures. Overall, the KVI evaluation confirms that the platform provides significant benefits in terms of safety, coordination, and highly reliable mission-critical communications enabled by advanced 5G capabilities. **Error! Reference source not found.** summarizes the outcomes of the KVI evaluation across all assessed dimensions for Use Case 3.

KVI dimension	Outcome
Safety	High overall score (4.46/5), with excellent ratings for situational awareness and responder coordination (4.7/5).
Digital Inclusivity	Good scalability and user acceptance (3.77/5); network reliability identified as the main area for improvement.
Security	High organizational maturity supported by governance processes, dedicated security teams, and operational procedures.
Representative	Participant role distribution matched the target policing workforce.
Trustworthiness	Communication performance met the requirements expected of public safety critical networks with a high call success rate across trial sessions.
Flexibility	The platform maintained stable performance even amid the pressure of a large, crowded public event.

Table 6: UC3 KVI Outcomes

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The evaluation further demonstrated that the platform maintained stable operation during large-scale public events despite significant pressure on the public mobile network. The combination of 5G network slicing, traffic prioritization, and rapid service deployment enabled continuous operation of mission-critical voice and video services, reinforcing the suitability of public 5G infrastructure for emergency response applications.

Results Summary

The UC3 large-scale trials successfully demonstrated that 5G-enabled Mission Critical Services can provide reliable, low-latency, and high-quality communications for public safety operations during large-scale events. The platform exceeded the target performance for mission-critical voice and video services while maintaining communication continuity under periods of network congestion through the effective use of 5G network slicing and traffic prioritization. Rapid application and network service deployment further demonstrated the platform's operational agility and suitability for emergency response scenarios.

The KVI evaluation confirmed the platform's value in improving safety, situational awareness, coordination, and organizational security maturity, while also identifying opportunities to further enhance network robustness under varying operational conditions. This validates the strong potential to enhance public safety operations through reliable, low-latency 5G mission-critical communications. Together, the KPI and KVI evaluations demonstrate that the proposed architecture successfully satisfies the objectives of the UC3 trial campaign.

Overall, the trial confirms the feasibility of deploying mission-critical services over public 5G networks and provides practical evidence that advanced 5G capabilities can effectively support first responders and public safety organizations in real operational environments.

1.3.4 Future potentials and recommendations

The trial demonstrated the strong potential of 5G-enabled Mission Critical Services for public safety operations and highlighted several opportunities for future enhancement. Beyond the project timeframe, emerging 5G capabilities should be further exploited to improve operational effectiveness and resilience.

In particular, the integration of 5G Location Services (LCS) could provide more accurate and reliable positioning of first responders, enhance situational awareness and enable faster decision-making during emergency operations. Similarly, the adoption of 5G Proximity Services (ProSe) would allow direct device-to-device communications between user equipment, improving service continuity, reducing network dependency, and strengthening communications in areas with limited coverage or during network congestion. Future trials should also validate performance as deployment scales to a greater number of officers and simultaneous communications, building on the stability already demonstrated under large, crowded public events.

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1.4 UC6.1 - On-site XR-assisted emergency surgical operations

1.4.1 Introduction & Value Proposition

UC6.1 presents a practical model for XR-assisted public-safety response when specialist medical expertise cannot reach the incident scene immediately. In the trial scenario, an on-site responder uses an Extended Reality (XR) headset to receive anatomy-aligned guidance and procedural prompts, while a remote medical expert enters the same shared scene and provides live supervision. Led by ORamaVR, this use case shows how 5G-enabled XR can turn remote expertise into an operational support service rather than a purely experimental visualisation tool.

The service architecture combines the User Equipment Application (UEA) on the headset, a GPU-based Remote Rendering Service (RRS) using NVIDIA CloudXR, and a shared Physics Service (PhyS) that synchronises scene state and interactions between participants. This separation is strategically important: it keeps the field device lighter, reduces on-device processing demands, and supports a common Augmented Reality (A0/ Virtual Reality (VR) operational picture for collaborative guidance.

In emergencies, the right medical expertise is often not available on the scene when decisions must be made quickly. UC6.1 shows how 5G-enabled XR can connect an on-site responder with a remote medical expert in a shared AR/VR environment, making real-time guidance more practical and immersive. By offloading rendering to edge/cloud resources, the solution can keep field devices lighter, more responsive, and more energy efficient. This makes remote expert support more realistic for future emergency-response and PPDR scenarios.

1.4.2 Trial Setup and Targets

Validation was carried out at the PNET/UoP testbed through a staged campaign spanning laboratory integration, connectivity stress testing, orchestration validation, the integrated Large-Scale Trial (LST), and post-LST optimisation. The main field configuration used XR headsets, 5G-connected smartphones, one GPU-enabled virtual machine per active Remote Rendering Service (RRS) instance, and a shared virtual machine hosting the Physics Service (PhyS). The integrated LST formed part of the broader Patras accident-response scenario and ran alongside UC6.2 and the iSAFECO Open Call trial.

The objectives of the trial campaign were to demonstrate end-to-end XR-assisted emergency medical guidance over a 5G network, validate remote rendering and shared scene synchronisation under different network conditions, assess the benefits of dedicated network slicing, and quantify the performance of the distributed XR platform. Figure 7 below, illustrates the LST setup and the high-level architecture with dashed boxes indicating how the setup scales if more XR users are involved, as long as there are GPU resources and User Equipment available.

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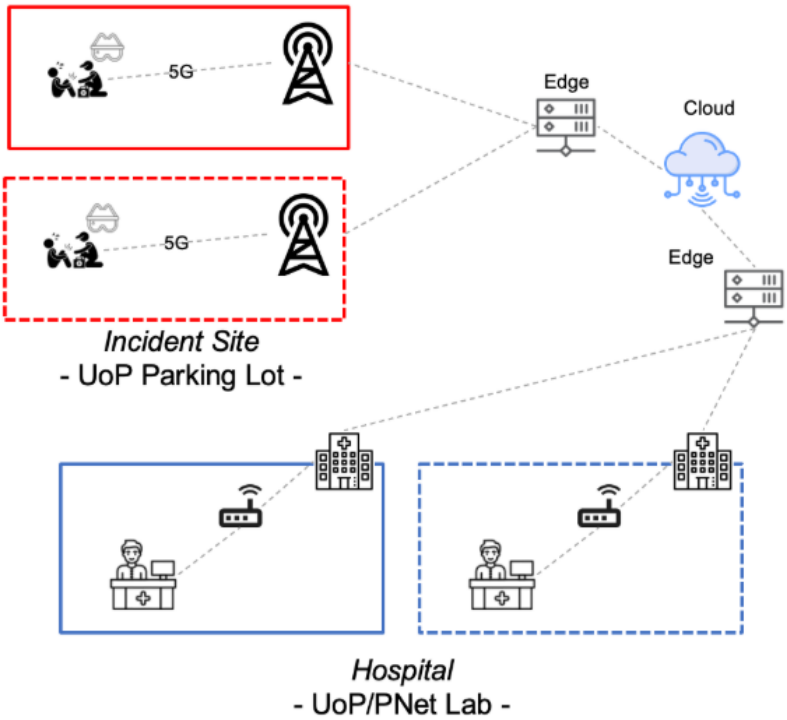

Figure 7: UC6.1 High-level Architecture

The platform and infrastructure were evaluated against the following KPIs:

- per-device downlink throughput,
- application latency,
- round-trip time (RTT),
- rendering framerate,
- device-side energy efficiency,
- deployment robustness under different network conditions, and
- service orchestration performance.

Figure 8 illustrates the UC6.1 Large-Scale Trial (LST) activities, showing an on-site responder assisting an unconscious patient using AR glasses connected to a shared XR scene with a remote medical expert (VR user).

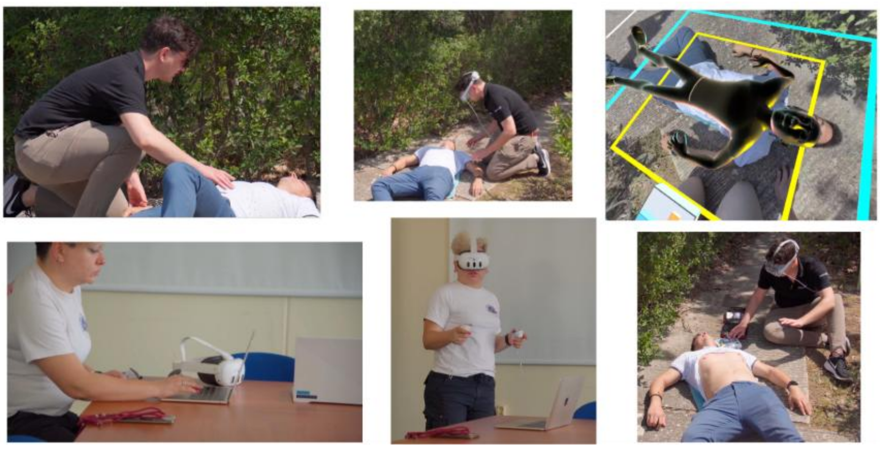

Figure 8: UC6.1 Large-Scale Trial: XR-assisted emergency medical response scenario

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1.4.3 Key findings and results

Technical Results

Relative to the target KPIs, the UC6.1 trial successfully validated the performance of a distributed XR-assisted emergency response service over a 5G network. The campaign demonstrated stable end-to-end operation of the shared AR/VR environment, reliable remote rendering through the Remote Rendering Service (RRS), and continuous scene synchronisation via the Physics Service (PhyS). Dedicated network slicing improved responsiveness under load, while Maestro-based orchestration enabled automatic deployment and integration of the distributed application. The successful parallel execution with UC6.2 and the iSAFECO Open Call further demonstrated the interoperability of the solution within a multi-application trial environment. Table 7 summarizes the key experimental results and the main findings obtained during the evaluation campaign.

