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Deliverable D4.2

First results of Use Cases implementation for eHE domain

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List of Acronyms and Abbreviations

Acronym	Description
AI	Artificial Intelligence
AR	Augmented Reality
B5G	Beyond 5G mobile network
CNN	Convolutional Neural Network
CNR	Consiglio Nazionale delle Ricerche
CPE	Customer Premises Equipment
DoF	Degrees of Freedom
DL	Deep Learning
eHE	eHealth and Emergency
EMG	Electromyography
EMS	Emergency Medical Services
ES	Experimental Session
5G	Fifth generation of mobile communications
HD	High Definition
HW	Hardware
IIT	Fondazione Istituto Italiano Di Tecnologia
IMU	Inertial Measurement Unit
KPI	Key Performance Indicator
KVI	Key Value Indicator
MCI	Mass Casualty Incident
ML	Machine Learning
MQTT	Message Queuing Telemetry Transport
MS	Milestone
NN	Neural Network
QoS	Quality of Service
RGB	Red-Green-Blue
TEI	Ericsson Telecomunicazioni SpA
TIM	Telecom Italia SpA
UC	Use Case
UC3M	Universidad Carlos III de Madrid
VPN	Virtual Private Network
VR	Virtual Reality
WINGS	Wings Ict Solutions
WP	Work Package
XR	eXtended Reality
USB	Universal Serial Bus

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Executive Summary

The D4.2 is a public deliverable, elaborated in the context of Work Package 4 (WP4) operating in the eHealth and Emergency (eHE) domains. The activities of WP4 are carried out in the overall project framework mainly addressing two important objectives: to perform trials of the Beyond 5G (B5G) technology specifically devoted to eHE domains, supporting innovative applications (e.g., Remote Proctoring and Smart Ambulance) in large-scale environments (e.g., hospitals), and introducing societal benefits in the eHE areas to facliate an early adoption of such new technologies.

While D4.1 [1] defines the use cases (UC) in terms of their initial application design, components, and functionalities, along with the preliminary technical requirements and the definition of the related Key Performance Indicators (KPIs) and Key Value Indicators (KVIs), D4.2 outlines the project's progress up to this point and focuses on reporting the initial implementation outcomes. The use cases within WP4 are organized into three main clusters, connecting expertise from Greece, Italy (Pisa site), and Spain. On such basis, for each use case, the deliverable provides a concise summary of the objectives and contexts, as well as a detailed explanation of the final application design and the preliminary integration and testing activities in terms of laboratory tests, on-field tests, and early demonstrations, shedding light on performance insights and potential challenges encountered during these activities. Finally, the document concludes with updates on the implementation plan for each use case, including a review of milestones and progress tracking.

WP4, as well as WP3 and WP5, is responsible for implementing the vertical use cases, WP4 specifically in the eHealth and Emergency domain. WP4 work is split into three main phases: the first phase is for use case definitions, captured in D4.1 [1], the second phase is to provide the initial results of the domain, reported in this current document and the third phase, dealing with providing the final implementation of the trials including the ones added through the Open Calls, will be considered in D4.3. To support the trials developed in WP4, WP2, responsible for the platforms and network solutions deployment, works in strict collaboration with WP4 to receive their requirements and providing back the complete infrastructure to perform the related trials. For WP4, and especially for UC7 and UC8, the interactions with WP2 are particularly intensive since a specific experimental infrastructure is going to be deployed from the scratch, tailored to accomplish their requirements. Preliminary design of such infrastructure is documented in public deliverable D2.1 [2]. The identification of KPIs, including their measurement, and KVIs is a cornerstone of the work reported in this document. In this context, WP4 is benefitting by the work of harmonization of the KPIs provided in WP6 and reported in D6.1 [3] as well as the Data Management Plan adopted by the project. It is also important to notice that the use case development and implementation constantly considers the ethic requirements defined in WP8.

A short summary for each use case scope and activities performed including first results is given below.

Use Case 6 "Mass Casualty Incident (MCI) and Emergency Rescue in Populated Area" (Athens/Madrid): It aims to offer cutting-edge technological solutions created by TrialsNet for the most effective coordination for first-case responders in the context of triage and coordination of resources at the scene of mass casualty incidents, which could be building collapses, earthquakes, fires, or other large-scale emergencies, and emergency evacuation in the context of a crowded sporting or cultural event. The evacuation part of the use case is going to be implemented both in Athens and in Madrid sites with the use of a different 5G infrastructures. For these use cases, some lab tests have been conducted as well as two early demos. In Athens site, two main scenarios/steps have been identified and tested. The first scenario focuses both on the patient profile creation and the device assignment to obtain the vital signs measurements and the final patient's health status from crowded images/videos. In the second scenario a new patient profile has been created and gets simulated vital signs for the triaging. The first results are encouraging and satisfying, in particular about the Recall (i.e., how often the algorithm correctly predicts a positive outcome out of all the actual positive outcomes) that is expected as the most critical KPI. The UC6 in Madrid has gone through a laboratory testing phase to obtain preliminary KPI measurements (throughput in particular) and assess behaviour in a controlled environment.

Use Case 7 "Remote Proctoring" (Pisa): It aims to support remote proctoring activities in the field of interventional cardiology, offering innovative solutions based on smart tools for telepresence in the surgical field to connect expert proctors and remote hospitals. It is going to be deployed by connecting two sites (Pisa and Massa) at a geographical distance. A private 5G indoor cell will cover the site where the proctor is located. The initial laboratory experiments were conducted in April 2023 within the Ericsson labs located in Pisa, at the Consiglio

Nazionale delle Ricerche (CNR) Campus area designated for the upcoming trial. From the application point of view, using video streaming, live communication tools, and XR supported by 5G, are improved so that a remote proctor can observe a surgical procedure in real-time and offer advice, feedback, and guidance, even if they are not physically present in the same location. The tests aimed to assess the impact of latency on the performance of eXtended Reality (XR) tools identified for use in the trial. In December 2023, tests on field were conducted within the CNR Campus, in internal premises. These tests aimed to assess the influence of the proposed technological innovations on the psychophysiological states and manual task performance of clinical users, identifying the maximum application one-way latency (defined as the amount of time it takes at application level from the source to the destination application) in about 20 ms, compatible with 5G SA performances.

Use Case 8 "Smart Ambulance" (Pisa): It proposes a 5G-connected smart ambulance operating outdoor in mobility. The use case is going to develop an infrastructure enabling ambulances to share diagnostic information with the main centre. In the current smart ambulance scenario, the employment of Virtual Reality (VR) and Augmented Reality (AR) spans two distinct sites, mirroring the framework explored in UC7. The key difference here is that one of these "sites", the ambulance, is moving. This adds an extra layer of complexity to maintaining consistent and reliable communication, requiring advanced connectivity to accommodate the dynamic nature of the ambulance's location. The infrastructure able to deploy UC8 will be designed ah-hoc in WP2 context, incorporating an outdoor antenna (micro cell, in mmWave spectrum) for area coverage and utilizes a specialized 5G Customer Premises Equipment (CPE) for the ambulance. The laboratory tests conducted for UC7 were intended to test the XR devices that will also be used in the context of the smart ambulance, albeit in a mobility scenario. The requirements that such devices demand from the network are the same as those for the UC7 scenario.

Use Case 9 "Adaptive Control of Hannes Prosthetic Device" (Pisa): This use case will focus on designing advanced control capabilities for prostheses using Artificial Intelligence (AI) methods and deployment on the Hannes arm. The main aim of UC9 is to improve the user experience, leveraging radio 5G connectivity to provide sufficient computing power to the prosthesis to deploy AI methods with high reliability and minimal latency. In this first phase the goal has been the assessment of the developed prototypes and their integration until an advanced level of readiness of the system is achieved. From an application point of view, one of the challenges has been to equip the prosthetic arm with different sensors, such as Electromyography (EMG) sensors (measuring the muscle activation of the user), an Inertial Measurement Unit (IMU) and a video camera mounted on the palm of the prosthesis and connected to an embedded electronic board. This latter is equipped with 5G network devices (such as a phone tethering) that allows to stream the data via radio from the sensors to a server, where the AI method runs. A set of tests has been already carried out to define the network performance baselines. One of the aims of these activities was to characterize the components to find the best configuration for each of them and to detect the possible network and application bottlenecks. These activities have been carried out both in the IIT and Ericsson laboratories in Genoa.

The information reported in this deliverable represents significant intermediate results concerning the use case implementation related to the eHE domain, stemming from the current versions of the applications and their preliminary laboratory and/or on-field evaluations tests, including KPIs measurements. These results will be used as basis for further progress towards the final trials phase, that will be based on the final implementation of the applications and the related platform and network solutions deployed in the different sites. The final results will be documented in the last WP4 deliverable D4.3 that will be released in September 2025.

1 Introduction

This deliverable, titled "First results of Use Cases implementation for eHE domain" provides a comprehensive report on the progress made in the implementation of four use cases: UC6 “Mass Casualty Incident and Emergency Rescue in Populated Area”, UC7 “Remote Proctoring”, UC8 “Smart Ambulance”, and UC9 “Adaptive Control of Hannes Prosthetic Device”.

The document provides in-depth insights into the application design, development activities, and the results of preliminary integration and tests for each use case.

Section 2 provides an in-depth report on the status of the four use cases. For each use case, it offers a summary of the respective objectives and contexts, and presents a detailed discussion on the implementation process, including the final application design, any deviations from the initial design, and the rationale behind these changes. It also covers the various development activities undertaken during the implementation phase and offers a clear view of the progress made in each use case.

Section 3 presents a detailed explanation of the initial integration and testing activities carried out for each use case. It reports on laboratory tests, field tests, and early demonstrations, and provides insights into the performance and potential issues encountered during these activities. The section provides test summaries, setup descriptions, and results for each trial, offering insights into the effectiveness and reliability of the use case implementations.

Section 4 updates on the implementation plan for each use case are provided. It includes a review of the milestones set out for each use case, tracking the progress made towards these goals. The section also covers issues encountered during the implementation process and explains how they have been or will be managed to minimize their impact on the project.

Finally, Section 5 reports the conclusions of the document that summarize the main findings from the use cases as well as outlines the subsequent steps related to WP3 activities, which will include the integration of application components with the final platform and network solutions, detail the final implementation and trial results.

2 Use Cases implementation status

This section presents a detailed report on the status of the four use cases, namely UC6 through UC9, encompassed within WP4.

For each use case, a summary is provided, recapping from D4.1 [1], to establish a clear understanding of the respective objectives and contexts. This sets the stage for a subsequent, more detailed discussion on the implementation process. Following this, an in-depth overview of the final application design for each use case is presented. This includes details about the architecture, modules, functionalities, interfaces, etc. Should there be any deviations from the initial application design as reported in the first deliverable, these variations are identified and described. The rationale behind these changes is also clarified, ensuring transparency, and understanding of the development process.

The next part of the use cases' descriptions delves into the various activities that have been undertaken during the development phase. This encompasses software/GUI development, algorithms implementation/integration, metaverse/XR environment development, and content production. The objective here is to offer a clear view of the practical elements of the project and to convey the progress made in the development of each use case.

2.1 UC6: Mass Casualty Incident (MCI) and Emergency Rescue in Populated Area (Athens/Madrid)

2.1.1 Use Case recap

This use case provides strategies for the basic approach to MCI response procedures, regardless of the type of threat. Safety resources should be built to handle MCI scenarios. The UC6 has the ambition to demonstrate the viability of a coordinated response in a densely populated area as well as more effective and digitally traceable pre-hospital care by first responders in the event of MCI. The UC6 has also the ambition to showcase the feasibility of a coordinated response in a densely crowded location during which the collected data will be utilized to derive insights for emergency crews to provide an optimal evacuation plan. Such a plan includes, with priority, optimal routes to the intervention targets (victims of the disasters), considering any obstacles or inaccessible sections that have been already identified. Through this use case, cutting-edge (and 5G/B5G) technologies will be shown off in a large-scale field exercise for more effective first responder communication, quicker and more efficient triaging, pre-hospital treatment and optimal evacuation routes, and they will be compared to the baseline approach using conventional approaches. Triage is of utmost importance in disasters and MCI, as it refers to contingency planning, the actions to be taken and the guidelines to be followed for the effective management of emergencies as well as the optimal evacuation plan. In addition, the UC presents non-limiting scenarios that demonstrate the possibilities offered using this technology for the development of individual tools that offer increased situational awareness to all involved users. In Athens both the Mass Casualty Incidents and Emergency evacuation cases (Trial 6.1 see section 3.1.1) will be trialed while in Madrid the focus will be on the Emergency evacuation (Trial 6.2 see section 3.1.2).

2.1.2 Final application design

The application design is based on the STARLIT++ platform developed by WINGS [4] (an enhancement of the WINGS STARLIT platform) and involves the deployment of devices such as drones/robots with the appropriate equipment (cameras, sensors, etc.) for real-time monitoring of a serious incident e.g., a fire, collapsed buildings which can cause injuries, or casualties during a cultural event/concert. The devices capture images, video, and other data, which are transmitted over 5G networks to a central platform for processing and analysis using AI models and techniques. For the MCI case, devices will also comprise certified wearable devices, that offer reliable medical information, for monitoring of vital signs, such as heart rate, oxygen saturation, body temperature, blood pressure, etc, which currently communicate via 4G for sending data of the vital signs. The platform comprises AI powered mechanisms for providing insights on a range of factors (e.g., estimated number of victims, potential issues for first responders to address in the field, estimated location of users, user’s vital signs evolution, forecasting of future issues and health emergencies, notification for designated doctors and first responders, etc) as shown in Figure 1.

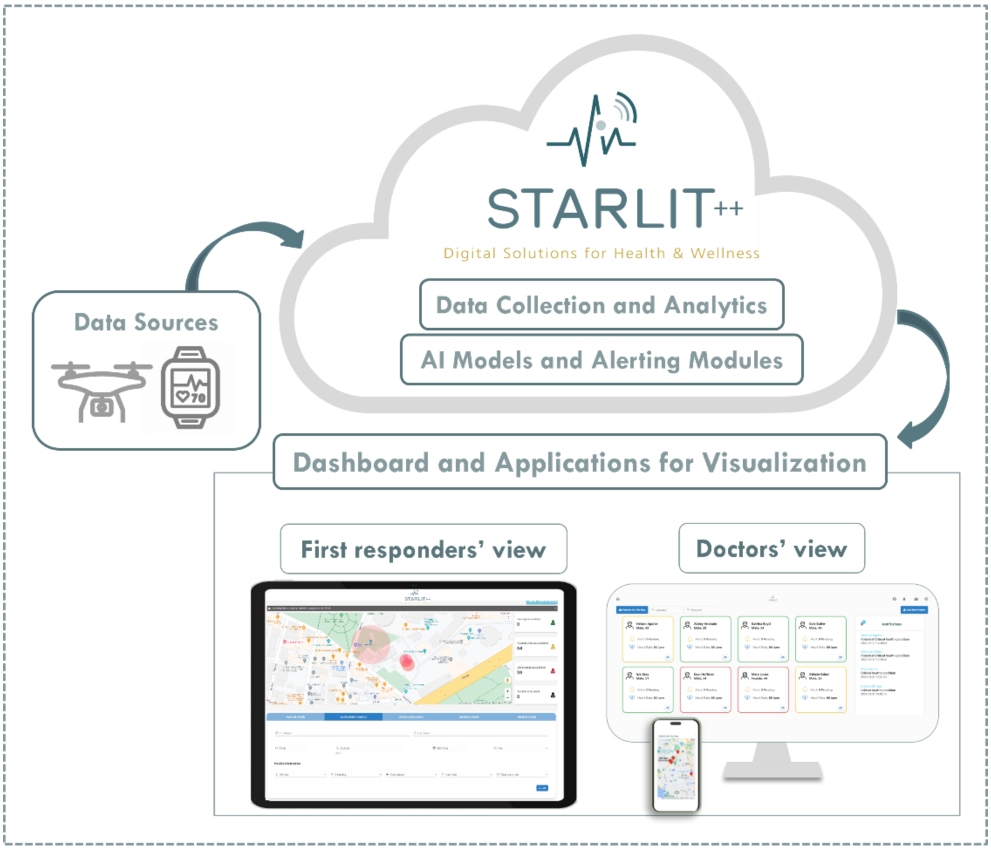

Figure 1. UC6 - Final application design for the MCI.

A high-level application architecture of the UC6 for the MCI is depicted in Figure 2 where a further analysis of the backend services for the data processing, the data storage, and in total the business logic is included.

