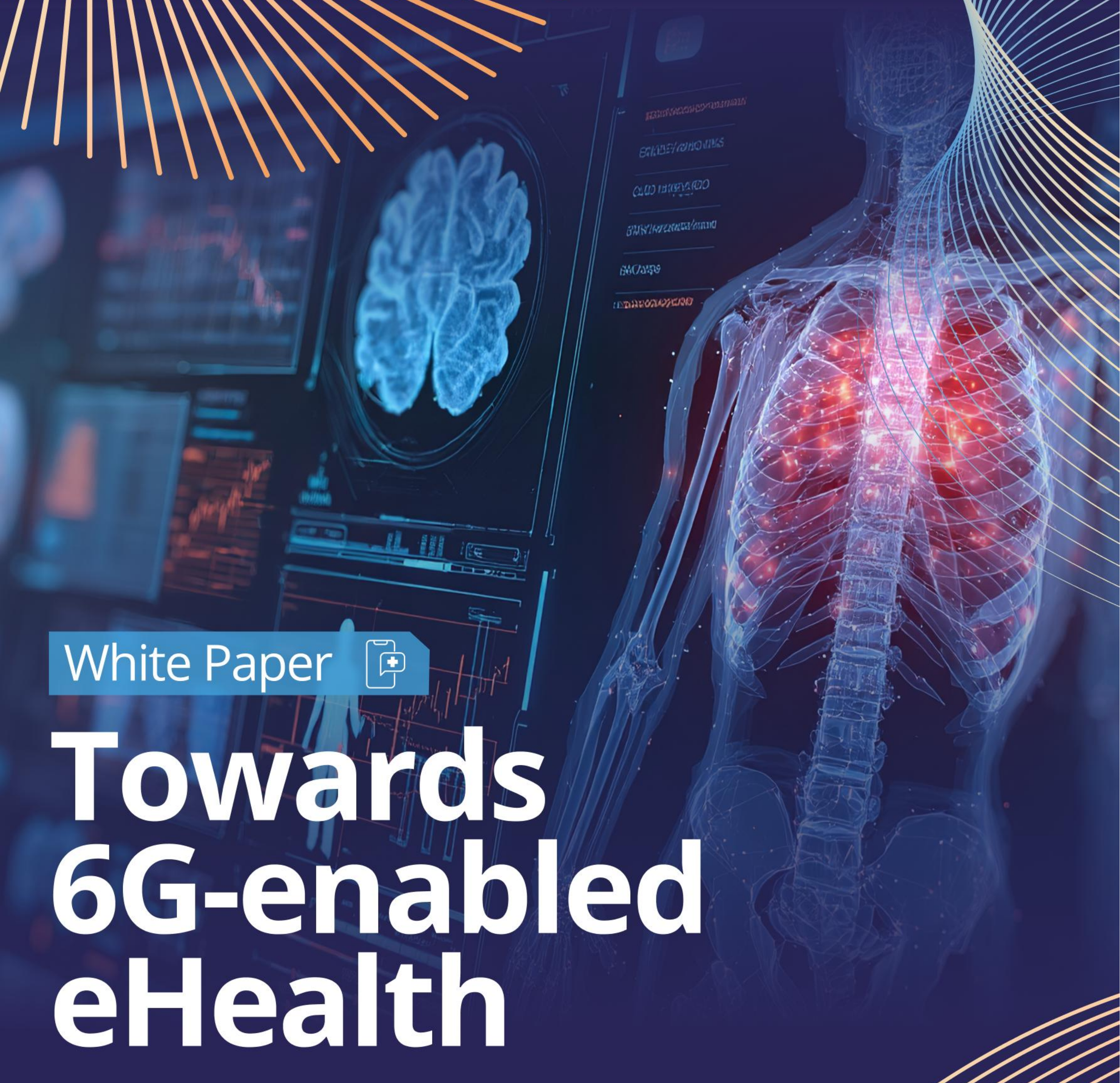
6G SNS

Smart Networks and Services
Joint Undertaking (SNS JU)
Technology Board (TB)



White Paper

Towards 6G-enabled eHealth

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EXECUTIVE SUMMARY

The adoption of innovative eHealth solutions leveraging B5G and 6G network platforms represents a pivotal moment for European healthcare, enabling services that are simultaneously more accessible, resilient, and effective. This SNS JU white paper consolidates findings from leading European research projects, demonstrating how next-generation network architectures, artificial intelligence (AI), edge computing, and advanced data security mechanisms are transforming care delivery across the continent. Over 2024 and 2025, these projects have successfully advanced from conceptual frameworks to validated, real-world implementations across diverse clinical specialties and geographic regions.

VALIDATION OF CORE EHEALTH CAPABILITIES AND USE CASES

The research portfolio successfully deployed fifteen distinct eHealth use cases that address critical healthcare challenges, moving the capabilities of advanced networks beyond theory into clinically safe and operationally viable practice.

A landmark trial conducted on July 7, 2025, exemplifies this progress. A cardiac surgeon performed an interventional procedure while wearing augmented reality (AR) smart glasses, streaming a first-person perspective of the operating field to a remote expert. The expert, monitoring crucial cardiac imaging modalities concurrently, provided immediate guidance throughout the surgery. This B5G-enabled telepresence validation proves that remote expertise delivery is a safe and viable approach for both surgical training and patient care, effectively overcoming the geographic dependency on specialized medical centres.

Beyond surgical telepresence, the platform supports a wide array of high-impact applications:

- **Continuous Monitoring:** Wearable ultrasound patches integrated with AI provide real-time cardiac monitoring in hospital, ambulatory, and home settings, detecting functional changes that would have previously gone undetected. Similarly, predictive reprogramming of implantable cardiac devices dynamically adapts therapy to the patient’s physiological state, reducing inappropriate shocks and extending device longevity.
- **Remote and Home-Based Care:** Advanced rehabilitation platforms deliver AR-guided therapy directly to patients' homes. This system enables clinicians to supervise multiple patients simultaneously, drastically reducing hospital traffic and improving patient adherence to treatment plans.
- **Novel Sensing Paradigms:** Some projects project pioneered contactless sensing architectures, using distributed wireless antennas embedded within a home environment to continuously monitor respiration and detect abnormal events without requiring the patient to wear devices or actively interact with technology. This is a critical breakthrough for elderly populations, those with limited dexterity, or anyone who resists

traditional wearable solutions, simultaneously laying the groundwork for shared safety and security applications.

- **Emergency Response and Training:** High-bandwidth, low-latency connectivity enables Extended Reality (XR) training platforms, where prehospital nurses practice emergency procedures on remotely controlled manikins, guided by instructors in real-time from distant locations. Furthermore, autonomous emergency response robots, supported by these networks, can extend trauma care capabilities to rural and remote regions facing specialist scarcity.

TECHNICAL PERFORMANCE, SECURITY, AND GOVERNANCE

The technical validation is rigorous, demonstrating that B5G/6G architectures meet the demanding reliability and performance standards required for mission-critical healthcare:

- **Mission-Critical Performance:** Projects consistently achieved end-to-end latencies below 20 milliseconds, the required threshold for real-time clinical interaction. Furthermore, service availability reliably exceeded 99.99%. Positioning accuracy reached 1 centimetre in trials, enabling precise location-aware services like fall detection.
- **Network Optimization:** Network slicing technologies enable the dynamic separation of clinical workflows based on urgency, ensuring time-critical interventions never compete for bandwidth with routine monitoring. Data throughput has been optimized to support the simultaneous monitoring of hundreds of connected devices while adhering to the strict energy budgets of battery-powered wearables.
- **Security and Interoperability:** Regulatory and governance frameworks were developed alongside technical implementation. Projects demonstrated full GDPR compliance through end-to-end encryption, granular access controls, and secure network slicing. Crucially, interoperability with emerging European health data standards, particularly HL7 FHIR and the European Health Data Space framework, has been validated. This ensures 6G-eHealth solutions integrate seamlessly within the broader European digital health ecosystem, avoiding the creation of isolated data silos.

MULTIDIMENSIONAL IMPACT: SOCIAL, ECONOMIC, AND ENVIRONMENTAL GAINS

The white paper documents the platform's impact across four critical dimensions, positioning it as a key driver of comprehensive healthcare reform:

Social Impact and User Experience

The new platform drastically improves accessibility to specialized care in underserved regions, accelerating the diagnosis of critical conditions. Trials directly address the concentration of cardiac expertise by extending specialized monitoring and supervision to rural populations and those limited by geographic barriers. User experience improves through reduced latency, translating to more natural clinical interactions. Healthcare professionals report a reduced cognitive load as AI handles routine monitoring, freeing up time for complex decision-making. Patients, especially the elderly, express higher satisfaction with non-intrusive contactless monitoring that respects their privacy and autonomy.

Environmental Sustainability

Significant environmental gains are achieved by eliminating unnecessary travel—both by patients attending appointments and specialists traveling to remote sites—which directly reduces transportation-related carbon emissions. Early detection capabilities (e.g., cardiac or respiratory decline) enable preventive intervention, avoiding more resource-intensive emergency responses and hospitalizations. Across the project portfolio, estimated reductions in carbon footprint **range from 40% to 60%** per clinical episode compared to traditional in-facility care models.

Economic Sustainability

For health system administrators facing budget pressures, economic sustainability is highly compelling. Remote proctoring multiplies the reach of experienced surgeons, enabling them to supervise multiple remote procedures simultaneously. Continuous monitoring facilitates early intervention before health changes escalate into expensive emergency presentations. Home-based rehabilitation reduces facility operating costs while improving therapist productivity. Collectively, these mechanisms suggest potential healthcare cost reductions of 15-25% at scale, making specialized, high-quality care more affordable.

Achieving these substantial cost reductions and widespread benefits requires a significant upfront investment across the value network. This includes upgrading networking infrastructure to 6G standards, procuring new eHealth devices and systems, and establishing secure, interoperable data platforms. The initial capital outlay must be carefully weighed against the anticipated long-term savings from improved efficiency, reduced facility costs, and preventative care. A comprehensive cost-benefit analysis suggests that while the payback period may vary by region and organization, the economic benefit of sustaining specialized, high-quality care and avoiding escalating operational costs strongly justifies the necessary initial expenditure.

In conclusion, the validation across diverse use cases, regions, and specialties confirms that 6G-enabled eHealth is not a niche capability but a foundational, broad-platform technology capable of supporting the entire breadth of healthcare delivery while maintaining the highest standards of safety, security, and clinical efficacy.

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ABBREVIATIONS

Abbreviation	Definition
3GPP	Third Generation Partnership Project (standards body)
5G	Fifth Generation wireless technology
6G	Sixth Generation wireless technology
6G-LEADER	Project on Extended Reality and Robotics for emergency response
6G-PATH	Project on personalized healthcare via 6G
AI	Artificial Intelligence
AMAZING-6G	Project on wearable cardiac monitoring and device management
AoA	Angle of Arrival (positioning)
API	Application Programming Interface
AR	Augmented Reality
ARVR	Augmented Reality / Virtual Reality
B5G	Beyond 5G technology
BS	Base Station
CCS	Call Control System
CDS	Clinical Decision Support
CHHA	Connected Home for Healthy Ageing
cm	Centimeters
CMUT	Capacitive Micromachined Ultrasonic Transducer
CNR	Consiglio Nazionale delle Ricerche
CO_2	Carbon Dioxide
CoA	Center of Activity
CPE	Customer Premises Equipment
CSI	Channel State Information
DASH	Data Access and Security Hub
DCA	Drone Care Angel
DGA	Drone Guard Angel
DL	Deep Learning
Docker	Containerization platform

EC	European Commission
ECG	Electrocardiogram
EGM	Electrogram
EHDS	European Health Data Space (regulation)
eHealth	Electronic Health / Digital Health
EHR	Electronic Health Record
EMA	European Medicines Agency
ETSI	European Telecommunications Standards Institute
EU	European Union
FHIR	Fast Healthcare Interoperability Resources
FiWi	Fiber-Wireless integration
FR1	Frequency Range 1 (sub-6 GHz, used in 5G/6G)
FR2	Frequency Range 2 (mmWave, used in 5G/6G)
FR3	Frequency Range 3 (7-24 GHz, potentially used in 6G)
Gbps	Gigabits per second
GDPR	General Data Protection Regulation
GNSS	Global Navigation Satellite System
GPU	Graphics Processing Unit
HIPAA	Health Insurance Portability and Accountability Act
HL7	Health Level 7
HMD	Head-Mounted Display
ICD	Implantable Cardioverter-Defibrillator
ICU	Intensive Care Unit
IEC	International Electrotechnical Commission
IEEE	Institute of Electrical and Electronics Engineers
IMAGINE-B5G	Research project on B5G-enabled healthcare services
IoMT	Internet of Medical Things
iORCathLab	Interventional Operating Room / Catheterization Laboratory
IoT	Internet of Things
IPCEI	Important Project of Common European Interest

1. INTRODUCTION

This white paper addresses one of the most pressing challenges of contemporary European healthcare: the need to deliver equitable, high-quality, and sustainable care to an aging population across geographically dispersed regions, while managing rising costs and workforce shortages. Current healthcare systems rely on legacy infrastructure—fragmented across jurisdictions, constrained by limited bandwidth, and the need to support real-time clinical decision-making or continuous patient monitoring. The convergence of demographic change, technological advancement, and fiscal pressure creates both urgency and opportunity to rethink healthcare delivery.

The SNS Joint Undertaking (SNS JU), through its portfolio of European research projects funded under Horizon Europe and IPCEI initiatives, has mobilized a diverse ecosystem of industry, academic institutions, healthcare providers, and policy stakeholders to explore how 6G and advanced B5G networks can fundamentally reshape eHealth service architecture and delivery models.

1.1. DOCUMENT STRUCTURE

This white paper is organized as follows:

- Executive Summary: Captures the principal findings, validated technologies, and cross-cutting impacts.
- Introduction: Outlines the strategic context, current technology limitations, and societal motivations for 6G-enabled eHealth in Europe.
- Complete Use Case Collection: Presents fifteen diverse eHealth scenarios—from remote cardiac surgery proctoring to cognitive health monitoring, elderly care automation, and emergency response robotics—with detailed technical requirements, clinical benefits, and sustainability considerations.
- Challenges and Impacts: Synthesizes technical performance requirements (latency, reliability, throughput, coverage, AI capabilities), societal impacts (equity, accessibility, clinical outcomes), and cross-cutting dimensions (sustainability, affordability, user experience, regulatory compliance).
- Regulatory and Ethical Considerations: Addresses GDPR, EHDS compliance, ethical use of AI in clinical settings, and data governance frameworks.
- Conclusions and Future Outlook: Reflects on validated achievements, identifies remaining research gaps, and proposes pathways for scaled deployment beyond the 12-24 month horizon.

2. COMPLETE USE CASE COLLECTION

This section explores some use cases developed inside a group of SNS-JU project across call 1, 2 and 3. Table 1 reports project participating in the present white paper.

Table 1. Projects contributing in the white paper.

Project	**Website**
TrialsNet TRials Supported By Smart Networks Beyond 5G	https://trialsnet.eu/
Amazing-6G Amazing Large-Scale Trials and Pilots for Verticals in 6G	https://amazing6g.eu/
SUSTAIN 6G SUSTainability Advanced and Innovative Networking with 6G	https://sustain-6g.eu/
6G-Path 6G Pilots and Trials Through Europe	https://6gpath.eu/
MultiX Advancing 6G-RAN through multi-technology, multi-sensor fusion, multi-band and multi-static perception	https://multix-6g.eu/
6G Leader Building the Path to 6G Innovation	https://6g-leader.eu/
IMAGINE-B5G Advanced 5G Open Platform for Large Scale Trials and Pilots across Europe	https://imagineb5g.eu/

2.1. TRIALSNET - MASS CASUALTY INCIDENT (MCI) AND EMERGENCY RESCUE IN POPULATED AREAS

2.1.1. DESCRIPTION AND OBJECTIVES

Mass casualty incidents (MCIs) in densely populated environments—such as cultural events, sporting venues, transport hubs, and urban centers—pose severe challenges to emergency response systems. In such contexts, rapid situational awareness, efficient triage, and coordinated pre-hospital emergency care are critical to minimizing mortality and long-term health impacts. Traditional emergency response workflows rely heavily on manual assessment, fragmented information flows, and voice-based coordination, which can be insufficient under conditions of scale, time pressure, and infrastructure disruption.

This case presents a next-generation emergency healthcare solution that leverages beyond-5G (B5G) and future 6G connectivity, combined with AI-driven analytics, robotics, and wearable medical devices, to support large-scale emergency response in real time. The main objective is to enable continuous situational awareness, semi-automated triage, and data-driven coordination of rescue and medical operations during mass casualty incidents. By integrating heterogeneous data sources, including robotic perception, live video streams, location data, and physiological measurements, into a unified operational platform, the system aims to improve decision-making, optimize the allocation of emergency resources, and ultimately improve patient outcomes during large-scale emergencies.

2.1.2. TARGET HEALTHCARE SCENARIOS AND ENVIRONMENTS

The use case is designed for crowded and complex urban environments where the likelihood and impact of MCIs are high. Typical settings include stadiums, concert halls, cultural venues, transport interchanges, large public gathering areas, and dense city centers. These environments are characterized by high user density, dynamic mobility patterns, partial infrastructure damage, and the need for rapid deployment of temporary emergency services. Representative scenarios include earthquakes with building collapses, fires, explosions, structural failures, and other large-scale incidents requiring coordinated evacuation, victim search and rescue, and medical triage. In such situations, emergency responders must rapidly locate victims, assess injury severity, prioritize care, and coordinate transport to medical facilities, often under conditions of limited visibility, network congestion, and extreme time pressure. The use case has been evaluated in realistic operational environments typically hosting thousands of people, providing stress conditions suitable for assessing network performance, system scalability, and human–machine interaction under mission-critical emergency workloads.

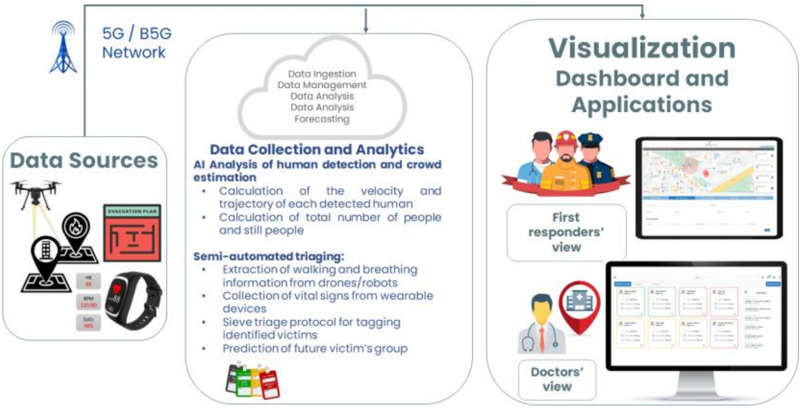

Figure 1: Mass Casualty Incident and Emergency Rescue in Populated Areas

2.1.3. EXPECTED BENEFITS AND IMPACT ON PATIENT CARE

This solution is expected to significantly improve the efficiency, speed, and reliability of emergency healthcare operations during mass casualty incidents. Continuous monitoring of casualties through wearable medical devices and AI-assisted triage reduces dependence on purely manual assessments and lowers the risk of human error in high-pressure environments.

Patient safety is enhanced through earlier detection of physiological deterioration, faster prioritization of critically injured patients, and more timely initiation of life-saving interventions. Semi-automated triage and continuous vital-sign monitoring support more accurate classification of injury severity and enable proactive medical decision-making before hospital admission.

From an operational perspective, enhanced situational awareness—supported by real-time video, victim localization, and health-status dashboards—enables emergency coordinators and first responders to make faster and better-informed decisions. This leads to improved coordination of rescue teams, more efficient allocation of ambulances and medical staff, and reduced response times.

Overall, the approach strengthens pre-hospital care by enabling earlier interventions, smoother handover to hospital services, and more effective management of large numbers of casualties in crowded urban environments.

2.1.4. TECHNICAL REQUIREMENTS AND DEPENDENCIES

Implementing this use case requires a highly reliable, low-latency, and high-throughput wireless communication infrastructure capable of supporting mission-critical public safety services. Key technical requirements include ultra-low end-to-end latency (below 100 ms at the application level) to support real-time triage, robotics control, and live video streaming, as well as high service availability and reliability suitable for emergency response operations.

The network must provide sufficient uplink and downlink throughput to sustain simultaneous high-definition video feeds from robots and drones, along with continuous vital-sign data from large numbers of wearable devices. Accurate and robust positioning capabilities are also required to enable reliable localization of victims, responders, robots, and drones in complex and partially obstructed urban environments, including indoor settings.

To meet these requirements, the use case depends on advanced B5G and early 6G capabilities, including edge computing for low-latency analytics, scalable cloud processing and robust connectivity mechanisms for operation under network congestion or partial infrastructure failure. Security and privacy mechanisms, such as encryption and secure authentication, are also essential to protect sensitive medical and situational data.

2.1.5. ENVIRONMENTAL, SOCIETAL, AND ECONOMICAL CONSIDERATIONS

From a societal perspective, this approach enhances public safety and trust by enabling more transparent, reliable, and effective emergency response in high-risk public spaces. Faster response times, improved triage accuracy, and better coordination directly contribute to improved survival rates and long-term health outcomes. First responders also benefit from reduced cognitive load, as AI systems support continuous monitoring and preliminary triage tasks.

From an economic perspective, more efficient use of emergency services and healthcare resources can lower the cost of large-scale incident management and reduce downstream hospital burden through improved pre-hospital care. Early detection of deterioration and better triage accuracy can also reduce avoidable hospital admissions, emergency room congestion, and associated healthcare costs.

2.1.6. IMPLEMENTATION

Trials were conducted in Athens (Technopolis area) and Madrid (Movistar Arena), to validate the feasibility and performance of the proposed emergency system under real-world conditions. The trial involved simulated mass casualty scenarios with multiple victims, first responders, robots, and wearable medical devices operating concurrently.

