5G smarT mObility, media and e-health for toURists and citizenS

Deliverable D5.4

Final Safe City use case results

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List of Acronyms and Abbreviations

Acronym	Description
3D	3 Dimensional
3GPP	Third Generation Partnership Project
4K-HDR	4K High Dynamic Range
5G	5th Generation mobile Wireless Communication System
5G PPP	5G Public Private Partnership
5GC	5G Core
A/V	Audio-visual
AAC	Advanced Audio Codec
AI	Artificial Intelligence
ANFR	Agence Nationale des Fréquences (National Frequency Agency)
API	Application Programming Interface
APN	Access Point Name
AQI	Air Quality Index
AR	Augmented Reality
ATE	Augmented Tourism Experience
AWS	Amazon Web Services
BMSC	Broadcast Multicast Service Centre
BSCC	Broadcast Service & Control Centre
CDN	Content Delivery Network
CHU	Centre Hospitalier Universitaire (University Hospital Center)
CNF	Cloud-native Network Function
CO	Carbon Monoxide
CO_2	Carbon Dioxide
COAP	Constrained Application Protocol
CPE	Customer Premise Equipment
CPU	Central Processor Unit
DC	Datacentre
DNL	Digital Navigation Link Ultrasound
EBU	European Broadcasting Union
ECG	electrocardiogram
eMBB	enhanced Mobile Broadband
eMBMS	evolved Multimedia Broadcast Multicast Service
eNB	Evolved Node B
ENM	Ericsson Network Manager
enTV	Enhancement for TV Service
EPC	Evolved Packet Core
EPG	Evolved Packet Gateway
FEC	Forward Error Correction
FeMBMS	Further evolved Multimedia Broadcast Multicast Service
FTP	File Transfer Protocol
GAM	Modern Art Galley
GDP	Gross Domestic Product
GPU	Graphics Processing Unit
GTP	GPRS Tunneling Protocol
gNB	5G Node B
HDR	High Dynamic Range
HEVC	High Efficiency Video Coding
HPA	High Power Amplifier
HPHT	High-Power High-Tower
HSS	Home Subscriber Server
HTTP	HyperText Transfer Protocol
ICT	Information and Communication Technology
IFB	Interference Free Band
iFN	Institut für Nachrichtentechnik - University of Braunschweig
IIT	Istituto Italiano di Tecnologia
IoT	Internet of Things
JSON	JavaScript Object Notation
KPI	Key Performance Indicator
KVM	Kernel-based Virtual Machine
LED	Light Emitting Diodes
LIDAR	Light Detection and Ranging
LTE	Long Term Evolution
MANO	NFV management and network orchestration
MBMS	Multimedia Broadcast Multicast Service
MBMS-GW	MBMS Gateway
MCE	Mobile Cloud Engine
MCS	Modulation and Coding Scheme
MCU/SFU	Multipoint Conferencing Unit / Selective Forwarding Unit
MEC	Multi-Access Edge Computing
MME	Mobility Management Entity
mMTC	massive Machine Type Communications
MNO	Mobile Network Operator
MR	Mixed Reality
MQTT	Message Queue Telemetry Transport
NB-IoT	Narrow Band IoT
NR	New Radio
NSA	Non Standalone
open-WRT	OPEN Wireless RouTer
OSS/BSS	Operations support system and business support system
P2P	Peer-to-Peer
PNF	Physical Network Function
ONAP	Open Network Automation Platform
QoE	Quality of Experience
QoS	Quality of Service
RAN	Radio Access Network
RGB	Red Green Blue
ROS	Robot Operating System
SAMU	French: Service d'aide médicale urgente, English: Urgent medical aid service
SBA	Service Based Architecture
SDI	Serial Digital Interface
SDN	Software Defined Networking
SCTP	Stream Control Transport Protocol
SDN	Software Defined Networking
SDR	Single Data Rate

SFN	Single-Frequency Network	*UHD*	Ultra HD
SGI	LTE interface to the Packet Data Network (PDN)	*UI*	User Interface
SLA	Service-Level Agreement	*UNESCO*	United Nations Educational, Scientific and Cultural Organization
SLAM	Simultaneous Localisation and Mapping	*UPF*	User Plane Function
SRTP	Secure Real Time Transport Protocol	*URL*	Uniform Resource Locator
STEAM	Science Technology Engineering Arts Mathematics	*USB*	Universal Serial Bus
SVG	Scalable Vector Graphics	*UWB*	Ultra Wide Band
TCP	Transmission Control Protocol	*VHF*	Very high frequency
TS	Transport Stream	*VLC*	VideoLAN Client
TV	Television	*VNF*	Virtualized Network Function
UC	Use Case	*VPN*	Virtual Private Network
UDP	User Datagram Protocol	*VR*	Virtual Reality
UE	User Equipment	*WebRTC*	Web Real-Time Communication
		WP	Work Package
		XR	Extended Reality
		YARP	Yet Another Robot Platform

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Executive Summary

One of the three main themes addressed by the 5G-TOURS project is the safe-city, focusing on connected and remote healthcare use cases enhanced by 5G technology. This document describes the outcome of the work performed during the course of the project in work package 5 (WP5). In WP5, the following use cases are defined, being designed and implemented to address the safe city theme:

- UC6 - Health monitoring and incident driven communications prioritization. This use case addresses solutions for remote health monitoring of people, especially patients with a critical and/or chronic disease. This involves remote health monitoring technology /services and reliable / timely technology /services to notify relevant care professionals and family members in case of detected health deterioration and/or acute care needs.
- UC7 - Teleguidance for diagnostics and intervention support. This use case shows the importance of providing care as early as possible, before the arrival at the hospital, to prevent irreversible deterioration and save the life of critical patients. Ultrasound diagnostics at the incident site are needed to decide what to do and start the right treatment directly. Teleguidance by a remote expert proved to be of vital importance in this case, requiring reliable low latency communication of audio, high resolution video and ultrasound images.
- UC8 - Wireless Operating Room. The goal of the use case is to demonstrate the impact of 5G inside the operating room. Among other things, advantages are that wireless imaging devices are easier to install, connect and synchronize with other imaging equipment and easier to keep sterile. This use case will face low latency and high reliability requirements in addition to a significant amount of video data to be transferred in real-time.
- UC9 - Optimal ambulance routing. This use case addresses real time navigation of an ambulance, both to the site of the emergency, to ensure that medical help will be provided as quickly as possible, as well as from the incident site to the hospital. This will prevent loss of time due to e.g., traffic, road works/blocks as much as possible. The goal is to improve the overall health outcome for the patient by minimizing the time-to-care.

The COVID-19 crisis has accelerated, and still is accelerating the demand for connected healthcare solutions, which has further elevated the relevancy of these use cases since the start of the 5G-TOURS project.

All use cases are finalized in terms of their definition, the integration of application components, design of the application architecture, their implementation and testing. Furthermore, the definition of the network infrastructure needed for the implementation of these use cases on the experimental 5G network of the Rennes node is described in its final setup.

Network deployment in terms of antenna placement, available frequency bands, base stations and edge/core networks is also defined, deployment achieved, and testing done to meet initial commitments to the project. This includes the definition of VNFs, UPF and CPF allocation, VPNs between hospital, BCOM premise and the 5G EVE core network of Orange in their Châtillon datacenter. Also, the overall network architecture has been designed, while the above-mentioned VPNs have been characterized. Antennas have been integrated, deployed and been tested for both Rennes locations.

Compared to the original plan, the execution delay of use case implementation, network installation, and trial, due to the inaccessibility of critical sites, because of the COVID-19 crisis, have been absorbed by the end of the project thanks to the adoption of different ways of working and the resiliency of the project team.

This deliverable D5.4 is in line with the activities of the other work packages, in particular:

- WP2 – NEST templates definition for the slices deployment on 5G networks;
- WP3 – Network architecture and deployment for the selection of the technologies to be deployed and innovations of the service layer;
- WP7 – System Integration and evaluation for the evaluation of the overall achieved results;
- WP8 – Business validation and exploitation for their impact on techno-economic plans.

1 Introduction

5G technology has the potential to help save lives, as an underlying component of a modern healthcare service. Technologies, such as high-resolution video consultations, assistance robots and smart wearables can be enabled by 5G and help increasing the efficiency of treatments. Wherever and whenever needed, the health status of patients should be monitored and analysed, to detect health problems in time and take necessary actions, such as dispatching an ambulance to the patient while taking care that the most optimal / least time-consuming route is taken and that the route is cleared from other traffic. Also, in case of emergencies, 5G network slicing can ensure the minimally required quality of service for communicating audio/video and real-time diagnostic information such as ultrasound images and ECG between an ambulance and the hospital. Next, inside the hospital in all departments, the best treatment plan can be made by ensuring that all information is available at any time and at the right quality through indoor 5G networks. Finally, inside the operating room, invasive procedures can be speeded up and precious time saved by using indoor 5G connected imaging equipment that automatically connect, synchronize and perform image fusion to support complex image guided interventions. In addition , WP5 has performed a multisite integration and demonstration for UC8, as well as migrated, deployed, and tested use cases 6 and 9 in the Athens node (WP6).

The above wellbeing and healthcare use cases are described in work package 5 (WP5), and this document shows the progress achieved before the final phase of the project. In particular these use cases are:

- UC6: Health monitoring and incident driven communications prioritization
- UC7: Teleguidance for diagnostics and intervention support, focused on emergency care
- UC8: Wireless operating room
- UC9: Optimal ambulance routing

Section 2 of this document is dedicated to describing the network infrastructure used by the use cases and their requirements. Sections 3, 4, 5 and 6 of this document are dedicated to the report on the status of each of these use cases, describing them in more details compared to the original high-level definitions given in D5.1, D5.2~~.~~ In particular, section 3 reports on UC6, section 4 on UC7, section 5 on UC8 and, section 6 on UC9, for each use case the following is described:

- UC definition and progress.
- UC implementation in terms of:
    - Application components
    - Terminal equipment components
    - Interfaces
- Integration and test in lab when appropriate
- Test in the network.

2 Network Infrastructure

Use cases in the "Safe City" work package (WP5) was trialled in 2 locations:

1. **Rennes**, using the mobile network infrastructure of Orange and Nokia at BCOM's and CHU premises. This is applicable to use cases 7 and 8.
2. **Athens**, using the mobile network infrastructure deployed in the WP6 at OTE premises. This location will host use cases 6 and 9.

This document will detail the deployment of the infrastructure in the Rennes node, whereas the infrastructure of the Athens node is detailed in the D6.4 document [47], with parts relative to the use cases 6 and 9 mentioned here when necessary for understanding the testing infrastructure.

2.1 Mobile network for IoT use cases

The commercial LTE-M mobile network of Orange initially described as candidate for use cases requiring IoT type access with sensors and devices was not selected. This was a proposal to solve the lack of a 5G mMTC experimentation network in Rennes. This network was initially proposed to implement some of the requirements of UC6 and UC9 in particular.

As Sections 3 and 6 will detail, the selected trial network for UC6 and UC9 respectively is described in the WP6 Athens node. This is further described in Section 7 of D6.4 [47].

2.2 Experimental 5G network of Rennes node

This network implements URLLC and eMBB slices required for use cases of WP5 sharing the requirement of having low latency in the testbed. This trial network mainly concerns the UC7 and the UC8 implemented in the city of Rennes.

2.2.1 Network Deployment

Two mobile network deployments are ongoing for 5G NR:

1. Outdoors: at the BCOM premises, for the connected ambulance, as shown in Figure 1. BCOM has selected and purchased the Nokia 5G NR antenna which has been installed on the roof of the BCOM building, using primarily the 26 GHz frequency band for data transmission and 2.6 GHz as the anchor frequency band. The antenna has been integrated with an open source-based core network, named *Dome* from BCOM in a 5G NSA mode. Demo using this 5G NSA network has been setup in September 2021, all details of this demo are then explained in the section dealing with the UC7.
2. Indoors: at the Wireless Operating Room at CHU Rennes to provide high-speed, low-latency wireless access for medical imaging devices, using 26 GHz for data transmission and 2.6 GHz as the anchor frequency band, see Figure 2. In that purpose, Nokia RAN and 4G/5G antennas have been selected and deployed in a real operating room, i.e., ThérA-image room (name of the room in the Rennes University Hospital) used for both experimental activities and surgery with real patients. Installation has been done in April 2022. As it was the first 5G indoor experimentation using 26 GHz, it is also important to mention that 5G radiation and exposure measurements were carried out in the operating room by 2 external auditors (ANFR https://www.anfr.fr/accueil/ and Emitech https://www.emitech.fr/en) to validate the level of 5G radiation and exposures inside this room.

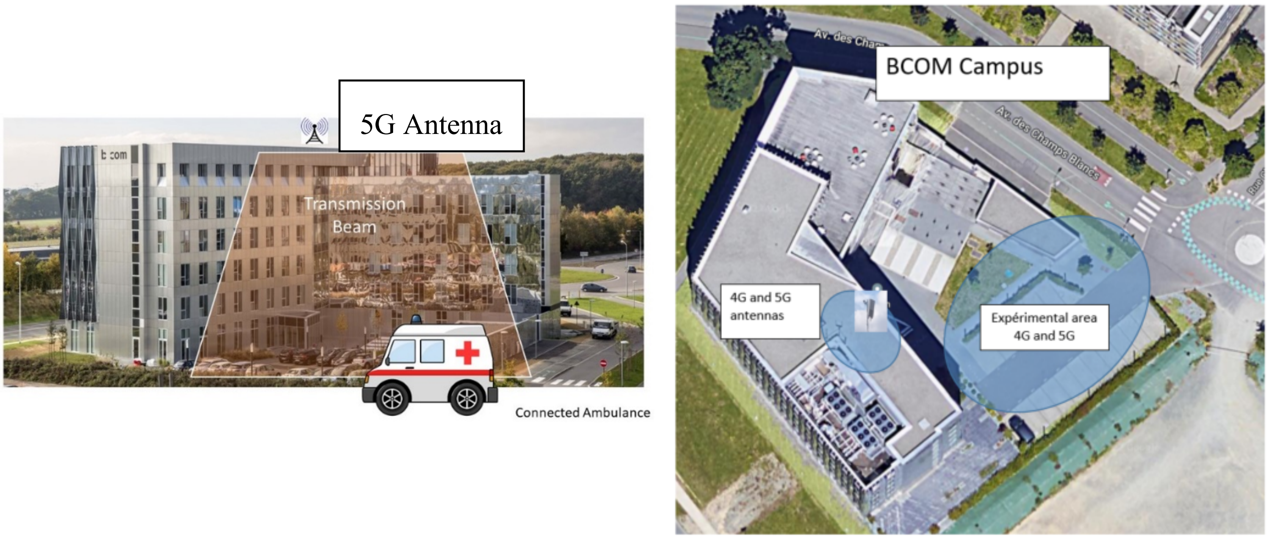


Figure 1. 5G-TOURS 5G NR NSA wireless coverage at BCOM.

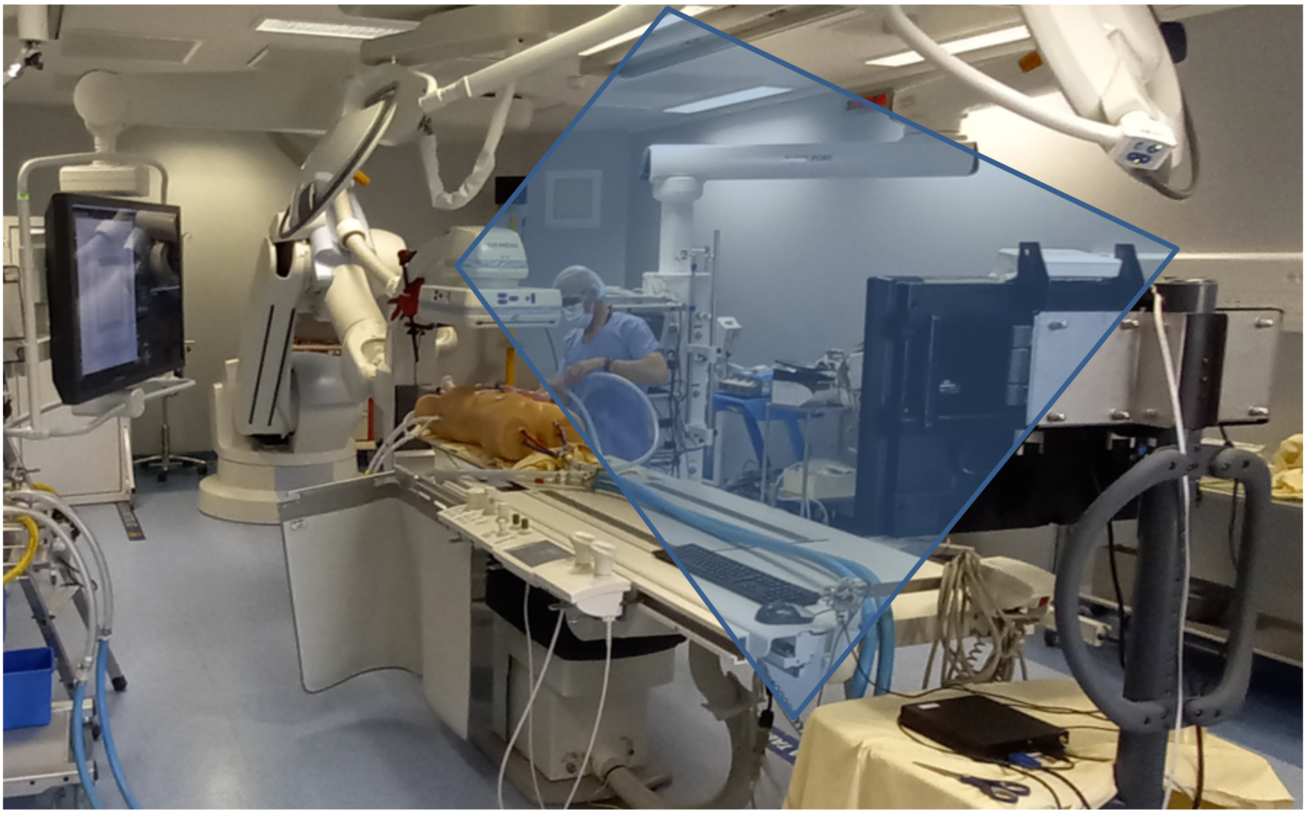


Figure 2. 5G TOURS 5G NR wireless coverage in the Wireless Operating Room at CHU.

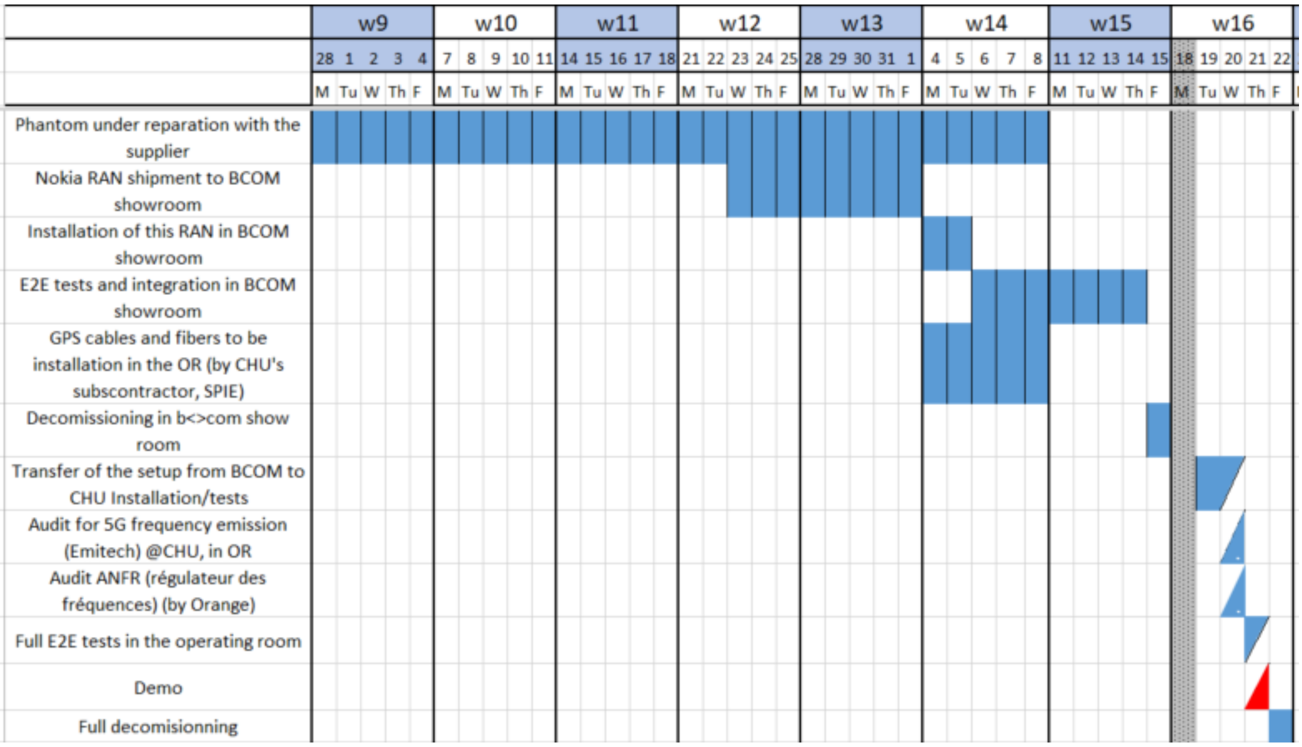


Figure 3. Planning to setup the demo in the operating room.

Figure 3 reminds the agenda for the final demo and to remind the complexity to synchronise all partners and stakeholders in the setup. At the BCOM premises, the 5G base station with a local virtual UPF, part of the so-called *Dome* has been integrated. Similarly, there is the DOME UPF at the hospital that connects to the DOME core network hosted in the BCOM datacentre through a dedicated VPN backbone. This is depicted in Figure 4. This enables the setting of end-to-end network performance KPIs and the prioritization of data traffic between the ambulance and the hospital to guarantee the required quality of service. Furthermore, the DOME Core Network deployed in BCOM datacenter manages the DOME UPF at the hospital to connect the 5G terminals of the Wireless Operating Room.

In addition, for the non-critical overall network orchestration and automatic deployment of the DOME core network, Orange provides an ONAP orchestrator in their Châtillon datacenter as part of their 5G EVE infrastructure. ONAP enables the user or the experimenter to deploy and configure the DOME Core Network on demand.

The Orange datacenter had already been connected to the BCOM datacenter in the scope of the 5G EVE project. This is also shown in Figure 4.

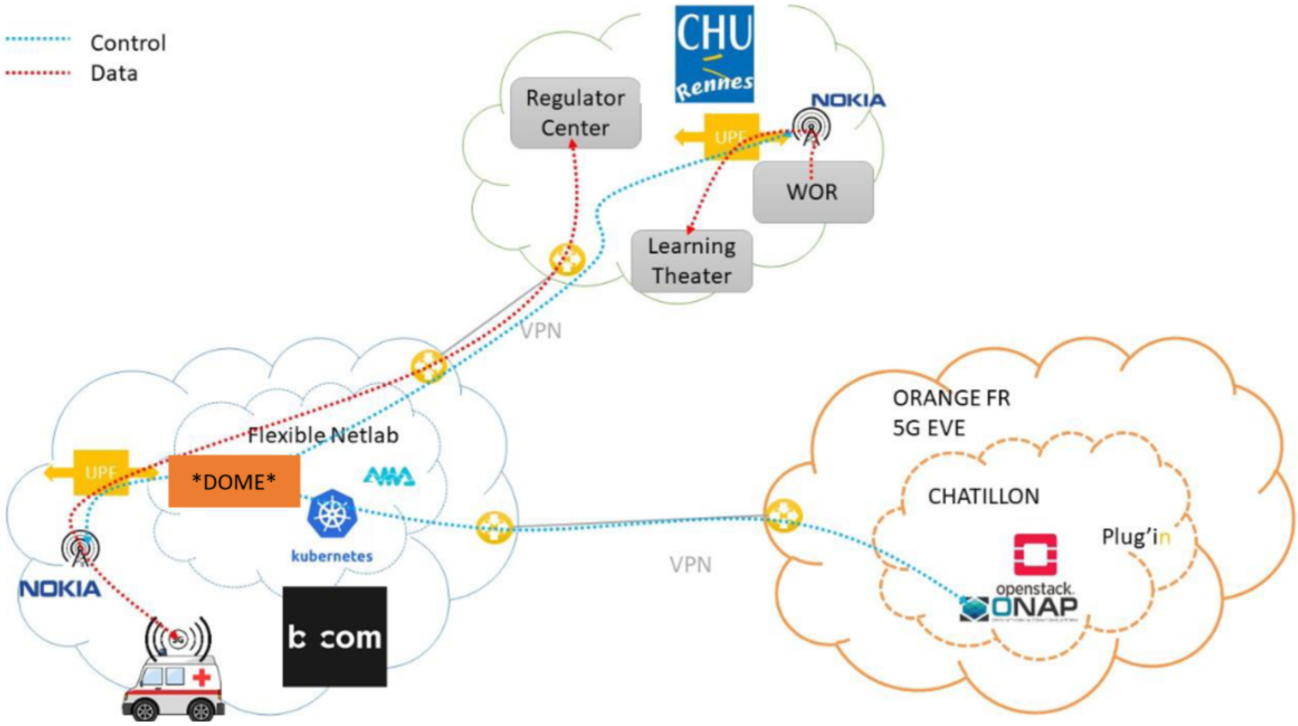


Figure 4. Overall network architecture and physical deployment of network equipment and functions.

2.2.2 Network Equipment

2.2.2.1 Control plane network equipment

The control plane is a virtual 4G/5G Core Network compatible with the 5G NSA standard (3GPP Rel-15). The Control Plane is part of the DOME solution developed by BCOM [39]. It is deployed as a set of Docker containers managed by a Kubernetes [1]cluster. This cluster is hosted on the *xG Testbed* platform in the BCOM datacenter [25]. The Control Plane is deployed and orchestrated by an instance of the ONAP orchestrator hosted by Orange.

2.2.2.2 User plane network equipment

The user plane equipment provides connectivity between the RAN equipment and the data network (Internet). The main component is the User Plane Function (UPF) component of the DOME provided by BCOM. Two instances of the UPF will be deployed as part of 5G-TOURS.

The first instance will be a VNF i.e., a purely virtual UPF deployed in BCOM datacentre as a virtual machine hosted on an OpenStack cluster provided by *xG testebed*. This virtual machine hosts an OpenVSwitch (OVS) virtual switch that acts as a tunnel endpoint for the GTP tunnels coming from the RAN equipment deployed at BCOM for use case 7. The DOME Control Plane manages the virtual switch under control of the OpenDaylight SDN controller that is deployed in the control plane.

The second instance is a PNF i.e., an appliance built from a COTS network switch and a COTS 1U server. The server is a KVM hypervisor that hosts an OVS-based virtual machine similar to the one deployed in BCOM rack which is installed in the technical room of the Rennes CHU and interconnects the RAN equipment deployed

[1] Kubernetes is an open-source container-orchestration system for automating computer application deployment, scaling, and management. https://kubernetes.io

there with the various components required by use case 8. The same DOME Control Plane manages this UPF through the VPN established between BCOM and the CHU.

2.2.2.3 RAN equipment

For 5G-TOURS, the Nokia Small Cell technology is the RAN equipment chosen. Two cells are deployed: one at the Rennes CHU to provide coverage for the Wireless Operating Room operated by Nokia and one at BCOM premises to cover the outside area for UC7, operated by BCOM. Both use the 26GHz/2.6GHz bands in 5G NSA mode. Both deployments combine the Nokia RAN with BCOM Core Network.

Selected frequencies, which are in n257 band for 5G and B38/41 band for 4G which have been allowed by ARCEP, the French regulator. In both cases, the BCOM DOME Core network is used and connected to this RAN, so that the two uses cases can rely on a complete E2E 5G NSA network. Such integration allowed the validation of the 5G NSA network, deployed in both sites, at the ThérA-Images room of the CHU Rennes and at BCOM parking, and using the same type of BBU (Base band unit) on each site connected

The medical devices such as the ultrasound probes from Philips are connected to the CPE Askey via an Android smartphone, for which the UE capabilities include the required frequency bands, after having upgraded the firmware and used by the emergency doctor of the UC7 and the cardiologist of the UC8 are connected to a 26GHz compatible smartphone which allows the 5G transmission of such streams.

RAN solution, composed by RRH (Remote Radio Head) and BBU, is depicted in Figure 5.

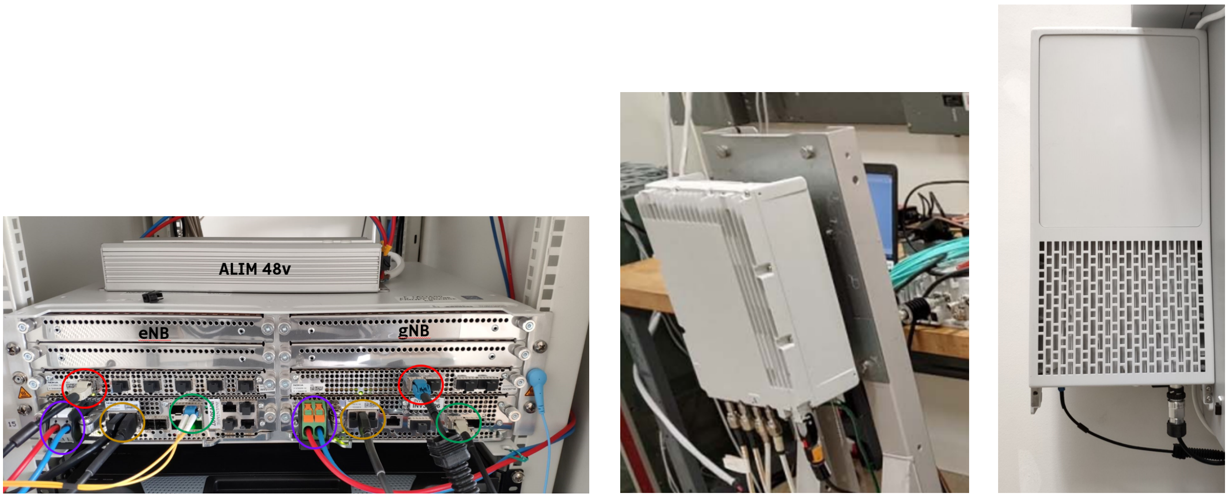


Figure 5. BBU, RRH 4G and RRH 5G used for the experimentations.

Figure 6 and Figure 7 show the installation of the 5G antenna inside the operating room and in BCOM building

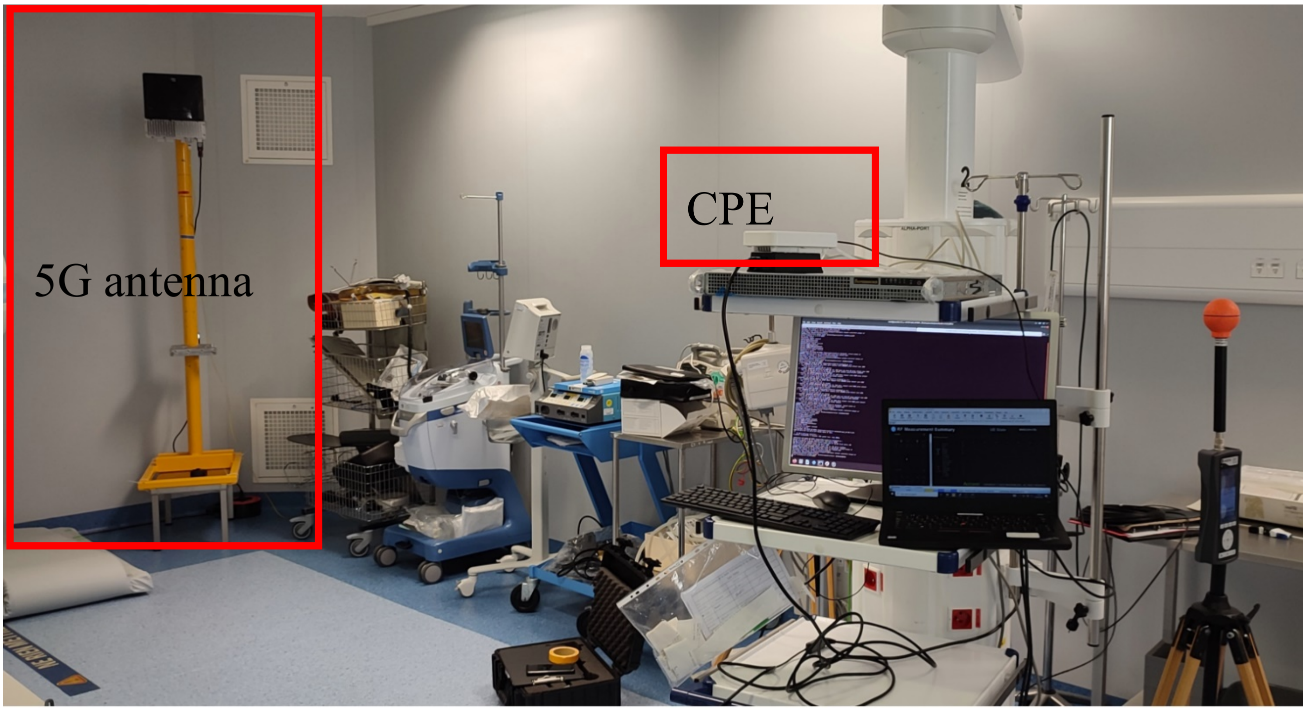


Figure 6. 5G Antenna and CPE deployed in the ThérA-image room in Rennes hospital.

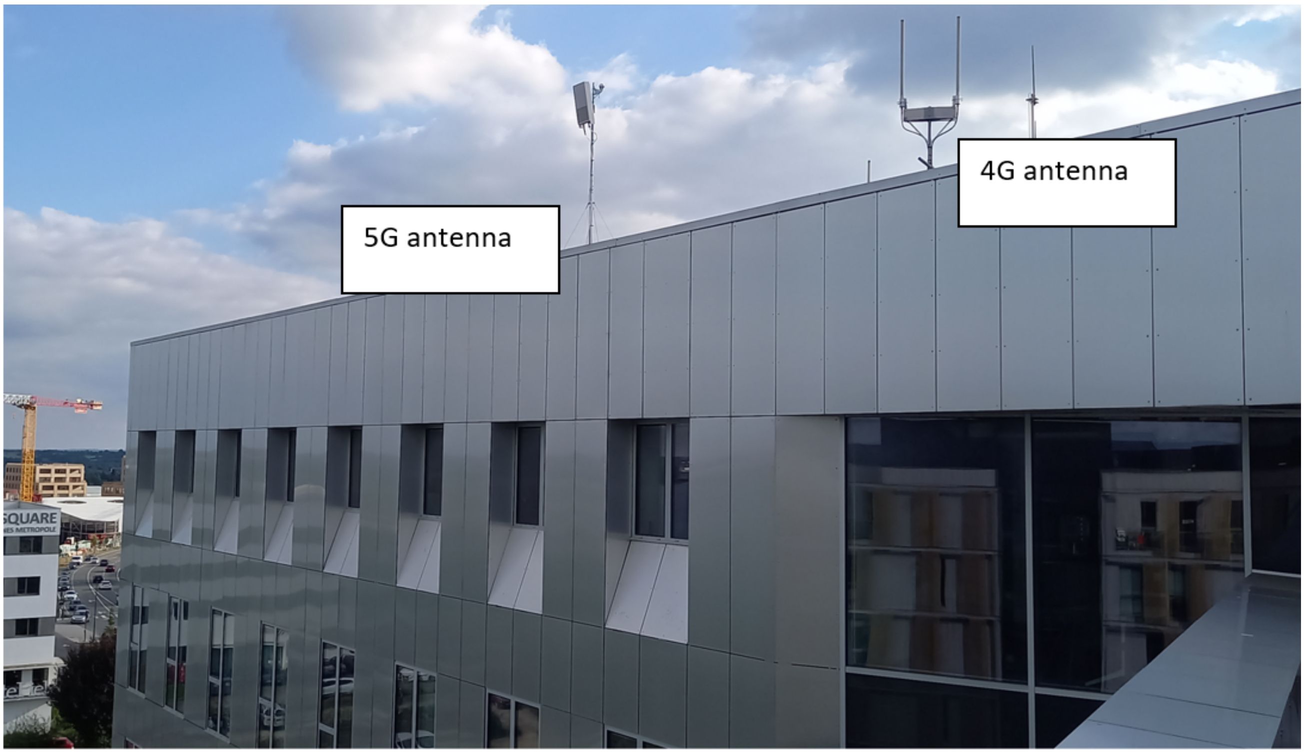


Figure 7. 5G and 4G Antennas deployed in BCOM building.