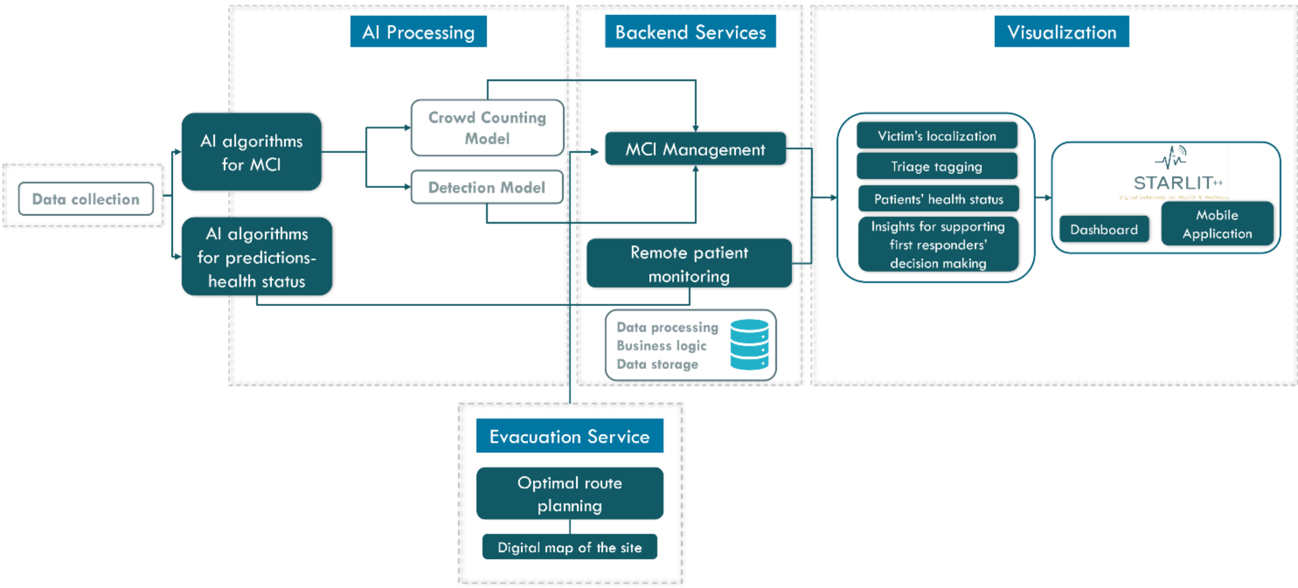

Figure 2. UC6 - High-level application architecture.

The equipment, the technologies and the devices required to develop and test the system for this use case are described in D4.1 [1] in section 3.1.2.2.

An evacuation service tool has been also developed that will utilize the collected data in the STARLIT++ platform to calculate and provide the optimal evacuation route for both victims and rescuers (Figure 3).

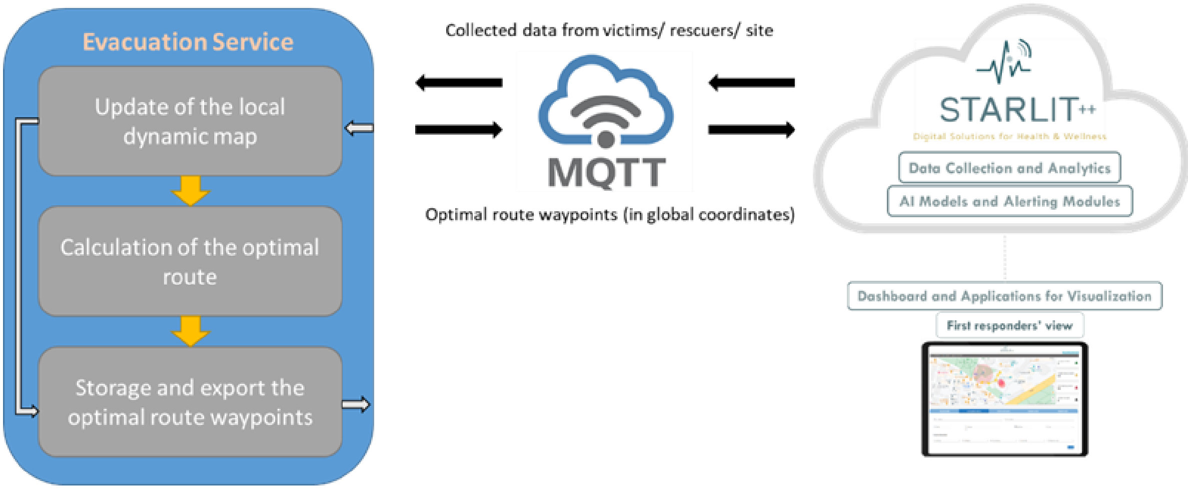

Figure 3. UC6 - High-level Evacuation Service architecture and link to the STARLIT++ platform.

From the side of the victims the evacuation service takes into account the position, the existing obstacles due to occurred disasters on the site, the available exits along with their maximum flow capacity and the possible need to direct groups of crowd and calculates the optimal route for each victim (shows the path to a direct exit). In the case of the rescuers, the app uses the same site-related data (obstacles, available exits, position of all victims, etc.) and calculates the optimal route that goes through all victims' positions by avoiding all obstacles and leading to a save exit. The latter is particular useful in the coordination of Search And Rescue (SAR) operations in closed/ confined areas, as it can provide in a very short time insights of a comprehensive operation action plan from the entrance to the exit of the rescuers, minimizing the risk of wrong decision-making and allowing for the human factor to focus on other arbitrary issues.

2.1.3 Development activities

This section describes the development activities that have been performed for what concern the main functionalities of the application previously described.

2.1.3.1 Analytics for the MCI

Different analytics mechanisms have been implemented for exploiting data from deployed devices (drones/robots/wearables) and the process of being integrated with the other components of the MCI use case has been developed (Figure 4). The plan is to focus on the full development of the MCI backend and visualization components as well as the integration with the analytics and the devices and subsequently their testing in the trials. A crowd estimation model has been implemented that allows a rough calculation of the number of casualties involved (crowd counting) as well as their status (moving or still/immobile). This procedure has been tested by using a pre-recorded video. In the following, details of the different modules reported in Figure 4 are provided.

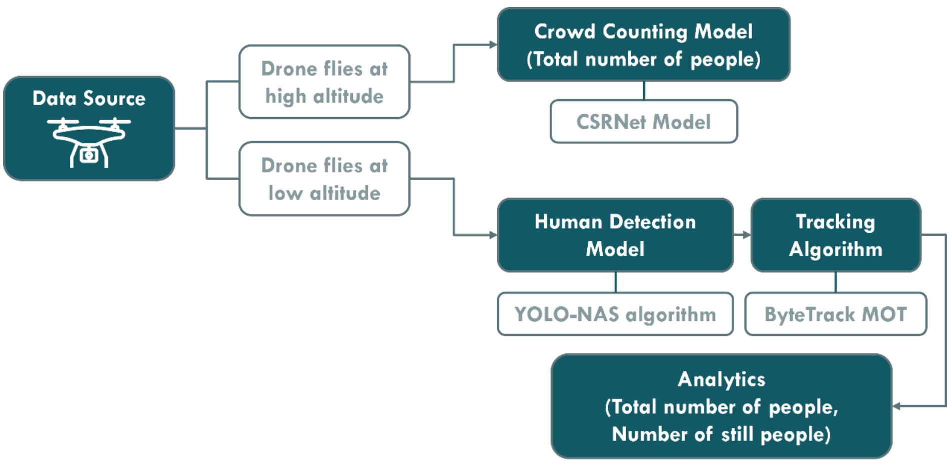

Figure 4. UC6 - High-level architecture for AI crowd estimation and detection models for the MCI.

Crowd Counting Model

More specifically, a model for identifying human movement has been developed. The drone captured video is used as input and processed frame-by-frame. When the drone flies high a pretrained model CSRNet [5] is used to estimate the total number of people in a crowded area. This model gets an image as an input, the generates a density map and sums all the cells in the density map leading to the estimated number of people. This process, summarized in Figure 5, provides first information for the first responders before they arrive at the scene.

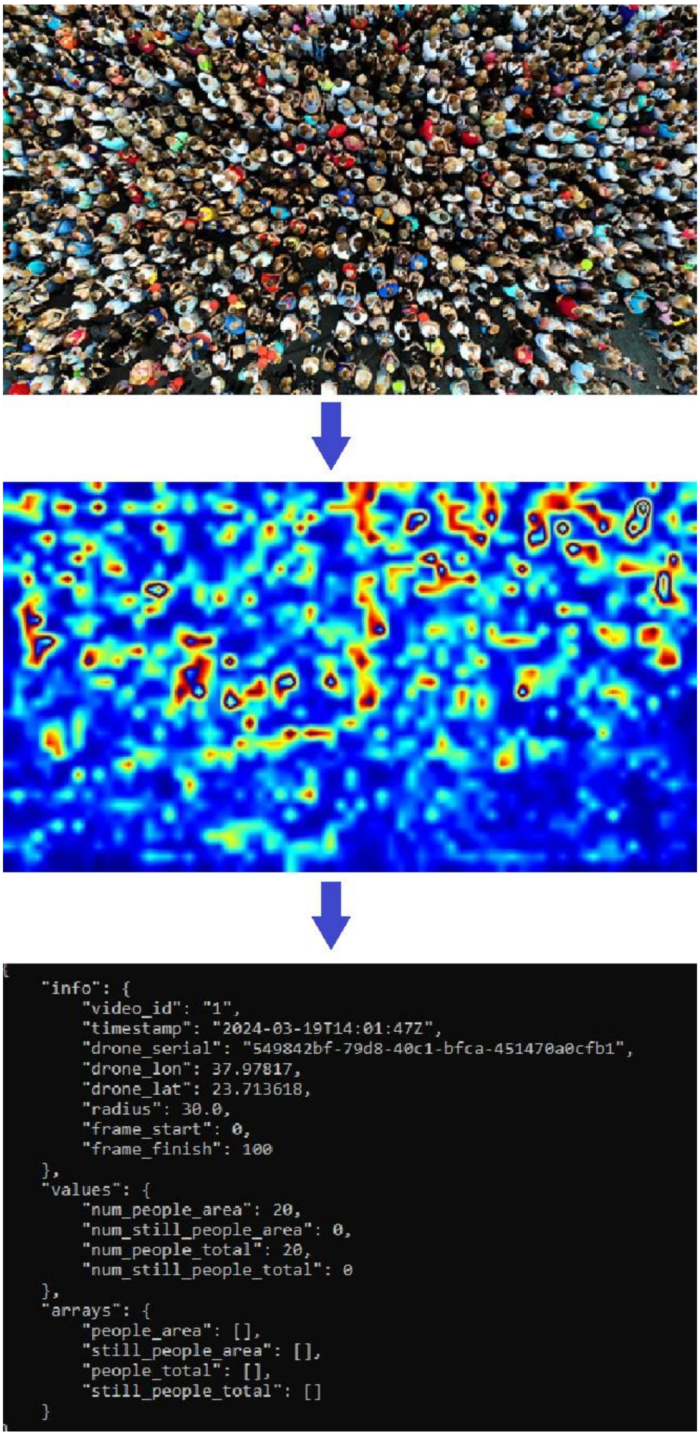

Figure 5. UC6 - The flow of the Crowd Estimation model for the MCI.

Human Detection Model

An object detection model based on YOLO-NAS algorithm [6], which can detect multiple objects in a single image, has been developed. The analysis of a video/stream is therefore performed frame-by-frame. The frame is given as an input to the model and the detections are the output of the model, as summarized in Figure 6.

Figure 6. UC6 – The flow of the Detection model for the MCI.

This model is trained by using the CrowdHuman Dataset [7]. CrowdHuman is a benchmark dataset to better evaluate detectors in crowd scenarios. The CrowdHuman dataset is large, rich-annotated and contains high diversity. It contains 19.370 images. There are 470K human instances from train and validation subsets and 23 persons per image, with various occlusions in the dataset. Each human instance is annotated with a head bounding-box, human visible-region bounding-box and human full-body bounding-box. The dataset has been passed through the augmentation procedure. From each image of the train and validation set, 10 more images were produced by zooming, rotating, brightening, warming the original images to train the model in various environmental conditions. Thus, the dataset finally consists of 176.294 images and their corresponding label files. When running the inference, the detections of each image are transferred to the tracking algorithm.

Tracking Algorithm

For this task, ByteTrack Multi-object tracking (MOT) [8] algorithm is used. This algorithm aims at estimating bounding boxes and identities of objects in videos by associating almost every detection box instead of only high-scoring frames, which is the main method applied by other algorithms. The tracking results contain the objects' ids, classes, detection confidence levels, coordinates of the bounding boxes as well as some video information like frame id and frame rate. This information is used for the post processing procedure.

Analytics

Having the ids, coordinates, the frame ids and the time interval between the frames, the total number of people, their trajectories, and their instantaneous speeds (measured in pixels/sec) are calculated. The number of different trajectories (after filtering "noise" trajectories) equals to the total number of people in the video. The peoples' speeds are then transformed to km/h by applying some factors that correlate with the size of the object and the angle of the camera. Knowing the drone speed, the relative velocity can be calculated. This leads to a classification of the moving and still people.

2.1.3.2 Semi-automated triaging process

Once the first responders have arrived on the scene, a semi-automated triaging process starts, based on users' vital signs (e.g., electrocardiogram (ECG), oxygen saturation (SpO_2), blood pressure, etc.), position and movement data derived via wearable devices. The semi-automated triaging approach is two-fold. Firstly, the aim is to classify patients into one of four triage categories according to the Sieve triage protocol [9]. The second part addresses the forecasting of the next triaging status of a patient in the next minutes. These two objectives, consisting in two steps are schematically reported in Figure 7.

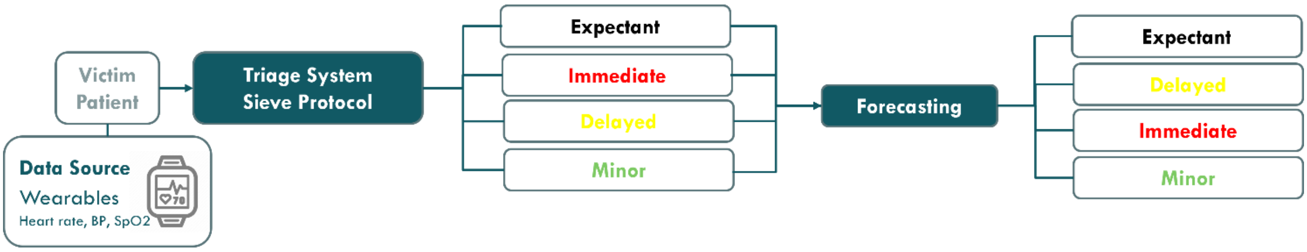

Figure 7. UC6 - Semi-automated triaging architecture for the MCI.

The initial classification is based on walking and breathing capabilities, as well as the vital signs. The assumption is that the wearable devices have been fit on victims by the first responders during the initial triage assessment. To develop the mechanism for the derivation of the respiratory rate from ECG an open dataset of 198 patients has been used. More specifically the initial step of data preprocessing involves extracting Heart Rate (HR) and Respiratory Rate (RR) time series data from each patient. The data has been transformed to a standardized frequency of 5 minutes, computed as the average value over each 5-minute interval, because wearables will extract values every 5 minutes which is the minimum time that can be reliably supported by the current wearable devices. Handling missing values is critical, and linear interpolation is employed to fill gaps in the time series. To enhance model convergence, MinMax Normalization is employed on the data. This comprehensive preprocessing pipeline, illustrated in Figure 8, aims to create a well-structured dataset, fostering the development of accurate and robust models for time series forecasting. Developing an effective time-series forecasting model involves creating and training a multi-input, multi-output architecture, specifying the number of timesteps to look back and predict. This is achieved by transforming the dataset into a supervised learning problem utilizing the observation from the last time step (t-1) as the input and the observation at the current time step (t) as the output for both heart and respiratory rate. A Long-Sort Term Memory (LSTM) model and tree based regressors including the Machine Learning (ML) techniques such as XGBoost [10], LightGBM [11], CatBoost [12] and Random Forest [13] were examined.

This comprises signals and metrics acquired from critically ill patients during hospital care, respiration and ECG signals, Heart Rate (HR), Respiratory Rate (RR) and Oxygen saturation (SpO2) metrics. The derived respiratory rate is then used along with other vital signs derived from the wearable devices for updating the triaging status of each casualty.

```
1/1 [==============================] - 0s 368ms/step
Input Values:
        {'patient_id': 2, 'heart_rate': 58, 'respiratory_rate': 20}
Predicted Values:
        {'patient_id': 2, 'predicted_heart_rate': 59, 'predicted_respiratory_rate': 20}
INFO:     127.0.0.1:56636 - "POST /triage-forecasting HTTP/1.1" 200 OK
```

Figure 8. UC6 - Current health measurements as input and predicted values (next 5 minutes) as output.

```
Input Values:
{'patient_id': 2, 'walking_status': False, 'breathing_status': True, 'opened_airway': False, 'respiratory_rate': 20, 'heart_rate': 58}
Output Values:
{'patient_id': 2, 'triage_status': 'yellow'}
```

Figure 9. UC6 - Current health measurements as input and health triage status (yellow) as output.