In these trials, a robot equipped with a camera provided real-time scene scanning and victim detection, while certified wearable medical devices attached to casualties continuously streamed vital signs such as ECG, heart rate, SpO_2, temperature, and blood pressure. Live video streams and physiological data were transmitted over a 5G/B5G network to an operational platform, where AI-based analytics supported human detection, movement analysis, respiratory rate estimation from ECG signals, and semi-automated triage classification.

Edge computing resources were used to enable low-latency analytics close to the incident scene, while cloud-based components supported large-scale data aggregation, visualization, and coordination for emergency command centers. The trial involved real-time dashboards for emergency coordinators and first responders showing victim locations, triage status, and health trends, enabling dynamic prioritization of rescue and medical resources.

The trial demonstrated that the system could meet key performance indicators for latency, throughput, reliability, and positioning accuracy under high-load conditions. User-centric value indicators—such as usability, trustworthiness, and operational acceptance, were rated highly by participating first responders. These results confirm the technical readiness and practical feasibility of B5G, and 6G-enabled emergency response systems for real-world mass casualty scenarios.

Figure 2: Elements of the Mass Casualty Incident and Emergency Rescue trial: robot equipped with a camera.

2.2. TRIALSNET - REMOTE PROCTORING

2.2.1. DESCRIPTION AND OBJECTIVES

The newly trained surgeons for interventional cardiology must undergo training in hospitals with demonstrated experience in the field. Usually, the newly trained interventionalists require the physical presence of an experienced proctor to safely observe the activity and ultimately act if any sort of complications occur when comes the time to perform the very first cases. This use case presents a solution for remote proctoring in interventional cardiology, utilizing advanced telepresence technologies and next-generation wireless connectivity. The main objective is to enable newly trained surgeons to receive expert supervision during early procedures without requiring the physical presence of experienced proctors. By replacing conventional wired networks with a wireless 5G setup, the system aims to demonstrate the effectiveness and safety of this telepresence support.

2.2.2. TARGET HEALTHCARE SCENARIOS AND ENVIRONMENTS

The use case is specifically designed for scenarios requiring real-time expert guidance for clinicians adopting new surgical techniques, benefitting from live supervision.

In this use case, the expert proctor is located at a central hospital hub site and the remote hospital site hosts, geographically separated, the surgical training room where newly trained interventionalists perform under the remote observation of the expert proctor. As illustrated in Figure 3, this use case aims to specifically deploy an indoor in-field cellular coverage network, based on a dedicated 5G network, for real-time remote proctoring applications. The remote proctor in the central hospital hub is equipped with a telepresence station to monitor and support the surgeons in the surgery training room in the remote hospital via the telepresence system. This enables the experienced proctors to supervise many surgical operations and, using wireless connectivity, instead of cable one, has the advantage of being location-independent and enables it to be a truly portable tool that expert proctors can use even outside of a specific hospital (Figure 3).

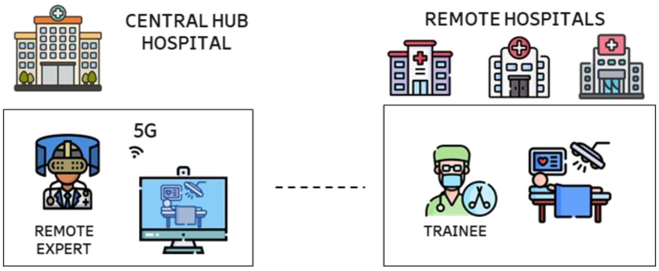

Figure 3: Remote proctoring use case concept.

2.2.3. EXPECTED BENEFITS AND IMPACT ON PATIENT CARE

This solution is expected to significantly enhance training accessibility by enabling clinicians to benefit from expert guidance without logistical delays or the need for onsite proctor presence. Patient safety is improved as experienced specialists can promptly intervene if complications arise, reducing risks associated with the learning curve in new surgical techniques. The approach also allows for optimal use of specialized personnel, as experienced proctors can provide support to multiple operations remotely, thereby increasing the reach and efficiency of expert knowledge. Additionally, because the system is wireless and portable, it has the potential for widespread deployment, making high-quality supervision possible in varied healthcare settings.

2.2.4. TECHNICAL REQUIREMENTS AND DEPENDENCIES

Implementing this use case requires a robust, reliable, high-bandwidth connection provided by a dedicated indoor cellular network based on 5G technology, ensuring the stable and high-quality transmission of video and data. Security is paramount, so measures such as virtual private networks are necessary to protect the confidentiality and integrity of patient information during remote sessions. The telepresence platform must offer seamless, real-time communication capabilities, allowing proctors to observe, communicate, and interact with surgical teams as though they are physically present. Both remote experts and onsite surgical teams need appropriately equipped workstations to facilitate effective telepresence interactions.

2.2.5. ENVIRONMENTAL, SOCIETAL, AND ECONOMICAL CONSIDERATIONS

This approach enhances sustainability by minimizing expert clinicians' travel, reducing carbon emissions, expanding access to quality surgical training in underserved areas, and lowering costs through improved efficiency—thereby supporting environmentally friendly, socially equitable, and economically effective healthcare.

2.2.6. IMPLEMENTATION

A live trial was conducted on July 7, 2025, employing the experimental TrialsNet beyond-5G network to connect two distant healthcare facilities in real time. In this trial, a cardiac surgeon performed a procedure while wearing Rods&Cones smart glasses, which streamed a real-time, first-person view of the operating field to the remote expert. The expert simultaneously monitored this feed along with streaming cardiac imaging modalities such as echocardiography and angiography, providing immediate guidance and clinical support throughout the surgery. The low latency and high reliability of the B5G connection ensured seamless visual and diagnostic data exchange, allowing continuous, clear, and robust remote supervision.

The main participants in this use case include expert clinical proctors (physicians) and the surgical teams at the remote hospital sites. A real patient has been involved. Methodologically, the remote proctoring trial integrated XR-based telepresence tools (Rods&Cones system) with the deployment of a dedicated private 5G network at the proctor site. The trial rigorously assessed the impact of latency on application performance and evaluated the psychophysiological state and task performance of clinical users. The telepresence system allowed real-time bidirectional audiovisual communication and interactive surgical guidance Figure 4 shows the on-field surgeon wearing the Rods&Cones system's smart glasses in which he receives directions from the Remote Proctor (left) and Experienced surgeon acting as Remote Proctor at CNR Campus in Pisa (right).

Figure 4: The on-field surgeon (left) and Experienced (right)

The infrastructure comprised an end-to-end smart telepresence platform supported by a dedicated TrialsNet B5G wireless network, offering stable, high-throughput connection with ultra-low latency. The proctor’s site featured customized 5G indoor coverage, while the remote surgical site was equipped with wearable smart glasses streaming live video to the proctor station. Advanced network slicing and VPN technology guaranteed secure, reliable communication.

2.3. TRIALSNET – SMART AMBULANCE

2.3.1. DESCRIPTION AND OBJECTIVES

The Smart Ambulance use case investigates how 5G network connectivity can enhance emergency medical services by enabling real-time remote collaboration and advanced diagnostics during patient transport. The primary objective of is to implement an outdoor 5G mobile infrastructure that allows ambulances to transmit high-resolution diagnostic data and receive timely decision support from hospital-based specialists while en route. To achieve this, the system integrates state-of-the-art audio/video communication alongside augmented and virtual reality (AR/VR) technologies, including head-mounted displays that support hands-free interaction. This setup enables paramedics to collaborate seamlessly with remote experts, receive guided instructions, and maintain continuous situational awareness during critical interventions.

2.3.2. TARGET HEALTHCARE SCENARIOS AND ENVIRONMENTS

The Smart Ambulance use case is designed for time-critical pre-hospital care where clinical outcomes depend on rapid assessment, early intervention, and coordinated decision-making before hospital arrival. It is particularly relevant for emergencies such as suspected acute cardiac events, stroke-like symptoms, major trauma, or severe respiratory compromise, situations in which early specialist input and access to diagnostic-grade data can influence triage, treatment priorities, and the choice of the most appropriate destination facility (Figure 5).

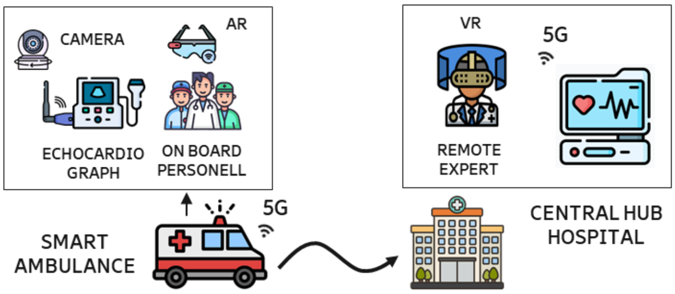

Figure 5: Smart ambulance use case concept.

2.3.3. EXPECTED BENEFITS AND IMPACT ON PATIENT CARE

The smart ambulance use case is expected to improve patient care by shifting critical clinical support earlier in the pathway, effectively extending hospital expertise into the ambulance during transport. Earlier specialist engagement can also strengthen triage and destination planning, helping patients reach the right facility the first time and reducing the likelihood of secondary transfers. Early pre-notification and richer clinical context can help hospitals prepare teams and resources before arrival, potentially reducing delays at handover and improving continuity of care.

2.3.4. TECHNICAL REQUIREMENTS AND DEPENDENCIES

The smart ambulance use case requires an end-to-end solution capable of sustaining reliable, low-latency communication and robust uplink capacity while the ambulance is in motion, since it must support simultaneous audio/video interaction, continuous streaming of diagnostic data, and AR/VR-assisted guidance. Service continuity across coverage changes and handovers is essential, along with mechanisms to prioritize clinical traffic so that critical diagnostic images and interactive communication remain stable even when conditions degrade. The platform must also integrate heterogeneous onboard sources, medical devices and cameras. into a coherent, time-synchronized stream for remote telepresence. A core element is support of the use case is the ER Innovative Orchestrator, which enables service differentiation by dynamically coordinating network resources based on service priority. For the smart ambulance use case, it applies QoS policies, allocates bandwidth efficiently, and enforces SLAs across mission-critical, business-critical, and non-critical traffic to protect essential clinical flows under constrained conditions, an approach that also supports network monetization through premium, assured-performance services.

This differentiation is enabled by 5G SA network slicing, which can guarantee not only throughput but also latency and location-specific performance. In TrialsNet, the orchestrator can bind services to slices in a defined geographical area and manage them end-to-end, spanning both the radio and transport domains, so that radio-level performance is preserved without over-provisioning. To meet QoS targets while optimizing resources, an Admission Control (AC) function checks per-service traffic against agreed KPIs and can limit traffic when violations occur, while the orchestrator can re-route flows to mitigate congestion and maintain continuity.

2.3.5. ENVIRONMENTAL, SOCIETAL, AND ECONOMICAL CONSIDERATIONS

Overall, the smart ambulance use case demonstrates the potential of 5G low-latency, high-bandwidth connectivity to transform ambulances into intelligent, connected nodes within the healthcare system, improving coordination, accelerating clinical decision-making, and strengthening continuity of care from the field to the hospital.

2.3.6. IMPLEMENTATION

On June 2025, a live trial of the Smart Ambulance use case was conducted at the CNR Campus in Pisa. The trial simulated a time-critical medical emergency, such as an acute myocardial infarction occurring in a remote area, requiring rapid diagnosis and intervention during patient transport. The smart ambulance was equipped with a 5G SA connectivity, advanced cardiological diagnostic instrumentation, and immersive AR/VR technologies to enable real-time collaboration between the onboard emergency team and a remote clinical specialist based in Massa. During the transport phase, the specialist continuously monitored live echocardiographic data and provided step-by-step guidance to the paramedic via an AR headset. The trial successfully demonstrated how 5G-enabled telemedicine can enhance clinical decision-making, improve situational awareness, and reduce response times in critical care scenarios.

Figure 6: Paramedics in ambulance with AR glasses and portable ultrasound scanner (left) and Remote expert in hospital with VR glasses (right)

TrialsNet partners involved in the smart ambulance trial were Ericsson (coordinator), CNR-IFC, Scuola Superiore Sant'Anna, TIM, and Fondazione Gabriele Monasterio.

This trial was made possible through the essential collaboration of Pubblica Assistenza di Pisa, which provided both an ambulance and operational staff for the full duration of the simulation. Their contribution enabled the proposed solutions to be tested and validated in a realistic, real-world operational context.

2.4. TRIALSNET - ADAPTIVE CONTROL OF HANNES PROSTHETIC DEVICE

The use case entitled "*Adaptive Control of the Hannes Prosthetic Device*" aimed at enhancing upper-limb prosthetic functionality through sensor-driven shared autonomy, artificial intelligence (AI), and advanced communication technologies. This activity focuses on the development and experimental validation of an adaptive prosthetic control framework in which user intention and environmental perception are synergistically integrated to reduce cognitive and physical burden during grasping and manipulation tasks. The Hannes prosthetic hand is equipped with multimodal sensing, including vision and electromyography (EMG), while exploiting off-board AI computation enabled by high-performance 5G wireless connectivity. The system leverages distributed intelligence, where computationally intensive perception and decision-making algorithms are offloaded to a remote server, allowing the prosthetic device to remain lightweight, energy-efficient, and responsive. This paradigm enables the implementation of advanced computer vision and learning-based control strategies that would otherwise be impractical on embedded hardware alone. An overview of the system architecture and experimental setup is illustrated in Figure 7, showing the Hannes prosthesis embedding the camera in the palm.

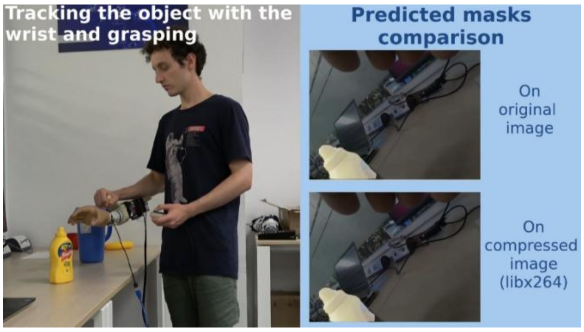

Figure 7: Application setup (left) and predicted masks output on compressed and original images (right).

2.4.1. DESCRIPTION AND OBJECTIVES

The primary objective of this use case is to improve the integration of wearable upper-limb prostheses with sensor-driven autonomous behaviors to reduce the reliance on explicit user control over multiple degrees of freedom (DoFs), particularly during grasping actions. Conventional myoelectric prosthetic devices require the user to sequentially and cognitively manage wrist orientation, hand opening, and finger closure, which can lead to increased mental workload and suboptimal usability. The proposed system aims to alleviate this burden by embedding shared autonomy mechanisms that assist the user during critical phases of the grasping process. The Hannes prosthesis is augmented with a camera embedded in the palm and EMG sensors placed on the user's contralateral forearm. These heterogeneous sensory inputs are processed through AI-based methods to infer grasp intention and environmental context, enabling automatic adaptive wrist configuration aligned with the target object. A key scientific objective is the real-time interpretation of the user's grasping intention by exploiting multimodal sensory fusion and learning-based perception, while ensuring that the final execution remains under voluntary user control. In this respect, the system implements a shared autonomy paradigm in which transport and orientation phases are delegated to the AI controller, whereas the final grasping action is initiated and regulated by the user through EMG signals.

2.4.2. TARGET HEALTHCARE SCENARIOS AND ENVIRONMENTS

This use case is designed to operate across a wide range of healthcare and daily-life scenarios involving individuals with limb differences. Its primary target environment is outpatient rehabilitation and assisted daily living, where users are expected to interact with common objects. Beyond structured laboratory conditions, this application explicitly aims to pave the way toward deployment in unstructured real-world environments, where the objects encountered by the user are not known a priori and are not necessarily included in the training datasets of the AI models. The ability to recognize and interact with novel objects represents a key objective of the proposed adaptive control framework and constitutes a necessary step toward truly autonomous and context-aware prosthetic behavior in everyday life, rather than operation limited to predefined object sets. In controlled laboratory environments, the system can be implemented using relatively bulky setups, where AI models may be deployed locally on dedicated computing platforms without relying on wireless communication. Such configurations are appropriate for development, and validation phases, where physical constraints are less critical. However, these solutions are intrinsically unsuitable for real-world prosthetic use, which requires compactness, wearability, and user comfort. In daily-life scenarios, users are expected to operate the prosthesis in dynamic and unconstrained contexts, potentially anywhere and at any time. This necessitates a lightweight and portable setup in which the computational burden on the prosthetic device is minimized to preserve ergonomics and battery life. In this context, offloading AI models to remote computing resources becomes particularly beneficial, as it enables the execution of advanced perception and control algorithms without increasing the physical and energetic footprint of the prosthesis itself. In this regard, the experimental protocol of this use case involved able-bodied participants using the prosthesis through an adapter to perform object grasping tasks under two conditions: wireless connectivity and fully wired connectivity reported in Figure 8. A robust wireless communication pipeline is therefore not merely a technical convenience but a fundamental enabler for translating laboratory-grade AI capabilities into practical assistive technologies.

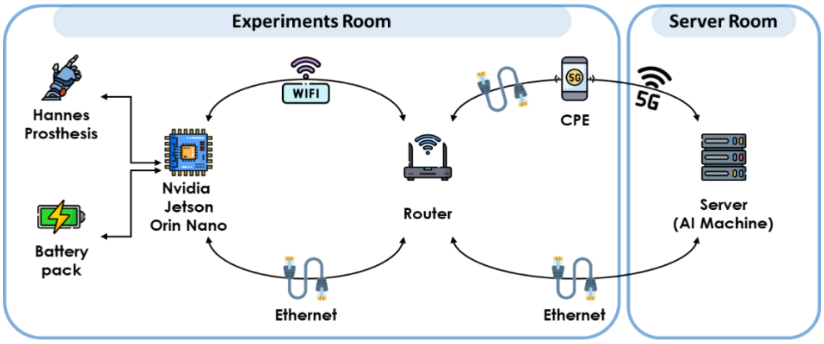

Figure 8: Scheme of Hannes prosthesis connectivity to the server.

2.4.3. EXPECTED BENEFITS AND IMPACT ON PATIENT CARE

This use case is expected to yield significant benefits in terms of usability, functional performance, and patient quality of life. By reducing the need for explicit multi-DoF control, the system aims to lower the cognitive workload associated with prosthetic use, thereby promoting more natural and intuitive interaction. One of the primary impacts lies in improved grasp reliability and task success. Experimental trials demonstrated high grasping success rates across different connectivity conditions, indicating that AI-assisted wrist control does not compromise operational robustness. From a human factors perspective, user experience evaluations using standardized tools such as the NASA Task Load Index (NASA-TLX) and the System Usability Scale (SUS) revealed that users perceived the system as highly usable, with workload levels comparable to conventional wired solutions and overall usability scores in the “excellent” range. In patient care, such improvements translate into increased autonomy, reduced frustration during prosthetic use, and potentially higher long-term prosthesis acceptance rates. By facilitating more fluid and reliable interaction with the environment, the system supports a more active and independent lifestyle, which is a critical determinant of psychosocial well-being in individuals using upper-limb prostheses.

2.4.4. TECHNICAL REQUIREMENTS AND DEPENDENCIES

The technical realization of this use case relies on a tightly coupled interaction between sensing, communication, and computation layers. The prosthetic system integrates an RGB camera embedded in the palm producing images at 640×480 resolution and 30 frames per second, and EMG sensors placed on antagonist muscle groups for voluntary control. These components are managed by an embedded computing platform based on the NVIDIA Jetson Orin Nano, selected for its superior computational capabilities compared to previous solutions and its ability to handle real-time image compression and communication. Given the raw data rate of approximately 220 Mbit/s for uncompressed video, efficient image compression is mandatory. A comparative analysis of several codecs demonstrated that MPEG-2 provides the most favorable trade-off between bandwidth usage, latency, and preservation of segmentation accuracy. Maintaining application-level latency below 10 ms is a fundamental requirement for ensuring imperceptible delay in prosthetic actuation, and experimental evaluations confirmed that this constraint can be satisfied under optimized configurations, with measured latencies around 7 ms. The AI algorithm implements a vision-based shared autonomy strategy inspired by human reach-to-grasp behavior, which is typically decomposed into transport, rotation, and grasping phases. The adopted approach automates the first two phases through visual servoing and object-part segmentation, while leaving the final grasp execution to user control via EMG. The system therefore depends critically on reliable object segmentation under compressed video input, real-time bidirectional communication between prosthesis and remote AI, and stable synchronization between perception and actuation. Any degradation in these dependencies, such as packet loss or excessive jitter, directly affect control stability and safety, highlighting the need for robust network-level quality of service mechanisms.

2.4.5. ENVIRONMENTAL, SOCIETAL, AND ECONOMICAL CONSIDERATIONS

From an environmental perspective, the use case promotes energy-efficient design by offloading computationally intensive tasks to remote servers, thereby reducing onboard power consumption and extending battery life. This approach supports longer daily usage without increasing device weight or size, which is essential for sustainable and user-friendly prosthetic solutions. Societally, the system contributes to the broader goal of inclusive technology by enabling individuals with limb differences to interact more naturally with their environment. Enhanced prosthetic usability fosters social participation, professional reintegration, and independence, which are key factors in reducing long-term social and healthcare costs associated with disability. Economically, while the integration of AI and advanced connectivity introduces initial infrastructural costs, these may be offset by long-term benefits such as reduced need for clinical supervision, fewer device adjustments, and lower abandonment rates. Furthermore, scalable deployment of such systems can stimulate innovation within the prosthetics and digital health sectors, fostering new business models based on remote services, personalization, and data-driven optimization.