2.2.2.4 Integration with the 5G-EVE project

The integration of 5G-TOURS with 5G EVE is achieved as depicted in Figure 8. The Service Layer interacts with the 5G EVE Portal through a programmable REST API to request the deployment and instantiation of the whole vertical service by the 5G EVE platform.

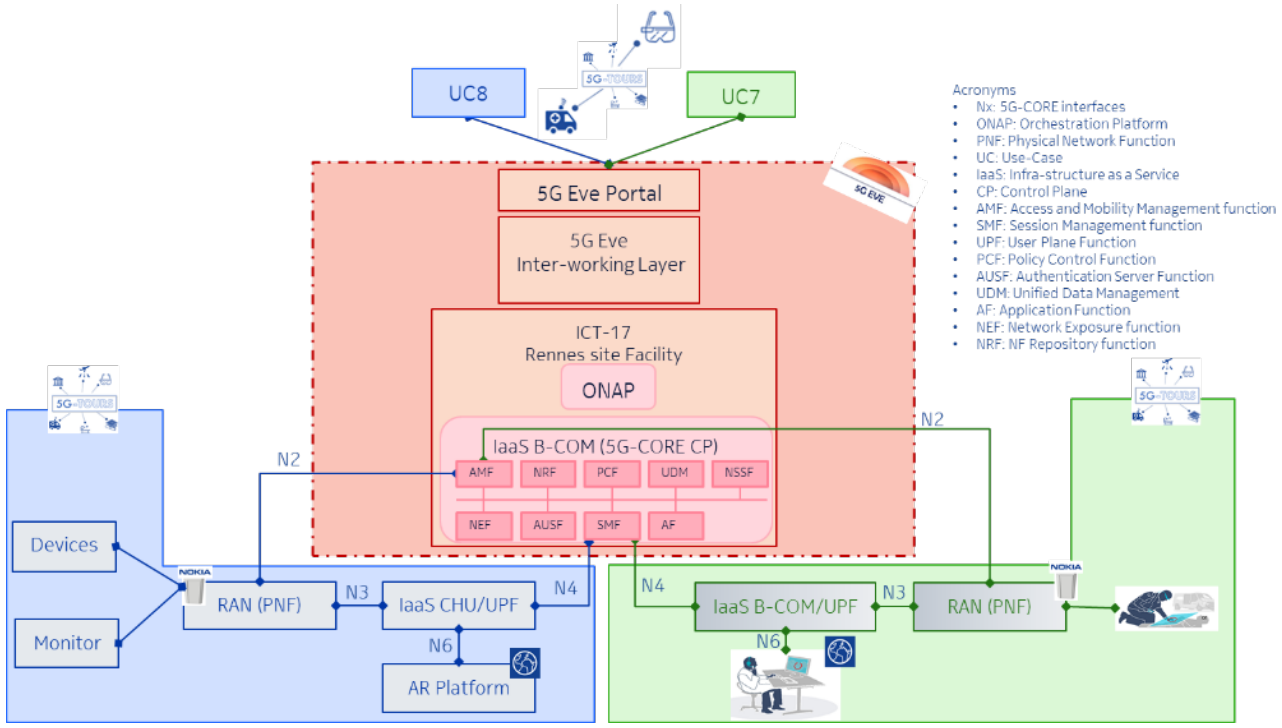


Figure 8. 5G-TOURS integration with 5G EVE.

The 5G EVE Portal API enables a programmable interaction between 5G-TOURS and 5G EVE at the portal level. Such API documentation is available in 5G EVE D4.2, which includes the general description and the functionalities of the first version of the portal, and in 5G EVE D4.3, which includes the functionality extensions made to the first version [41], [42]. The 5G EVE Portal API supports experiment lifecycle management operations (e.g., instantiation, termination, polling status, etc.), whilst all the experiment design operations are available only through the 5G EVE Portal GUI. This means that a preliminary offline step was needed through the 5G EVE Portal GUI to create blueprints and descriptors for the experiments associated to the vertical (sub-) service in 5G EVE platform.

In addition, it was assumed that a pre-provisioning of connectivity between 5G-TOURS and 5G EVE sites is already in place through a secure VPN.

The integration relies on the interworking capabilities of the 5G EVE platform for handling multi-site services and experiments. Following this concept, the coordination of the provisioning of the end-to-end service is entirely delegated to the 5G EVE platform.

The first step was to define the vertical service and its subcomponents and onboard the related blueprints on the 5G EVE platform, using the 5G EVE Portal GUI.

As depicted in Figure 8, the 5G CORE control plane is part of 5G EVE infrastructure. The 5G CORE user plane named UPF was instantiated in the EDGE node deployed in CHU Rennes and in the B-COM datacentre. Table 1 lists the prerequisites for the UPF execution environment named IaaS B-COM/UPF.

Table 1. Prerequisites for IaaS B-COM/UPF.

Operating System	Ubuntu 16.04
CPU	1 vCPU, RAM: 512 MB, Network Interfaces: 4
Management	1 (For administration purpose)

	• SDN-MNGT: 1 (For the SMF-SDNC to manage the UPF) • GTP interface: 1 (To assure the connection in between the RAN and the UPF) • WAN interface: 1 (To provide access to the Data Network)

The UPF execution environment is deployed as VMs using a KVM hypervisor and OpenStack as IaaS manager, see Figure 9. OpenStack provides an API to manage the provisioning and deployment of the VMs as well as its network configuration. It is compatible with the ONAP orchestrator used in the 5G EVE project.

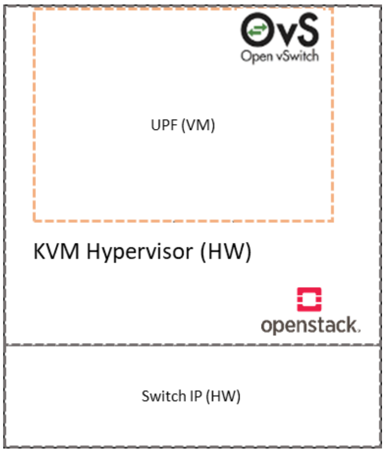


Figure 9. UPF deployment over OpenStack execution environment.

In terms of monitoring, the 5G EVE platform is responsible of providing the collection and visualization functionalities for the monitoring of data of the entire vertical service, as the VNFs developed by 5G-TOURS support the required extensions to publish monitoring data into the 5G EVE monitoring platform. The 5G EVE platform supports the visualization of monitoring data through the 5G EVE portal GUI and provides internal functionalities for performance validation and evaluation based on KPIs.

2.3 Test environment

Following the description of the French sites' facilities, it was clear that several frequency bands are available to lead the experimentation either in **indoor** or **outdoor** environments. For outdoor radio transmission, sufficiently large coverage was achieved thanks to the Nokia Small Cell deployment. The tests were planned to generate "real traffic" specific to the vertical especially for URLLC scenarios. The 4G/5G devices are used as modem to interface with the specific vertical's equipment.

As an example, traffic emulation has been used for testing the VPN interconnection between French sites facilities and Orange gardens. We used iperf and ping for these tests [35]. Some initial performance has been evaluated, as shown in the MS5 video [48], with the VPN interconnection performance evaluation between the Orange Châtillon and BCOM premises that are about 300 kilometres apart in direct line.

Figure 10 illustrates the following. The results have shown that:

- the 1 Gbps tunnel was quasi filled with UDP and TCP Packets.
- the Jitter was very small: less than 0.06 ms and the delay is equal in average to 28 ms.

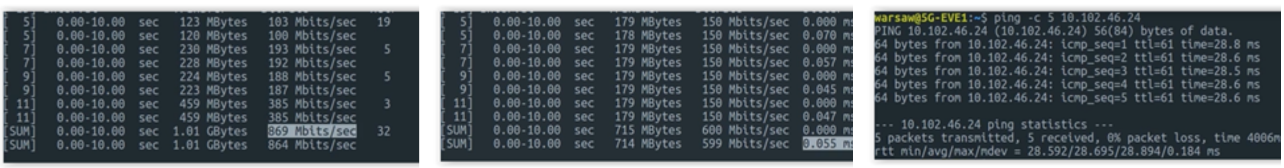


Figure 10. Orange and BCOM interconnection performance results: throughput, jitter and latency values.

With respect to the VPN connection between the Rennes University hospital (CHU Rennes) and the BCOM premise, network performance characterisation tests have been done. The following network KPIs were measured .

Table 2).

Table 2. Collected KPI measurements.

Latency	~ 16 ms average.
Bitrate	• From BCOM to CHU Rennes: ~ 50Mbps; • From CHU Rennes to BCOM: ~ 136Mbps.
Jitter	< 0.2 ms.

Early measurements showed that supporting the use cases is possible over the integrated infrastructure used in our tests. The minimum requirements for the use case are 4 720p streams (4x4Mbps) and 4Mbps for management and control.

3 UC6 - Health monitoring and incident-driven communications prioritization

3.1 UC6 definition

This UC addresses solutions for remote health monitoring of people, especially when already diagnosed with a critical disease still compatible with home care (e.g., some form of cardiovascular disease, hypertension, diabetes, etc.). The main features offered by this UC involve: (a) remote health monitoring services, (b) quick, reliable notifications to nearby ambulances, medical professionals, and family members in case of a health incident or a health emergency prediction. The UC leverages wearable devices tracking a tourist's vital signs and having them aggregated inside an IoT-based platform named STARLIT (Solutions for digital health and wellness based on Artificial Intelligence and IoT) [36], see Figure 11 below. STARLIT offers a dashboard for medical professionals enabling them to monitor the vital signs and health status of several patients at a time. It also provides the option of setting up a video call with a certain patient. Alarms are raised notifying of current or potential future issues.

The current coronavirus (COVID-19) pandemic has increased the incentives for efficient remote health monitoring. The pandemic has on the one hand led to a reduction of on-site referrals for routine care due to the risk of contamination in clinical settings; on the other hand, it has caused an increase in the need to continuously monitor the status of non-critically ill patients (either quarantined at home or at dedicated venues such as hotels or suffering from chronic issues that cannot be checked up on as regularly) [1]. Remote health monitoring requires foremostly clinician acceptance which depends, among others, on the service being perceived as efficient [2], [3]. While this depends on various factors, at least from a technological perspective, 5G offering high-speed, ultra-reliable low-latency communication is instrumental for efficiency of remote health monitoring [4], allowing it to become a reality [5]. In this current context, the trial and validation activities in the scope of this use case within 5G-TOURS are more important than ever.

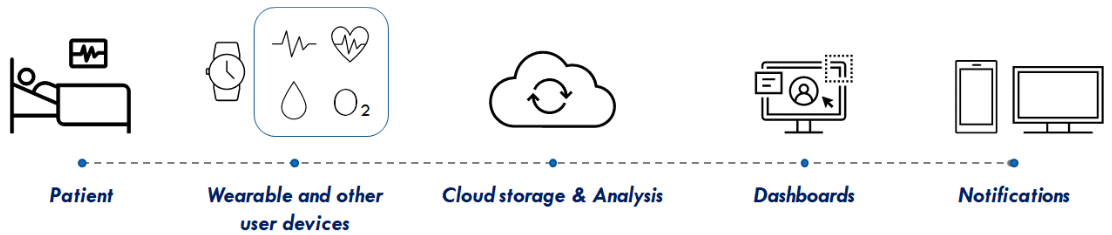


Figure 11. Remote health monitoring and emergency situation notification overview.

The scenario for the trial corresponding to this use case supposes Maria, the mother of the tourist family, to have a family history of chronic cardiac pathology and as such to be medically followed by a remote medical team.

Various parameters related to health/vital signs of such a traveller with a health condition are continuously collected from wearable devices. Parameters of interest may include blood pressure, heart rate, saturation of oxygen, electrocardiogram (ECG), echography and CO levels if the patient is intubated. As actual patients will not be involved in the trials [50], measurements are derived from emulated users and potentially medical phantoms and focus on blood pressure, heart rate and oxygen saturation. Real-time (emulated) data are transmitted and displayed continuously to remote medical experts as well as the traveller and family members via an appropriate dashboard. This dashboard is implemented as a Web-based User Interface (UI) and thus, is accessible through mobile devices as well as laptops, desktops, and tablets. In the event of observed abnormalities in the vital sign values collected, notifications are sent to medical experts and alarms are raised (via pop-up windows in the dashboard, SMS and e-mail, depending on the preferences set by the users) to trigger the necessary actions (e.g., if the blood pressure or the heart rate are abnormal and there is a history of cardiovascular disease, notifications to nearby ambulances, medical professionals and family member are sent). Notifications/alarms are also raised in case something is not yet abnormal, but the data analysis of recorded values show a trend towards a potential problematic situation (e.g., increasing blood pressure which has not yet reached a certain threshold, but may still be worrying). In this case, a notification is issued to the user's smartphone that informs the user of the possible upcoming health situation. At the same time, designated doctor/health care professionals are informed about the possible health abnormality of the person under supervision. In both cases (reactive and proactive), if the medical experts deem it necessary, an ambulance will be dispatched immediately to the current location of the user.

This use case is quite challenging from the network side as its real deployment would involve an extremely large density of sensors involving mMTC requirements, which is one of the key features of 5G era. Furthermore, one important requirement of this use case is reliability, due to the criticality of health monitoring, which adds another challenge from the network side. The technology developed for this use case shows the potential for providing these features.

3.2 UC6 implementation

3.2.1 Application components

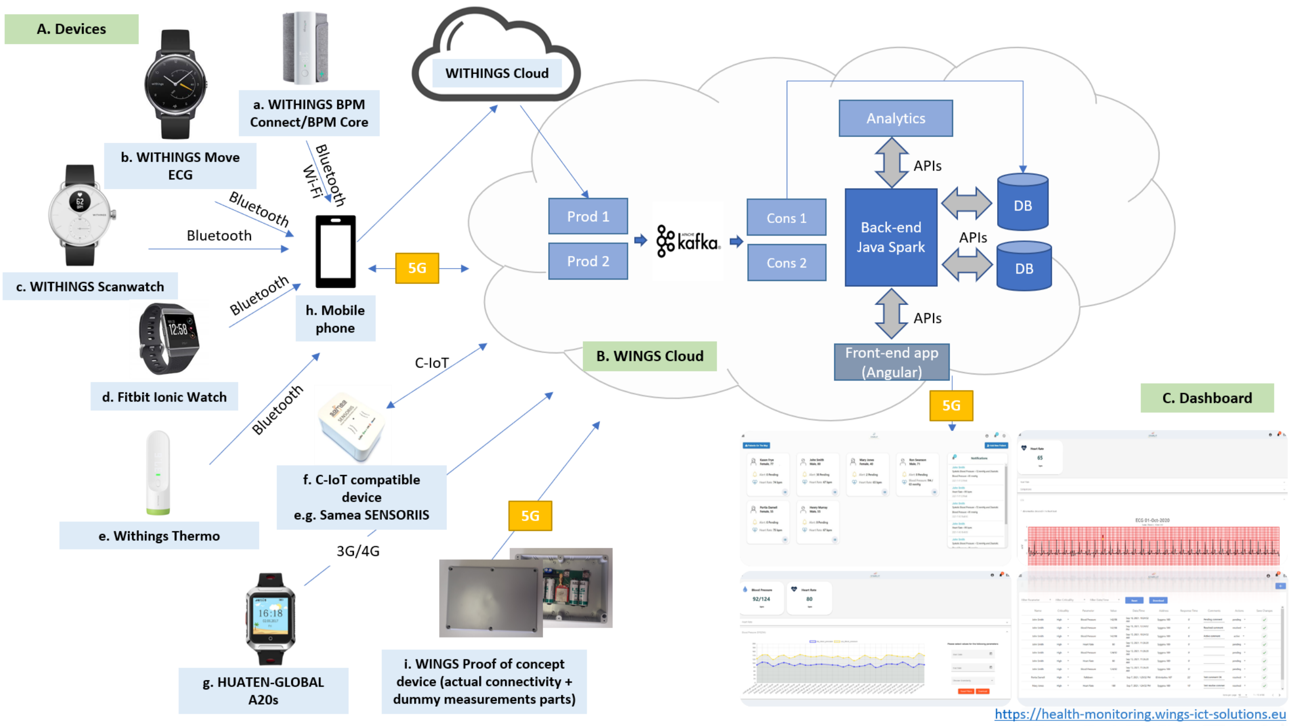


Figure 12. High level system architecture for remote health monitoring.

Figure 12 depicts a high-level view of the system architecture for remote health monitoring. The key components of the implementation of the STARLIT platform for the remote health monitoring use case include:

- A dashboard designed for providing the user, family members and health care professionals with visualization of health monitoring data, notifications, and alerts. The alerts/notifications are raised in case of: (a) main vital signs such as heart rate, blood pressure or oxygen saturation are critical or are out of range (based on certain predefined thresholds), (b) recorded values show a trend towards a potential problematic situation leading to health emergencies, or (c) the patient leaves a specific predefined geographical area (geofencing). The system supports the detailed recording of multiple patients and video calls with patients if deemed necessary by medical staff. It should be noted that the look and feel of the dashboard has been recently further updated.
- Intelligence for the (a) identification of current issues, (b) forecasting of future issues and health emergencies and (c) notification for users, family members or healthcare professionals.
- Wearable devices (Withings ScanWatch [6], Withings Move ECG[7], Withings BPM Core [8], Fitbit Ionic Watch[9], Huaten- Global (A20s) [10], Beurer PO 60 Bluetooth pulse oximeter [11], Withings Thermo[12], C-IoT compatible device) used for the heart rate, blood pressure, cardiac rhythm (electrocardiogram/ECG) and oxygen saturation monitoring.

The wearable devices monitor the state of the respective patient and enable real-time monitoring of their physiological data. This enables emergency notifications and can become a core component of preventive healthcare. The devices and the corresponding interfaces are explained in more detail in sections 3.2.1 and 3.2.2 respectively. The relational database, which is maintained on the server side hosted in the WINGS cloud infrastructure, also contains information regarding the patient's status, historical information, alerts as well as information about the wearable devices he possesses, emergency contacts and doctor(s) (if available). In parallel, a High-Performance Object Storage, which contains analytics and application data files (e.g., doctor reports, patient examinations) and other potential information for each patient, is also maintained on the server side hosted in the WINGS cloud infrastructure[2]. It should be noted that in Figure 12 one mobile phone appears to be connected to most wearable devices; this depiction is for the sake of simplicity of the figure. Most of these devices are complementary to each other, thus, it is not expected to have more than two used simultaneously per user, connected to the same mobile.

The dashboard, in the form of a web application, provides the patient, family members and health care professionals with a visualization of health monitoring data. Moreover, intelligent systems provide the patient as well as doctors and family members with notifications of current issues and alerts of health emergencies. The administrator of the platform (e.g., the administrator of the hospital dispatch centre) should, initially, register on the web application. Then, the application assigns this particular user as Administrator with special permissions compared to other roles. Every time a new user registers, the backend is informed, and user's credentials are stored in WINGS database. Upon successful login, the user will be redirected to the main dashboard. Depending on the user's credentials (e.g., doctor, patient) the main content of the application will differ. Each patient can monitor his/her vital signs such as blood pressure, heart rate, oxygen saturation while doctors and system administrators will also receive the patients' overview table. Each of the cards in the overview table depicts a patient subscribed to the service and will provide a more detailed view of his/her vital signs.

There is a set of elements in the architecture depicted above in Figure 12 that are hosted in Docker containers. The main functional components comprised in the WINGS Cloud (Figure 12) are:

Kafka Broker: The Kafka broker is utilized to stream the data from wearable devices to WINGS Cloud. There is a specified Kafka topic for the wearables to send the measurements, acting as producer. Then a Kafka consumer subscribes to the specified topic, retrieves the measurements and stores them in the PostgreSQL database. The Apache Kafka implemented architecture consists of a single node setup and supports horizontal scalability when a multi-node cluster setup is required.

Backend Web Server: The Health Monitoring Platform is implemented as a Java Spark server, deployed on a virtual machine different from the one hosting the Kafka node described above. The server utilizes a Java thread as a Kafka consumer that subscribes to the specified topic and retrieves the measurements.

Frontend Application Server: The frontend SPA (single page application) is generated with Angular CLI and the UI is based solely on Angular Material.

Analytics: A deep convolutional neural network is developed to analyse the ECG signal obtained from Withings wearable devices. For this purpose, the Pytorch python library is utilized to build the neural network since it provides tensor computing with strong acceleration via graphics processing units and a tape-based automatic differentiation system. Similarly, a seq2seq network for the prediction of the Blood Pressure signal has been developed and a deep convolutional neural network for the analysis of the Oxygen Saturation signal.

3.2.2 Terminal equipment components

As described in the previous, currently 9 devices (six wearable and three additional ones) can be used to monitor patients' physiological data. It is worth noting that we use Bluetooth technology for the communication with some of the wearables, due to the limitations on commercial wearable devices based on 5G.

[2] In real deployments, the database will be hosted on a server fully approved to host health data and with procedures that comply with all the clauses of the General Data Protection Regulation (GDPR).

Withings ScanWatch: ScanWatch is a smartwatch that allows to continuously scan vital parameters to detect heart health conditions and help improve overall fitness. It boasts a medical-grade ECG and an oximeter for SpO2 measurements. Overall, it provides tracking of the following metrics: Heartbeat notifications: high or low heart rate, irregular heartbeat, Heart rate: beats per minute, Breathing disturbances: detection via oxygen saturation, Electrocardiogram: tracing of a 30-seconds ECG recording on a millimetric grid, Oxygen saturation level (medical-grade SpO2), and various others [6].

Withings ECG Move: belongs to the category of fitness trackers providing ECG monitor on the user's wrist and activity tracker. The device consists of three sensors, namely an ECG sensor with 3 electrodes, an altimeter and an accelerometer, while providing automatic detection of activities and sleep monitoring. The watch can be connected to the mobile App with Bluetooth and the Connected GPS feature can be used once location settings are enabled. Finally, ECG Move is equipped with an easy to replace button cell battery that can last up to 6 months. ECG Move is a clinically validated device [7].

Withings BPM Core: belongs to the category of health monitors utilized for smart health tracking. Similar to ECG Move, the device consists of an ECG sensor with 3 stainless steel electrodes while it is also equipped with a blood pressure monitor and a digital stethoscope. In addition, the on-device storage provided enables storing up to 8 measurements between synchronizations. BPM Core is equipped with a rechargeable battery that can last up to 6 months and can be connected to the mobile app with Bluetooth while it is also able to connect directly to the Cloud with WiFi. Finally, it is equipped with a dot-matrix style LED screen that displays information, one line at a time. BPM Core is a medically accurate blood pressure & heart rate measuring device compliant with European medical device standards [8].

Fitbit Ionic: is a smartwatch and, as such, enables both fitness tracking and controlling functions on the user's smartphone. The device consists of multiple sensors, the most important ones are the optical heart rate monitor, the built-in GPS as well as the 3D accelerometer and gyroscope. In addition, the on-device storage provided enables storing up to 7 days of detailed motion data, minute by minute between synchronizations. Furthermore, Fitbit Ionic syncs automatically and wirelessly to computers and to iOS, Android and Windows devices using Bluetooth 4.0 technology. Finally, it is equipped with a Lithium-polymer rechargeable battery that can last up to five days with a battery life of up to 10 hours when GPS is enabled.

Beurer PO 60 Bluetooth pulse oximeter: is a pulse oximeter offering measurements of arterial oxygen saturation and heart rate. Measured values are transferred to the "Beurer HealthManager" via Bluetooth. According to Beurer this medical device is particularly suitable for persons with heart failure, chronic obstructive pulmonary diseases and bronchial asthma [11].

Withings Thermo: is an accurate smart thermometer that measures body temperature. It is a Bluetooth- and Wi-Fi-connected smart thermometer that pairs with your phone or tablet to measure the temperature through the arteries in forehead [12].

HUATEN-GLOBAL A20s: is a smart watch that offers: two-way calling communication, real-time GPS tracking, SOS emergency call and notification, geo-fencing, blood pressure and heart rate monitoring and fall detection [10].

Mobile phone: To make use of the 5G network available, a 5G compatible phone is essential. The Samsung S10 is the device currently used in the test set up.

C-IoT device: To make use of the high reliability of the Cellular IoT (C-IoT) technologies, their availability benefits in cases of mobility or no phone battery, as well as their successfully tested capabilities against the 5G mMTC requirements, C-IoT compatible devices will be essential. Such devices can provide a variety of valuable data regarding patients and/or their environment condition. One possible C-IoT compatible device under consideration is SENSORIIS which is a multi-sensor IoT device able to monitor and report on building environmental conditions such as temperature, humidity, atmospheric pressure, air quality/CO2, noise, light, and movement. It can connect to most 4G/5G LTE-M or NB-IoT available networks (17-bands coverage, frequencies from 700MHz to 2.2GHz) and runs in ultra-low power, targeting more than 3 years battery lifetime with reporting every 10 minutes up to 2 hours. SENSORIIS is powered by a SEQUANS Monarch single-chip LTE Cat-M1/Cat-NB1 solution whereby baseband, RF transceiver, power management, and RAM memory are integrated into a tiny package, running SEQUANS LTE protocol stack, an OMA lightweight M2M (LWM2M) client for over-the-air device management, and a rich set of AT commands.

3.2.3 Interfaces

The Remote Health Monitoring platform consists of a combination of different components and interfaces aiming to cover the needs and requirements that have been identified in the previous phase of the project.

The wearable devices, described in the section above, can store the fitness and health data on the device and can sync with the user's smartphone using Bluetooth 4.0 technology. In order for these devices to communicate with the smartphone, the dedicated mobile app, provided either by Fitbit or Withings, must be installed on the user's smartphone. Using BLE to keep general connectivity, fitness and health data can be transmitted to the smartphone in real-time and, by using the experimental 5G network or the commercial network, data is sent to the WINGS Cloud. A custom REST API has been developed between Fitbit Ionic and STARLIT platform in order for the users' data to be available on the platform in real-time. For every new measurement that the device tracks, an HTTP POST request is sent to the STARLIT platform and then the data is stored to the database in order to be available to the front-end application. Regarding BPM Core and Move ECG, Withings provides a built-in REST API in order to integrate with the devices and retrieve the users' data from the Withings Cloud.

Whenever a new record is registered to a device, the Withings API notifies the STARLIT platform to retrieve the available data based on a specific timeframe. The communication is based on OAuth2 protocol, which uses HTTPS requests and utilizes access and refresh token authentication in order to ensure security in all communications. A custom TCP server has been implemented for the Huaten-Global A20S integration. The server receives TCP/IP packets and parses them into JSON objects which are sent to the Remote Health monitoring REST API while the C-IoT device sends data as JSON objects directly to the REST API using HTTPS requests. For the Beurer PO 60 Bluetooth pulse oximeter integration, an Android application, running on the paired device, receives the data using the BLE protocol and then parses and sends them as JSON objects to the Remote Health monitoring REST API using HTTPS requests. This operation is not successfully completed so the integration of Beurer pulse oximeter is ongoing, however the oxygen saturation measurements are collected via Withings Scanwatch smartwatch.

The application components, described in section 3.2.2, communicate with the following corresponding interfaces:

- **Kafka Broker:** Kafka producers and consumers communicate with Kafka Broker using a binary protocol over TCP. The protocol defines all APIs as request response message pairs. All messages are size delimited and are made up of primitive types, in particular BOOLEAN, INTEGER, LONG, FLOAT, UUID, STRING, BYTES and ARRAY.

- **Backend Web Server:** The backend server offers an API to receive incoming HTTP requests from the frontend application server and responds accordingly based on the request with a JSON object or creates/updates the specified resource. The backend server communicates with the PostgreSQL database using the JDBC (Java Database Connectivity) API and utilizing the PostgreSQL JDBC driver.

- **Frontend Application Server:** The application consumes the REST API endpoints served by the backend web server described above and communicates with the backend web server using HTTP requests, in particular GET, POST, PUT and DELETE, with specified URL parameters.

- **Analytics:** Data serving the analytics component will be retrieved from the database through dedicated REST APIs and inference will be handled by a REST API implemented within the Uvicorn server. The analytics service expects HTTP POST requests and responds with a JSON object containing the analysis or prediction result of the ECG, Blood Pressure and Oxygen Saturation signals.

3.3 Integration and test in labs

Analytics: The deep convolutional neural network for the analysis of the ECG signal has been developed and tested using open data repositories, specifically the MIT-BIH (Massachusetts Institute of Technology and former Boston's Beth Israel Hospital (now the Beth Israel Deaconess Medical Center)) Arrhythmia Database [13] and the PTB (Physikalisch-Technische Bundesanstalt) Diagnostic ECG Database[14]. Both databases are used as data sources for labelled ECG recordings both from healthy subjects and subjects suffering from different kinds of arrhythmias and myocardial diseases. The training procedure is currently performed offline to make use of acceleration software (GPUs).

The seq2seq network for the prediction of the Blood Pressure signal has been developed and tested using the MIMIC-III Waveform Database Matched Subset open data repository. The database is used as data source for the systolic and diastolic Blood Pressure recordings of patients in Intensive Care Units (ICUs). The training procedure is personalized and is performed online using a patient's past Blood Pressure recordings.

The deep convolutional neural network for the analysis of the Oxygen Saturation signal has been developed and tested using the UCD (St. Vincent's University Hospital / University College Dublin Sleep Apnea Database) open data repository. The database is used as a data source for labelled Oxygen Saturation recordings from adult subjects with respiratory events (obstructive, central apneas and hypopneas and periodic breathing episodes).

Dashboard (Frontend): As described, a new user (already registered by the system administrator) can provide his/her credentials which are stored in the database and log in the web application through the login page. The authentication service sets at the local storage of the client's browser the current user information object from the server response and the routing guard will check the user's role and permissions and will redirect the user to the view requested. The main content of the application, after successful login, shows the patients overview table as presented in Figure 13. Each card on the board contains information about the pending alerts/notifications that have been raised for the respective subscribed patient. Notifications are marked as active (red), pending (orange), resolved (green), or none (green), the status of which can be changed by the user (Figure 13). The criticality (very high, high, moderate and low) of the incident can be also changed. Emails are sent at each status and criticality change. Pending and active alerts/notifications are also displayed on the home page of the dashboard. The administrator may click on a card or a notification to see the patient details' view which provides real-time graphs of his/her vital signs as presented in Figure 14.

Devices: See section 3.2.2.

To summarize, all components have been integrated and tests have been conducted in WINGS Athens premises. Specifically:

- The smart devices described in section 3.2.2 have been integrated with the STARLIT platform while the User Interface has been enhanced and tested.
- The analytics component has been developed and tested using open data repositories.
- The integration of SENSORIIS device with the STARLIT platform had been considered for transmitting data directly to the network using C-IoT communication to serve the mMTC use case, but the actual device could not become available to send data to the custom TCP server. Instead, a SEQUANS evaluation kit (EVK) is used, powered by a similar C-IoT connectivity modem as the SENSORIIS device, in order to establish the requirements for transmitting data directly to the network and perform demo testing of the communication. To this end, WINGS and SEQUANS initially resolved how to feed data into cloud and successfully tested basic Laptop-based connectivity to push dummy data from the SEQUANS Paris lab. Next, configurations in EVK device were identified and implemented in order to push data according to server required format as well as for putting in place a setup for continuous blood-pressure and heart-rate data flow to WINGS cloud. In addition to the integration activities, a realistic C-IoT module power model was developed to assess the energy usage of the communication device in such use case and compare different network/device configurations (e.g., various parameter combinations from enabled eDRX or PSM features, different traffic profiles, etc.). The results on evaluation of the device battery lifetime for this use case, according to modem power characteristics and the different configurations and traffic scenarios, will be reported in the final deliverable of WP7, D7.4 "Final integrated 5G-TOURS ecosystem and technical validation results".

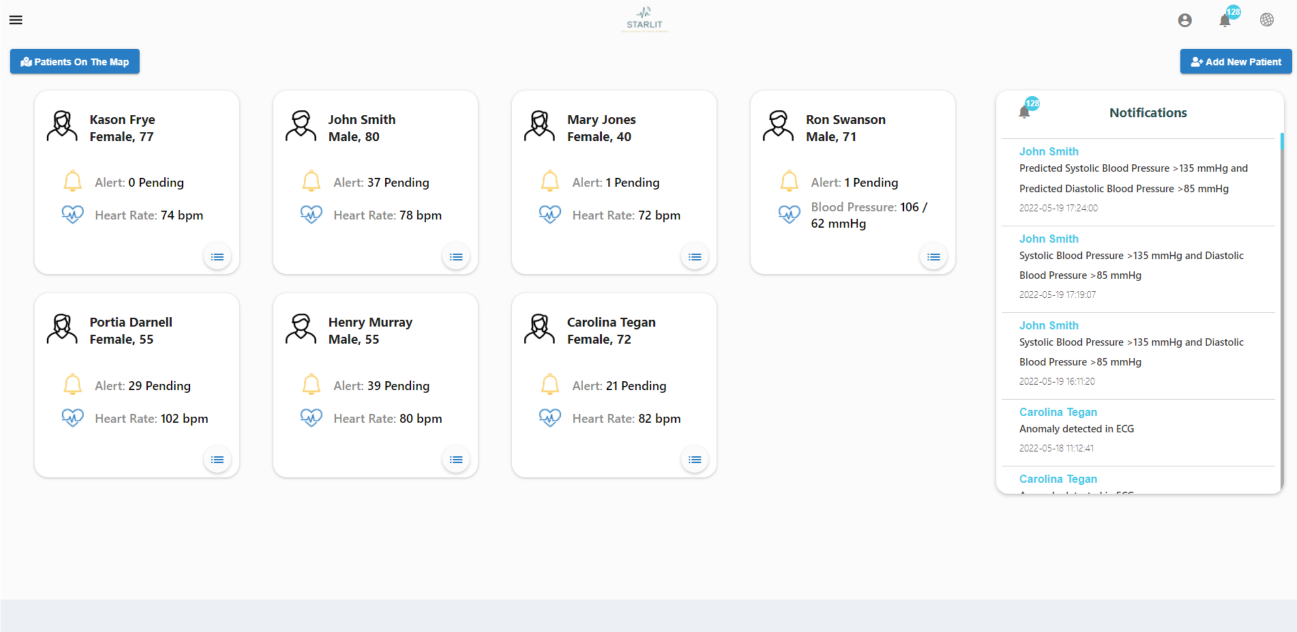


Figure 13. WINGS STARLIT Remote Health Monitoring patients view.

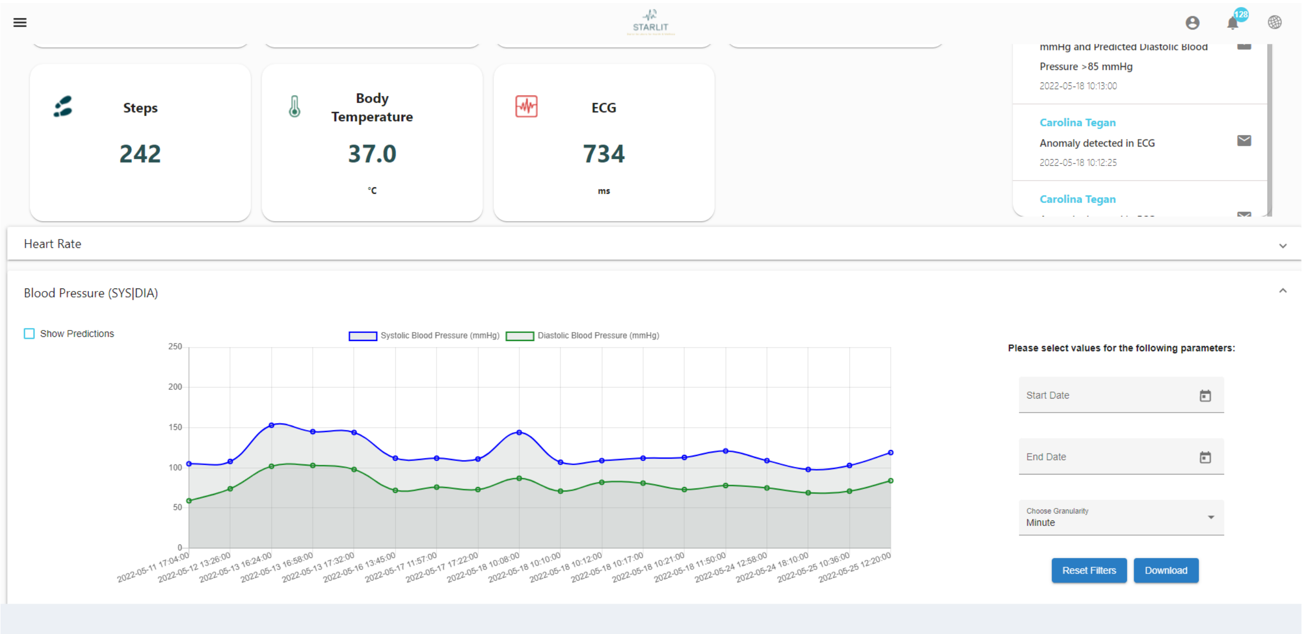


Figure 14. WINGS STARLIT Patients detailed personal information.