KPI	Experimental Results	Assessment
Application latency	Best observed application latency of 75 ms	Responsive XR interaction successfully demonstrated.
Network latency	Best observed RTT of 25 ms	Low-latency communication enabled real-time collaboration.
Downlink throughput	Average 18 Mbps; peak 47 Mbps per XR device	Sufficient throughput maintained for remote rendering.
Rendering performance	Stable rendering up to 77 fps	Smooth and visually coherent XR experience demonstrated.
Device energy efficiency	Approximately 30% lower battery consumption compared to standalone rendering	Remote rendering significantly reduced device-side energy consumption.
Deployment robustness	Successful operation under laboratory, field, sliced, and stressed network conditions	Stable end-to-end workflow successfully validated.
Service orchestration	Automatic Maestro deployment and PhyS-RRS integration	Automated deployment successfully demonstrated.

Table 7: UC6.1 Highlighted KPI Results

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User feedback and KVI Results

KVI feedback from eight Hellenic Rescue Team participants was positive overall. Across the questionnaire responses and debriefing feedback, objective technical measurements, and demographic comparison, the results consistently highlighted trust in the system, confidence in the systems current performance, perceived usefulness and training value as the strongest aspects. At the same time, the responses pointed to areas that still need refinement, especially cognitive load, seamless communication under stress or in resource-limited conditions, and confidence in transferring the experience to more demanding emergency conditions. Overall, the findings suggest that the concept is already seen as valuable and supportive, while further field validation, with a broader and larger participant group, is needed before making stronger claims about operational readiness. The summary of the KVI outcomes is summarized in the table below.

KVI dimension	Outcome
Trustworthiness	Participants consistently expressed trust in the system as one of the strongest aspects of the solution, showing confidence in the system’s current performance and reliability.
Representative	The UC engaged a younger, urban participant group; broadening representation to better reflect the target demographics would strengthen future evaluations.
PPDR Safety	Task performance was strong overall, with further refinement to reduce cognitive and attentional load expected to support responders even more effectively.
Mitigation Strategies	The use case began tracking network and device energy use, laying groundwork for future environmental impact monitoring.
Digital Inclusivity	Participants rated the platform's accessibility and reach positively overall, but pointed to opportunities to strengthen connectivity reliability in rural or high-stress conditions.
Protection of Humans	The platform was seen as strongly valuable for training, with further validation expected to build confidence in its role for real-time medical guidance during active emergencies.
Flexibility	Core functionality held up across a range of network and device configurations, with further testing planned to expand its use to more demanding environments.
Security	Dependencies on shared cloud infrastructure were acknowledged and incorporated into planning.
Energy Efficiency	Offloading to the edge/cloud noticeably extended headset battery life compared to standalone use.

Table 8: UC6.1 KVI Outcomes

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Results Summary

In summary, UC6.1 validated a distributed AR/VR public-safety workflow that combines remote expertise, edge rendering and 5G connectivity into a coherent end-to-end service. Participants expressed confidence in the concept while indicating that additional field validation is required before claiming full operational readiness. The platform was perceived as valuable and supportive for XR-assisted emergency response and remote medical guidance with a particular emphasis on its value for training. Its strongest findings are the stability of the shared session, the consistently good framerate behaviour, the benefit of slicing under load, and the reduction in device-side battery drain enabled by offloading. The main area for further improvement is keeping the service stable when network conditions become congested or variable, considering the need for seamless communication during stressful operational conditions. In other words, the trials showed that the remaining work is to make field performance more consistent, not to rethink the core UC6.1 concept.

1.4.4 Future potentials and recommendations

UC6.1 has clear potential beyond the project as a support capability for emergency medicine, PPDR training and remote expert assistance where specialist presence is constrained. The validated PhyS/RRS architecture also offers a reusable foundation for other collaborative XR services that require low-latency synchronisation, shared scene awareness and lightweight field devices.

The most valuable next steps are targeted rather than architectural: further optimisation of slicing and bandwidth allocation, broader validation with medical and PPDR stakeholders across different environments, more ergonomic and hands-free interaction design, and continued expansion of the evidence base across devices and network profiles. Current results do not point to a need for major redesign; they point to incremental hardening of connectivity provisioning, orchestration maturity and user experience.

1.5 UC6.2 - AR for improving Law Enforcement Agents situational awareness

1.5.1 Introduction & Value Proposition

Public safety operations are often unpredictable, and situations can change very quickly. Law enforcement officers and first responders need to understand what is happening around them, identify important elements in the scene, and make decisions under pressure. UC6.2 explores how Augmented Reality, AI, edge computing, and 5G can support this need by providing contextual information directly in the user’s field of view, without requiring them to look at a separate device or screen.

Live video captured from AR devices is transmitted over the 5G network to FORTH’s edge-based Network Application for remote scene analysis and AR annotation. The scene is analysed in real time using AI, and relevant information is filtered and returned to the user device as AR annotations. By moving the demanding processing to the edge, the user device remains lightweight, while 5G connectivity enables low-latency video streaming and timely delivery of annotations for real-time situational awareness.

In summary, UC6.2 supports public safety users by providing relevant information directly in their field of view, helping them enhance situational awareness while keeping their attention on the physical environment around them. For law enforcement agents, this can support the recognition of potential threats and other operationally important elements, while for first responders it can help with the identification and prioritisation of injured persons. In both cases, the aim is to support clearer situational assessment and more informed action in time-critical conditions.

1.5.2 Trial Setup and Targets

The UC6.2 large scale trial was conducted at the PNET/UoP 5G infrastructure in an outdoor parking area at the University of Patras campus, where a major accident scenario was simulated. UC6.1 and the iSAFECO Open Call were also part of the broader scenario, creating a shared emergency response environment. The trial was followed by complementary measurements to assess how the AR service behaves under different connectivity and load conditions.

The setup involved AR devices and 5G smartphones connected to FORTH's edge-based Network Application, which was deployed as containerized services on virtual machines with GPU acceleration. More specifically, the Magic Leap 2 headset was used as the main AR device and was connected to the 5G network through a 5G smartphone, since the headset does not provide native 5G connectivity. Live video from the headset camera was streamed to the edge, where the video was analysed using machine learning algorithms and the most relevant information was returned to the user as AR annotations. The Hellenic Rescue Team participated as end users, providing realistic feedback from an emergency-response perspective and helping assess how AR annotations could support the identification and prioritization of injured persons in the scenario.

The validation covered both normal and more demanding network settings, including single and multiple device operation, shared and dedicated slicing, added background traffic, additional connected devices and bandwidth limitation. These conditions were used to evaluate the stability of the AR annotation and the effect of network load and available bandwidth on the service. The main KPIs considered were application latency, uplink throughput, and frame rate. These measurements were used to evaluate whether the application could maintain real-time video streaming, AI-based scene analysis, and timely AR annotation delivery under both favourable and more demanding network conditions. Figure 9 illustrates the high-level architecture of the UC6.2 deployment.

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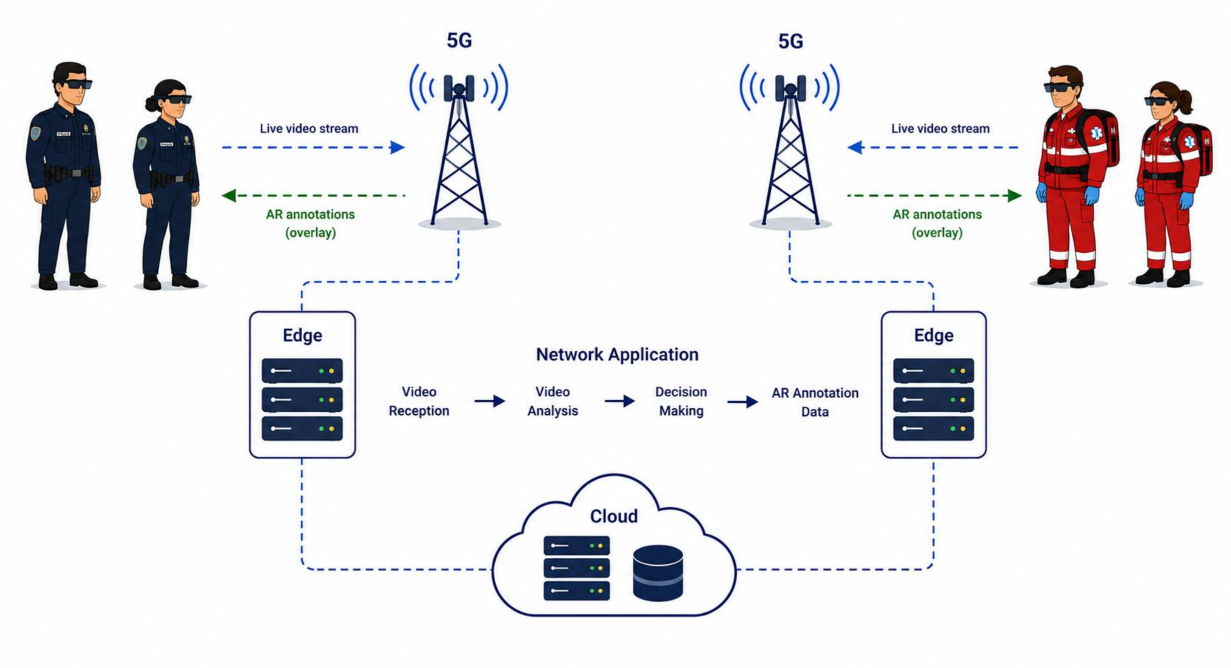

Figure 9: UC6.2 High-level Architecture

1.5.3 Key findings and results

Technical Results

Relative to the target KPIs, the UC6.2 trial successfully validated the performance of a 5G-enabled edge-assisted AR platform for public safety operations. The evaluation assessed real-time AR annotation, application latency, uplink throughput, frame rate, and service behaviour under varying network conditions, including dedicated and shared network slicing, additional background traffic, and bandwidth limitations. The trials demonstrated that AI-based scene analysis can be successfully offloaded to the network edge while maintaining timely AR annotation delivery and responsive user interaction. Dedicated network slicing further improved service stability under network load, confirming the suitability of the proposed architecture for real-time situational awareness. **Error! Reference source not found.** summarizes the key experimental results and the main findings obtained during the evaluation campaign.