2.4.6. IMPLEMENTATION

The implementation of the use case followed a multi-stage process encompassing hardware integration, algorithm development, pre-trial validation, and experimental trials with human participants. The final system (Figure 9.1) integrates the Hannes prosthesis with the Jetson Orin Nano board, running a Linux operating system and managing Bluetooth communication with the prosthetic hand as well as wireless or wired connectivity with the remote AI server. A schematic of the connectivity configurations (wireless and wired) adopted during experimental validation is shown in Figure 8. Pre-trial activities focused on validating the communication pipeline and image compression strategies. Network performance was assessed ensuring compliance with stringent latency and throughput requirements. The experimental setup and the grasped objects used for the trials are depicted in Figure 9.2. Each participant completed multiple repetitions across a set of standardized objects, with task success defined by stable lifting and holding of the object. Key performance indicators included uplink throughput, application latency, grasp success rate, and subjective workload and usability scores. The results demonstrated that the wireless configuration achieves performance comparable to the wired baseline, confirming the feasibility of AI-assisted prosthetic control over advanced wireless networks.

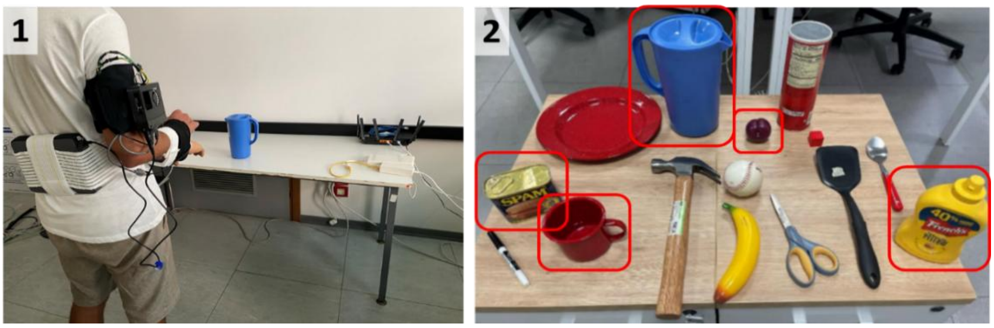

Figure 9: Application setup for trials: (1) experimental setup worn by the participant; (2) selection of five objects used for grasping tasks.

2.5. AMAZING-6G - WEARABLE ULTRASOUND PATCH FOR CARDIAC FUNCTION MONITORING

2.5.1. DESCRIPTION AND OBJECTIVES

Echocardiography (i.e., cardiac ultrasound imaging) is an indispensable tool for diagnosis, intervention and follow-up of heart (and other) patients. In medical emergencies, and especially during hospitalization and intensive care treatment for life-threatening heart (and other) diseases, heart function is always a question and hard to assess without echocardiography. In traumatology, (close to) real-time monitoring of heart function is needed in the field, during a short time frame, for patients with hypovolemic shock, in order to assess volume replacement and other critical parameters. Furthermore, after undergoing repair surgery or implantation of structural heart devices (e.g., prosthetic heart valves) patients need frequent follow ups after discharge to assess their cardiac function.

However, echocardiography is a highly specialized task which needs to be performed by a cardiologist. Therefore, it can only be performed intermittently and only while the patient is present in the hospital. Furthermore, the frequency of such assessments will be limited by the availability of cardiologists (i.e., staff shortage), as well as by financial constraints (i.e., cost of care). In other words, echocardiography can never be performed for extended periods of time (i.e., continuous monitoring) and often not exactly when and where indicated.

New adhesive-patch-based, ultrasound devices, leveraging Capacitive Micromachined Ultrasonic Transducer (CMUT) and similar transducer technologies, are appearing on the market, enabling totally new ways of exploiting cardiac functional imaging[1]. These patches, which are semi-permanently attached to the patient’s body, promise to enable more frequent and even continuous assessments and monitoring for longer periods of time. This

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[1] Hu, H., Huang, H., Li, M. et al. A wearable cardiac ultrasound imager. Nature 613, 667–675 (2023). https://doi.org/10.1038/s41586-022-05498-z

way critical time points before, during, and after hospital interventions (e.g., surgery) can be covered. Furthermore, patients can be monitored during advanced treatments for heart failure, such as intensive care therapy or while being moved in the ambulance. Finally, patients can be monitored at home, at work, on-the-move, or even during exercise.

Patch-based, cardiac ultrasound assessment can be automated by deploying AI-based, ultrasound image analysis algorithms on the edge. These algorithms will extract cardiac function parameters, such as ejection fraction. Also, hemodynamic (e.g., blood pressure) and Electro-Cardiogram (ECG) data can be integrated into analyses for addressing different clinical situations.

2.5.2. TARGET HEALTHCARE SCENARIOS AND ENVIRONMENTS

Figure 10 depicts the cardiac assessment solution comprising a 6G-enabled, ultrasound patch (ECG and blood pressure sensing are optional) on the left-hand side and the 6G RAN and Core hosting AI-based image analysis on the edge on the right-hand side. The AI-based assessments are communicated to the cardiologist via the Clinical backend which is connected to the 6G-System via a Data Network such as the Internet (Figure 10).

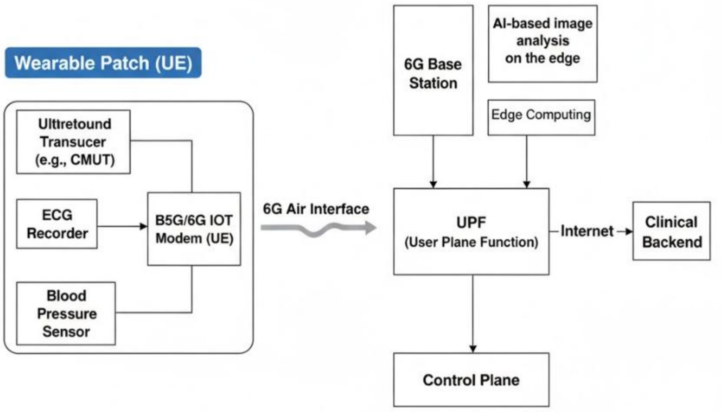

Figure 10: Wearable ultrasound patch for cardiac function monitoring use case concept.

Two clinical scenarios are of particular interest: (1) daily recording of short cardiac ultrasound clips (~ 1 minute) for monitoring at home or on the move, in particular during exercise and (2) continuous, real-time recording just before (ambulance), during (iOR/CathLab), and directly after intervention (ICU). While the former scenario requires a battery-powered device, for the latter scenario tethered power will be available.

2.5.3. EXPECTED BENEFITS AND IMPACT ON PATIENT CARE

This solution proves to be a powerful new tool for early detection of critical changes in cardiac function and complications to treatment, such as cardiac effusions, cardiac tamponades, and pulmonary hypertensive crises. Similarly, the effects of drug treatment can be monitored more closely by continuous registration of cardiac ultrasound data in the hospital and by providing daily short registration updates when discharged to home or lower-level care settings. The latter also enables early discharge from the hospital. In short, cardiac ultrasound patches combined with edge-based AI analysis will improve patient outcomes and lower the cost of care, while improving patient and caregiver experience i.e., they will serve the quadruple aim in healthcare[2].

2.5.4. TECHNICAL REQUIREMENTS AND DEPENDENCIES

This clinical scenario (i.e., battery-powered device) requires high-bandwidth (< 100 Mbps) upload, with minimal energy consumption, also under indoor coverage situations. Current 5G Advanced technologies, such as NR-RedCap, are very unlikely to be sufficient, which is why this clinical scenario and the associated KPIs have been submitted to 3GPP SA1 as input to the 6G requirements. This contribution has been agreed upon at its Dallas meeting in November 2025 and will find its way into the technical report the second clinical scenario (i.e., tethered device) requires high bandwidth (< 100 Mbps), high availability (99.9999%), while the total round-trip time (i.e., including AI-analysis on the edge) should be less than half a second. For in-hospital scenarios, a Non Public Network (NPN) may be assumed but during transport in the ambulance also a Public Land Mobile Network (PLMN) will be in the loop.

2.5.5. ENVIRONMENTAL, SOCIETAL, AND ECONOMICAL CONSIDERATIONS

This approach enhances sustainability by reducing travel for patients and healthcare professionals, especially in underserved areas, as continuous heart monitoring does not require physical presence. Furthermore, early warning and diagnosis leads to improved patient outcomes and reduced cost of care (e.g., shorter and fewer hospital stays).

2.6. AMAZING-6G – PREDICTIVE REMOTE REPROGRAMMING OF IMPLANTABLE CARDIAC DEVICES

2.6.1. DESCRIPTION AND OBJECTIVES

On-body and implantable devices are fundamental in the management of cardiac conduction and rhythm disorders. Permanent pacemakers (PMs) are designed to maintain adequate heart rates in patients with bradyarrhythmia, while implantable cardioverter-defibrillators (ICDs) are intended to terminate life-threatening ventricular tachycardia. These systems deliver low-energy electrical pulses to stimulate myocardial depolarization, or combine pacing with high-energy shock therapy to terminate cardiac arrest, thereby ensuring both acute protection and long-term prevention of sudden cardiac death.

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[2] https://www.philips.com/a-w/about/news/archive/blogs/innovation-matters/20190402-five-ways-in-which-healthcare-innovation-has-changed-over-the-past-15-years.html

Reprogramming of PM/ICD is essential to ensure that device performance remains aligned with the patient’s evolving clinical needs. While these devices are initially configured according to the patient’s condition, physiological changes, disease progression, and lifestyle factors often necessitate subsequent adjustments. Current technologies largely lack real-time, predictive reprogramming capabilities, which would enable timely modification of detection or therapy algorithms before adverse outcomes occur. Such predictive adaptability has the potential to reduce inappropriate shocks, extend battery life, and enhance patient safety, comfort, and therapeutic efficacy, especially during transitions in human activity. Event-aware, real-time predictive reprogramming of PM/ICD is proposed to adapt device performance to a patient's daily activities in a closed-loop, remote, and automated setup. This requires continuous communication between the implanted device and the edge, currently a power-hungry limitation. To mitigate communication constraints, a wearable patch is proposed as a gateway between the PM/ICD and mobile networks. For the event-aware reprogramming, an AI-based algorithm is deployed at the edge, enabling semantic pacing and sensing adjustment of the device, leveraging greater computational resources compared to the more limited capabilities of the patch device. The edge infrastructure also supports sensor fusion from devices like accelerometers to recognize patient activity context.

2.6.2. TARGET HEALTHCARE SCENARIOS AND ENVIRONMENTS

Figure 11 depicts the cardiac assessment solution comprising a 6G-enabled patch on the left-hand side and the 6G RAN and Core hosting AI-based signal analysis on the edge on the right-hand side. The patch obtains electrogram (EGM) data from the PM/ICD via RFID and subsequently transmits it via NR-RedCap to the edge. The edge may send back reprogramming instructions via the same path. All of this has the occur – literally – within a heartbeat. The use of RFID (backscatter) communication allows all reading and writing from/to the PM/ICD to be powered by the patch, rather than by the battery of the pacemaker, safeguarding its lifetime. The AI-based assessments are communicated to the cardiologist via the Clinical backend which is connected to the 6G-System via a Data Network such as the Internet.

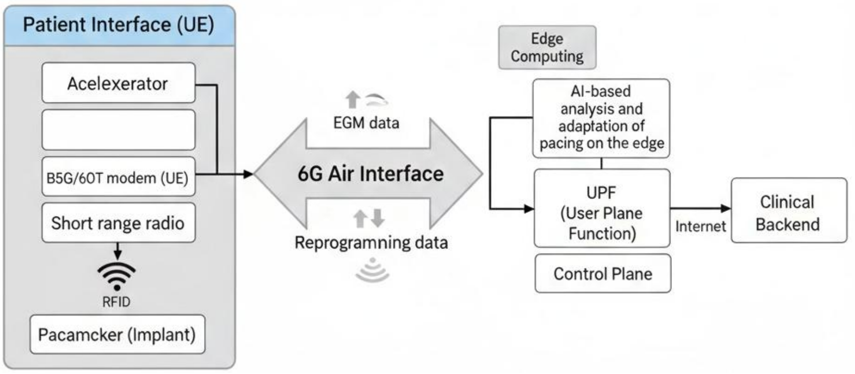

Figure 11: Predictive remote reprogramming of implantable cardiac devices use case concept.

2.6.3. EXPECTED BENEFITS AND IMPACT ON PATIENT CARE

At the patient level, this solution enhances safety and therapeutic efficacy by reducing inappropriate shocks and improving arrhythmia management through context-aware pacing and shock delivery. It also enables personalized therapy, with device parameters that adapt dynamically to daily activities such as rest, walking, or exercise, thereby minimizing over- or under-treatment. From a quality-of-life perspective, patients benefit from fewer adverse events, reduced hospitalizations, and more comfortable device management with less need for manual reprogramming. At the clinical level, continuous access to EGM and sensor fusion data supports informed decision-making and therapy optimization.

2.6.4. TECHNICAL REQUIREMENTS AND DEPENDENCIES

On the communication side, latency below one heartbeat period and significant reductions in implant communication energy consumption are critical KPIs, along with sufficient throughput for continuous EGM streaming. Patch performance is measured by battery life (e.g., >7 days continuous use per charge), and small form factor/light weight (<50 g) for wearability. Algorithmic KPIs include high prediction accuracy (>95%) for arrhythmias and recognition accuracy (>90%) for activity. Clinical performance is assessed using metrics such as the percentage reduction in inappropriate shocks and the rate of false pacing events (false positives or false negatives), which should remain below 5%.

2.6.5. ENVIRONMENTAL, SOCIETAL, AND ECONOMICAL CONSIDERATIONS

The proposed system offers sustainability benefits by extending device longevity, reducing the need for hospital visits for reprogramming, and thereby lowering both travel-related environmental impact and healthcare costs. It also contributes to improved patient outcomes, enhanced patient experience, and greater access to care from a social perspective.

2.7. SUSTAIN-6G: REMOTE REHABILITATION ASSESSMENT

2.7.1. DESCRIPTION AND OBJECTIVES

This use case addresses the remote rehabilitation of patients through a Mixed Reality (MR)/Augmented Reality (AR) application combined with real-time AI-based analysis. The aim is to enable at-home physiotherapy sessions under clinical supervision without requiring the patient to travel to a medical facility. Rehabilitation frequently necessitates patients returning to hospitals or clinics to perform therapeutic exercises under physician supervision. This entails physical, psychological, and economic costs, particularly for people with limited mobility or who live in underserved or rural areas.

The patient wears AR glasses or head-mounted displays (HMDs) that run a rehabilitation application guiding them through motor exercises. A camera (e.g., webcam or smartphone) captures the user's movements. The video stream is transmitted in real-time to an AI system hosted on edge or cloud servers. The AI performs inference tasks to evaluate whether the patient is performing the movements correctly and provides real-time feedback to the AR application. The rehabilitation experience can then proceed, pause, or be adapted depending on the correctness of execution. If deviations are detected, the system can either recommend corrective actions directly or notify a remote physician, who can observe the session live, review the AI insights, and provide targeted feedback.

The primary objectives are:

- To provide a unique framework for home-based rehabilitation adhering to principles of personalized medicine.
- To optimize treatment outcomes while reducing adverse effects.
- To enable immersive, intuitive, and adaptive rehabilitation therapies supported by AR and AI.
- To facilitate continuous clinical monitoring, remote adaptation of therapy programs, and automated reporting.

2.7.2. TARGET HEALTHCARE SCENARIOS AND ENVIRONMENTS

This case study focuses on upper limb rehabilitation, especially for patients suffering from phantom limb pain, a condition in which sensations persist in a limb after amputation. The system builds on the principles of mirror therapy but introduces an advanced alternative using AR and deep learning (DL) to deliver personalized digital therapies remotely. A virtual prosthesis is superimposed on the amputated limb, offering patients a first-person view simulating natural limb presence and movement. Movements of the healthy limb are tracked and mirrored in real-time onto the virtual counterpart.

Other potential target scenarios include post-surgery physiotherapy, neurological rehabilitation, and chronic pain management. These therapies are particularly beneficial for patients who are elderly, live in rural or underserved areas, or face mobility challenges that make frequent hospital visits difficult.

The environments for deployment include:

- Patient’s home equipped with AR glasses/HMDs and a webcam or smartphone camera.
- Edge/cloud servers hosting AI inference engines for analysing patient movements in real-time.
- Clinical interfaces accessible to physicians through PCs or tablets, enabling live or asynchronous supervision.

2.7.3. EXPECTED BENEFITS AND IMPACT ON PATIENT CARE

The system improves accessibility by allowing patients to carry out rehabilitation exercises at home, eliminating the need to travel. This is especially critical for those with mobility impairments.

The integration of gamified AR experiences improves patient motivation and adherence to rehabilitation protocols, a well-documented challenge in traditional therapies.

Continuous AI monitoring ensures that exercises are performed correctly, minimizing risks of injury and enhancing the likelihood of recovery.

From the clinician's perspective, automation reduces workload, allowing healthcare professionals to prioritize critical cases. Real-time and asynchronous data access enables more flexible scheduling and long-term tracking of patient progress. Furthermore, the system supports the collection of novel data about patient performance, which can be used to retrain and improve AI models, thereby continuously enhancing therapy quality.

2.7.4. TECHNICAL REQUIREMENTS AND DEPENDENCIES

The successful deployment of remote rehabilitation assessment requires robust technical infrastructure. Key requirements include:

- Network performance: Uplink throughput between 20–100 Mbps is necessary, depending on video resolution and frame rate. Latency must be kept between 1–10 ms to ensure real-time responsiveness.
- Bidirectional feedback mechanisms must be supported to allow AI engines to dynamically control AR applications.
- Devices: AR/MR glasses or HMDs, webcams or smartphones, and potentially laptops/PCs to manage peripherals and data routing.
- Infrastructure: AI inference engines hosted on edge/cloud servers with ultra-low latency connectivity.

The computational effort should be offloaded to servers, allowing the application to run on any patient's hardware.

2.7.5. ENVIRONMENTAL, SOCIETAL, AND ECONOMICAL CONSIDERATIONS

Environmental sustainability is promoted by reducing the need for patient travel, thereby avoiding mobility-related energy waste and lowering emissions. However, energy consumption at the network and server level, as well as electronic waste from device turnover (AR headsets, GPUs, controllers), must be considered.

Societal sustainability is strengthened by extending decentralized, high-quality care to patient homes. The immersive AR experience improves patient engagement, inclusiveness, and long-term adherence. At the same time, concerns about data security and privacy must be addressed to maintain public trust.

Economic sustainability derives from increased operational efficiency, reduced clinician workload, and deployment of scalable eHealth services. By reducing logistical costs, hospital visits, and insurance expenses, the system introduces savings across the healthcare chain while enabling new telemedicine business opportunities.

2.8. MULTIX — CONTACT-FREE HUMAN LOCALIZATION AND RESPIRATION DETECTION

2.8.1. DEFINITION OF THE USE CASE

This use case addresses non-invasive health monitoring in indoor residential environments using Integrated Sensing and Communication (ISAC) capabilities within advanced wireless networks (e.g., 5G-Advanced or 6G). It aims to enhance personal safety and well-being—particularly for elderly individuals or patients with chronic or mobility-limiting conditions—through contact-free detection of respiration and user localization without the need for wearable devices.

The monitored environment is equipped with multiple distributed antennas (N antennas), forming a dense sensing topology. These antennas establish several radio frequency (RF) links (M links), resulting in either a fully digital or hybrid sensing architecture depending on the N-to-M ratio. Human users are typically at rest or asleep, with their phone (User Equipment, UE) remaining static during the monitoring session. Monitoring may be performed either:

- Occasional, when requested (e.g., before sleep);
- Periodic, based on pre-set intervals (e.g., overnight).

The collected sensing data is processed locally or at the edge through a perception engine to determine respiration patterns, motion status, and location. Anomalies such as irregular breathing or lack of motion can trigger real-time alerts to caregivers or emergency services.

The MULTIX project supports this use case by providing a multi-static testbed infrastructure, real-time AI-enabled perception systems, and secure data access architecture that enable proof-of-concept validation and contribute to standardization activities for ISAC-based eHealth solutions.

2.8.2. EXAMPLE SCENARIOS

This use case targets two representative scenarios of non-contact health monitoring in a home environment, enabled by distributed wireless sensing. As shown in Figure 12, two representative scenarios are presented. Scenario 1 considers a sited person with potential interferer in a living room or meeting room, while Scenario 2 focuses on a sleeping person in a bedroom. Scenario 1 will first conduct localization of multiple persons, then estimate the breathing of the user; Scenario 2 will constantly be monitoring the breathing. Both scenarios assume UEs (smartphones) are static.

Scenario 1: Breathing of sitting user with interference

- During daytime, the same individual spends time seated in a room chair. The system continuously monitors:
- Respiratory signals, especially shallow breathing or long periods of inactivity.
- Location information of multiple persons, especially for interferes (other people) in the environment.

The user does not interact with any device, however, for validation, markers of motion capture cameras may be installed on the chest to track the movements led by breathing. Multi-antenna signals are coordinated across distributed sensing nodes. Time-series trends in location and respiration are logged to support preventive care.

Scenario 2: Contact-Free Sleep Monitoring

A person is sleeping in their bedroom during the night. Distributed antennas installed in the room form multiple RF links, passively monitoring:

- Respiratory rate and irregular breathing patterns, using micro-Doppler shifts and signal reflections detected across multiple links.
- Sudden anomalies, such as cessation of breathing or unexpected motion (e.g., a fall from bed).

All sensing data is mainly Perception System (MPS), and alerts are generated via the DASH component if critical health events are detected. No wearable device is required, and the phone (UE) remains static on a nearby surface as depicted in Figure 12.