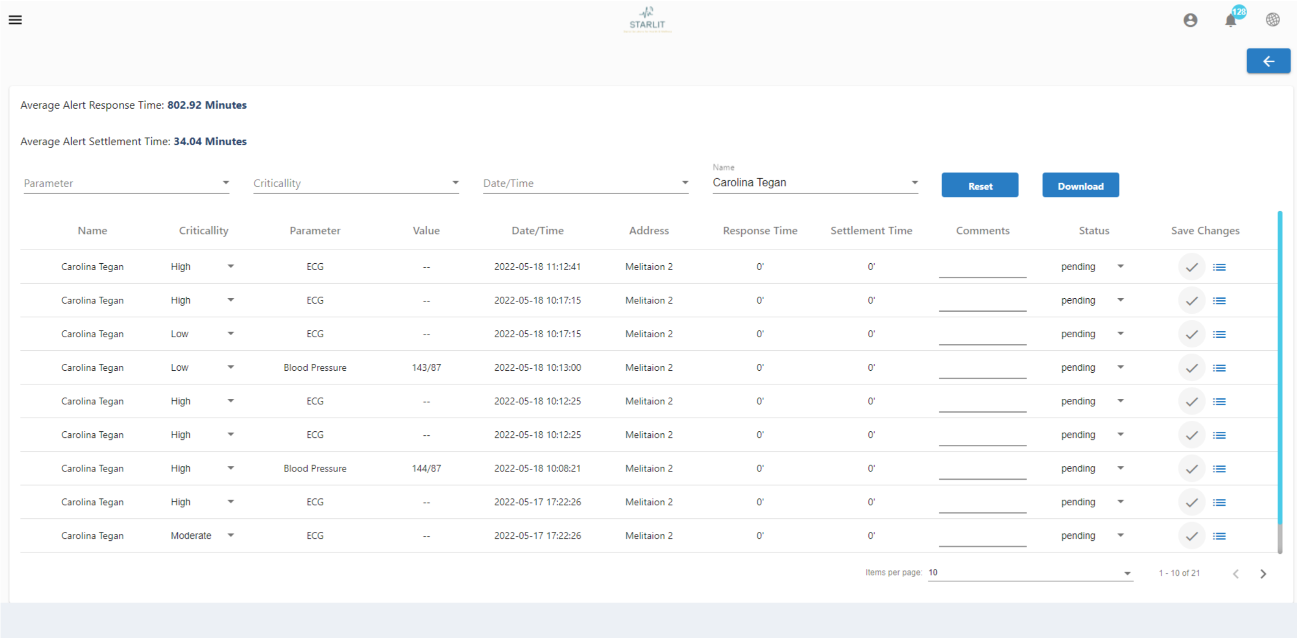


Figure 15. WINGS STARLIT Notifications and Alerts management

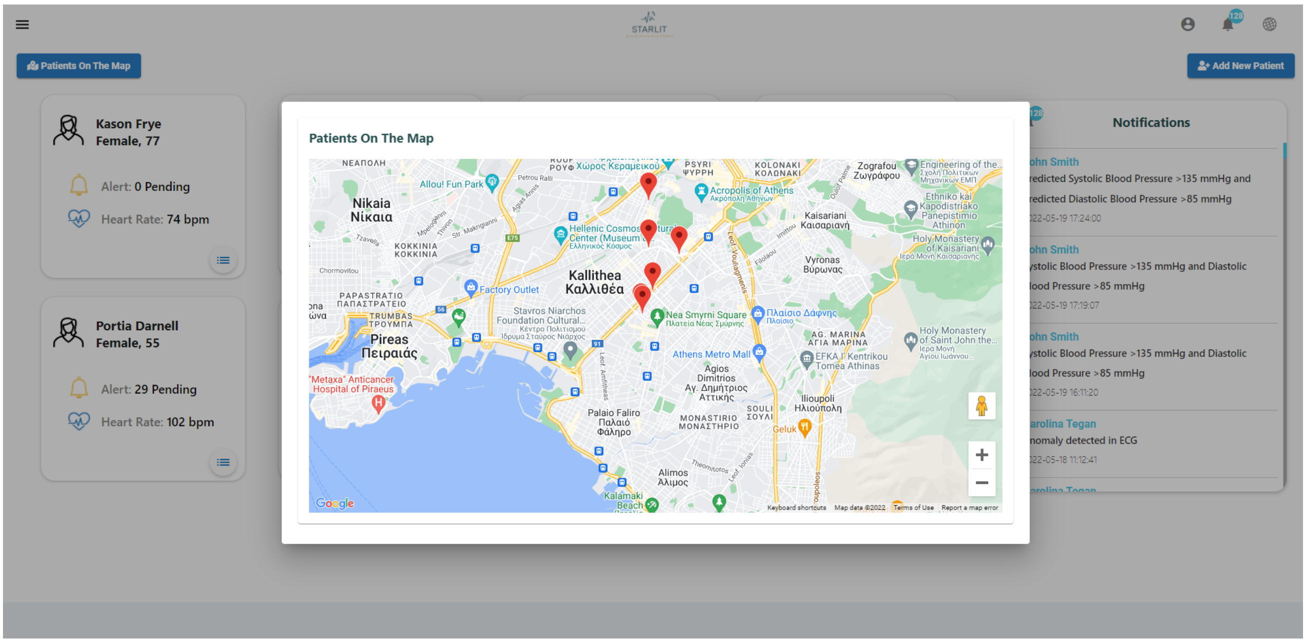


Figure 16. WINGS STARLIT Patients location monitoring (geofencing).

3.4 Test in the network

While UC6 as well as UC9 Optimal Ambulance routing (see also section 6) were initially scheduled to be trialled in Rennes, due to only commercial network availability in Rennes for these two use cases, their trialling was validated in the Athens site. Figure 18 and Figure 19 depict the connection and integration of the 5G-TOURS Safe city UC6 and UC9 hosted at the Athens site, respectively. As can be seen in Figure 19, the main back-end functionality is deployed at OTE premises in Psalidi. The front-end running on mobile phones or laptops has been tested at the Athens AIA premises, along with the wearables devices. Metrics have been recorded at the application layer as part of the testing and validation activities in line with 5G-TOURS [15].

5G-Tours - Use Cases: direct specific Technical requirements		Units	(reviewed) - UC6 –Remote health monitoring and emergency situation notification			Priority	Range	
			URLLC	mMTC	eMMB		Min	Max
General Vertical/Use Case Requirement								
1	Latency (in milliseconds) - round trip - Min/Max	msec	10	100	100	High	10	100
2	**RAN** Latency (in milliseconds) - one way	msec	5	10	10	High	5	10
3	Throughput (in Mbps) - Min/MAX - sustained demand	Mbps		1<	50	High	1	50
4	Reliability (%) - Min/Max	%	99,99%	99,99%	99,99%	High		
5	Availability (%) - Min/Max	%	99,99%	99,99%	99,99%	High		
6	Mobility (in m/sec or Km/h) - Min/Max	Km/h				High	5Km/h*	100 Km/h
7	Broadband Connectivity (peak demand)	Y/N or Gbps		No	0,1	High	0,1	0,1
8	Network Slicing (Y/N) - if Y service deployment time (min)	Y/N		Y	Y	Medium	1	1
9	Security (Y/N) - if Y grade i.e. "Carrier Grade"	Y/N		Y (baseline)	Y	Medium	N/A	N/A
10	Capacity (Mbps/m^2 or Km^2)	Mbps/m^2			12			12
11	Device density	Dev/Km^2					N/A	N/A
12	Location Accuracy	m		5	5	High	5	5

- Relevant KPIs
- Non relevant KPIs
- Relevant but not critical KPIs
- Difficult to be demonstrated KPIs

Figure 17. UC6 Remote health monitoring network requirements.

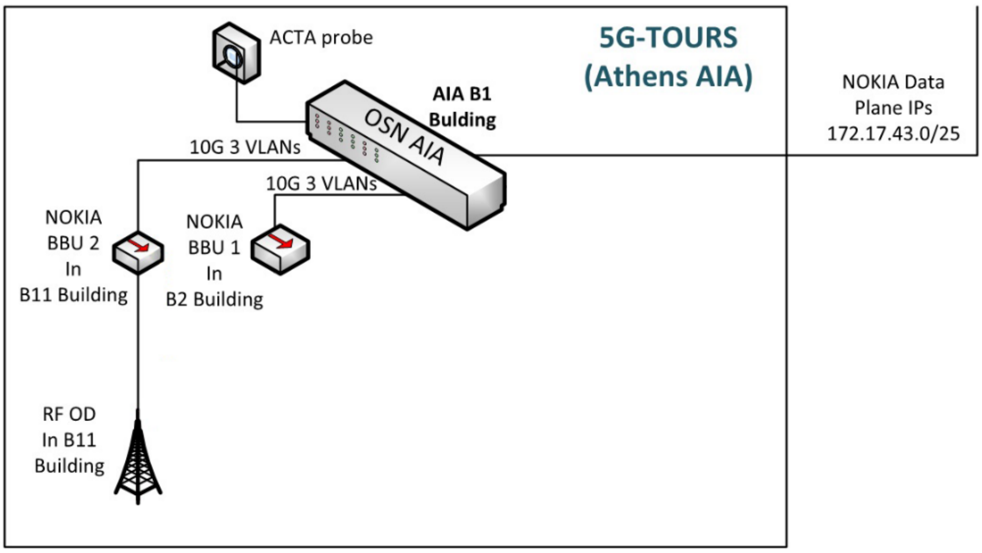


Figure 18. Connection of 5G-TOURS Safe city UC6 and UC9 hosted at the Athens site.

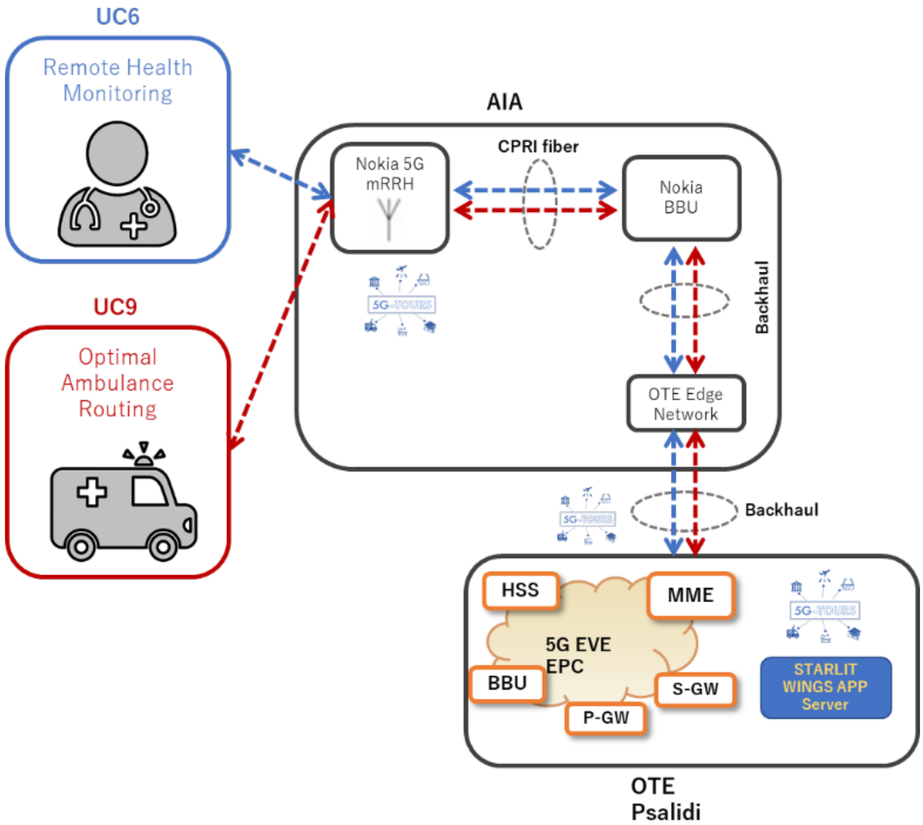


Figure 19. Integration of 5G-TOURS Safe city UC6 and UC9 hosted at the Athens site.

As reported in D7.2 [16], regarding network metrics, RTT latency and throughput (UL/DL) are validated. Regarding the application layer, RTT latency, throughput (uplink/downlink), service reliability and service availability have been collected and validated. During the initial phase of the trials, we selected as initial KPI the RTT latency in APP layer. For simplicity we started by collecting RTT latency metrics on the short path (located between the wearable devices and the server) as illustrated in Figure 20.

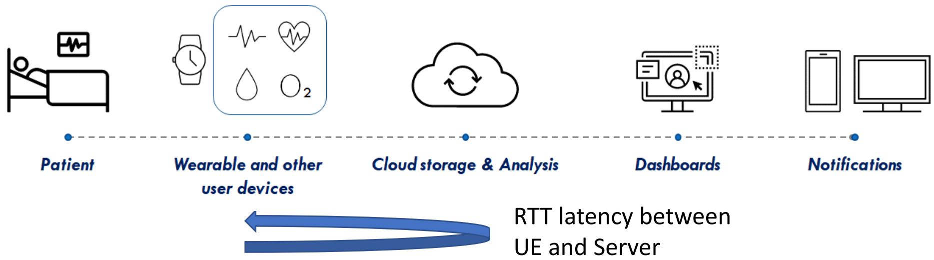


Figure 20. UC6 RRT latency metric collection.

The collection of RTT latency was realised by adding timestamps on all requests departed from the sensors. Then, the Server was responsible to duplicate this timestamp on the relative responses sent back to the sensors. Then, sensors calculate the RTT latency by subtracting this timestamp from the current timestamp of the system. Then, the results were propagated to the server by adding the results on the next application request.

During initial trials of UC6, RTT latency metrics were collected from 7 consecutive days (21/01/2021 to 27/01/2021). In total, 5300 samples (RTT latency results) were collected and analysed as illustrated in Figure 21. The average value of app layer RTT latency is around 113 ms. In addition, from the figure it becomes obvious that the app layer latency is relatively stable with small fluctuations of 10 ms.

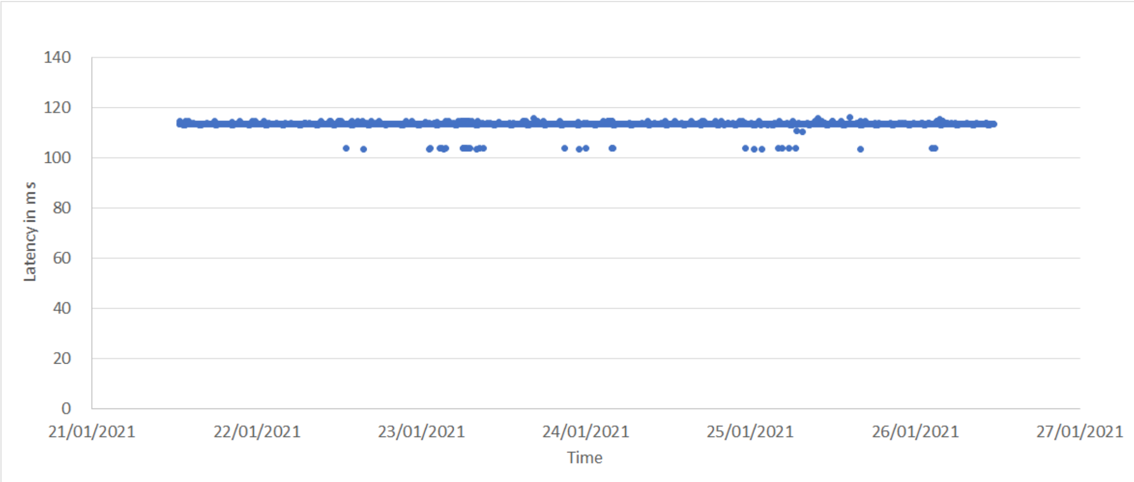


Figure 21. UC6: Initial results on RRT latency.

Additional tests were later conducted (November 2021) where data was collected through the ACTA KPI Monitoring and Validation Platform (VIAVI FUSION based) which allows for automated collection of data, running 24x7, with 1 min monitoring granularity and 10 ms sampling granularity.

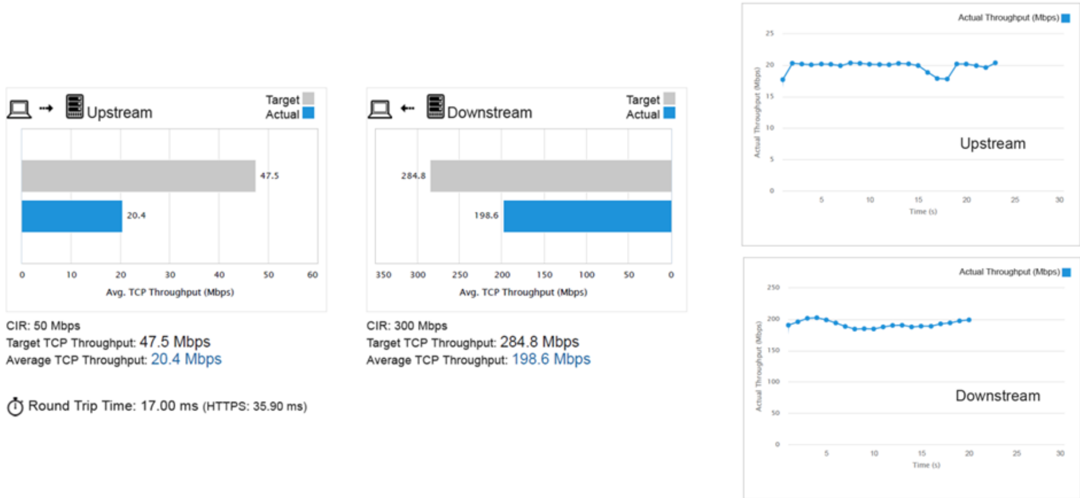


Figure 22. Throughput and RTT (L4) test results for UC 6.

Various (physical and virtual) probes have been installed in AIA and OTE Labs to be able to measure KPIs along the transport and radio segments of the 5G TOURS Greek node network. Data was collected from testing the UC6 front-end and devices in the Athens International Airport (AIA) satellite building (indoors) served by B11 BBU. L3 performance measurements over the transport paths/segments were stable and of infinitesimally small value, specifically as follows Loss 0%, Delay 1 ms, jitter 0,04 ms on average. Figure 22 presents Throughput and RTT (L4) test results for UC 6 from the satellite building area.

The TCP throughput and RTT were measured with the TrueSpeed url, in trials run from the satellite building indoor area. The average values of 200 Mbps downstream and 20 Mbps upstream reflect the particularities of the network (40 MHz bandwidth), while RTT was measured around 20 ms (with peaks of up to 70 ms). Additional metrics have been collected. These are reported in the final Deliverable of WP7 (D7.4 “Final integrated 5G-TOURS ecosystem and technical validation results”).

4 UC7 - Teleguidance for diagnostics and intervention support

4.1 UC7 definition

The goal of the use case is to develop profound understanding on how 5G can be used to improve emergency care, in particular, how it can improve the communication between care givers in the ambulance / near the patient, the medical regulator (dispatch), remote experts and emergency department staff to save the life of more patients than before. This should improve the outcome for and wellbeing of patients on the short and longer term, reduce the workload and stress of all care providers while improving their effectiveness, and last but not least, reduce the overall cost of care on the short and longer term so that patients can participate fully in society again after a quick recovery. To save lives and improve outcomes for patient, it is essential to realize fast and precise diagnosis of life threatening conditions in order to be able to give patients the necessary lifesaving treatment as quickly as possible, e.g. drain fluids from the pericardium in case of a cardiac tamponade, or directly start the treatment of critically ill patients to reduce irreversible health damage as much as possible, e.g. start anti-coagulant medication treatment ASAP to save heart muscle in case of a myocardial infarction.

The solution developed for this use case is built on streaming live video, live ultrasound images, in addition to voice communication, leveraging the capability of new 5G cellular networks to give the high-quality video and reliable medical feeds to the emergency care regulators for best decision making.

In particular, the solution will enable the SAMU regulator (or any remote expert in a medical emergency call center) to see the patient in context via the smartphone of a bystander. This pre-hospital solution is used in medical emergency call centers where the doctor can now add a video feed to understand the situation and not only rely on a traditional voice call. With a better understanding of the situation, the regulator can make better decisions on which equipment/teams to send. The regulator can also better support bystanders in helping the patient before the ambulance arrives. The bystander will receive a link from the regulator to open a dedicated video channel on their smartphone and show the patient to the SAMU regulator.

Once the ambulance crew has arrived, the regulator can "look over their shoulder" via the XpertEye [38] smart glasses solution provided by AMA. One advantage of this solution is to offer an immersive experience to distant users via a real time video transmission. Another key element offered by XpertEye solution is a conference mode that eases sharing of the emergency between several remote medical experts.

Furthermore, the solution developed for this use case will enable the ambulance crew to use teleguided ultrasound. Ultrasound is a highly versatile diagnostic tool "to look inside the patient" in such emergency situations. It enables rapid and quantitative examination of a variety of organs, including the heart, lungs and abdomen, using different types of ultrasound imaging techniques such as B-Mode (Brightness) that shows a two-dimensional cross-section of tissue, Doppler showing movement of tissue and blood flow, Elastography showing the elastic properties and stiffness of soft tissue and, 3D ultrasound [24][18]. The major drawback is that the correct placement of an ultrasound probe is difficult, for the acquisition of images of diagnostic quality and for the interpretation of these images. Ultrasound has therefore limited usefulness without an expert doing the probe handling and the image interpretation. However, it is expected that a less experienced ambulance doctor could do effective ultrasound diagnostics, when guided by a remote expert. This would require live transmission of ultrasound images and bi-directional audio/video communication. The Philips Lumify-Reacts solution [18] provides such a solution for educational purposes. It has not yet been approved for remote diagnostic use.

The combination of both solutions is key to develop a remote support solution for the ambulance based on Philips' Lumify Reacts portable ultrasound and AMA's XpertEye solutions. The remote expert (SAMU regulator) will be able to see the patient (video), look inside the patient (ultrasound) and support all kinds of diagnosis and treatment procedures, including support for US probe positioning (video). The glasses' display offers the ambulance doctor / paramedic hands-free access to relevant information (such as live US images, video, etc…).

In one of the scenarios tested for this use case, a cardiac problem is suspected. In this case, the regulator-doctor makes the decision to send a team equipped with the above-mentioned solutions and he/she can already find an available cardiologist to help remotely. This expert can stay at the remote hospital, no travel needed. While the ambulance is on its way, a bystander shows the patient to regulator and cardiologist. This pre-hospital solution relies on the public network as it uses the smartphone of a witnesses located close to the patient while being supervised by a hospital expert, as well as mobile network connected medical devices used by the ambulance crew.

Current network technologies do not always provide sufficient coverage or reliability with sufficiently low latency communication for remotely assisted tele sonographic diagnostics and guided interventions. Moreover, also for remote video assistance, it is essential that network performance KPIs are always guaranteed in case of an emergency, even in overcrowded spaces with network overloading, as may happen in a football stadium.

It is expected that 5G technology will provide the key differentiating network KPIs for remote video assistance and teleguided ultrasound solutions that enable remote collaboration scenarios between care providers, where an expert guides a remote doctor or paramedic in performing a critical treatment, an ultrasound exam or an ultrasound guided intervention. On demand guaranteed Quality of Service is of key importance in this case, which 5G network slicing technology can provide.

4.2 UC7 implementation

4.2.1 Application Components

The Philips remote ultrasound application / solution and the remote video communication application / solution of AMA are integrated through real-time screen sharing of 5G Android smartphones running the Lumify and XpertEye apps. This is depicted in Figure 23.

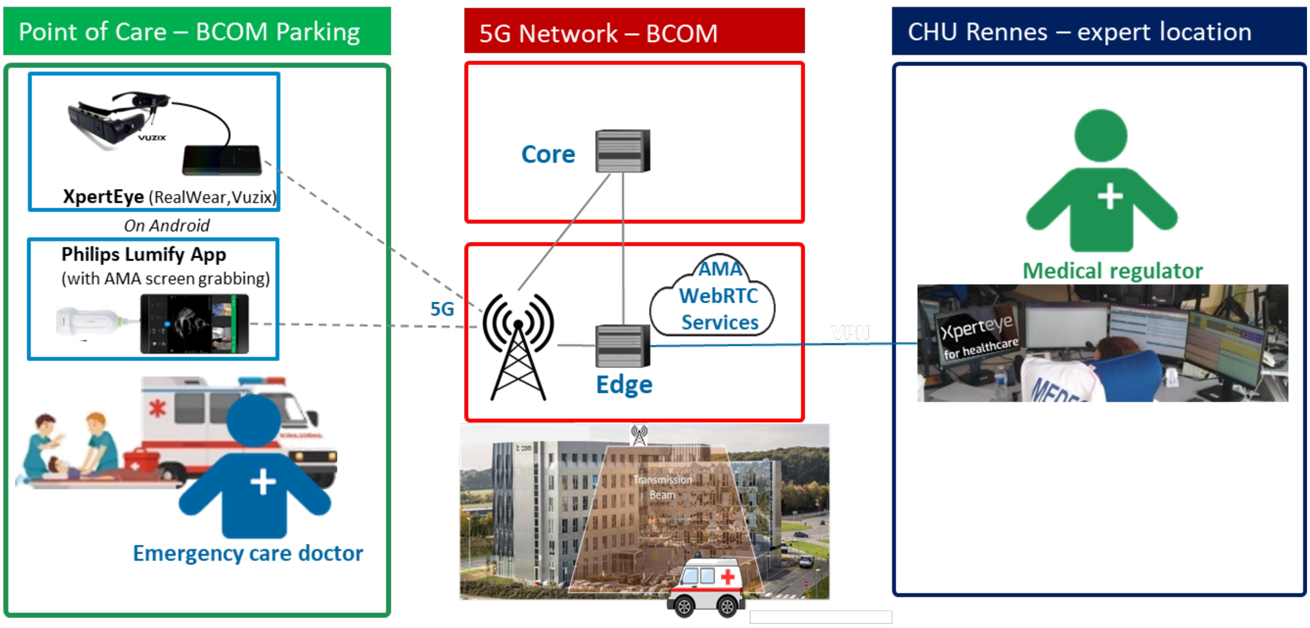


Figure 23. Application architecture overview: Lumify ultrasound App on Android with AMA screen grabbing.

Yet another implementation is the use of a Windows device running experimental ultrasound acquisition and processing applications that can transmit ultrasound images together with associated metadata via 5G and AMA's WebRTC services. This is depicted in Figure 24. It would be possible to use a 5G enabled laptop to run these applications, but the use of a 5G CPE with a standard Windows laptop is also possible. For advanced video communications AMA's XpertEye is used in parallel.

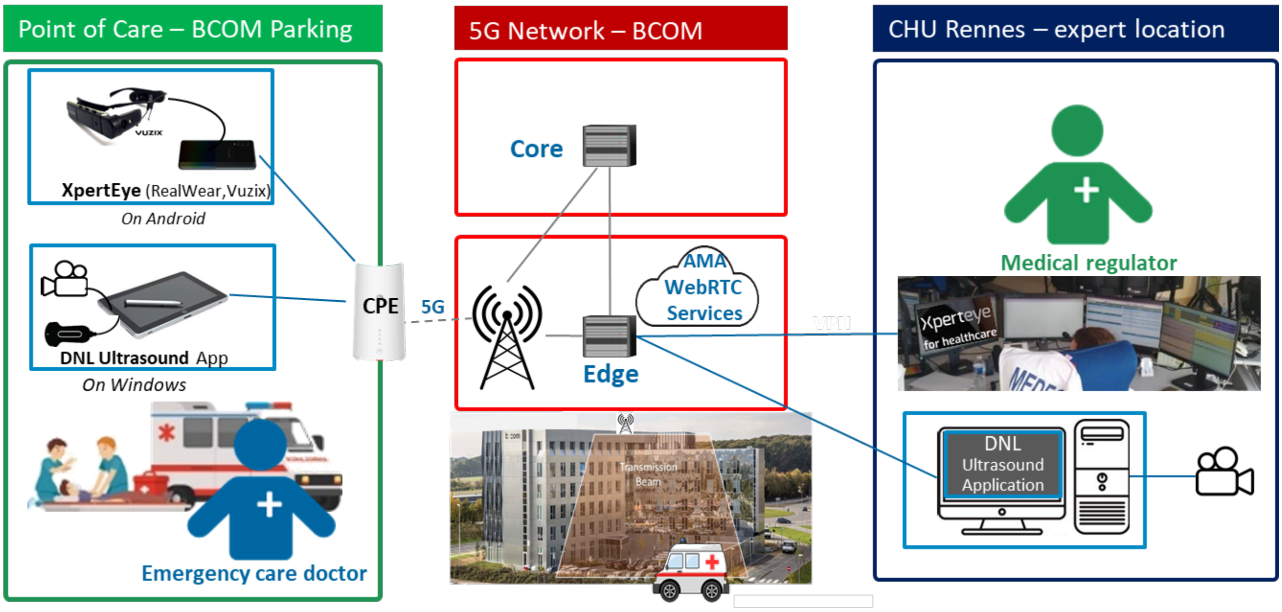


Figure 24. Application architecture overview: ultrasound with metadata transport in parallel with XpertEye video.

4.2.1.1 Remote ultrasound and video communication

The XpertEye solution [21] from AMA is an on-premises WebRTC server solution deployed in BCOM's Flexible Netlab platform alongside the DOME core network components. This solution is available on a wide range of devices (smartphones, smart glasses, tablets, laptops) supporting secured WebRTC video communications in a web browser (Chrome, Edge, Firefox, Safari).

On premises allows us to build a closed and dedicated network where we can more easily manage and monitor all network constraints, making the data collection of experiment much easier to analyse. It offers a fully controlled testing environment and security. We made this choice instead of using SaaS solution that would have forced us to get all traffic through the internet with unpredictable results and security risks.

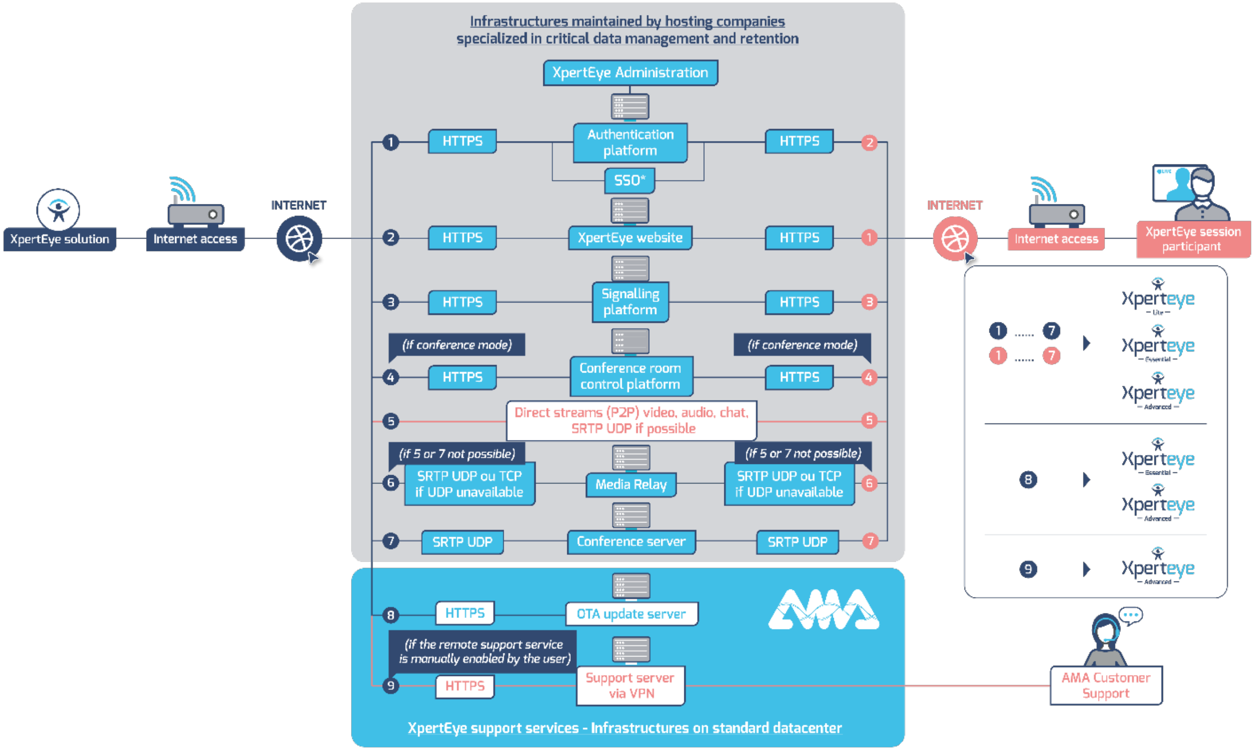


Figure 25. XpertEye network architecture diagram.

This solution relies on WebRTC audio/video/data channels with SFU server. This architecture has the ability to work with asymmetric bandwidth for sending and receiving. In a conference with several participants, a new and recent evolution of XpertEye solution for this project consists in having two video streams displayed simultaneously at screen (Figure 26). All participants keep on sharing audio with others.

Figure 26. XpertEye two video streams feature.

The first tests of this new two video streams feature were tested in September 2021 demo session in the 5G network of BCOM in Rennes. This feature allows to show to medical experts and paramedics both smart glasses video and Lumify application video screen sharing at the same time.

4.2.2 Terminal Equipment components

4.2.2.1 Remote ultrasound

The Philips remote ultrasound terminal equipment consists of a Philips Lumify ultrasound probe with a USB plug.

First experiments were only done with this ultrasound probe that is connected via an USB cable to an Android device for probe control, image processing and visualization through the Lumify App (Figure 27, Left/Middle). There are 3 different types of probes [19], each optimized for a particular purpose: cardiac, abdominal, or vascular echography. During the first experiments, the cardiac probe was used, which is also suited for abdominal ultrasound diagnostics (yet not ideal). The Lumify / Reacts solution provides an extension to the Lumify App, enabling it to perform live ultrasound streaming from the Lumify App on an Android device to a Reacts end user application on the laptop/PC of the remote expert [24].

Mode selection menu *Color Doppler mode operation with linear probe* *Reacts call in operation*

Figure 27. Lumify App screen on Android devices in different modes of operation.

More recently some experiments were also done with a remote ultrasound solution under Windows .NET environment currently under development that not only enable the transmission of ultrasound images but also associated metadata. It is based on experimental .NET Windows software for the acquisition, processing, visualization, and transmission of Digital Navigation Link (DNL) ultrasound [42] over AMA's WebRTC services. DNL ultrasound is a Philips proprietary data format and transmission protocol for transferring 2D and 3D ultrasound images with associated metadata between devices to enable advanced medical analytics or automatic ultrasound probe manipulation guidance [42]. The first tests of this solution in the 5G network of BCOM at Rennes have been done on September 27 and 28, 2021.

The main terminal equipment components related to ultrasound are depicted in Figure 28.