KPI	Experimental Results	Assessment
Application latency	Average latency around 35 ms under favourable conditions, decreasing to approximately 28 ms in the best-performing runs.	Responsive real-time AR annotation successfully demonstrated.
Uplink throughput	Average uplink throughput around 70 Mbps, with peak values exceeding 80 Mbps.	Sufficient throughput maintained for continuous video streaming and AI processing.

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Frame rate	Average frame rate close to 30 FPS, reaching approximately 35 FPS during peak performance.	Smooth AR visualisation successfully demonstrated.
Network slicing	Dedicated slicing maintained lower latency and more stable throughput and FPS under additional network load compared to the shared network.	Network slicing effectively protected real-time AR performance under congestion.
Device energy efficiency	Battery consumption remained similar during full-bandwidth and bandwidth-limited tests.	Edge offloading reduced processing demands on the user device.
End-to-end annotation workflow	Successful capture, transmission, AI analysis, filtering, and return of AR annotations throughout the trials.	Complete real-time AR feedback loop successfully validated.
Service orchestration	Automatic Maestro deployment and Network Application integration	Fast automated deployment successfully validated.

Table 9: UC6.2 Highlighted KPI Results

User feedback and KVI Results

The KVI evaluation covered trustworthiness, safety, digital inclusivity, flexibility, protection of humans, security, representativeness, and energy efficiency. Most indicators were assessed through participant questionnaires completed during the Large-Scale Trial, while selected findings were supported by technical measurements, including network-load testing and battery-consumption analysis. Overall, participants considered the solution useful, understandable, and relevant for public safety operations. In particular, users recognised the value of real-time AR annotations for improving situational awareness and supporting field decision-making, while also identifying cognitive load and confidence during critical situations as areas requiring further refinement. **Error! Reference source not found.** summarizes the outcomes of the KVI evaluation for UC6.2.

KVI dimension	Outcome
Trustworthiness	Participants considered the AR support system understandable and trustworthy during the trial. Future work is needed to build trust around reliability in critical situations.
Safety	Real-time AR annotations were perceived as beneficial for improving situational awareness during emergency operations.
Digital Inclusivity	Overall feedback indicated that the solution was understandable and accessible to participants.
Flexibility	The platform successfully supported operation under different network configurations and load conditions.

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Protection of Humans	Participants recognised the value of AR guidance for identifying and prioritising injured persons during emergency scenarios.
Security	Dependencies on shared cloud infrastructure were recognised and included in planning.
Energy Efficiency	Battery-consumption remained stable and consistent across different network conditions, establishing a reference point for future work and already showing the benefits of edge processing by limiting additional processing on the user device.
Representative	The UC engaged a younger, urban participant group; broadening representation to better reflect the target demographics would strengthen future evaluations.

Table 10: Table 10: UC6.2 KVI Outcomes

Results Summary

Overall, UC6.2 demonstrated that AR, AI-based scene analysis, edge processing, and 5G connectivity can be combined into a practical real-time support service for public safety operations. The trial validated the full annotation loop, from video capture and edge processing to the delivery of AR overlays back to the user device.

Compared with the previous version developed in the DARLENE project, the system was redesigned in FIDAL to better exploit the capabilities of 5G and edge computing. The main improvement was the separation of the demanding processing functions from the user device, the AR User Application now mainly captures and streams video from the headset camera through the 5G network, while the edge hosted application receives the stream and performs frame by frame machine learning analysis using more powerful computing resources. This makes the AR device lighter and more flexible, as it does not need to execute intensive AI processing locally or depend on highly specific proprietary headset capabilities. In this way, FIDAL demonstrates a more scalable architecture for AR and computer vision services, where low latency and high-speed connectivity allow complex processing to be moved away from the wearable device while still supporting real time situational awareness in the field.

The strongest outcomes were the low latency achieved under favourable conditions, the improved stability provided by dedicated slicing, and the ability to keep the user device lightweight by offloading AI processing to the edge. The results also showed that the application remains operational under more demanding network conditions, although performance consistency under shared network load should be further improved in future trials.

The remaining challenges are mainly related to scaling and hardening the solution, including maintaining FPS under shared load, testing with more simultaneous users, and validating the system in more diverse environments.

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1.5.4 Future potentials and recommendations

UC6.2 has strong potential as a real-time information layer for public safety users in the field. Its value is not only in displaying AR annotations, but in helping users receive relevant information while keeping their attention on the surrounding environment. This can be especially useful in situations where law enforcement officers or first responders need to quickly understand the scene, identify important elements, and make decisions under pressure.

Future work should focus on extending validation to more varied operational settings and larger user groups, while fine-tuning the way information is presented through AR. Further optimisation of slicing and bandwidth allocation would help maintain stable latency, throughput, and FPS when more users or traffic are present. Overall, UC6.2 provides a strong basis for future 5G-enabled AR services for public safety, with the next step being broader validation and operational refinement rather than a change in the core concept.

FIDAL use case trials in Media

1.6 UC4 - Advanced sports area media services

1.6.1 Introduction & Value Proposition

Use Case 4 (UC4) focuses on the live uploading of Professional User-Generated Content (PUGC) and standard User-Generated Content (UGC) during high-density sports events. This media serves as a dynamic supplement to the primary live-streaming feeds provided by broadcasters, which traditionally rely on dedicated microwave links. By employing technologies like beamforming and network slicing, the project utilizes an advanced 5G connection designed for high availability and extreme upload throughput. The goal is to prove that evolved 5G networks can support ultra-high-definition (UHD) uplink transmissions from densely populated areas—such as stadiums—without suffering from network congestion, thereby enabling the seamless integration of alternative viewing angles captured by attendees.

The service architecture relies on the EKTACOM StreamSelector Network Application, which processes incoming streams, and a Video Mosaic Builder that allows a director to select feeds for an audience. This architecture is heavily dependent on advanced 5G features, including high-capacity bandwidth for UHD and 360° video, ultra-low latency for real-time processing, and edge computing to reduce computational delays.

Key to the success of this UC is the integration of advanced features that address the stringent requirements of bandwidth, latency, and scalability for large-scale deployments. For instance:

- **High-Capacity Bandwidth**: enables seamless streaming of UHD and 360° video content, allowing fans to explore multiple camera angles and AR-enhanced replays without interruptions.
- **Ultra-Low Latency**: Critical for real-time video feed processing and AR applications, it ensures minimal end-user-perceived latency, allowing users to experience the content instantaneously.

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- **Beamforming and Network Slicing**: These advanced techniques create dedicated high-throughput connections for individual users or groups, ensuring optimal performance even in high-density environments like sports arenas.
- **Edge Computing Integration**: With edge computing, computational tasks such as video transcoding, mosaic assembly, and AR rendering can be processed closer to the user, significantly reducing latency and improving responsiveness

1.6.2 Trial Setup and Targets

The Large-Scale Trials (LSTs) for UC4 were designed to evaluate the end-to-end media service architecture under varying constraints, utilising EKTACOM's StreamSelector Network Application and Video Mosaic Builder. The following figure provides the high-level representation for both scenarios, including all the considered deployment and end-user options. Considering the first scenario necessary equipment is a UGC application running on Android smartphones that are compatible with 5G SA, which captures and stream live video content. This smartphone app includes a video stream pushing capability, the streams the content of a pre-encoded file, like if it was live content captures from a camera. This feature has been used for being able to get some of the KPIs.

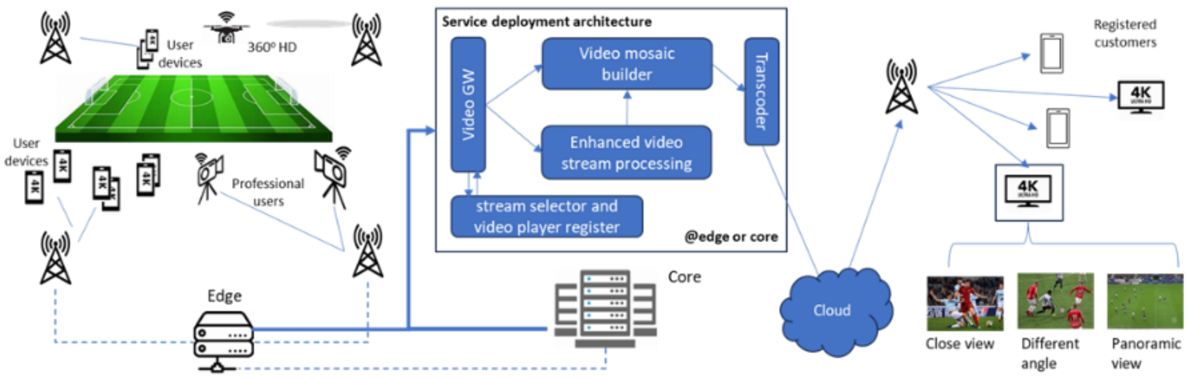

Figure 10: UC4 High-level Architecture

LST1 (Real-World Constraints - Dec 2025): Since University of Patras football field is not covered with its own 5G network, it was decided to execute the test at Athens stadium and send streams to University of Patras testbed infrastructure using NOVA public network. This is a perfect environment, with lots of people around, matching real conditions. EKTACOM provided software for streaming video content on smartphones to a network application, that produced a mosaic view and routed streams to playback device for audience. It is expected that thanks to 5G capacity in dense environment (lots of UEs in small area), quality of video streams will be good enough for proposing good quality of live video playback for the audience.