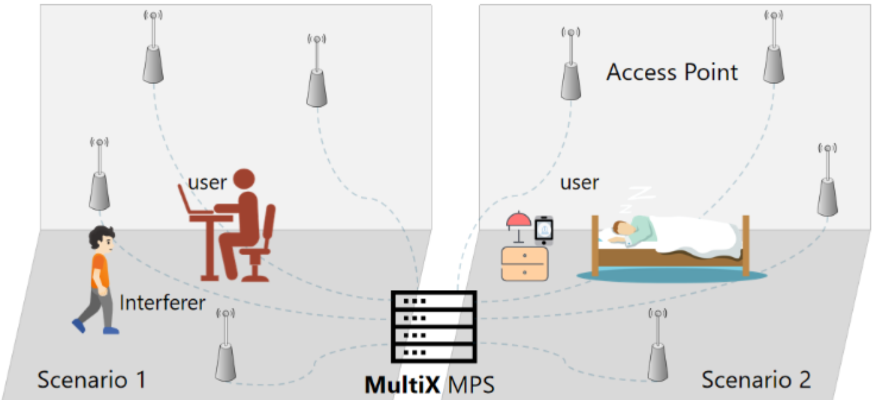

Figure 12: Use case illustration in two representative scenarios

- Sleep and sitting states involve extremely subtle motion, like chest displacement from breathing. Breathing and micromotion tracking depend on phase/frequency sensitivity and temporal coherence — even small estimation noise or pilot contamination can distort the inferred signal. The challenge lies in accurately isolating and detecting physiological micro-signals from cluttered, multi-reflection indoor channels.
- Over time, small changes in environment (e.g., phone position, blanket movement) may shift the propagation paths, affecting the CSI signature. This leads to calibration drift and false variation in breathing detection. Thus, the compensation is needed.

- While the UE transmits pilots, clock differences, propagation delays, or RF chain impairments can distort CSI phase and timing, which are essential for ToF/AoA-based localization or micromotion detection.
- MultiX involves multiple testbeds with differing RF frontends (e.g., massive MIMO, cell-free, USRP devices, commercial UEs). Integrating them into a coherent sensing setup with unified control and synchronization is non-trivial.
- From RF data capture to edge processing and remote monitoring, the testbed must maintain a reliable end-to-end pipeline under load — often with constrained compute and networking infrastructure.

2.9. MULTIX — SMART HOME VIRTUAL SECURITY

2.9.1. DEFINITION OF USE CASE

A smart home is a house environment where devices, appliances and systems are interconnected through communication networks to provide automation, security, entertainment, energy efficiency, and other enhanced user experiences. Smart homes use Internet of Things (IoT) sensors, wireless communication, AI-driven automation, and cloud-based services to enable seamless interaction between users and their surroundings. Smart home ecosystems typically utilize WiFi, Bluetooth, Zigbee, Z-Wave, and 3GPP communications to provide connectivity between devices such as smart switches, lighting systems, security cameras, motion sensors, door locks, voice assistants, and entertainment systems. The primary goal of a smart home is to improve convenience by automating routine tasks, optimizing energy consumption, and ensuring a safer living environment through real-time monitoring and control.

In this use case we concentrate on the security aspect of the smart home and in particular on the intruder detection ability, not only for the indoor part of the premises but also for the surrounding area of the house. By doing this, we exemplify how ISAC technology can create new business opportunities for telecom operators and other service providers allowing them to offer new services for the smart home sector.

The proposition is that a homeowner wishes to be informed of intruders wherever they may be, outside or inside their private property, that can be a person or a harmful animal, to ensure that residents at home feel comfortable and secure. Currently, this service is mainly achieved by utilizing IP/CCTV cameras, passive infrared sensors and microwave radars capable of monitoring and detecting objects and/or motion. However, these sensors require line-of-sight, their monitoring area capabilities are limited, and they can be easily accessed and damaged by malicious intruders. Wireless signals provided by 3GPP base stations (BS), Wi-Fi Customer Premises Equipment (CPE) and User Equipment (UE) with sensing capabilities make it possible to monitor wider areas without line-of-sight, with these devices being very hard or even impossible to be accessed and tampered with by the intruders. In addition, the fusion of the sensing data of 3GPP and non-3GPP wireless devices can improve accuracy and ubiquity of the intruder detection service.

For the purposes of this use case, we consider a homeowner, Bob, who has been a subscriber to a certain telecom provider, called TELE. TELE informs Bob about a new security service, called SENSE, which can secure Bob's house with a virtual security system that does not require him to install any equipment or sensors to his premises. The new security system is able to protect both the interior and the surrounding area of Bob's house, without the installation of any equipment, since it is based on the new sensing capabilities provided by the wireless network (3GPP BSs, WiFi CPEs and UEs), as shown in figure 1. With SENSE service Bob will receive tamper-proof sensing information from the outdoor base stations, covering the entire outdoor area with high accuracy and no blind spots. TELE will also upgrade the homeowner's Wi-Fi CPE and smartphone(s) with ones supporting sensing functionality, allowing them to receive high-accuracy sensing information also for the indoor of the house, again with high accuracy and no blind spots. In this way, Bob will be notified of both outdoor and indoor intruders knowing their exact location (Figure 13).

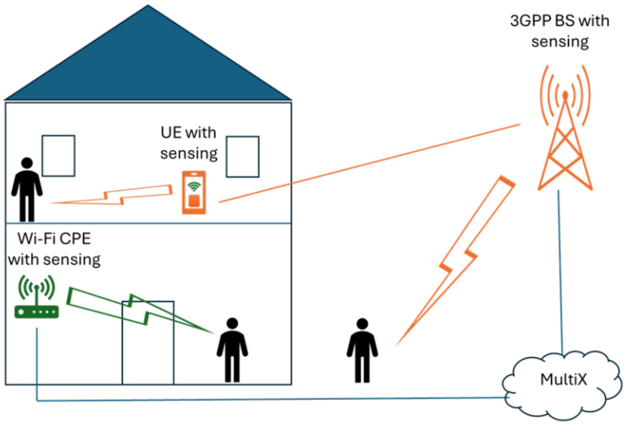

Figure 13: Smart home virtual security

2.9.2. EXAMPLE SCENARIOS

- Outdoor intruder detection can be achieved by using 3GPP BSs to detect intruders within a surveillance area in the external perimeter of a home. Using ISAC technology, one or more BSs could detect movement and environmental changes, alerting homeowners or security personnel. Of course, this scenario can be extended so it can provide also non-human intrusion detection in the surveillance area of the home including animals, vehicles, UAVs, etc.
- Indoor intruder detection can be achieved by using 3GPP UEs and WiFi Customer Premises Equipment (CPE) with sensing ability to detect intruders within a home. Using ISAC technology, multiple small cells could detect movement and environmental changes, alerting homeowners or security personnel. This capability, similar to advanced home security systems, opens up new monetization opportunities for telco operators to offer security-focused services.

2.9.3. TECHNICAL CHALLENGES AND SOLUTIONS

Today smart home solutions in general face several technical challenges due to the variety of sensors and their communication technologies that are utilised within the home environment. Current smart home solutions utilise a mixture of WiFi, Bluetooth, Zigbee, Z-Wave, and other wired or wireless sensors, which most of the times require specific gateways for their interconnection. This makes their installation and use quite complex for everyday users. Many smart home setups even require manual configuration and separate cloud accounts. In addition, most of these devices are easily accessible to intruders and they can be easily damaged and become unfunctional.

MultiX may overcome these technical challenges by providing a seamless, plug-and-play solution that eliminates the use of any sensor installation, the need for multiple gateways, specialized routers, and complex manual configurations. Unlike traditional smart home ecosystems that rely on separate hubs for WiFi Bluetooth, Zigbee. Z-Wave and other communications protocols, MultiX integrates multi-sensor multi-band and multi-technology capabilities directly into the 6G-RAN architecture. The MP6R controller (MP6RC) acts as an intelligent RAN orchestrator. Additionally, the Data Access and Security Hub (DASH) provides a unified platform for secure data processing storage and privacy management. Most importantly, MultiX introduces a plug-and-play framework that makes smart home adoption more accessible, reliable, and future-proof for everyday users.

2.10. 6G-PATH – 3D HYDROGEL PATCH FOR CHRONIC WOUNDS

2.10.1. DESCRIPTION AND OBJECTIVES

Chronic wounds are a growing challenge in elderly care, requiring both treatment of underlying diseases and stage-specific wound assessment. Improved technology for high-quality imaging and reliable remote data transmission is essential to support effective digital wound therapy, particularly in rural areas.

This use case addresses this gap by employing a B5G-enabled medical service supported by nomadic micro-networks in a vehicle, which provides secure and dependable connectivity at the patient’s location, as well as computational resources and bioprinting capabilities. The approach aims to combine digital wound documentation, 3D wound scanning, and on-site bioprinting to deliver personalised hydrogel wound dressings.

The objective is to develop a custom-made 3D-printed hydrogel patch derived from a digital wound model, ensuring an exact fit to the wound bed, edges, and surrounding tissue (Figure 14). This process will improve the quality of care for patients with chronic wounds, particularly in underserved rural areas.

Figure 14: Use case overview

2.10.2. TARGET HEALTHCARE SCENARIOS AND ENVIRONMENTS

A dedicated mobile scanning application is used to capture the wound and generate a detailed 3D model. This model is subsequently transferred into the Nurse Care App. Nurses on site add clinical information about the wound to enrich the dataset. The scan generates both a 2D image and a detailed 3D wound model, which are uploaded to the Patient Data Storage Server for further processing. Data transfer occurs via the B5G nomadic micro-network, leveraging private and secure connectivity to ensure high performance for high-resolution image transmission and edge computing capabilities.

Once images are received at the edge, the wound data undergo image processing to compute clinically relevant parameters, including surface area, depth, and volume of the wound. This quantitative analysis facilitates monitoring of wound progression. Based on these calculations, an individualised hydrogel patch design is automatically generated in a printable format (Figure 15).

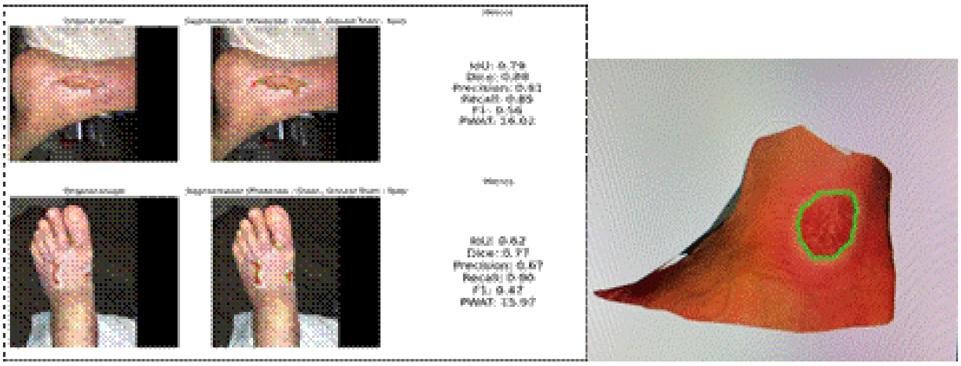

Figure 15: Wound analytics

In the vehicle, through the bioprinter (depicted in Figure 16), the personalised wound dressing is fabricated. The bioprinter processes the received patch model and produces a hydrogel-based dressing that is individually tailored to the wound's geometry, providing an optimal fit for the patient.

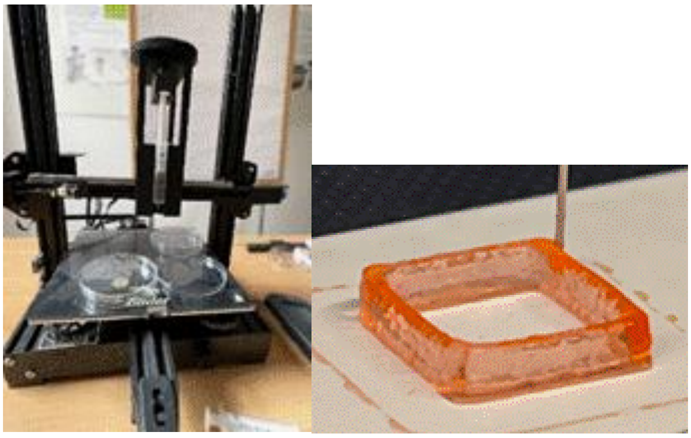

Figure 16: Bioprinter and hydrogel patch example

2.10.3. EXPECTED BENEFITS AND IMPACT ON PATIENT CARE

This innovative use case delivers transformative benefits across clinical, operational, and socioeconomic domains.

From the clinical perspective, personalized 3D bio printed hydrogel patches provide precise anatomical conformity, ensuring optimal wound bed contact, enhancing healing efficiency, reducing infection risk, and shortening healing time. Further, the integration of quantitative wound-parameter tracking supports objective monitoring of wound progression and enables evidence-based treatment adjustments.

In terms of socioeconomic impact, the deployment of mobile B5G enabled bioprinting infrastructure promotes equitable access to healthcare, and more specifically advanced wound care, by extending the services to underserved and rural populations, ensuring societal benefits. By reducing geographical barriers, this approach alleviates the travel burden for elderly and mobility restricted patients and supports more inclusive healthcare delivery. The capability to administers on-site treatment also decreases hospital admissions, reduces the need for costly emergency interventions, lowers costs, and improves allocation of nursing resources. These benefits are reinforced by secure edge computing technologies, which provide real-time clinical decision support while maintaining full GDPR compliance.

Healthcare system operational efficiencies are also ensured through the shift toward on-site/point-of-care treatment. Managing wounds directly at the patient's location reduces reliance on hospital-based resources, and streamlines clinical workflows. Real-time clinical decision making through secure edge computing further enhances treatment continuity, responsiveness and regulatory alignment.

From a patient-centric perspective, individualized therapy improves quality of life by accelerated healing, reduced pain, and enhanced autonomy in day-to-day activities. Digital wound documentation contributes to comprehensive longitudinal health records, enabling predictive analytics and the design of personalized care pathways. Collectively, this paradigm shift positions B5G connectivity as a critical enabling infrastructure for precision medicine delivery within community healthcare settings.

2.10.4. TECHNICAL REQUIREMENTS AND DEPENDENCIES

From the medical process point of view, the most important functional requirement is the employment of AI for wound analysis to compute the surface, volume, and depth of the wound using 2D and 3D wound segmentation without the employment of conventional methods like a ruler. For this, the demanded accuracy is at least 90 percent, and the image processing results are used for both documentation and comparative visualization and for generating a matching hydrogel patch. Furthermore, the wound expert should be able to edit the extracted wound model to create a better matching patch, as the wound has to be covered only 80% of the volume to allow for the best healing chance.

The nurse attending patients from remote areas expects to have a private network available on-site for connecting to the clinic where the wound expert resides. The following identified ICT features of the private area of key interest:

- High availability by employing also satellite connection as a backhaul (99.99%).
- High bandwidth and low latency for video consultations and high-resolution scanning data transfer (approximately 3 MBytes in less than 2 seconds).
- Minimal delay and secure communication between the devices (phone to bio-printer), which in the context of beyond 5G networks, derives as a local breakout (65 ms between mobile application and FHIR store, including TLS handshake).
- Encrypted storage of the medical data and granular access control for different types of roles and dynamic consent-based association between nurses and patients.

2.10.5. IMPLEMENTATION

In the implementation, a 3GPP aligned prototype of the Core Network, the Open5GCore Edge Router enables the connectivity reliability over available backhauls from mobile operators and satellite providers. The application-level data access requirement is fulfilled by employing OAuth2.0 authentication and authorization framework and the HL7 FHIR standard for storing the patient data. As end devices, the smartphone or tablet are used to scan the wounded area and the Nurse Care App is used to send the data and ask for wound analysis. The prototype is validated with a do-it-yourself 3D bio-printer, based on a 3D printer that can be connected via a 5G Customer Premises Equipment (CPE) (see Figure 17).

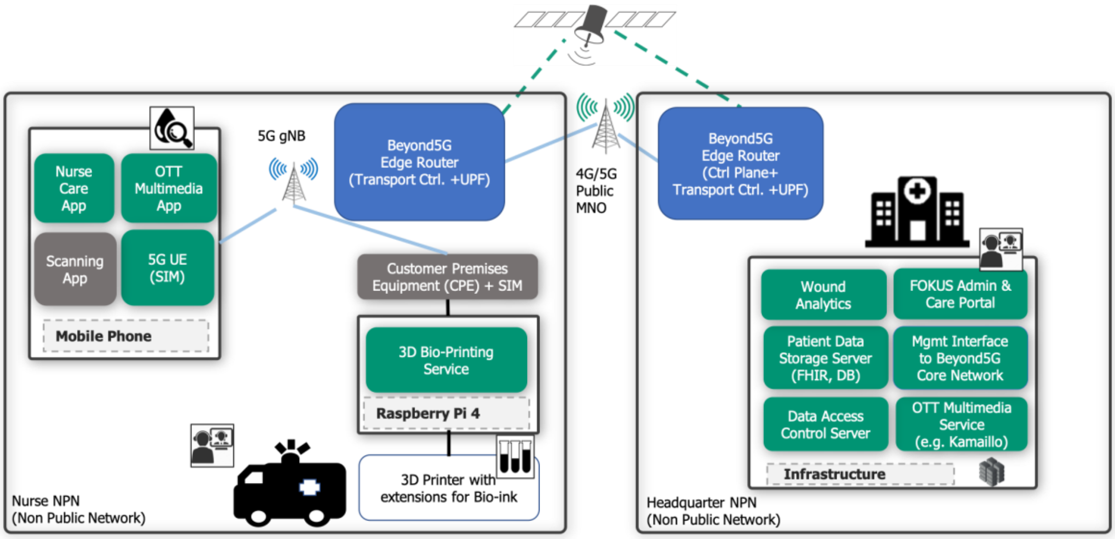

Figure 17: 6G-PATH - 3D Hydrogel Patch use case topology

2.10.6. ENVIRONMENTAL, SOCIETAL, AND ECONOMICAL CONSIDERATIONS

This use case presents multidimensional sustainability implications spanning environmental stewardship, social equity, and economic viability.

From an environmental perspective, on-site bioprinting significantly reduces carbon footprint by eliminating extensive medical supply chain logistics and reducing reliance on single-use packaging. The use of biodegradable hydrogel biomaterials further mitigates the environmental burden associated with conventional non-degradable wound dressings. In addition, mobile micro-network architectures optimize energy consumption, providing a more sustainable alternative to permanent infrastructure deployment in sparsely populated regions.

the societal impact of this intervention is equally significant. By extending specialized wound care services to marginalized rural communities, the approach directly addresses longstanding critical healthcare inequities, with particular benefits for elderly populations who are disproportionately affected by chronic wounds. Complementary digital health literacy programs that accompany the deployment promote technological inclusion, while improved healing outcomes reduce caregiver burden, enhance family wellbeing and facilitate greater social participation.

Economic viability is reinforced through multiple mechanisms. Lower hospitalization rates, reduced complications, and accelerated healing translate to substantial long-term cost savings within the healthcare system. Prevention of wound-related disabilities helps maintain workforce productivity among working-age populations, while initial infrastructure investments are offset by operational efficiency gains and reduced pharmaceutical expenditure over time.

Overall, this holistic approach aligns closely with the UN Sustainable Development Goals, demonstrating how advanced connectivity can enable sustainable, equitable and resilient transformations in healthcare delivery.

2.11. 6G-PATH – ELDERLY MONITORING

2.11.1. DESCRIPTION AND OBJECTIVES

The Elderly Monitoring use case focuses on the continuous collection and analysis of vital signs and mobility parameters for older adults in rehabilitation and daily living contexts. It combines wearable technologies, such as the MCS SmarKo smartwatch, with 3D body-tracking sensors embedded in the meineReha rehabilitation platform to create a comprehensive monitoring system. The objective is to prevent falls, detect early signs of health deterioration, and improve rehabilitation outcomes by providing real-time insights to caregivers and clinicians. Beyond pure monitoring, the system is designed to allow one healthcare professional to remotely supervise up to ten patients simultaneously, with integrated live video communication enabling therapists to guide exercises or respond immediately to abnormal measurements. The overarching aim is to reduce caregiver workload, improve patient safety, and enable a more scalable and efficient model of elderly care (Figure 18).

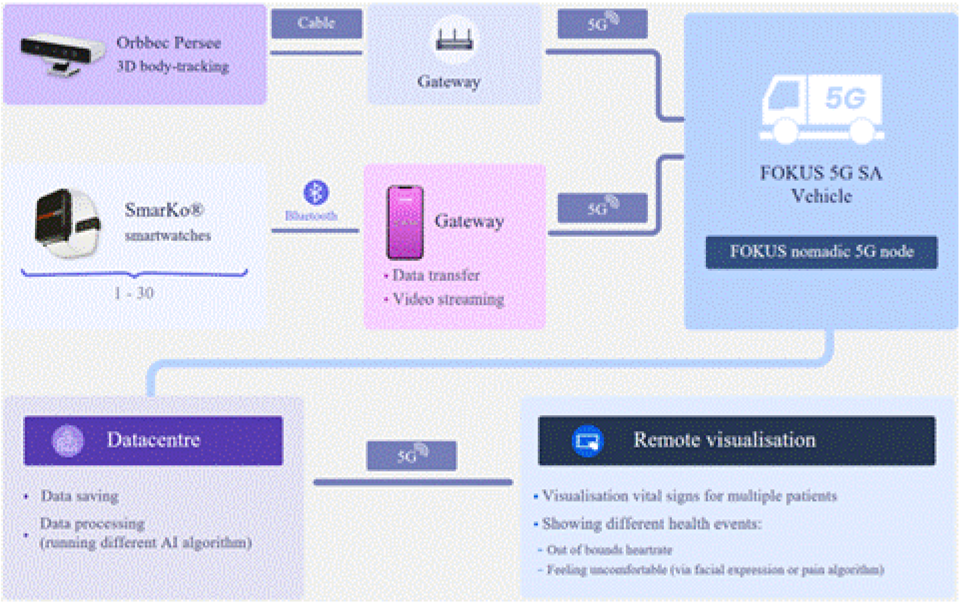

Figure 18: Use case overview

2.11.2. TARGET HEALTHCARE SCENARIOS AND ENVIRONMENTS

The use case addresses a wide range of healthcare environments. In rehabilitation clinics, it supports physiotherapists in monitoring progress during training sessions and enables direct interaction through video support when patients require correction or encouragement. In nursing homes, the system allows for staff to monitor residents simultaneously, automating the collection of vital data and alerting them only when intervention is necessary. In-home settings, the platform extends telemedicine and telecare services by providing continuous monitoring outside the clinic, helping elderly individuals maintain independence for longer while remaining connected to professional oversight.

