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

Deliverable D5.2

First safe city use cases implementation 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
AI	Artificial Intelligence
A/V	Audio-visual
API	Application Programming Interface
APN	Access Point Name
AQI	Air Quality Index
AR	Augmented Reality
ATE	Augmented Tourism Experience
BMSC	Broadcast Multicast Service Centre
CHU	Centre Hospitalier Universitaire
CLI	Command Line Interface
CO	Carbon Monoxide
CP	Control Plane
CPE	Customer Premise Equipment
CO_2	Carbon Dioxide
COTS	Commercial Off-The-Shelves
CPF	Control Plane Function
CPU	Central Processor Unit
DC	Datacentre
DHCP	Dynamic Host Configuration Protocol
DVI	Digital Video Interface
E2E	End to End
eMBB	enhanced Mobile Broadband
eMBMS	evolved Multimedia Broadcast Multicast Service
eNB	Evolved Node B
ENM	Ericsson Network Manager
enTV	Enhancement for TV Service
ECG	Electro Cardiogram
EPC	Evolved Packet Core
EPG	Evolved Packet Gateway
EVE	European Validation platform for Extensive trials
FeMBMS	Further evolved Multimedia Broadcast Multicast Service
GAM	Modern Art Galley
GDP	Gross Domestic Product
GPS	Global Positioning System
GPU	Graphics Processing Unit
gNB	5G Node B
GTP	GPRS Tunneling Protocol
GUI	Graphical User Interface
HD	High Definition
HDR	High Dynamic Range
HPHT	High-Power High-Tower
HSS	Home Subscriber Server
HTTP	Hyper Text Transfer Protocol
HTTPS	HTTP over Secure socket layer
IaaS	Infrastructure as a Service
ICT	Information and Communication Technology
IFB	Interference Free Band
IIT	Istituto Italiano di Tecnologia
IoT	Internet of Things
JDBC	Java Database Connectivity
IP	Internet Protocol
JSON	Java Script Object Notation
KPI	Key Performance Indicator
KVM	Kernel-based Virtual Machine
LED	Light Emitting Diodes
LIDAR	Light Detection and Ranging
LTE	Long Term Evolution
M2M	Machine to Machine
MANO	Management and Orchestration
MAO	Museum of Oriental Arts
MAUA	Museum of Augmented Urban Arts
MBB	Mobile Broadband Communication
MBMS	Multimedia Broadcast Multicast Service
MBMS-GW	MBMS Gateway
MEC	Multi-Access Edge Computing
MME	Mobility Management Entity
MTC	Machine Type Communication
mMTC	massive Machine Type Communications
MM	Medical Manager
MNO	Mobile Network Operator
MR	Mixed Reality
NAT	Network Address Translation
NB-IoT	Narrow Band IoT
NO_2	Nitrogen Dioxide
NR	New Radio
NSA	Non Standalone
O_3	Ozone
OMA	Open Mobile Alliance
ONAP	Open Network Automation Platform
OR	Operating Room
OSM	Open Source MANO
OVS	OpenVSwitch
P2P	Peer-to-Peer
PNF	Physical Network Function
PM	Paramedic
PTP	Precision Time Protocol
QoE	Quality of Experience
QoS	Quality of Service
PoC	Point of Care
RAI	Radio Televisione Italiana
RAN	Radio Access Network
REST	REpresentational State Transfer
RGB	Red Green Blue

ROS	Robot Operating System
RRH	Remote Radio Head
RTT	Round Trip Time
RTP	Real Time Protocol
RTCP	Real Time Control Protocol
SaaS	Software as a Service
SA	Stand Alone
SAMU	Service d'Aide Médicale Urgente" (Urgent medical help service)
SDN	Software Defined Network
SDI	Serial Digital Interface
SGI	LTE interface to the Packet Data Network (PDN)
SLAM	Simultaneous Localisation and Mapping
SMF-SDNC	Session Management Function-SDN Controller
SO_2	Sulphur Dioxide
SPGW	Session Packet Gate Way
SPGW-C	Control plane SPGW
SSO	Single Sign On
STEAM	Science Technology Engineering Arts Mathematics
STUN	Simple Traversal of UDP (User Datagram Protocol) through NAT (Network Address Translation)

TURN	Traversal Using Relay NAT
TCP	Transmission Control Protocol
TV	Television
UC	Use Case
UDP	User Datagram Protocol
UE	User Equipment
UI	User Interface
UNESCO	United Nations Educational, Scientific and Cultural Organization
UP	User Plane
UPF	User Plane Function
URL	Uniform Resource Locator
uRLLC	Ultra Reliable Low Latency Communication
UWB	Ultra Wide Band
VM	Virtual Machine
VNF	Virtual Network Function
VPN	Virtual Private Network
VR	Virtual Reality
WAN	Wide Area Network
WebRTC	Web Real-Time Communication
WEF	Wireless Edge Factory
WP	Work Package
XR	Extended Reality

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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 progress to date of the ongoing work 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 aims to provide care as early as possible, before the arrival at the hospital, to prevent irreversibly deterioration and save the life of critical patients. Ultrasound diagnostics at the incident is needed to decide what to do and start the right treatment directly. Tele guidance by a remote expert is very helpful in this case, requiring reliable low latency communication of audio, hires 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 imaging equipment is easier to install, easier to connect and synchronize with other imaging equipment and, easier to keep sterile. This use case will face very low latency requirements and a significant amount of video data to be transferred in real-time, in addition to very high reliability requirements.

- UC9: Optimal ambulance routing. This use case addresses real time navigation of an ambulance, both to the site of the emergency situation, 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, 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.

Since the release of deliverable D5.1 [47] and internal report IR5.1 [50], all use cases have progressed in terms of the level of detail of their definition, the integration of application components, design of the application architecture, their implementation and testing.

Furthermore, considerable progress has been achieved in the definition of the network infrastructure as needed for the implementation of these use cases on the experimental 5G network of the Rennes node. At this point, network deployment in terms of antenna placement, available frequency bands, base stations and edge/core networks has been defined. 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.

Implementation and testing of the use cases on the Rennes 5G network is an ongoing activity. First test results have been achieved and are reported in this document. Compared to the original plan, there is some delay in execution of the use case implementation and network installation due to the inaccessibility of sites, because of the COVID-19 crisis. However, by having adopted different ways of working, we think that this delay will be recovered by the end of the project.

This deliverable D5.2 is in line with the ongoing activities of the other work packages, in particular:

- WP2 – Use cases design for the definition of the involved use cases, see in particular the deliverable D2.1 [22] and D2.2 [41];

- WP3 – Network architecture and deployment for the selection of the technologies to be deployed and the actual deployment of the trials, references are in the deliverable D3.1 [23] and D3.2 [42];

- WP7 – System Integration and evaluation for the evaluation of the overall achieved results [26];

- WP8 – Business validation and exploitation for their impact on techno-economic plans, the reference documentation is the deliverable D8.1 [25].

1 Introduction

5G technology has the potential to safeguard the wellbeing and health of individuals in a city, by providing access to healthcare services and care providers anywhere and at any time. Wherever and whenever needed, the health status of patients should be monitored and analysed, to detect health problems in time and take necessary action, 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 theatre, 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.

The above wellbeing and healthcare uses are covered in work package 5 (WP5). In particular these are:

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

Sections 3, 4, 5 and 6 of this document report on the status of each of these use cases, describing them in more detail compared to the original high-level definitions given in D5.1. In particular, section 3 reports on UC6, section 4 on UC7, section 5 on UC8 and, section 6 on UC9, where 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.
- Test in the network.

Since there is a common network infrastructure for mMTC use cases (UC6, UC9) and a common 5G-TOURS network infrastructure for uRLLC / eMBB use cases (UC7, UC8), a separate section is dedicated to network infrastructure, i.e., section 2.

Due to COVID-19, UC7 and UC8 have suffered some delay, but we think this can recovered by the end of the project. The updated work plan for integration and test for the coming period is described in section 7, along with the WP5 project execution risks and the planned mitigation actions. Conclusions are given in section 0.

Note that this document describes the progress to date of ongoing work in WP5.

2 Network Infrastructure

All use cases in the “Safe City” work package (WP5) will be trialed in Rennes, using the mobile network infrastructure of Orange and Nokia. This infrastructure currently supports a 4G LTE network for mobile broadband (MBB) communication, as well as a LTE-M network for machine type communication (MTC) of IoT devices. For the 5G-TOURS project, an experimental 5G network is being created to be used in URLLC use cases. This is described in more detail in the following subsections.

2.1 Mobile network for IoT use cases

The commercial LTE-M mobile network of Orange will be used for use cases 6 and 9, since these use cases rely on IoT sensors and devices. This is a temporary solution, because of the lack of a 5G mMTC experimentation network in Rennes. Once this becomes available, i.e. a 3GPP Release-14 or higher compliant 5G mMTC network [1], use case 6 and 9 will start using this network. There are no guarantees to date that such a network will be available within the time frame of the 5G-TOURS project.

2.2 Experimental 5G network for eMBB and uRLLC use cases

2.2.1 Network Deployment

There will be two deployments of 5G NR wireless coverage:

1. Outdoors: at the BCOM premises, for the connected ambulance, as shown in Figure 1. A suitable 5G NR antenna will be installed on the roof of the BCOM building, using primarily the 26 GHz frequency band.
2. Indoors: at the Wireless Operating Room at CHU Rennes to provide high-speed, low-latency wireless access for medical imaging equipment, using 26 GHz for data transmission and 2.6 GHz as the anchor frequency band, see Figure 2. The anchor frequency band refers to the 4G frequency used to carry the control messages in a 5G Non-Stand Alone (NSA) network. We have currently no plan to deploy a 5G Stand Alone network in the scope of 5G-TOURS.