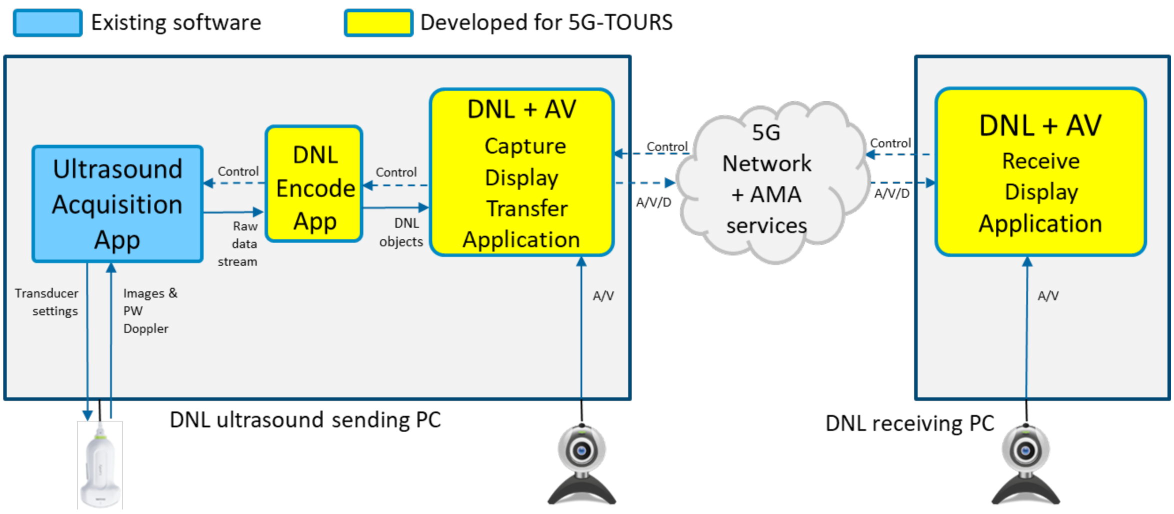


Figure 28. Main terminal equipment components for ultrasound.

The *Ultrasound Acquisition* App is a Philips legacy application that is not approved for usage on living subjects. The *DNL Encode* App provides an easy-to-use interface to control the *Ultrasound Acquisition* App and acquire ultrasound images and metadata. This interface is used by the *DNL + AV Capture Display Transfer* Application, to capture and visualize live DNL ultrasound from the ultrasound probe. Furthermore, the *DNL + AV Capture Display Transfer* Application interfaces with the AMA WebRTC services to transmit the DNL ultrasound stream(s). There are two major options for the transfer of DNL ultrasound:

1. Transfer as binary packets in the DNL format over a WebRTC data channel.
2. Transfer as video and Json, where video is used for the transfer of an ultrasound image stream over a WebRTC video channel and where Json is used for the transfer of ultrasound metadata over a data channel.

The advantage of the first option is that no additional video encoding and decoding of ultrasound images is required, which potentially reduces the End-2-End latency. However, the stream transport control protocol (SCTP) – as used for the WebRTC data channel – favours reliability over real-time behaviour, which causes a lot of jitter in delivery time when the underlying network is not highly reliable. Figure 29 shows the peer-2-peer data communication test setup that has been used to verify the performance of data channel communication under optimal network conditions.

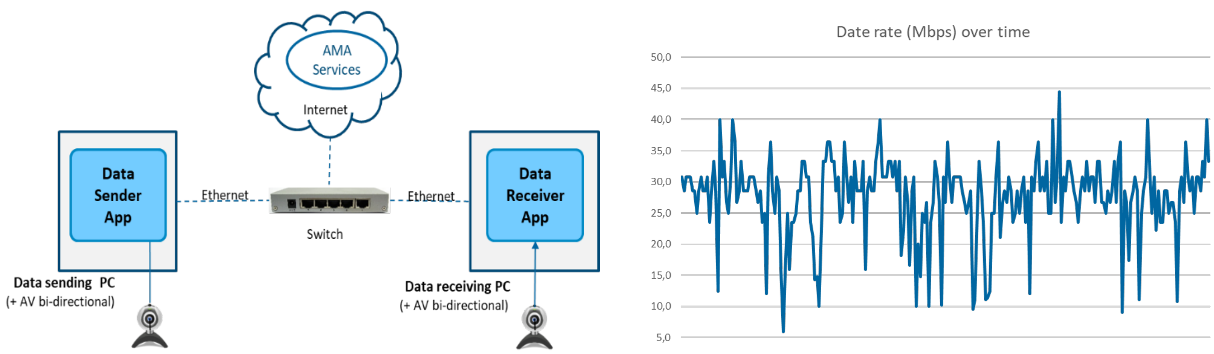


Figure 29. Performance characterization of WebRTC data channel under optimal network conditions.

As the graph in Figure 29 shows, data rates vary between 5 Mbps and 45 Mbps.

The advantage of using video for ultrasound image transfer is that a WebRTC video channel can be used, using the SRTP transport protocol that favours real-time behaviour over reliability, providing a better user experience and medical usability (low jitter), at the cost of some added (video encoding/decoding) latency and loss of resolution. In addition, a selection of the most interesting ultrasound metadata can be sent reliably over a WebRTC data channel.

Figure 30 shows a screenshot of the *DNL + AV Capture Display Transfer* Application transmitting ultrasound images encoded as video stream. It contains controls for joining or leaving a call and selecting camera or ultrasound video for transmission.

Transmission / reception control window DNL ultrasound acquisition viewing window

Figure 30. Screenshot *DNL + AV Capture Display Transfer* Application.

It also shows (on the left bottom) the image video (ultrasound) stream that is sent, and the video stream received (large video camera image) from the remote peer. Chat and important event information, such as who joined or left the call, are shown in the chat panel (left-middle). Finally, there is a button for sending DNL data as binary packets over a data channel. This can be used for performance testing, in particular bandwidth, jitter and latency.

At the ultrasound video receiving side, the *DNL + AV Receive Display* application receives the ultrasound image stream as video (via video channel) and the ultrasound metadata stream as data (via data channel), see Figure 31.

Figure 31. Screenshot of *DNL + AV Receive Display* application.

The *DNL + AV Receive Display* application provides expanders to hide or show information and/or controls. As Figure 32 shows, the left side panel containing the messages and video from the own camera can be collapsed (left hand side), but also the top panel that contains the controls as well as the DNL metadata panel (right-hand side). This way, the window/panel showing the received ultrasound image stream can be maximized to improve the diagnostic possibilities for the remote expert.

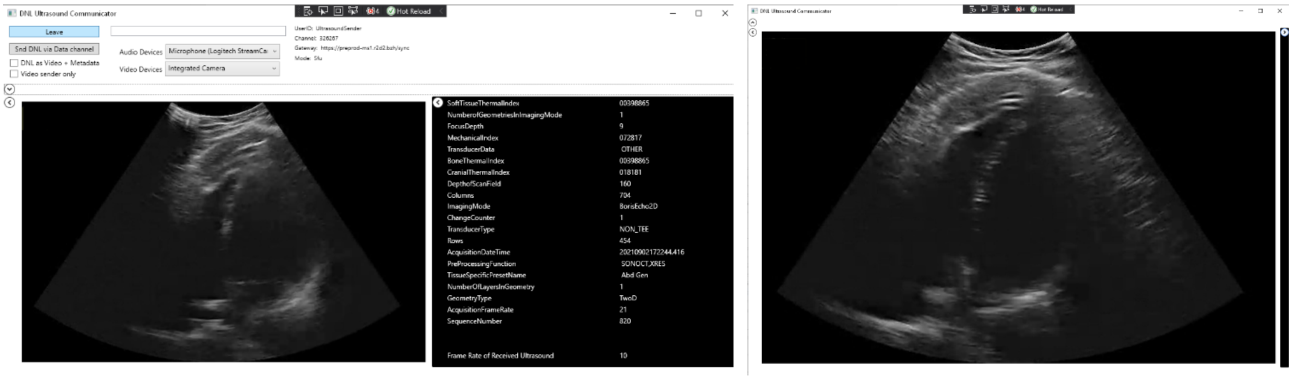


Figure 32. Screenshot of *DNL + AV Receive Display* application: varies options for hiding/showing information.

4.2.2.2 Remote video communication

AMA’s XpertEye solution provides video communications based on secured WebRTC services (Figure 25) to share real-time video between experts and workers. This solution offers one-to-one and conference modes.

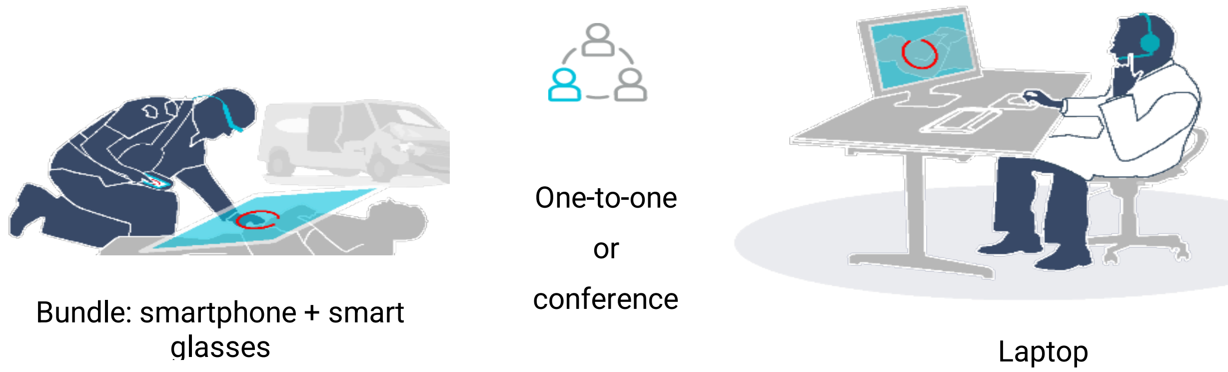


Figure 33. XpertEye remote assistance with smart glasses + smartphone and laptop computer at remote expert.

XpertEye advanced Android application can now be used on any Android smartphone. This mobile phone connected to cellular network transmits in real time the video from smart glasses worn by a user active close to the patient (Figure 33). An important interest of XpertEye application on Android mobile is to use the XpertEye solution with dedicated USB devices, e.g., smart glasses, dermatoscope, microscope, endoscope, thermal video camera, webcam.

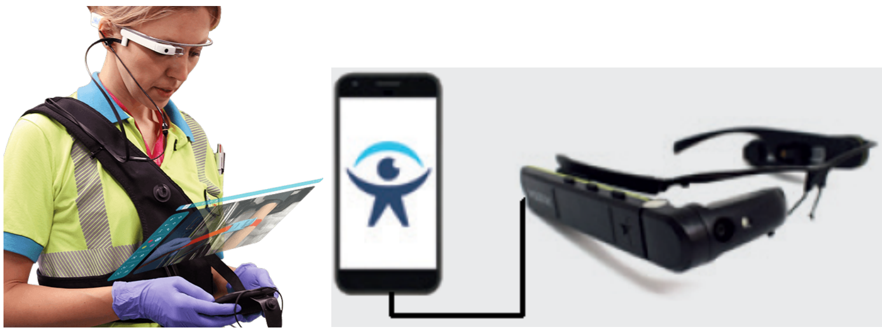


Figure 34. Smartphone + Smart glasses.

The XpertEye solution uses head-mounted technologies such as smart glasses to remotely share real-time data and knowledge between experts and workers. Among the different types of smart glasses, the Vuzix M300 model offers good performances and ease of use (Figure 34, Figure 35).

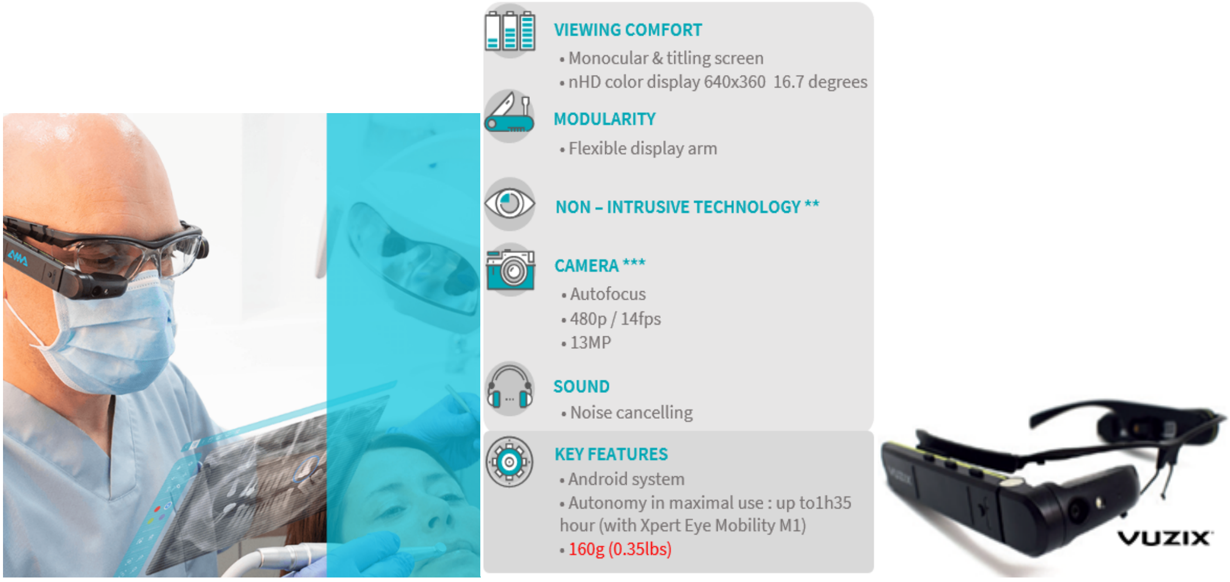


Figure 35. Vuzix M300 smart glasses for XpertEye solution.

Several other smart glasses are being integrated in XpertEye solution and tested by medical staff. This offers the opportunity to get feedback regarding viewing comfort and pertinence of information shared with medical staff. The selected smart glass devices are depicted in Figure 36.

Figure 36. Other smart glasses for XpertEye solution.

Using these new devices offer higher XpertEye video resolutions particularly adapted to 5G high data rates networks. XpertEye WebRTC server streaming part is also adapted to support these better video resolutions.

XpertEye solution offers to users a “see what I share” service including a remote camera management (zoom, take a picture, flashlight) and recent evolution with luminosity and brightness management. A user share with participants precise video and echograph information while keeping his/her hands free.

Figure 37. XpertEye assisted reality.

For 5G experimentation, XpertEye Solution has been adapted for 5G smartphones allowing the use of promising new capacities offered by 5G cellular networks (Figure 38). The choice of device is being done according to 5G frequencies available for this experiment.

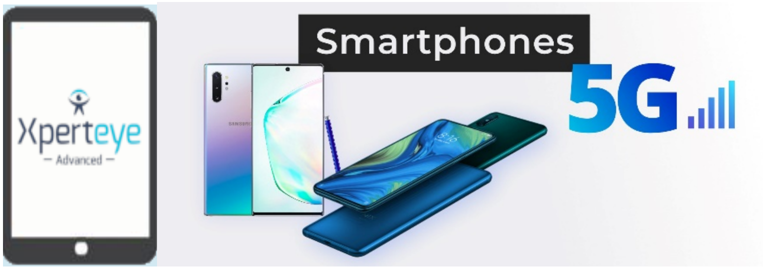


Figure 38. 5G smartphone.

For testing on the 5G Amarisoft BCOM platform, a 5G Samsung mobile phone connected on the 3.5 Ghz band is used, see Figure 39.

Figure 39. Samsung Galaxy A90 5G smartphone.

Then on Nokia 5G BCOM-CHU-Orange platform, the Sony Xperia J9010 experimental smartphone is used (Figure 40).

Figure 40. Sony Xperia J8010 mmWave experimental 5G smartphone.

Lastly an ASUS/Qualcomm 5G mmWave Android smartphone supporting the correct 4G/5G RF Band for this project has been used (Android 11, Qualcomm® Snapdragon™ 888 5G Mobile Platform, other specifications [45] [43] [44]).

Figure 41. Asus/Qualcomm mmWave 5G smartphone.

4.2.3 Interfaces

A high-level view of the platform components is depicted in Figure 42. The main part of this platform is a 5G radio and core network part. A first interface is the VPN connection of the hospital regulator office equipment to this 5G network through a fiber optic link. The AMA's XpertEye on premises server is connected to the 5G network through a LAN connection. This server hosting several Virtual Machines is deployed in BCOM's Flexible Netlab. Then, 5G mobile phones located in or close to an ambulance are connected to the 5G radio access network of BCOM. One or several cameras are also available for this experimentation and connect through 5G wireless CPEs.

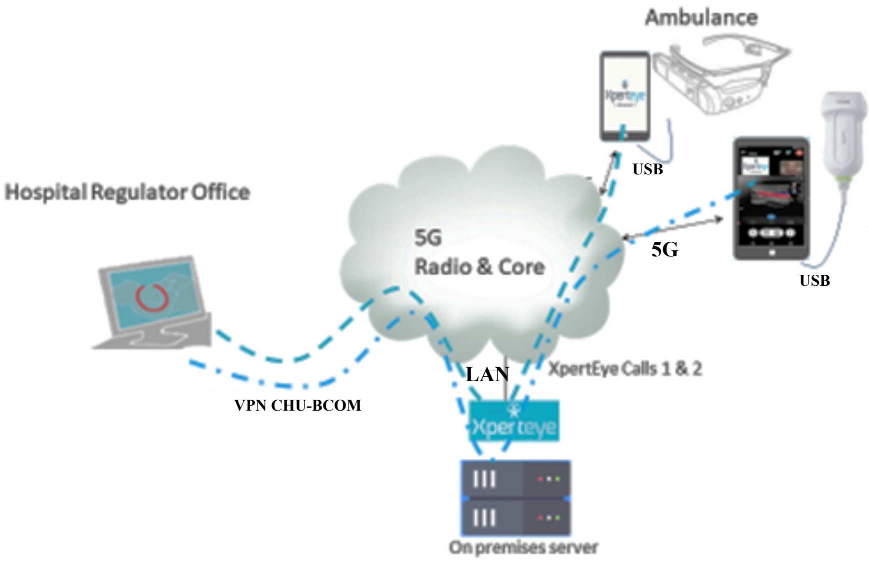


Figure 42. Platform's architecture high-level view.

4.3 Integration and test in labs

A first demo was set up in BCOM showroom in October 2020.

In this experimental setup, we showed the technical feasibility of using 5G to transmit signals from multiple devices during a simulated emergency intervention.

A later demo was done in BCOM showroom in February 2021 that offered the opportunity to a cardiologist to use smart glasses and give his feedback while using an ultrasound probe. He was wearing smart glasses to share his view with a remote expert.

4.3.1 Network Architecture

The 5G Network was set up through the BCOM core network, the DOME, and UPF User Plane Function for Data Plane deployed in BCOM data center. These tests used Amarisoft 5G radio. The applications, Smart Glasses from AMA was deployed in the EDGE cloud in the same data center to optimize the latency.

Real-time video signal from smart glasses and from Lumify ultrasound probe was transmitted to other participants of conference using a single private 5G infrastructure.

The video stream from the AMA smart glasses, which are connected to a 5G smartphone was transmitted to XpertEye local Edge server.

Ultrasound Lumify application video screen sharing of another 5G smartphone was also transmitted to XpertEye local Edge server.

Only one video stream is sent at a time to local screens in the room and for later tests to a remote display located in CHU facilities.

4.3.2 Lab test results

We started by testing the network components alone to determine the bitrate supported by our experimental 5G networks and then we ran functional tests that involved the smart glasses provided by AMA and Lumify ultrasound probe from Philips.

Networking tests

These tests were done both for UC7 and UC8 use cases as they share the same BCOM testing network.

In terms of bitrate, we achieved a constant uplink speed of 70 Mbps with the CPE set 5m from the antenna using two UDP packets streams. The tests were conducted with the iperf3 tool [36]. It is important to remember that these were done with the RAN set to its minimal power output which explains the relatively low bitrate.

We also measured the jitter at an average of 0.22ms and the latency at an average of 25ms. We found the latency varied constantly between 10ms and 30ms.

The various networking tests that we conducted during this phase highlighted the importance of properly calibrating the RAN using a GPS connection to achieve a stable level of performance.

Functional tests

First integration tests validated XpertEye application with smart glasses, 5G mobile and PC connected to local BCOM platform.

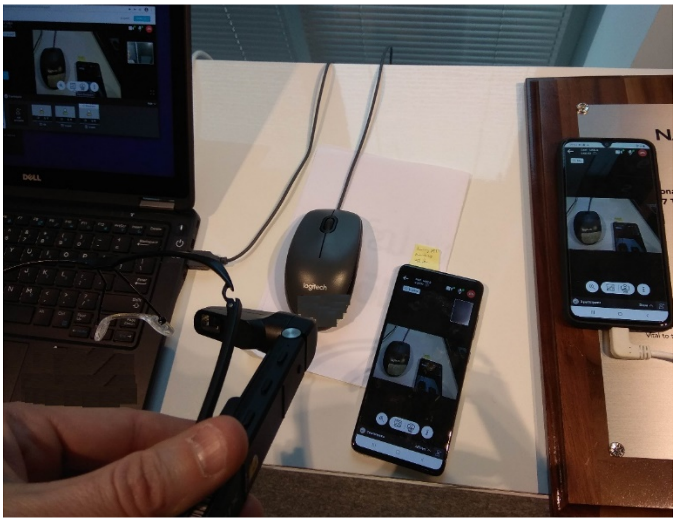


Figure 43. Smart Glasses first functional testing in conference on 5G BCOM network.

Some other testing was done with Lumify ultrasound probe and video screen sharing of the associated Lumify Android application.

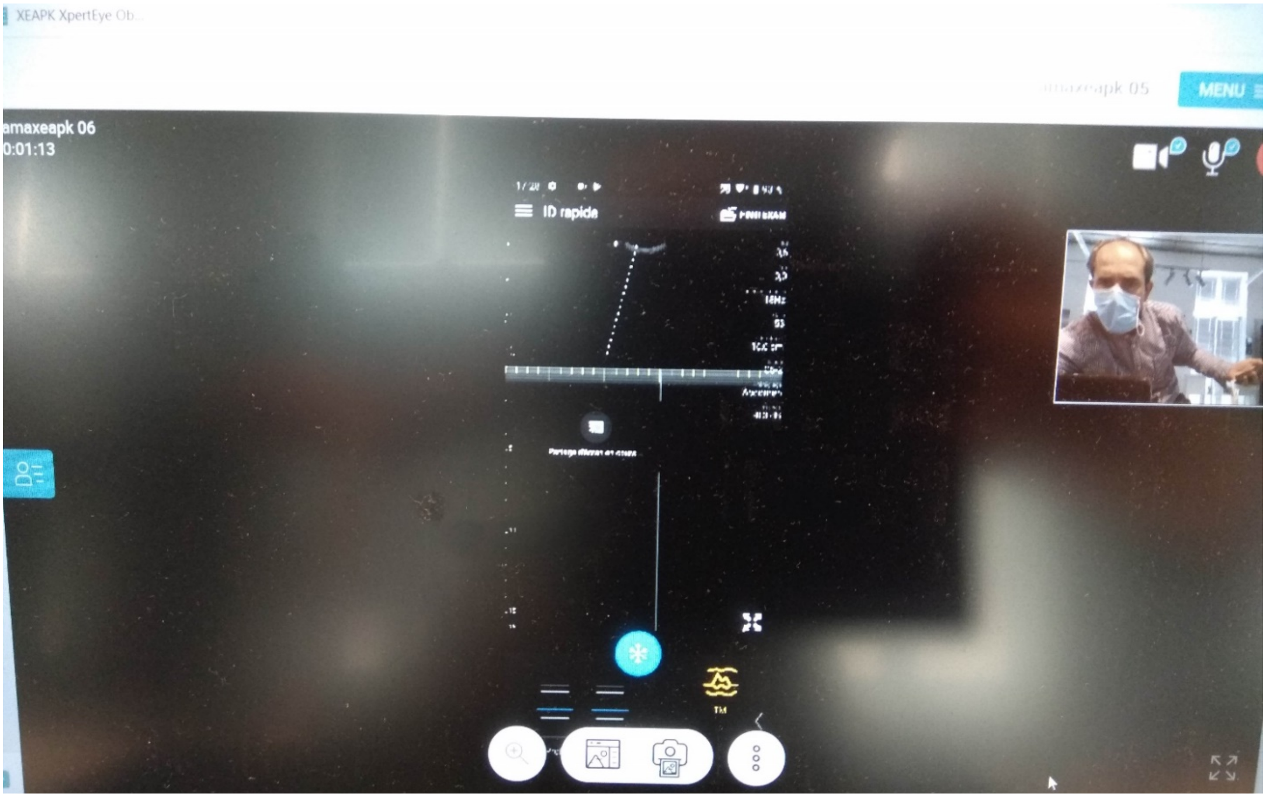


Figure 44. Testing Lumify Android application screen sharing on Android device in 1to1 call on 5G BCOM network.

Figure 45. Smart Glasses and ultrasound probe presentation to CHU Rennes medical experts during a workshop at BCOM in October 2020.

Figure 46. Ultrasound Lumify app screen demonstration using Lumify ultrasound application on Android to CHU Rennes medical experts.

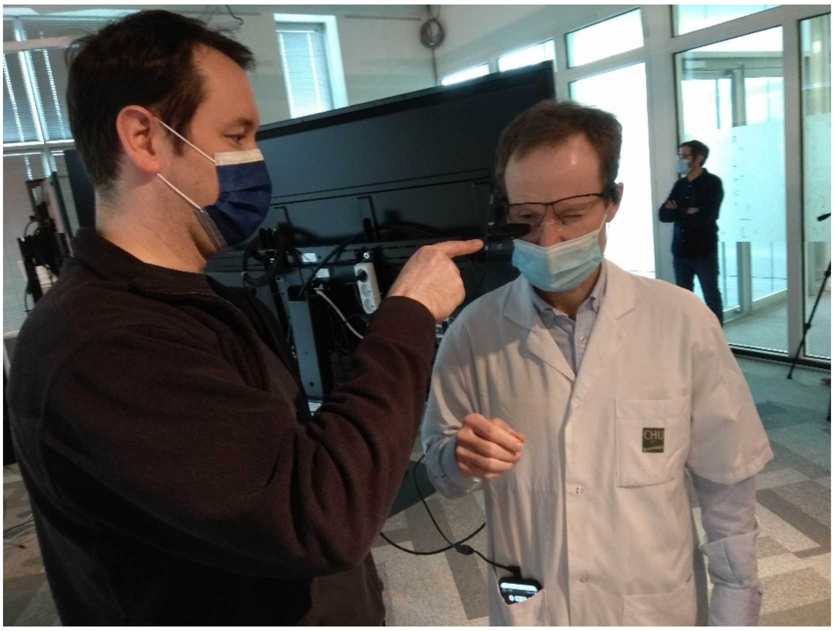


Figure 47. Smart Glasses testing and feedback from cardiologist. Cardiologist wearing smart glasses with 5G smartphone in his pocket leaving its hands free. It was comfortable to keep his own glasses for view correction.

Figure 48. Cardiologist testing Smart Glasses with ultrasound probe. Cardiologist handling an ultrasound probe and sharing video stream from his smart glasses transferred to local displays and also a remote doctor in the CHU Rennes.

The Quality of the video and the audio streams was evaluated by the medical team and considered to be good enough. We encountered some communication cuts due to experimental 5G radio part that did not occur with 5G Nokia RAN testing.

Traces and metrics have been collected and were compared with next phases testing. A more precise focus was done on network latency/throughput and also on WebRTC metrics such as video resolution adaptations.

4.4 Test in the network

A demo of the project has been done on September 28th, 2021. The complete use case was successfully tested with all equipment and ambulance at BCOM outdoor 5G coverage area.

For the tests, the 5G network infrastructure deployed in BCOM was connected through a VPN with the 5G network infrastructure at Rennes Hospital, but regulation centre was simulated in a local showroom and not involved for this test.

The connection to the Core Network of Orange in their Châtillon datacenter was ensured through a VPN between BCOM and Orange.

This demo session involved two setups for ultrasound applications:

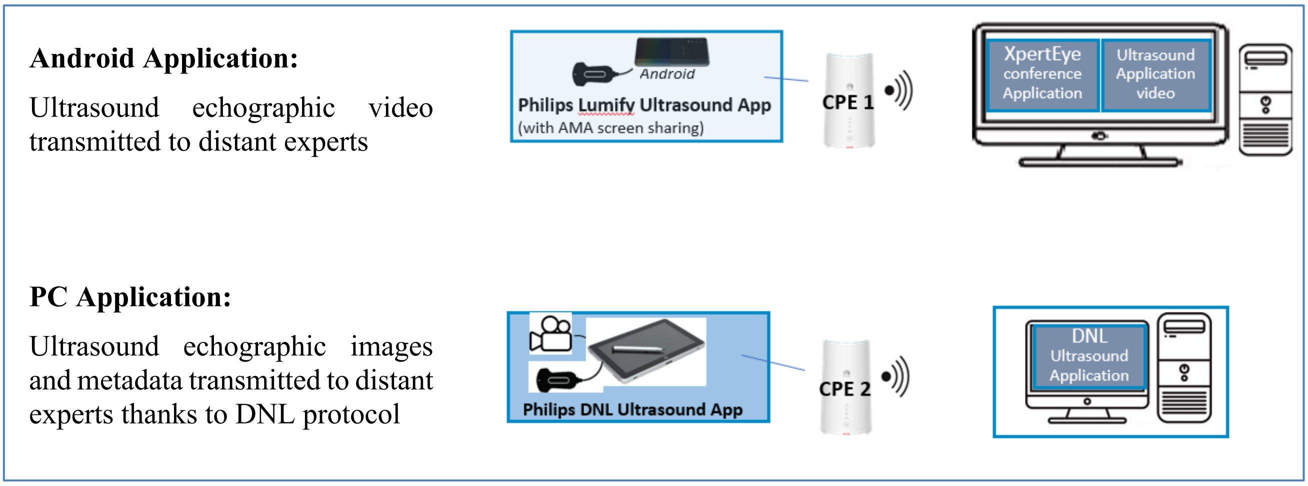


Figure 49. Two setups for ultrasound application successfully tested with 5G.

The following figures are presenting the network architecture with both experiments.

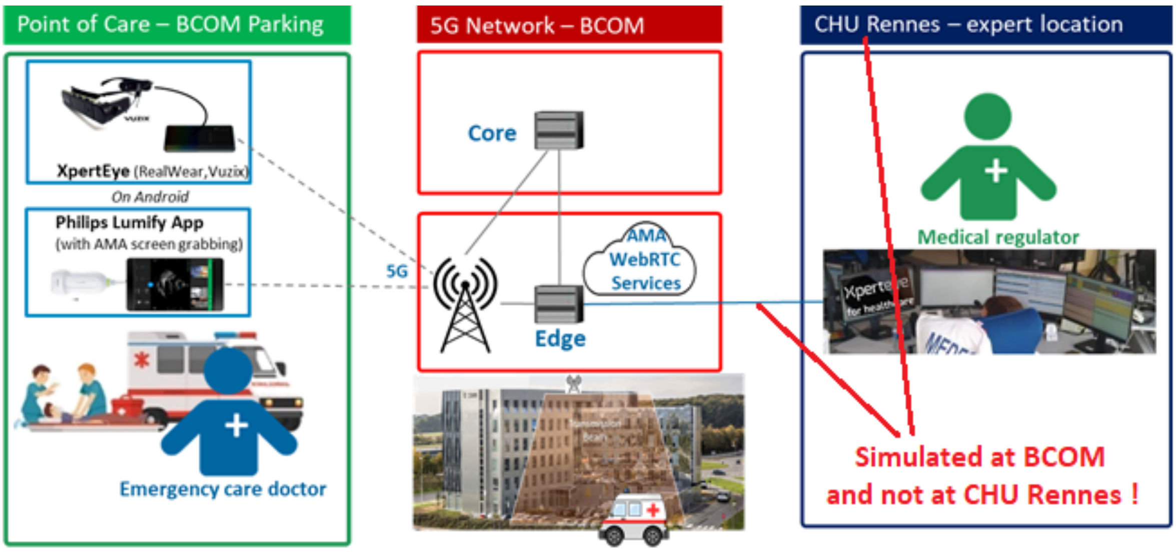


Figure 50. Application architecture overview test in the network: Lumify ultrasound App on Android with AMA screen grabbing.

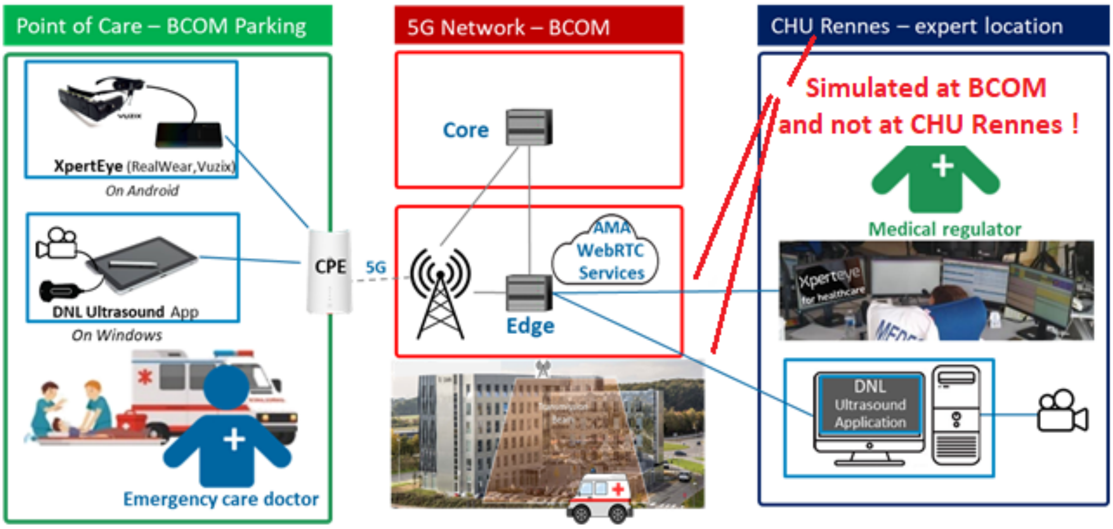


Figure 51. Application architecture overview test in the network: ultrasound with metadata transport in parallel with XpertEye video.

Some performance tests using the Nokia RAN and Askey CPE with the DOME UPF deployed on the target hardware were conducted. Regarding AMA application several improvements were tested and validated:

- Dual video streams to show both smart glasses and ultrasound Lumify application in real time
- Improved application screen sharing video resolution
- New LLVision smart glasses with better 720p video resolution

A video has been done demonstrating this emergency ambulance use case 7 testing at Rennes, and the link to this video is provided at [46].

Two Android mobiles and one PC were connected to two 5G CPE that wirelessly communicated over BCOM 5G mmWave (26 GHz) wireless private network with a 5G base station antenna at the roof top of BCOM building.

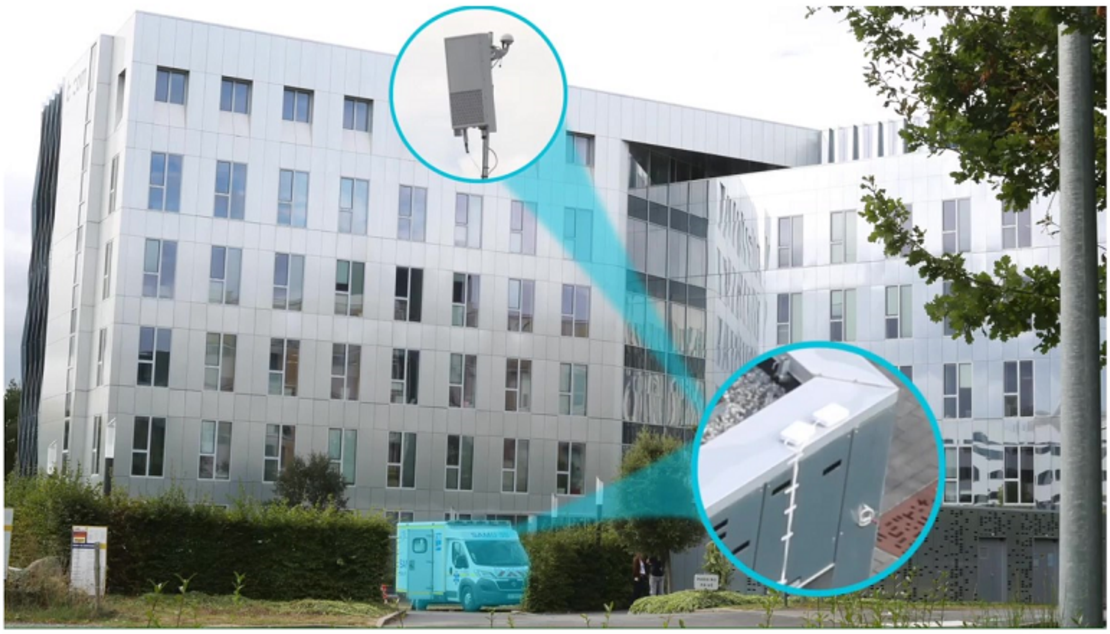


Figure 52. 5G mmWave private network at BCOM Rennes.