2.1.3.3 Backend service and Dashboard

In terms of the development of the backend service for MCI, work has focused on the creation of the database model, the endpoints for facilitating the triaging workflow (communication of the backend with the various analytics mechanisms) and the integration with the current frontend implementation. The STARLIT++ platform [4], database, and backend service was extended to fully support the triaging workflow. More specifically, after the detection of the MCI the first responder arrives at the detected location to evaluate the health condition of the victims (still/non-moving people have been detected by computer vision service). Figure 10 reports an example of dashboard where are localized areas with possible victims, with a preliminary triaging. The example refers to the Technopolis area in Athens.

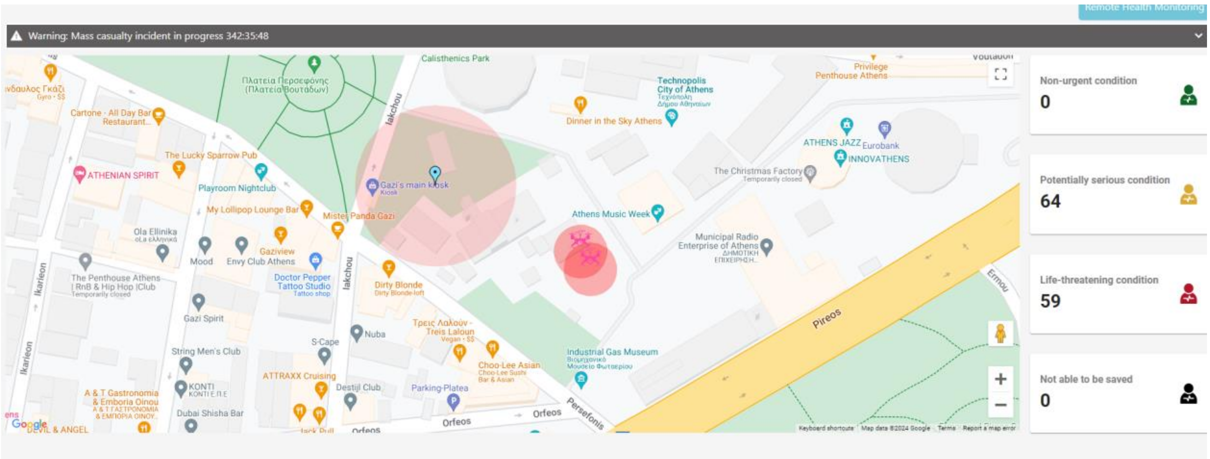

Figure 10. UC6 - Detection of the MCI in the dashboard (Technopolis Area).

The first responder can create a new (simple) patient profile in STARLIT++ platform, as illustrated in Figure 11, including the MCI part, and he can also complete the device assignment (smartwatch) to provide the vital signs measurements as an input for triaging workflow which is represented in the Figure 12. The created patient with the triaging health status is shown in the STARLIT++ remote health monitoring dashboard, in the main patient view.

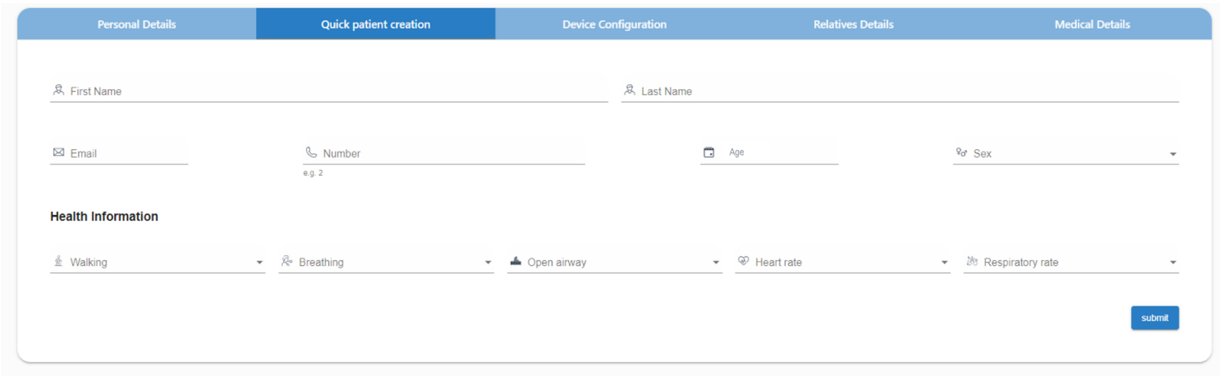

Figure 11. UC6 - Quick patient creation in WINGS STARLIT remote health monitoring platform.

Figure 12. First vital signs (heart rate) representing the input for the triaging flow.

Also, the total number of victims per health status is shown in the MCI dashboard, Figure 13. While the patient is being transported from the casualty incident location to the hospital, the vital signs are continuously measured to update his health status which is now supported by the platform. In order this workflow to be completed, a new view in the WINGS STARLIT platform was created to support the new (simple) patient profile according to the triaging appropriate user input, and WINGS STARLIT backend workflow was extended to support the new patient creation and integration with the MCI backend part. Moreover, the input from the device was extended to support the continuous patient's health status in real-time (an example is shown in Figure 13), where every new health measurement is also available in the new MCI part as well. Also, the forecasting of the next triaging status of a patient in the next minutes is calculated and described in detail in 2.1.3.2 and the predicted values reported in Figure 8 and in Figure 9.

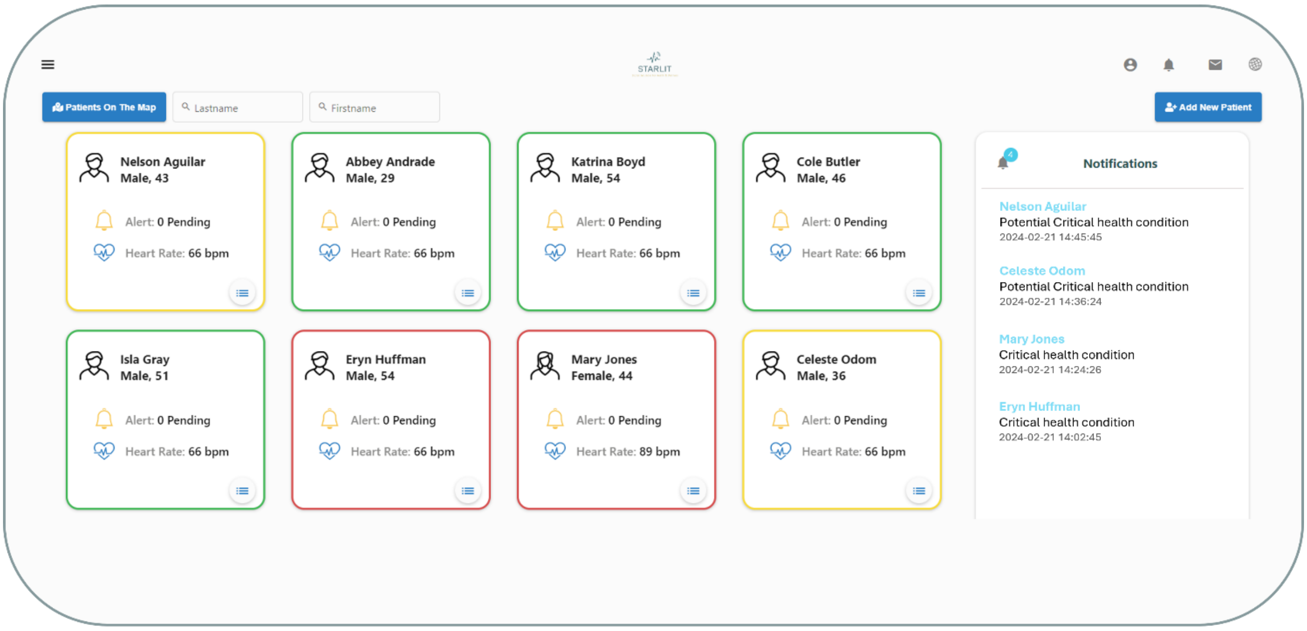

Figure 13. UC6 - An overview of patients' health status.

Finally in the above-mentioned workflow (scenarios/steps), the first results and KPIs measurements are obtained and described in detail in the 3.1.1.1 section.

2.1.3.4 Optimal route planning process for the Evacuation

In the context of this UC a tool has been developed to assist both the strategic planning of the rescue operation and the survival of victims by providing safe, direct and in real-time evacuation information. This is useful in open spaces which cannot have a fixed evacuation plan and escape scenarios directly depend on the type and effects of the disaster.

The tool receives the data from the triaging processing regarding the identification/ detection of the victims and the obstacles imposed by the occurred disaster. To produce these optimal routes, the local map of the site has been converted to a digital map consisting of nodes and lines indicating the potential gathering points/ locations of humans and all possible routes within respectively. These data are imported to different sets of algorithms developed for the specific UC, based on the Travelling Salesman Problem (TSP), the path is approximated to TSP which is then solved using the Simulated Annealing Method (optimization of the planning) [14]. Different sets of algorithms are automatically applied depending on whether the rescuer is using same exit as the entrance or if different exits are available and potentially optimal and of course a different set is applied for the victims located within the site which leads them to the safest and nearest evacuation exit. The outcome of this tool is a set of coordinates for each case comprising the optimal route, as indicated in Figure 14, either for the victims or the rescuers. These coordinates are transformed from local to world geodetic and are sent to the dashboards using a Message Queuing Telemetry Transport (MQTT) broker.

Figure 14. UC6 – Optimal route calculation for the Evacuation.

2.2 UC7: Remote Proctoring

2.2.1 Use Case recap

Surgical remote proctoring uses technology to remotely monitor and support surgical procedures. This can be particularly useful for training (instructors can provide guidance surgeons in training) and supporting (experienced surgeons can provide supervision to less experienced surgeons). Commercial systems for remote proctoring can be found on the market. These systems are designed considering 4G bandwidth availability and use standard PCs for the proctor, therefore non-verbal communication is mediated trough mouse and keyboard only. Using video streaming, live communication tools, and XR supported by 5G, a remote proctor can observe a surgical procedure in real-time and offer advice, feedback, and guidance, even if they are not physically present in the same location. Today, new cutting-edge technologies for high-interactive telepresence can make remote proctorship just as effective as conventional proctor support to safely direct the surgery.

Specifically, the use case will be deployed across two Italian hospitals, located in Pisa and Massa, involving the development of an end-to-end solution that hinges on a telepresence platform. The experiment comprises two operational macro-modules, one located in a remote hospital site (Massa) and the other within a central hospital (Pisa). The distance between Pisa and Massa is about 50 km.

2.2.2 Final application design

The primary objective of this use case is to showcase the feasibility of implementing advanced telepresence [15][16] support within the surgical domain through a 5G wireless network, as opposed to the currently used 4G or wired connections. At this scope, as depicted in Figure 15, this use case intends to establish an indoor cellular coverage network dedicated to real-time remote proctoring applications, which will rely on a 5G network to guarantee optimal connectivity. Figure 10 represents the final architecture of the use case including all the main components.

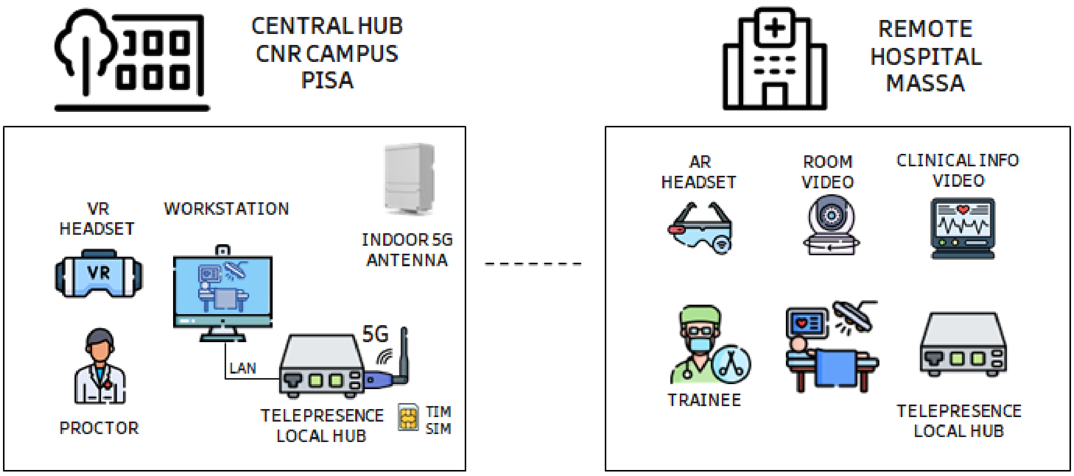

Figure 15. UC7 - Remote Proctoring – Architecture and main components.

The subsequent sub-sections will describe the design of applications pertaining to the Massa and Pisa sites. These applications will utilize software linked to the commercial devices in conjunction with custom-developed software modules. These modules are designed to integrate these devices, especially XR ones, into the context of the use case.

2.2.2.1 Remote Hospital application design

The remote hospital in Massa will accommodate an interventional training room, where newly trained clinicians will operate under the remote supervision of the proctor located in Pisa. The remote hospital's macro-module features an enhanced clinical-certified real-time telepresence system for surgical room training with data acquisition tools, a connection hub in the surgical room, a wired LAN, and a linked gateway. The main part of the system is a telepresence local hub system produced by Rods&Cones [17] this system includes the Vuzix M400 Smart Glasses [18] which are certified for usage in clinical contexts. The smart glasses are worn by a newly trained clinician to capture video footage of surgical activities within the operating room using a front-facing camera of smart glasses. The footage of surgical activities is transmitted in real-time to a remote expert proctor. Simultaneously, any pertinent information or practical corrections related to the ongoing procedure from remote expert proctor are relayed to the newly trained clinician via the telepresence local hub. This information is displayed on a small screen positioned at the rear of the glasses relative to the front-facing camera. This screen shows both the real-time image captured by the clinician's front camera and any overlaid corrections or guidance provided by the remote expert proctor. Additionally, to compare the usability of these devices with alternative solutions, the applications have been ported to a RealWear HMT-1 [19]. The HMT-1 features an independently orientable High Definition (HD) camera, separate from the display, allowing for an evaluation of whether this design leads to superior ergonomic comfort during use. Preliminary tests on this device are documented, as detailed in Section 3.2.1.2. All these systems are linked to a connection hub, which connects the hospital in Massa with the CNR campus in Pisa.

2.2.2.2 Central Hospital application design

The expert proctor will be positioned at a central hospital hub within the CNR campus in Pisa. The central hospital's macro-module for remote experts includes a telepresence platform with HD monitors, control interfaces, a VR headset for complete immersion, and a 5G indoor network infrastructure. Figure 16 shows the remote proctoring kit. The telepresence software shows the surgeon's view, the entire operating room, and clinical monitors, and enables audio/video communication between the remote expert proctor and operating surgeon. Through this system, experts will have the same point of view as surgeons, enabling them to see the operative field as the surgery is performed. They will have the capability to adjust camera lighting, angle, and zoom. Furthermore, they can communicate by sending messages, speaking directly to the operating surgeon, taking screenshots, and making real-time annotations to significantly enhance patient outcomes.

Figure 16. UC7 – Rods&Cones Remote Proctoring kit.

The feasibility of using a VR headset as a remote expert interface will be explored, providing an immersive surgeon's point of view when connected to the workstation. The VR device used in the trial is the Meta Quest 3 equipment which is a VR and mixed reality (MR) headset developed by Reality Labs, a division of Meta Platforms. It is a cutting-edge device, released on the market on October 2023. This specific headset has been selected, among various alternative options, as it provides unique, immersive experiences with a true sense of presence. In addition, for a more comfortable usage by the proctor, this headset is not only curvier and less bulky to wear, but it features an improved cushioning system. Preliminary tests on this device have been conducted as reported in Section 3.2.1.2.

2.2.3 Development activities

The development activity of the application scenario proceeded according to plans, parallel to the network infrastructure planning. As deeply reported in [1], the Pisa trial involves the creation of a 5G network from the scratch. In terms of XR devices applications, as illustrated in Figure 17, two variants of the initial application of the Remote Proctoring use case have been developed. Variant 1 connects a remote proctor to an in-place operator wearing the Vuzix M400 Smart Glasses (or the Realwear HMT-1) and support by the remote proctor is provided to the operator by means of voice and Mouse pointing and clicking indications. The Variant 2 offers an equivalent experience, but it is developed in an immersive 3D environment and uses 6 Degrees of Freedom (DoFs) as a pointing interface for the remote proctor.