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

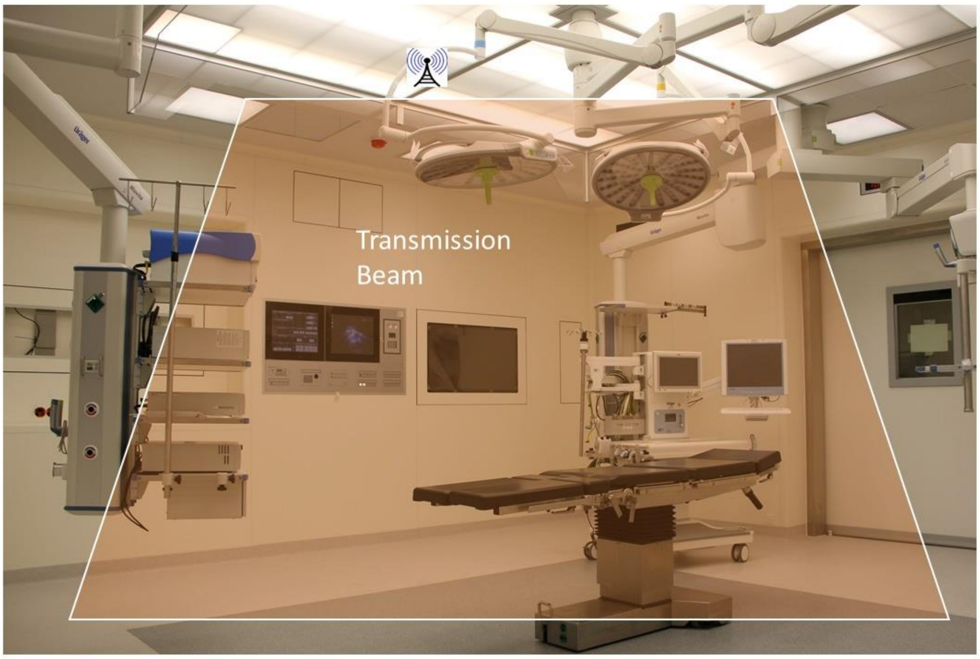


Figure 2. 5G TOURS 5G NR wireless coverage in the Wireless Operating Room at CHU.

At the BCOM premises, there will be a 5G base station with a local virtual UPF, part of the so-called "Wireless Edge Factory" (WEF) [27]. Similarly, there will be a WEF UPF at the hospital that connects to the WEF core network hosted in the BCOM datacentre through a dedicated VPN backbone. This is depicted in Figure 3. This will enable 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 WEF Core Network deployed in BCOM datacenter will manage the WEF 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 WEF 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 WEF Core Network on demand. It could also be used to deploy the user plane part of the WEF.

The Orange datacenter has already been connected to the BCOM datacenter in the scope of the 5G EVE project. This is also shown in Figure 3.

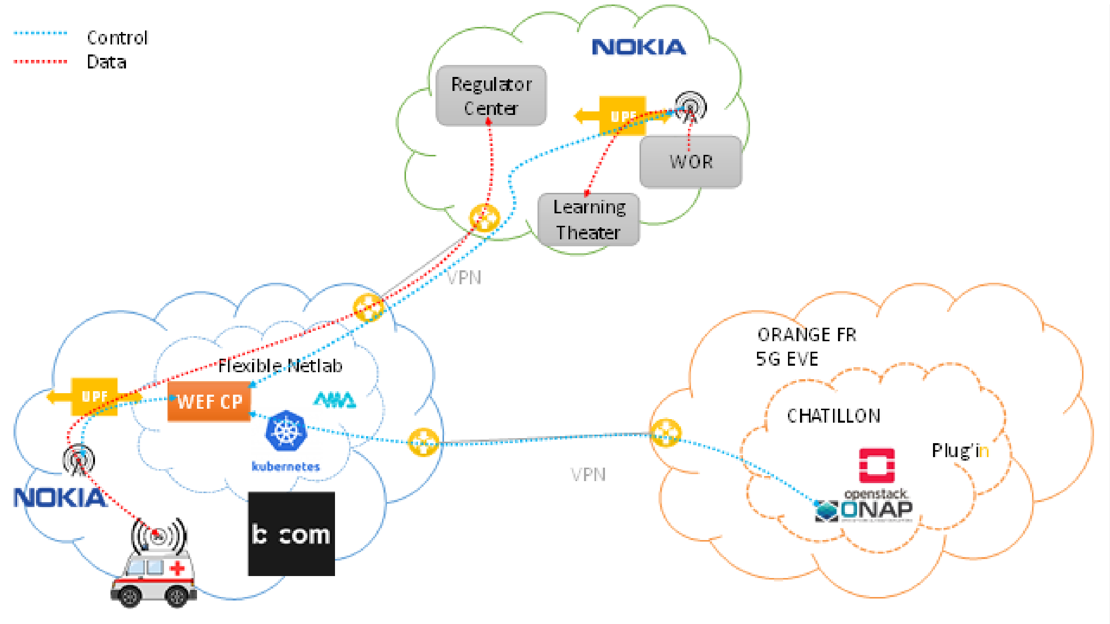


Figure 3. Overall network architecture and physical deployment of network equipment and functions.

2.2.2 Network Equipment

The network equipment is described below in three steps: control plane (CP), user plane (UP), and radio access network (RAN) equipment.

2.2.2.1 Control plane network equipment

The control plane is a virtual 4G Core Network compatible with the 5G NSA standard [28]. The Control Plane is part of the WEF solution developed by BCOM. It is deployed as a set of Docker containers managed by a Kubernetes cluster. This cluster is hosted on the Flexible Netlab platform [29] in the BCOM datacenter. 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 WEF 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 datacenter as a virtual machine hosted on an OpenStack [35] cluster provided by Flexible Netlab. This virtual machine hosts an OpenVSwitch [36] (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 (UC7). It is thus used to connect this RAN equipment to the Rennes CHU through the VPN described in section 2.2.1. The WEF Control Plane manages the virtual switch under control of the OpenDaylight [37] 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 mini-ITX PC. The PC is a KVM [38] hypervisor that hosts an OVS-based virtual machine similar to the one deployed in Flexible Netlab. It will be installed in the technical room of the Rennes CHU and will interconnect the RAN equipment deployed there with the various components required by use case 8 (UC8). The same WEF Control Plane will manage this switch through the VPN established between BCOM and the CHU.

2.2.2.3 RAN equipment

For 5G-TOURS, we will use Nokia Small Cell technology as our RAN equipment. Two small cells will be deployed: one at the Rennes CHU to provide coverage for the Wireless Operating Room and one at BCOM premises to cover the outside area for UC7. Both will use the 26GHz/2.6GHz bands in 5G NSA mode. The Nokia RAN at BCOM will be deployed and operated by BCOM while the one at the CHU will be deployed and operated by Nokia. In addition, we conducted the first integration tests for UC8 in the BCOM showroom. These tests are carried out with Amarisoft Classic Callbox RAN equipment [34]. This equipment uses the 3.5GHz band and is also compatible with 5G Non Stand Alone (NSA) mode. At this point, we do not plan to move to a 5G Stand Alone (SA) network in the future.

All medical equipment that requires 5G wireless connectivity has been connected to this RAN equipment through a Huawei 5G Pro CPE component [44].

2.2.2.4 Relationship with the 5G EVE project

The integration of 5G-TOURS with 5G EVE is achieved as depicted in Figure 4. 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.

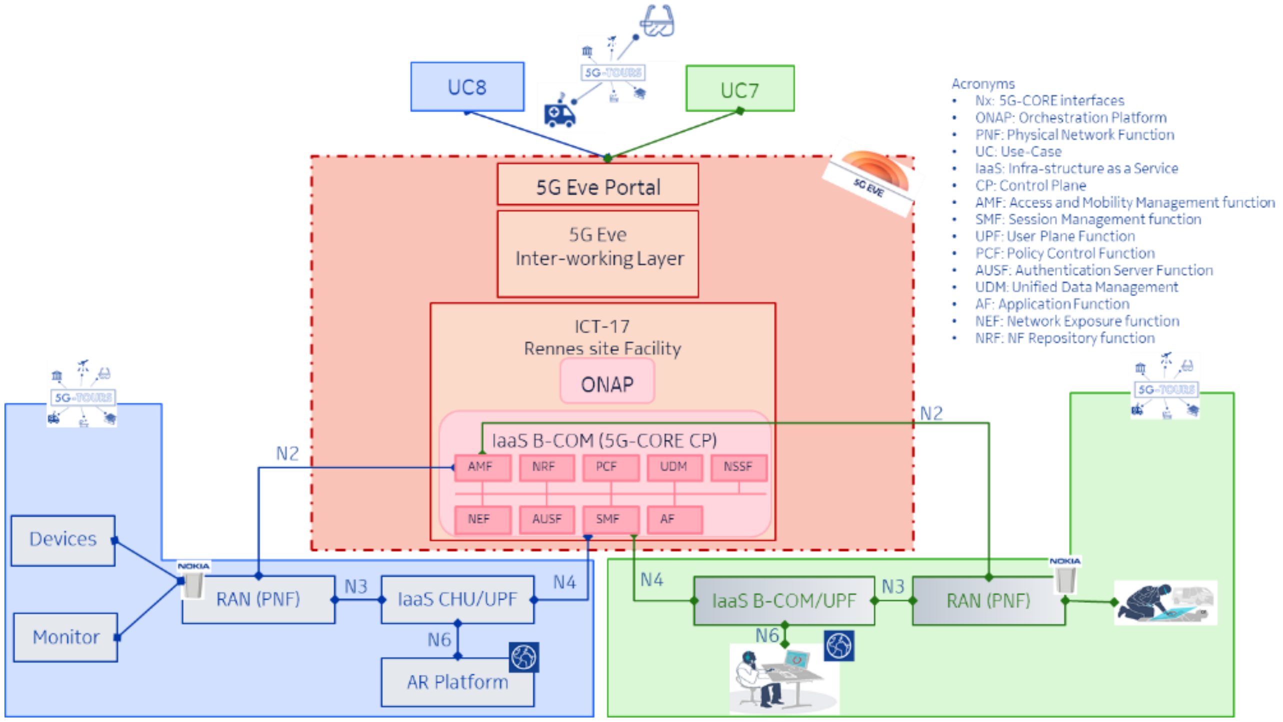


Figure 4. 5G-TOURS integration with 5G EVE.

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 [48], which includes the general description and the functionalities of the first version of the portal, and in 5G EVE D4.3 [49], which includes the functionality extensions made to the first version. 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 will be 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 is 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 is 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 4, the 5G CORE control plane will be part of 5G EVE. The 5G CORE user plane named UPF will be instantiated in the EDGE node deployed in CHU Rennes and in the B-COM datacenter. Table 1 lists the prerequisites for the UPF execution environment named IaaS B-COM/UPF (Figure 4).