Video, audio and data channels provided by AMA XpertEye WebRTC communication services is deployed on EDGE to optimize the latency.

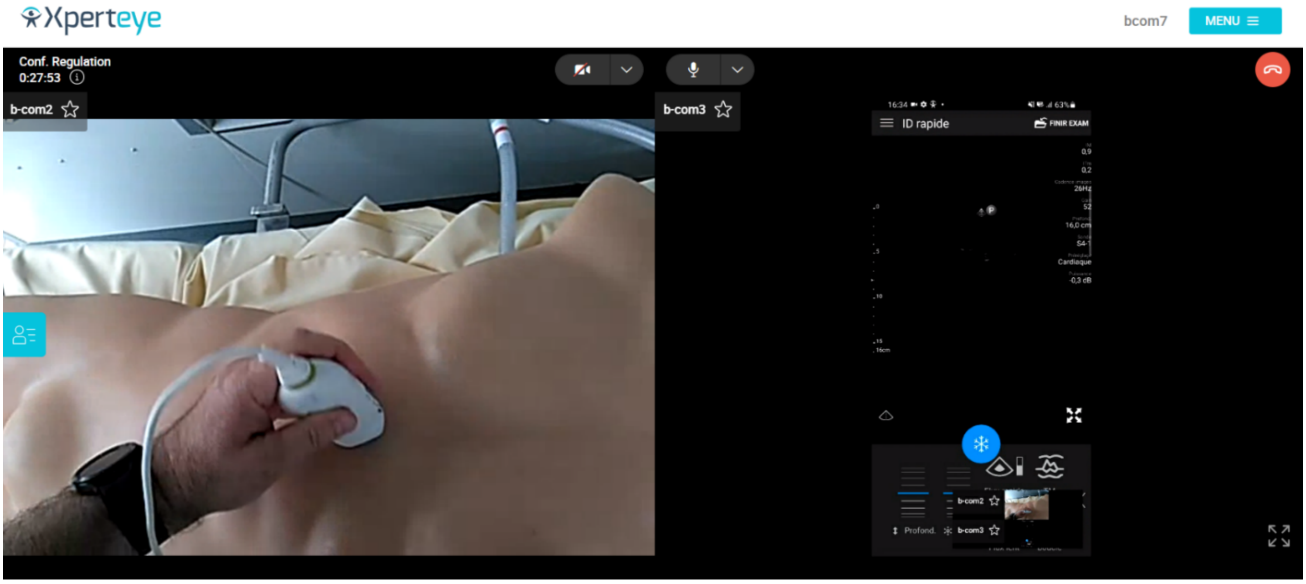


Figure 53. Emergency doctor's view and ultrasound echography remotely shared.

The emergency doctor shared *smart glasses* video stream showing the patient and Philips *ultrasound echograph* to interact with remote medical experts.

Figure 54. Emergency ambulance crew close to the patient.

Figure 55. A cardiac problem is suspected for a patient: emergency doctor interacts with remote medical experts.

With a better understanding of the situation, medical regulator in medical emergency call center and medical specialists can *make better decisions*.

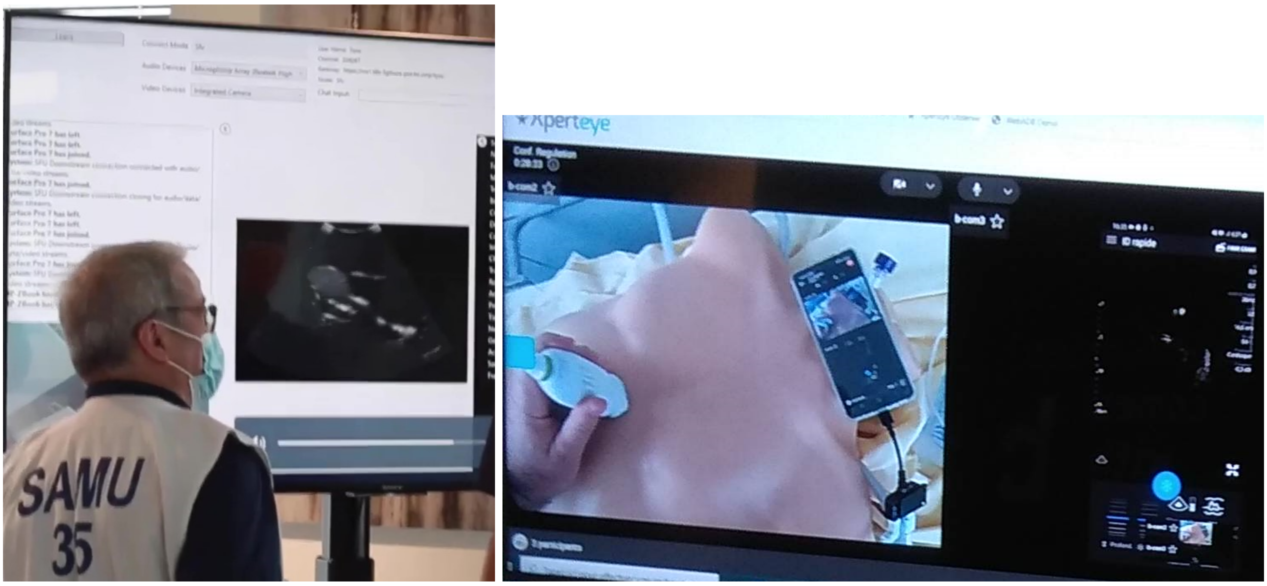


Figure 56. Remote medical experts immersion.

Immersive experience for distant medical experts provides support and advice for the ambulance staff until the patient stability is achieved.

Remote video assistance and teleguided ultrasound solutions *ease remote collaboration* scenarios thanks to 5G mobile network.

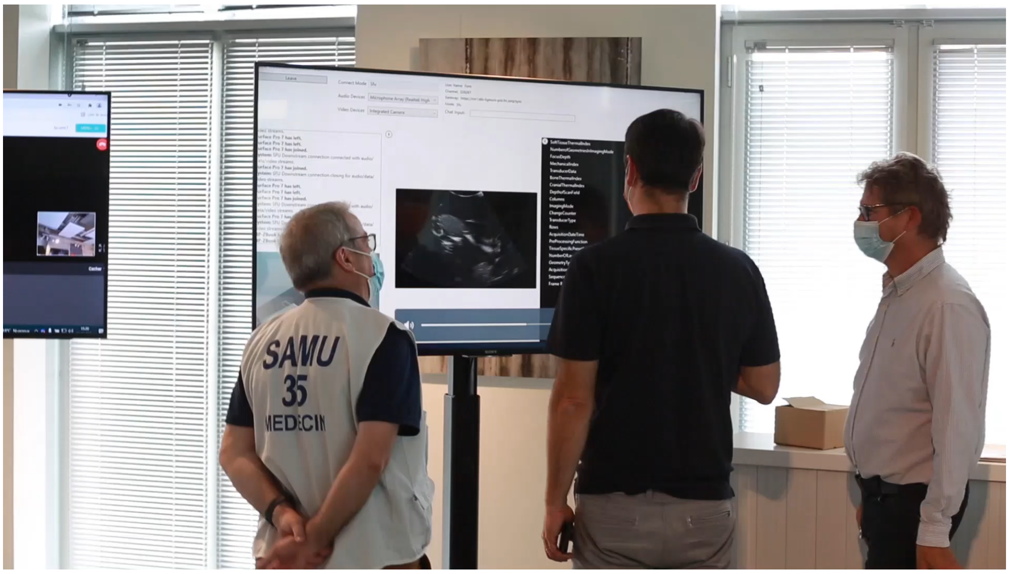


Figure 57. Philips DNL ultrasound application.

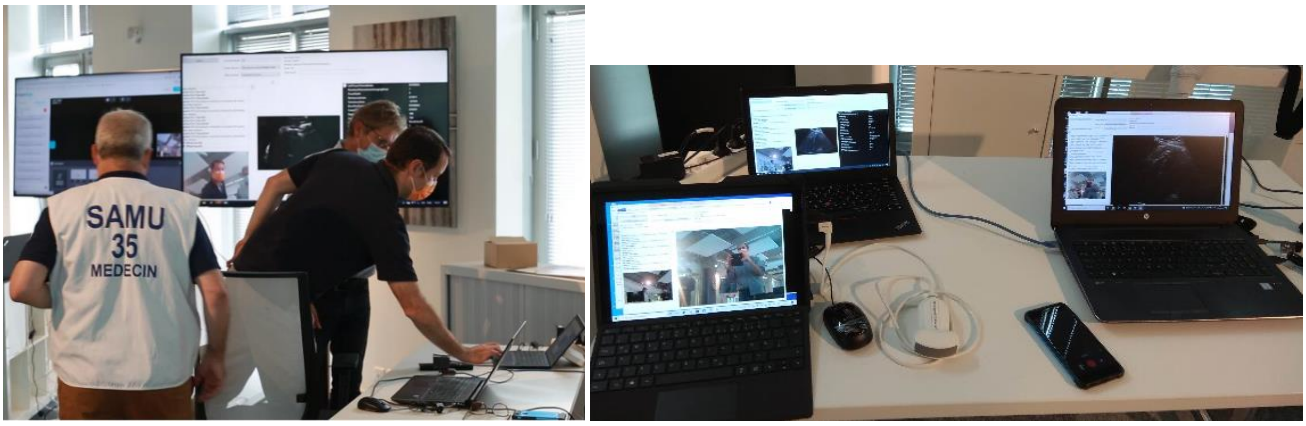


Figure 58. Philips DNL ultrasound application setup.

All this demo session has been done using CPE for 5G mmWave transmission/reception :

Figure 59. 5G mmWave CPE.

Some other testing has been performed in January 2022 using recent 5G mmWave smartphones [45] compliant with 4G and 5G frequency bands for this 5G private network.

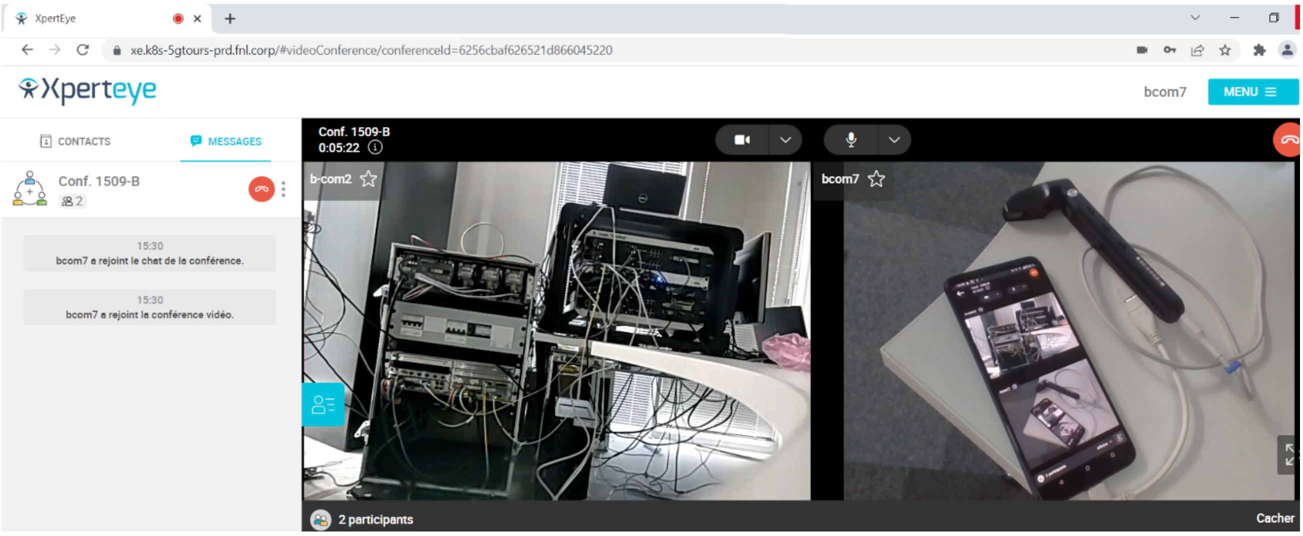


Figure 60. 5G mmWave smartphone and 5G RAN and core network.

The quality of experience and performances were the same as previously using CPE.

4.5 3D telepresence setup

4.5.1 Application Components and Architecture

One of the routes to enhance and enrich the telepresence is moving from 2D video to 3D video. For this, 3D capture equipment is added to the Point of Care equipment setup. Optimal viewing and interacting with 3D video put the remote expert in an XR or VR setup. This is shown in Figure 61 below.

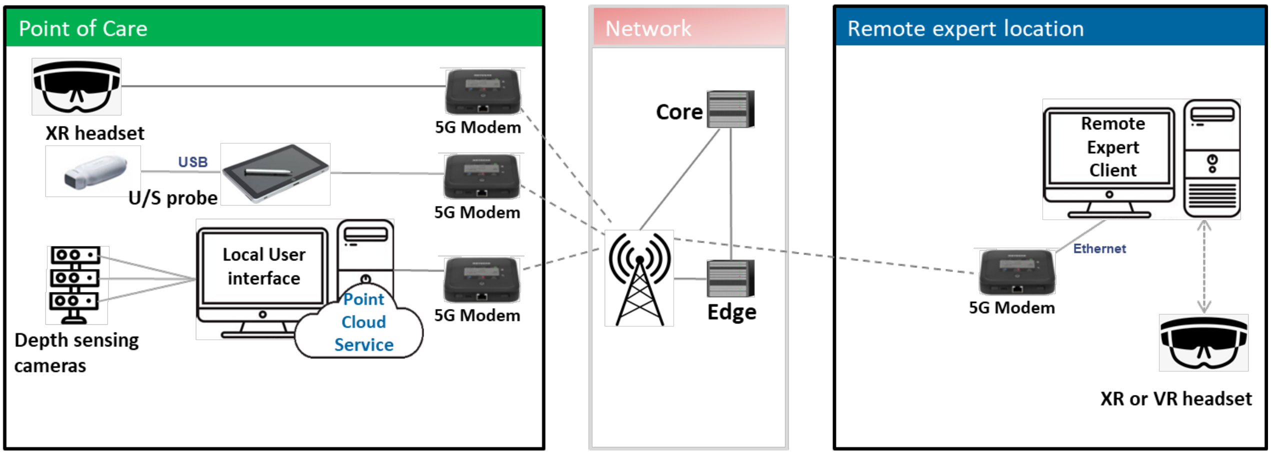


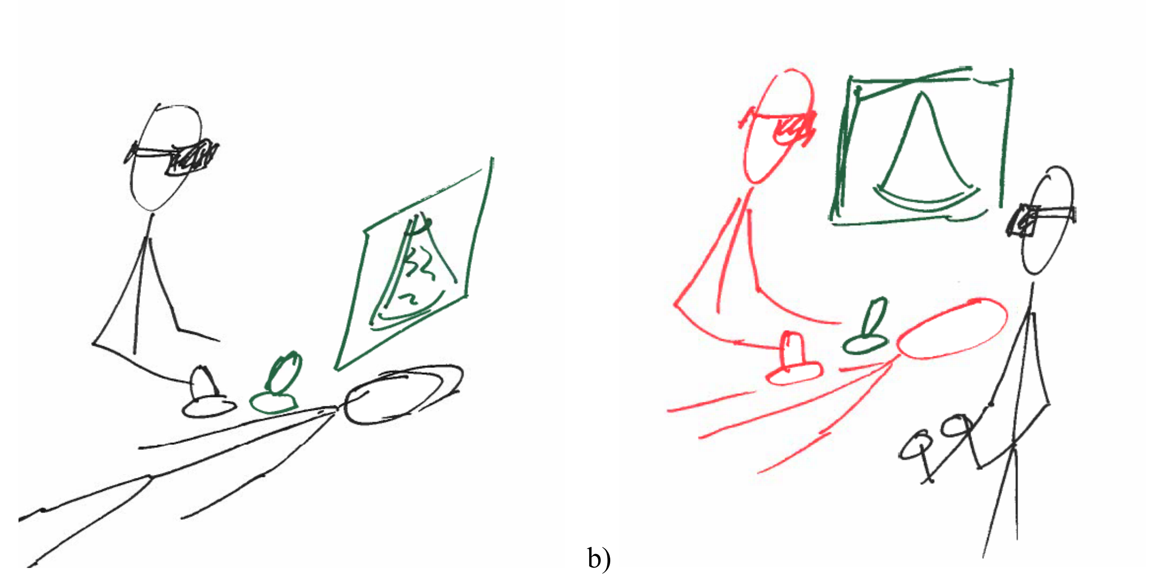
Figure 61. Architecture view of the 3D telepresence application.

Three major components change.

- The local doctor uses an XR headset, to enable spatial interaction. User interface elements such as video displays, clinical data displays and control elements of the Ultrasound equipment can be virtualized.
- The 2D video capture has been replaced by a set of depth cameras. Depth cameras allow the capture of a 3D image. By using multiple cameras, multiple sides of an object can be captured, to minimize occlusion.
- The Remote Expert views the scene with a XR or VR headset. He can interact with a virtual probe to provide guidance to the local physician.

We have used the following devices in this test setup:

- XR headset: HoloLens 2. The HoloLens 2 is deployed in two different ways.
  - For the local physician, a standalone application is used, receiving the US data and probe positioning feedback.
  - On the remote expert side, the HoloLens is deployed as a holographic remoting device. Rendering takes place on a host PC, after which the video is streamed to the HoloLens. Conversely, camera and sensor data are sent to the host PC for evaluating interaction and camera perspective. As there is noticeable latency in the interaction for this setup, we do not use this setup for tests involving interactivity.
- VR headset: Oculus Quest 2. We use the Quest as a tethered device, with all rendering and communication being handled by the host PC. The Quest allows interaction to be done with two handheld controllers, with imperceptible latency. This is the setup used for tests including interactivity.
- Depth cameras: Azure Kinect. Uncompressed, a single Kinect camera can generate up to 6 Gbps video and depth data. By using reduced resolution, we shrink this to retain about 30 MB per camera per frame. Figure illustrates how the work settings are perceived by the users. The local physician and the remote expert have a shared 3D view on the scene. The local physician has a virtual ultrasound screen and a virtual probe displayed by the XR headset. Guidance with this virtual probe is given by the remote expert, who manipulates a virtual object in the virtual scene presented to him. Both can see the ultrasound image data and can place it in a convenient spot in the work environment.



a) b)

Figure 62. Schematic view of the 3D telepresence.

Figure 62 presents 2 contexts:

a) context of the local physician - The ultrasound display and probe (in green) are augmented images.

b) context of the remote expert - The red elements are the 3D scene capture. Probe and ultrasound display are added as virtual objects. The remote expert is effectively working in a VR setting

Section 4.5.2 describes how the camera image capture results in a point cloud to be shared with the remote expert. This includes the alignment of the multiple cameras and the registration of the HoloLens. In the figure above, we assumed the ideal situation where all devices are directly connected to the 5G RAN. For testing, this was not possible. The different network topologies in the tests are described in detail in Section 4.5.3. Interaction with the applications is covered in Section 4.5.4. The final section covers the test activities.

4.5.2 3D capture & calibration

For live capturing of the scene with patient and caregiver, an array of RGB/depth cameras is set up. Specifically, in our experiments, KinectDK cameras are used. Each of these cameras needs to be aware of its position and orientation, such that the output of each of the cameras can be overlaid to create a single 3D-scene reconstruction. This position is called registration. Three methods of registration have been examined: manual, marker-based and point cloud.

4.5.2.1 **Manual registration**

Two kinds of manual calibration have been tried. The first one involves fully manually rotating and translating the image. This was difficult to setup but had a decent registration performance, provided that one took the time for it. The second one used a physical marker with three cubes. Both cameras looked at the three cubes and you had to manually overlay virtual cubes to the three cubes on the point cloud. These points (two times three points for two point clouds) were subsequently used in the Kabsch algorithm to align the two point clouds. Since the results of this experiment were poor and the registration took a lot of time, this method is not recommended and won't be discussed in detail. However, we have seen accurate manual registration methods, but these always take quite some time; in the order of multiple minutes or more.

4.5.2.2 **Marker-based registration**

Marker based registration is a common, simple and efficient method which allows for real-time registration. We have implemented the OpenCV for Unity library, and more specifically the Aruco tools, to achieve marker-based registration. This library allows to estimate the transformation between the camera and the visible Aruco marker. There are three main components necessary to feed in this pipeline: Camera parameters (the intrinsic and extrinsic values), the Aruco marker parameters, and the raw image coming out of the camera.

The pipeline used for registering multiple Azure Kinect cameras inside Unity works as follows: importing the intrinsic and extrinsic values of the camera to be registered, noting the Aruco marker details, importing the raw image, converting the image to an OpenCV file, feed all of this this to the library which estimates a pose and finally apply the extrinsic value of the Azure Kinect. In most cases, the example of OpenCV for Unity has been followed. In some cases, we made some adjustments, which are noted below.

Intrinsic and extrinsic values

Every Azure Kinect is pre-calibrated and stores intrinsic and extrinsic calibration values inside the camera. These values can be retrieved by the Azure Kinect SDK. The intrinsic values are compatible with OpenCV. The camera also stores extrinsic values. Since the RGB and Depth camera do not have the same location, we must correct the point cloud's location with this extrinsic matrix.

Aruco parameters

The Aruco details necessary are the following: Marker type, dictionary, and marker length. We used the canonical marker, the Dict_6x6_1000 dictionary and a marker length of 0.25 meter. A Charuco board has been tried as that would result in improved calibration, however we were not able to get that to work inside Unity. The values and size have been chosen at convenience.

Raw image

Within Unity we can request a raw image from the Azure Kinect SDK. This image is converted to a so called 'Mat' texture which is compatible with OpenCV. OpenCV provides an example code to do this. However, one should note the orientation of the image retrieved from the camera. We figured that without any adjustment the image is upside down by default. This gives false results of the transformation matrix. We also noticed that this pipeline is sensitive to the format in which the image is stored. As we retrieved an RGBA image from the Kinect in our case, our texture format used was RGBA32.

Transformation

The output of this pipeline is a transformation from the camera to the Aruco marker. While this is correct in most circumstances as our camera is standing still and the marker is moving, we inverted this transformation. By doing this our camera is moving in the Unity scene and the marker is standing still. This 'trick' makes it easier to register multiple cameras to each other as they all have the same point to which they register in the Unity scene.

Refinement

To refine the result, multiple images are analyzed, and the average value is taken. Also, during the calibration the highest possible resolution is used. Next to that, since we would like to display this in a virtual world, we must make sure the ground is levelled. For this we read out the IMU transformation matrix of the Kinect and apply the inverse of this to the virtual marker.

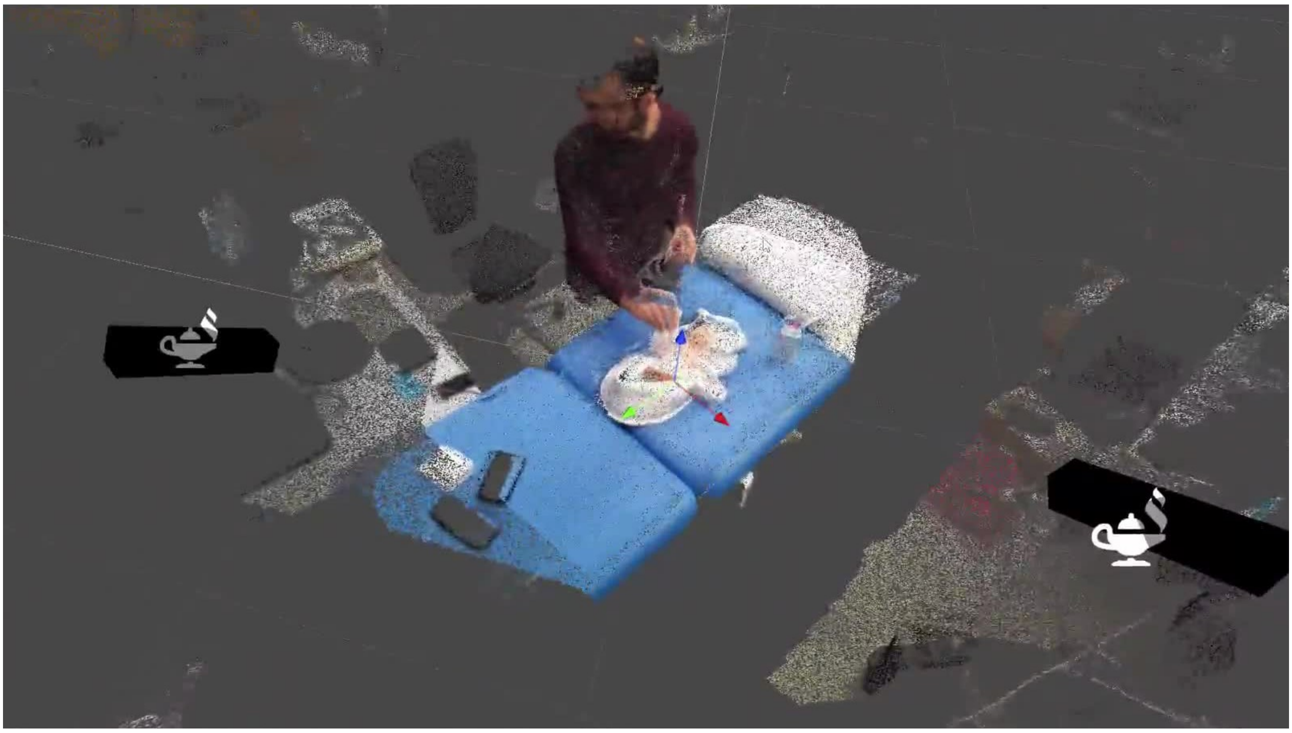


Figure 63. The output result of the pointcloud in unity: The black bars are representing the different cameras.

Performance

The output of the pipeline above is performing a registration, however this is far from perfect. As seen in the image below, there is a clear offset visible in the two different point clouds. By trial and error many adjustments have been made, e.g., increasing the marker size, using different markers, using offset parameters, averaging multiple frames, using different image capturing resolutions and different camera positioning. Only averaging and adjusting the position of the cameras had a significant impact. The averaging is already applied in the example shown below and the positioning is one that is reasonable for this setup. Bringing the camera's closer to each other decreases the error.

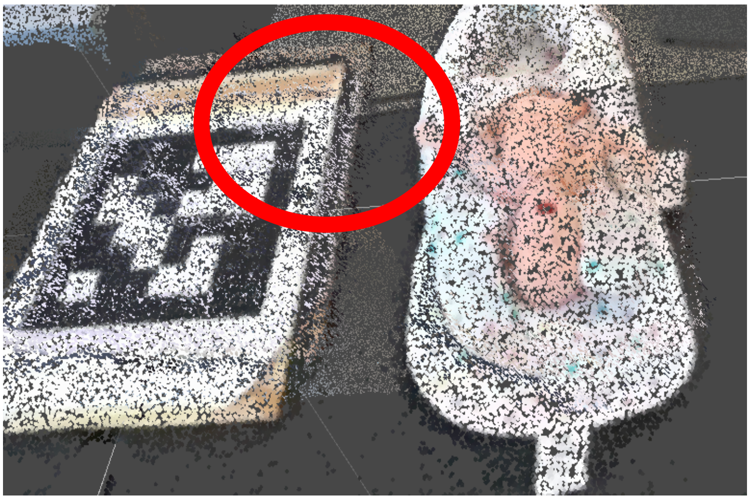


Figure 64. Misalignment between two captured point clouds.

4.5.2.3 Point cloud registration

Different point clouds overlap as close as possible. Since we do not know which two points correspond to each other in real life, this is mostly an iterative process. There are methods to find features inside the point cloud which can be directly matched. However, these are mostly in the research phase. Point cloud matching itself is outside the scope of this project.

As we can already make a good estimate of the transformation between the two points clouds by our marker detection, an iterative process might be sufficient. The point cloud registration will therefore be used on top the marker-based registration. The theoretical problem we then face is that the point clouds are not completely identical. That means that a lot of points do not have any corresponding point in the other point cloud. Regular methods like iterative closest points struggle with this problem as they consider all the points.

Again, an open library is used for creating this part. Open3D for Python has been used. Inside python we follow the example of Open3D for point cloud registration with colored ICP and robust kernels. The robust kernels are a way to overcome partially overlapping point clouds. Details on the method used can be found on the Open3D website.

Since Unity does not have native support for Python 3 in which Open3D works, we make a Dynamic Link Library (DLL) of the Python code. This DLL has bindings which can be used inside Unity C# scripting. Inside Unity we have to pass on the estimated transformation between the two point clouds and a list containing the vector3 positions of the point cloud points. Results will be added on later as this is finished.

Preliminary results in which the full registration is done with point cloud registration can be seen below in Figure 65.

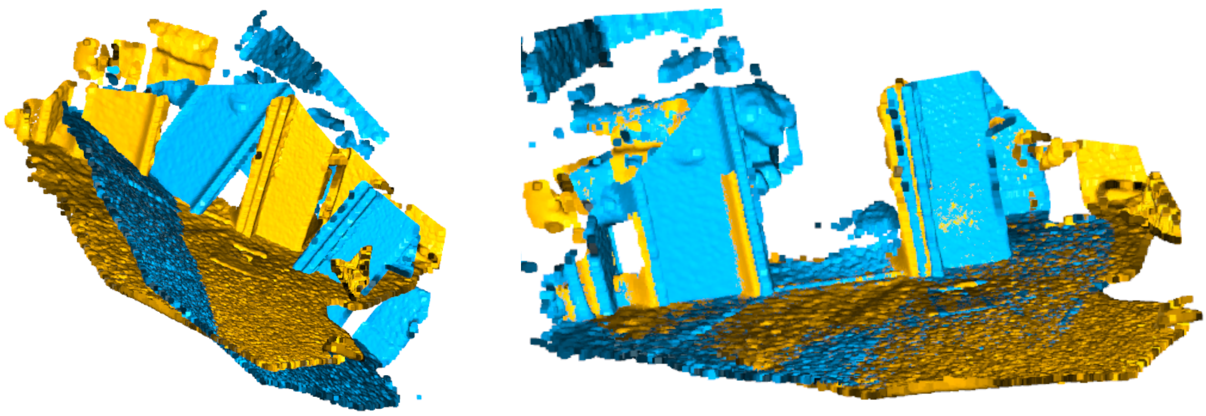


Figure 65. Two points clouds distinguished by the colors (blue and yellow).

Two points clouds captured by the Kinect had been saved in a text file and loaded into Python for this use case. Left: Point clouds before ICP + Robust kernels registration. Right: Point clouds after registration.

While this method seems to be having high potential, we were not able to apply this in a way that improved the previous results significantly.

4.5.2.4 Capture

To capture and reproduce the scene with patient and caretaker live the array of depth + RGB cameras (KinectDKs) are pre-calibrated. Calibration holds position and orientation in the real world relative to a marker for all depth + RGB cameras. In this setup the cameras cannot move during use however a future expansion could include live calibration to enable moving cameras.

The calibration information is kept at the patient-scene hardware setup – the server – in form of json file(s). All viewers connecting to this server – the clients - receive calibration data at connect (no duplicate data is stored client side). In case of the KinectDK the serial number of the camera is used in all occurrences of the camera in software at any point (be it in memory or on storage device) to prevent misinterpretation. Other data shared at connect includes for example resolution of RGB and depth streams; a client should be able to connect without any prior knowledge of the setup server side.

As well server side as client side per depth + RGB data stream a point cloud is constructed live. These point clouds use real world sizes (no scaling / skewing) so that all (calibrated) cameras combined produce overlapping point clouds, reconstructing the scene client side live enabling viewing on monitor or in AR/VR.

The first implementation over TCP/IP sends the depth + RGB as separate data blobs, one for depth and one for RGB, per frame. The client polls the latest frame from the server. The RGB data blob is compressed as lossless PNG, the depth blob holds a floating-point formatted texture with pre-processed vertices - per pixel an x, y, z pair of floating point values, zip compressed.

The pre-processing is converting incoming raw depth to projected real-world sizes and position, a standard processing available in the KinectDK SDK + PointCloud for Unity.

Client side the expert user can position a virtual US probe on the point cloud reconstruction (e.g., via a controller in VR). The position and orientation of this probe is then shared with the server in order to visualize it at the caretaker's view (e.g., via the Hololens). This way the expert can guide US probe position for the caretaker.

4.5.3 Network structure

Streaming point clouds can quickly produce large amounts of data. Uncompressed, a single Kinect camera can generate up to 6 Gbps video and depth data. Onboard MJPEG video compression brings this down to 850 Mbps, which would still be well beyond the capacity of the available test networks. In order to still arrive at a testable configuration, we bring the frame size down, and only send frame updates. Compression of the stream is possible but falls outside the scope of this project.

Networks can often have asymmetrical up and download speeds. Figure 66 and Figure 67 below illustrate the two variants. The first figure shows the ambulance case. All devices are shown to be linked directly to the 5G RAN. High upload speed is required here to allow the 3D scene to be sent across. The remote expert in the hospital is assumed to have a wired connection, i.e., no limitation in bandwidth on his end. The reverse topology in Figure 67 requires high download capacity.

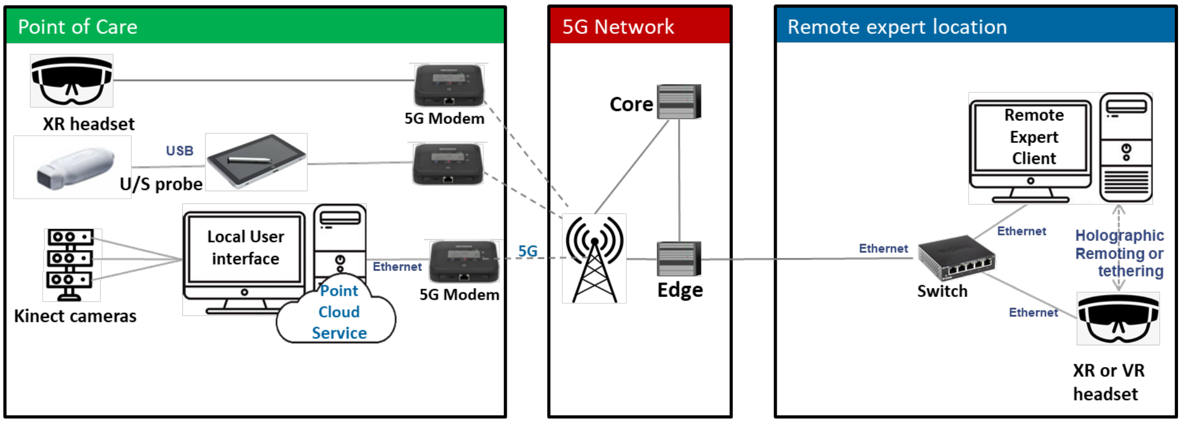


Figure 66. Network layout for the ambulance scenario.

All devices on the Point of Care side are connected to the 5G RAN. The remote expert sitting in the hospital. This topology demands high upload speed for transmission of the 3D scene.