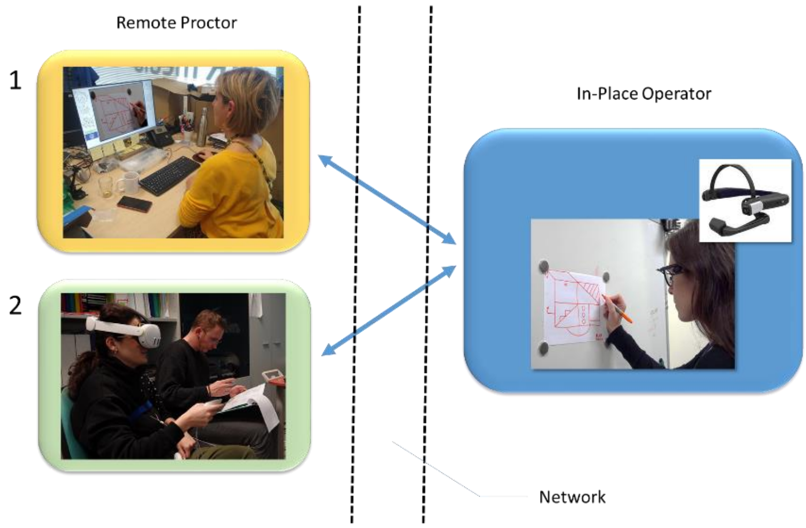

Figure 17. UC7 – Variants 1 and 2 of the application.

The applications are developed using a variety of tools and software technology: Variant 1 of the Remote Application is a 2D Web Application developed in standard Javascript [20], Variant 2 is a fully immersive application developed on the Meta Quest3 using WebXR and Three.js [21] for the real-time rendering (that takes place at 90Hz). Finally, Figure 18 reports the XR devices that will be used. These Smart Glasses applications (both for the Vuzix and for the Realwear) are native Android applications developed in Java with some injection of Javascript by means of an embedded WebView component. Communication between the Remote Proctor and In-Place Operator takes place by means of WebRTC [22] to establish an UDP-based, point-2-point, low latency communication between the end points. In the preliminary laboratory tests, the devices communicated via a Wi-Fi network as indicated in the section 3.2.1.1. Subsequently, the communication will benefit from the 5G network developed in the trial.

Figure 18. UC7 - The XR devices used in the trial.

In terms of network protocols used, the applications communicate with each other in a peer-to-peer fashion using the standard WebRTC (WEBRTC). This is a state-of-the art-communication protocol where communication initiates with a signaling phase. Initially, or a direct connection can be made, peers exchange all the required data using a signaling server. This server acts as an intermediary known to each peer and each peer connects to the signaling server, and then one peer can request another by prompting the signaling server to relay specific data to another peer, thus facilitating mutual recognition. Both clients exchange the necessary data (including network details) and subsequently establish a direct peer-to-peer connection. Post-establishment, the server is no longer utilized. The signalling server solely functions to relay information between peers. However, during the negotiation phase, another server plays a crucial role in establishing a direct connection: the STUN (Session Traversal Utilities for NAT) server. STUN is an instrument used by communication protocols to identify and navigate through Network Address Translators (NATs) located along the communication path between two endpoints. It operates as a lightweight client-server protocol, necessitating only straightforward query and response transactions with a third-party server situated on a common, accessible network, typically the internet. Figure 19 illustrates the overall Connection Negotiation process and data flow.

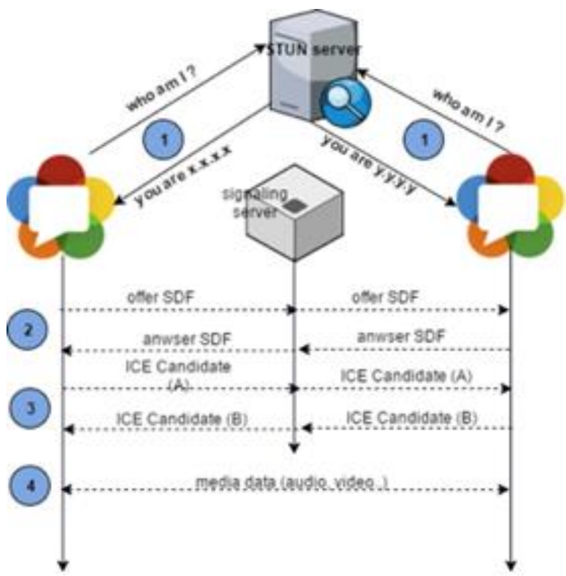

Figure 19. UC7 - Connection Negotiation and data flow.

After the negotiation phase concludes, a direct peer-to-peer connection is established between the endpoints, enabling the transmission of audio, video, and data. The diagrams in Figure 20 illustrate the data flow utilized in the preliminary tests.

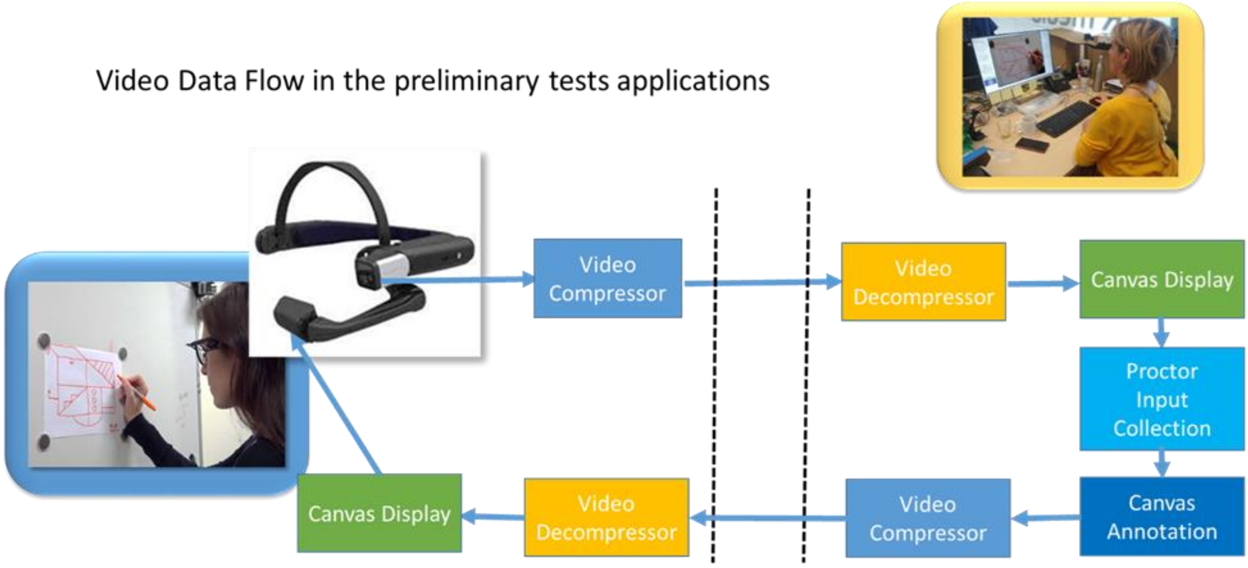

Figure 20. UC7 – Video Data Flow.

As highlighted, the flow of video data in this setup markedly deviates from that of a standard video conference. In this unique configuration, the visual input captured by the smart glasses' camera undergoes a dual compression and decompression process before it is rendered on the smart glasses' display. Additionally, this data stream is subject to network latency twice over. This distinctive architectural choice was made as a preliminary measure to facilitate the utilization of natural gesturing communication through video, a methodological approach that the project intends to delve into in the forthcoming months. By adopting this double compression pipeline, it is ensured that both the proctor and the on-site operator are interacting with the exact same video frame, thereby fostering collaboration.

However, this enforced synchronization comes at the cost of additional delays, attributable to the repeated network traversal and the operations involved in the double compression-decompression-display pipeline. As the project progresses, there are plans to investigate a more conventional approach, involving two parallel video and data streams. This strategy will also be influenced by the data gleaned from initial user tests. Regardless of the approach, a fundamental objective remains: to minimize both network latency and the time taken by the acquisition-rendering pipeline. Achieving these goals is pivotal for establishing a convincing telepresence and facilitating effective collaboration.

2.3 UC8: Smart Ambulance

2.3.1 Use Case recap

The prognosis of acute coronary syndromes relies on timely reperfusion. Delays increase mortality and muscle loss, causing cardiac dysfunction. Ambulances offer rapid transport, pre-hospital assessment, accurate diagnosis, and initial therapeutic support to minimize these risks. In some cases, specialists in hospitals can be called to remotely assist the emergency operator on ambulance (usually paramedics) with specific treatments or diagnostic tests while the ambulance is getting to the hospital. In addition, the specialists in the hospital can better manage and treat the emergency patients if they are a detailed patient heath view before her/his arrival in hospital. Finally, ambulances are not equipped with instruments that allow HD real-time patient vision, and echocardiographic video to allow an efficient real-time visualization of patient heath information for the remote expert in the hospitals. XR systems can increase the ability of the remote expert in this respect.

This use case proposes a 5G-connected smart ambulance with high-definition imaging and echocardiographic video capabilities, enabling remote visualization of patient and related real-time data. The main components of the overall system are illustrated in Figure 21.

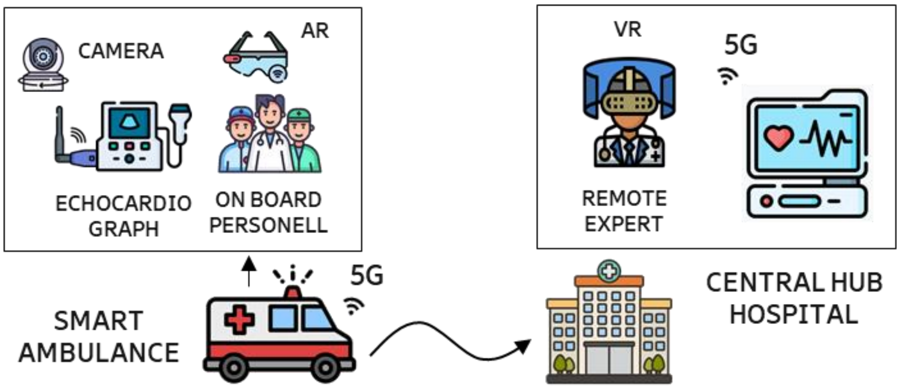

Figure 21. UC8 - Smart Ambulance scenario and main components.

2.3.2 Final application design

The telepresence applications based on AR and VR related to UC7 are also used in the context of UC8. For this purpose, reference can be made to Section 2.2.2. Additionally, the smart ambulance also carries portable ultra-sound systems whose applications are proprietary and are not subject to development within the project. It is intended in the following to recall some contextual information to understand how these applications will be used.

The smart ambulance process, illustrated in Figure 22, begins when an emergency call is received at the Emergency Medical Service (EMS) dispatch center. Trained dispatchers gather essential information about the nature of the emergency, the location of the accident, and any other relevant details.

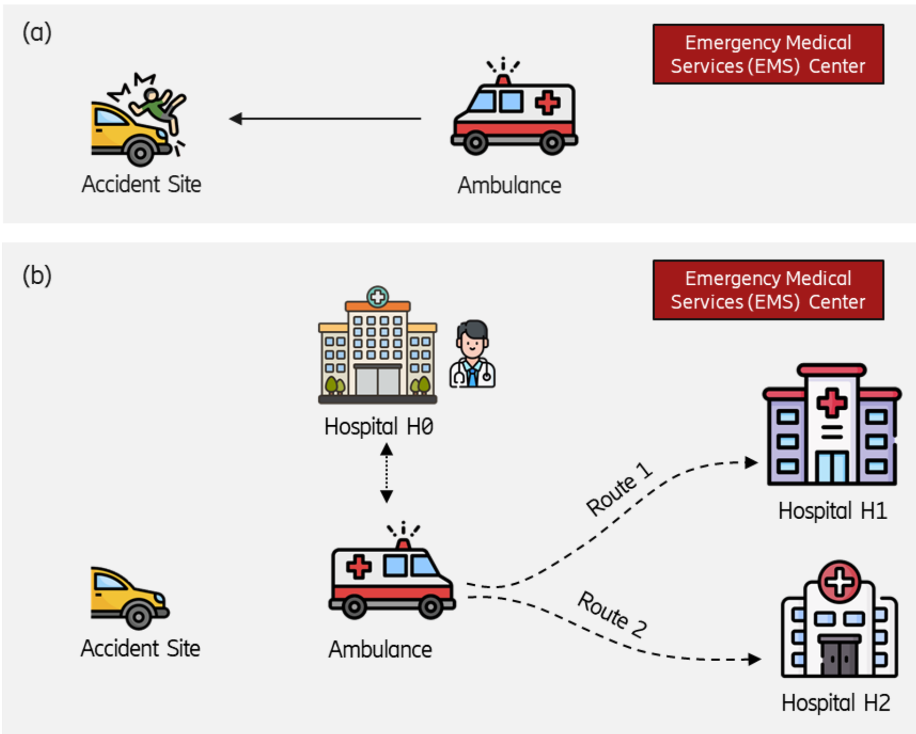

Figure 22. UC8 - Smart Ambulance scenario.

The ambulance's connectivity needs, such as bandwidth and latency, are predetermined to accommodate onboard diagnostic and XR equipment. The accident site is designated as the "starting point" for the network slice that will support connectivity for the return trip to the chosen hospital. Ambulance crews rely on navigation systems to identify the fastest route to the accident site or may receive route guidance from the EMS. During transit, communication with the EMS center is possible for additional medical advice or to obtain patient updates. Once at the accident site, the crew provides immediate medical care and stabilizes the patient for transport, with the option for telepresence/XR devices to facilitate remote consultations with hospital medical staff. Selecting the appropriate hospital, factoring in trauma care, specialty services, and capacity, is vital. Remote consultations with experts at Hospital H0 aid in this decision. The ambulance then proceeds to Hospital H1 or H2 via the quickest route. Telepresence/XR devices are crucial for providing real-time remote guidance, for example, when using an echocardiograph. The connectivity needs between the accident site, the selected hospital, and Hospital H0 for remote consultations are met by a radio-transport resource configuration.

The infrastructure operating in the CNR Campus area will employ a "hub and spoke" strategy to share diagnostic information and equips the ambulance with advanced cardiac tools and smart XR devices. The robust 5G connection will facilitate high-speed transport in congested zones, allowing remote experts to employ VR headsets for a comprehensive view of the patient's condition and to receive diagnostic data. AR headsets with cameras are used by ambulance operators to share visuals from the emergency site, thereby enhancing early intervention.

In the current smart ambulance scenario, the employment of VR and AR spans two distinct sites, mirroring the framework explored in UC7 “Remote Proctoring”. The key difference here is that one of these “sites”, the ambulance, is moving. This adds an extra layer of complexity to maintaining consistent and reliable communication, requiring advanced connectivity to accommodate the dynamic nature of the ambulance's location.

2.3.3 Development activities

The development activities associated with UC8 are closely connected to those involving UC7, detailed in Section 2.2.3. Both use cases utilize the same XR devices and the same 5G network. However, UC7 benefits from indoor coverage, while UC8 benefits from outdoor coverage.

The transmission of ultrasound data through the mobile network will also be part of the use case of the smart ambulance. In this regard, the GE Versana Active 4D Ready system will be used. It is an advanced and adaptable ultrasound system that combines the imaging capabilities of a traditional console with the convenience of a portable solution. This system can be transported on board of the ambulance streaming data toward the hospital for examinations including cardiac, vascular, abdominal, small organ, and musculoskeletal exams. As this system allows for real-time three-dimensional views in HD, the performance of the radio network shall be adequate to ensure a continuous and stable flow of huge amount of data even when the ambulance will move at high speed.

2.4 UC9: Adaptive Control of Hannes Prosthetic Device

2.4.1 Use Case recap

The goal of UC9 is to improve the integration of wearable prosthetic arms with sensor-driven autonomous behavior to reduce the need of explicit control from the user during object grasping. For this, the Hannes prosthesis [25] is used and equipped with a video-camera providing images of the environment (e.g., the object to be grasped), Electromyography (EMG) sensors measuring the muscle activation of the user and an Inertial Measurement Unit (IMU). The task is to interpret the user’s grasp intention, through AI methods, exploiting this sensory information, and control some of the available prosthesis’ DoFs accordingly, such as the ones in the wrist and in the thumb. Using information, such as IMU and EMG signals together with images allows to obtain a multimodal fusion architecture which proved to be fundamental to successfully accomplish the task [26]. However, all these sensors stream information at high frame rates. For this reason, high and stable data rates are required.

The Deep Neural Networks (DNNs) used as AI methods to control the prosthesis, represent an established solution. However, they require powerful and specialized hardware for both training and deployment. At the same time, the control system must be reactive to the user’s intention and to the changes of the surrounding environment. For this reason, in UC9, the computation is de-localized at the edge of the Network and an ultra-reliable low latency connection is needed to allow the continuous interaction between the sensors, the device and the AI machine that is located outside the prosthesis. Finally, the system controls a part of the Degrees of Freedom of the prosthesis while the user drives it and controls the complementary ones. Therefore, the system needs to be accurate, reactive, and highly reliable. However, being embedded in a wearable device, it presents specific constraints in terms of efficiency as well, motivating the adoption of devices that have small footprints in terms of power consumption, space, and weight.