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

Operating System	Ubuntu 16.04
CPU	1, 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 [45] and OpenStack as IaaS manager, see Figure 5. 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.

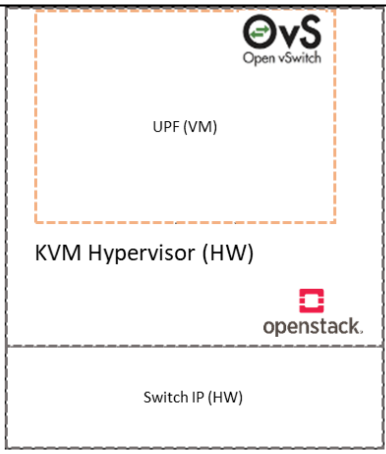


Figure 5. UPF deployment over OpenStack execution environment.

The RAN will be deployed using a mm-wave NOKIA 5G gNodeB (26Ghz).

In terms of monitoring, the 5G EVE platform will be responsible of providing the collection and visualization functionalities for the monitoring of data of the entire vertical service, provided that 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 becomes clear that several frequency bands are available to lead the experimentation either in **indoor** or **outdoor** environments. For outdoor radio transmission, sufficiently large coverage can be achieved thanks to Nokia Small Cell deployment. The tests are planned to generate "real traffic" specific to the vertical especially for eMBB (for instance virtual video content for the Virtual Reality visit) and uRLLC scenarios. The 4G/5G devices are used as modem to interface with the specific vertical's equipment. For traffic emulation, TCP, UDP, RTCP and HTTP could be used for testing and debugging.

As an example, traffic emulation has been used for testing the VPN interconnection between French sites facilities and Orange gardens. Some initial performance has been evaluated, as shown in the MS5 video. The VPN interconnection performance evaluation between the Orange Châtillon and BCOM premises that are about 300 kilometres apart in direct line. The first 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. The last latency value could be improved a little bit. Figure 6 illustrates the achieved values.

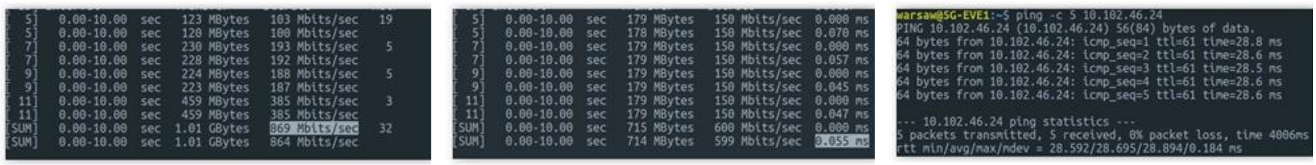


Figure 6. Orange and BCOM interconnection performance results: throughput, jitter and latency values.

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.

3 UC6 - Remote health monitoring and emergency situation notification

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, and (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 (Smart living platform powered by Artificial intelligence & robust IoT connectivity), see Figure 7. STARLIT offers a dashboard for medical professionals enabling them to monitor the vital signs and status of several patients at the time. It also provides the option of setting up a skype 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 COVID-19 patients (quarantined at home or at dedicated venues such as hotels) [2]. Remote health monitoring requires foremostly clinician acceptance which depends, among others, on the service being perceived as efficient [3][4]. 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 [5], allowing it more than ever to become reality [6] . In this current context the trial and validation activities planned in the scope of this use case within 5G-TOURS become more important than ever.

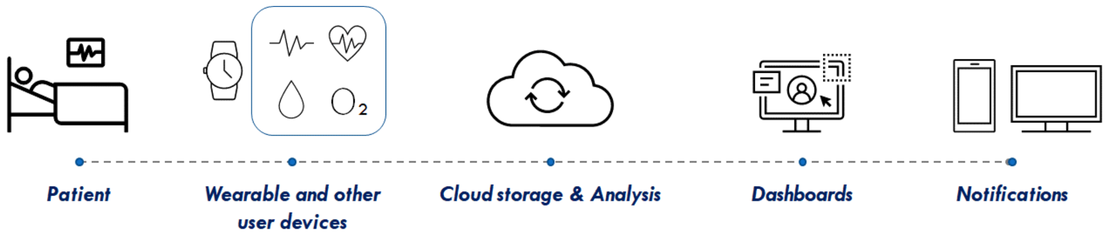


Figure 7. Remote health monitoring and emergency situation notification overview.

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, measurements will be derived from emulated users and potentially medical phantoms and will focus on blood pressure, heart rate and oxygen saturation. Real-time (emulated) data will be 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, will be accessible through mobile devices as well as laptops, desktops, and tablets. In the event of observed abnormalities in the vital sign values collected, notifications will be sent to medical experts and alarms will be 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 will be sent). Notifications/alarms will also be 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 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 a real deployment of this use case 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 will show the potential for providing these features.

3.2 UC6 implementation

3.2.1 Application components

Figure 8 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) heart rate, blood pressure or oxygen saturation are critical or are out of range (based on certain predefined thresholds) and (b) recorded values show a trend towards a potential problematic situation leading to health emergencies. The system supports the detailed recording of multiple patients and video calls with patients if deemed necessary by medical staff.
- 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 Move ECG [7], Withings BPM Core [8], Fitbit Ionic Watch [9], Huaten-Global (A20s)[10] and Beurer PO 60 Bluetooth pulse oximeter [11]) used for the heart rate, blood pressure, cardiac rhythm (electrocardiogram/ECG) and oxygen saturation monitoring.

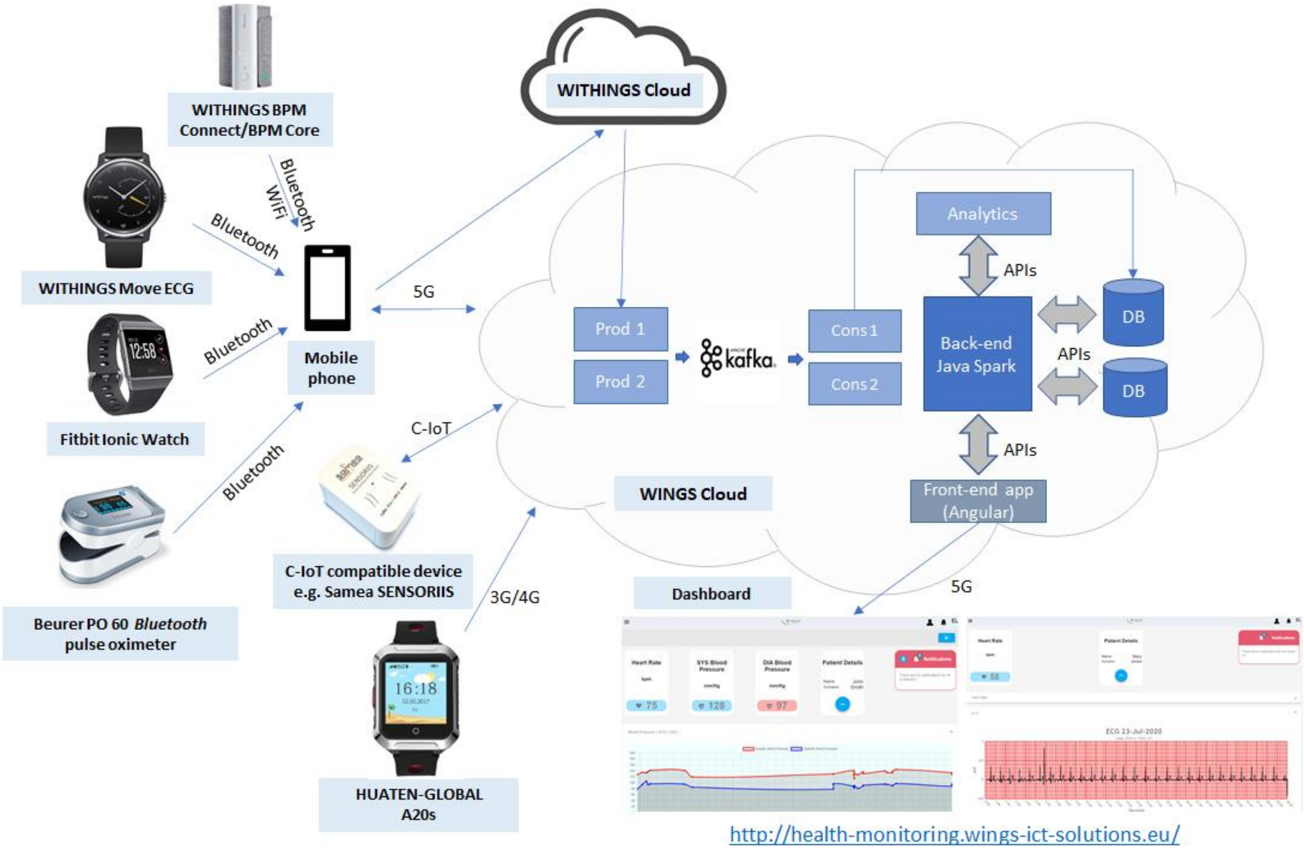


Figure 8. High level system architecture for remote health monitoring.

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. Among the wearable devices currently integrated there are two devices from Withings, namely ECG Move and BPM Core, both clinically validated for their reliability and accuracy. The open API provided by Withings enables accessing and retrieving data stored in the Cloud, which is then be stored in a relational database for further analysis. In addition, the Fitbit Ionic smartwatch is used in Remote Health monitoring to provide real time measurements of patients' vital signs. A custom REST API has been developed between the Fitbit Ionic and STARLIT platform in order for the patients' data to be stored in a relational database for further analysis. 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. The Huaten-Global A20S transmits data only as TCP/IP packets and is programmable through responses from a TCP server, therefore the communication between device and Remote Health monitoring platform required the implementation of a custom TCP server in the WINGS cloud infrastructure. The data received are parsed into JSON objects, sent to the Remote Health monitoring REST API and then stored in the relational database. The SENSORIIS device sends data using the HTTPS protocol (POST request) in JSON format to the Remote Health monitoring REST API where the data are stored in the relational database. The Beurer PO 60 Bluetooth pulse oximeter sends data using the Bluetooth Low Energy (BLE) protocol to a paired Android device. An Android application, running on the paired device, parses and sends the oximeter data as JSON objects, using HTTPS requests, to the Remote Health monitoring REST API where the data are stored in the relational database. It should be noted in Figure 8 one mobile phone appears to be connected to all wearable devices; this depiction is for the sake of simplicity of the figure. Most of these devices are complementary to each other and thus per user it is not expected to have more than two used simultaneously, connected to the same mobile.