Deployed at the Atromitos FC Stadium during a live Greek Super League match using the commercial NOVA 5G public network. The setup involved seven participants distributed across the stands, using 5G smartphones running the NomadeApp UGC application to stream HEVC 1080p30 video via RTP. The streams were routed via a public IP to the StreamSelector hosted at the University of Patras testbed. The goal was to establish a baseline in a dense, live environment and identify the practical constraints of unmanaged network traffic.

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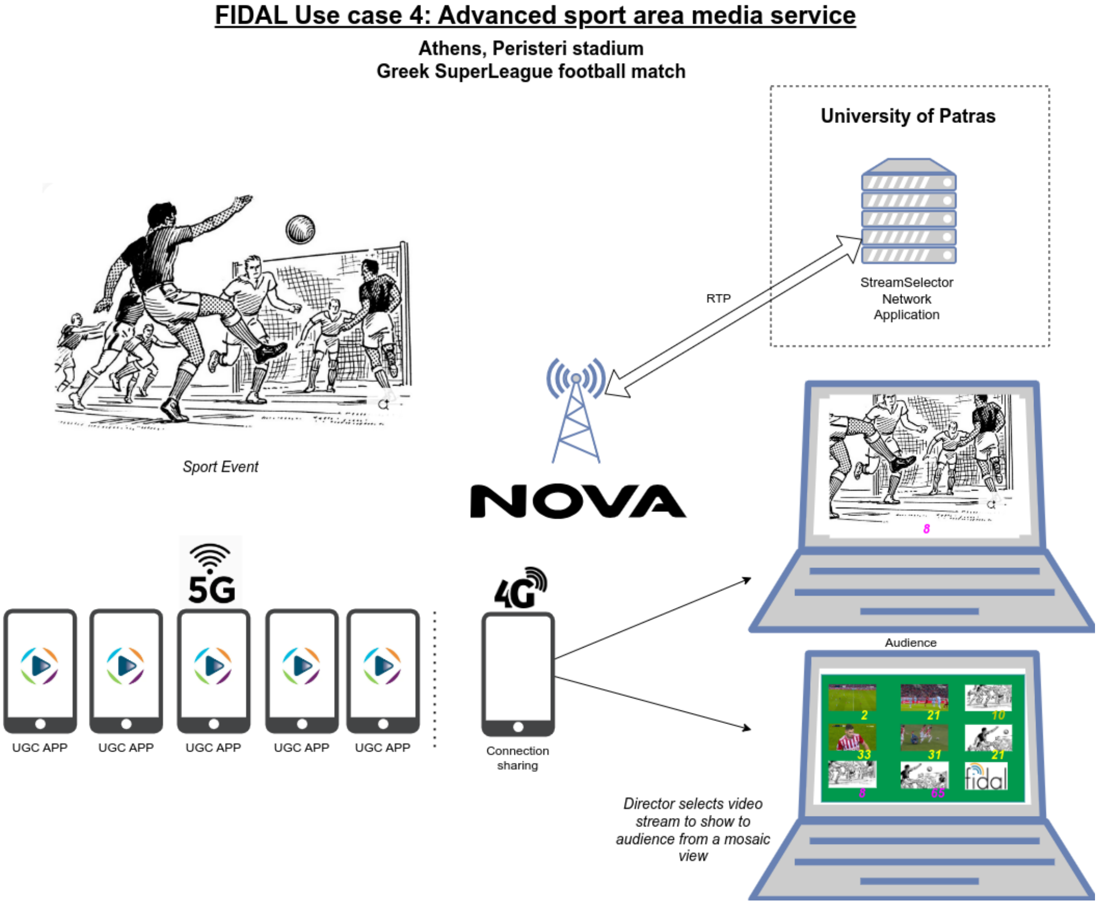

Figure 11: UC4 Advanced sport area media service (LST1 High level presentation)

As the results observed during LST1 revealed certain software anomalies and uplink capacity constraints inherent to a shared public 5G network, it was decided to replicate the test environment at the University of Patras using their dedicated 5G testbed for LST2. This second phase of the trial involved the maximum number of simultaneous video streams that the StreamSelector network application could handle. LST2 was structurally divided into two distinct parts: the first part focused strictly on technical experimentation and KPI extraction under controlled network conditions, while the second part involved external end-users to gather Key Value Indicator (KVI) feedback and evaluate the overall user experience.

LST2 (Controlled Testbed - Mar/Apr 2026): Conducted at the University of Patras 5G testbed to systematically optimize the system based on LST1 findings. User Generated Content smartphone application captures music video clip played back on flat TV screen, and streams content to StreamSelector Network Application using the 5G testbed.

Streaming music video clip from TV screen was preferred to sport because there are no contracts required to access contents and such video has often lots of moving images that requires more Mbps to playback high-quality video than sports.

- A director user observes all streams at once thanks to a mosaic view generated by the StreamSelector.

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- ➢ The director user picks the stream of interest from the mosaic view to playback on another screen for audience.
- ➢ The director user can change the stream proposed to audience.

Eight smartphones streamed high-motion music videos (HEVC 1080p30) to the local StreamSelector. The trial was structured into two parts:

- Part 1 (KPI Focus): Tested two configurations with artificial congestion (five virtual UEs generating 10 Mbps each).
  - Configuration 1 (Constant Bitrate): 4 UEs on a default fair-scheduling slice and 4 UEs on a prioritized slice, all pushing 4 Mbps streams. Congestion was then introduced to the default slice.
  - Configuration 2 (Variable Bitrate): All 8 UEs started on the default slice with automatic bitrate adaptation (0.5 to 6 Mbps) enabled. Congestion was introduced, and finally, 4 UEs were dynamically moved to the prioritized slice.
- Part 2 (KVI Focus): Volunteers used the UGC application to capture local scenes with automatic bitrate adaptation enabled on the default slice, interacting with the system to provide experiential feedback.

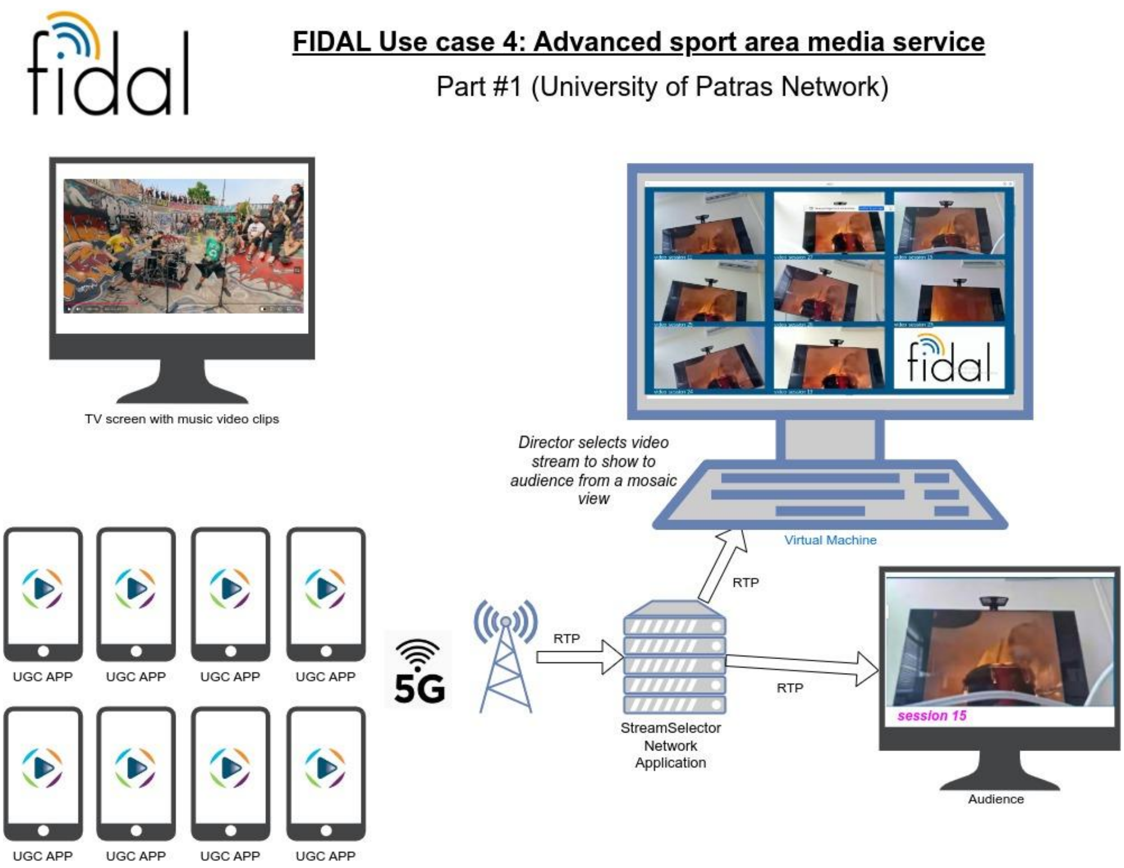

Figure 12: UC4 LST part 1 setup at University of Patras

Two configurations have been tested:

1. UGC application sends a 1080p30 stream at constant bitrate (4Mbps) through the 5G network.

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2. UGC application sends a 1080p30 stream at variable bitrate (0.5 to 6 Mbps) through the 5G network, automatic adaptation bitrate feature activated on UGC. The experiment would demonstrate that smartphone (UE) streams are all viewable by the audience even if additional parasite UEs are consuming radio resources at same moment.