2.11.3. EXPECTED BENEFITS AND IMPACT ON PATIENT CARE

These comprehensive elderly monitoring systems fundamentally transform senior care delivery through proactive health management and scalable supervision models. Continuous vital sign monitoring and 3D body-tracking enable early detection of physiological drop, allowing pre-emptive interventions before critical episodes occur. Fall risk assessment through gait analysis and mobility pattern recognition significantly reduces injury incidence, a leading cause of morbidity and mortality among elderly populations.

The one-to-ten patient supervision ratio revolutionizes resource utilization, enabling healthcare professionals to maintain quality oversight across multiple patients simultaneously through intelligent alerting systems that prioritize clinical attention. Real-time video communication facilitates immediate therapeutic guidance during rehabilitation exercises, ensuring correct technique execution and preventing injury while maintaining personalized care delivery despite physical distance.

Patients experience enhanced autonomy and dignity through extended independent living capabilities, supported by continuous professional oversight that provides safety reassurance. The seamless integration across rehabilitation clinics, nursing homes, and domestic environments ensures care continuity throughout the elderly care journey. Automated data collection eliminates subjective reporting bias, creating objective longitudinal health records that support predictive analytics and personalized intervention strategies, ultimately improving rehabilitation outcomes and quality of life.

2.11.4. TECHNICAL REQUIREMENTS AND DEPENDENCIES

Realising this use case requires an integrated technical ecosystem. Smart devices such as the MCS SmarKo smartwatch and Orbbec 3D body-tracking sensors collect multimodal data through the B5G private network. From there, the data is processed in near real-time at the edge, where AI algorithms analyse, in real-time, patterns for fall detection, vital sign anomalies, and activity recognition. The infrastructure is designed for high device density and scalability up to 10,000 concurrent users. Standardised HL7 FHIR resources are employed for the exchange of care plans and exercise outcomes, ensuring compatibility across healthcare systems. Security and privacy are safeguarded through strong encryption and network slicing, isolating health-critical data streams from other traffic.

2.11.5. ENVIRONMENTAL, SOCIETAL, AND ECONOMICAL CONSIDERATIONS

This use case embodies a model of sustainable healthcare innovation that responds to the social, environmental, and economic challenges confronting ageing societies.

From an environmental sustainability perspective, remote monitoring significantly reduces transportation related emissions by reducing both patient clinic visits and the need for healthcare professionals to travel for home assessments. The transition to digital data infrastructure eliminates paper based medical documentation, thereby reducing the material footprint of healthcare delivery. Moreover, energy-efficient wearable technologies and cloud-based data processing optimize resource consumption when compared with facility-based monitoring systems that require continuous staffing and operational infrastructure.

The societal value of this approach is particularly notable within the context of Europe's demographic transition, where aging populations increasingly intensify the pressure on traditional caregiving models. Technology-enabled independent living supports older adults in maintaining dignity, autonomy and social integration, while simultaneously alleviating family caregiver burden, which is an increasingly important consideration as multigenerational households become less common. In addition, technology mediated care reduces social isolation through maintaining regular connections with healthcare professionals, while digital literacy programs introduced alongside system deployment promote technological inclusion and cognitive engagement among elderly users.

Economic efficiency is strengthened through the one-to-ten supervision model, which delivers substantial labour productivity gains and helps address healthcare workforce shortages issues. Early detection and intervention prevent costly emergency hospitalizations and reduce the need for institutional care placements. Preventing fall-related injuries averts expensive treatment cascades, generating further system level savings. Further, scalable telemedicine infrastructure extends healthcare access to rural regions without the financial and environmental burden of duplicating physical facilities.

This paradigm represents a fiscally responsible and environmentally conscious evolution of healthcare delivery that meets the demographic realities of the 21st-century.

2.12. 6G-PATH – XR HEALTH TRAINING

2.12.1. DESCRIPTION AND OBJECTIVES

The XR health training use case focuses on enhancing the training of prehospital nurses. Prehospital nurses must acquire a blend of cognitive and practical skills to effectively manage a wide range of medical emergencies. Practical training is a crucial part of their education and is typically obtained through two methods: (i) working with manikins in simulated environments, and; (ii) supervised participation in real clinical prehospital care scenarios. This use case specifically targets the simulated scenario with manikins, which is the focus of the experimentation.

Manikins replicate human anatomy and physiology, allowing learners to enhance their knowledge through lifelike situations. During manikin-based training, the instructor is usually situated in an adjacent room, providing voice responses and controlling certain reactions based on the students' actions. For example, the manikin’s breathing may change when students move its head to clear its airways. The more realistic the scenarios simulated with manikins, the better the learning experience. The proposal is to relocate the manikin from its fixed classroom to locations that offer a more authentic medical scenario, such as inside an ambulance. This setup will enable the manikin to be remotely controlled, allowing prehospital nursing students to engage in remote simulated acute/ambulance scenarios in a flexible manner. The overall objective is to enhance healthcare education by providing more authentic, flexible and scalable training.

2.12.2. TARGET HEALTHCARE SCENARIOS AND ENVIRONMENTS

Within 6G-PATH we focus on the training of prehospital nurses, as they represent highly skilled medical professionals with high requirements on authenticity in the training. However, training in simulated scenarios with manikins is applicable to training for a broad range of medical professionals as well as to training of public safety personnel in general. While we focus on training in simulated scenarios, similar technical solutions can also be applied in real prehospital care scenarios.

2.12.3. EXPECTED BENEFITS AND IMPACT ON PATIENT CARE

While this use case primarily focuses on healthcare education rather than direct patient care, its benefits cascade significantly into improved clinical outcomes. Enhanced training realism through authentic ambulance-based scenarios develops superior decision-making capabilities under pressure, directly translating to improved emergency response competency. Prehospital nurses trained in high-fidelity simulated environments consistently demonstrate greater procedural accuracy, shorter response times, and enhanced situational awareness when faced with actual emergency situations.

The use of remotely controlled manikin technology allows unlimited scenario repetition without the constraints of physical resources, enabling learners to master complex interventions before performing them on real patients and thereby eliminating training-related patient risk exposure. The capacity to deliver training across geographically distributed settings removes cohort and institutional disparities, ensuring consistent educational quality regardless of location or institutional resource availability. Instructors can dynamically adjust manikin responses to progressively challenge learners, creating personalized training pathways based on individual competency development.

In addition, the flexible deployment model facilitates continuous professional development and routine refresher training throughout clinical careers, helping maintain high standards of practice across the healthcare workforce. Ultimately, patients benefit from interactions with better-prepared emergency responders equipped to deliver evidence-based interventions with confidence and precision during critical golden-hour scenarios. This enhanced preparedness significantly improves survival rates and recovery outcomes in prehospital emergency care.

2.12.4. TECHNICAL REQUIREMENTS AND DEPENDENCIES

Implementing this use case involves several components as illustrated in Figure 19. The manikin will be placed at the simulated medical site, equipped with cameras for high-quality video and microphones/speakers for audio input and output. Control of the manikin will occur at a remote site. Additionally, rendering devices at a (possibly distributed) remote training site, such as audio-video peripherals (e.g., monitors or head-mounted displays), will be used by remote students to participate in the immersive scenario.

Figure 19: Components of the XR health training use case

To meet the low latency, reliability, and uplink capacity requirements of the use case, several aspects of B5G networks come into play. The medical site, when connected over a B5G network, can take advantage of network slicing capabilities. Use of a high priority slice for the manikin control, audio and multiple video feeds will ensure the quality of the remote control even in the face of heavy background traffic. To manage end-to-end latency and prevent any queuing delays, low latency features such as L4S (Low Latency, Low Loss Scalable) are beneficial. Computing nodes, responsible for generating XR content by integrating multimodal inputs collected at the medical site and any additional non-real-time information, can take advantage of network edge infrastructure. Additionally, the application server(s) that provide access to the XR content for students at the training site will also make use of this infrastructure.

Numerical target KPIS:

- Motion-to-photo latency requirement: Below 10 ms
- Round Trip Time (RTT) achieved: Average of 20 ms (between client application and server)
- Data rate requirement: Expected to exceed tens of Gbps
- Coverage RSRP (received signal strength power): Varied between -78 and -95 dBm, with requirement of more than -90 dBm

- Coverage RSRQ (received signal quality): Stayed at -11 dB throughout, with requirement of achieving above -10 dB

2.12.5. ENVIRONMENTAL, SOCIETAL, AND ECONOMICAL CONSIDERATIONS

The XR health training paradigm represents a sustainable transformation of medical education infrastructure with far-reaching environmental, social, and economic implications.

From an environmental perspective, remote training delivery significantly reduces carbon emissions associated with student and instructor travel to centralized training facilities. The use of shared digital infrastructure eliminates the need for redundant physical manikin laboratories across institutions, thereby optimizing resource utilization. Virtual scenario generation further reduces the consumption of medical supplies typically expended during conventional training exercises. In addition, energy-efficient 6G networks that support distributed learning offer lower energy consumption compared with maintaining multiple heated, illuminated, and fully equipped physical simulation centres dispersed across geographical regions.

This approach also has equally notable societal impacts. By democratizing access to high-quality training, XR-enabled education addresses longstanding inequities in healthcare education, particularly benefiting rural and resource-limited institutions that lack sophisticated simulation facilities. Enhanced competency among prehospital nurses directly improves public safety outcomes and community resilience during emergencies. Flexible, remote training schedules accommodate the diverse circumstances of learner, thereby promoting workforce diversity and inclusion. Further, standardized scenario libraries ensure consistent educational quality nationally, helping to reduce regional disparities in healthcare competencies.

Economic efficiency is advanced through the reduction of infrastructure investment requirements, which lower institutional barriers to establishing and sustaining training programs. Scalable remote supervision capabilities enable instructors to train multiple cohorts simultaneously across different locations, optimizing educator productivity. The combined reduction in facility overhead costs, equipment duplication, and travel costs generate substantial operational savings while expanding overall training capacity.

Taken together, this innovation exemplifies how advanced connectivity can transform the sustainability of professional education while maintaining and enhancing pedagogical excellence.

2.13. 6G-LEADER – EXTENDED REALITY AND ROBOTICS FOR AUTONOMOUS DYNAMIC TRAUMA RESPONSE

2.13.1. DESCRIPTION AND OBJECTIVES

The following use case serves as a possible real world scenario where core technological innovations of the project can be impactful. Even if it is not implemented in the project, it provides contextualizing for the Proof of Concept (PoC#1) focused on XR and UAV seamless real-time interaction.

This Use Case describes a mission-critical eHealth system designed to provide intelligence and expert guidance to first responders operating in dynamic disaster environments in a hyper-connected scenario. The system integrates wearable Extended Reality (XR) interfaces (Head-Mounted Displays, HMDs) used by field medics with a cooperative network of heterogeneous mobile robots, such as Unmanned Aerial Vehicles (UAVs), and Unmanned Ground Vehicles (UGVs).

The underlying network infrastructure relies on Artificial Intelligence (AI) and Machine Learning (ML)-driven semantic communications, which filter and prioritise information based on its relevance to the task performed in the field (e.g., victim location or hazard identification). This semantic approach is necessary to satisfy the stringent performance requirements of XR, which far exceed the capacity of existing wireless networks.

The objective of introducing 6G advanced technologies is to overcome obstacles that emergency response teams often face, such as inadequate real-time situational awareness (SA) and restricted access to remote medical expertise.

2.13.2. TARGET HEALTHCARE SCENARIOS AND ENVIRONMENTS

This Use Case was defined considering the infrastructure requirements for pre-hospital emergency care applications. Specifically, it addresses time-critical, high-stakes medical interventions in disaster and emergency zones. These scenarios are placed in unstructured, chaotic disaster zones where conditions often dynamically evolve in time and are characterised by uncertainty. These include unstable and dangerous situations such as collapsed buildings and structures, zones contaminated by toxic material spills, or environments where fires can spread unpredictably and victims' conditions can deteriorate rapidly if not rescued promptly. Besides, operations typically occur in zones where wireless signals may be obstructed or delayed, thus making reliable, high-bandwidth communication challenging. These limitations have a significant impact on operations, since robotics and XR operational conditions necessitate robust navigation and communication systems.

Healthcare scenarios related to this Use Case are typically associated with pre-hospital emergency operations, such as Mass Casualty Incident (MCI) Triage (provisioning of real-time clinical decision support (CDS) to enhance triage accuracy and speed), Remote Procedural Guidance (e.g. hands-free guidance from specialised remote experts (e.g., trauma surgeons) for complex procedures), and Tactical Emergency Medicine (support for law enforcement and rescue operations with the support of remote guidance in high-acuity scenarios).

2.13.3. EXPECTED BENEFITS AND IMPACT ON PATIENT CARE

The transformative system for enhancing first response fundamentally improves both data transmission and clinical efficacy by leveraging semantic communication and robotics in conjunction with Augmented Reality (AR). This holistic integration results in substantial gains across several key areas: Operational Efficiency is boosted by AR-guided tools that decrease the time to task completion for critical interventions, such as patient assessment and casualty counting during Mass Casualty Incidents (Apiratwarakul et al., 2022), directly translating into faster response times. Clinical Efficacy is elevated through hands-free, real-time AR guidance from remote experts for complex field procedures, ensuring improved quality and strict protocol adherence, which studies show enhances expert procedure quality ratings (Glick et al., 2021). Furthermore, Situational Awareness (SA) is enhanced as the system intelligently fuses aerial and ground sensor data into a unified display, utilizing essential AR elements like navigation interfaces and object highlighting to improve perception and comprehension without increasing the responder's perceived workload (Ntoa et al., 2024). Simultaneously, the system streamlines Cognitive Processing by using AR to effectively reduce information clutter, focusing the responder’s attention exclusively on the semantically critical cues, a function highly relevant for time-sensitive situations under immense pressure. Ultimately, these integrated improvements in care delivery efficiency and clinical decision-making converge to positively impact Patient Outcomes, as the timely and accurate care facilitated by these AR interventions has been linked to a reduction in early deaths following traumatic injuries.

2.13.4. TECHNICAL REQUIREMENTS AND DEPENDENCIES

This Use Case is driven by the need to overcome the critical limitations present in current first response systems. The core requirement is the deployment of AR/VR-assisted first responders connected via mobile networks to provide a shared, semantically enriched digital representation of a disaster zone. A successful implementation of this Use Case requires introducing advancements in the current architecture to make it capable of supporting the demands of Extended Reality (XR) services, e.g. motion-to-photo latency below 10 ms and high data rates (which are expected to exceed tens of Gbps) (Zhang et al., 2022). Utilising semantic-aware communication over 6G networks to transmit only the most relevant and actionable information (e.g., victim location or triage recommendations) allows for effectively reducing latency and supporting XR, which allows for reducing the cognitive load on the medic, a requirement when acting under extreme time pressure in highly dynamic, uncertain environments.

Coordinated aerial-ground frameworks are essential for Search and Rescue (SAR) operations in unknown environments. The integration and close coordination of heterogeneous mobile robots, such as aerial drones (UAVs) for wide-area situational mapping and ground robots (UGVs), is essential for the system's operation and its capability for close-range monitoring and tool delivery. To this aim, the underlying integration network infrastructure should be designed to enable UAVs and/or UGVs to operate in coordination, so that it is possible to provide advanced functionalities to operators such as victim detection and monitoring evolving hazards (Farrell et al., 2025). Sustainable connectivity can be achieved by adopting solutions that increase the system's energy and spectrum efficiency, derived from semantic-driven data prioritisation. These approaches are of great importance for operations that can happen even in resource-constrained environments.

2.13.5. ENVIRONMENTAL, SOCIETAL, AND ECONOMICAL CONSIDERATIONS

This Use Case brings several considerations regarding sustainability. From the environmental point of view, energy and spectrum Efficiency ensure that the network only transmits the most relevant information needed for the task, enabling sustainable operation even in resource-constrained environments. From a societal perspective, the Use Case demonstrates how technologies can enhance the quality of life of citizens and better and safer working conditions for operators. By providing timely, improved, expert-level emergency healthcare in remote and critical environments, it also contributes to raising inclusion of communities that would not have the same quality of emergency care. Finally, from the economic point of view, introducing a more effective emergency healthcare delivery has the potential of reducing the long-term societal and economic burdens associated with delayed or suboptimal care.

2.14. IMAGINE-B5G – MOBILE HEALTH MONITORING AS A SERVICE ENABLED BY B5G

2.14.1. DESCRIPTION AND OBJECTIVES

The Drone Care Angel[3] (DCA) t is an IMAGINE-B5G Open Call 1 vertical experiment project led by Load Interactive[4] and Instituto Pedro Nuno[5]. The project demonstrates how unmanned aerial vehicles (UAVs), artificial intelligence (AI), and augmented reality (AR), supported by beyond-5G (B5G) connectivity, can provide real-time, context-aware health supervision for individuals on the move. Developed as an evolution of the Drone Guard Angel (DGA)

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[3] https://imagineb5g.eu/dca-in-imagine-b5g-open-call-1/

[4] https://load.digital/about

[5] https://www.ipn.pt/

concept, DCA extends UAV functionality from personal safety monitoring to proactive healthcare support.

A UAV autonomously accompanies a designated user, acquiring continuous high-definition video and physiological data through onboard sensors and connected Internet-of-Medical-Things devices. The information is transmitted via the B5G network to edge-computing nodes, where AI-based image recognition and AR-enhanced visualisation transform raw data into actionable insight. When an irregular pattern, such as a fall, fainting episode or abrupt vital-sign change is detected, the system dynamically reallocates network resources through slice prioritisation to maintain the latency and throughput required for medical-grade streaming. Remote clinicians receive a real-time, augmented visual feed that supports rapid triage and intervention.

The overarching objective of DCA is to validate the ability of B5G-enabled UAV ecosystems to deliver adaptive, low-latency and secure health services that combine aerial sensing, edge intelligence and immersive communication for faster and more effective emergency response.

2.14.2. TARGET HEALTHCARE SCENARIOS AND ENVIRONMENTS

DCA addresses healthcare needs in mobile and semi-urban environments where continuous observation and situational awareness are difficult to achieve with conventional wearable-based or fixed monitoring systems. The service focuses on individuals who are medically vulnerable but wish to maintain independence and mobility in everyday outdoor activities.

During standard operation, the UAV follows the user along a predefined path, transmitting video and biometric data to the edge for continuous processing. AI algorithms extract postural and physiological parameters and detect deviations from normal patterns. When an anomaly occurs, the communication slice is reconfigured to prioritise high-bandwidth, low-latency transmission so that enriched video and sensor data reach the edge within sub-100-millisecond delay. The processed feed, augmented with AR overlays highlighting the user’s condition and surroundings, becomes instantly available to healthcare professionals for remote assessment. This seamless workflow exemplifies how UAV-assisted sensing and edge analytics can extend clinical oversight beyond the boundaries of traditional healthcare infrastructures.

2.14.3. EXPECTED BENEFITS AND IMPACT ON PATIENT CARE

By integrating autonomous aerial sensing, intelligent data analytics and agile network management, DCA shortens the interval between incident detection and clinical response. The fusion of visual and physiological information improves diagnostic precision and situational understanding, enabling medical teams to make timely and well-informed decisions. For vulnerable users, the system enhances personal safety without restricting mobility, allowing rapid assistance during emergencies and reducing the likelihood of severe complications. At system level, the approach demonstrates how adaptive, context-aware telemedicine can complement existing care pathways through continuous, high-quality monitoring in dynamic environments.

2.14.4. TECHNICAL REQUIREMENTS AND DEPENDENCIES

The implementation of the DCA relies on the IMAGINE-B5G platform and the Portuguese facility site infrastructure, integrating network slicing, mobile-edge computing and orchestration capabilities, as illustrated by figure. Dynamic slicing ensures reliable performance under fluctuating data-rate and latency demands, while edge nodes host the AI and AR modules close to the data source to minimise delay. Secure communication protocols protect sensitive medical information, and an orchestration framework coordinates UAV control, sensor fusion and backend analytics through standardised interfaces. This architecture combines scalability, interoperability and responsiveness suitable for time-critical healthcare applications.

Numerical target KPIS:

- Uplink throughput: 8-14 Mbps (depending on resolution tier)
- Base tier data rate: 8-10 Mbps
- Base tier latency: 13-15 ms
- Premium tier data rate: 12-14 Mbps
- Premium tier latency: 10-13 ms
- Network slicing: ≥ 2 dynamically instantiated network slices simultaneously
- Reliability and availability achieved: 99.5-100%
- Connection density: 20-30 connected devices per facility (NPN)

2.14.5. ENVIRONMENTAL, SOCIETAL, AND ECONOMICAL CONSIDERATIONS

The DCA concept contributes to environmental, societal and economic sustainability within the European digital-health landscape. Environmentally, it reduces unnecessary ambulance deployment and associated emissions by enabling early remote assessment, while UAV flight paths are optimised for energy efficiency. Societally, the system enhances equality in access to timely medical support, strengthens trust in autonomous health technologies and supports ageing-in-place strategies. Economically, earlier diagnosis and intervention reduce hospitalisation and emergency-response costs while creating opportunities in UAV-assisted telemedicine and B5G service markets. Economically, earlier diagnosis and intervention reduce hospitalisation and emergency-response costs while creating opportunities in UAV assisted telemedicine and B5G service markets.

2.14.6. IMPLEMENTATION

The DCA use case validates B5G capabilities for real-time, context-aware health monitoring of individuals in motion. Conducted between March and October 2024, all participants were members of the technical teams simulating user and operator roles, ensuring compliance with ethical and GDPR requirements.