The dashboard in the form of a web application provides the patient, family members and health care professionals 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 8 that are hosted in Docker containers. The main functional components comprised in the WINGS Cloud (Figure 8) 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.

3.2.2 Terminal equipment components

As described in the previous, currently five wearable devices can be used to monitor patients' physiological data (Figure 9).

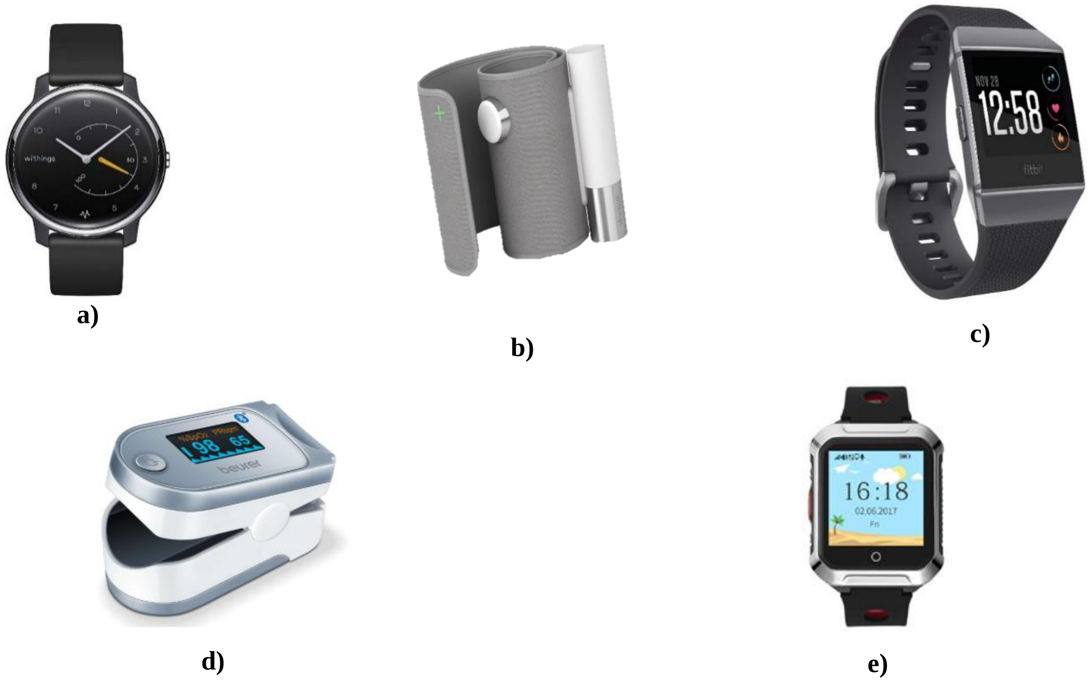


Figure 9. Wearable devices: a) Withings ECG Move, b) Withings BPM Core, c) Fitbit Ionic, d) Beurer PO 60 Bluetooth pulse oximeter, e) HUATEN-GLOBAL A20s.

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].

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].

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].

Figure 10. Additional devices used: a) Samsung S10; b) SENSORIIS.

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 (Figure 10a). For the actual testing in Rennes an alternative device will be sought that is more compatible with the Rennes network set-up.

SENSORIIS: 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 (Figure 10b), 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 (featuring throughputs of 375Kbps download and 375Kbps upload) whereby baseband, RF transceiver, power management, and RAM memory are integrated into a tiny package, running Sequans carrier-proven 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, also known as Bluetooth Low Energy (BLE). Bluetooth is extremely energy-efficient which extends wearables’ battery life and thus users do not need to recharge them as often. 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 data can be transmitted to the smartphone in real-time and, by using an experimental 5G network (or the commercial network), data is sent to 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, that 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 SENSORIIS 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.

The application components, described in section 3.2.1, 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 Flask server. The analytics service expects HTTP GET requests and responds with a JSON object containing the analysis result of the ECG signal.

3.3 Integration and test in labs

Analytics: The deep convolutional neural network 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 [39] and the PTB (Physikalisch-Technische Bundesanstalt) Diagnostic ECG Database [40]. 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).

Dashboard (Frontend): As described, a new user has to register in the platform and provide his/her credentials that will be stored in the database. If the user is already registered, he/she can 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 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 11. Each card on the board will have a special colour coded header. If the colour is yellow / red means the patient's real time vital signs appear to be higher than normal, so the administrator may click on a card to see the patient details' view which provides real-time graphs of his/her vital signs as presented in Figure 12.

Devices: Currently two types of smart devices are being used in order to collect the patient's vital measurements, Fitbit and Withings. Fitbit Ionic is a smartwatch which collects heartbeat and geofencing measurements. On the other hand, two Withings devices have been integrated, the Move ECG smartwatch and the BPM Core blood pressure monitor. The Withings devices are tracking measurements related to the patient's heart such as blood pressure, heartbeat and ECG.

To summarize, most of the components have already been integrated and preliminary tests have been conducted in WINGS Athens premises while work is ongoing for other components. Specifically:

- The smart devices described in section 3.2.2 have already been integrated with the STARLIT platform and a first version of the User Interface has been developed and tested.
- The analytics component has been developed and tested using open data repositories, though it is not fully integrated with the platform yet (currently only the functionality for detection of heart rate anomalies is included).
- The integration of SENSORIIS device with the STARLIT platform will be considered for transmitting data directly to the network using C-IoT communication to serve the mMTC use case, once the device becomes available. In the meantime, it has been agreed to use a SEQUANS evaluation kit (EVK), powered by a similar connectivity modem as the SENSORIIS device, in order to establish the requirements for transmitting data directly to the network and perform some demo testing. To this end,

WINGS and SEQUANS have initiated discussions on how to feed data into cloud and successfully tested basic Laptop-based connectivity to push dummy data from the SEQUANS Paris lab. Some configurations in EVK device, in order to push data according to required format as well as for putting in place a setup for continuous data flow to WINGS cloud, have been identified and work is ongoing on that aspect. In addition to the above, the possibility to evaluate the power consumption of the C-IoT device for battery lifetime KPI assessment is being explored. To this end, SEQUANS is looking into ways of either real-time monitoring or forecast analysis of the device's battery usage, while WINGS is looking into the need for dashboard updates.

Finally, the aim is to test the WINGS Remote Health Monitoring Platform on Rennes node when the network becomes available. More details on the timing and the next steps can be found in section 7.

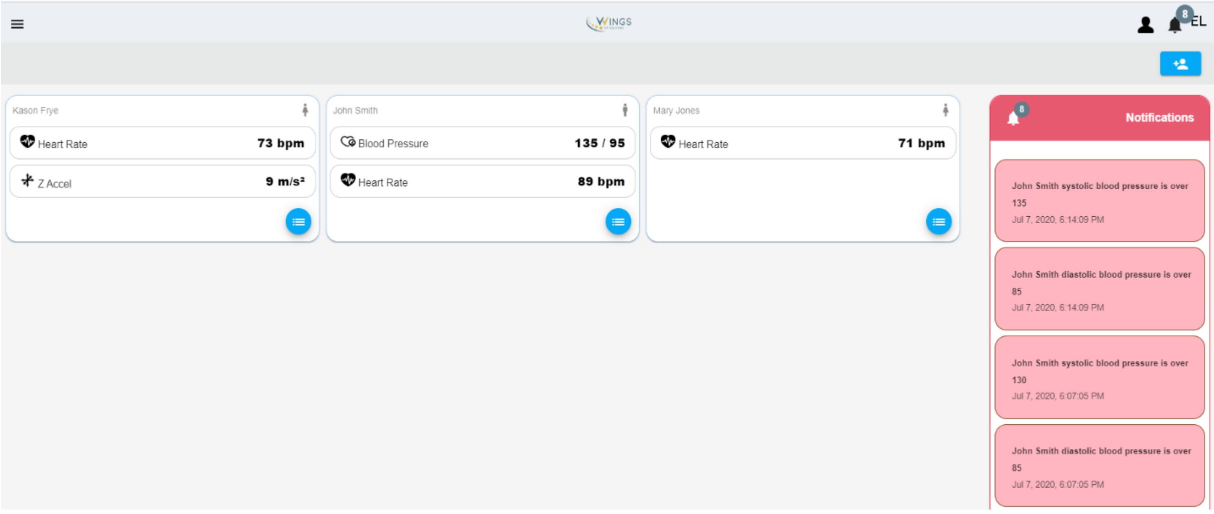


Figure 11. WINGS Remote Health Monitoring patients view.

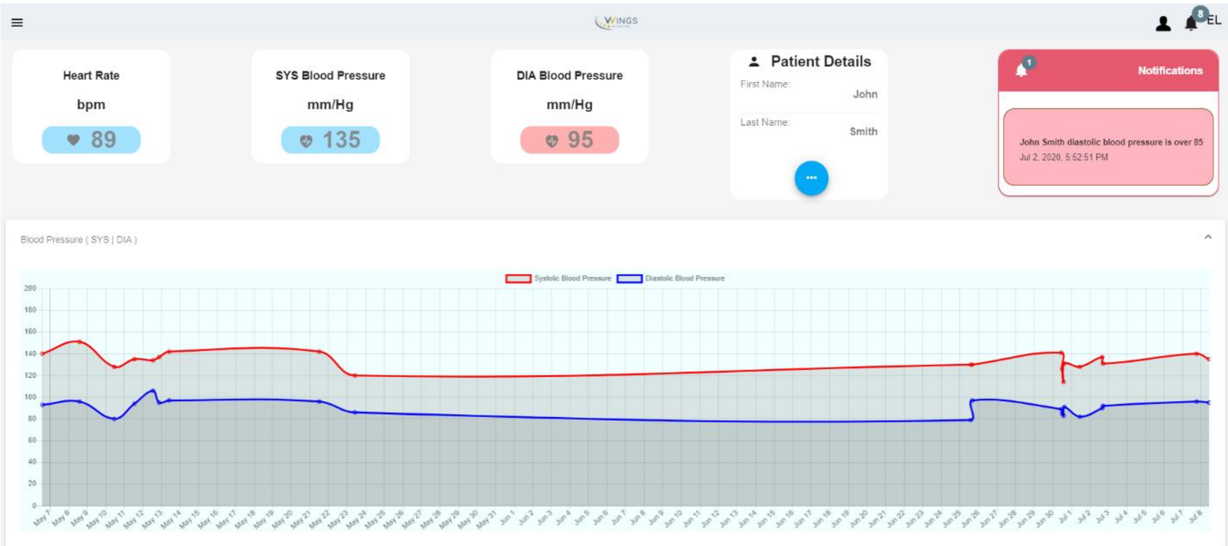


Figure 12. Patients detailed personal information.