2.4.2 Final application design

The final application design did not undergo any remarkable modifications with respect to what is described in deliverable D4.1 [1].

2.4.3 Development activities

The development activities done in the first months of project's lifetime followed the time plan described in D4.1 [1]. Firstly, as planned, all the components of the application have been identified, developed, and refined, when needed. Then, these components have been successfully integrated and, finally, the performance baselines have been identified through a set of tests, performed in the Ericsson R&D Laboratory in Genoa. The Figure 23 presents some of the components of the UC9 application: (a) the prosthetic arm with the able-body adapter, (b) the USB video camera and (c) final setup of the video camera embedded into the Hannes palm. In the next paragraphs, the details of each activity is described.

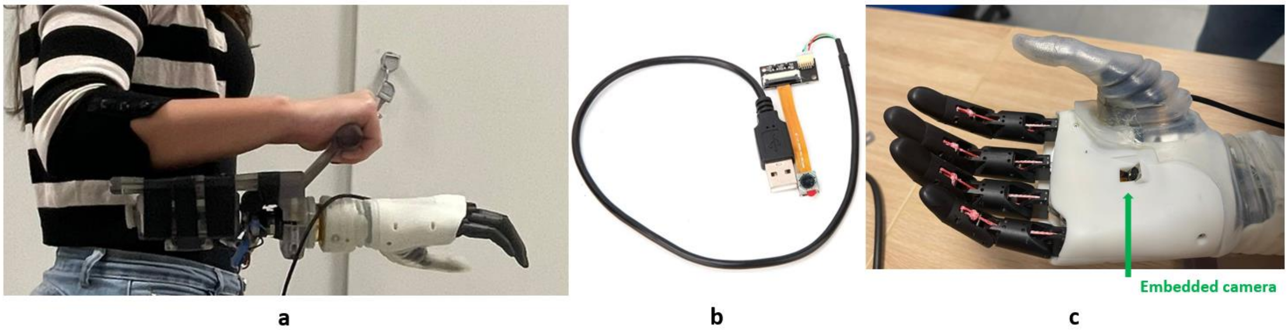

Figure 23. UC9 - Components of the UC9 application.

Single Components development
The result of this activity is the identification and development of the main components that are part of the application. Specifically, they are as follows:

- **Prosthetic arm**: For this hardware component, the Hannes prosthesis [25] has been confirmed. It consists of three main components: a myoelectric poly-articulated prosthetic hand that exploits a differential underactuated mechanism; a flexion-extension (F/E) and prono-supination (P/S) wrist module; and a myoelectric interface/controller that includes two surface EMG sensors, an IMU sensor, battery pack, and control electronics. Since the prosthesis needs to be driven by healthy subjects (no amputee patients involved), an able-body adapter has been added to the prosthetic setup (see Figure 23a).
- **Embedded USB video camera:** For this hardware component, a compact USB camera [29] has been chosen (refer to Figure 23b). This is a Red-Green-Blue (RGB) camera, with an OV5640 sensor [33][29]mounted. The field of view is 60°, the resolution is 640x480 pixels and the frame rate is 30 frames per second. The dimension of the board is 26,2x12,7 mm and the flat cable is 46,8 mm. Refer to Figure 23c for a picture of the camera integrated into the prosthesis palm.
- **Embedded electronic board:** For this hardware component, a Variscite board has been chosen, specifically, the DART-MX8M-PLUS System [34]. This has a 1.8GHz Quad Cortex™-A53 NXP i.MX 8M Plus processor with 800MHz Cortex™ and a M7 Real-time co-processor. It has several interfaces, among the others: the USB, USB-c, the HDMI and the ethernet interfaces. Finally, it comes with a development board that can be used to perform preliminary tests before the final integration into the prosthesis.
- **AI Machine:** For this hardware component, a Dell Alienware X17 R1 Gaming Laptop (2021) has been chosen. This has a Core i7 with 16GB RAM and a 512GB SSD. Furthermore, it is equipped with a a NVIDIA RTX 3070 graphical card which is necessary to run the DNNs-based approach for the prosthesis control.
- **Signal pre-processing module:** This software component pre-processes the images from the video-camera before they are taken as input by the DNN. In the final version of the application, this module will run on the Embedded electronic board and it will compress, if needed, the images, before sending them via radio to the AI Machine.

- **DNN-based control system:** This module is based on the algorithm developed in [26]. It is based on a DNN model trained to process the images coming from the camera on the palm of the hand and predict the necessary adjustments to the Hannes DoFs to complete the grasp. The different submodules of this component run on the AI Machine.
- **Direct control system for Hannes DoFs:** This module directly controls the movements of the different joints of the prosthesis according to the predictions of the DNN-based control system. This runs on the electronic board mounted on Hannes.

First integration activity

After the different components' development and refinement, these have been integrated with the aim to perform the first tests and retrieve the first baselines for network performance. For this activity, several tasks have been performed which are presented in the next paragraphs.

Firstly, at the software level, the YARP (Yet Another Robot Platform) middleware [30] is used to integrate all the software modules of the application. YARP supports building a robot control system as a collection of programs communicating in a peer-to-peer way, with an extensible family of application connection types (YARP Fast_TCP, YARP TCP, etc.) that can be chosen to meet different needs. It also supports similarly flexible interfacing with hardware devices. Thanks to YARP, the network nodes and backbone are transparent to the different application modules, increasing their re-use in different settings.

Then, all the software modules run on Docker [31] containers. Docker is an open platform for developing and running applications that enables users to separate applications from the infrastructure. Docker provides the ability to package and run an application in a container, a loosely isolated environment. Many containers can run simultaneously on a given host. One of the great advantages of using Docker is that it drastically reduces the installation effort on different machines. The containers built for this application contain everything needed to run all the software modules and they have been installed in the AI machine and in the Variscite electronic board.

Furthermore, at the network level, the integration work has been done with the 5G infrastructure available at the Ericsson laboratory in Genoa. The Variscite electronic board is used with the available development kit to ease the development and debugging activities and it is connected to the 5G network through a phone tethering. The AI machine instead, is cable connected to the 5G core network. The current solution is implemented with the following nodes: (i) Ericsson baseband BB6630 and BB5216, (ii) Radio 4422 (NR) and (iii) Radio 2203 for LTE anchor [35].

Finally, a VPN (Virtual Private Network) has been used to enable all the different application components to communicate over the 5G network. For this, the OpenVPN [32] solution has been used.

Baselines definition activity

After this first step of integration, a set of tests has been carried out to define the network performance baselines. One of the aims of these activities was to characterize the components of the application to find the best configuration for each of them. Moreover, another main objective was to collect the first connection performance to detect the network and application components to work on and that need improvements to be done in the following months and possible bottlenecks. These activities have been carried out both in the IIT and Ericsson laboratories. The main results are reported in the Section 3.4.

3 First integration and test activities

This section summarizes the key aspects of the trials. It outlines the laboratory tests performed, possibly on networks other than 5G, like LAN or Wi-Fi. It also reports test on field, performed where the 5G coverage is already in place. Finally, where applicable, reports on early demos intended as stable tests that can be properly disseminated (e.g., video, paper, mid-term review, etc.).

The measurement of KPIs has adopted the harmonized terminology as outlined by WP6 and detailed in D6.1 [3]. KPIs are numbered with KPI IDs as specified in Annex A off the present document. Furthermore, the data collection process, including the results of measurements and other relevant data, has been conducted in accordance with the guidelines established in the Data Management Plan defined by the project. Although the plan is still not publicly available, its methodology has been rigorously followed for the collection and management of data.

3.1 UC6: Mass Casualty Incident (MCI) and Emergency Rescue in Populated Area (Athens/Madrid)

3.1.1 Trial 6.1 - Mass Casualty Incident (MCI) in Populated Area

The trial of the UC6 aims to showcase on one side how relevant operations could be improved and on the other side how major KPIs necessary for this use case are addressed by the 5G/B5G technologies for the Scenario 1 (Earthquakes and building collapses/with fires - Pre-hospital treatment) which is described in detail in D4.1 [1] in the section 3.1.4. Trial 6.1 is addressed in Athens site and focuses on MCI detection and the pre-hospital treatment as two different laboratory tests which are described in the following section.

3.1.1.1 Laboratory tests

Lab01 - Evaluation of the detection model without 5G network
The Lab01 refers to the evaluation of the detection model and the objective of the test focuses on how often the algorithm is correct when it predicts a positive outcome or/and out of all the actual positive outcomes and the Harmonic mean of precision. The analytics and mechanisms that are used for the detection model are described in detail above (see section 2.1.3.1).

The test results in terms of measured KPIs and analysis and eventual feedback from beta-users at high-level (details to be captured as part of the KVIs work in D6.2), where the considered KPIs are Precision (KPI#11), Recall (KPI#12), and F1 score (KPI#13).

Table 1. Test summary for Trial 6.1 (Lab01).

Test summary	
Trial ID	6.1
Test setup ID	Lab01
Facility/Site	WINGS
Objective	How often the algorithm is correct when it predicts a positive outcome or/and out of all the actual positive outcomes and the Harmonic mean of precision.
Description	Evaluation of detection model
Executed by	Nikos Maidonis, Gianna Karanasiou
Components involved	N/A
Targeted KPIs	KPI#11 (Precision) KPI#12 (Recall) KPI#13 (F1 score)

Measurement tools	N/A
Ethics requirements implementation	N/A
Involvement of beta-users	N/A

The first results are encouraging and satisfying as are shown in detail in Table 2. The large number of objects (multiple people in an image) that were labeled in the dataset was expected to influence the Recall and will be improved with the retained model.

Table 2. First results for the detection model (Lab01).

Preliminary measurements	
Total number of ground truth positives (all bounding boxes) in test dataset	85860
True Positive detections in test dataset	45288
False Positive detections in test dataset	8502
Precision (the number of positive predictions that are actually positive)	0.8419
Recall (the number of positive predictions made of all positive ground truths)	0.5274
F1 score (the harmonic mean of Precision and Recall)	0.6485

For the next steps, the metrics will be improved by collecting a custom dataset and the detection model will be retrained.

Lab02 - Evaluation of the 5G network latency in the WINGS testbed

The Lab02 refers to a client that simulates the communication between the frontend and the backend which was developed to calculate the average time (in milliseconds) that is needed for the application in order to complete the tasks of creating new patient profile, getting through the smart watch the vital sign measurements and update patients health status with the triaging status (application roundtrip). The objective focuses on the amount of time is needed for all the flows to be completed, in the application level, in a 5G network, where the average time after 100 iterations was kept and the tests were applied in the WINGS Testbed.

Test results in terms of measured KPIs and analysis and eventual feedback from beta-users at high-level (details to be captured as part of the KVIs work in D6.2) where the considered KPIs is the application roundtrip latency (KPI#08).

Table 3. Test summary for Trial 6.1 (Lab02).

Test summary	
Trial ID	6.1
Test setup ID	Lab02
Facility/Site	WINGS
Objective	The amount of time it takes for the application to receive a response or output after sending a request or input to a server or network
Description	Evaluation of 5G network latency in the WINGS testbed
Executed by	Dimitris Plakas, Nikos Sintoris, Gianna Karanasiou
Components involved	N/A
Targeted KPIs	KPI#08 (Application roundtrip latency)
Measurement tools	N/A

Ethics requirements implementation	N/A
Involvement of beta-users	N/A

In the application level two flows are triggered, first the creation of the patient profile flow, which creates a new patient entry to WINGS STARLIT platform and the MCI part, and then the triaging flow and the updated health patient status are triggered. In the case of roundtrip KPI measurements were used simulated values for the vital signs. In the Table 4 the roundtrip measurements (KPI#08) are presented. The Lab02_01 represents the creation of the new patient profile flow, the Lab02_02 represents the measurements of the vital signs (simulated) flow and the Lab02_03 represents the triaging and the updated patient health status flow. In these test cases, timestamps were added in the client part and the differences between request and the final response were calculated to get the roundtrip measurement.

The first results of the KPI#08 are satisfying as are represented in the Table 4 below for the three different flows that were created, following the test requirements measurements.

Table 4. First results for the Application roundtrip latency (Lab02).

Preliminary measurements	
The creation of new patient profile flow	96.704 ms
The measurements of the vital signs (simulated) flow	68.431 ms
The triaging and the updated patient health status flow	69.136 ms
In these test cases, timestamps were added in the client part and the differences between request and the final response were calculated to get the roundtrip measurement.	

For the next steps, the tests will be repeated for more than 100 iterations and with more in parallel requests in order to analyse the new measurements and try to improve the procedure if it is needed.

Finally, Table 5 represents the results obtained during all the tests (Lab01 and Lab02) in terms of UC6 KPIs.

Table 5. Test cases results for Trial 6.1.

Test case ID	Test requirement	Measurement result	Validation
6.1_Lab01_01	KPI#11: >0.80 KPI#12: >0.65 KPI#13: >0.70	KPI#11: 0.8419 KPI#12: 0.5274 KPI#13: 0.6485	The first results are encouraging and satisfying. The large number of objects (multiple people in an image) that were labeled in the dataset was expected to influence the Recall. This metric will be improved when collecting a custom dataset, the model will be retrained.
6.1_Lab02_01	10ms < KPI#08: < 100ms	KPI#08: 96.704 ms	The first results are satisfying and follow the test requirement
6.1_Lab02_02	10ms < KPI#08: < 100ms	KPI#08: 68.431 ms	The first results are satisfying and follow the test requirement
6.1_Lab02_03	10ms < KPI#08: < 100ms	KPI#08: 69.136 ms	The first results are satisfying and follow the test requirement

3.1.1.2 Tests on field

As of the publication date of this report, no tests on field have been conducted.

3.1.1.3 Early demo

The first early demo took place in the EuCNC & 6G Summit 2023 in Gothenburg, Sweden where the first implementation of the UC6 application was showcased (Figure 24). The overall concept of the UC6 was presented through a pre-recorded video including both the first implementation of the MCI dashboard for the first responders and the image processing for the crowd estimation and human movement analysis without integrated analytics and backend services. The MCI dashboard represented the Technopolis area in Athens, where different areas with possible victims were localized, with a preliminary triaging. When the victims are detected through the appropriate AI algorithms that are used, some pins are created to represent the victim's location on the map in order to the first responder to go directly to them for the prehospital treatment. A video related to this early demo is available on YouTube [37].

Figure 24. UC6 – First Early Demo at EuCNC & 6G Summit 2023 in Gothenburg.

The second early demo took place in the third project plenary meeting in Athens (September 2023), where the overall concept of the UC6 was presented including both the first implementation of the MCI dashboard for the first responders and the first integration with the backend functionalities, image processing for the crowd estimation and human movement analysis (Figure 25). In real-time during the meeting the MCI was detected through the AI algorithms, and the first responder assignment to the indicated location of the incident was completed. Some of WINGS team act the role of the victim-patient and by wearing the smartwatch the first vital signs are measured for the triaging procedure and the patient health status. After these measurements, the first level of the prehospital treatment and the patient triage summary was presented on the dashboard.

Figure 25. UC6 – Second Early Demo at TrialsNet plenary in Athens (September 2023).

3.1.2 Trial 6.2 - Emergency evacuation in Populated Area

The goal of the UC6 in Madrid is the same as for the UC6 in Athens, but in the Scenario 2 (Evacuation in the context of a large-scale event in a sports venue) which is described in detail in D4.1 [1] in the section 3.1.4.. The on-field trial will be executed in a crowded sport event (basketball stadium of the Spanish first division), which involves different constraints and limitations, as well as different numbers of users, presenting different behaviors and patterns. Preliminary tests have been performed in the laboratory to verify the technology, architecture, and interaction among the different involved components.

3.1.2.1 Laboratory tests

The UC 6 in Madrid has gone through a laboratory testing phase to obtain preliminary KPI measurements and assess behavior in a controlled environment. In particular, the laboratory testing was executed in the 5Tonic facility [2], using the architecture shown in Figure 26. As end-devices, a laptop was used, emulating wearable devices, and communicating with the backend provided by WINGS for the Athens UC6 instance. Communication with the backend was performed through the Internet connectivity of the testbed, as shown in Figure 26.