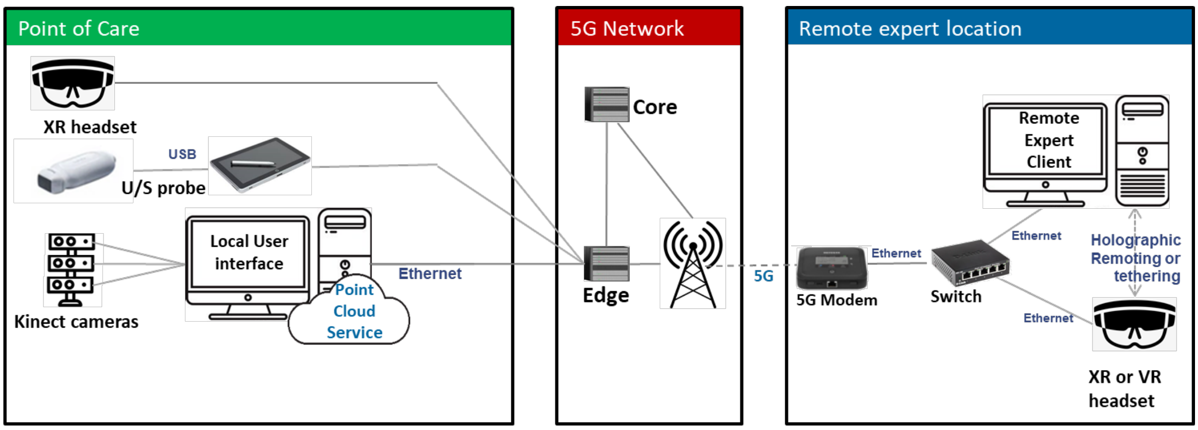


Figure 67. The reverse topology.

The remote expert receives the 3D scene over the 5G RAN, requiring high download speed.

As reference we also use a topology without RAN, as shown in Figure 68.

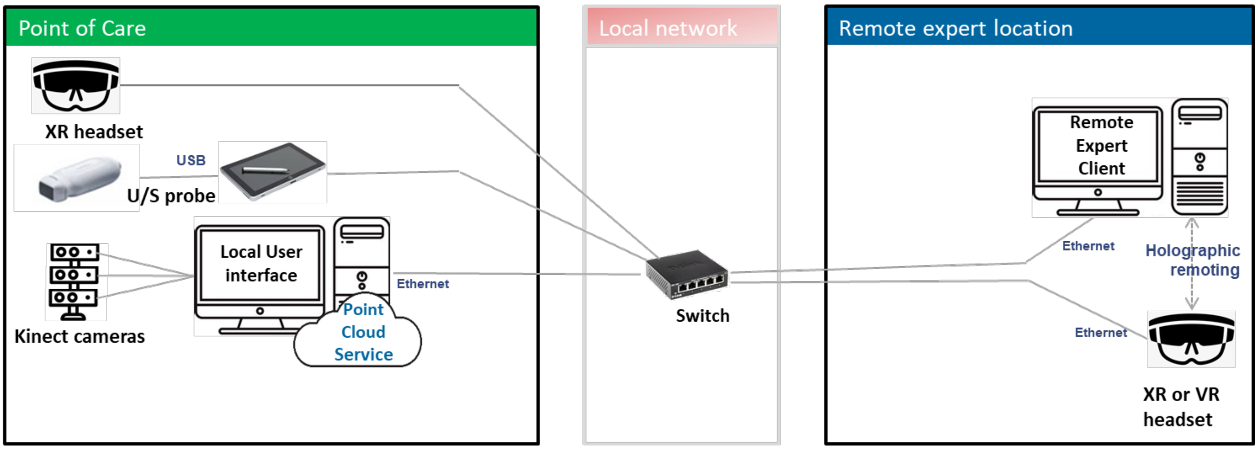


Figure 68. Reference layout for network measurements, without 5G RAN.

4.5.4 Interaction

Each of the XR workspots has its own specific interaction requirements. First, we describe the local physician's interface for connectivity and ultrasound. After that, we describe the interaction of the remote expert.

4.5.4.1 Point of Care interface

Interaction with the XR display is done with voice as much as possible, to maintain hands-free use.

For selection of the signalling server set and for tests, a small number of buttons are attached to a menu following the user, as shown in Figure 69. The buttons are taken from a standard HoloLens toolkit (MRTK). The menu can be hidden with a voice command.

The local physician controls video, audio and ultrasound feeds with voice control. By default, the windows open 2m in front of the user's current position, oriented towards the user, resulting in a view as shown in Figure 70. If the screens need repositioning, this is likewise done with voice commands.

The 2m distance is chosen to avoid focus/convergence conflicts when viewing the content. The screens are sized relatively large to allow viewing of enough detail.

The virtual probe controlled by the remote physician and will show up in view of the local physician, as illustrated in Figure 71.

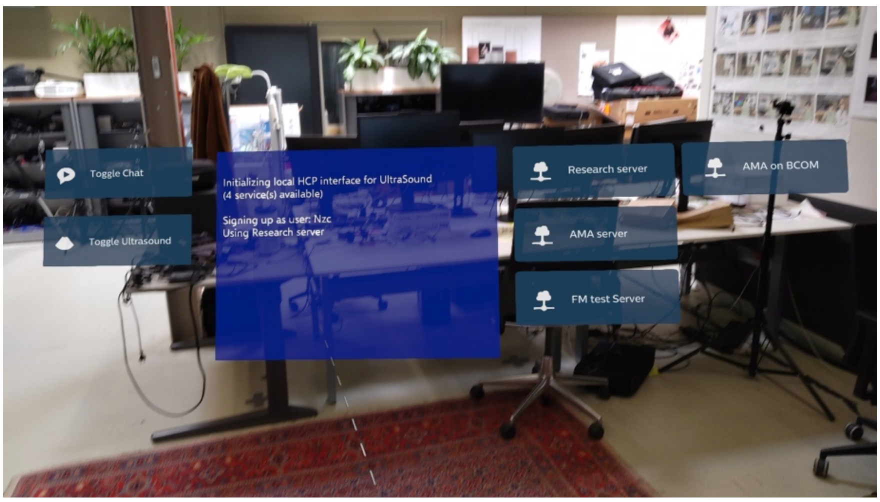


Figure 69. Signalling server selection and debug buttons.

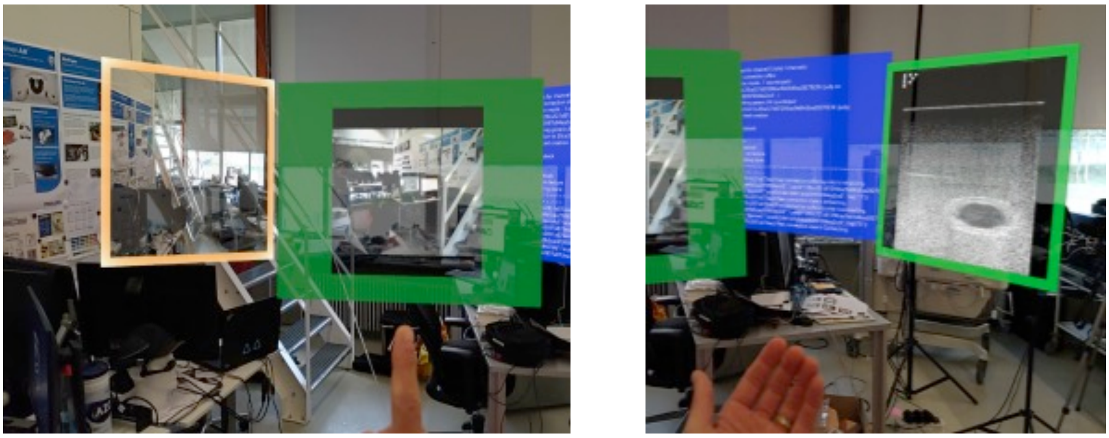


Figure 70. Impression of the view through the HoloLens.

In this sample you can see (from left to right): the local camera feed, a remote camera feed, and the live ultra-sound feed. The blue window is a debug console that is normally hidden from the end user.

Figure 71. Virtual and real probe as seen by the local physician.

4.5.4.2 Remote expert interface

The remote expert interface has two variants. One variant is for viewing only. In this instance, the point cloud is rendered by the host PC. The HoloLens is connected through holographic remoting. This interface allows inspection of the scene only – there are no controls.

The main interface for testing is implemented on a tethered VR device. Also here, we rely on the PC to do the render of the point clouds. Two hand controllers are used for interaction. The left hand is decorated with a wrist menu – this is a menu that becomes active when the user raises his hand and looks into the palm. There are three buttons:

- A toggle to connect/disconnect to the 3D scene
- A toggle to connect/disconnect the Ultrasound feed
- A mode switch to rotate between selection of the 3D scene, the Ultrasound screen, or the virtual probe. The selected object can then be translated and rotated by the index triggers.

Figure 72, Figure 73 and Figure 74 illustrate the operation of these buttons.

The application virtual ultrasound probe acts as a marker object. The controllers can be used to manipulate the object.

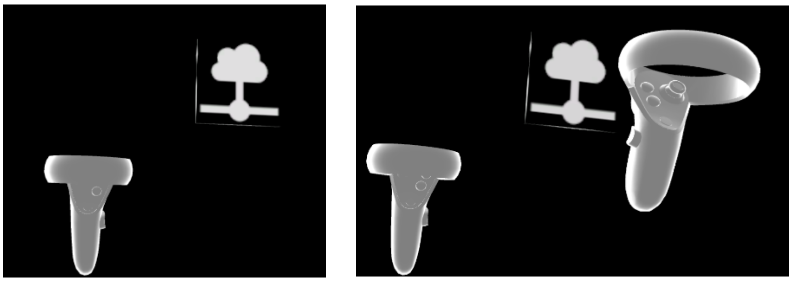


Figure 72. Start situation for the Remote Expert.

The button on the menu opens the connection. This is activated by tapping with the second controller.

Figure 73. The button at the right bottom indicated the movement selected for a) the virtual probe, b) the ultra-sound display, c) the entire 3D scene.

The actual movement is performed with the index buttons on the VR controllers. The top left button toggles the ultrasound feed.

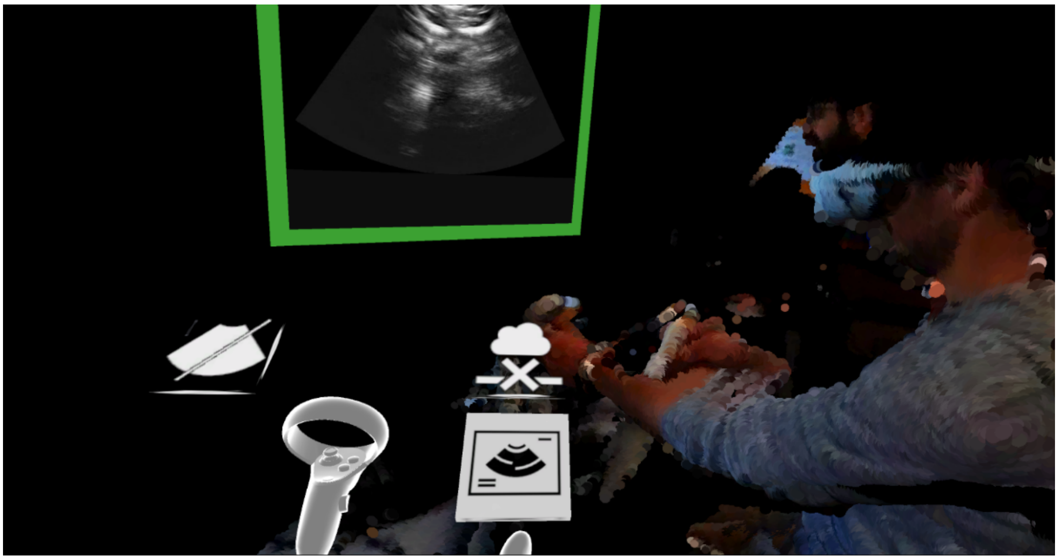


Figure 74. Impression of the working situation with active ultrasound.

The captured scene shows the user with VR headset, and ultrasound probe.

Figure 75. Virtual prob, a marker in the 3D scene.

4.5.5 Integration and test

The KPIs for the 3D telepresence case are comparable to the general 2D case, as shown in Figure 76. The main difference is the increased bandwidth required. Due to the limitations in test mobility and duration, we focus KPI measurements on bandwidth and latency. We will evaluate capture framerates, application latency, RAN latency, throughput and user experience.

5G-Tours - Use Cases: direct specific Technical requirements		Units	UC7 – Teleguidance for diagnostics			Priority	Range	
			URLLC	mMTC	eMMB		Min	Max
General Vertical/Use Case Requirement								
1	Latency (in milliseconds) - round trip - Min/Max	msec			100		10	25
2	**RAN** Latency (in milliseconds) - one way	msec			10			
3	Throughput (in Mbps) - Min/MAX - sustained demand	Mbps			1000		600	1500
4	Reliability (%) - Min/Max	%			99.990%		99.00%	99.999%
5	Availability (%) - Min/Max	%			99.990%		99.00%	99.999%
6	Mobility (in m/sec or Km/h) - Min/Max	Km/h			130		0	130
7	Broadband Connectivity (peak demand)	Y/N or Gbps			2		0.6	4
8	Network Slicing (Y/N) - if Y service deployment time (m	Y/N			Y(1)		1	5
9	Security (Y/N) - if Y grade i.e. "Carrier Grade"	Y/N			Y		Y	Y
10	Capacity (Mbps/m^2 or Km^2)	Mbps/m^2			6		1	10
11	Device Density	Dev/Km^2			30		5	30
12	Location Accuracy	m			1		1	25

Figure 76. Network KPIs for 3D remote telepresence.

A network test has been performed in the 5G-Hub on the High-Tech Campus (Eindhoven, NL). These tests showed poor network performance of around ~60mbps, which is around 10x lower than achieved wired. The 5G network available should be able to achieve ~100mbps. The source for this low throughput is still unknown and more tests have to be performed to pinpoint the problem.

Two emergency physicians were asked to try out the application on the High-Tech Campus. A local network was used for maximum performance. Despite using a local network, the physicians noticed the lack in detail and the low framerate. Increasing both would require connections faster than 1Gbps. However, the value of the use case was recognized by both participants.

We will be executing testing on the testbed in Rennes on the B-com RAN in June 2022. The results of this test will be shown in the last WP7 deliverable (D7.4).

5 UC8 - Wireless Operating Room

5.1 UC8 definition

This use case 8 is aimed at demonstrating the impact of 5G inside the operating room. This use case will address very low latency requirements and important amount of video data to be transferred. The scenario for the trial corresponding to this use case considers a situation where a patient must undergo a cardiac intervention procedure based on live, simultaneous X-Ray and ultrasound imaging.

The procedure follows an accident that was in fact due to an acute heart failure happening to the tourist patient secondary to a rupture from an acute heart rhythm dysfunction. The interventional procedure starts with a 3D Angiography X-Ray acquisition enabling the doctors to obtain the 3D volume of the heart auriculum. Then, a radiofrequency ablation is performed, guided by fluoroscopy, complemented by Doppler ultrasound to estimate the blood flow, and superimposed on the fluoroscopy image, using advanced segmentation and matching algorithms with an Augmented Reality application that generates a guidance image displayed on a monitor, which is 5G connected. The use of complementary imaging sources is justified to limit the use of X-Ray and contrast product at the minimum.

The tourist patient has been previously operated in his country, Italy, by a cardiologist who is so able to interact with his Rennes colleague to improve the quality of the procedure, via a teleconference performed using smart glasses. During the patient intervention, this cardiologist is travelling in Athens for business and he is able to follow the cardiac intervention and interact with the cardiologist from Rennes.

The video of the ultrasound probe is transferred as wireless video over IP, thanks to the recent DICOM-RTV standard, enabling synchronized real-time communication of video and associated metadata. However, the data stream from the X-RAY, which is a fixed device in the Operating Room and thus won't move from different operating rooms inside the hospital, will be wired connected to the AR platform.

The stream of the smart glasses, connected to a 5G smartphone ASUS, compatible with 5G NSA mode in the n257 band, is transmitted through the 5G network inside the operating room to the doctor in Athens, thanks to a secured VPN.

The overall architecture is designed as shown in Figure 77. Two video sources, with ultrasound and smart glasses, and one display for the augmented reality view are considered, all connected over a 5G wireless network through 3 gateways, two CPE and one smartphone.

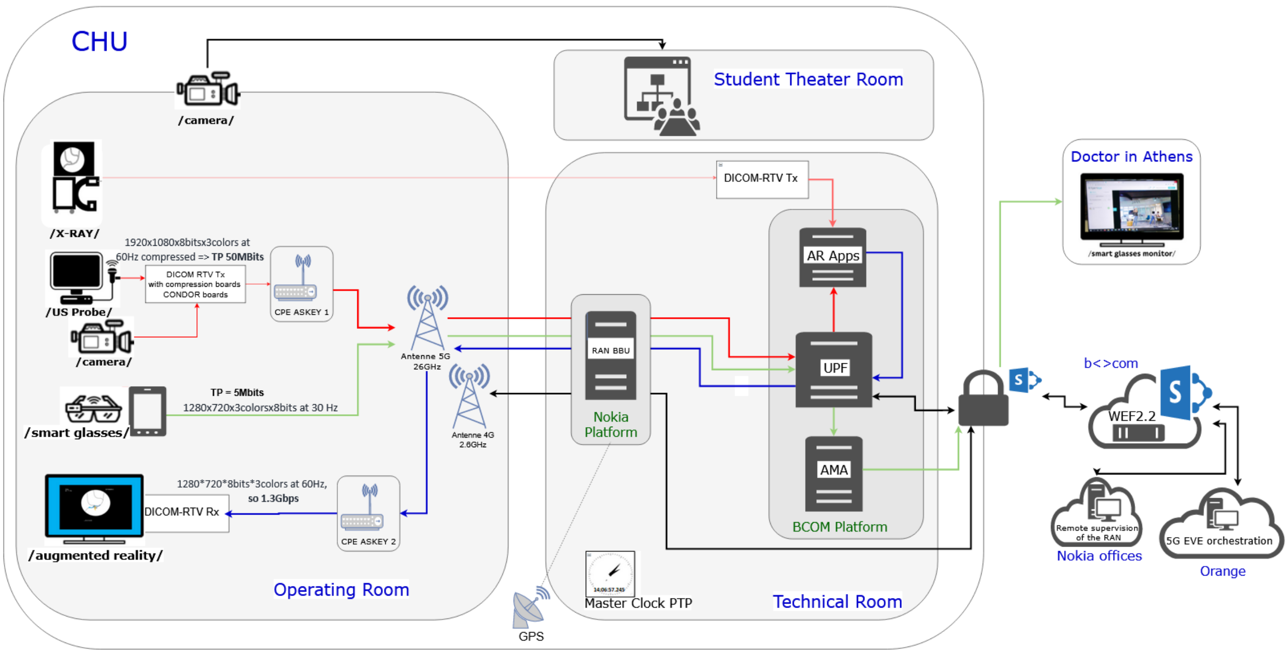


Figure 77. High level architecture of the UC8 Wireless Operating Room.

5.2 UC8 implementation

5.2.1 Application Components

DICOM-RTV transfers

In order to provide a precise synchronization of the different incoming images, the augmented reality platform operates DICOM-RTV streams. DICOM-RTV is a new standard based on the recent video over IP standards, SMPTE 2110, and enables the transfer of metadata, related to the video, such as patient information, device in use or tools' position.

Specific modules were designed to perform the emission and reception of these streams. The video signal retrieved from the ultrasound is 1080p60 (1920*1080 at 60Hz), which leads to 3 Gbps to be transferred. This is currently not possible over a 5G network, especially in uplink, so this signal needs to be compressed by the DICOM-RTV-Tx (Transmitter) module. The video signal coming from the X-Ray is also 1080p60. Knowing that the X-Ray is already heavily connected inside the operating room and not transportable, there was no real point of transferring its signal over 5G. Moreover, we need to keep this video signal uncompressed because it is used as a reference to merge the signals. At reception side, a dedicated AR platform was setup. This platform receives the two incoming streams, performs the different calculation and video processing and sends the resulting view over a 5G downlink. Knowing the downlink bandwidth is also not able to transfer a 1080p60 video signal, the augmented reality output has been reduced to 720p20. The AR platform embeds a video decoding board to decompress the signal coming from the ultrasound with the minimum possible latency. One DICOM-RTV-Tx (Transmitter) is located in the operating room, close to the medical equipment, and the second one is settled in the technical room with the AR platform, just next to the TherA-image room. To receive the results of the AR platform, a DICOM-RTV-Rx (Receiver) is placed in the OR next to a secondary monitor and to display the fusion of the two images.

Probe localization

To be able to align geometrically the images coming from the ultrasound and X-Ray, a registration has to be performed. To do that, it is firstly mandatory to perfectly know the position of the ultrasound probe. Several solutions are already available for that, such as:

- Optical localization solution such as NDI Polaris based on small lighted spheres trackers;
- Magnetic localisation solution such as NDI Aurora based on magnetic sensor trackers;
- RGD-B camera providing point cloud enabling to find and track known objects.

Figure 78. NDI Polaris, NDI Aurora and RGB-D camera.

The use of magnetic sensor trackers can be problematic in case of X-Ray acquisition. In the operating room, the presence of multiple electronic devices can interfere with the magnetic sensors and alter the precision of the tracking.

The use of NDI Polaris could be an option, but the price of this device is much more important than the one of standard RGB-D cameras. Since localization algorithms using depth camera are available at BCOM, it has been decided to use this technology.

The probe to be tracked is relatively small and can be heavily occluded by hand (Figure 79). To prevent the loss of tracking, first tests were conducted by adding a 3D marker on top of the probe. Results are encouraging (Figure 80) and further work will be performed to try to reduce the size of the marker (note that such reduction is not a part of 5G TOURS project).

Figure 79. Ultrasound probe to be tracked.

Figure 80. First test of localization of US probe using depth camera and marker.

The poses calculated by the localization system are then transported as DICOM-RTV metadata so that the AR application can realign the images coming from the ultrasound and X-Ray.

Augmented Reality application

In a first step, our goal is to perform multimodal registration between fluoroscopy (X-Ray) and echography (ultrasound) as shown in Figure 81.

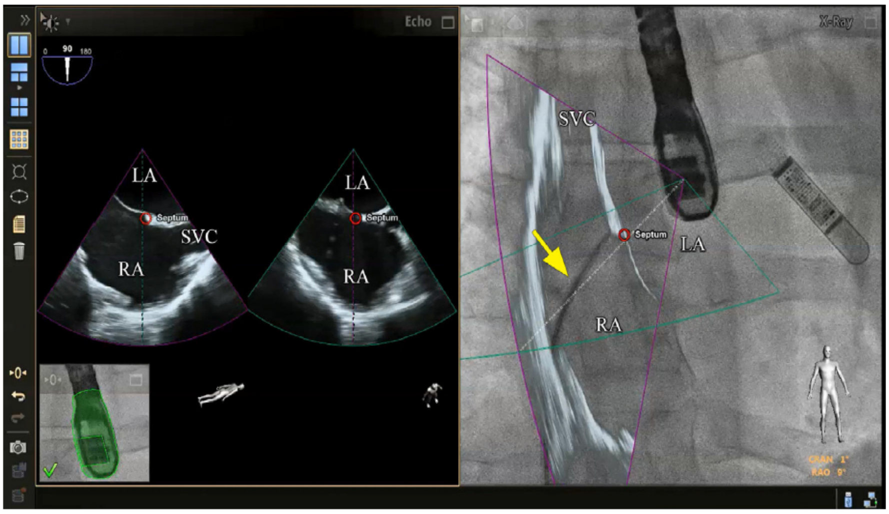


Figure 81. Ultrasound (US) and X-Ray registration.

To display the ultrasound image in the same plane as the fluoroscopy image, the transformation between the 2 references has to be known. In fact, there are other references involved in the workflow and a procedure needs to be defined to go from one to another. To simplify the procedure, it was considered that the camera and the C-Arm would not move during the interventional procedure. Two calibration steps also need to be defined, one for the ultrasound and one for the X-Ray. Main ideas for these calibrations are presented below.

Since the position of the RGB-D camera is fixed, the World coordinate system in Figure 82 is defined by the camera, with its origin at the optical center and the x, y and z axes following the geometry of the camera. The ultrasound calibration aims to align the ultrasound images with the World information. This can be realized by chaining two transformations: 1) the first one maps the pixel coordinates to the local probe coordinates (TUS-Probe) and 2) the second one from the probe system to the World (TProbe-CAM). Since the probe is tracked by the RGB-D camera, the relationship between the probe and the World is known. The goal becomes now to estimate the transformation TUS-Probe, of which the parameters can be estimated using a standard N-wire phantom. The X-Ray calibration aims to compute a transformation matrix that maps the World information to the fluoroscopy images. Since both the camera and the C-arm have fixed positions, this transformation has constant parameters. Those parameters are estimated using a phantom with metal landmarks, via a dedicated calibration procedure.

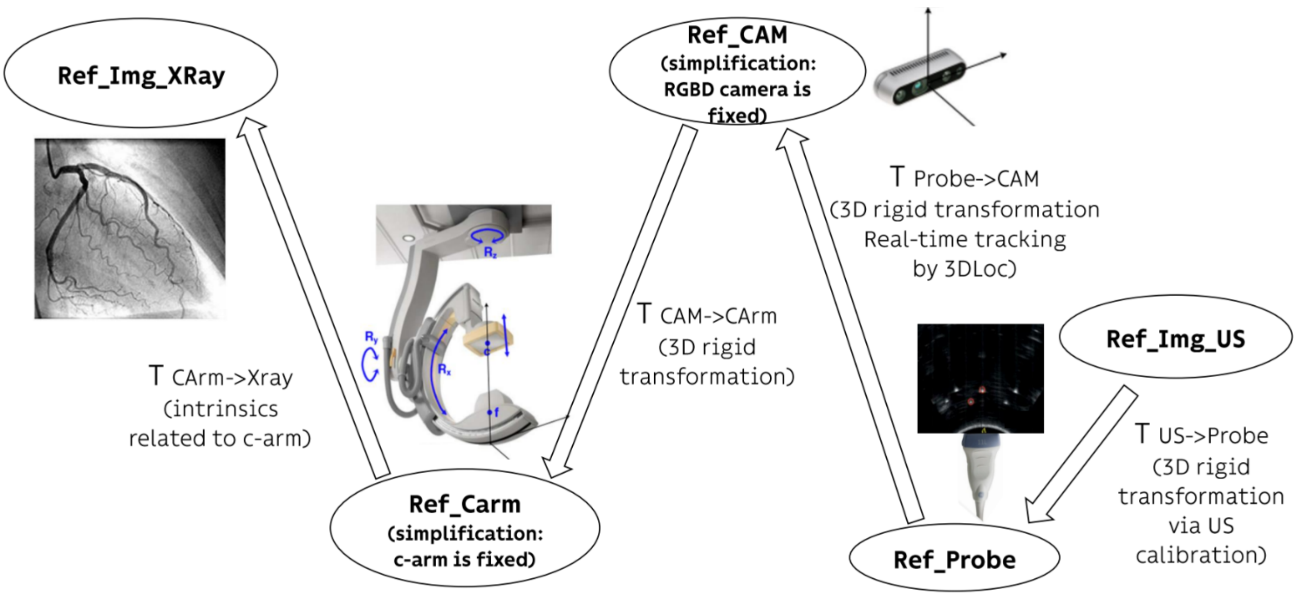


Figure 82. Multiple references involved.

The transformation $T_{US\text{-}Prob}$ can be retrieved using a dedicated calibration workflow that has been set up for the project (Figure 83). Basically, we use a 3D printed phantom with holes and place metal wires to form a N inside it. Then, we start an ultrasound acquisition and localize the dots formed by the wires in the US image. Knowing the positions of the wires and the position of the probe thanks to the 3D marker, we are finally able to retrieve the calibration parameters.

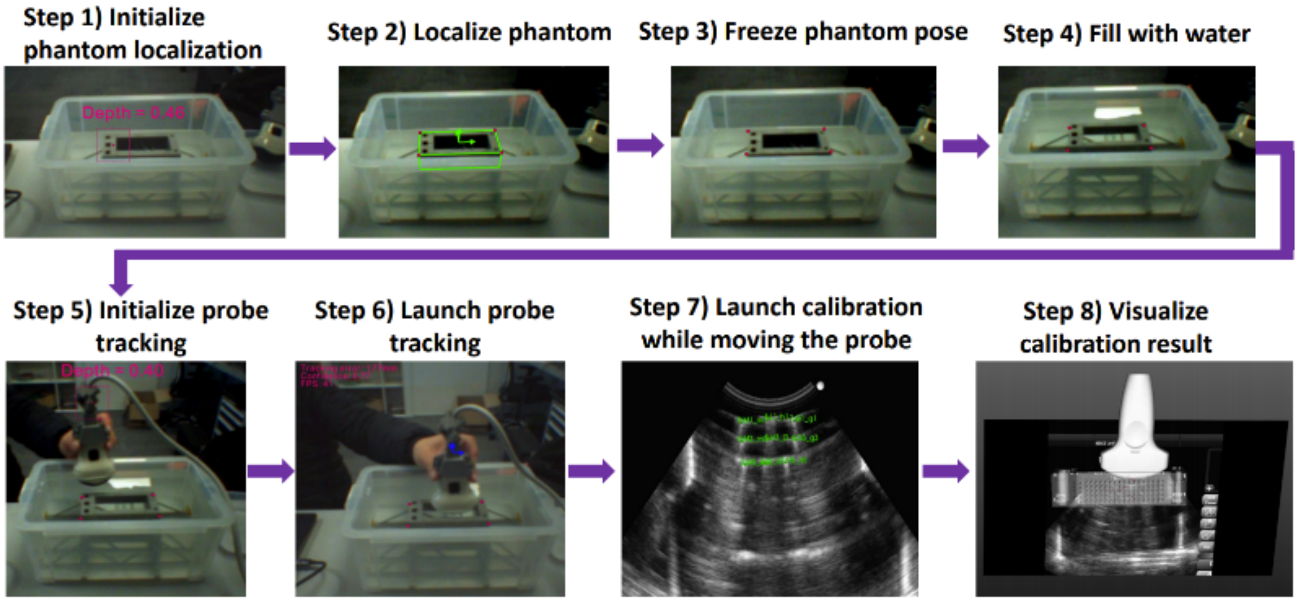
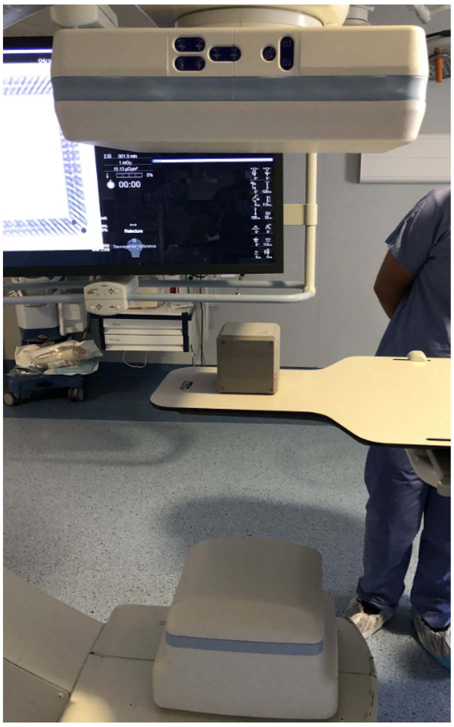


Figure 83. Ultrasound calibration procedure.

To estimate the parameters from the XRay, we printed another phantom with metal balls. Indeed, metal is highly visible in X-Ray images and enables to easily detect and segment objects. Acquisitions have been performed in July 2021 in the TheraImage room to adjust the size of the phantom and to adapt the calibration parameters. As for the ultrasound, the metal balls are segmented automatically in the X-Ray image and using the localization of the phantom and the position of the balls, we can extract the X-Ray calibration matrix.



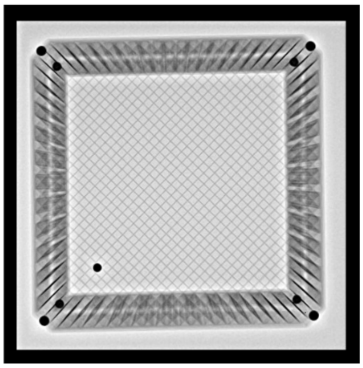


Figure 84. X-Ray phantom acquisition.

Next step is to combine the matrices coming from these 2 calibration procedures to be able to display the ultra-sound image in the same plane as the fluoroscopy image.

5.2.2 Terminal Equipment components

At first, the ultrasound-imaging device GE Vivid E95 [35], available at the Rennes CHU was considered to be used in the project, allowing real-time 2D/3D imaging of both cardiac structures and blood flow with a relatively high spatial resolution. However, a Telemed ArtUs EXT-1H [39], depicted on Figure 85, smaller and more portable device, was acquired and used for the experiment. This ultrasound device does not come with a dedicated monitor but is directly plugged to a laptop using a USB connector.

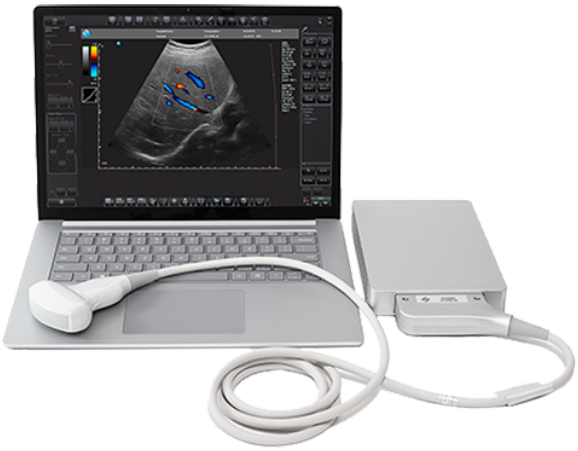


Figure 85. Telemed ArtUS EXT-1H.

The C-arm Angiography/Fluoroscopy machine present in TherA-Image room is manufactured by Siemens. The signal can be directly retrieved on the control monitor (behind the primary display) using a DVI female connector.

The tele-mentoring application relies on the AMA XpertEye solution, comprising smart glasses and a 5G smartphone as gateway, as shown in Figure 86. The XpertEye solution is implemented over WebRTC to reach the remote user.

Figure 86. AMA XpertEye solution with the doctor with the smart glasses and the smartphone.

Those Smart glasses were connected to the ASUS Smartphone, compatible with the n257 band NSA mode (same than for the UC7), allowing the transmission of the smart glasses through the 5G network. Cardiologist wore those smart glasses and carried the smartphone on his jacket.

An Occipital Structure Core depth camera was used to localize the US probe. Localization algorithms were deployed on a Microsoft Surface Pro tablet directly linked to the camera, to provide visual feedback during calibration phase and to send poses data to the DICOM-RTV-Tx.

A secondary monitor was placed inside the OR to display the view of the AR application.

As mentioned earlier, DICOM-RTV-Tx and DICOM-RTV-Rx were provided to operate DICOM-RTV transfers. Work and studies were conducted to reduce the form factor of those servers to process those streams; indeed, processes were initially done with a standard desktop computers and are currently done with a NUC (Next Unit of Computing), for which the form factor is quite small, with the same performances.

Figure 87. 2 CPE ASKEY used for 5G uplink and downlink paths to carry the streams of the ultrasound probe and the data of the Augmented Reality streams.

As depicted on Figure 87, two CPEs from ASKEY were required to connect the devices, one for the uplink path with the ultrasound probe and one for the secondary monitor which receives the Augmented Reality view through the 5G network.

5.2.3 AR processing platform

Processing platform has been designed with rackable servers for network and AR processing, with high computational resources and dedicated hardware to perform video compression/decompression if necessary (Figure 88). This platform was installed inside the technical room (Figure 89).

Figure 88. BCOM platform for processing (User plane and Augmented Reality).

Figure 89. TheraImage technical room.