3.4 Test in the network

Testing options in Rennes are slightly restricted as currently, for this use case, only the commercial network in Rennes can be used. In the second phase of the project, if there will be a 5G network deployed with capabilities to connect cellular IoT devices to a 5G core, this will be used for the experiments. Initial testing will also be performed via the Athens site. The KPIs that will be collected are latency (round trip time), throughput and battery consumption.

In terms of 5G-TOURS network innovation aspects the plan for the remote health monitoring use case is outlined in the Table 3. It should be noted that these will be tested only on the Greek node as this is connected to additional work performed in the scope of WP3 and WP7, which cannot be supported by the Rennes site. This work on AI enhanced MANO and diagnostics is implemented using OSM whereas in the Rennes site ONAP for VNF management is used. Moreover, the connected performance diagnosis tools require additional metrics and KPIs (e.g., VM/Container metrics, link metrics, application level metrics etc) that are not offered by the Rennes site.

Table 3. UC6 Network related innovation.

	Network Innovation		
Use cases	**Service layer**	**Enhanced orchestration**	**Other**
Remote health monitoring and emergency situation notification	Active Performance Measurement while the Service is Running (on the Greek node). This is shown to the customer through the service layer interface.	Resource allocation, deployment and migration of Network Services in an automatic and optimized way using various metrics (infrastructure, VNFs, Applications, etc) and verticals' requirements. (5G EVE OSM upgrade, Greek node)	Correlation of user QoE (WP7) with Active Service KPIs to identify relation between network performance, Quantitative Service KPIs and QoE.

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, 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 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 [30]. Major drawback is that 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 [14] 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 U/S probe positioning (video). The glasses’ display offers the ambulance doctor / paramedic hands-free access to relevant information (such as live U/S images, video, etc.,).

In one of the scenarios to be trialed 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 such 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 and Architecture

Currently, the Philips remote ultrasound application / solution and the remote video communication application / solution of AMA are integrated through real-time screen sharing of a 5G Android smartphone running the Lumify and XpertEye apps. A next step that will improve user experience, described in the previous section, is to also integrate ultrasound and video inside the smart glasses of the ambulance doctor, augmented with visual instructions from the regulator on how to hold and show (through video) the ultrasound probe on the patient's body. Furthermore, the plan for the next iteration is to enable transmission of ultrasound metadata along with ultrasound images and video, see the work plan (section 7).

4.2.1.1 Remote ultrasound

Currently, for all the clinical cases where remote ultrasound is being tested, the Philips Lumify / Reacts solution is being used [14]. Philips Lumify is an ultra-mobile ultrasound solution for care professionals to perform Point of Care (PoC) diagnostics and PoC image guided interventions.

Reacts is a platform that provides secure interactive communication and collaboration services for medical professionals, care teams, and their patients, including real-time A/V streaming [12]. It is based on WebRTC services (hosted in Canada), see Figure 13, and an existing end user application for all major platforms and Google Chrome (Figure 16).

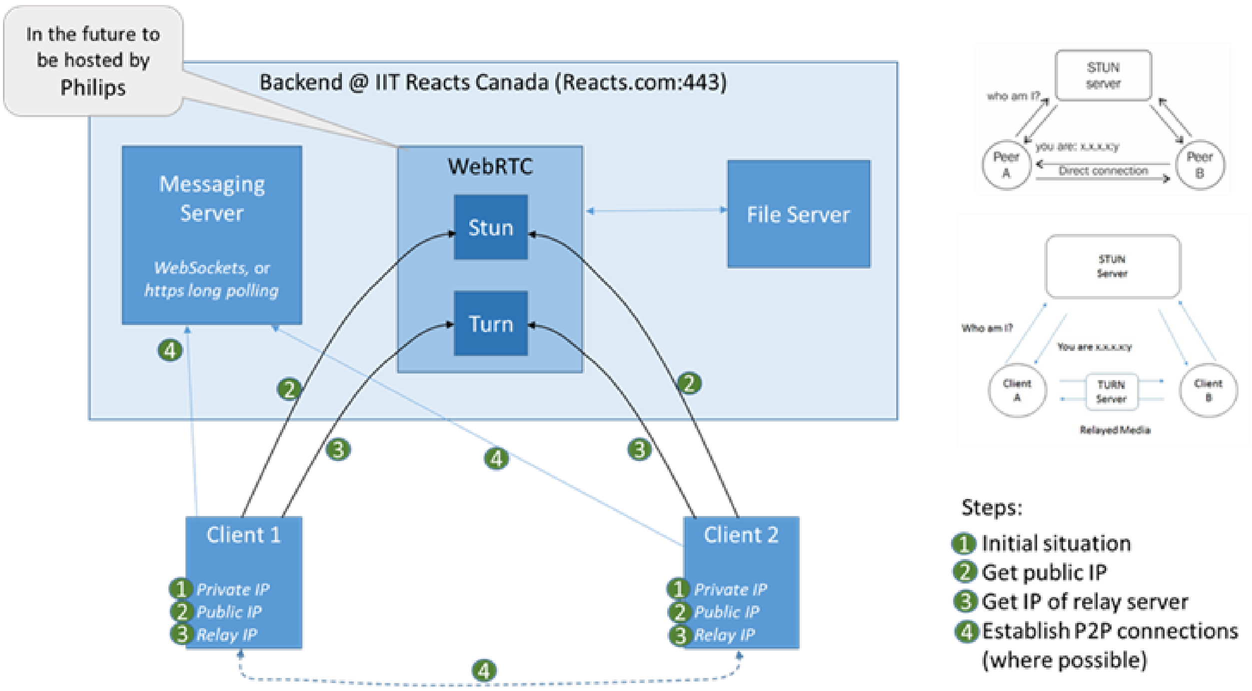


Figure 13. WebRTC services and hosting servers of Reacts in Canada.

Figure 13 depicts the basic flow that a (Reacts) WebRTC application goes through. By communicating with a central server, IP addresses are exchanged between communicating devices in order to select and setup the shortest most direct connection possible, if possible, peer-2-peer for two communicating devices in the same subnet. The figure shows how connections are established between participants using the WebRTC protocols (STUN, TURN), in this example for the Reacts servers located in Canada.

In the next iteration / evolution of this use case, it is the plan to use the WebRTC services of AMA and have these hosted at BCOM.

4.2.1.2 Remote video communication

AMA's XpertEye solution provides video communications based on secured WebRTC services (Figure 14) to share real-time video between experts and workers. This solution offers one-to-one and conference modes.

The XpertEye solution is available in SaaS mode. It can either be configured for a global use or for a specific geographical area, such as Europe, APAC regions and, Americas according to various customer requirements, e.g. security, confidentiality and, latency. XpertEye authentication services are available that can be connected with SSO services.

This infrastructure is maintained by hosting companies specialized in critical data management and retention. This solution is also available as on-premises solution for companies that need extra security and makes it mandatory to have all services deployed only on their own servers. For this experimentation, we have the choice to use either the SaaS solution or the on premises one. Using the SaaS solution will force us to get all traffic through the internet. On premises allows us to build a close and dedicated network where we could more easily manage and understand all network constraints, making the data collection of experiment much easier to read.

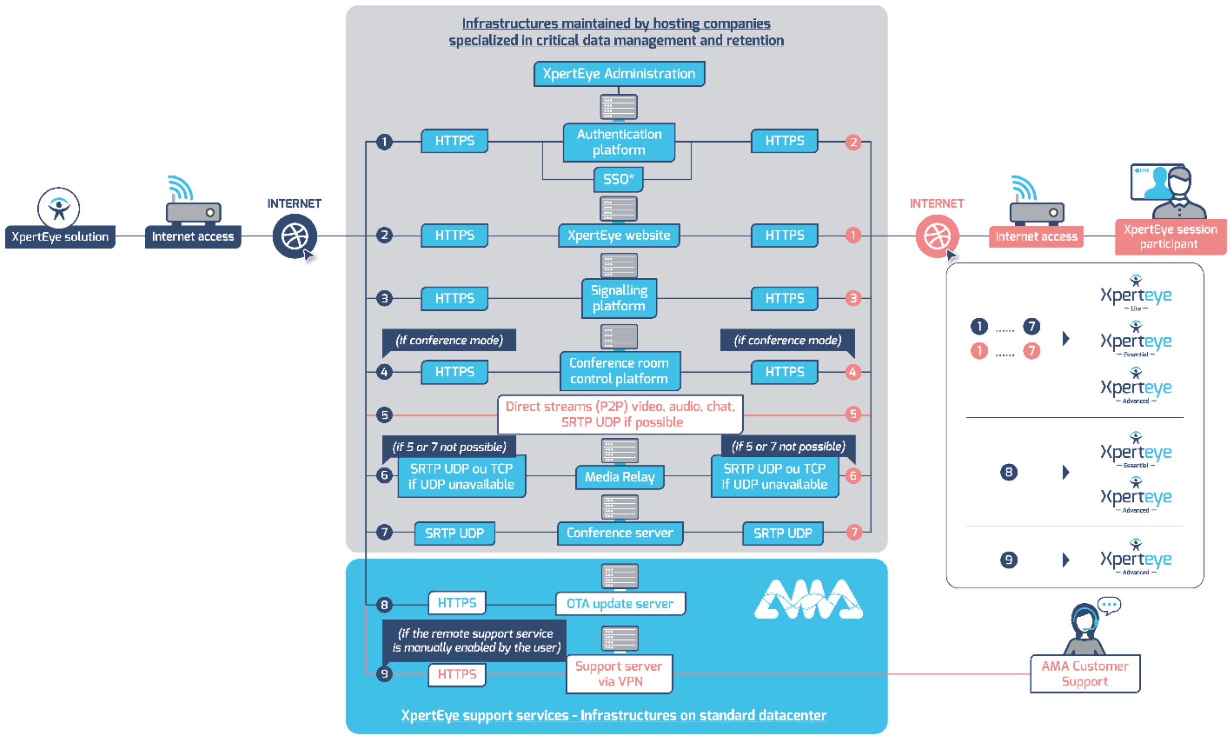


Figure 14. XpertEye network architecture diagram.