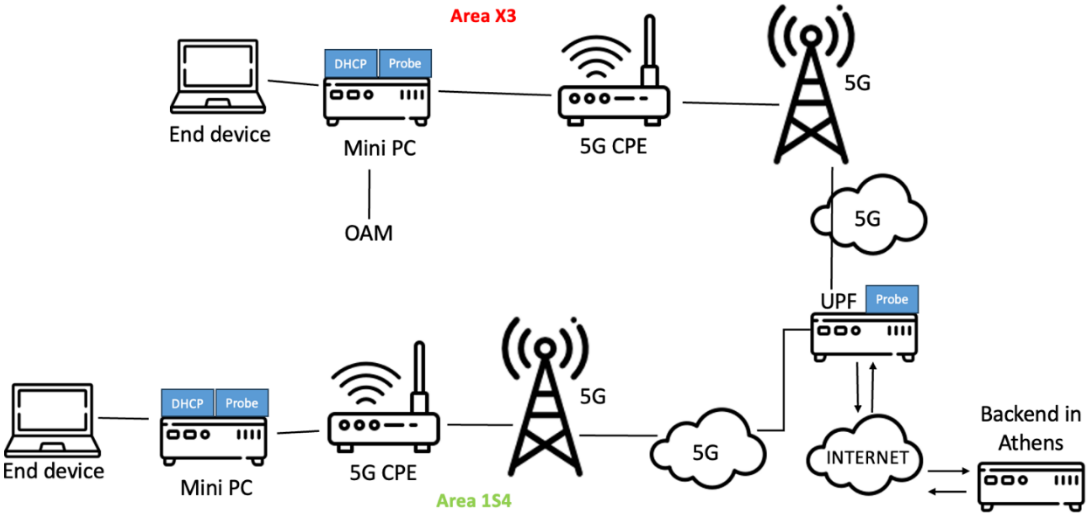

Figure 26. UC6 – Testbed Architecture.

With respect to the KPIs intended to be measured, the probes only provided information about the throughput, reported in the Figure 27. The probes are located in the Mini PCs and in the UPF, as reported in Figure 26.

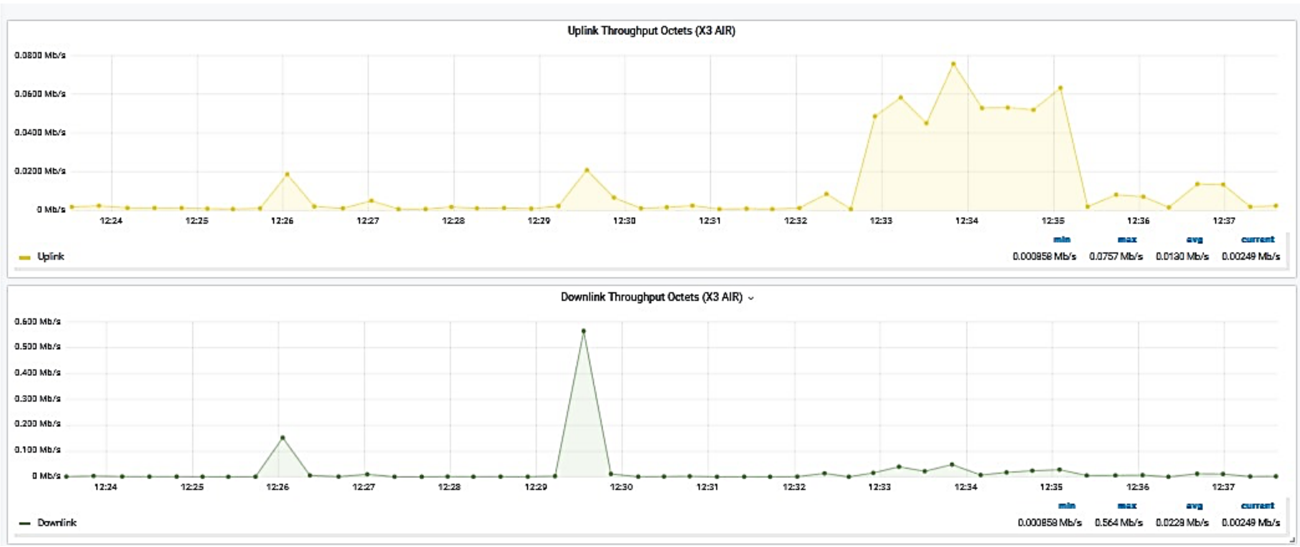

Figure 27. UC6 – Throughput measurements.

Measurements of latency and jitter were also expected but the probe did not report them correctly. To fix this issue, a new laboratory testing will be executed to check that they can be measured without issues, as happened for the other UCs in the same cluster. For what concerns measurements of network reliability and network availability, they have not yet been implemented in the probes, but they are expected to be in time for the pre-trial. Table 6 and Table 7 reports the results obtained during all the test (Lab01) in terms of UC6 KPIs.

Table 6. Test summary for Trial 6.2 (Lab01).

Test summary	
Trial ID	6.2
Test setup ID	Lab01
Facility/Site	5TONIC
Objective	Test the emulation software, test the measurement tools.
Description	Validation of emulator and measurement tools
Executed by	Aruna Prem Bianzino, Fernando Beltran Gonzalez
Components involved	N/A
Targeted KPIs	KPI#05 (Downlink throughput per device) KPI#06 (Uplink throughput per device) KPI#08 (Application round-trip latency)
Measurement tools	Ericsson Probe
Ethics requirements implementation	N/A
Involvement of beta-users	N/A

Table 7. Test summary for Trial 6.2 (Lab01).

Test case ID	Test requirement	Measurement result	Validation
6.2_Lab01_01	KPI#05: 50 Mbps	Refer to Figure 27 (green plot)	The goal of this test was to assess the measurement capacity of the probe. It was possible to measure this KPI
6.2_Lab01_02	KPI#06: 10 Mbps	Refer to Figure 27 (yellow plot)	The goal of this test was to assess the measurement capacity of the probe. It was possible to measure this KPI
6.2_Lab01_03	KPI#08: <100 ms	N/A	The goal of this test was to assess the measurement capacity of the probe. It was not possible to measure this KPI. The test will be repeated

3.1.2.2 Tests on field

As of the publication date of this report, no tests on field have been conducted.

3.1.2.3 Early demo

As of the publication date of this report, no early demos have been conducted.

3.1.3 Remarks and next steps

As the outcome of the testing activity of the Trail 6.1 (Athens site), the following remarks can be made:

- The development of the visualization dashboard integrated with the backend services.
- Preliminary tests were performed were applied in the WINGS Testbed for100 iterations where the initial KPIs were measured with satisfying result covering the test requirements and measurements ranges (e.g. 10ms < KPI#08: < 100ms).
- Detection model: the large number of objects (multiple people in an image) that were labeled in the dataset was expected to influence the Recall and will be improved with the retained model.
- Two early demos were done, the first one took place in the EuCNC & 6G Summit 2023 in Gothenburg, Sweden where the first implementation of the UC6 application was showcased and the second one took place in the third project plenary meeting in Athens (September 2023), where the overall concept of the UC6 was presented including both the first implementation of the MCI dashboard for the first responders and the first integration with the backend functionalities, image processing for the crowd estimation and human movement analysis.

Based on the above, the next steps and coming tests are summarized below:

- By collecting a custom dataset, the detection model will be retrained, and the metrics will be improved.
- The tests for the KPI#8 will be repeated for more than 100 iterations and with more in parallel requests in order to analyze the new measurements and try to improve the procedure if it is needed.
- Integration of network infrastructure and devices.
- Additional KPIs will be measured, and the test will take place on the field by using the commercial network.
- A third early demo will be presented in the EuCNC & 6G Summit 2024 in Antwerp, Belgium.

For what concern the Trial 6.2 (Madrid site), further tests will be performed in order to measure the application round-trip latency due to the issues on the probes side during this preliminary phase.

3.2 UC7: Remote Proctoring

3.2.1 Trial 7.1 - Remote Proctoring

The goal of UC7 is to support remote proctoring activities in the field of interventional cardiology, offering innovative solutions based on smart tools for telepresence (e.g., XR tools) in the surgical fields to connect expert proctors and remote hospitals. Firstly, laboratory tests have been conducted to assess the impact of latency on the performance of XR tools planned to be used in the trial. Subsequently, on-field tests were conducted to evaluate the influence of the proposed new remote proctoring system on psychophysiological states and manual task performance of clinical users by measuring physiological states (HRV and Respiratory rate), task accuracy (Complex Figures scores), and Cognitive Load (NASA Task Load Index score). These tests are used to start assessing the two KVIs of UC7 that are the improved user experience and realistic telepresence.

3.2.1.1 Laboratory tests

The initial laboratory experiments were conducted in April 2023 within the Ericsson labs located in Pisa, at the CNR Campus area designated for the upcoming trial. The tests, carried out collaboratively by Ericsson and Scuola Superiore Sant'Anna, aimed to assess the impact of latency on the performance of XR tools scheduled for use in the trial. For these tests, Vuzix M400 and Realwear HMD-1 smart glasses were wirelessly linked to a computer equipped with the Netem (Network Emulator) tool [36], which was in turn connected to the LAN network. Figure 28 illustrates the Netem CLI while Figure 29 is taken in the Ericsson labs during a test session.

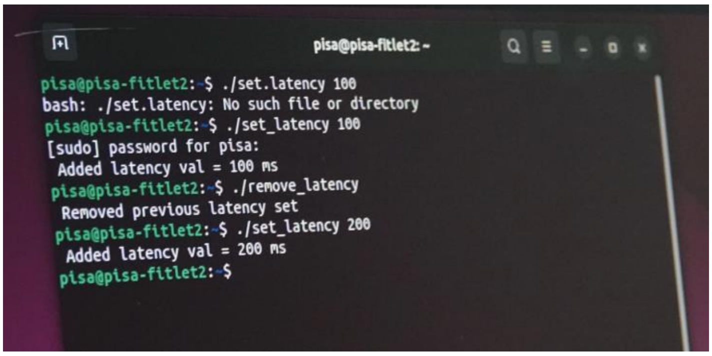

Figure 28. UC7 - Netem Command Line Interface (CLI).

Netem is a tool that extends Linux's traffic control capabilities, enabling the simulation of various network conditions such as delay, packet loss, duplication, and more on outgoing packets from a chosen network interface. It utilizes the existing Quality of Service (QoS) and Differentiated Services (diffserv) features within the Linux kernel. Netem's primary application is in protocol testing, where it emulates the attributes of wide area networks (WANs).

Figure 29. UC7 - Preliminary laboratory test.

With the use of Netem, incremental delays ranging from 100 ms to 2 seconds in steps of 100 ms were introduced during the tests. These tests evaluated the usability of the AR glasses under different latency conditions to determine the maximum end-to-end latency that is acceptable for the particular application. This acceptable latency budget will then need to be allocated among various processes including AR application processing time, video compression time, and communication time. The focus of these experiments was to ascertain the maximum latency that the 5G radio network must accommodate, which is critical for ensuring the proper functioning of AR applications.

The following tables reports the test setup description, test summary and results for Trial 7.1.

Table 8. Test setup description for Trial 7.1 in laboratory.

Test setup parameters	Test setup ID: Lab01
Network type	LAN+WiFi
Device type	VUZIX M400
Device number	1
Device speed	0 km/h
Latency Trimmer	Netem

Table 9. Test summary for Trial 7.1 in laboratory.

Test summary	
Trial ID	7.1
Test setup ID	Lab01
Facility/Site	Ericsson Research lab in CNR Campus
Objective	Determine the maximum tolerable latency for the XR-based telepresence system for the remote proctoring use case (and for the smart ambulance use case)
Description	The tests with AR smart glasses, connected wirelessly to a computer with the Netem tool introducing variable latency.
Executed by	Fabio Ubaldi and Fabio Del Vasto (Ericsson Research) with Prof. Franco Tecchia (Scuola Superiore Sant'Anna)
Components involved	VUZIX M400, Netem tool
Targeted KPIs	KPI#03 (Downlink aggregate throughput) KPI#09 (Application one-way latency) KPI#17 (Service availability)
Measurement tools	WebRTC test suite
Ethics requirements implementation	N/A
Involvement of beta-users	N/A

The availability parameter KPI#17 is not measured for the motivations explained in the following. The parameter of availability is calculated by dividing the uptime (the period during which the radio link is functional) by the total time the radio link is intended to be in operation. Given that the target availability for KPI#17 is "five-nines" (99.999%), achieving a meaningful statistical measure of availability would necessitate a prolonged period of continuous testing, often extending to at least a year. This duration is required to capture any significant "out of order" periods and to accurately reflect the network's reliability. Further-more, the radio system employed in the pilot project will not incorporate a full 1+1 redundancy (where an entire backup system is in place to take over in the event of a failure) due to cost considerations. In contrast, a fully deployed commercial network would generally include such redundancy to enhance reliability and minimize downtime. As a result, the availability measurements that could be obtained within the pilot area are likely to yield lower values compared to those expected from commercial deployments with full redundancy.

Table 10. Test cases results for Trial 7.1 in laboratory.

Test case ID	Test requirement	Measurement result	Validation
7.1_Lab01_01	KPI#03: 50 Mbps KPI#09: 20 ms	KPI#03: 30 Mbps KPI#09: 23 ms	The first results are satisfying and follow the test requirement
7.1_Lab01_02	KPI#03: 50 Mbps KPI#09: 20 ms	KPI#03: 82 Mbps KPI#09: 15 ms	The second results are satisfying and follow the test requirement

3.2.1.2 Tests on field

In December 2023, tests on field were conducted within the CNR Campus, in internal premises made available by the vertical partners of the project (IFC-CNR, Fondazione Monasterio). These tests aimed to assess the influence of the proposed technological innovations on the psychophysiological states and manual task performance of clinical users. This involved a network setup employing a local LAN/Wi-Fi network and the mentioned Netem tool to adjust latency levels.

The researchers aimed to gauge the cognitive load and fatigue experienced by remote experts and trainees while performing standardized drawing tasks using two distinct communication interfaces such as i) a traditional PC setup with a screen and mouse, and ii) an XR interface. These interfaces were assessed under varying levels of network latency to understand how these conditions might affect user experience and efficiency, particularly for tasks requiring real-time interaction or response. Figure 30 and Figure 31represents moments during the tests.

Figure 30. UC7 – Test on field: proctor room.

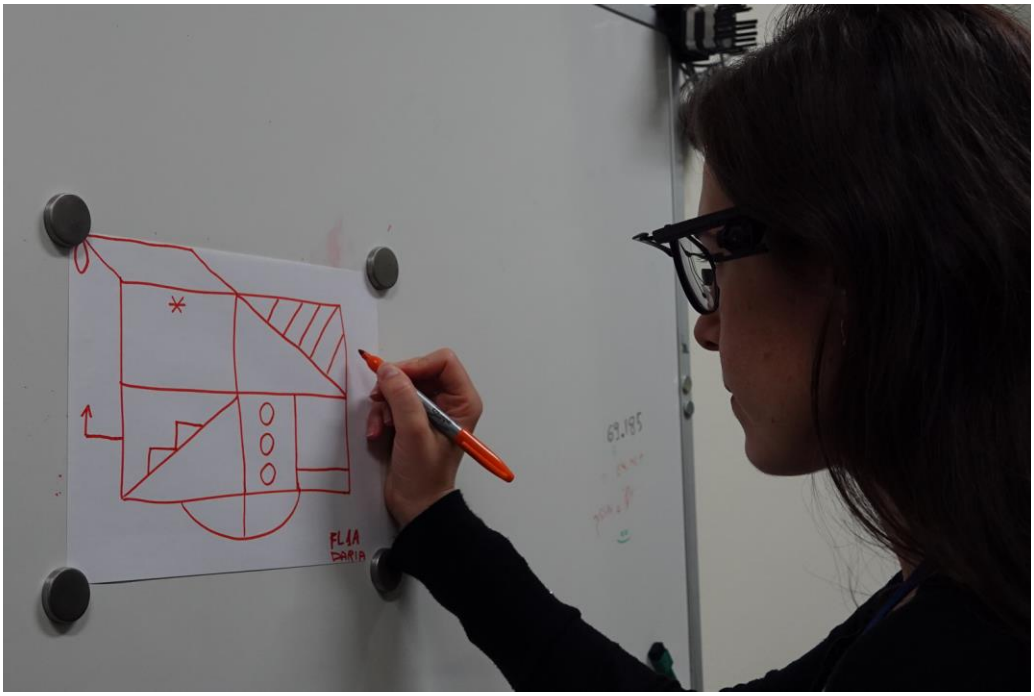

Figure 31. UC7 – Test on field: trainee room.

Several psychophysiological variables were measured on a beta-tester user:

- **Cognitive Load**: The NASA Task Load Index was used to measure cognitive load. This subjective assessment tool is designed to gauge the perceived workload and consists of six subscales: mental demand, physical demand, temporal demand, performance, effort, and frustration. The participants rate their perceived level of these factors on a 21-point scale, providing a comprehensive understanding of the cognitive load experienced during the task.