High level design of the BCOM AR platform is depicted on Figure 90 and tools and process embedded in this platform are:

- On the networking side, the DOME User Plane Function PNF is deployed as described in section 2.2.2.2;
- For the AR processing, the platform must be able to perform video decompression using a dedicated board.
- Another application, called DICOM-RTV-Configurator, was also deployed on one server of the platform to configure the DICOM-RTV transfers;

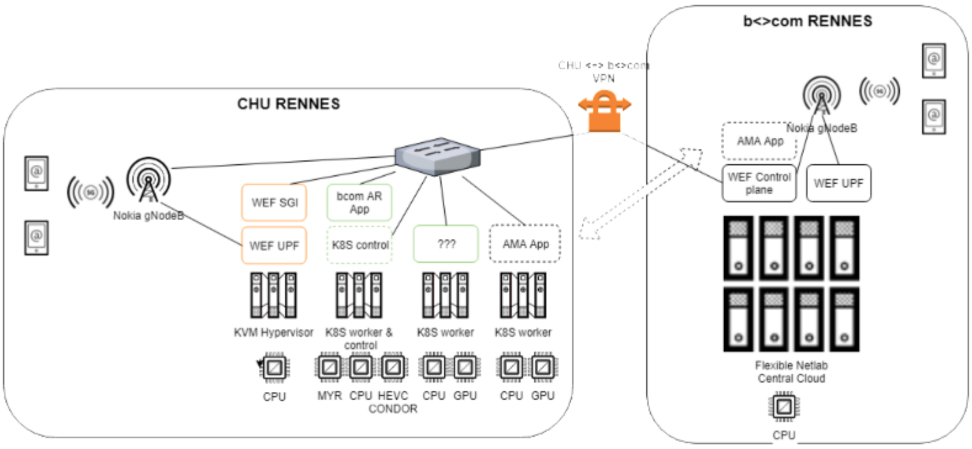


Figure 90. High level Design of the BCOM AR platform, VPN connected to BCOM data center.

5.2.4 Interfaces

The interfaces between the different devices are presented in Figure 77. Video signal is retrieved and displayed using DVI or SDI connectors and transferred over IP thanks to the DICOM-RTV standard. For the network part, the various applicative components used in UC8 are interconnected through the UPF (User Plane Function) provided by BCOM. The UPF is comprised of a programmable virtual switch running on a COTS 1U server and a COTS hardware switch. Both components are connected to the gNodeB using the 5G radio. The UPF component is directly connected to the gNodeB, the AR platform and the various DICOM-RTV components. This UPF is also remotely connected to the virtual Core Network of the DOME hosted in BCOM datacenter. The Core Network is in charge of programming the OpenVSwitch virtual switch of the UPF to manage the GTP tunnels to the gNodeB. This is accomplished by using the OpenFlow and OVSDB protocols.

The gNodeB is connected to the Core Network and both follow the 5G NSA connectivity standard. The DOME Core Network is hosted on a Kubernetes Cluster in BCOM datacenter and is orchestrated by an ONAP orchestrator deployed in the Orange datacenter in Châtillon. BCOM and this Orange datacenter are already connected by a VPN since they are both part of the 5G EVE project infrastructure.

5.3 Integration and final tests

In the setup of the final demo, we could perform complete integration and tests in situ, i.e., in the operating room of the hospital, in the Théra-image room. We could then show the technical feasibility of using 5G to transmit signals from multiple devices during an intervention. A cardiologist is using an augmented reality application relying on two imaging devices, while wearing smart glasses to share his view with a remote expert in Athens, through a dedicated and secured links (VPN set up between the two locations). All three real-time video signals are transmitted to the processing devices using a single private 5G infrastructure (Figure 77).

- The first signal is ultrasound imaging. A special 3D printed marker attached to the probe and tracked by an RGB-D camera allows to know its location in space at all times.
- The second signal is from an external camera filming the probe and the patient.

Figure 91. Probe with the 3D marker and the video of the camera to localize the probe in its environment

  - Both video flows are converted to DICOM-RTV standard then transmitted to the processing device thanks to the CPE ASKEY, @26GHz.
  - They are then registered and fused by the augmented reality application to produce the display received by a second CPE ASKEY @26GHz, connected to the DICOM RTV module and then to a monitor. The cardiologist can then analyse the 2 superposed images for his diagnostic.

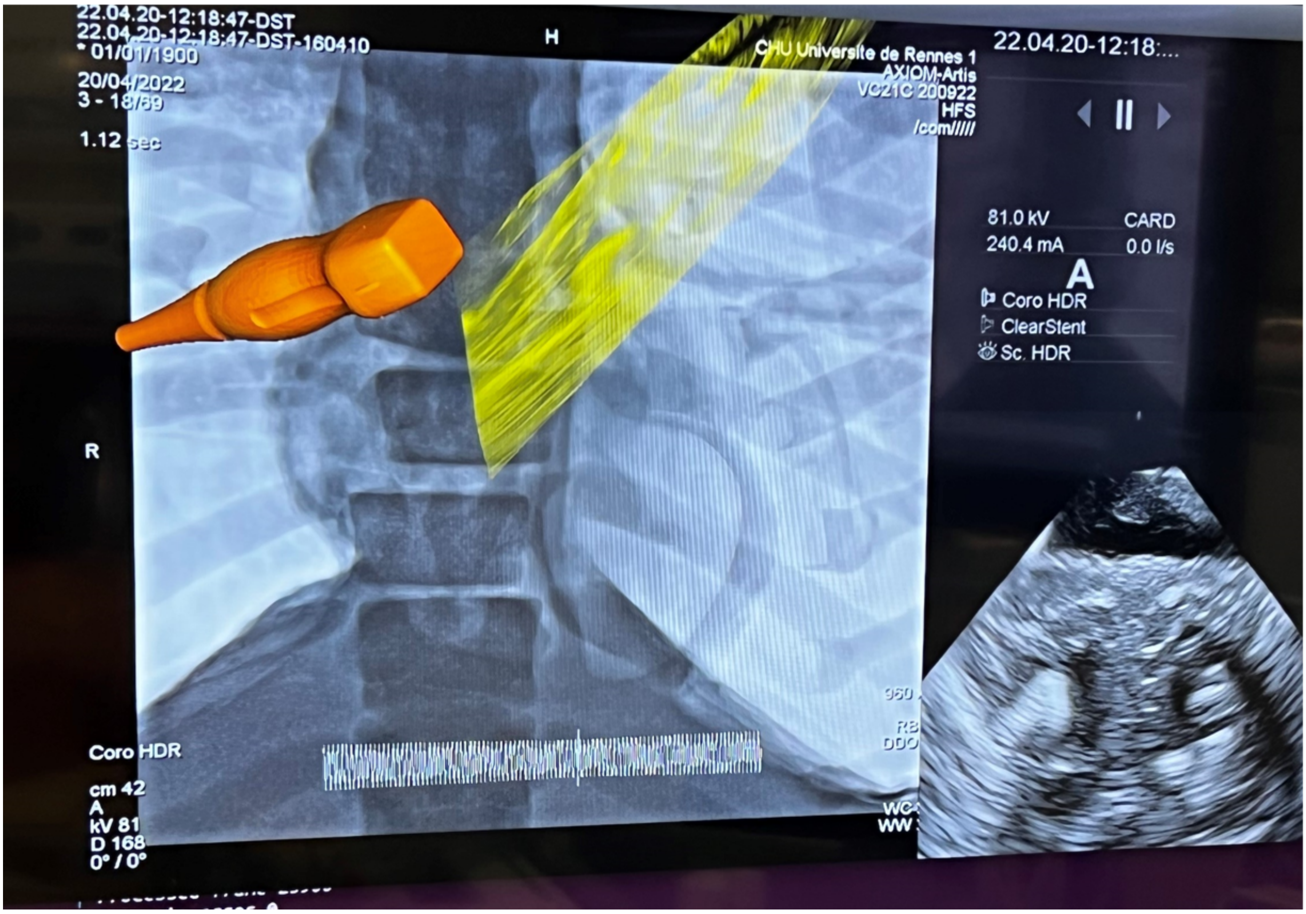


Figure 92. Augmented Reality images combining the X-RAY and the ultrasound images

- The third signal is from the AMA smart glasses, which are connected to the 5G smartphone ASUS, compatible with the 5G NSA mode in the 26GHz band. It is transmitted to a local Edge server, then sent to both a remote display located in CHU operating room (for control only) and mainly to the Greek doctor, allowing interaction between both doctors during the medical intervention.

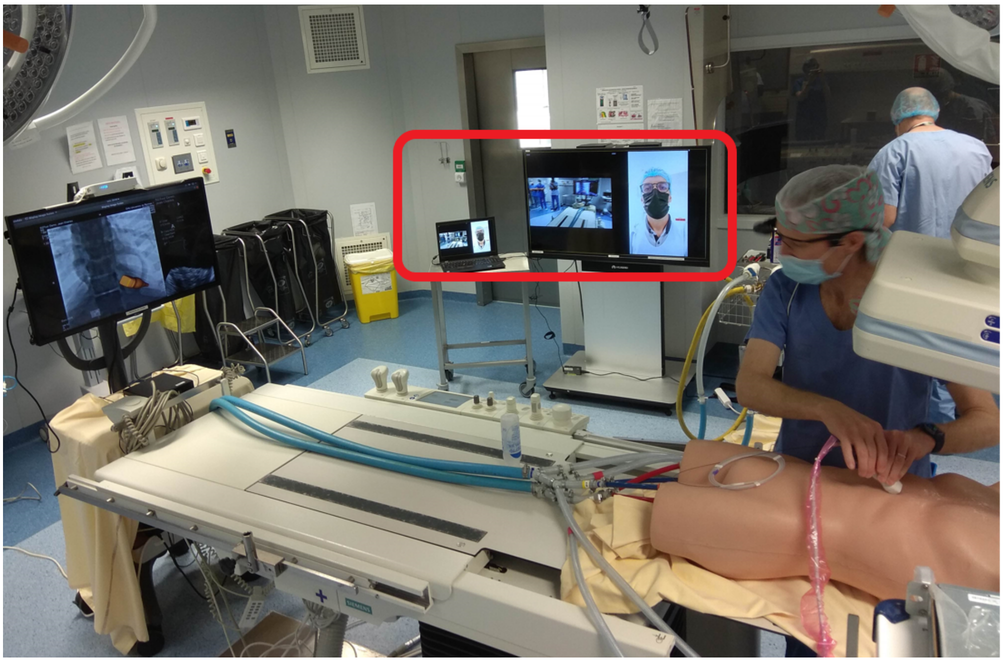


Figure 93. Monitor inside the OR to control the smart glasses stream.

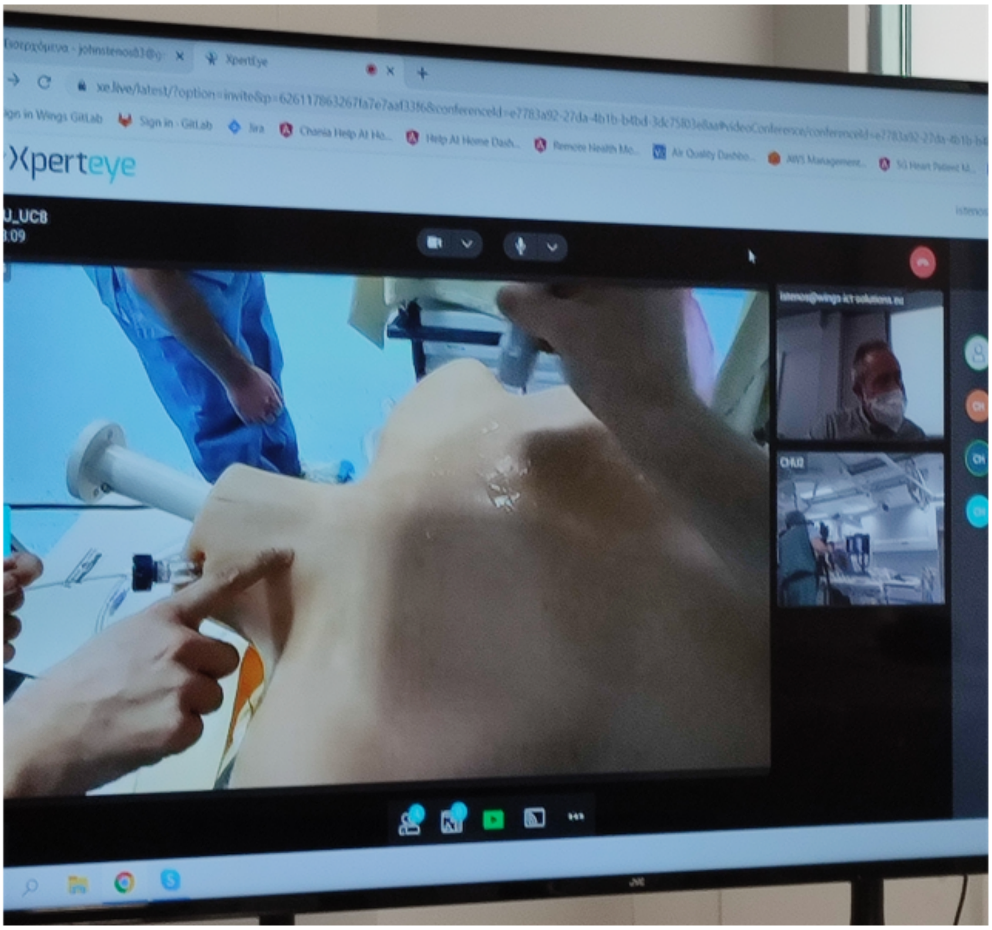


Figure 94. Remote screen in Athens showing what the Greek doctor was watching. Video recorded with the French doctor's glasses.

5.3.1 Network architecture

The network architecture of the test setup, explained in the previous section and to show use case UC8, is shown in Figure 95.

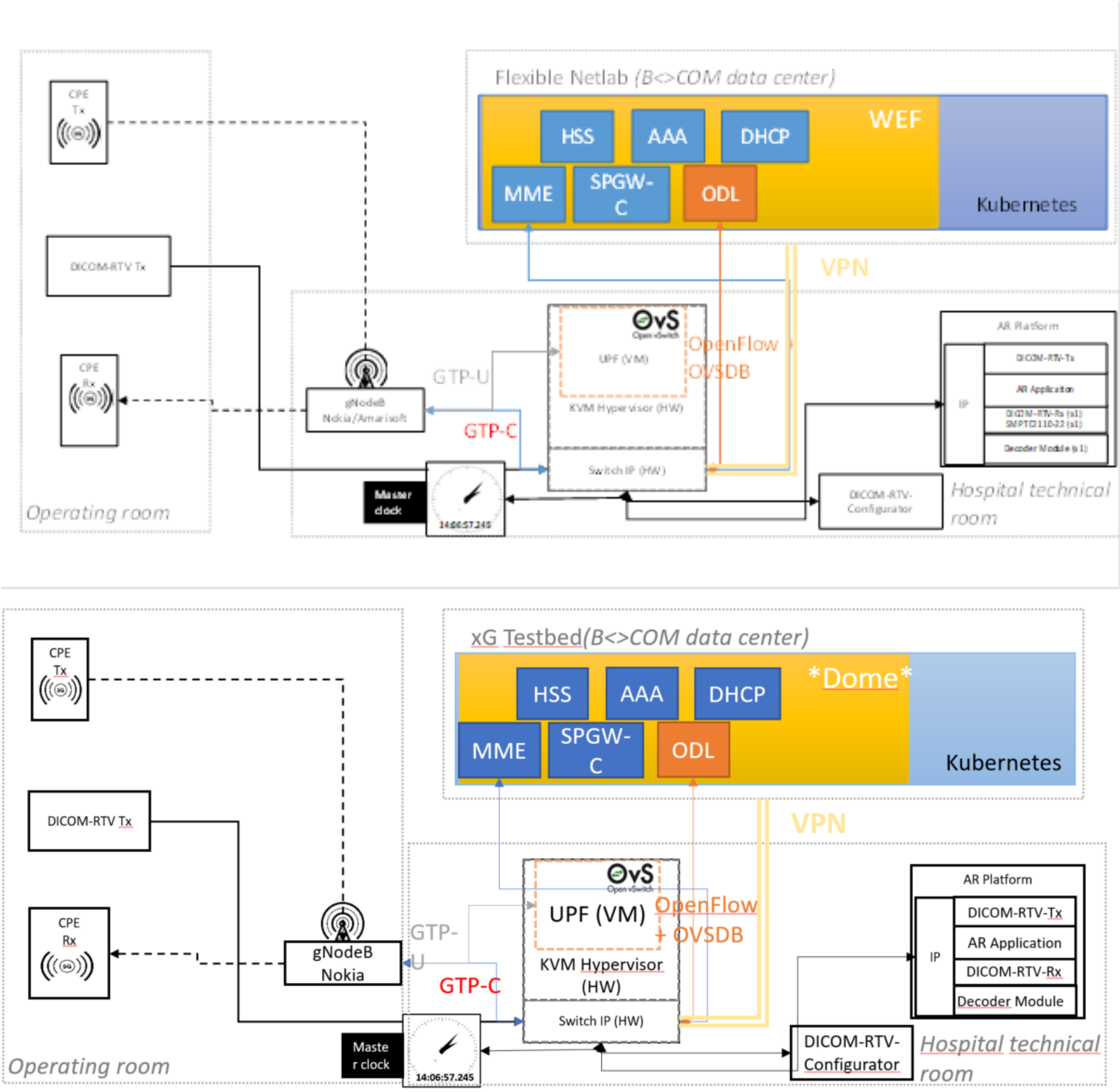


Figure 95. UC8 Network architecture.

5.3.2 Network testing results

During the demo in the ThérA-images room in April 2022, measurements of the 5G network performances have been carried out. These tests used the architecture depicted in Figure 95. We first tested the network components alone to determine the throughput supported by our experimental 5G networks and then performed functional tests involving the AR application of BCOM and the smart glasses provided by AMA.

With respect to the KPI and metrics defined in the project in WP2 and WP7, Figure 96 is a reminder of the table which pointed out the metrics and their target for this use case, fully detailed in D7.2 deliverable.

5G-Tours - Use Cases: direct specific Technical requirements		Units	UC8 – Wireless Operating Room			Priority	Range	
			URLLC	mMTC	eMMB		Min	Max
General Vertical/Use Case Requirement								
1	Latency (in milliseconds) - round trip - Min/Max	msec	20				10	30
2	RAN Latency (in milliseconds) - one way	msec	5				2	7
3	Throughput (in Mbps) - Min/MAX - sustained demand	Mbps	800				600	7000
4	Reliability (%) - Min/Max	%	99,99999%					
5	Availability (%) - Min/Max	%	99,99999%					
6	Mobility (in m/sec or Km/h) - Min/Max	Km/h	0					
7	Broadband Connectivity (peak demand)	Y/N or Gbps	0,8					
8	Network Slicing (Y/N) - if Y service deployment time (min)	Y/N	Y (5)					
9	Security (Y/N) - if Y grade i.e. "Carrier Grade"	Y/N	N					
10	Capacity (Mbps/m^2 or Km^2)	Mbps/m^2	N/A					
11	Device Density	Dev/Km^2	N/A					
12	Location Accuracy	m	N/A					

Figure 96. UC 8 Wireless Operating Room network requirements.

Measurements carried out in the operating room give that in terms of bitrate, we achieved a constant uplink speed (throughput) up to 100Mbps with the CPE placed 5m away from the antenna using two UDP packets streams launched simultaneously (one in UL, one in DL) and up to 550Mbps in downlink. The tests were conducted with the iperf3 tool. It is important to remember that these were done with the current RAN releases in the dates of the demo.

We also measured the jitter at an average of 0.22ms and the latency at an average of 25ms. We found the network latency varied consistently between 10ms and 30ms.

For the E2E latency, results showed a latency of 300ms including all devices and the complete setup.

The various networking tests that we conducted during this phase highlighted the importance of properly calibrating the RAN using a GPS connection to achieve a stable level of performance.

We could then compare those tests carried out in the operation room with the tests done at BCOM showroom during the integration phase and reported in the deliverable D5.2 [49]. Results are showing similar values and performances and, in this scenario and in case of a need to duplicate it, we could assume that tests carried out in BCOM lab can give a clear indication of the results we can expect in this operating room in the case of further tests need to be carried out.

Complete explanations of those results will be reported in the deliverable D7.4.

5.3.3 EMF mitigation of mobile networks

Before the installation of the mm-wave RAN product named AWEUA, an intensive simulation campaign has been conducted in order to validate that the RF exposure is:

- below the applicable limits for workers, even when touching the antenna
- below the applicable limit for the general public (61 V/m) at 2.4 m height above ground and below
- below 6 V/m at 1.5 m above ground level (representative of the spatially averaged value) for a mechanical tilt of 0.

This section is exposing the methodology and the RF exposure compliance boundaries regarding both general population and occupational exposure.

5.3.3.1 RF exposure limits

The applicable RF exposure limits are defined by [28] and [29] to in Europe and ICNIRP countries, by [30] in Australia and New Zealand, by [31] in Canada and by [32] in the US and related countries such as Bolivia, Estonia, Mexico and Panama. The applicable power density limits are recalled in Table 3 for the frequency range applicable to the equipment under test.

Table 3. Applicable RF exposure levels in n257 band expressed in power density.

Region of application	General Population/Uncontrolled Exposures	Occupational/Controlled Exposures
EU/ICNIRP, Australia/NZ, Canada, US/related	10 W/m²	50 W/m²

Figure 97 and Figure 98 depicts the limit of the average power density per main locations. We observe that the Canadian regulation is more constrained than USA and EU.

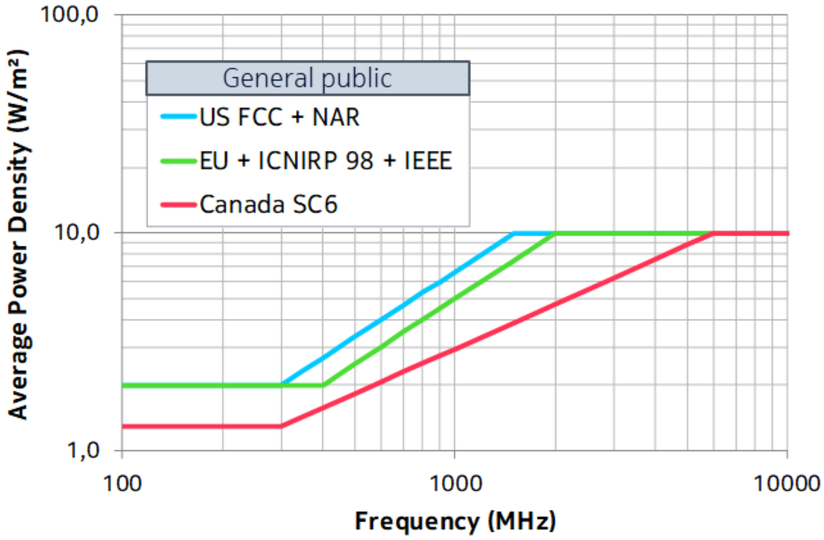


Figure 97. General public 26 GHz: 10 W/m² (61 V/m).

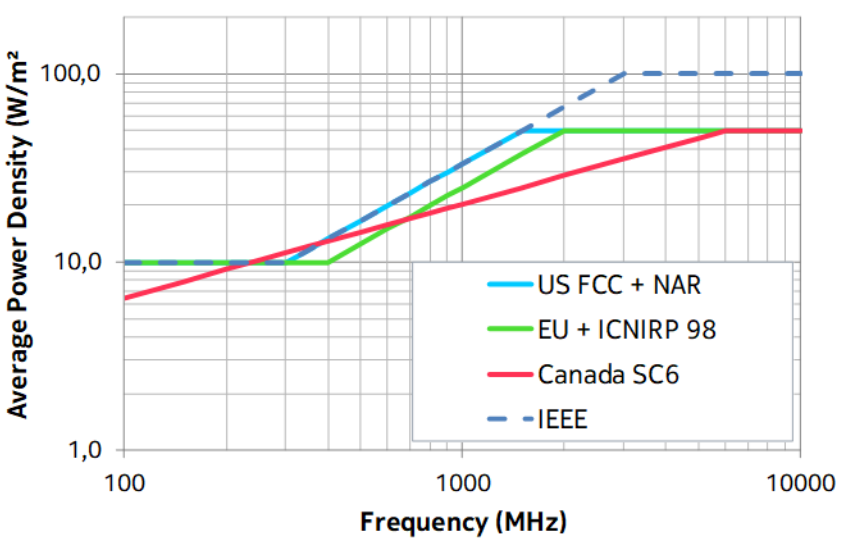


Figure 98. Workers 26 GHz: 50 W/m² (137 V/m).

5.3.3.2 Description of the equipment under test

The main technical characteristics of AWEUA product are reproduced in Table 4.

Table 4. AWEUA product general technical characteristics

Parameter	Value
Radio unit	AWEUA
Max gain	24 dBi
Duty cycle factor	80%
Configured Tx power (pMax)	12 dBm per carrier 4 carriers
Total Tx power	21 dBm (126 mW)
EIRP	45 dBm / 800 MHz

In order to provide a conservative assessment on the frequency range, we performed the calculation at 26 GHz using the maximum gain over all similar steering directions. The compliance boundary is defined by the box shape perimeter shown in of IEC 62232:2017 and displayed in Figure 99. The distances Df, Ds, Da,u and Da,d are taken from the nearest point of the antenna. For convenience, the distances Dsc, Duc and Ddc (respectively) taken from antenna center are also provided.

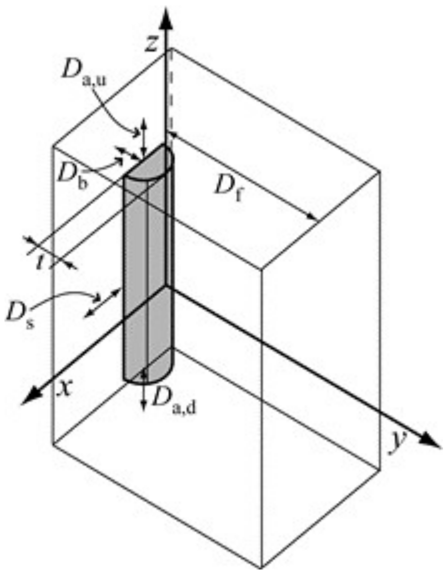


Figure 99. Shape of the compliance boundary used for the RF exposure compliance assessment.

The surgery room has been modelled following Figure 100. The objective was to determine the best place to place the antenna.

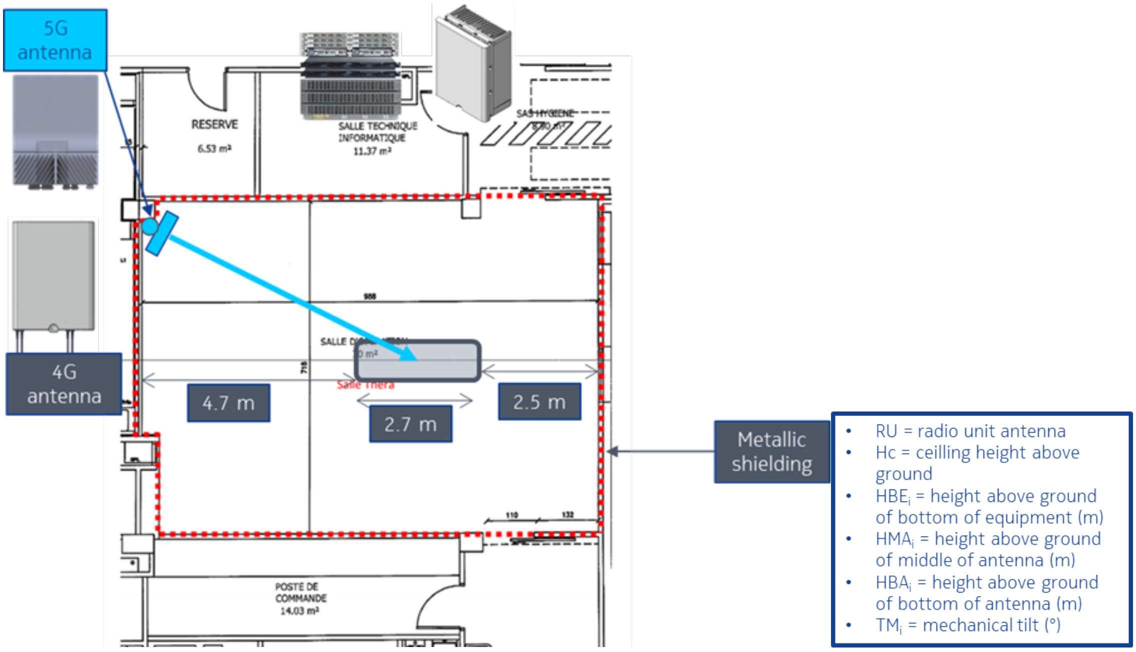


Figure 100. Placement of the antenna in the operating room.

5.3.3.3 RF exposure computation results

The computed power density 2D distributions are displayed in Figure 67 for RF exposure limits defined in [27], [28] for EU/ICNIRP countries, [29] Australia/NZ, [30] Canada and [31] for US/related countries.

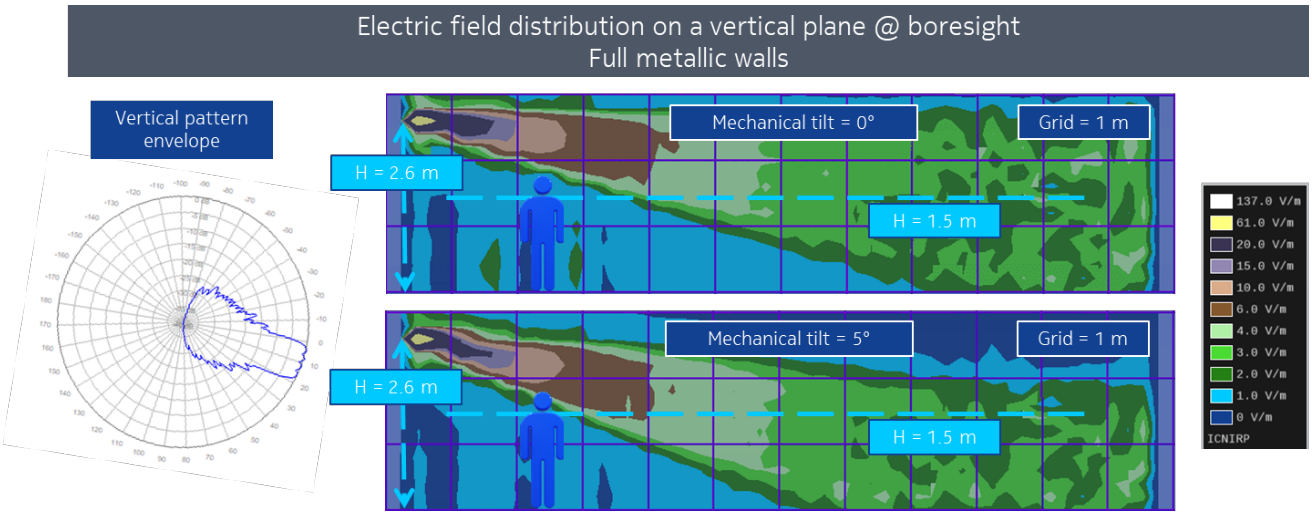


Figure 101. Electric field distribution on a vertical plane @ boresight, Full metallic walls.

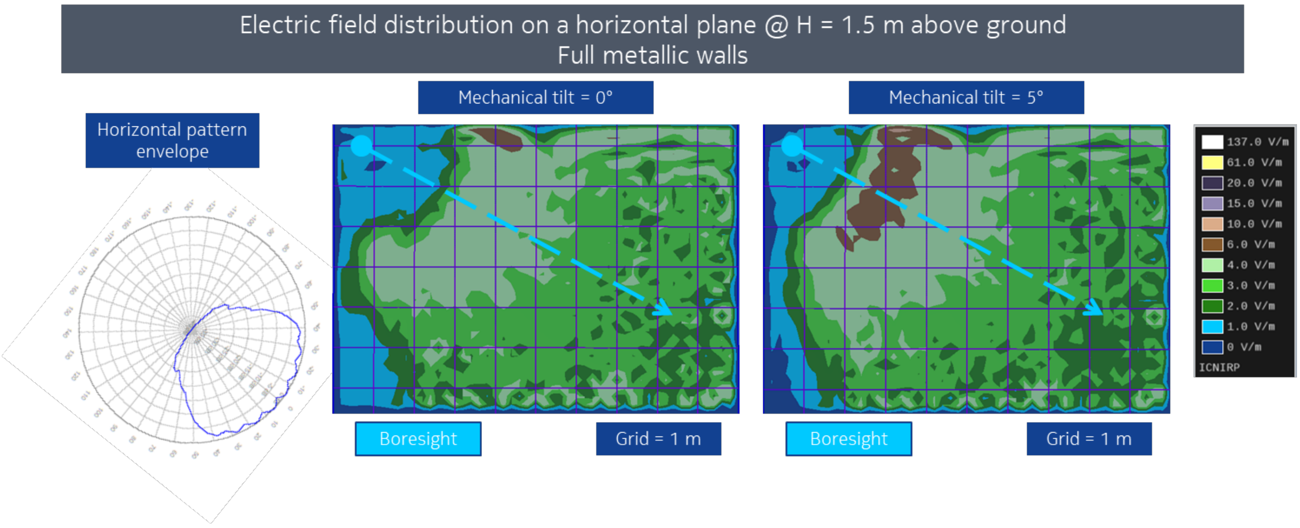


Figure 102. Electric field distribution on a horizontal plane.

5.3.3.4 RF exposure measurement campaign

This section presents the results of the measurement campaign performed as part of the public electromagnetic fields in the band 100 kHz - 40GHz.

The measurement campaign has been conducted by an independent cabinet EMITECH and also, the ANFR (Agence Nationale des Fréquences).

The measurement has been carried out in a very strict framework, from a quality point of view, to be valid. The accreditation issued by the French Accreditation Committee (COFRAC) to EMITECH and compliance with the measurement protocol established by the ANFR are proof of the independence and competence of laboratories performed the measurements. In particular, the ANFR protocol rigorously describes the steps of measurement, the instruments to be used and the processing of the data collected in such a way as to obtain objective results and reliable. All measuring sheets are communicated to the ANFR and made public on a dedicated website: www.cartoradio.fr.

The tests were carried out according to the measurement protocol ANFR/DR 15-4 for which EMITECH is accredited by COFRAC (www.cofrac.fr).

In this section, we present the results collected by EMITECH. The report made by ANFR will be available later on their website. This report was not ready at the date of writing this document.

- Chronological evolution of the measurement campaign

Upon arrival at the site, EMITECH searched for visible transmitters according to place of the experimentation and the need of the project to run the measurement in the surgery room. Using two broadband probes (100 kHz at 6 GHz and 1 MHz at 40 GHz), the electric field is measured, at 1.5m from the ground and at different places in the surgery room. The analysis according to the ANFR protocol is usually at the point where there is the highest electric field.

In accordance with the ANFR protocol, the analysis of this point is carried out, according to the project request in one step which measures the electrical field at 1.1m, 1.5m and 1.7m from the ground.

- Site location

Figure 103 depicts the location of the surgery room/CHU of Rennes and the neadby transmitters in the area.

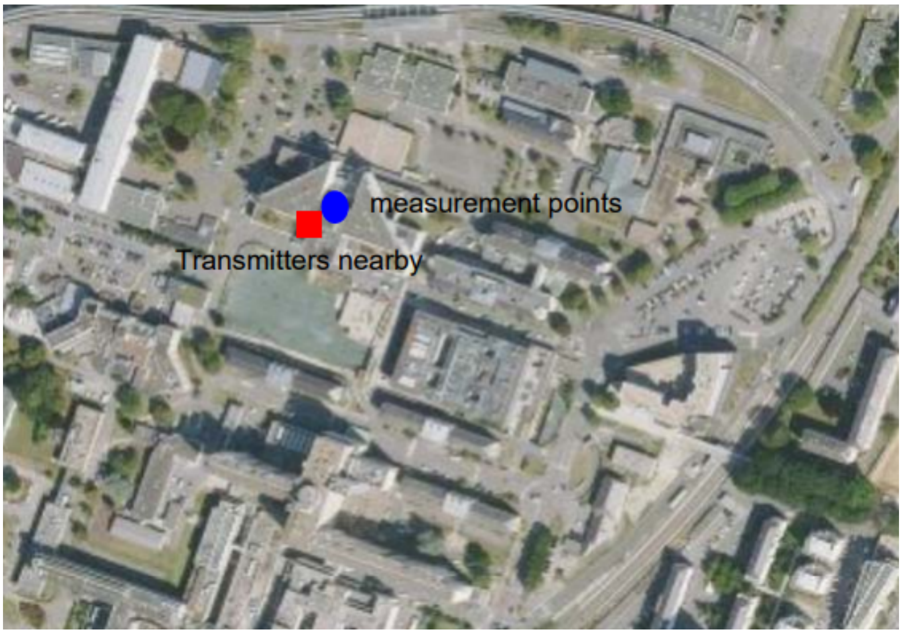


Figure 103. Coordinates of measurements location

	Coordinates of measurements location			
	Degrees (°)	Minutes (‘)	Seconds and 10th (’’)	North / South and East / West
latitude	48	7	14.67	North
longitude	-1	41	41.48	West

- Configuration of the measurement

Figure 104 depicts a synoptic scheme of the surgery room. The 5G antenna is placed according to the simulation results. The distance is named b. The Askey devices has been placed near the head of the phantom. The distance to the ground is named a. The distance between the 5G device and the antenna is named c.