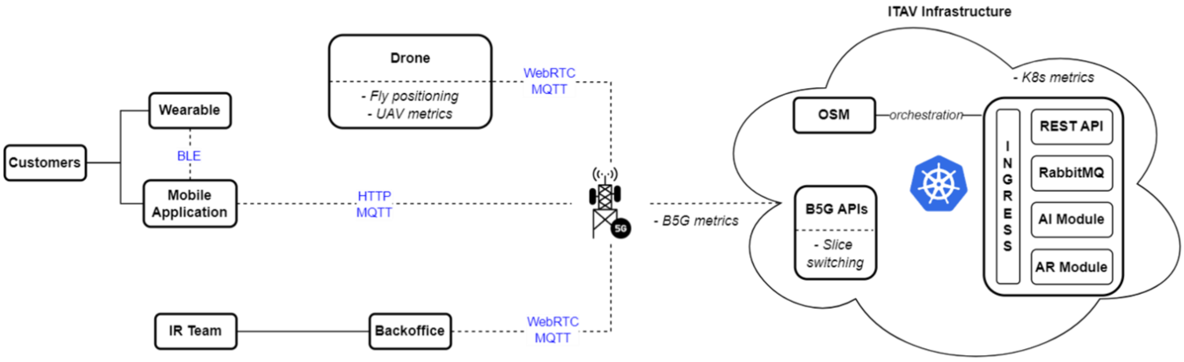

Figure 20: Architecture for the DCA use case implementation

As illustrated by figure 12, the DCA architecture relies mainly on the IMAGINE-B5G platform and the Portuguese facility site infrastructure. It also combines unmanned aerial vehicles equipped with high-resolution cameras and Internet of Medical Things devices connected to a Mobile Edge Computing (MEC) node. Artificial Intelligence-based image recognition and Augmented Reality modules deployed at the edge enable real-time data processing. During the trial, the drone continuously followed a moving user and transmitted full-HD video and biometric information to the edge platform. When an anomaly such as a fall or visible bleeding was detected, the AI module triggered a REST-API call to the network-slice manager, activating a higher-priority slice to increase throughput and reduce latency. The enhanced 1080p video stream, augmented with contextual AR overlays, was then visualised by a remote medical assistant through a dedicated mobile interface.

The experimental setup included an NVIDIA Jetson-powered drone with an integrated 5G modem, an outdoor 5G cell site approximately 350 metres from the test area, and an edge-cloud cluster with GPU support orchestrated through Open Source MANO (OSM) and Kubernetes. The platform incorporated advanced B5G features such as dynamic slice switching, edge-cloud orchestration, and secure API exposure, providing adaptive Quality of Service. All data were processed locally and in real time, without long-term storage.

The DCA trials demonstrate the feasibility of integrating drones, AI-based perception, AR visualisation, and B5G network orchestration into a coherent health-monitoring framework. The system consistently met latency, reliability, and throughput targets, maintaining stable performance in dynamic network conditions. Remaining limitations concern dataset diversity and the absence of clinical-grade trials, which are planned in forthcoming iterations.

2.15. IMAGINE-B5G – CONNECTED HOME FOR HEALTHY AGEING (CHHA)

2.15.1. DESCRIPTION AND OBJECTIVES

The CHHA vertical experiment has been initiated, by the Institute of Electronics and Telematics Engineering of Aveiro[6] as an IMAGINE-B5G Open Call 2 project. The project explores how B5G connectivity can transform homes into intelligent, health-supportive environments. Its goal is to help older adults and people in rehabilitation live safely and independently through continuous monitoring, guided physical activity, and preventive care powered by advanced communication networks and edge analytics. This open call project relies on key B5G capabilities such as enhanced Mobile Broadband (eMBB), edge computing, and network slicing to deliver low-latency, privacy-preserving health applications that operate autonomously in residential settings while remaining interoperable with healthcare systems.

Two complementary use cases were implemented. The Gamified Virtual Gym enables users to perform guided exercises at home while receiving real-time feedback from AI-based motion analysis, encouraging adherence through gamification and social engagement. The Radar-Based Activity Monitoring System provides continuous, non-intrusive motion tracking using radar sensors, which capture mobility patterns without visual data, preserving privacy while detecting inactivity, falls, or abnormal movement.

The overall objective is to demonstrate how B5G infrastructures can deliver reliable, adaptive, and secure communication for home-based eHealth services. By combining active and passive monitoring, CHHA illustrates how AI and edge intelligence can enhance safety, autonomy, and healthcare efficiency, advancing Europe's vision of preventive, person-centred, and digitally enabled care for an ageing population.

2.15.2. TARGET HEALTHCARE SCENARIOS AND ENVIRONMENTS

CHHA focuses on home-based contexts where user empowerment and continuous supervision coexist. The Gamified Virtual Gym supports individuals engaged in rehabilitation or preventive physical activity, transforming exercises into interactive sessions processed at the network edge through AI-driven pose recognition that delivers immediate feedback and progress tracking.

The Radar-Based Monitoring use case complements this by enabling passive observation of daily mobility. Radar units installed in living areas collect motion data, securely transmitted via the B5G network to edge nodes for analysis. The system identifies mobility anomalies such as reduced activity or irregular movement and can alert caregivers or clinicians when required.

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[6] https://www.ieeta.pt/

Both scenarios were conceived for deployment in semi-urban residential environments and were validated.

2.15.3. EXPECTED BENEFITS AND IMPACT ON PATIENT CARE

The CHHA experiment demonstrates how B5G technologies can deliver proactive, personalised healthcare at home. The Gamified Virtual Gym promotes physical and cognitive well-being while reducing social isolation. The Radar-Based Monitoring system enhances safety through unobtrusive observation and early detection of health deterioration.

For healthcare providers, CHHA enables data-driven decision-making and efficient resource use. Continuous contextual data improves clinical awareness, supporting earlier intervention and reducing hospitalisations. Together, the two use cases enhance care quality, lower costs, and improve quality of life for ageing citizens.

2.15.4. TECHNICAL REQUIREMENTS AND DEPENDENCIES

CHHA validates B5G's ability to sustain concurrent, data-intensive health services. The Gamified Virtual Gym requires uplink throughput above 10 Mbps for Full-HD video and latency below 50 ms for real-time feedback. Edge nodes orchestrated through Kubernetes and Open Source MANO handle local anonymised processing to preserve responsiveness and privacy. The Radar-Based Monitoring use case operates with lower bandwidth but demands high reliability and continuous connectivity. Radar sensors transmit encrypted data via lightweight gateways to edge servers for feature extraction and anomaly detection. Both use cases need to rely on network slicing for differentiated and reliable Quality-of-Service and GDPR-compliant data handling, showing how cloud-edge orchestration supports secure, scalable connected-home healthcare.

2.15.5. ENVIRONMENTAL, SOCIETAL, AND ECONOMICAL CONSIDERATIONS

CHHA contributes to sustainability across multiple dimensions. Environmentally, remote rehabilitation and monitoring reduce patient and caregiver travel, cutting emissions and energy use. Societally, non-invasive sensing extends healthcare access for elderly and mobility-limited users, promoting inclusion and dignity. Economically, early detection of health issues and fewer hospital visits lower costs and optimise professional resources. At scale, connected-home models like CHHA can strengthen the resilience and affordability of European healthcare systems.

2.15.6. IMPLEMENTATION

The project implementation was conducted at the IMAGINE-B5G Portuguese facility between March and October 2024. The experiment involved simulated end users representing elderly and rehabilitating individuals. The testbed provided outdoor and indoor 5G coverage, edge-cloud orchestration, and integration with commercial radar and camera systems. For the Virtual Gym, HD video was captured locally and transmitted to cloud-based processing units where AI-based pose estimation and feedback generation were performed. The system provided real-time visualization to the user through a local display and haptic or auditory cues. For the Radar-Based Monitoring, radar sensors continuously recorded movement data that were processed on an edge node, extracting features such as motion intensity and duration. The processed data were visualized in dashboards accessible to healthcare personnel. The experiment validated network stability and service continuity under varying loads, confirming the feasibility of deploying these services over a shared B5G infrastructure.

2.16. IMAGINE-B5G – ADVANCING POPULATION COGNITIVE HEALTH WITH B5G (COGNETCARE)

2.16.1. DESCRIPTION AND OBJECTIVES

The CogNetCare[7] vertical experiment developed within the IMAGINE-B5G project and led by NeuroInova[8] investigates how advanced B5G infrastructures can enable population-scale cognitive monitoring and early detection of the cognitive and neurological disorders. As illustrated by figure 13, the experiment combines two complementary medical solutions—Brain on Track, a certified remote cognitive assessment platform, and Neuro on Stride, a gait-monitoring tool using centimetre-level positioning to create an integrated solution for assessing both cognitive and motor functions beyond clinical environments.

The objective of CogNetCare is to demonstrate that B5G networks can sustain the performance requirements of digital cognitive health applications, including low latency, high reliability, and accurate positioning, ensuring that cognitive and gait assessments remain valid, precise, and independent of network variability. By doing so, the project addresses an urgent societal challenge: the need for continuous, accessible, and affordable tools to detect early cognitive decline and support long-term neurodegenerative disease management.

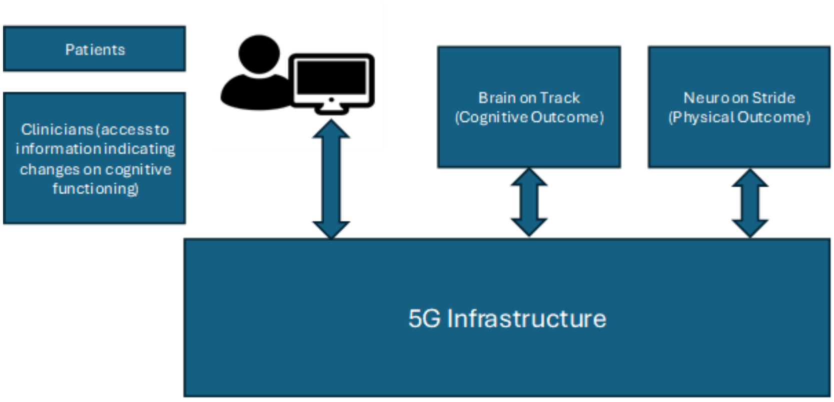

Figure 21: High level architecture for the CogNetCare use case

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[7] https://imagineb5g.eu/cognetcare-in-imagine-b5g-open-call-2/

[8] https://neuroinova.com/pt/home/

2.16.2. TARGET HEALTHCARE SCENARIOS AND ENVIRONMENTS

CogNetCare targets large-scale cognitive screening and continuous follow-up of patients in non-clinical contexts, such as residential facilities, community health centres, and population-based campaigns. The Brain on Track module allows individuals to complete interactive, game-based cognitive tests on tablets, measuring attention, memory, and executive function with clinical-grade precision. The Neuro on Stride module complements this by quantifying gait speed and stability, an important correlate of cognitive health.

Both tools operate over a B5G standalone infrastructure deployed at the Portuguese IMAGINE-B5G facility. Network slices were configured to guarantee ultra-reliable low-latency communication for data transmission and real-time edge processing. This configuration enables smooth test execution, instant feedback, and precise mobility tracking, validating B5G’s suitability for distributed health monitoring in semi-urban and residential environments.

2.16.3. TECHNICAL REQUIREMENTS AND DEPENDENCIES

The CogNetCare deployment required stringent network performance parameters to preserve the fidelity of medical data and user experience. The requirement from the infrastructure is to maintenance latency below 15 ms, reliability above 99.9 %, and availability above 99 %, which could be achieved through dedicated URLLC slices and the dynamic slicing solution that is custom made at the Portuguese facility site.

Brain on Track was hosted on virtual servers within the IMAGINE-B5G facility, using Docker-based orchestration to ensure scalability and reproducibility. Secure TLS connections protected cognitive data transfers, guaranteeing GDPR-compliant communication. Neuro on Stride used RTK-corrected GNSS signals delivered through a local NTRIP service, achieving positional precision of approximately 1 cm at a 10 Hz update rate, sufficient for clinical gait analysis.

Both solutions relied on edge-cloud collaboration, where local computation ensured minimal response time and encrypted data channels protected privacy.

2.16.4. ENVIRONMENTAL, SOCIETAL, AND ECONOMICAL CONSIDERATIONS

CogNetCare contributes to sustainability across multiple dimensions. Environmentally, it reduces the need for physical hospital visits and clinician travel, lowering energy consumption and associated emissions. Societally, it increases access to cognitive healthcare for individuals living in remote or underserved regions by enabling autonomous screening and remote supervision. Economically, it demonstrates cost efficiency by extending the reach of existing clinical resources allowing each practitioner to support more patients with reduced logistical burden.

At scale, such digitally enabled monitoring frameworks can contribute to the European Green Deal objectives by coupling environmental efficiency with social inclusion, reinforcing the sustainability of healthcare delivery.

2.16.5. IMPLEMENTATION

The CogNetCare trials were executed at the Portuguese IMAGINE-B5G facility between March and September 2025. Brain on Track was deployed first, validating network impact on cognitive testing under both optimal and constrained conditions. Neuro on Stride application and integration followed, integrating RTK-corrected GNSS modules with Android smartphones connected via a dedicated URLLC slice to achieve precise gait tracking.

Both trials confirmed that the B5G infrastructure consistently met application requirements, maintaining end-to-end latency near 12 ms and throughput up to 160 Mbps downlink and 40 Mbps uplink. This performance ensured accurate timing in cognitive response tasks and reliable spatial precision in gait measurement, validating the end-to-end feasibility of B5G-enabled cognitive health monitoring.

The CogNetCare experiment demonstrated that 5G infrastructures can support clinically valid, real-time cognitive and motor assessments. However, several challenges emerged during deployment. Achieving sub-15 ms latency across heterogeneous devices required advanced network slicing and precise edge orchestration. Ensuring interoperability among medical devices, maintaining GDPR compliance, and sustaining user engagement throughout the trials were equally demanding.

Despite these constraints, the trials confirmed that B5G technologies can extend cognitive screening and gait monitoring beyond traditional hospital environments. This enables earlier detection of neurological decline, greater accessibility for ageing populations, and more continuous patient monitoring.

2.17. IMAGINE-B5G – LEVERAGING EDGE OPTICAL SENSING FOR EMERGENCY DIAGNOSTICS (LEOSED)

2.17.1. DESCRIPTION AND OBJECTIVES

LEOSED[9] is an IMAGINE-B5G[10] Open Call 1 vertical experiment project that is led by Huawei, Germany. The project explores the feasibility of contact-less vital-sign monitoring using optical wireless sensing of pulse and blood oxygen saturation (OWSPOS) integrated with a B5G/6G edge infrastructure. The project aims to demonstrate that remote physiological assessment can be achieved without physical contact, without storing personal data, and

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[9] https://imagineb5g.eu/meet-leosed-a-project-by-huawei-that-was-born-after-imagine-b5g-open-call/

[10] IMAGINE-B5G Deliverable D3.3, *Vertical Trials and Pilots Demonstrations over IMAGINE-B5G Platform*, v1.0, Dec. 2024, https://imagineb5g.eu/results/#deliverables (accessed 23 Jan 2026)

without expensive standalone equipment. Its primary objective is to separate sensing from processing so that lightweight sensors can forward raw optical data to an edge server for real-time extraction of heart rate and oxygen saturation. A further objective is to scale this architecture so that multiple sensing stations can operate concurrently, supporting both rapid triage and continuous monitoring. By validating OWSPOS over a B5G testbed, LEOSED targets diagnostic reliability comparable to traditional integrated systems while reducing per-device cost and operational complexity.

2.17.2. TARGET HEALTHCARE SCENARIOS AND ENVIRONMENTS

The use case addresses two forms of remote care: short-duration vital-sign admission checks and long-term monitoring of patients requiring frequent observation. Both scenarios are designed for clinical environments where staff availability is limited or where contact-based measurement creates workflow constraints, such as emergency rooms, step-down units, small rural facilities, and high-throughput admission centres. Although conceived for deployment in remote and semi-urban healthcare settings, the validation was carried out at the IMAGINE-B5G Norwegian testbed, which provided realistic indoor conditions and full 5G standalone connectivity for testing optical sensing under operational constraints.

2.17.3. EXPECTED BENEFITS AND IMPACT ON PATIENT CARE

LEOSED improves access to essential physiological assessment by enabling rapid, hygienic, and automated measurement of oxygen saturation and heart rate. For admission scenarios, it reduces the likelihood of incorrect triage assignment by accelerating initial vital-sign collection. For continuous monitoring, it offers a contact-less alternative that removes cables, wearables and manual measurement routines, supporting uninterrupted observation without burdening clinical staff. The immediate extraction of vitals at the edge reduces waiting time and can accelerate intervention in cases of deteriorating respiratory or cardiovascular status. The approach is especially relevant for infectious disease contexts, high-volume screening points, and regions with limited medical staff.

2.17.4. TECHNICAL REQUIREMENTS AND DEPENDENCIES

OWSPOS places stringent demands on upstream network performance because high-frequency optical signals must be streamed to the edge without degradation. Reliable operation requires stable uplink throughput of at least 50 Mbps per sensing unit, low application-level latency below one second, and jitter below 20 ms to maintain signal integrity. The edge server must support low-latency optical signal processing and host diagnostic and statistics modules with sufficient compute capacity to process consecutive video frames in near real time. Network slicing and standalone 5G operation are required to isolate the flow and guarantee predictable uplink performance.

2.17.5. ENVIRONMENTAL, SOCIETAL, AND ECONOMICAL CONSIDERATIONS

LEOSED reduces environmental impact by limiting patient transfers and enabling diagnostics at the point of care. Its compact optical sensors require less energy and infrastructure than conventional imaging systems. Societally, it improves access to rapid assessment in emergency settings and supports timely clinical decisions through remote expertise. Economically, it offers a lower-cost alternative to specialised diagnostic equipment and helps streamline patient flow in resource-constrained facilities.

2.17.6. IMPLEMENTATION

LEOSED reached a prototyped and experimentally validated stage, with two fully functional client systems and one edge-server implementation deployed at the IMAGINE-B5G Norway facility. The trials spanned the full 12-month project duration and involved indoor testing of both the admission and monitoring scenarios under controlled lighting and calibrated measurement conditions. No patients or clinical staff participated; instead, developers and volunteers acted as test subjects, as the system processes no personal identifiers and stores no data.

Testing followed a phased methodology: evaluation of network capacity using iPerf and RTT measurements; assessment of uplink throughput and stability during continuous sensing sessions; and controlled validation of optical vital-sign accuracy under calibrated conditions. The infrastructure consisted of two client stations equipped with optical cameras, calibrated lighting, a touchscreen interface, and a 5G modem. The edge server hosted the sensing, diagnostics and statistics modules and was connected to the NW's facility standalone core through a dedicated address and network slice.

2.18. IMAGINE-B5G – XR-ENABLED TELE-REHABILITATION WITH REAL-TIME BIOMECHANICAL TRACKING (5G4REHA)

2.18.1. DESCRIPTION AND OBJECTIVES

5G4Reha[11] is an IMAGINE-B5G Open Call 3 vertical experiment project spearheaded by NISSATECH[12]. The project relies on an advanced tele-rehabilitation system that combines real-time biomechanical monitoring with XR-based guidance. The system builds on the D2Rehab platform, which uses wearable Inertial Measurement Units (IMUs) to compute movement parameters such as velocity, force and power. Through B5G connectivity, these indicators are transmitted to a remote clinician who supervises the rehabilitation session and adapts training steps as the patient performs them. The objective of this vertical experiment project is to restore the immediacy of in-person supervision by enabling clinicians to detect anomalies and provide corrective actions during the session. A further

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[11] https://imagineb5g.eu/5g4reha-in-imagine-b5g-open-call-3/

[12] https://nissatech.com/

goal is to support dynamic agility tests, where instructions are delivered through AR glasses and adjusted on the fly according to biomechanical feedback. The ongoing project aims to validate how B5G can sustain low-latency, high-stability transmission required for this interactive loop.

2.18.2. TARGET HEALTHCARE SCENARIOS AND ENVIRONMENTS

5G4Reha is intended for post-injury rehabilitation of athletes and physically active individuals who require precise monitoring of agility, strength, and movement control. It supports both indoor and outdoor environments, allowing exercises to be conducted in realistic conditions that better reflect sport-specific demands. This OC3 project is planned to be validated using the IMAGINE-B5G Norwegian facility, providing it with a reliable 5G access and controlled conditions. The target operational environment is semi-urban settings where XR-guided rehabilitation can be performed outside laboratory spaces while maintaining clinical oversight.

2.18.3. EXPECTED BENEFITS AND IMPACT ON PATIENT CARE

5G4Reha aims to improve rehabilitation precision by giving clinicians continuous access to biomechanical measurements that are normally available only in specialised labs. Patients receive immediate, personalised corrective feedback, improving adherence and accelerating functional recovery. Remote operation reduces the need for frequent clinic visits and enables clinicians to monitor more patients within the same time window. For athletes, the objective of the system is to offer more realistic performance assessment than standard, predefined tests.

2.18.4. TECHNICAL REQUIREMENTS AND DEPENDENCIES

The system requires stable low-latency uplink transmission to ensure timely delivery of biomechanical parameters from wearable sensors to the remote clinician. AR visual cues must also be delivered without delay to preserve the reactivity of the dynamic agility test. Processing relies on a cloud-based service fed via smartphones acting as gateways; thus, the end-to-end path between the user equipment and the cloud is the critical segment.

Key Performance Indicators (KPIs):

- Latency requirement: < 10 ms end-to-end (motion-to-response), essential for real-time AR visual delivery and preservation of test reactivity
- Uplink throughput: 12-14 Mbps (premium tier), required for timely delivery of continuous biomechanical parameters from wearable sensors
- Jitter stability: < 20 ms (to prevent packet overlap or congestion), critical to maintain test validity
- Data streaming continuity: 100% frame delivery required, with zero packet loss tolerance for uninterrupted IMU-based analytics

- Service availability: ≥ 99.99%, ensuring continuous cloud service connectivity during therapy sessions
- Connection density: Support for simultaneous multi-patient monitoring with dynamic network slicing (≥ 2 simultaneous slices)
- B5G capacity: Sufficient to support concurrent multimedia streams (sensor data + AR video) without congestion-induced degradation

B5G capacity and jitter stability are essential, as packet overlap or congestion directly influences test validity. Accurate IMU-based analytics depend on continuous sensor data streams without frame loss.