1.6.3 Key findings and results

The LST phases highlighted a clear contrast between unmanaged public networks and controlled 5G slicing environments. While LST1 highlighted some software behaviours and the uplink capacity limits of a commercial public network, LST2 successfully established the necessity and operational effectiveness of prioritized 5G slicing. No freeze occurred on Mosaic as well as Audience player. Audience user reported that most of the video playbacks were of good quality, excepted at some moment when selected stream was one from a UE not in prioritized 5G slice and virtual UEs saturating the bandwidth. Based on results, UEs within the prioritized 5G slice behaved as expected, being able to stream video of good quality for end users. Constant bitrate streams sent by UEs within default 5G slice aren't viewable as soon as the cell overall Uplink capacity is reached. In such setup, it would be interesting to configure automatic bitrate adaptation feature of UGC application for UEs in default 5G slice to provide a viewable video stream for end user.

The following points can be noted:

- Some of the Kubernetes pod CPU requirements were underestimated and induced troubleshooting time to fix (raise CPU limit).
- All bugs spotted on LST1, and LST2 part1 lab replay were fixed.
- 5G Slicing has real impacts for end user experience when network is saturated.
- Identifying UEs with StreamSelector reception gateway statistics was not easy because they don't report statistics per session but per network receive socket.
- Having more video players to collect more statistics requires more vCPU for the virtual machine running Kubernetes worker node.

Technical Results

KPI results

During LST1, empirical data logged by the StreamSelector illustrated the effects of network saturation. Pre-match, input gateways successfully received streams near the 1.2 Mbps target. However, post-kick-off and down-bitrate charts displayed fluctuating bitrates. The average RTP sequence gap metric indicated packet loss and sequence disordering due to the dense crowd traffic. Furthermore, device-side RTCP metrics confirmed these transmission fluctuations, though data collection was partially limited by an HEVC decoder bug.

LST2 provided granular insights into 5G slicing performance under heavy load across its testing phases:

- **Director Operations:** The director successfully monitored all streams via the mosaic view without any freezes and selected specific streams for audience playback.
- **Part 1, Configuration 1 (Slicing Efficacy):** The total cell uplink reached its physical maximum (approx. 40.7 Mbps) during congestion. Despite this saturation, the 4 UEs on the prioritized slice successfully maintained a stable video bitrate of ~4 Mbps with consistent ~30 fps framerates. Conversely, constant-bitrate streams on the default slice suffered medium stream degradation,

with framerates dropping and sequence gaps rising sharply as the network struggled to accommodate the traffic.

- **Part 1, Configuration 2 (Adaptive Bitrate Performance):** When dummy traffic saturated against the default slice, the UGC application's automatic adaptation algorithm triggered, successfully decreasing stream bitrates to limit packet loss. While this prevented total stream failure, it resulted in a saw-tooth bitrate pattern. The dynamic migration of 4 UEs to the priority slice mid-test successfully restored their bitrates to optimal levels. However, the remaining default UEs struggled to recover and showed erratic bitrates, indicating that the automatic adaptation algorithm adjusted too rapidly and requires further tuning to maintain fair bandwidth allocation.
- **Part 2 Operations:** Audience and volunteers reported high-quality video playbacks, with quality drops occurring only when non-prioritized streams were actively selected during periods of intentional bandwidth saturation.

Compared to the target expectations, the prioritized 5G slices successfully met the throughput and stability requirements needed for broadcast media, whereas the default streams highlighted the limits of best-effort scheduling in congested 5G cells.

User feedback and KVI Results

From a user experience perspective, LST1 proved that the UGC application was highly energy efficient, requiring no extra battery packs for the smartphones during the football match. However, physical stadium stands were deemed sub-optimal for streaming due to the distance from the field, leading to poor viewing angles. In LST2, utilizing volunteers for Part 2 confirmed that the system is reliable from an end-user perspective, with the mosaic view operating smoothly and audience members satisfied with the video quality when optimal streams were selected.

The UC4 KVI evaluation covered seven dimensions: Representative, Community Participation/Cultural Connection, Trustworthy, Digital Inclusivity, Flexibility, Privacy & Safety, and Security. Participants saw value in the platform's ability to extend access to community sport and maintain connection across distance, building on already shifting online streaming viewing habits. At the same time, feedback pointed to governance and organisational areas for development, particularly around consent clarity, content archiving policies, and security processes, suggesting that future steps for UC4 lie in the frameworks that support the technology as much as the technology itself in order to provide the desired impact. Table 11 summarizes the outcomes of the KVI evaluation across all assessed dimensions for UC4.

KVI dimension	**Outcome**
Trustworthiness	Most participants did not experience network quality issues. The UC should focus on building confidence in the platform under less stable conditions since surveys showed that the lower-connectivity settings where its value is strongest.
Cultural Connection	Value was particularly noted for diaspora communities staying connected to their local teams from afar. Building awareness, drawing on existing trends in viewing happens is a strong opportunity to grow community participation further.

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Digital Inclusivity	Participants were highly confident using the technology themselves and optimistic about its reach to underserved areas,
Flexibility	The system adapted smoothly to real-world variation in signal and load across concurrent users; testing under more extreme conditions, such as very poor signal or dense crowds, is a recommended next step.
Privacy and Safety	Participants placed strong importance on clear venue streaming policies; expanding consent literacy and in-app privacy controls would further strengthen trust in the platform.
Security	Training and dependency-management processes for this use case are still at an early stage.
Representative	The trial engaged a participant group skewed toward younger, male spectators; broadening representation to better reflect the target audience would strengthen future evaluations.

Table 11: UC4 KVI Outcomes

Results Summary

The trials confirmed that 5G network slicing has a tangible, significant impact on the end-user experience when a network is saturated. UEs operating within a prioritized slice can reliably stream high-quality video for audience playback, validating the core premise of the use case. Unprioritized streams require dynamic adjustments to avoid degradation under heavy congestion. Furthermore, the trials identified that underlying infrastructure resources, such as Kubernetes pod CPU limits, must be appropriately scaled to handle multi-stream data collection and prevent localized bottlenecks.

1.6.4 Future potentials and recommendations

To enhance future trials and advance this technology for commercial media deployment, several recommendations were identified:

- **Adaptive Bitrate Tuning:** It is highly recommended to configure an automatic bitrate adaptation feature for UEs operating on default 5G slices to keep streams viewable under load, particularly in lower-connectivity conditions where the platform's community and diaspora-connection value is strongest. However, the current adaptation algorithms adjust too rapidly and must be fine-tuned to ensure fair and stable bandwidth distribution among users.
- **Iterative Field Validation:** Before returning to a live stadium environment, intermediate testing should occur in crowded public spaces to verify that smartphones can successfully force and maintain 5G network locking.
- **Remote Production Architecture:** All stream monitoring and mosaic building should remain at remote testbeds or production centres (such as the University of Patras testbed). Monitoring directly at the stadium introduces untrusted local network variables that can be mistakenly identified as video decoding artifacts.

1.7 UC5 - Virtual Reality Networked music performance

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1.7.1 Introduction & Value Proposition

UC5 explores how a distributed music ensemble can rehearse and perform together across two geographically separated sites using 5G-enabled media and audio streams. The value proposition is to enable low-latency networked music performance where musicians can hear and see each other well enough to play together, while a remote audience can later experience the performance through synchronized 360° video and audio.

The use case is technically demanding because musical co-performance is highly sensitive to delay, jitter, packet disordering, and timing instability. Unlike many media streaming services, where buffering can hide short-term network variation, networked music performance requires the audio path between musicians to remain close to real time. Even delays of a few tens of milliseconds can be perceived by musicians and may affect timing, comfort, and the ability to perform complex musical material together.

The UC5 solution combines EKTACOM's RemoteBand, StreamSelector, MixingBand, FidalStreamer, and FidalPlayer components with professional audio devices, video cameras, 360° video capture, GPS/PTP-based timing, and the TNOR 5G testbed. The trial therefore evaluates not only network capacity, but the full end-to-end chain needed for real-time musical collaboration, including timing, audio rendering, media transport, video contribution, audience distribution, and operational setup across two sites.

1.7.2 Trial Setup and Targets

The UC5 validation followed a phased approach. A dry-run was carried out at Fornebu in July 2025 to integrate the software and equipment and to validate audio-only, video-only, and combined audio, video, and 360° streaming configurations. The first trial was then executed between Fornebu and NTNU ManuLab in Trondheim in November 2025 (LST#1). The use case trial connected musicians located at Telenor's Research and Innovation Centre at Fornebu and NTNU ManuLab in Trondheim, approximately 500 km apart. The lessons from this trial directly shaped the preparation for the final trial 10th April 2026 (LST#2).

That is, EKTACOM improved the "RemoteBand" component by adding a small 5 ms buffer to reorder packets or substitute a previous packet in case of loss, allowing audio to be rendered directly through the Dante/AES67 audio devices rather than through the desktop sound stack. A premium GPS antenna was also added at the Trondheim site, and software was developed to monitor time shift between the sites. Before the live trial, additional validation was performed using the EKTACOM's Streamix tool between Fornebu and Trondheim, RemoteBand latency measurements in France, between the cities of Brest and Les Ulis over fibre, and a musician test between the cities of Athis-Mons and Les Ulis.