- **Task accuracy**: The score of 6 standardized complex figures (Taylor Complex Figure, Modified-Taylor Complex Figure, and The Four Medical College Complex Figures) was used to assess the accuracy of the task. These neuropsychological tools are particularly relevant to surgical training, as they measure visuo-spatial memory and visuo-constructive skills, both crucial for surgical tasks that often involve intricate, spatially complex procedures. During these tests, each participant is asked to reproduce a complicated line drawing driven by a remote expert.
- **Physiological Aspects**: Heart Rate Variability (HRV) and Respiratory Rate were measured as indicators of physiological response to cognitive load and fatigue.

By examining these variables, the study will provide valuable insights into how these new technological interfaces could affect user performance and physiological state in clinical settings and varying network conditions. At the time of publication of this deliverable, data emerging from a large set of test iterations are under collection and analysis.

The LAN-based network complemented by Wi-Fi will be replaced by the indoor 5G network in the subsequent development of the trial.

3.2.1.3 Early demo

As of the publication date of this report, no early demos have been conducted.

3.2.2 Remarks and next steps

Quantitative and qualitative tests have been used to assess the values of network quality parameters which can guarantee an adequate QoE for the proctor and the trainee when using XR devices. The 5G network that will be deployed in the CNR campus is expected to support such network performances.

More broadly, it has been considered to adjust the compression level of video streaming to find the optimal trade-off between required throughput and acceptable latency in case that the 5G network could present saturation.

The next steps will be to perform the tests using the indoor 5G network coverage as soon as it becomes operational according to the project timeline.

3.3 UC8: Smart Ambulance

3.3.1 Trial 8.1 - Smart Ambulance

The goal of UC8 is to propose a 5G-connected smart ambulance operating outdoor in mobility and develop an infrastructure that can enable the ambulance to share diagnostic information with the main center. The smart ambulance will be equipped with i) new audio/video communication tools (XR headsets) between operators on the ambulance and supporting experts in the hospital, ii) diagnostic tools for cardiological pathology and iii) devices to guarantee an efficient and fast 5G connection in remote locations and mobility conditions. The laboratory test conducted in UC7 to test XR devices will also be used for the smart ambulance.

3.3.1.1 Laboratory tests

The laboratory tests conducted for UC7 were intended to test the XR devices that will also be used in the context of the smart ambulance, albeit in a mobility scenario. The requirements that such devices demand from the network are the same as those for the UC7 scenario.

3.3.1.2 Tests on field

As of the publication date of this report, no test on field have been conducted.

3.3.1.3 Early demo

As of the publication date of this report, no early demos have been conducted.

3.3.2 Remarks and next steps

The remarks and next steps reported for UC7 are applicable also for UC8. In addition, test on field will be required to verify the smooth support of medical systems on board of the ambulance once the network will be operational.

3.4 UC9: Adaptive Control of Hannes Prosthetic Device

3.4.1 Trial 9.1 - Adaptive Control of Hannes Prosthetic Device

The goal of UC9 is to improve the experience of a user driving a prosthetic arm, leveraging on radio connectivity to provide sufficient computing power to the prosthesis for the deployment of the AI methods, ensuring high reliability and minimal latency. The final system will be validated with experiments on the field with the Hannes prosthetic arm. The performance will be verified in both laboratory and field tests, in terms of accuracy, reliability and efficiency.

Each trial consists of different tests where a user grasps different objects, placed on a table, with different approaching directions. Each grasping execution is structured as follows:

- The participant, driving the prosthesis (by means of the external able-bodied adapter), stands in front of the object to grasp, placed on a table (see Figure 32a).
- After a starting trigger (either a keyboard signal or an EMG signal from the user can be used), the user approaches the object, moving the prosthesis towards it as if to grasp it. The approach lasts ~2 seconds and the system collects color frames from the camera mounted on the prosthesis.
- These frames, together with the EMG and IMU sensors signals are sent to the embedded electronic board (through USB connection) and then from the board to the DNN-based methods in the AI machine through 5G network.
- The DNN-based method processes the received signals and the hand pre-shape is predicted after ~2 seconds.
- The pre-shape class is converted into the corresponding thumb configuration.
- The thumb configuration is sent through the 5G network to the embedded electronic board which translates it into control signals for the prosthesis DoFs.
- The pre-shape is executed and then the fingers close around the object, after a user command.

Figure 32 illustrates the application setup for the trials: (a) the prosthesis is driven by the user via the able-body adapter to grasp an object and (b) all the objects considered for the experiments.

a b

Figure 32. UC9 - Application setup for the trials.

In the final trial, the application will be evaluated from two different perspectives:

- **Application level:** the grasping success rate is measured to evaluate the effectiveness of the developed system to help users in grasping objects with the prosthesis.
- **User level:** the users' experience provides feedback on how the network connection impacts on the execution of the different movements and on the reactiveness of the prosthesis. These aspects are collected through ad hoc questionnaires.

The use case is currently implemented and tested in a laboratory context, in the Ericsson R&D Laboratories in Genoa, while the final trial phase will take place in Pisa. Specifically:

- **Laboratory tests:** The Ericsson R&D Laboratory site is currently used for the first phase of the use case implementation to test the developed prototypes and their integration. The trials follow the steps described above and the results are used to refine the design of the architecture and of the required 5G network infrastructure as well as to tune all the different components.
- **Fields tests:** The second experimental site will be the CNR premises in Pisa. This site will be used for the final trials of the use case to test the integrated system. The trial will be executed following the steps as reported in the previous paragraphs and will be used to evaluate the performance of the system.

3.4.1.1 Laboratory tests

As described in the previous section, the goal of the first phase of the use case testing is the assessment of the developed prototypes and their integration until an advanced level of readiness of the system is achieved. In particular, a set of tests has been already carried out to define the network performance baselines. One of the aims of these activities was to characterize the components to find the best configuration for each of them and to detect the possible network and application bottlenecks. These activities have been carried out both in the IIT and Ericsson laboratories.

For performance evaluation during these tests, the latency between the two main components of the application (i.e., the Variscite electronic board embedded into the prosthesis and the AI machine) has been measured. For this purposes, the use of a YARP software tool [30] allows to monitor the network performance during an exchange of packages between two network nodes, at the application level. Specifically, this tool allows to connect two nodes of the network, establishing a connection at the application level and exchanging messages with varying payloads. At the same time, it records the latency occurring during this packets exchange. Since our interest is in measuring the performance in both directions (from the prosthesis to the AI machine and vice-versa), both latency measurements have been reported. Figure 33 schematically illustrates the test architecture, and in the following paragraphs, the experimental setups, the main tests details and the obtained results will be described.

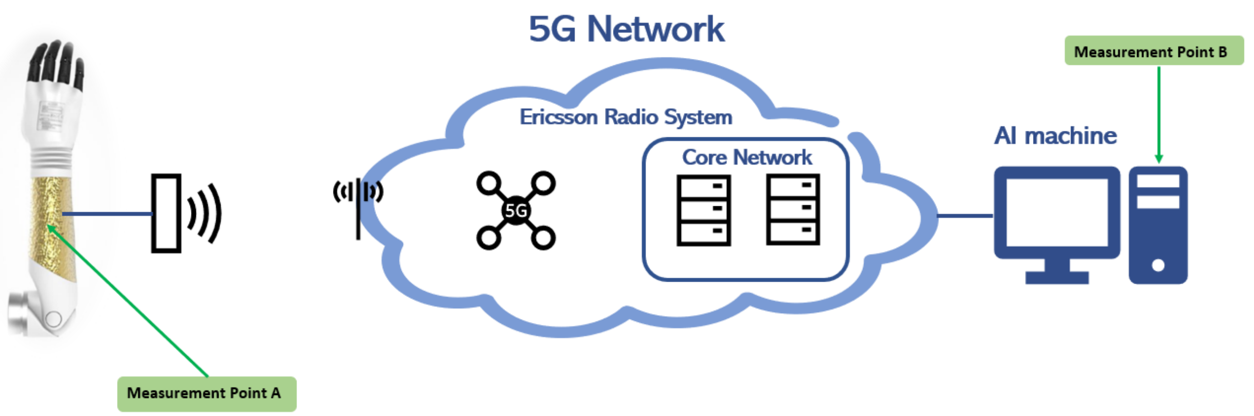

Figure 33. UC9 - Adaptive Control of Hannes Prosthetic Device architecture and probes positioning.

To define the baselines that will be used at later stages of the project, two testing setups have been considered:

- **Lab01**: this experimental setup involved the internal IIT network (i.e., no 5G network).

- **Lab02**: this experimental setup involved the 5G network available at the Ericsson R&D laboratories in Genoa. The details of this test setup are available in Table 11.

Table 11. Test setup Lab 02 details.

Test setup parameters	Test setup ID: Lab02
Radio access technology	5G NR
Network type	Standard
Standalone / Non-Standalone	Non-standalone
Cell Power	Laboratory Environment
Frequency band	n78
Bandwidth per component carrier	80 MHz
Sub-carrier spacing	30 kHz
MIMO	4x4
Duplex mode	TDD
Device type	Variscite tethered with mobile phone
Device number	1
Device speed	N/A
Slice Configuration	None
Background / simulated traffic	None

The activities carried out in the above laboratory settings had different goals for the full characterization of the UC9 components and architecture. In the following, the performed tests are described in detail.

Configuration test

This test was performed with the test setup Lab01, i.e., IIT facilities without 5G network. The objective was to understand the best configuration for the devices of the application, with a focus on the characterization of the Variscite board. To this aim, the different network interfaces (USB, USB-c and Wi-Fi) available on the Variscite board have been compared. The choice of the best interface, indeed, is crucial for the development of the application since that interface will be used to get the 5G connectivity through a phone tethering. The considered KPI was the latency between the Variscite board and the AI machine. Test summary is reported in Table 12.

Table 12. Test summary for the Configuration test.

Test summary	
Trial ID	9.1
Test setup ID	Lab01
Facility/Site	IIT
Objective	Evaluation of network latency due to Variscite’s ports’ management
Description	Characterization of application devices, with a focus on the Variscite board, comparing the network interfaces available (USB, USB-c and Wi-Fi)
Executed by	Elisa Maiettini, Federico Vasile, Dario Di Domenico
Components involved	Prosthesis, Variscite electronic board, AI machine

Targeted KPIs	KPI#09 (Application one-way latency) from A to B endpoints (see Figure 33)
Measurement tools	YARP software tool
Ethics requirements implementation	N/A
Involvement of beta-users	N/A

For this test, the AI machine is cable connected to the IIT internal network, while varying the different Variscite board interfaces, used for the phone tethering. The connection latency from the Variscite board to the AI machine for growing payload sizes (from 1 Byte to 2000 Byte) has been measured. In Figure 34, the average latency (solid line) and the variance (shadow) for 100 different tests for each of them are reported. Specifically, test 2 (yellow) represents the performance obtained using the Variscite board USB-c interface for the phone tethering, test 3 (green) represents the performance obtained using the USB interface for the phone tethering. Finally, test 1 (red) is reported as a reference (upper-bound) and represents the performance obtained connecting the Variscite board to the IIT network via Wi-Fi.

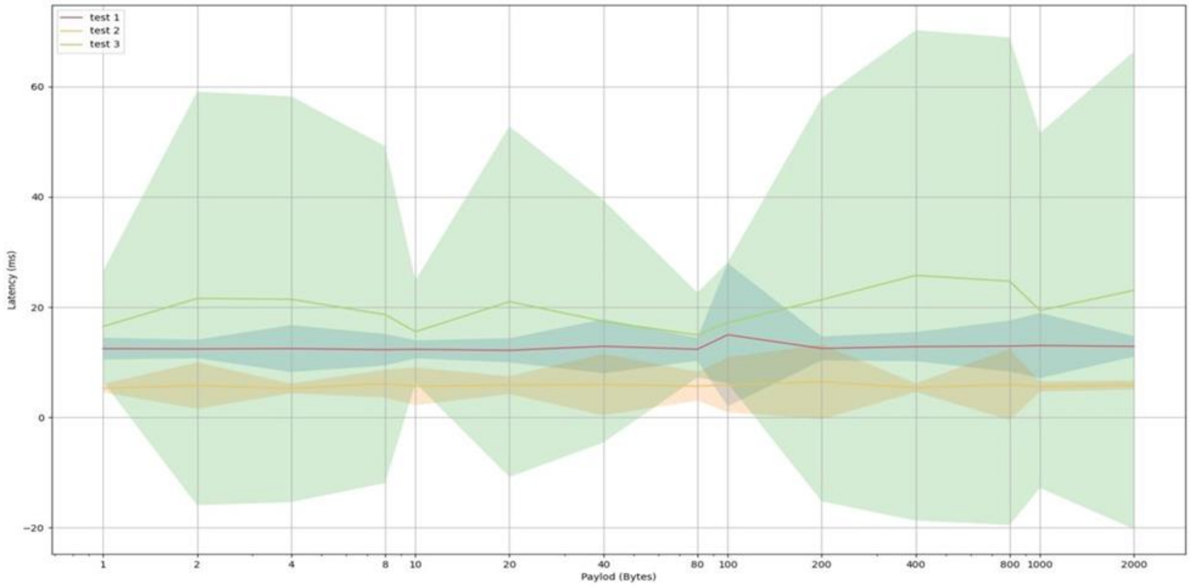

Figure 34. UC9 – Latency vs payload for the Configuration test.

The results show that the best performance for phone tethering connection is obtained with the Variscite board USB-c network interface. Thus, in the next trials (and for the rest of the project), this network interface is used.

Protocol test

This test was carried out with the test setup Lab02, i.e., in the Ericsson R&D laboratories in Genoa, with the available 5G network. The goal was to compare the communication protocols available with the YARP middleware. Specifically, these are protocols at the application level, used by the middleware to send messages through the network. For this test, two different YARP protocols, namely, the YARP TCP and the YARP Fast_TCP protocols has been compared. The KPI considered for performance evaluation in this test is the latency between the Variscite board and the AI machine (i.e., from endpoint A to endpoint B in Figure 33) and vice-versa (see additional details in Table 13).

Table 13. Test summary for the Protocol test.

Test summary	
Trial ID	9.1
Test setup ID	Lab02

Facility/Site	Ericsson Genoa
Objective	Preliminary characterization of the latency using a NonStandalone architecture, before upgrading the network laboratory environment.
Description	Comparison between YARP TCP and YARP Fast_TCP protocols (Protocol test) and the effect of different payloads on the network latency (Payload test).
Executed by	Mara Piccinino, Giancarlo Sacco, Elisa Maiettini, Marco Randazzo, Federico Vasile, Dario Di Domenico, Carmela Calabrese
Components involved	Prosthesis, Variscite, AI machine
Targeted KPIs	KPI#09 (Application one-way latency) from A to B endpoints and from B to A endpoints (see Figure 33)
Measurement tools	YARP software tool
Ethics requirements implementation	N/A
Involvement of beta-users	N/A

In Figure 35 and Figure 36, the plots show the average latency (solid line) and the variance (shadow) for 100 different tests with the two different YARP communication protocols. Specifically, Figure 35 represents the latency for the payloads sent by the Variscite board (endpoint A) to the AI machine (endpoint B) whereas Figure 36 shows the results the other way round (B to A). The red line corresponds to the configuration where the transmission relies on YARP Fast TCP protocol whereas the results in green display the values recorded during YARP TCP communication. As for the previous experiment, the YARP connection latency for growing payload sizes (from 1 Byte to 2000 Bytes) has been measured. Note that, this is different from the latency that can be measured with the ping, since it already involves protocol at the YARP application level.

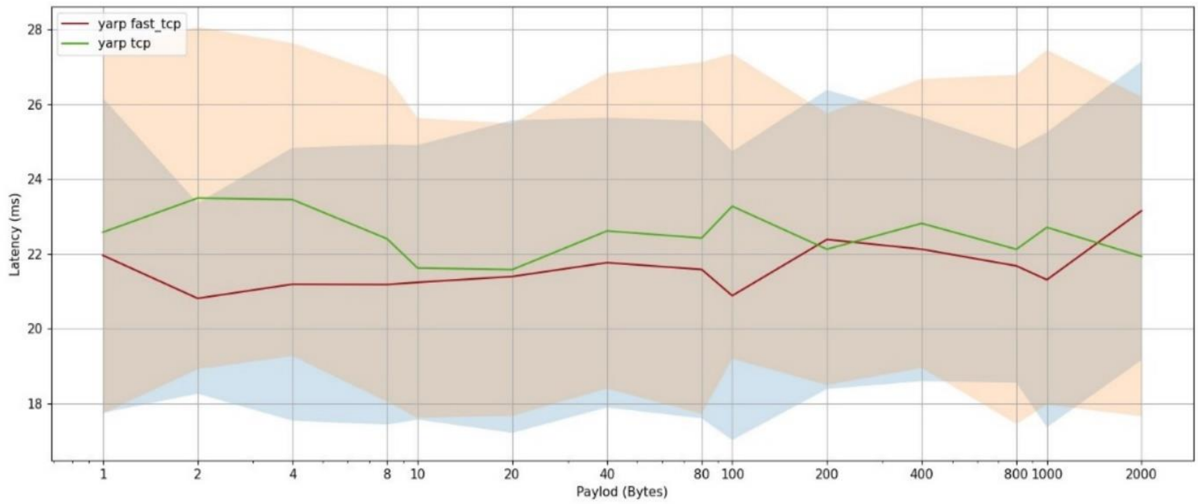

Figure 35. UC9 - Latency vs payload for the Protocol test (from A to B endpoint).