2.18.5. ENVIRONMENTAL, SOCIETAL, AND ECONOMICAL CONSIDERATIONS

Although the vertical experiment is still under evaluation, the system shows clear sustainability potential. Remote supervision reduces travel needs and mitigates reliance on resource-intensive motion-analysis laboratories. Wearables and XR interfaces require less energy and infrastructure compared with traditional in-clinic assessment setups. Societally, the system promises to increase access to specialised rehabilitation for patients with mobility limitations or living far from physiotherapy centres. Economically, it lowers the cost per session by replacing high-end laboratory equipment with cloud-supported, B5G-connected tools and enables scalable remote rehabilitation services.

2.18.6. IMPLEMENTATION

The implementation of 5G4Reha consists of integrating IMU sensors, AR glasses, and the D2Rehab mobile application with the B5G platform. During trials, the athlete or patient receives dynamic movement instructions through AR glasses, performs the requested action, and streams sensor data via smartphone to the cloud-based processing service. Biomechanical indicators are computed in real time and displayed to the remote expert, who selects subsequent movement commands.

Trials conducted at the Norwegian IMAGINE-B5G facility are expected to compare performance over commercial 4G, Wi-Fi, and local 5G.

3. CHALLENGES AND IMPACTS

3.1. CHALLENGES (FROM KPIS RESULTS)

European 6G and B5G projects identify critical technical challenges for eHealth applications. Key Performance Indicators (KPIs) define measurable targets addressing performance, network functionalities, and infrastructure requirements necessary to deliver reliable, responsive healthcare services.

3.1.1. PERFORMANCE REQUIREMENTS

eHealth use cases impose stringent performance demands across latency, reliability, data rate, and energy efficiency dimensions.

Latency and Responsiveness constitute the primary performance challenge. TrialsNet remote proctoring and smart ambulance require end-to-end latency < 20 ms to enable real-time surgical guidance and paramedic decision support. AMAZING-6G cardiac monitoring scenarios span a wider latency range depending on urgency: critical patient monitoring (e.g., in ambulance, ICU, Cath Lab) tolerates < 100 ms, while pacemaker real-time reprogramming requires < 10 ms to ensure patient safety. IMAGINE-B5G eHealth applications target ≤ 15–100 ms depending on use case—critical for fall detection (≤ 100 ms) but requiring ≤ 15 ms for cognitive health monitoring. SUSTAIN-6G rehabilitation assessment allows < 20 ms end-to-end latency for AR-guided exercises. In 6G-PATH for the hydrogel patch use case it is required to send the 3D scan caring about 3 MBytes in less than 2 seconds, the project has achieved a delay of 65 ms end-to-end (between mobile application and FHIR store, including TLS handshake) with an average RTT of 25 ms, and in the case of the XR training, targeting a RTT between the client application and the server, an average of 20ms was achieved.

Reliability and Availability require near-continuous service. All projects target > 99.99% communication service availability, with mean time between failures exceeding 1 month to 1 year depending on use case acuity. IMAGINE-B5G's mobile health monitoring achieved 99.5–100% reliability and availability in trials, exceeding 99% targets. AMAZING-6G's ICU/ambulance and implantable device scenarios demand 99.9999% availability, reflecting life-critical requirements. A very high availability, over 99,99% for data transmission was also achieved in the 6G-PATH project in the hydrogel patch and elderly monitoring use cases.

Data Rate and Uplink Capacity challenge resource-constrained devices. TrialsNet requires < 100 Mbps uplink for remote operating environment data streams. AMAZING-6G home monitoring patches transmit < 100 Mbps, while pacemaker data requires only 4 kbps uplink but with stringent reliability. IMAGINE-B5G supports multi-tiered throughput: mobile health monitoring uses 8–14 Mbps (depending on resolution tier), while enhanced care facilities require 40–160 Mbps for HD streaming and positioning.

AI related KPIs, in terms of Accuracy requires a high performance when assisting the medical personnel, while the AI Processing Time is required to be under 1 minute. In 6G-PATH, the accuracy of the wound segmentation for non-large wounds was between 90 and 95% and the time to perform of 30 to 40 seconds.

The user experienced **Video Quality** (VQ) was investigated in the 6G-PATH project and based on the required VQ score of more than 3.5, it was achieved 3.672.

Energy Efficiency demands long battery life in wearable devices. AMAZING-6G patches must operate on 3.3V batteries < 1000 mAh capacity for several hours while transmitting 3.2 GB/day. SUSTAIN-6G imposes equivalent battery constraints for stationary rehabilitation monitoring. This represents a fundamental challenge: combining high data rate uplink (medical imaging), low latency, high reliability, and extreme energy efficiency simultaneously. The smart watch from the 6G-PATH project had a requirement of at least 24 hours lifetime while actively monitoring the patient.

3.1.2. NETWORK FUNCTIONALITIES

Beyond raw performance, healthcare applications require specialized network capabilities.

Connection Density varies by scenario. TrialsNet, AMAZING-6G, and SUSTAIN-6G support 10–100 UEs/km^2 for geographically distributed patient monitoring. AMAZING-6G's ICU/hospital scenarios handle 20–30 connected devices per facility NPN, requiring managed access control and resource allocation. IMAGINE-B5G trials successfully managed ≥ 2 dynamically instantiated network slices simultaneously, supporting both base and premium service tiers. High density of the supported PDU connections is required for the Health use cases, especially in hospital and nursing homes environments. In 6G-PATH project, the use cases achieved a density of around 10.000 simultaneously connected emulated devices.

AI-Driven Network Capabilities enable intelligent resource allocation. SUSTAIN-6G explicitly requires AI-supervised network routing and intelligent slicing to deliver required latency and throughput within energy constraints. IMAGINE-B5G measured fall detection accuracy ≥ 80%, body-part detection ≥ 80%, and blood-detection accuracy ≥ 80% in trials, demonstrating that application-level AI built on B5G networks enhances diagnostic accuracy. Smart network slicing allows separation of base tier (8–10 Mbps, 13–15 ms latency) and premium tier (12–14 Mbps, 10–13 ms latency) in trials.

Coverage and Deployment Flexibility address geographic disparity. TrialsNet requires indoor coverage for hospitals and outdoor coverage for smart ambulance. AMAZING-6G extends coverage to "country-wide including rural areas and indoor", addressing the fundamental challenge of healthcare equity. In the 6G-PATH XR training use case, the coverage RSRP varied between -78 and -95 dBm, with a requirement of more than -90 dBm, and the RSRQ stayed at -11 dB throughout, with the requirement of achieving above -10dB.

Positioning and Localization supports emerging eHealth scenarios. IMAGINE-B5G achieved < 5 cm positioning accuracy target, with actual trials achieving ≈ 1 cm accuracy. This precision enables geofenced medication alerts, room-based care coordination, and emergency responder dispatch in healthcare facilities. IMAGINE-B5G demonstrated sub-1-cm positioning accuracy, enabling location-aware fall detection and emergency response in facilities and homes.

3.1.3. INFRASTRUCTURE DEPLOYMENT

Service Area Requirements impose deployment constraints. SUSTAIN-6G specifies country-wide coverage including rural areas and deep indoor, served by stationary UEs (rehabilitation centres or homes). AMAZING-6G extends across scenarios from stationary home monitoring to high-speed air ambulances (< 250 km/h), demanding seamless handover and non-stationary coverage. TrialsNet focuses on indoor hospital environments requiring reliable coverage.

Spectrum Efficiency and Frequency Bands shape deployment. 6G-LEADER targets optimized spectrum usage across FR1 and FR3 frequency bands for healthcare applications, reducing infrastructure requirements while maintaining coverage. AMAZING-6G's medical ultrasound monitoring scenarios reference 3GPP TS 22.263 profiles for "UHD video medical examination," and go beyond by proposing more stringent requirements on battery life as input to 3GPP's 6G standardization effort[13], indicating alignment with emerging standards.

Edge Computing and Network Segments determine latency achievable. eHealth applications require RAN, Transport, Core, and potentially Edge/Far-Edge processing layers to meet < 20 ms latency targets. IMAGINE-B5G's results confirm that latency distributed across these segments can achieve target performance: 13–15 ms for remote health monitoring (< 100 ms target) and 27–33 ms for elderly care facilities (≤ 50 ms target). SUSTAIN-6G's AR rehabilitation requires edge-based AI inference for real-time motion analysis without introducing unacceptable latency.

3.1.4. OTHER OPERATIONAL REQUIREMENTS

Mobility and UE Speed vary dramatically by scenario. TrialsNet smart ambulance requires high-speed mobility (approximately up to 130 km/h). AMAZING-6G home monitoring suits stationary patients, while ambulance scenarios require < 140–250 km/h mobility, and air ambulances up to < 250 km/h. Maintaining > 99.99% availability across these speed regimes requires sophisticated handover algorithms and network optimization.

Battery Life Under Realistic Load presents a critical challenge for long-term adherence. AMAZING-6G's 3.2 GB/day upload requirement from a < 1000 mAh battery demanded novel approaches to data compression, network efficiency, and selective transmission. Real-world validation of this remains a key challenge as trials progress.

Interoperability and Standardization ensure deployability. Projects align with 3GPP TS 22.261/22.263 standards where possible and propose new requirements into 3GPP where not, ensuring compatibility with existing and planned 5G/6G infrastructure. 6G-LEADER's emphasis on standardization contributions prevents proprietary lock-in in healthcare deployments. 6G-PATH employs open standards, and apart 3GPP, uses HL7 FHIR for patient data operations and OpenID, based on OAuth2.0, for authentication and authorization.

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[13] 3GPP S1-254427, "New Use Case on Medical applications in 6G".

3.1.5. SYNTHESIS: TECHNICAL CHALLENGE SUMMARY

eHealth applications across European 6G/B5G projects face **convergent technical challenges**:

- **Performance**: Sub-20-ms latency for real-time procedures contrasted against > 99.99% availability and extreme energy efficiency—pushing fundamental technology limits;
- **Network Functionalities**: Intelligent slicing, AI-driven routing, and high-density connectivity enabling simultaneous multi-patient monitoring with diverse QoE requirements;
- **Infrastructure**: Country-wide coverage extending to rural and indoor locations while maintaining backhaul connectivity to edge computing resources for low-latency AI inference;
- **Operationalization**: Seamless mobility, long battery life, standardization, and interoperability enabling practical, scalable deployment across diverse healthcare settings and patient populations.

These challenges—quantified through project-specific KPI targets and validated through 2025 trials—define the technical roadmap for 6G/B5G healthcare applications.

3.2. IMPACTS

This section summarizes the impacts of eHealth use cases developed within European 6G and B5G projects—TrialsNet, AMAZING-6G, Multi-X, 6G-PATH, 6G-LEADER, IMAGINE-B5G, and SUSTAIN-6G. These use cases demonstrate measurable outcomes across social, experiential, environmental, and economic dimensions. The analysis is based on Key Value Indicators (KVIs), which complement traditional technical KPIs by focusing on how advanced communication technologies deliver value beyond network performance. KVIs help translate societal and user-centric values into technology requirements, guiding the development of mobile solutions that align with sustainability and impact goals. By evaluating KVIs within specific use cases, the focus shifts from technical delivery to the real-world benefits and outcomes of technology adoption.

3.2.1. SOCIAL IMPACT

The social impact of 6G-enabled eHealth solutions encompasses improvements to patient outcomes, quality of life, healthcare equity, and accessibility. These impacts address fundamental societal challenges in healthcare delivery, particularly for underserved populations and patients with chronic conditions requiring continuous monitoring.

- **TrialsNet** validated social benefits through 2025 trials. The Mass Casualty Incident use case (UC6, June 2025) demonstrated support for first responders by proving enhanced situational awareness, tools for faster triage, and timely interventions in crowded urban emergencies. Remote Proctoring (UC7, July 2025) enabled cardiac surgeons with smart glasses to receive real-time expert guidance while sharing diagnostic data, addressing geographic barriers in specialized care. Smart Ambulance (UC8, June 2025) turns emergency vehicles into intelligent, connected nodes in the healthcare ecosystem, enhancing coordination, speeding clinical decision-making, and ensuring seamless continuity of care from the scene to the hospital.

- **SUSTAIN-6G** addresses social impact through AI-supervised remote rehabilitation with tailored clinical feedback and improved health outcomes. The KVI "Social Inclusivity" ensures underserved/rural areas receive equivalent rehabilitation service quality, measured through rehabilitation outcome metrics across locations. "Improved health" is measured through outcome improvements compared to standard practice. "Patient experience" is enhanced through immersive AR visualization during exercises, measured by patient satisfaction surveys.
- **AMAZING-6G** measures social impact through reduced time to diagnosis and lower morbidity and mortality via early cardiac detection, and patient reach in rural areas tracked by number of patients served remotely.
- **Multi-X** enables contact-free eHealth monitoring without wearables, making health monitoring accessible to patients unable or unwilling to use traditional sensors.
- **6G-PATH** significantly expands the social impact by democratizing access to chronic wound care through mobile bioprinting infrastructure, addressing elderly care crisis via a 1-to-10 supervision scalability that combats healthcare workforce shortages, and ensuring standardized prehospital nurse training regardless of institutional resources. The elderly monitoring system enables extended independent living while maintaining dignity, an increasingly critical consideration as multigenerational households continue to decline across Europe. Mobile delivery of hydrogel patches reduce geographical disparities for immobile elderly populations, ensuring equitable access to advanced treatment. At the same time, XR-enabled training provides consistent emergency response competency nationwide, directly improving public safety outcomes and community resilience.
- **IMAGINE-B5G** integrated wearable sensors with emergency responder-specialist collaboration, improving response capabilities.

3.2.2. ENHANCED USER EXPERIENCE

Enhanced user experience in 6G-enabled eHealth applications focuses on convenience, ease of use, reduced burden, and improved interaction with healthcare systems. The user experience dimension encompasses both patient-facing and healthcare provider-facing aspects, recognizing that Quality of Experience (QoE) in healthcare applications differs fundamentally from traditional telecommunications services.

- **TrialsNet** achieved seamless experience through low-latency B5G connectivity. Smart glasses provided clear first-person operating field views with streaming cardiac imaging. AR/VR headsets enabled intuitive paramedic-specialist interaction with decision support overlays. Portable, 5G connected, ultrasound scanners carried onboard ambulances enable paramedics to collaborate with a remote sonographer in real time, supporting pre-hospital ultrasound assessment and early diagnosis before hospital arrival. Robots equipped with cameras and 5G connectivity enable emergency coordinators and first responders to obtain a better view of the situation in the field, in the case of MCIs, while wearable devices monitoring vital signs and corresponding analytics can support both triage for acute emergency response and contribute to improved pre-hospital care.

- **SUSTAIN-6G** measures user experience through caregiver experience (reduced therapist overload via AI-triggered contacts only, measured by average cognitive load scores) and patient experience (immersive, engaging AR exercise visualization, measured by satisfaction surveys).
- **6G-LEADER** targets low latency improvements enabling microsecond-level responsiveness for immersive remote procedures. Validated usability through multiple video feeds, audio communication, and low-latency transmission supporting remote simulator control with real-time instructor feedback.
- **AMAZING-6G** reduced non-essential visits through remote optimization, measured by follow-up visits per year, and enabled activity-aware device adaptation preserving performance across daily activities.
- **6G-PATH** advances user experience across clinical care, rehabilitation, training, and elderly support. On-site personalized 3D hydrogel patch fabrication eliminates the need for multiple clinical visits typically required for iterative wound assessment, while real-time, video-supported rehabilitation enables immediate corrective feedback during home-based exercises. For healthcare learners, unlimited repetition of authentic scenarios allows skill mastery for learners without exposing patients to risks. The intelligent alerting system reduces alarm within the elderly monitoring platform further improves usability by reducing alarm fatigue and notifying caregivers only when intervention is necessary. In addition, ambulance-based manikin training provides unparalleled realism, while objective quantitative wound tracking, capturing parameters such as area, depth, and volume, replaces subjective visual assessment, thereby enhancing clinician confidence in treatment decisions.

3.2.3. SUSTAINABILITY (BEHAVIORAL)

The sustainability impact of 6G-enabled eHealth solutions addresses environmental footprint reduction through decreased carbon emissions, reduced travel, extended device lifecycles, and optimized resource utilization. As healthcare systems worldwide commit to climate action—with many pledging 50% emissions reductions by 2030 and net-zero by 2050—telemedicine enabled by advanced networks becomes a critical tool for environmental sustainability.

- **TrialsNet** reduces professional travel by eliminating surgeon travel to remote sites (UC7) and enabling rapid specialist consultation during transport (UC8), reducing patient transfer to distant centers.
- **SUSTAIN-6G** prioritizes sustainability with three environmental KVIs: Energy efficiency (FiWi technologies reduce hospital power consumption, measured via smart meters); Carbon footprint reduction (remote rehabilitation eliminates patient travel, measured by estimated CO_2 avoided per session and number of avoided travels); Waste reduction (edge-based AI motion evaluation eliminates need for patient hardware upgrades, measured by number of devices not requiring hardware replacement).

- **6G-LEADER** develops energy-efficient 6G networks with reduced energy consumption and EMF exposure through optimized spectrum usage in FR1/FR3 bands. Multi-X unifies sensing and communication in a single energy-efficient system.
- **AMAZING-6G** measures sustainability through estimated CO_2e avoided per patient per year (tracked via avoided hospital travels and captures reduced CO_2-eq per patient lifetime through extended device durability, fewer surgeries, and reduced clinical travel.
- **6G-PATH** contributes to sustainability by streamlining the medical supply chain through on-site bioprinting and replacing non-degradable conventional wound dressings with biodegradable hydrogel materials. Paperless digital wound documentation eliminates physical records, while virtual training scenarios reduce training consumable usage in educational settings. Shared simulation infrastructure across institutions prevent equipment duplication, and nomadic micro network deployments optimize energy consumption in rural areas. Home based elderly monitoring reduces the need for routine assessment visits, and mobile wound care units minimize facility energy consumption compared to permanent rural clinic infrastructure. Collectively, these innovations lower the environmental footprint of healthcare delivery.

3.2.4. AFFORDABILITY (ECONOMIC SUSTAINABILITY)

The affordability, i.e. economic sustainability, encompasses the financial viability and affordability of healthcare delivery for patients, providers, payers, and society. The 6G-enabled eHealth use cases demonstrate substantial potential for cost reduction while maintaining or improving care quality, addressing the critical challenge of rising healthcare expenditures globally.

- **TrialsNet** multiplies specialist capacity through remote expertise and enables early intervention preventing ICU complications.
- **SUSTAIN-6G** measures economic value through: Operational cost savings (economic value of reduced patient mobility, measured by total cost per travel); Increased productivity (therapist contacts patients only when AI signals problems, measured by mean number of patients per therapist); New business opportunities (expanded eHealth services, measured by number of new rehabilitation pathologies treated); Network resource efficiency (AI-driven routing and intelligent slicing provide required latency/throughput, measured by end-user latency, jitter, and throughput).
- **6G-PATH** delivers economic and operational efficiencies through transformative innovations. The system delivers a revolutionary 1-to-10 elderly patient supervision ratio, generating substantial labour productivity gains, while preventing costly fall-related injury cascades and emergency hospitalizations. The mobile bioprinting unit enhances capital efficiency by serving multiple rural communities and reduces chronic wound related hospitalization through accelerated healing. Instructor productivity is amplified through remote multi-cohort training, while the elimination of redundant simulation facilities across institutions lowers infrastructure investment requirements, allowing pharmaceutical expenditure. Early detection of health deterioration prevents costly acute-care interventions, and standardized training ensures consistent institutional quality without proportional increases in operational costs.

- **6G-LEADER** reduces operational complexity and network management costs through Open RAN standardisation.
- **IMAGINE-B5G** shifted operations toward efficiency models.
- **AMAZING-6G** reduces cost of care by reduced hospital visits and stays and earlier intervention avoiding the cost of complications.

3.2.5. SYNTHESIS: INTEGRATED IMPACT SUMMARY

European 6G/B5G projects demonstrate convergent impacts across dimensions:

- **Social Impact:** Early diagnosis improving outcomes, geographic equity in rehabilitation quality, AI-enhanced clinical feedback, and professional training advancement (6G-PATH).
- **Enhanced User Experience:** Sub-10ms latency enabling immersive procedures, reduced caregiver overload, intuitive AR/VR interfaces, and fewer unnecessary visits.
- **Sustainability:** Travel elimination for professionals and patients, energy-efficient architectures, CO_2 reductions per session/patient/year, and waste reduction through intelligent edge computing.
- **Affordability:** Specialist capacity multiplication, reduced patient mobility costs, device lifetime extension, increased therapist productivity, and scalable training deployment.

These impacts—validated across diverse applications from cardiac interventions to rehabilitation to emergency response—demonstrate that 6G/B5G technologies deliver simultaneous benefits in clinical effectiveness, user experience, environmental responsibility, and economic viability.

3.3. REGULATORY AND ETHICAL CONSIDERATIONS

Today we experience the convergence of 6G and eHealth promising immense opportunities for predictive diagnosis, personalized medicine, remote monitoring, and AI-driven clinical support. However, the potential of 6G also raises significant regulatory and ethical challenges. These range from safeguarding patient privacy and ensuring cybersecurity to addressing the fairness of AI-driven decisions and defining liability in critical healthcare use cases. The regulatory and ethical frameworks established **General Data Protection Regulation (GDPR)**, **AI ACT**[14] **and CYBERSECURITY ACT**[15] will determine whether 6G-enabled healthcare systems evolve in ways that are trustworthy, equitable, and sustainable.