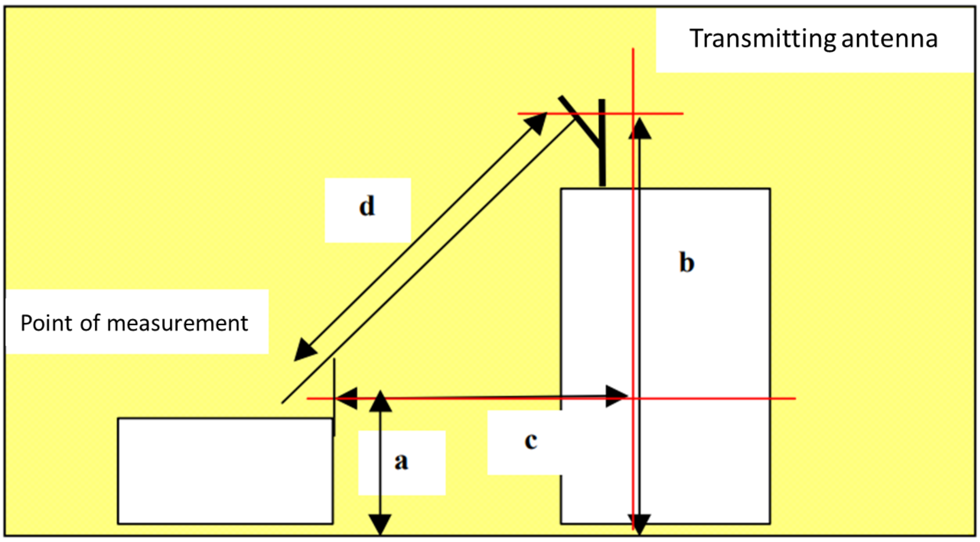


Figure 104. Measurement’s configuration.

In our case of the surgery room, the following values are selected.

Distance (m)			
a	b	c	d
1.5	2.5	4	4.71

Figure 105 depicts the 5G antenna place in the surgery room:

Figure 105. 5G antenna placement in the surgery room.

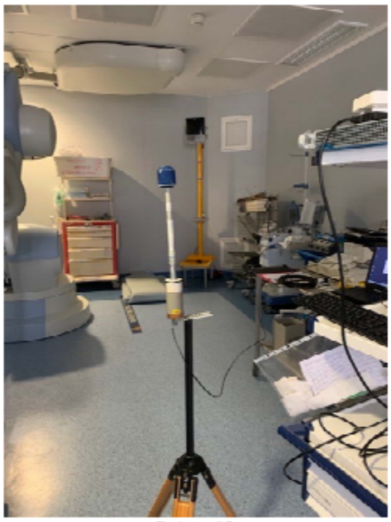
- Photographs of the different areas of the surgery room:

Figure 106 shows the different points selected for the measurement. A first probe has been used: 100kHz-6GHz wide band probe measurement. The RMS (Root Mean Square) detection has been selected to compile the results.

Figure 106. Different points of measurements in the surgery room.

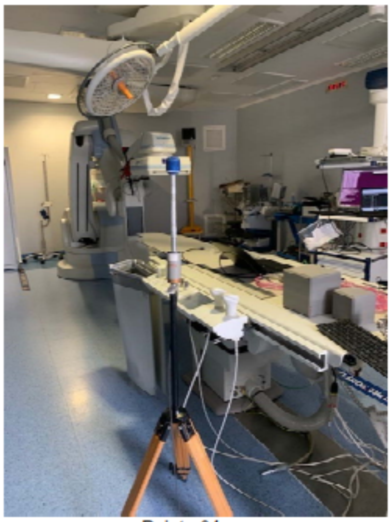
Figure 107 shows the second probe used: 1MHz-40GHz in the same points.

Point n°1



Point n°2

Point n°3



Point n°4

Point n°5

Point n°6

Figure 107. Different points of measurements in the surgery room, second probe.

- Measurements results

Table 5summarizes the level of exposure measured in the surgery room.

Table 5. Level of exposure measured in the surgery room by external auditors.

Height (m)	Measured level (V/m)	Spatial mean (V/m)	Exposition threshold (V/m)	% compared to the limit
1.7	3.2	3.5	28	12.5%
1.5	3.8			
1.1	3.4			

It shows that the total electric field is 8 times lower than the most restrictive reference level. The levels measured are well below the limits of the Workers' Directive 2013/35/EU (61V/m for the frequency range 100kHz-300GHz) which is conforming to the simulation and measurements made in anechoic room and described in beginning of this section.

5.3.3.5 Conclusions

After the analysis and the simulation results, the RF exposure assessment for AWEUA is:

- Below the applicable limits for workers, even when touching the antenna
- Below the applicable limit for the general public (61 V/m) at 2.4 m height above ground and below
- Below 6 V/m at 1.5 m above ground level (representative of the spatially averaged value) for a mechanical tilt of 0

6 UC9 - Optimal ambulance routing

6.1 UC9 overview

This use case essentially acts as the step following the health monitoring described in section 3 (UC6). In this context, this use case shows how city sources can be exploited towards real-time vehicle navigation taking into consideration the live status of the city, especially a touristic one with lots of cultural events being organized potentially in public locations and streets.

This use case addresses real time navigation of the ambulance, both to the site of the emergency, to ensure that medical help will be provided as quickly as possible, as well as from the site of emergency to the hospital, as soon as possible once the patient has been stabilized on site (i.e., on emergency location). While optimal ambulance positioning and routing has been addressed extensively from a decision-making perspective and a more theoretical aspect, the emergence of technologies such as 5G actually enables the fast and reliable acquisition of data on changing factors of an urban or suburban environment such as traffic flow, changing road graph, population mobility, and hospital capabilities, and availability to be exploited by AI powered decision making for dynamic optimal ambulance routing.

WINGS' platform, STARLIT capabilities are exploited to calculate the optimal route both from the ambulance dispatch location to the emergency location as well as from the emergency location to the nearest (or in another way most appropriate) hospital, while taking into account relevant patient data. Information taken into consideration, in this respect refers to traffic conditions, regulations and other mobility related factors. Moreover, for the optimization procedure, it will be taken into account if the patient's condition demands rich data exchange, in which case, a steady 5G coverage during the journey is most needed (e.g., in case that the patient needs an on-the-fly treatment through a high-definition video streaming). Open data APIs that provide access to traffic-mobility related data (traffic congestion, traffic incidents, etc.), such as the ones offered by the city of Rennes, could be leveraged for comprehensive decision-making. Real-time route updates will be performed as new information arrives. As mentioned also in section 3.4 while UC6 as UC9 were initially scheduled to be trialled in Rennes, due to only commercial network availability in Rennes for these two use cases, their trialling was done in the Athens site so the city of Rennes wasn't used.

In the meantime, the nearest hospital that has been selected out of a list of hospitals by the medical professionals in the ambulance will have been notified so that the arrival of the patient is expected.

The scenario for the trial corresponding to this use case roughly evolves as follows (as part of the overall safe city use case):

- An ambulance needs to be dispatched to an emergency site;
- Optimal ambulance routing for the specific ambulance is initiated, taking into account the site location, the available routes, traffic conditions, speed limits, city events (e.g., road closures), 5G coverage measurements. Relevant data is continuously retrieved to select and update the optimal route on the go;
- Once it is decided that the patient(s) should be transferred to hospital based on the assessment of the medical experts involved, optimal routing is initiated to dynamically calculate the route to the most suitable hospital and emergency department.

For the sake of showcasing, the operation of the optimal ambulance routing is tested under various conditions (traffic incidents, areas that do not support 5G). Aspects of the trial are emulated such as the ambulance on route, the traffic conditions, the 5G coverage, etc.

6.2 UC9 implementation

6.2.1 Application Components

Figure 108 and Figure 109 depict a high-level view of the architecture for optimal ambulance routing from an application perspective.

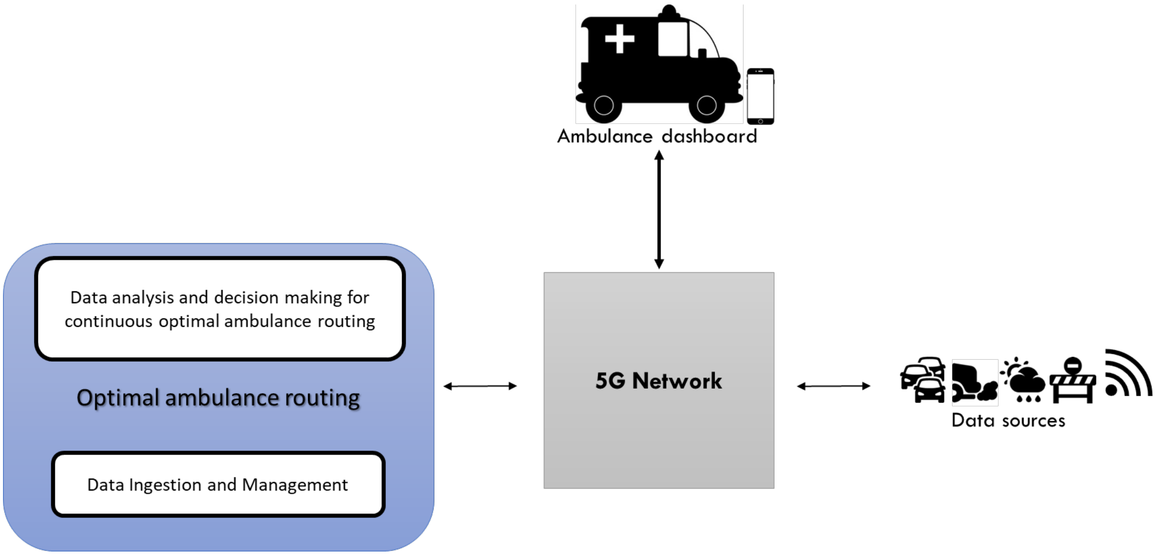


Figure 108. Optimal ambulance routing use case.

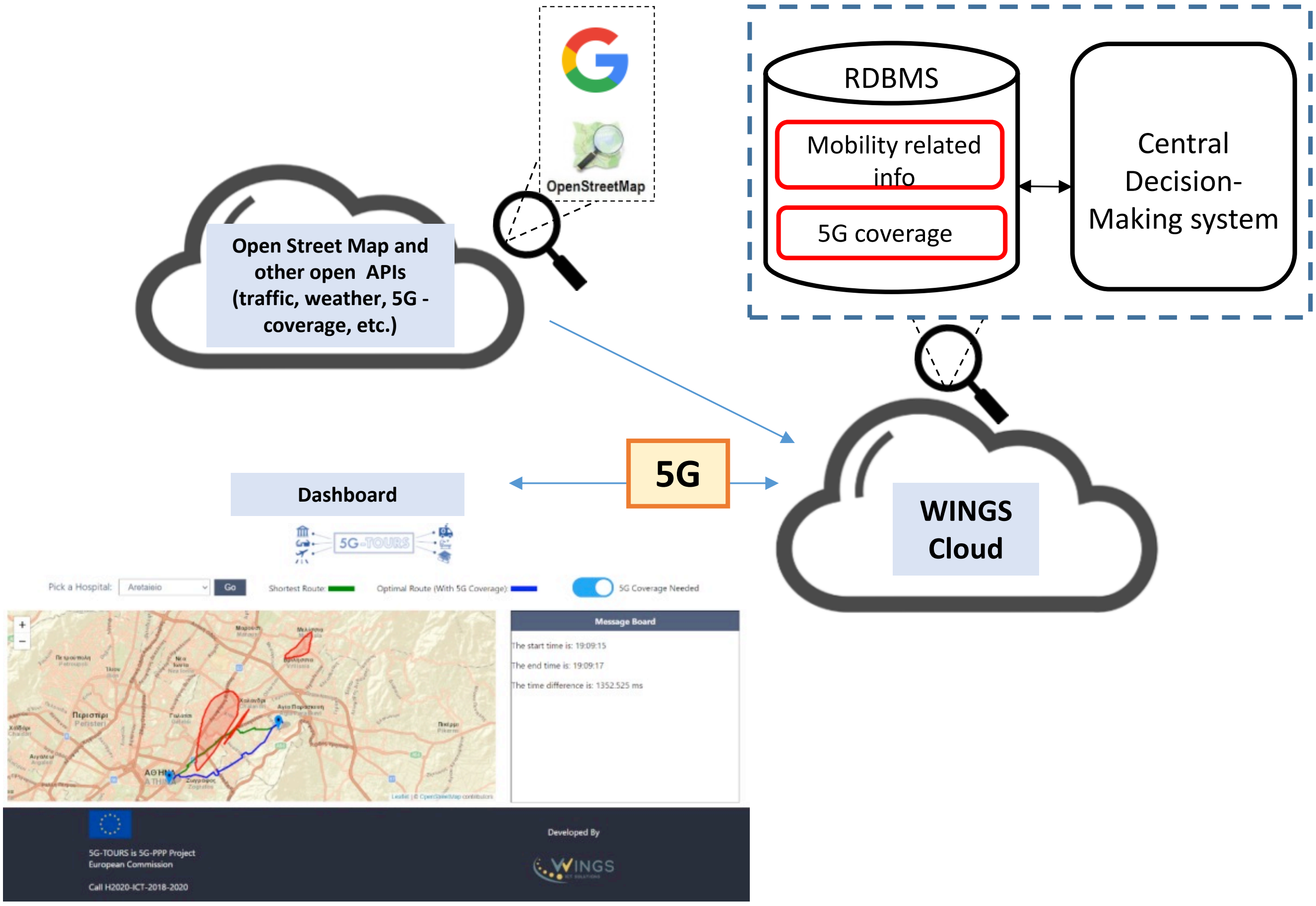


Figure 109. Optimal ambulance routing use case trial architecture.

The key components include:

- Various data sources which may be open APIs or other devices potentially connected via a Gateway with different connectivity options.
- The STARLIT platform for the collection, management and analysis of the data and the derivation of the corresponding actions.
- An ambulance dashboard for the visualisation of the continuously updated optimal ambulance routings, notifications and alerts and the dashboard for the Ambulance Dispatch Centre showcasing the progress

of the ambulance towards the emergency site as well as towards the emergency call centre and the hospital.

The relevant intelligence in the STARLIT platform for optimal ambulance routing takes into account the factors mentioned previously, so as to provide a recommendation on the optimal route to reach the patient, as well as the hospital. First, a set of candidate routes to the desired destination are identified. Then, among these routes the optimal one is selected, taking into account the aforementioned information with the appropriate weighting. The aim is to select the optimal route in terms of the minimum time required to reach the destination, while also minimising the exposure to potentially hazardous situations (e.g., avoiding an area where an accident has occurred, or if necessary, avoiding areas for which 5G coverage is not ensured), and taking into account the patient's health condition. Multi-criteria decision-making methods are used for this purpose, including the severity of the patient's condition in terms of the need for on-board treatment, and the need for high quality video streaming throughout the route. In order to implement such a system, Openrouteservice [17] was leveraged. All the information considered, is translated into spatial points or areas to be avoided or preferred. For instance, a traffic incident or accident is given as a spatial point with the appropriate coordinates, then through a buffer this point information is extended to an area-street that should be avoided. On the other hand, in the case of an area that does not offer 5G- coverage, the corresponding area is translated into a closed-form polygon. This cumulative spatial information which encloses the areas to be avoided is in turn given to Openrouteservice and the optimization result is the fastest route towards the destination.

6.2.2 Terminal Equipment components

To provide the ambulance with the real-time guidance described through the 5G network available, a 5G compatible device is needed. For this purpose, Samsung S10 5G (section 3.2.2.) and alternative mobile phones/tablets were used to demonstrate the service.

6.2.3 Interfaces

For the current implementation and from the application point of view, the key programming interfaces are depicted in Figure 110.

- **Kafka broker:** Kafka uses a producer that collects the packet sent from the respective server and stores it in a Kafka topic. Then a Kafka consumer retrieves that data from the topic and store them in the database;
- **Backend server:** A python **REST** framework as the central backend system responsible for orchestrating the database, the analytics component and for delivering the information to the frontend;
- **End-user device application/Dashboard:** The end-user device/devices responsible for delivering the appropriate information (current location and status, preferred destination, etc.) to the cloud server in **'json'** format for further processing and visualizing the relevant information (routing, estimated arrival time, etc.) received from the cloud server;
- **Analytics:** A python-based module that encodes the information from the various data sources (external APIs, sensors, etc.) and outputs the optimal route in '**json**' format;
- **External APIs:** External Application Programming Interfaces (**Openrouteservice**, **Google Maps**) utilized to retrieve data to be processed by the backend from external resources (e.g., traffic condition and incidents, 5G - coverage, etc.).

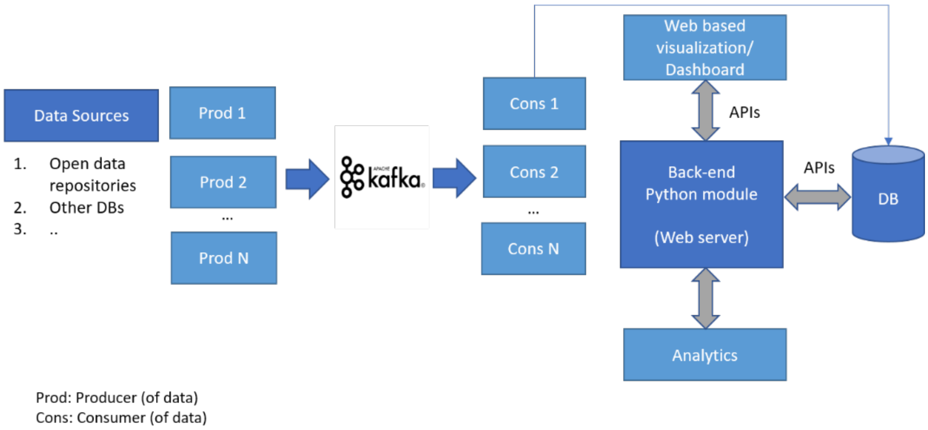


Figure 110. Functional architecture of the provided system.

6.3 Integration and test in labs

For simulating the service provided, the scenario described below was considered. An end user (ambulance) is supposed to need a routing to the closest medical centre, which is able to provide treatment based on the needs of the patient. The end device makes a request to the cloud service, which calculates the fastest route available and sends it to the end device, along with the distance and the estimated time of arrival as shown in Figure 111.

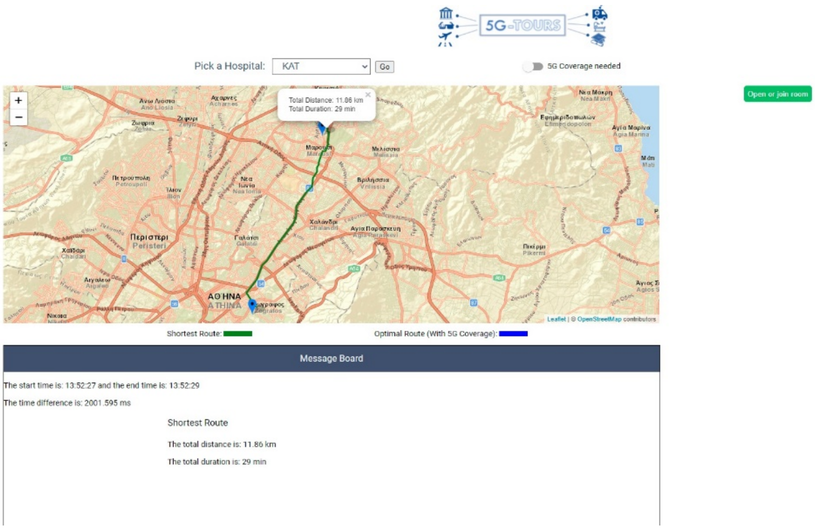


Figure 111. Regular routing of the ambulance asking for directions towards the optimal medical centre.

In another scenario, some artificial data has been created to represent the 5G coverage of the area under consideration. Assuming a scenario in which the patient needs an on-the-fly treatment through video streaming, it will be crucial to maintain 5G connectivity throughout the journey. As can be seen in Figure 112 the fastest route (green) as well as the route with the 5G-coverage (blue) are both provided to the ambulance's medical staff. Here the red polygons represent the areas with no 5G-coverage.

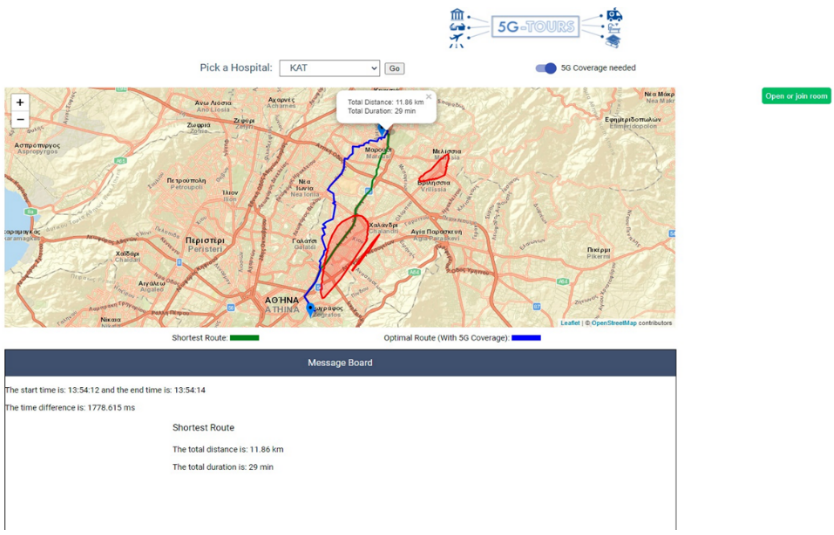


Figure 112. Ambulance dashboard view: Route with 5G coverage.

Finally, in the case that a video call is required, the user (ambulance personnel) presses the green button to start a call with a hospital (Figure 112). The user allows the application to access the camera and microphone of the device. A WebRTC server allows real-time, peer-to-peer, media exchange between two devices. As soon as the user on the other side presses the green button, a new connection starts in the media server. 5G allows high throughput & low latency in case of HD video streaming, offering superior user experience. Each user can see on their dashboard both the ambulance and the hospital stream (Figure 113). The red button can be used to end the call.

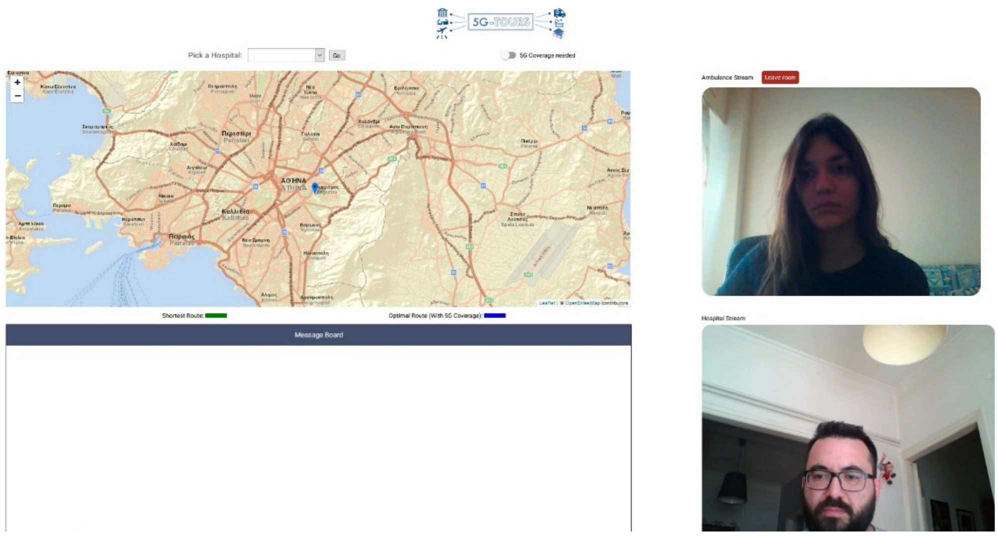


Figure 113. Optimal ambulance dashboard – Video call.

6.4 Test in the network

As mentioned also in section 3.4 while UC6 as UC9 were initially scheduled to be trialled in Rennes, due to only commercial network availability in Rennes for these two use cases, their trialling was done in the Athens site. The back-end functionality for UC9 has been deployed at OTE premises in Psalidi and continuous testing was performed to collect metrics as part of the testing and validation activities within 5G-TOURS. During the initial phase of the trials, we selected as initial KPI the RTT latency in the application layer (between the Ambulance Dashboard UE and the Optimal Ambulance Routing back-end server).

UC9 Optimal ambulance routing network requirements

5G-Tours - Use Cases: direct specific Technical requirements		Units	UC9 – Optimal Ambulance Routing			Priority	Range	
			URLLC	mMTC	eMMB		Min	Max
General Vertical/Use Case Requirement								
1	Latency (in milliseconds) - round trip - Min/Max	msec		10		High	10	50
2	RAN Latency (in milliseconds) - one way	msec		1		High	5	10
3	Throughput (in Mbps) - Min/MAX - sustained demand	Mbps		50		High	10	50
4	Reliability (%) - Min/Max	%		99,9999%		High		
5	Availability (%) - Min/Max	%		99,99%		High		
6	Mobility (in m/sec or Km/h) - Min/Max	Km/h		>=100Km/h		High		
7	Broadband Connectivity (peak demand)	Y/N or Gbps		Y (1)		High		
8	Network Slicing (Y/N) - if Y service deployment time (mi	Y/N		Y (1)				
9	Security (Y/N) - if Y grade i.e. "Carrier Grade"	Y/N		Y		Medium		
10	Capacity (Mbps/m^2 or Km^2)	Mbps/m^2		n/a				
11	Device Density	Dev/Km^2		n/a				
12	Location Accuracy	m		0,1		High		

Non relevant KPIs

Relevant KPIs (will be collected and demonstrated)

Relevant but not critical KPIs

Difficult to be demonstrated KPIs

Figure 114. UC9 Optimal ambulance routing network requirements.

The corresponding results are depicted in Figure 115, with an average ping value of 37.5 ms and an average RTT value of 95 ms.

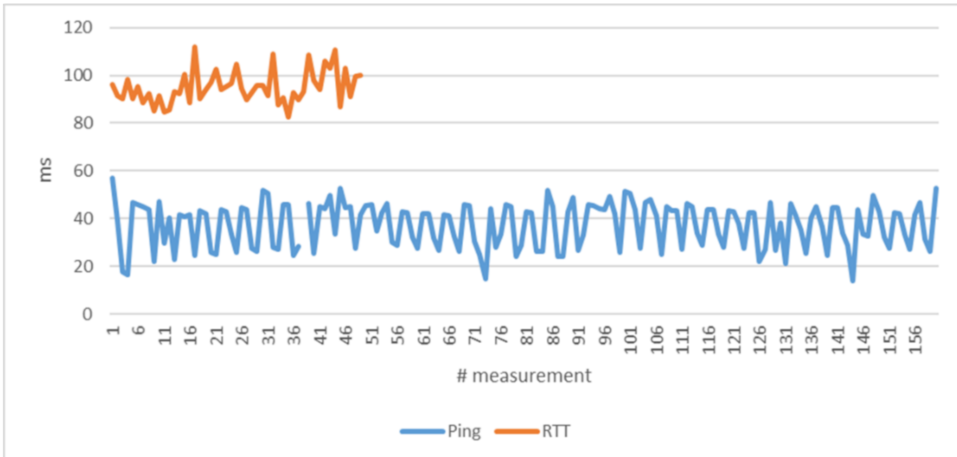


Figure 115. RTT latency (application layer) between ambulance UE and UC9 backend server.

The final results from the testing and validation activities are reported in the final Deliverable of WP7.

7 Network and applications innovation aspects

The Rennes node of the 5G-TOURS architecture provides a specific healthcare-related usage enhanced for responsiveness, privacy and performance. The initial 5G-EVE infrastructure was extended to include mmWave communications in indoor setup using private 5G, orchestrated by ONAP and integrated with commercial-grade applications for use cases 7 and 8. Use cases 6 and 9 were integrated to the Athens node and demonstrated additional support for new devices, an enhanced UI and dashboard with new functionalities such as geofencing. Table 6 summarizes the innovations in the use cases.

Table 6. WP5 UCs mapping (use of blueprints in phase 2).

UC	Phase 1				Phase 2				
WP5	**Reference Network**	**Service Accessibility**	**Objectives**	**Availability target dates**	**Reference Network**	**Service Accessibility**	**Objectives**	**PoC/Additional development**	**Availability target dates**
UC6	Outdoor extended 5G EVE NOKIA-GR / OTE infrastructure (WP6)	Direct request*	Obj1	MS3[3] (31/03/2021)	Outdoor extended 5G EVE NOKIA-GR / OTE infrastructure (WP6)	Direct request*	Obj1	Additional supported devices, new dashboard, and functionalities	MS5[4] (31/3/2022)
UC7	Indoor at BCOM showroom	Direct request*	Obj1	MS3 (31/03/2021)	Outdoor at BCOM premises	5G EVE portal / Direct request	Obj1+ Obj2	Support outdoor mmWave 5G and integration	MS5 (31/3/2022)
UC8	Indoor at the BCOM showroom	Direct request*	Obj1	MS3 (31/03/2021)	Indoor at CHU of Rennes	5G EVE portal / Direct request	Obj1+ Obj2	Supporting Indoor mmWave and integration with applications, orchestartion through ONAP	MS5 (31/3/2022)
UC9	Outdoor extended 5G EVE NOKIA-GR / OTE infrastructure (WP6)	Direct request*	Obj1	MS3 (31/03/2021)	Outdoor extended 5G EVE NOKIA-GR / OTE infrastructure (WP6)	Direct request*	Obj1	Migration to Athens node, enhancement of the prioritization algorithm	MS5 (31/3/2022)

* Portal usage is not precluded

Obj1: Validate the need of 5G networks

Obj2: Demonstrate the benefits of 5G-TOURS innovations

For the implementation of the four Rennes node UCs, the existing infrastructure of 5G EVE French site was enhanced and extended with the BCOM's 5G NSA core network (Dome) deployed on a cloud infrastructure, NOKIA-FR's RAN, and integration to the network. This implementation followed two phases. During the first phase, the integration happened in a lab setup and in the second, the deployments and test campaigns happened on the field.

According to Table 7:

[3] MS3: Use case first implementation tested on initial network infrastructure

[4] MS5: Final implementation of all UCs, updates, optimization in infrastructure and use cases

- UC6 (mMTC and eMBB) requires high accuracy and low latency.
- UC7 (eMBB) requires a large throughput and high reliability.
- UC8 (URLLC and eMBB) requires high accuracy and reliability.
- UC9 (eMBB) requires high accuracy and low latency.

Table 7. Service types/slices for mobility efficient city UCs.

Areas	Use cases	URLLC	mMTC	eMBB
Safe city	Health monitoring and incident-driven communication prioritization		X	X
	Teleguidance for diagnostics and intervention support			X
	Wireless operating room	X		X
	Optimal ambulance routing			X

The Rennes node innovation comprises of two parts (**Table 8**):

- To deploy and use the 5G mmWave technology in conjunction to a smart orchestration layer
- To integrate a diverse set of technologies with 5G at the service of healthcare professionals and patients

Table 8. Safe city network innovations.

Network Innovations	WP6
Service Layer	Orchestration of BCOM's core network Dome with ONAP orchestration in the French node
AI-based enhanced Orchestration	Using AI driven resource prediction, a sufficiently accurate resource forecasting in 5G control plane, can give the operator the chance to reduce its cost and ensure that the virtualized resources are not over or under-loaded. This is implemented in the orchestration layer of UC7 and UC8.
Other	Correlation of the user QoE (WP7) with active service KPIs to identify relations between network performance, Quantitative service KPIs and QoE (UC6 and UC9).

8 Conclusion

This final report (D5.4) describes the work achieved in the "Safe City" work package (WP5) at the end of the project. It provides a detailed description of the design and implementation for the four use cases in WP5 (UC6, UC7, UC8, UC9) that were demonstrated in Rennes and Athens. For each UC, this document presents the architecture design, the network design and respective equipment deployed for the implementation of the pilots, the terminal equipment used as well as the application development achieved for each one of the trials for the evaluation of the solutions according to the expected KPIs. This document also covered the testing done for all UCs and the metrics gathered.

With respect to UC6, the look and feel of the dashboard has been updated and analytics enhanced with the integration of prediction of the Blood Pressure signal and analysis of Oxygen Saturation signal. An additional wearable device has been integrated (Withings ScanWatch, added in July 2021) bringing the current total of integrated devices up to 8. The main back-end functionality is deployed at OTE premises in Psalidi and the testing of the front-end running on mobile phones or laptops at the Athens AIA premises, along with the wearable devices followed. Tests for RTT have been completed, and additional KPIs (Service Reliability, Service Availability) were collected during the last period and show satisfying integration results for UC7 and UC8, and a promising deployment reporting related to UC6 and UC9. Finally, metrics from the UC6 back-end were sent to the 5G EVE Kafka (Greek node) aligned with the work of WP7.

For UC7, the XpertEye application evolved to display simultaneously both video streams from smart glasses camera and the Lumify ultrasound Android application. The remote expert (cardiologist, SAMU regulator) can see the patient and probe position (video) and can also look inside the patient (ultrasound) at the same time for better understanding of the patient medical situation. This has been successfully tested at BCOM premises, where these two Android mobiles were connected to a 5G CPE that wirelessly communicated the multiple audio / video streams over 5G mmWave with a 5G base station antenna at the roof top of the BCOM building. In addition, a separate application was developed that transmits digital ultrasound data, containing echographic images and image metadata over both video and data channels provided by XpertEye communication services. This application was also successfully integrated and tested at BCOM premises using the same 5G infrastructure. The last tests were focused at gathering qualitative through questionnaires and quantitative 5G network and applications performance metrics based on well-defined and repeatable test scenarios done in successive testing campaigns and field trials.

UC8 is aimed at transmitting important amount of video streams coming first by the fusion of X-RAY and ultrasound images, with DICOM RTV standard, and secondly by the video streams from AMA smart glasses over a 5G mmWave network. Tests of the 5G mmWave network were carried out first remotely between Nokia (where the RAN and the antennas were located) and BCOM (where the Core network is hosted in the datacenter) premises via secured VPN. With respect to the applications, Smart Glasses solution could be tested during the UC7 real experiment at BCOM premises in September 2021 and then the solution to process augmented Reality application, coming from the fusion of both US and X-RAY, has been tested in BCOM labs. The next step was to proceed with the complete integration of the setup of the demo, with RAN, Core, devices, applications, before the installation and deployment in the operating room, i.e., ThérAImage room in CHU Rennes. Inter site connection between Rennes and Athens was obtained by creating a secure VPN between the two cities, so that a Greek cardiologist was able to follow remotely the surgery done with the French cardiologist and to interact with him. As it was the first experiment in Europe in such conditions with 26GHz 5G frequency, external audits were performed for radiation and exposures measurements.

Concerning UC9, similar to UC6, back-end functionality has been deployed at OTE premises in Psalidi while the testing of the front-end running on mobile phones or laptops at the AIA premises will follow. First tests for RTT measurements have been completed. Additional KPIs (Service Reliability, Service Availability) were collected and will be displayed in the WP7 final deliverable. Finally, metrics from the UC9 back-end are sent to the 5G EVE Kafka (Greek node) aligned with the work of WP7. Metrics analysis confirmed the implementation choices and successful migration to Athens node based on the results.

Note that the content in this document is strictly aligned, on several levels, with almost all the WPs of the 5G-TOURS project in the definition of the use cases, selection of the suitable network technologies, and the evaluation of the impact on techno-economic plans. Due to COVID-19, UC 7 and UC8 experienced some delay, but this was recovered at the end of the project through the two-month extension.

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