The final trial setup involved a drummer and guitarist at Fornebu and a bass guitarist & vocal at Trondheim. Each site used professional audio and video equipment, including Dante/AES67 sound cards, mixers, high-resolution cameras, large screens, 5G CPE connectivity, and desktop PCs connected to the testbed. In addition, a 360° camera captured the Fornebu environment for later audience access through HLS, with audio mixed and synchronized by the StreamSelector/MixingBand chain.

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The primary technical targets included application and server accessibility, content load time, zero content freeze, sufficient uplink and downlink throughput for audio and video streams, network application deployment within five minutes, and end-to-end audio latency below 50 ms between musicians.

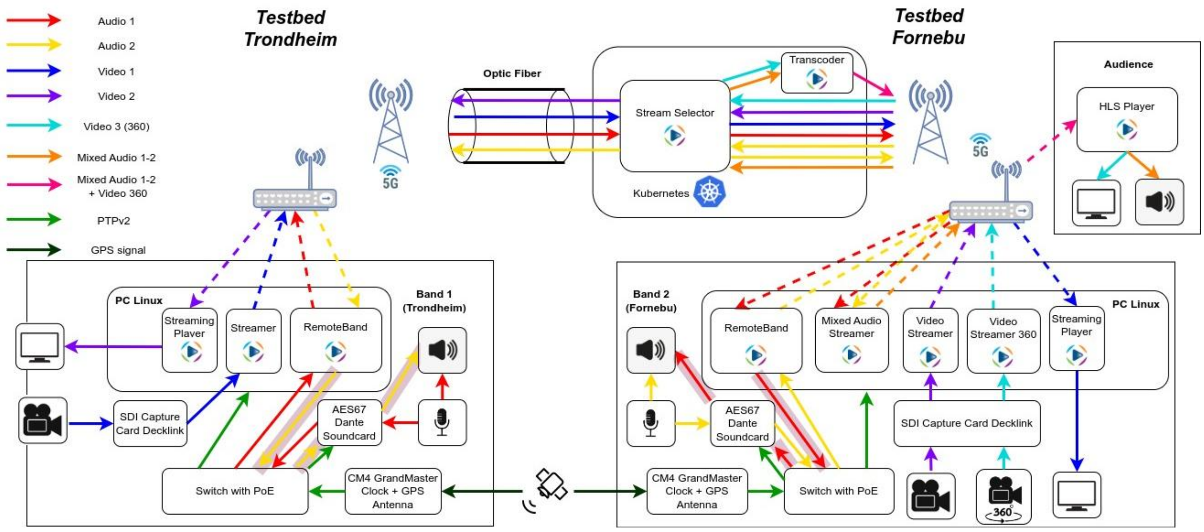

Figure 13: UC5 Final trial setup across Fornebu and Trondheim.

1.7.3 Key Findings and Results

The trial was considered successful as the distributed musicians could play the selected song together in sync, while a remote audience user could later access synchronized 360° video and audio using a browser or VR headset.

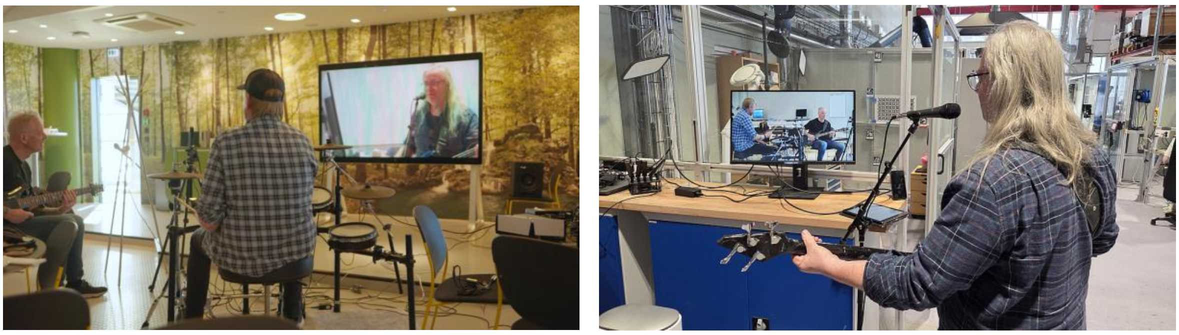

Figure 14: UC5 Musicians at Fornebu (left) and Trondheim (right).

Technical Results

The final UC5 technical results show a clear progression from the less successful first trial. The main achievement was that the musicians were able to play the whole song together across the two sites. This demonstrates that the revised architecture, improved packet reordering, better timing support, and more careful pre-trial validation made the networked music performance technically feasible under the tested conditions.

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KPI	Experimental results	Assessment
Network pre-validation	Streamix tests between Trondheim and Fornebu showed no packet loss, no packet disordering; local latency below 2 ms in one-way audio testing, and low jitter under the benchmark conditions.	The 5G testbed path was considered suitable for attempting the UC5 LST#2 configuration.
RemoteBand fibre baseline	Brest–Les Ulis fibre testing showed asymmetric one-way latency of approximately 5.5 ms and 7 ms, with an estimated round-trip time of 12.5 ms and total audio delay below 21 ms when adding sound acquisition and rendering.	The application chain was validated under good fixed-network conditions before the 5G trial.
Audio and video bitrate	During LST#2, the 360° video stream was around 15 Mbps, the Fornebu camera around 5 Mbps, low-latency audio streams around 1.2 Mbps each, and mixed compressed audio around 128 kbps.	The measured media stream rates aligned with the intended service setup and were supported by the testbed during the trial.
Application latency	RemoteBand measurements from a related setup showed average one-way latency around 50 ms at Trondheim and 35 ms at Fornebu, giving an approximate round-trip value of 85 ms. Adding audio acquisition and rendering resulted in total delay below 100 ms.	The achieved delay enabled the musicians to complete the song, but it was still close to the limit of comfortable musical performance.
Service continuity	No disconnection occurred during the full LST#2 performance, and a synchronized 360° video and audio recording was captured for audience access.	The end-to-end media chain operated reliably during the final trial.

Table 12: UC5 Highlighted KPI Results

The most important technical finding is that UC5 is not limited by nominal throughput alone. The available bitrate was sufficient for the tested media streams, but user-perceived performance depended strongly on latency, jitter, packet disordering, radio conditions, and timing stability. Compared with the controlled fibre baseline, the 5G testbed added approximately 40–45 ms of delay over a similar geographical distance. This additional delay was noticeable to the musicians and placed the performance near the boundary of what they considered acceptable.

The trial also showed that the Trondheim site experienced more variable application latency than Fornebu. A likely explanation is radio interference in the industrial lab environment, where poor radio conditions can lead the 5G NR layer to increase buffering and retransmission, adding delay and potentially causing packet disordering. This confirms that networked music performance requires not only high-capacity 5G connectivity, but also a well-controlled radio environment and strong visibility into both network and application-layer behaviour.

User Feedback and KVI Results

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The UC5 KVI assessment shows that participants strongly understood the value proposition of network-enabled music collaboration, even though the trial remained technically close to the limit for comfortable synchronized co-performance. The results therefore distinguish between the current prototype experience and the perceived potential of a mature commercial solution.

KVI dimension	Outcome
Representative	The participant group was small and skewed toward older male amateur musicians, with the 18-34 age group absent. Regional representation included suburban and rural participants, but the sample is only a starting point.
Trustworthy	Current connection stability averaged 3.7/5 and audio/video consistency 3.5/5, while confidence in a future commercial version averaged 4.3/5. Participants therefore trusted the concept more than the current prototype.
Digital Inclusivity	Participants saw strong potential for location-independent participation and community connection, but also identified the need for a packaged, easier-to-use setup and wider 5G SA availability.
Cultural Connection	The value proposition was strongly endorsed, particularly for rehearsing across towns, remote teaching, specialist access, and maintaining musical communities across distance.
Environmental impact	Participants rated the potential for reduced travel and environmental savings highly for co-play, though this reflects subjective expectations rather than objective carbon and energy measurements..
Privacy	Privacy confidence averaged 3.7/5, with stronger confidence for co-play than teaching. Future trials should assess data storage, recording, consent, and retention explicitly.
Flexibility	Co-play satisfaction remained low because latency was still perceptible, while the teaching scenario was more tolerant and received more positive feedback.

Table 13: UC5 KVI Outcomes

The KVI evidence suggests that UC5 has a credible and desirable social and cultural value proposition, but that the technical maturity threshold for consistently comfortable co-performance has not yet been fully reached. Teaching and guided music interaction appear more tolerant of modest latency than synchronized ensemble performance, while co-playing requires tighter timing, lower jitter, better predictability, and more musician-friendly operational conditions.

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Results Summary

UC5 can be considered successful in LST#2, because the musicians were able to complete the full song in sync across the Fornebu and Trondheim sites, with no disconnections and with synchronized 360° video and audio captured for audience access. This represents a clear improvement compared with LST#1, where increasing latency and packet disordering prevented sustained performance.

At the same time, the trial confirms that networked music performance remains one of the most demanding Media use cases in FIDAL. The system operated successfully, but musicians still experienced the added 5G-related delay as noticeable and not fully comfortable. This means the trial validates feasibility but also shows that further optimization is needed before the solution can be considered broadly suitable for concerts or complex ensemble performance across distributed sites.