For this reason, the XpertEye on-premise solution is going to be used, allowing a fully controlled testing environment and security compared with commercial cloud solutions. This on-premise solution will be deployed in BCOM's Flexible Netlab platform alongside the WEF core network components.

4.2.2 Terminal Equipment components

At this point in time, the Philips remote ultrasound and AMA remote video solutions are not yet integrated. Therefore, the terminal equipment is described separately for each.

4.2.2.1 Remote ultrasound

The Philips remote ultrasound terminal equipment consists of a Philips Lumify 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 15, Left/Middle). There are 3 different types of probes [13], 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 [14] 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, see (Figure 16).

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

Figure 15. Lumify App screen on Android devices in different modes op operation.

Next, the Lumify / Reacts solution enables bidirectional A/V streaming between the Android App and the Reacts end user application. To this purpose, the Lumify / Reacts App uses the cameras of the smartphone (Figure 15, Right) and the ultrasound data acquired by the probe. As mentioned before, Reacts also provides the infrastructure services to realize the end-to-end real-time communications.

Figure 16. Example screen layout of the Reacts end user application for care professionals.

4.2.2.2 Remote video communication

The XpertEye solution [32] from AMA is available on wide range of devices (smartphones, smart glasses, tablets, laptops) supporting secured WebRTC video communications in a web browser (Chrome, Firefox, Safari).

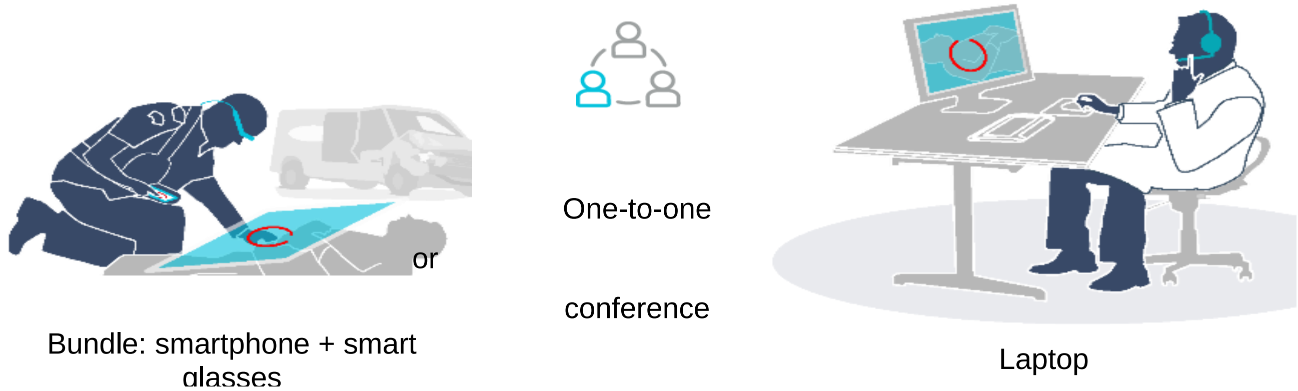


Figure 17. XpertEye remote assistance with smart glasses + smartphone and laptop computer at remote expert.

A mobile phone connected to cellular network (4G or 3.5G) transmits in real time the video from smart glasses worn by a user active close to the patient (Figure 17). Currently, an Android smartphone named M1 is customized and dedicated to use the XpertEye solution with dedicated USB devices, e.g. smart glasses, dermatoscope, microscope, endoscope, thermal video camera, webcam.

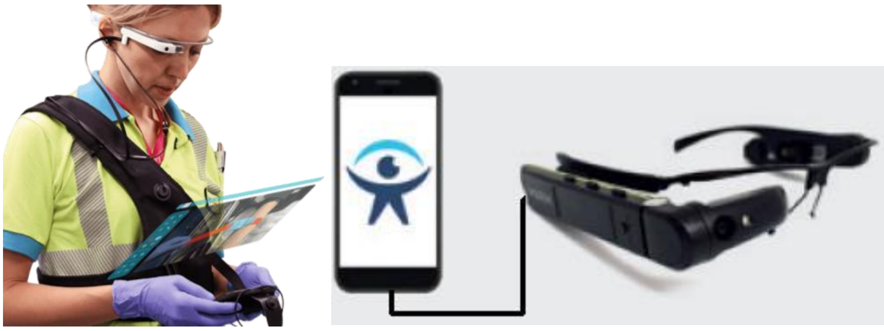


Figure 18. Smartphone + Smart glasses.

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 18, Figure 19).

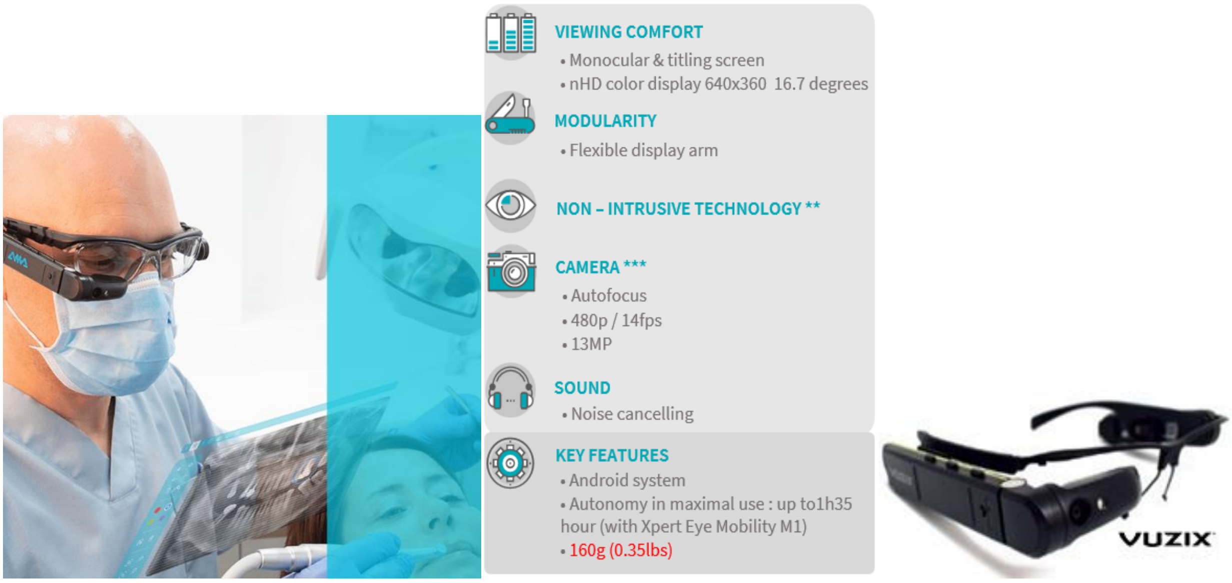


Figure 19. Vuzix M300 smart glasses for XpertEye solution.

Several other smart glasses are being integrated in XpertEye solution and tested by medical staff. This will offer 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 20.

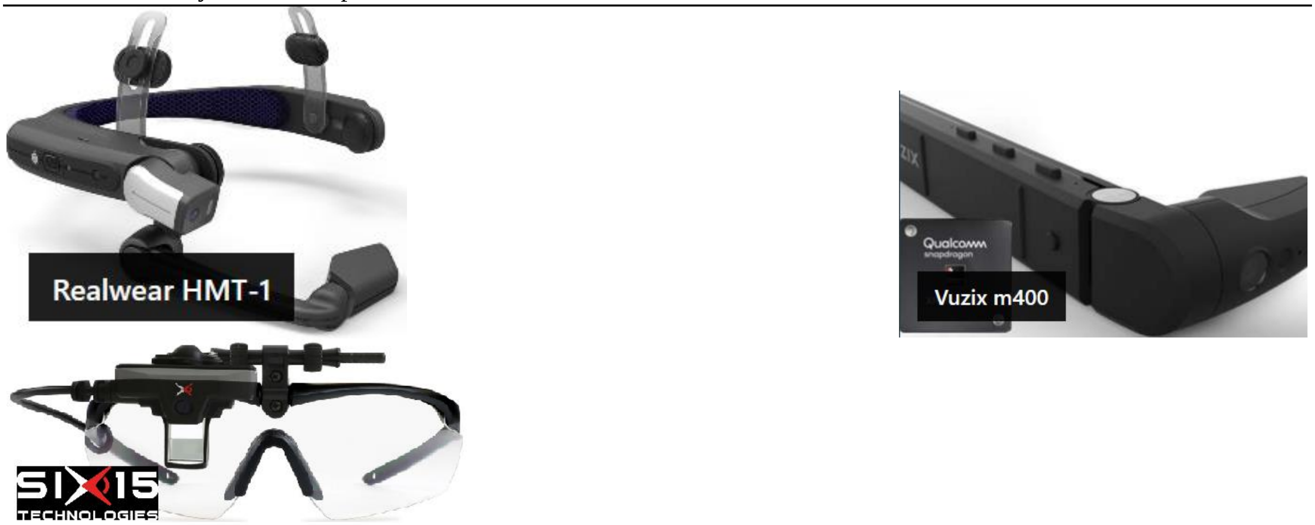


Figure 20. Other smart glasses for XpertEye solution.

Using these new devices will offer higher XpertEye video resolutions particularly adapted to 5G high data rates networks. XpertEye WebRTC server streaming part will also be 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 in upcoming releases (early 2021) luminosity and brightness management. A common board eases screenshot and image management that any user can annotate and share with participants, see Figure 21. A simple send image to remote glasses display functionality gives precise information while leaving the worker with his/her hands free.