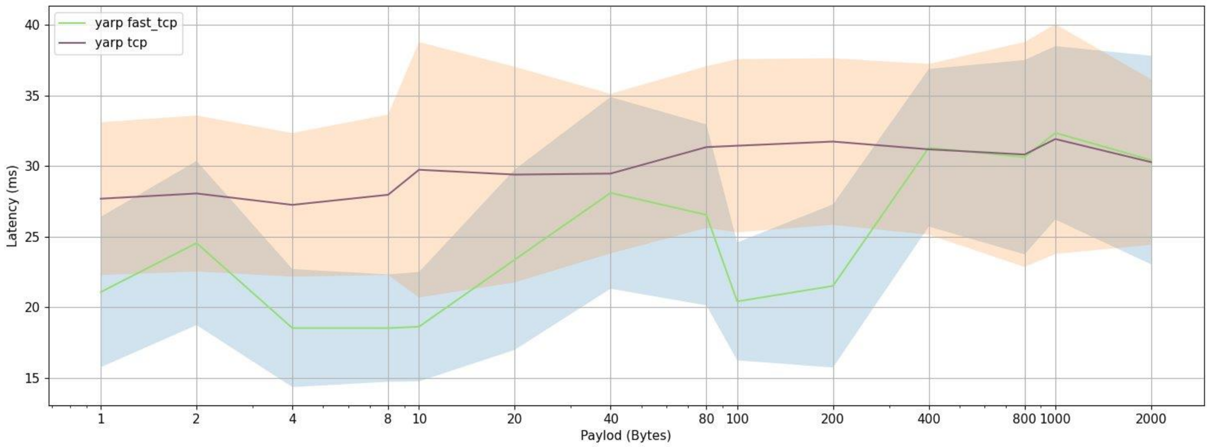

Figure 36. UC9 - Latency vs payload for the Protocol test (from B to A endpoint).

The latency recorded in this preliminary experimental session highlights that, on average, the YARP Fast_TCP protocol guarantees smaller delays in the communication between the two application endpoints.

Payload test

Within the same experimental context of the previous test case (i.e., the test setup Lab02), the connection between the Variscite board and the AI machine has been tested, using a packets size which more closely simulates a stream of images. The KPI considered for performance evaluation in this test is the latency between the Variscite board and the AI machine (i.e., from endpoint A to endpoint B in Figure 33) and vice-versa (see additional details in Table 13). In particular, Figure 37 reports the average latency (solid line) and the variance (shadow) for 100 different tests across the increasing number of packets sent by the Variscite board (endpoint A) to the AI machine (endpoint B) whereas in Figure 38 the latencies recorded in the other way round (B to A) are shown.

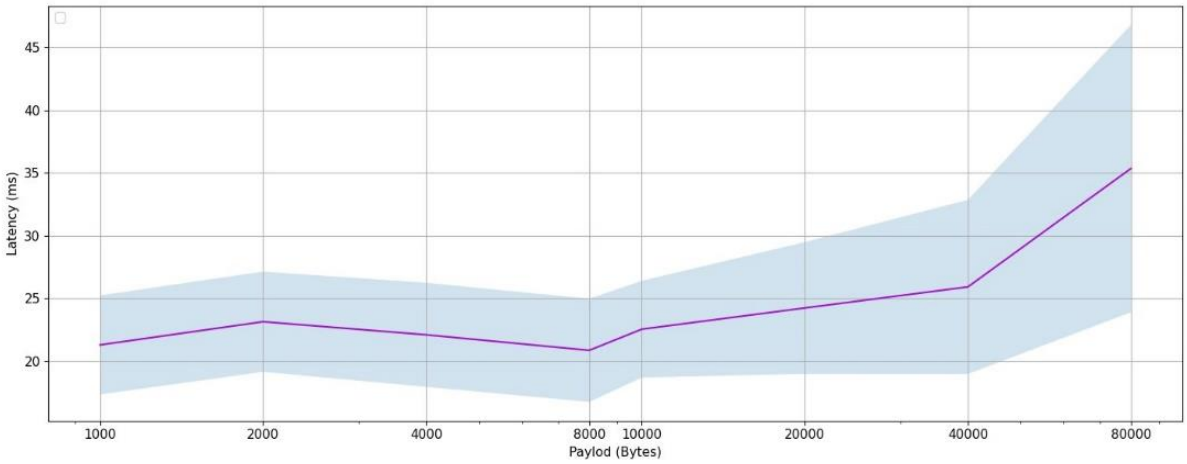

Figure 37. UC9 - Latency vs payload for the Payload test (from A to B endpoint).

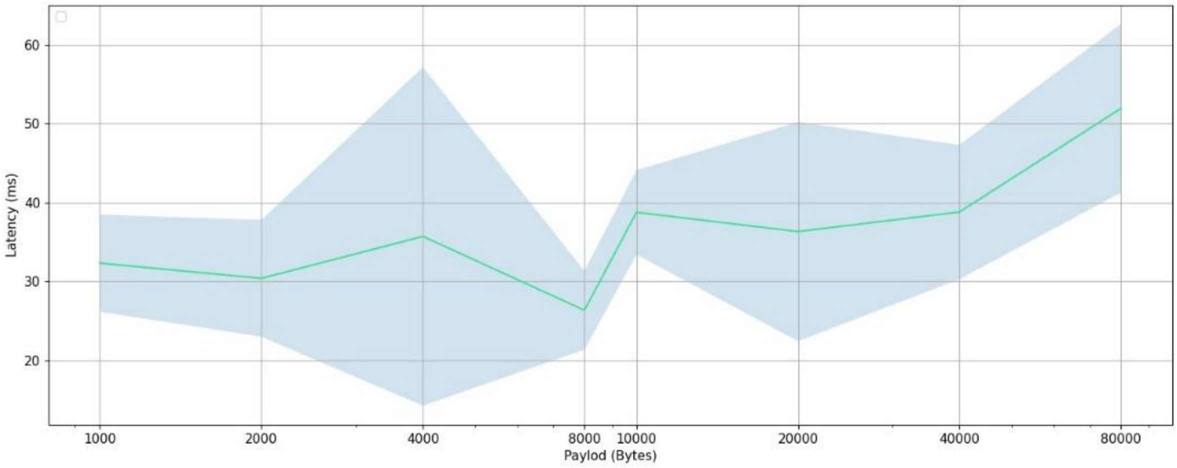

Figure 38. UC9 - Latency vs payload for the Payload test (from B to A endpoint).

The results obtained in this test session show that, on average, the delay in the communication between the two application endpoints, in both directions increases, for heavier payloads. This result is reasonable; however, it has to be considered as a baseline for future development and the aim of the next months will be to improve this performance significantly to meet the UC requirements.

Finally, Table 14 recaps the results obtained during all the tests in terms of UC9 KPIs.

Table 14. Test cases results for Trial 9.1.

Test case ID	Test requirement	Measurement result	Validation
9.1_Lab01_01	KPI#09 The test aim was to find the available device configuration with the minimal value.	KPI#09 The result is reported in Figure 34	For this experiment, different payloads have been tested. The results are reported in the plot in Figure 34.
9.1_Lab02_01	KPI#09: 10/15 ms	KPI#09 The results are reported in Figure 35 and Figure 36	For this experiment, different payloads have been tested. The results are reported in the plots in Figure 35 and Figure 36
9.1_Lab02_02	KPI#09: 10/15 ms	KPI#09 The results are reported in Figure 37 and Figure 38	For this experiment different payloads have been tested. The results are reported in the plots in Figure 37 and Figure 38.

3.4.1.2 Tests on field

Currently, all the tests are done in the Ericsson R&D laboratory in Genoa. The field tests in the CNR laboratory in Pisa are planned for the Q2-2025.

3.4.1.3 Early demo

The current state of UC9 does not allow wrapping up the work done in a consistent and independent dissemination product.

3.4.2 Remarks and next steps

In conclusion, the tests carried out in Q4 used for the characterization of UC9 architecture's latency shed lights on the following points:

- The results obtained in the Configuration test suggest that the USB-c port represents the best configuration for the connection of the Variscite board to the 5G network through the phone tethering.
- Results from the Protocol test highlight that, at the application level, communication through YARP Fast_TCP protocol ensures smaller delays than the YARP TCP.
- Results from the Payload test show the available 5G network performance in the current configuration for payloads that simulate the images size. These results represent the baselines for future developments.

In the next months, the planned activities involve taking the results obtained with the current application and network configurations (especially, the ones obtained for higher payloads) as starting points and driving the development activities towards the improvements of the connection performance to meet the application requirements.

4 Implementation plan updates

This section evaluates the progress made against the milestones outlined in the prior deliverable and reports possible critical issues associated to the UCs, if any.

4.1 UC6: Mass Casualty Incident (MCI) and Emergency Rescue in Populated Area (Athens/Madrid)

As described in D4.1 [1], the milestones of UC6 are as detailed below:

- **MS1** (Q2 2023): This milestone involves the definition of the trial, user needs and technical needs. The aim is to obtain a specific description of all the activities/tasks of UC6.
- **MS2** (Q4 2023): This milestone involves the design of technical tools needed for UC6. The main aim is the design of the network infrastructure. The HW and technical tools of telepresence system will be acquired, set-up and tested.
- **MS3** (Q4 2024): This milestone involves the development, set-up and integration of network infrastructure and devices.
- **MS4** (Q3 2025): This milestone involves the execution of control and ESs of the trial.

As of Q2 2023, all the scheduled activities/tasks for MS1 were completed, and by the end of Q4 2023, the HW and technical tools for MS2 have been tested.

During the first year of development for UC6, no critical issues emerged and activities progressed as planned.

4.2 UC7: Remote Proctoring

As described in D4.1 [1], the milestones of UC7 are as detailed below:

- **MS1** (Q2 2023): This milestone involves the definition of the trial, user needs and technical needs. The aim is to obtain a specific description of all the activities/tasks of UC7.
- **MS2** (Q4 2023): This milestone involves the design of technical tools needed to UC7. The main aim is the design of the network infrastructure. The HW and technical tools of telepresence system will be acquired, set-up and tested.
- **MS3** (Q4 2024): This milestone involves the development, set-up and integration of network infrastructure and devices.
- **MS4** (Q3 2025): This milestone involves the execution of control and ESs of the trial.

As of Q2 2023, all the scheduled activities/tasks for MS1 were completed. Within Q4 2023, the following activities were completed as scheduled, meeting the objectives for MS2: the hardware acquisition for end devices, including headsets and telepresence systems, was finalized, infrastructure design for the Pisa and Massa sites was carried out to support project deployment. Additionally, the setup and laboratory testing of the acquired end devices were performed to have a first assessment of the required network performances.

During the first year of development for UC7, no critical issues emerged and activities progressed as planned.

4.3 UC8: Smart Ambulance

As described in D4.1 [1], the milestones of UC8 are as detailed below:

- **MS1** (Q2 2023): This milestone involves the definition of the trial, user needs and technical needs. The aim is to obtain a specific description of all the activities/tasks of UC8.
- **MS2** (Q2 2024): This milestone involves the design of technical tools needed to UC8. The main aim is the design of the network infrastructure. The HW and technical tools of telepresence system will be acquired, set-up and tested.
- **MS3** (Q1 2025): This milestone involves the development, set-up and integration of network infrastructure and devices.
- **MS4** (Q2 2025): This milestone involves the execution of the demo of the trial.

As of Q2 2023, all the scheduled activities/tasks for MS1 were completed. Within Q1 2024 (release of this deliverable).

During the first year of development for UC8, no critical issues emerged and activities progressed as planned.

4.4 UC9: Adaptive Control of Hannes Prosthetic Device

As described in D4.1 [1], the milestones of UC9 are the following:

- **MS1** (Q4 2023): This milestone involves the accomplishment of the first three activities described in the Time plan. The main aim is to develop a first version of the required components and define the baselines of the system.
- **MS2** (Q3 2024): This milestone involves the accomplishment of the fourth and fifth activities described in the Time plan. The main aim is to refine the developed components according to the first results and perform integration tests.
- **MS3** (Q2 2025): This milestone involves the accomplishment of the last two activities described in the Time plan. The main aim is to record the performance of the system in the two trials sites considered for this UC (i.e., Ericsson laboratories in Genoa and the Pisa site).

At the end of Q4-2023, all the scheduled activities for MS1 were accomplished.

Along the first year of UC9 development, the partners did not tackle with any issue management to be reported and activities progressed as planned.

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5 Conclusions

This document provides an overview of the use cases currently being implemented by TrialsNet within the eHealth and Emergency domain. The document delves into the final application design, infrastructure components, functionalities, and initial KPIs measurements for each use case across the sites located in Greece, Italy, and Spain.

The use cases undergo lab trials, ensuring rigorous testing. Additionally, early demos have already been executed for the Athens use case. However, the latter three use cases of WP4 require a 5G network deployment from the scratch. Consequently, the first field trials are programmed in the second half of 2024.

In terms of KPIs, the most important metrics to be measured and tested are specific per use case. As an example, the recall is fundamental for the MCI use case, while it is essential to keep low latency for the others. Overall, initial tests show promising results, particularly from the application perspective. More in detail, the use cases have confirmed to have challenging requirements, in terms of latency (at most all the use cases) and uplink data rate (mainly UC6, UC7, and UC8). In addition, the Smart Ambulance use case (UC8) results particularly demanding since it requires very high performance for transmitting real-time high-quality video even in mobility.

Generally, the results captured in this deliverable will serve as basis to refine and optimize the platform and network solutions developed in the context of WP2 according to the TrialsNet framework defined on D2.1 [2], such as the deployment of new releases of the network functions, the use of different radio bands, the possible integration some network innovation introduced by the project's, or the improvement of the applications which, in some cases, could also entail the integration of new components coming from the Open Call. The next phase will involve integrating the application components of the use cases with the final platform and network solutions deployed in the different sites. Subsequently, a thorough review of the implemented use cases will take place before the final tests. Preliminary results, both in terms of KPIs and KVIs will guide WP6 in its initial evaluation activity which will be enriched by the further data that will be collected in the trial phase.

The results of the WP4 trials will be encapsulated in the third deliverable D4.3 scheduled for completion by the end of September 2025.

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Annex A

D6.1 [3] defined a harmonized list of KPIs to be adopted by all the use cases in order to have a common terminology shared at the project level. In the context of the test activities, and later to the trial phase, it is necessary to have also an efficient way to refer to each KPI in a unique and immediate manner. Therefore, for each KPI, a proper ID has been defined according to the following Table 15.

Table 15. Harmonised KPIs from D6.1 [3] and related IDs.

KPI Name	KPI ID	KPI Definition	KPI Category
Downlink throughput per user	01	Sustained throughput experienced from a user to receive data	Capacity
Uplink throughput per user	02	Sustained throughput experienced from a user to send data	Capacity
Downlink aggregate throughput	03	Sustained throughput, aggregated on multiple users, to receive data in the considered application	Capacity
Uplink aggregate throughput	04	Sustained throughput, aggregated on multiple users, to send data in the considered application	Capacity
Downlink throughput per device	05	Sustained throughput at device level to receive data	Capacity
Uplink throughput per device	06	Sustained throughput at device level to send data	Capacity
Coverage	07	Geographic area where a network signal can be received and used by a device	Capacity
Application round-trip latency	08	Amount of time it takes for the application to receive a response or output after sending a request or input to a server or network.	Latency
Application one-way latency	09	Amount of time it takes at application level from the source to the destination application	Latency
Accuracy	10	Proportion of correct predictions made by the algorithm.	Compute

Precision	11	How often the algorithm is correct when it predicts a positive outcome.	Compute
Recall	12	How often the algorithm correctly predicts a positive outcome out of all the actual positive outcomes.	Compute
F1 score	13	Harmonic mean of precision	Compute
Communication reliability	14	Success probability of transmitting a layer 2/3 packet within a maximum latency required by the targeted service (ITU-R M.2410)	Availability and Reliability
Service reliability	15	Period of time for which the service satisfies the required performance constraints (downlink/uplink capacity, end-to-end latency)	Availability and Reliability
Communication availability	16	Capability of transmitting a given amount of traffic within a predetermined time duration with high success probability	Availability and Reliability
Service availability	17	Ratio between the amount of time during which a specific component of the use case (application, server, network function, etc.) is responding to the received requests, and the total amount of time that the component has been deployed.	Availability and Reliability
Location accuracy	18	Accuracy in the positioning of the device obtained through the 5G network	Localization