The most important lessons are that the full end-to-end media chain must be engineered as a single low-latency system; packet disordering must be anticipated in 5G environments; GNSS/PTP timing is mandatory for the current architecture; and realistic radio conditions at both sites are as important as nominal throughput. The trial also shows that application-specific tools such as Streamix are essential for pre-validating UDP/RTP performance before live musical sessions.

Acknowledgement: NTNU ManuLab, Trondheim, Norway.

1.7.4 Future Potentials and Recommendations

Future work should focus on reducing and stabilizing end-to-end latency, rather than only increasing nominal throughput. Some additional buffering in StreamSelector could be removed, but the expected gain is limited to approximately 10 ms. The larger opportunity lies in improving the 5G testbed and end-to-end traffic handling so that low-latency audio receives predictable treatment across the UE, radio access network, core network, and transport path.

To fully exploit 5G features such as slicing, traffic prioritization, and low-latency operation, support must be available across the complete system: user equipment, base station, mobile core, and application chain. Today, only a limited number of UEs can prioritize low-latency traffic together with slicing. Until this becomes more widely available, 5G testbeds will struggle to provide the predictable latency needed for demanding networked music performance.

Timing should also be simplified. The current solution depends on PTP master clocks synchronized through GNSS, but GNSS reception proved difficult in modern energy-efficient buildings and required careful antenna placement. A future solution would benefit from PTP or equivalent precise time synchronization provided directly by the 5G network, for example through 5G TSN capabilities when commercially available.

For future pre-commercial trials, the recommended next step is to establish permanent or semi-permanent local trial facilities in selected cities or towns. These sites should include local 5G Advanced non-public networks, low-latency transport interconnection, edge resources for media processing, and a 5G SA core slice configured for predictable performance. Such facilities would allow musicians and bands to test different musical styles, group sizes, latency levels, and collaboration formats over time, creating a stronger evidence base for both technical feasibility and cultural value.

1.8 UC7 - Smart village engagement services

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1.8.1 Introduction & Value Proposition

UC7 explores how 5G-enabled media and communication capabilities can support smart village citizen engagement, remote participation, and multi-site live communication and interaction. The original use case focus was on helping rural or peripheral communities participate more actively in local and regional activities by connecting people, places, and events through high-quality audio and video communication. During the project, this evolved into a broader concept of ***multi-site live telecommunication***, where several distributed users at local sites can collaborate and interact based on precision exchange of live audio and video streams in real-time.

The value proposition is to make distance less limiting for participation in social, educational, cultural, and civic activities. Examples include remote music teaching, multi-site show-and-tell sessions, citizen engagement in village or city development, participation in local sport events, and shared cultural or community events across several locations. In this sense, UC7 broadens practical communication services that can facilitate citizen engagement and strengthen inclusion, local identity, and access to expertise, as well as facilitating citizen engagement and civic activities beyond national borders.

UC7 also complements UC5. While UC5 focuses on the most demanding sub-case of synchronized multi-site live telecommunication, that is, on networked music performance, UC7 explores a wider set of live communication situations where latency, audio/video quality, usability, and robustness still matter, but where the interaction may be more tolerant than strict musical co-performance. This makes UC7 an important bridge between technical 5G media experimentation and future community-oriented services based on 5G Advanced, local non-public networks, and low-latency edge-enabled communication.

1.8.2 Trial Setup and Targets

From this overall broad perspective, the UC7 trial work used a pragmatic and evolving setup that combined EKTACOM media tools, Telenor testbed resources, NTNU ManuLab facilities, browser-based live communication, and load-generation experiments. The main technical components included the EKTA user-generated content (UGC) smartphone application, the Whereby[1] browser-based audio-visual communication tool, and the EKTA Streamix tool for exploring controlled load scenarios and assessing the behaviour of the network under increasing uplink traffic.

Because the originally anticipated testbed capability for dynamic network configuration was not fully available, and because Whereby could not provide the expected application-level KPI support after its divestment by Telenor in spring 2026, the trial approach was adapted. Rather than relying only on one predefined smart village application, UC7 used the available tools to explore realistic mixed-use scenarios and to understand what is required for robust multi-site live telecommunication.

The central technical trial scenario was the multi-site interactive show-and-tell scenario. It was used to assess whether live audio and video communication could support remote interaction across sites and how the 5G uplink behaved when traffic load increased. The load scenario used streams from 1 Mbps up to 80 Mbps and examined packet loss, RTP sequence gaps, packet disordering, framerate stability, and the practical uplink limit of the 5G network.

[1] https://whereby.com/blog/

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The trial also included user-oriented exploration around remote music teaching and multi-site show-and-tell formats. These scenarios were used to develop and test an extended KVI assessment approach based on scenario-specific videos and online surveys, allowing a broader set of respondents to evaluate the perceived value of the solution beyond the small number of trial participants.

The main evaluation targets were stable uplink performance, low packet loss and packet disordering, usable audio/video quality, acceptable framerate at the receiving end, robust operation under realistic site conditions, and evidence of user value across effectiveness, cultural connection, digital inclusivity, trustworthiness, environmental impact, flexibility, and security-related dimensions.

1.8.3 Key Findings and Results

The UC7 trial demonstrated the potential of 5G-enabled multi-site live communication services to support digital engagement, knowledge sharing, and access to expertise across geographically distributed communities. Through the Music School Teaching and the Interactive Show & Tell scenarios, the trial explored how advanced connectivity, media streaming, and user-generated content can enable new forms of collaboration, learning, and community participation. The results confirmed the feasibility of such services, while also highlighting the importance of low-latency, stable uplink connectivity, robust audio/video synchronization, and simplified end-user solutions to achieve a high-quality user experience.

Figure 15: Music school student in Oslo being instructed by music school teacher located in Trondheim (left), Welding expert in Trondheim demonstrating 3D welding operation for viewers in Oslo (right).

Technical Results

The UC7 technical results show that the 5G uplink can support stable live communication traffic up to a practical threshold, but that the user experience deteriorates rapidly when the uplink becomes overloaded. The show-and-tell scenario was the main technical reference point. It showed stable 5G uplink behaviour up to approximately 55–60 Mbps, with the broader load scenario indicating an uplink limit around 70 Mbps. Once the overall uplink traffic exceeded this level, RTP sequence gaps increased and packet disordering or packet loss affected all streams.

KPI	Experimental results	Assessment

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5G uplink capacity	The load scenario used streams from 1 Mbps to 80 Mbps and showed stable uplink performance up to approximately 55–60 Mbps, with an overall practical uplink limit around 70 Mbps.	The network supported demanding live media uplink traffic, but only within a clear capacity envelope. This was still according to expectations.
Packet loss and packet disordering	Fraction loss and packet loss were zero until the overall uplink traffic approached around 70 Mbps. Above this level, packet disordering and/or packet loss increased and affected the KPIs.	Packet stability is a critical requirement for multi-site live telecommunication and must be protected under load.
RTP sequence gaps	Average RTP sequence number gaps remained stable with limited load, but became unstable when multiple UEs flooded the network.	The results indicate that the network alternated between sustaining and not sustaining the offered load when pushed beyond its stable operating range.
Video framerate at receiving end	EkPlayer measurements at Fornebu showed substantial frame drops and likely image losses at some moments.	Even when connectivity is available, framerate instability can significantly reduce audience experience.
Passive device power consumption	Power consumption on a passive Raspberry Pi modem was measured around 1.33–1.38 W, with no observable effect from network load.	Network load did not appear to be a dominant energy driver for the passive modem in the measured setup.

Table 14: UC7 highlighted KPI results.

The most important technical lesson is that UC7 is sensitive to the same network quality dimensions as other live media use cases, but in a broader and more varied set of contexts. Uplink capacity, packet ordering, frame continuity, local radio conditions, and end-device behaviour all affect whether the service feels usable. The instability observed at ManuLab also demonstrates that smart village or local community deployments cannot be assessed only from core network performance; the local access environment and venue-specific radio conditions are equally important.

User Feedback and KVI Results

The use case evolved from smart village engagement into a broader multi-site live telecommunication concept that can support several community, cultural, educational, and civic scenarios. The UC7 KVI work indicates that participants and observers saw clear potential in the concept, especially for improving remote participation, access to expertise, and inclusion across locations. At the same time, the evidence also shows that the current implementation was not yet stable or simple enough to fully demonstrate the expected value. The KVI findings therefore point to a promising value proposition that remains conditional on improved quality, stability, ease of use, and packaging.

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KVI dimension	Outcome
Cultural Connection	The concept supports participation in local cultural, educational, and community activities across distance, including music teaching and live community events.
Digital Inclusivity	UC7 can help people participate without travelling to a central location, but the solution must become simpler, more packaged, and easier to access for wider adoption.
Trustworthiness	User confidence depends strongly on stable audio/video quality and predictable performance. Current feedback points to the need for better quality, stability, and ease of use.
Environmental Impact	Observer assessments of travel and cost reduction potential were moderate. Time savings averaged 2.7/5, while cost savings and environmental impact reduction averaged 3.3/5.
Security	Security assessment showed some maturity in dependency awareness, with dependency scoring 7/10, but use-case contextualisation scored 3/6, indicating that security governance should be better connected to the human deployment context.

Table 15: UC7 KVI Outcomes.

The user feedback highlights several practical adoption requirements. Participants asked for a simpler technical solution, reduced sources of delay, better latency and audio/video quality, a packaged setup with audio and video equipment, and a solution that is user-friendly and cost-friendly. For the show-and-tell scenario, users also emphasized the need to optimize each sub-component and combine them into a more unified communication service. Separate microphones and loudspeakers, such as headset or earbud-based audio, were also suggested to improve usability.