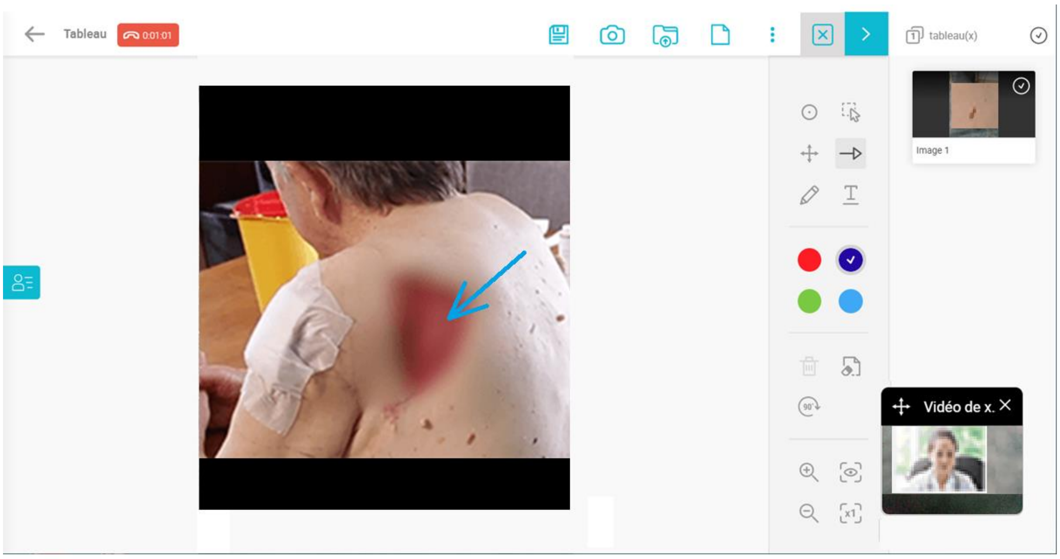


Figure 21. XpertEye shared image board with annotations.

One key feature for the first part of this experimentation is a real time video screen capture of what is displayed on the smartphone that is either sent to the remote conference participants or sent to the smart glasses display. Any application that is running on the smartphone can be seen in the smart glasses display allowing an "assisted reality" experience for the hands-free worker, see Figure 22.

Figure 22. XpertEye assisted reality.

For 5G experimentation, XpertEye Solution will be adapted for 5G smartphones allowing the use of promising new capacities offered by 5G cellular networks (Figure 23). The choice of device is done according to 5G frequencies available for this experiment.

Figure 23. 5G smartphone.

For testing on the 5G Amarisoft BCOM platform, a 5G Samsung mobile phone at 3.5Ghz is used, see Figure 24.

Figure 24. Samsung Galaxy A90 5G smartphone.

Then on Nokia 5G BCOM-CHU-Orange platform, the Sony Xperia J9010 experimental smartphone will be used (Figure 25).

Figure 25. Sony Xperia J8010 mmWave experimental 5G smartphone.

4.2.3 Interfaces

A high-level view of the platform components is depicted in Figure 26. 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 will connect through 5G wireless CPEs.

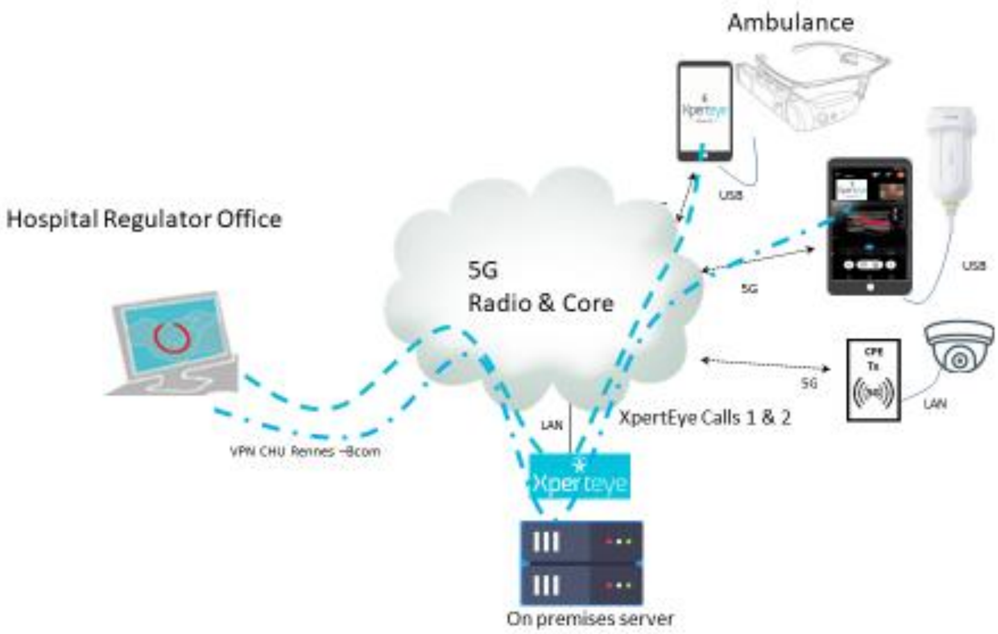


Figure 26. Platform’s architecture high-level view.

4.3 Integration and test in labs

For the demonstration, medical phantoms simulating an emergency use case will be at disposition from CHU Rennes.

Figure 27. Medical phantom and stretcher.

Regarding the telecommunication part, BCOM provides the cellular experimental networks with 4G/5G radio and 4G/5G core networks for the test demos. The Technology Research Institute has several 5G experimental networks available in Rennes (France) for this experimentation that are part of European 5G projects.

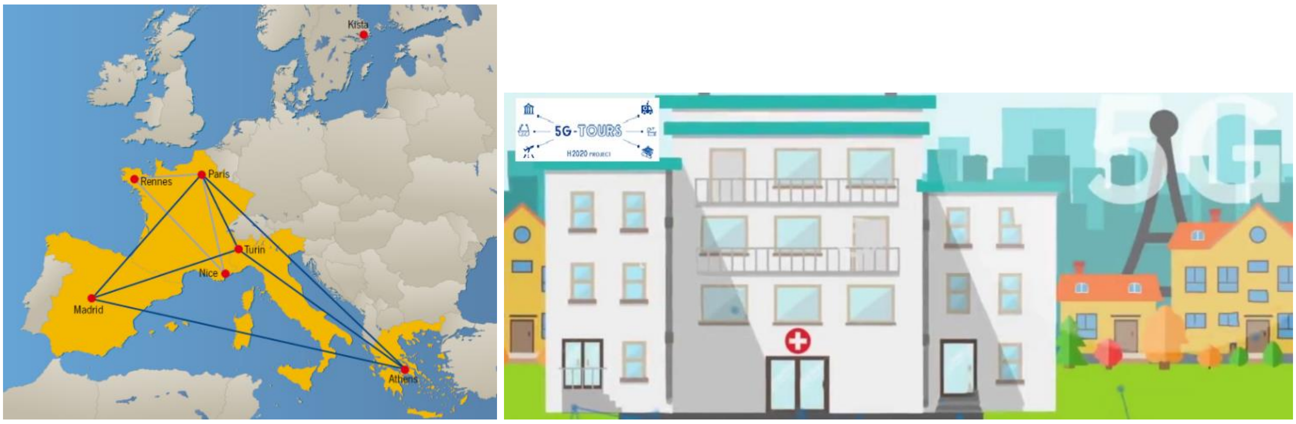


Figure 28. BCOM (Rennes) is a 5G EVE site facility for European 5G advanced testing.

The 5G network will be composed of Nokia equipment and software cloud-native environment providing a VNF infrastructure with radio access networks.

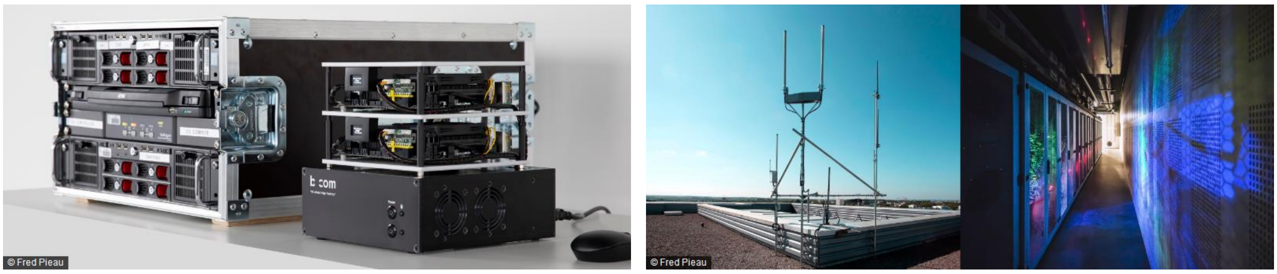


Figure 29. BCOM lightweight & compact 5G solution in "Flexible Netlab" environment.

4.3.1 Network Architecture

Different setups with several configurations (LAN/Wifi, 4G, 5G) are tested for video performance evaluations and comparisons.

1st setup:

This first setup consists in the integration of a Lumify/REACTS probe, app and service and AMA's smart glasses and RTC services, i.e. using separate devices for ultrasound image acquisition and transmission on the one hand and video capture and transmission on the other hand. All these connected devices will first be configured to validate that they communicate together with LAN/Wifi. Then all devices will connect through 4G wireless network: first using Rennes public network, then the private network at BCOM Lab.