3.3.1. DATA PRIVACY AND PROTECTION

Healthcare is among the most sensitive domains for data governance. Regulations such as the **General Data Protection Regulation (GDPR)**[16] in Europe and the **Health Insurance Portability and Accountability Act (HIPAA)**[17] in the United States impose strict rules on

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[14] https://digital-strategy.ec.europa.eu/en/policies/regulatory-framework-ai

[15] https://digital-strategy.ec.europa.eu/en/policies/cybersecurity-act

[16] https://eur-lex.europa.eu/eli/reg/2016/679/oj

[17] https://en.wikipedia.org/wiki/Health_Insurance_Portability_and_Accountability_Act

patient data handling. With 6G, where data flows across distributed, federated, and often cross-border systems, compliance becomes more complex as special categories of data (health, biometrics etc.) demand privacy-by-design architectures and fine-grained consent management.

New paradigms like **federated learning** and **zero-data movement**[18] can help protect patient privacy by training AI models without transferring data. Policymakers need to clarify how emerging techniques align with existing data protection frameworks and how new regulations are needed to account for sensitive and high-risk data distributed AI in healthcare. While Ethical considerations include transparency about secondary use of data and robust anonymisation for research.

From March 2025: The European Health Data Space (EHDS) Regulation enters into force. It is designed to benefit all EU citizens, including patients, healthcare professionals, researchers, policymakers, and industry players. The EHDS Regulation[19] aims to establish a common framework for the use and exchange of electronic health data across the EU. It enhances individuals' access to and control over their personal electronic health data, while also enabling certain data to be reused for public interest, policy support, and scientific research purposes. It fosters a health-specific data environment that supports a single market for digital health services and products. Additionally, the regulation establishes a harmonised legal and technical framework for electronic health record (EHR) systems, fostering interoperability, innovation, and the smooth functioning of the internal market.

3.3.2. SECURITY AND TRUSTWORTHINESS

6G networks will support applications such as **remote surgery, real-time monitoring, and AI-assisted diagnostics**, which are mission-critical and highly sensitive to disruptions. In a connected health system breach of security could compromise a patient´s identity and pose a threat to safety.

Hence robust health regulations must be ensured including (but not limited to):

- **End-to-end encryption** for all patient-related data flows.
- **Post-quantum cryptography** to prepare for future threats.
- **Robust identity and access management** across heterogeneous devices.
- **Zero-trust architectures** that verify all devices and users consistently.

Trust frameworks must also ensure that medical devices, networks, and cloud-based health services are certified and interoperable.

Overall, Health technologies must integrate lifecycle-aware design, energy-efficient edge computing, and ensure lawful processing, transparency, and user control compounded with responsible use of AI for optimisation.

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[18] Koutsopoulos, K., Mohnani, P., Gavras, A., Toscano, O., Ertl, B., & Ledakis, G. (2025, June 26). 6G Sustainable Privacy Preserving Framework Enabling Federated Learning for Health Data. https://doi.org/10.5281/zenodo.15744511

[19] https://health.ec.europa.eu/ehealth-digital-health-and-care/european-health-data-space-regulation-ehds_en

As decision-making shifts toward autonomous or semi-autonomous systems, responsibility boundaries must be defined among telecom operators, healthcare providers, device manufacturers, and AI vendors. Regulatory clarity is needed on liability in case of malfunction, incorrect advice, or data breaches. Ethical governance includes transparent documentation, auditable decision logs, and continuous monitoring. Whilst the global nature of 6G networks raises questions of jurisdiction, data localisation, and interoperability of regulatory regimes. Safe cross-border telemedicine requires alignment with EU adequacy decisions, standard contractual clauses, and secure multi-party computation for sensitive data exchange.

4. CONCLUSIONS AND FUTURE PATHWAYS

4.1. VALIDATED EVIDENCE AND TECHNOLOGICAL READINESS

The SNS JU portfolio has conclusively demonstrated that 6G and advanced B5G network technologies provide a technically sound, operationally viable, and clinically safe foundation for transforming European healthcare delivery. This assertion is not based on simulation, extrapolation, or theoretical analysis, but on validated outcomes from real-world deployments involving actual patients, actual healthcare professionals, and actual clinical workflows.

The TrialsNet Mass Casualty Incident and emergency response use case trial in June 2025 Field trials demonstrated that the corresponding solution meets or exceeds the defined key performance indicators, including latency, throughput, accuracy, reliability, and location precision. User-centric Key Value Indicators—such as user experience, trustworthiness, and resilience—were consistently rated above 4 out of 5, confirming both technical readiness and operational acceptance. Overall, the trial showcased that 6G-enabled eHealth and emergency response systems can operate safely, reliably, and effectively in real-world mass casualty scenarios, positioning next-generation networks as a foundational enabler for future public safety and emergency healthcare services.

The TrialsNet remote proctoring trial of July 2025 represents a watershed moment in this validation. A real cardiac surgeon performing a real interventional procedure on a real patient, guided in real time by a remote expert via augmented reality glasses and B5G connectivity, demonstrates that expertise can be decoupled from geography in a mission-critical healthcare domain. The technical performance was precisely as required: sub-20 millisecond latency enabled natural real-time interaction; high bandwidth supported simultaneous streaming of cardiac imaging modalities; network reliability never wavered. From a clinical perspective, the remote proctor assessed the procedure as equivalent in safety and quality to in-person guidance. From an operational perspective, the setup required no specially engineered facilities, just application of standard 5G deployment with appropriate network slicing. Replicating this across other cardiac centers, other surgical specialties, and other clinical domains is primarily a matter of systematic deployment rather than technological innovation.

The Smart Ambulance trial provides compelling validated evidence of technological readiness for 5G-enabled emergency telemedicine in motion. In a realistic time-critical scenario, an ambulance crew transmitted diagnostic-grade cardiological data while maintaining continuous audio/video collaboration with a remote specialist in Massa. Live echocardiographic streams were shared during transport, and the paramedic received step-by-step, hands-free guidance via an AR headset, demonstrating that hospital expertise can be extended into the ambulance at the moment when triage and early decisions matter most. The trial confirmed that the end-to-end integration of 5G SA connectivity, onboard diagnostics, and immersive telepresence can operate effectively under mobility constraints, supporting clinically meaningful remote support without requiring specially engineered facilities.

A key readiness enabler is the ER Innovative Orchestrator deployed in TrialsNet, which dynamically enforces service differentiation through 5G SA slicing so that mission-critical clinical flows remain protected as conditions change along the route.

Across the portfolio, latency validation consistently demonstrates sub-20 millisecond achievement in operational trials. IMAGINE-B5G trials achieved 13 to 15 milliseconds for remote health monitoring and 27 to 33 milliseconds for elderly care facilities, both comfortably within clinical requirements. SUSTAIN-6G remote rehabilitation achieved target latencies supporting real-time feedback during exercise. This consistency across independent project teams and diverse use cases strongly indicates that sub-20 millisecond latency is not an aspirational goal but an achieved technical characteristic of properly configured 6G and advanced B5G systems.

Service availability has similarly exceeded clinical requirements. Projects report 99.99% or better availability in operational trials, with mean time between failures exceeding 1 month in non-critical scenarios and 1 year or more in mission-critical deployments. These figures align with the reliability standards demanded by intensive care unit monitoring, emergency department operations, and surgical facilities. Availability at this level does not emerge accidentally; it reflects deliberate engineering incorporating redundancy, sophisticated monitoring, and automated recovery mechanisms. Yet these are well-established practices within telecommunications and data centre operations, requiring adaptation rather than innovation for healthcare applications.

Network slicing technologies have proven effective at enabling simultaneous support for diverse quality-of-service requirements. IMAGINE-B5G trials successfully maintained two separate service tiers—a base tier for routine monitoring and a premium tier for urgent notifications—simultaneously within a single network, with each tier maintaining its contracted performance characteristics. This capability directly addresses a key healthcare requirement: ensuring that routine monitoring never consumes resources needed for time-critical alerts. The technical mechanism—dynamic traffic routing and resource allocation based on packet tagging and service-level agreements—is well-established in telecommunications but represents a substantial advance when applied to healthcare workflows where the cost of prioritization failures is measured in human health rather than customer satisfaction.

Device interoperability and data integration have been validated through HL7 FHIR standardization efforts embedded within project work. Rather than requiring all devices to be replaced with 6G-native equipment, projects demonstrated seamless integration of legacy devices, new 5G-capable devices, and even non-connected systems through standardized data interchange protocols. This pragmatic approach to interoperability dramatically accelerates real-world deployment by enabling incremental technology adoption within existing healthcare environments rather than requiring wholesale infrastructure replacement.

Artificial intelligence integration at network edges has emerged as a core capability enabling new care delivery models. AMAZING-6G's wearable ultrasound patch cardiac monitoring use case proposes machine learning algorithms assessing cardiac function at network edges without transmitting raw cardiac data to cloud systems. This approach simultaneously reduces latency, minimizes privacy risk through data minimization, and reduces network bandwidth requirements. For its predictive reprogramming of implantable cardiac devices use case, AI is used for activity-aware forecasting of reprogramming parameters at the edge. This approach reduces on-device computational load and end-to-end system latency and improves sensing accuracy. SUSTAIN-6G rehabilitation systems deployed computer vision algorithms analysing patient movement quality in real time, generating feedback to patients and alerts to clinicians only when movement patterns deviate significantly from therapy targets. This selective alerting dramatically reduces information overload for healthcare professionals while maintaining continuous oversight. The collective effect is distributed intelligence throughout the network rather than centralized processing, with profound implications for both performance and privacy.

4.2. REMAINING RESEARCH FRONTIERS AND OPPORTUNITIES FOR IMPACT

Despite these achievements, several research and deployment frontiers remain open, presenting opportunities for continued innovation and strategic investment over the coming years and beyond.

Scaling Beyond Pilot Environments and Validation to Operational Reality - Current validations, while rigorous and clinically sound, have operated within bounded geographic regions and controlled settings. Translation to pan-European scale requires addressing coordination challenges that transcend individual projects. Spectrum allocations must achieve sufficient harmonization across member states to enable roaming for healthcare professionals and mobile patients. Network operators and healthcare system administrators must develop service-level agreements and liability frameworks appropriate for cross-border healthcare delivery. Clinical governance mechanisms must accommodate differences in national medical practice and regulatory frameworks while ensuring that basic safety standards remain consistent. Rural infrastructure investments must extend coverage to regions where commercial deployments lack economic incentive. These challenges are not primarily technical—the underlying technologies are proven—but rather organizational and governance challenges requiring coordinated policy action.

Artificial Intelligence Governance and Clinical Accountability in Autonomous Systems - As artificial intelligence becomes integral to clinical decision-making through continuous monitoring, alert generation, and therapy recommendations, critical questions emerge regarding governance, liability, and safety. How should medical AI models be evaluated for clinical safety when the models are continuously updated and refined? Traditional medical device approval processes assume static product characteristics; continuous learning systems violate this assumption. Who bears liability when an AI system fails to detect a critical condition, or alternatively, when it generates a false alarm triggering unnecessary intervention? Should liability rest with the device manufacturer, the healthcare organization deploying the system, or the physician relying on AI recommendations? How should algorithmic bias be detected and mitigated when AI systems may make decisions affecting diverse patient populations? What transparency and explainability standards are appropriate for clinical AI, balancing the need for clinician understanding against the reality that many machine learning approaches lack inherent interpretability? These questions demand engagement across technical communities (developing verifiable AI approaches), clinical communities (establishing appropriate trust and reliance frameworks), legal communities (developing accountability mechanisms), and ethical communities (ensuring equity and fairness).

Environmental Sustainability Deep-Dives and Lifecycle Analysis - While preliminary analyses suggest that 6G-enabled telemedicine can reduce healthcare carbon footprints by 40 to 60 percent per clinical episode, comprehensive lifecycle analysis remains incomplete. Manufacturing impacts of network infrastructure, including rare-earth materials, energy-intensive semiconductor production, and supply chain logistics, must be quantified. End-of-life considerations regarding electronic waste from devices with rapid technology cycles require attention. Comparative analysis between centralized cloud computing, distributed edge computing, and on-device processing—in terms of total environmental footprint—remains preliminary. The potential for rebound effects, where improved efficiency leads to expanded consumption patterns, must be monitored. What if widespread availability of virtual rehabilitation leads not to replacement of in-person therapy but to expansion of overall service volumes, partially offsetting carbon benefits? Environmental sustainability requires not merely technological efficiency but also policy mechanisms ensuring that efficiency gains translate to reduced aggregate environmental impact.

Integration with Complementary Network and Computing Paradigms - The white paper focuses on wireless connectivity, yet holistic healthcare ecosystems require integration with wired backhaul networks, satellite connectivity for truly remote regions, deterministic time-sensitive networking for surgical robotics and closed-loop therapies, and computing platforms spanning from ultra-low-power device processors to high-performance data centres. The relative maturity of different technology components creates integration challenges—wireless 6G architectures advance while some aspects of satellite 6G remain in early research phases, deterministic networking remains an emerging research area, and federated computing spanning edge to cloud involves coordination across heterogeneous infrastructure. Standardization efforts must ensure coherent integration rather than creating isolated silos.

Behavioural, Organizational, and Adoption Barriers - Technology alone does not ensure healthcare transformation. Understanding and addressing behavioural, organizational, and human factors represents a critical challenge. Healthcare professionals trained for decades in in-person patient care face significant change management when transitioning to technology-enabled remote care. Some clinicians will embrace new tools while others will perceive them as threatening professional autonomy or clinical quality. Patient acceptance varies dramatically—some elderly patients eagerly adopt wearable monitoring while others resist perceived intrusions on privacy. Healthcare organizations face governance questions about liability for outcomes mediated through technology, procurement challenges regarding budgeting and contracting for network services, and workflow redesign questions about optimal task allocation between human professionals and automated systems. These behavioural and organizational challenges are not more difficult than the technical challenges already overcome, but they are different in character and require different expertise—change management, organizational psychology, training and education, community engagement.

Equity Considerations and Avoidance of Digital Divides - While 6G-enabled eHealth promises to reduce healthcare disparities through democratizing access to specialist expertise, the pathways to deployment create risk of new digital divides. If 6G networks are deployed first in wealthy urban areas and slow to reach peripheral regions, the technology might initially worsen equity rather than improve it. If device costs or service pricing create barriers for lower-income populations, eHealth benefits might concentrate among wealthy demographics. If AI systems are trained predominantly on data from majority populations, algorithmic bias might disadvantage minority groups. Addressing these equity risks requires explicit governance mechanisms: equity-centred deployment strategies prioritizing underserved regions, pricing models ensuring affordability across income levels, and diverse training data for AI systems ensuring performance across demographic groups. Such mechanisms require both technical capability and policy commitment.

4.3. STRATEGIC RECOMMENDATIONS FOR 2025-2027 AND BEYOND

Building on demonstrated technical validation and recognizing the complexity of scaling innovation to transformation, the SNS JU community recommends coordinated action across multiple dimensions.

Immediate Actions: Consolidating Validation and Preparing Deployment (Late 2025–2026)

In the months ahead, priority should be given to consolidating proven technologies and preparing for systematic deployment. Establishing cross-border regulatory sandboxes involving the European Medicines Agency, national health authorities, and GDPR compliance bodies will create formal mechanisms for rapid certification of eHealth technologies while maintaining safety and privacy standards. Expanding clinical trials from single-site validations to multi-country, multi-institution deployments involving diverse patient populations and healthcare settings will generate evidence supporting broader adoption. Advancing standardization efforts through 3GPP, ETSI, and IEEE forums will ensure interoperability across vendor ecosystems and prevent proprietary lock-in. Targeted investment in rural and remote infrastructure through EU funding mechanisms and national programs will demonstrate commitment to equity and position peripheral regions as innovation testbeds for new care models.

Medium-Term Vision: Operational Deployment and Integration (2027–2028)

The next 18–36 months should mark the transition from validation to operational service deployment. Volunteer member states could serve as early adopters, converting successful pilots into ongoing operational services. These deployments will establish replicable models for other regions, incorporating lessons learned regarding procurement, training, governance, and change management. Development of AI certification frameworks will set EU-wide standards for pre-market and post-market surveillance of clinical AI applications. Implementation of EHDS-compliant data governance frameworks will enable secure, federated analytics across national boundaries while preserving privacy. Supporting professional training and accreditation programs will build the workforce competencies necessary for healthcare professionals to effectively utilize 6G-enabled systems.

Longer-Horizon Vision: Sustained Excellence Beyond 2028

Beyond this horizon, the strategic vision focuses on global positioning of European healthcare technology and system-level sustainability. Positioning European eHealth capabilities within international standards and partnerships will ensure that solutions developed within SNS JU are compatible with global health initiatives and exportable internationally. Ensuring equity-centric deployment at a systemic level—rather than episodic fairness efforts—will address structural barriers to access. Establishing permanent research consortia and innovation networks will maintain momentum in the 6G-eHealth domain as technologies, clinical practices, and societal needs continue to evolve.

4.4. CLOSING REFLECTION

This white paper represents a documentary record of a critical inflection point in European healthcare and 6G technology development. Projects have moved beyond theoretical potential to demonstrated, validated, clinically impactful outcomes. The evidence is clear: 6G technologies enable healthcare services that are simultaneously more accessible, more equitable, more sustainable, and more economically viable than existing models.

Yet evidence of feasibility does not guarantee implementation. History demonstrates that technically superior approaches often fail to displace incumbent systems due to organizational inertia, regulatory uncertainty, financing misalignment, or insufficient coordination among stakeholders. Healthcare systems across Europe remain organized around institutional and professional silos, with inadequate mechanisms for cross-border coordination, shared standards, or collective action toward common vision.

The opportunity before Europe is consequently not merely technical but fundamentally political and organizational. Policymakers must harmonize regulations and allocate infrastructure investment. Telecom operators must integrate healthcare workflows into network design and service prioritization. Healthcare organizations must embrace organizational change and workforce reskilling. Technology providers must prioritize interoperability and clinical robustness over narrow commercial advantage. Professional associations must develop training and certification standards for healthcare workers in 6G-enabled workflows. Educational institutions must incorporate digital health literacy into professional training curricula.

The technical foundation is solid. The clinical evidence is compelling. The societal benefits are substantial. The remaining challenge is coordination and commitment. If Europe's diverse stakeholders mobilize around this vision with even a fraction of the resources and energy mobilized for other strategic initiatives—whether climate transition, digital sovereignty, or advanced manufacturing—the result could be a healthcare system that is genuinely more equitable, more sustainable, and more humanistic than what exists today. The time for demonstration is now turning into the time for deployment.

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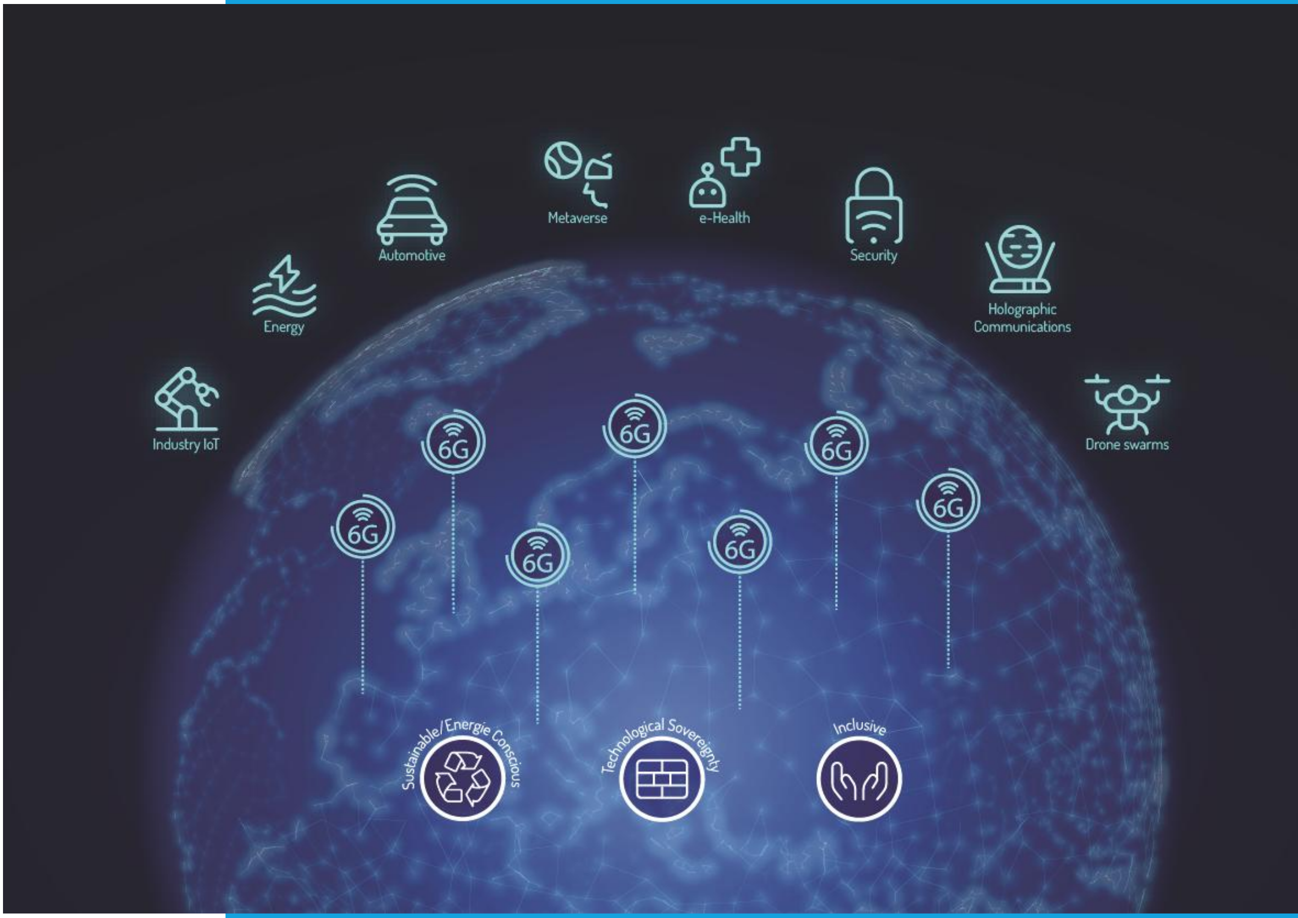

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