Complementary to the trial feedback, UC7 developed an expanded KVI assessment approach using scenario-specific videos and online surveys. This method is intended to gather feedback from larger respondent groups for scenarios such as remote music teaching and multi-site interactive show-and-tell, allowing the anticipated impact of the solution to be assessed across the same value dimensions as the live trial.

Results Summary

UC7 successfully evolved from an initial smart village engagement concept into a broader and more concrete exploration of multi-site live telecommunication. The trials demonstrated that 5G can support demanding live audio/video communication scenarios, but also showed that the service quality depends strongly on uplink load, packet ordering, local radio conditions, application integration, and usability.

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The technical results identify a stable operating range for the tested 5G uplink and show that quality degradation becomes visible once the network is pushed beyond its practical limit. The KVI results show that the concept is meaningful and relevant, especially for inclusion, access to expertise, local community engagement, and reduced travel. However, the current implementation needs further hardening before these benefits can be demonstrated consistently.

Overall, UC7 provides a valuable evidence base for future low-latency communication services in rural, local, and community settings. It shows that the strongest opportunity is not a single smart village application, but a reusable capability for connecting people and activities across several places through reliable, low-latency, high-quality live media communication.

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1.8.4 Future Potentials and Recommendations

Future work should focus on developing UC7 as a general multi-site live telecommunication capability for community, cultural, educational, and civic participation. This includes remote music teaching, distributed local events, citizen engagement in village or city development, local sport and festival participation, and other scenarios where people need to interact across several locations with live audio and video. The flexibility of supporting and managing an unplanned or partially planned participation of a variety of wireless devices (5G cameras, smartphones, smart glasses, and more) into such a multi-user & multi-site settings represents a general value proposition that seems promising, but requires further exploration and insight.

The next technical step should be to use local 5G Advanced or non-public networks with stronger support for low-latency connectivity, application-specific traffic handling, and predictable uplink performance. A dedicated slice or service profile for time-critical communication would help protect live media streams from congestion and reduce packet disordering when several devices are active at the same time.

Timing support is also important for future scenarios. Unlike UC5, many UC7 applications, such as remote music teaching or local community sessions, cannot realistically rely on separate PTP master clocks and GNSS antennas at every user location. Therefore, future deployments should explore how precise timing, including 5G TSN capabilities when available, can be provided directly by the network for time-critical collaborative activity.

From a service perspective, UC7 should be simplified into a packaged and repeatable solution. This means fewer technical components exposed to end users, better audio equipment recommendations, clearer setup guidance, improved application integration, and high-quality demonstration material for external users. The user feedback indicates that simplicity, stability, quality, cost, and ease of access will be decisive for adoption.

Finally, future trials should collect richer KVI evidence with larger respondent groups and better baseline data. For environmental and business value, participants could be asked to report the travel distance, time, cost, and mode they would otherwise have used to attend in person. This would allow the benefit of virtual participation to be compared with the energy used for the communication service and would make the sustainability case more evidence-based.

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Based on the above learning, experiences, and vision for future solutions and services, the following AI illustration was generated to provide inspiration for further work.

Figure 16: Multi-site live telecommunication enabled by 5G Advanced – Future vision and inspiration.

Considering User Value, Feedback, and KVIs in general

Several patterns emerged across the use cases. Trust in current performance was rated highly with participants satisfied with connection reliability, quality, and technical effectiveness, and seeing strong potential to support digital inclusivity. Flexibility testing reinforced this picture, showing that many of these tools could keep working across varied conditions. There was also demonstrated and anticipated promise around improved energy efficiency as these platforms move toward more advanced 5G and future 6G deployment.

At the same time, an important trust gap emerged. While trial participants were generally satisfied with current performance, they were not yet convinced of future reliability and dependability, especially under the real-world conditions in which some of these platforms would ultimately be deployed. The results also suggested that the conditions and voices included in the trials may not yet be representative enough for the full picture.

In the PPDR group, the KVI evidence points to strong outcome potential for these tools enhancing situational awareness, coordination, and operational decision-making. Participants across the emergency response and law enforcement use cases consistently valued the improved ability to track unfolding incidents and coordinate more effectively between field responders and command centres. The two XR/AR-based use cases also revealed an insightful trade-off worth further research: as they worked to augment a responder's awareness with additional information, they also introduced cognitive demand, adding new safety considerations alongside the ones they addressed. Paying attention to these kinds of trade-offs will be relevant for 6G research and innovation as a whole, as 6G introduces increasingly complex information streams and interfaces.

In the Media group, the KVIs captured a genuine belief in the prospect of connection across distance, even where current implementations fell short technically, whether for diaspora communities maintaining ties to local sports clubs or musicians and students accessing collaboration and expertise otherwise limited by geography. The value proposition of bringing together individuals and communities from afar clearly resonates with trial participants. However, questions remain about the governance around these systems, as well as their ability to work well in remote places. Future development needs to translate this enthusiasm into simple, reliable, and accessible experiences.

The KVI assessment also produced lessons about the methodology itself. Combining objective technical measurement with participant surveys proved more informative than either alone. In several cases, network or device logs explained patterns in the survey data that would otherwise have been difficult to interpret, and the two data sources sometimes revealed tensions between measured performance and perceived experience that neither would have revealed on its own. At the same time, trial participant numbers were small across the portfolio, meaning survey results are not statistically representative findings; if surveys are to become a primary KVI data gathering technique, the trial methods (and indeed, the activities throughout the project) need to adjust to support more robust survey results. A further lesson was that certain value dimensions, such as comparative energy or cost impact, require input from domain experts rather than end users, since neither participants nor many project partners have the expertise needed to judge them. Finally, some assessment instruments performed better when adapted to the specific technology and context being tested rather than applied in a standard, generic form.

Outlook and summarized recommendations

The FIDAL trials collectively demonstrate that advanced 5G networks can support a broad spectrum of demanding services spanning public safety, immersive communications, media production, remote collaboration, and community engagement. Across the use cases, the trials validated the feasibility of combining mobile connectivity with edge computing, network applications, AI-driven processing, cloud resources, and service orchestration to create new forms of interaction and situational awareness.

A common lesson across the trials is that successful service delivery depends on much more than network throughput. User experience was heavily influenced by latency, jitter, packet ordering, synchronization accuracy, uplink stability, radio conditions, and end-to-end application performance. Several use cases demonstrated that even when bandwidth was sufficient, service quality could be degraded by timing fluctuations, packet disordering, network congestion, or limitations in application integration. The findings therefore reinforce the need to design future services as complete end-to-end systems in which applications, edge resources, transport, timing, and network functions are optimized together.

An important outcome of FIDAL is the identification of a set of reusable network capabilities that proved valuable across multiple use cases. These include network slicing for traffic prioritization and

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predictable performance, edge computing for low-latency processing and AI inference, network application deployment and orchestration, secure service exposure through APIs, precise timing and synchronization mechanisms, and support for real-time media transport. Although the individual use cases addressed different sectors and requirements, many relied on the same foundational capabilities, suggesting that future 5G Advanced and 6G ecosystems can benefit from common programmable network platforms capable of serving multiple vertical domains.

The user and stakeholder evaluations further showed that the value of advanced connectivity extends beyond technical performance. Participants consistently highlighted benefits such as improved situational awareness, enhanced safety, remote access to expertise, cultural participation, digital inclusion, flexibility, training effectiveness, and reduced travel requirements. At the same time, users emphasized the importance of simplicity, reliability, predictable quality, and ease of deployment. The trials therefore indicate that future success will depend not only on network innovation but also on creating solutions that are easier to adopt, operate, and integrate into everyday workflows and operational environments.

Looking ahead, the FIDAL results point toward a future where communication networks evolve from connectivity providers into programmable service platforms. Future experimentation should focus on predictable low-latency performance, enhanced uplink capabilities, AI-assisted network and service management, edge-native application architectures, advanced synchronization support, and tighter integration between applications and exposed network capabilities. Larger-scale validations, broader user communities, and longer-term operational deployments will also be necessary to strengthen both the technical and societal evidence base.

Overall, the FIDAL trials provide a strong foundation for future 5G Advanced and 6G initiatives. The key recommendation is to build upon the reusable capabilities validated during the project—network slicing, edge computing, orchestration, secure API exposure, media optimization, and precise timing—and evolve them into robust, standardized, and easily consumable platforms. By doing so, future networks will be better positioned to support a new generation of immersive, collaborative, mission-critical, and community-oriented services that connect people, expertise, devices, and digital resources across locations in real time.

Conclusion

The FIDAL large-scale trials have demonstrated the potential of advanced 5G networks to support a diverse set of demanding services across public safety, immersive communications, media production, and community engagement. By combining connectivity with edge computing, network applications, AI-enabled processing, service orchestration, and network slicing, the project has provided practical evidence that next-generation mobile networks can enable new forms of real-time collaboration, situational awareness, remote expertise, immersive interaction, and multi-site participation. Across all use cases, the trials validated both the technical feasibility and the broader societal value of these services.

At the same time, the project highlighted that future success depends on more than network capacity alone. Predictable latency, synchronization, uplink performance, reliability, usability, and seamless integration between applications and network capabilities emerged as critical enablers for high-

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quality user experiences. The lessons learned and reusable capabilities identified throughout FIDAL—including network slicing, edge computing, service orchestration, real-time media transport, and secure API exposure—provide a strong foundation for future 5G Advanced and 6G initiatives. Collectively, the results show how communication networks are evolving from connectivity platforms into programmable service infrastructures that can support a new generation of immersive, collaborative, and mission-critical digital services.

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