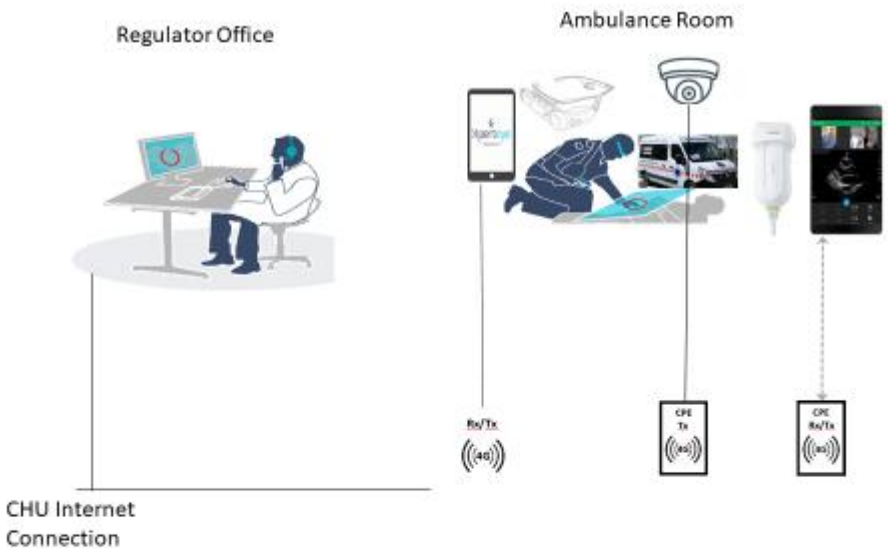


Figure 30. 1st setup – 4G based user tests.

<u>2nd setup:</u>

This second setup consists of the integration of Lumify probe in XpertEye mobile solution (Figure 31). This will be done using AMA screen grabbing of the Lumify ultrasound app UI on Android and AMA RTC services, so eliminating the REACTS services. The first part of this setup will use 4G connections: all devices will connect through the available 4G wireless network using the Rennes public network or private network at the BCOM Lab.

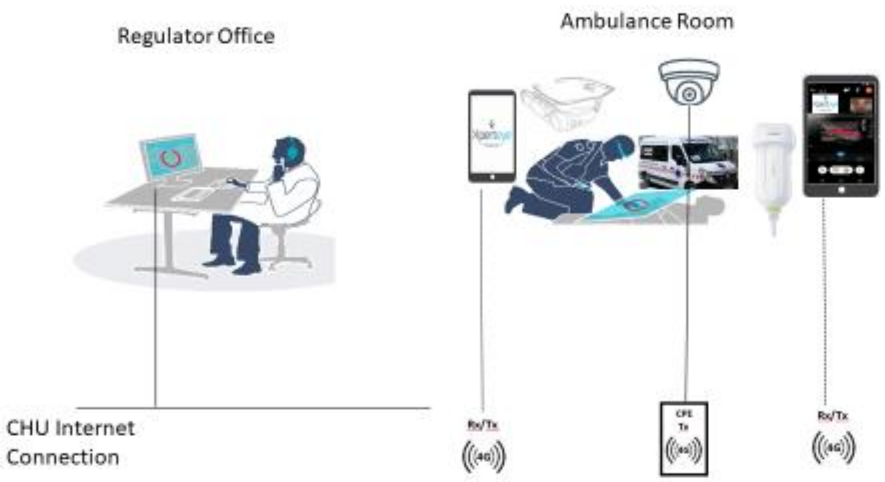


Figure 31. 2nd setup – 4G / 5G based user tests with Philips Lumify application screen shared in AMA XpertEye solution.

The second part of this setup will use 5G connections: all devices will connect through 5G wireless network using the private network at the BCOM Lab and if available, the Rennes public network.

4.3.2 Lab test results

The first lab tests were conducted at BCOM Rennes in October 2020. These tests have been demonstrated using the architecture depicted in Figure 26 and the 5G based user test setup depicted in Figure 31.

The same RAN network, as described in UC8 (section 5) based on Amarisoft 5G at 3.5GHz, was used (Figure 50).

Photographs (Figure 32 and Figure 33) of this setup were taken while using 5G transmission.

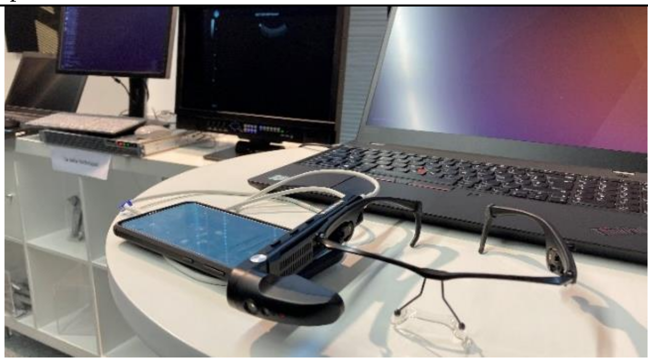


Figure 32. Smartglasses connected to 5G mobile.

A first demonstration was the transmission of smartglasses video to a distant regulator working on a PC using the following devices:

- Samsung Galaxy A90 5G with XpertEye advanced Android application
- Vuzix M300 smartglasses connected via USB to this mobile

Current smartglasses video resolution is 640x480 pixels at 30 frames per seconds. With WebRTC protocol being used for transfers, each uplink and downlink 5G data rates was about 1.5 Mbits/s.

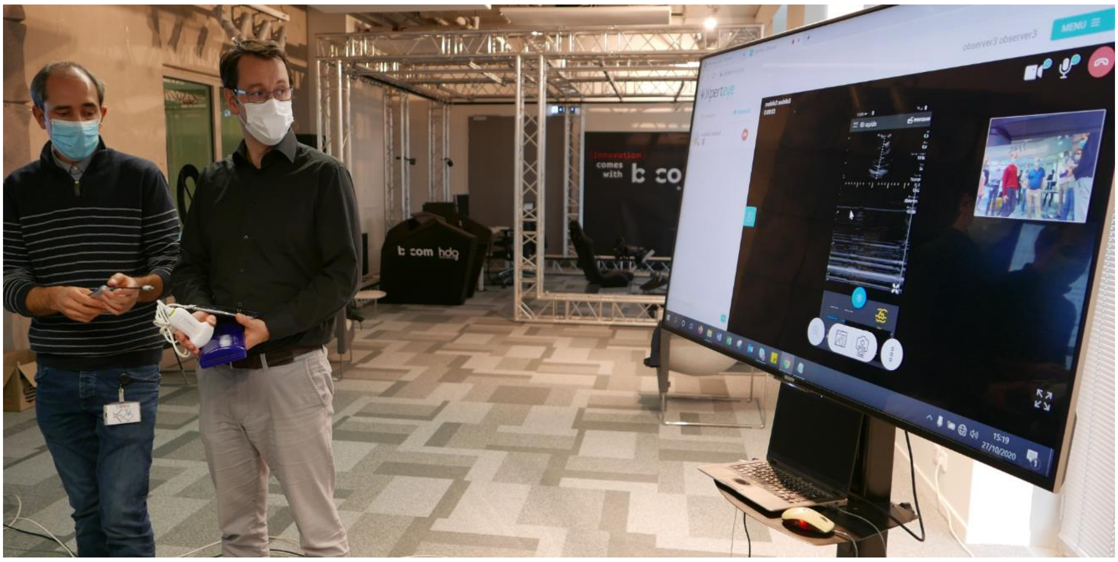


Figure 33. AMA XpertEye solution used with Philips Lumify echograph.

A second demonstration was the transmission of the Lumify application using XpertEye video screen sharing functionality to a distant regulator on PC using following devices:

- Samsung Galaxy A90 5G with XpertEye advanced Android application and Lumify application
- Philips Lumify echograph probe connected via USB to this mobile

Current screen sharing video resolution is 640x480 pixels at 15 frames per seconds. With WebRTC protocol being used for transfers, the uplink 5G data rate was about 1.1 Mbits/s.

4.4 Test in the network

For the final test, the 5G network infrastructure deployed in the Rennes Hospital will be connected through a VPN with the 5G network infrastructure at the Rennes BCOM facility.

The connection to the Core Network of Orange in their Châtillon datacenter will be ensured through a VPN between BCOM and Orange, see section 2.2.

In terms of 5G-TOURS network innovation aspects, the plan for the teleguidance for diagnostics and intervention support use case is outlined in Table 4.

Table 4. Network related innovation aspects for UC7.

	Network Innovation		
Use cases	**Service layer**	**Enhanced orchestration**	**Other**
Teleguidance for diagnostics and intervention support	The service layer can be used to monitor network quality on the fly.	Network Services Core Network deployment through 5G EVE.	On the terminal side, an interface is provided between the devises used for diagnostics (glasses, etc.) with the network.

4.5 User Experience (UX) exploration of the use case

4.5.1 UX experiment in French context – January 2020

First experiments have been performed in January 2020 at the Academic hospital (CHU) in Rennes (France) with the current Philips Lumify Reacts [31] portable ultrasound solution for remote collaborative ultrasound examination. This was done with CHU / SAMU doctors Dr. Tarik Cherfaoui and Pr. Erwan Donal, playing the role of ambulance emergency doctor and regulator respectively. Both doctors are experienced in using ultrasound. They imagined dealing with a cardiac emergency. The Philips Lumify Reacts solution consists of an ultrasound probe that connects to a tablet running the Philips Lumify ultrasound app (Figure 34 left-hand side) that can transmit video from the tablet camera's (one at a time) and ultrasound from the probe (and app screen) via the built-in Reacts real-time connectivity module to a remote computer that runs the Reacts application (Figure 34, right-hand side).

Figure 34. First remote collaborative ultrasound examination experiments at CHU Rennes. Left: Emergency/SAMU doctor. Right: Cardiologist, specialized in Echocardiography.

The backside camera of the tablet is used to show the patient to the remote expert as well as the position of the probe on the patient's body to improve the collaboration and remote guidance. The video of that camera is shown on the tablet, next to the ultrasound images. The ambulance doctor should regularly look at this video to check whether he/she aims the camera correctly to the probe. After trying the Philips Lumify app with the built-in Reacts connectivity, it was concluded that it will help the remote expert to see both the patient and the position of the probe on the patient's body. However, the SAMU doctor does not want to look "through" the screen of the tablet (i.e., to the probe video), because it feels much more natural to look directly at his own hand with the probe. Therefore, a solution, that serves both parties in the collaboration, would be a camera that does not need to be held, but is worn instead. This would be possible with the XpertEye smart glass solution provided by AMA. Next, if live ultrasound could be displayed inside the glasses with sufficiently high resolution, this would present a great opportunity for overall usability improvement. Because it solves the challenge of positioning the tablet near the patient, or holding it in one hand, and it may allow the ambulance doctor to make the ultrasound scan in a more comfortable body posture. The XpertEye solution [15] was also demonstrated for pre-hospital care purposes, but separate from ultrasound diagnostics, see Figure 35.

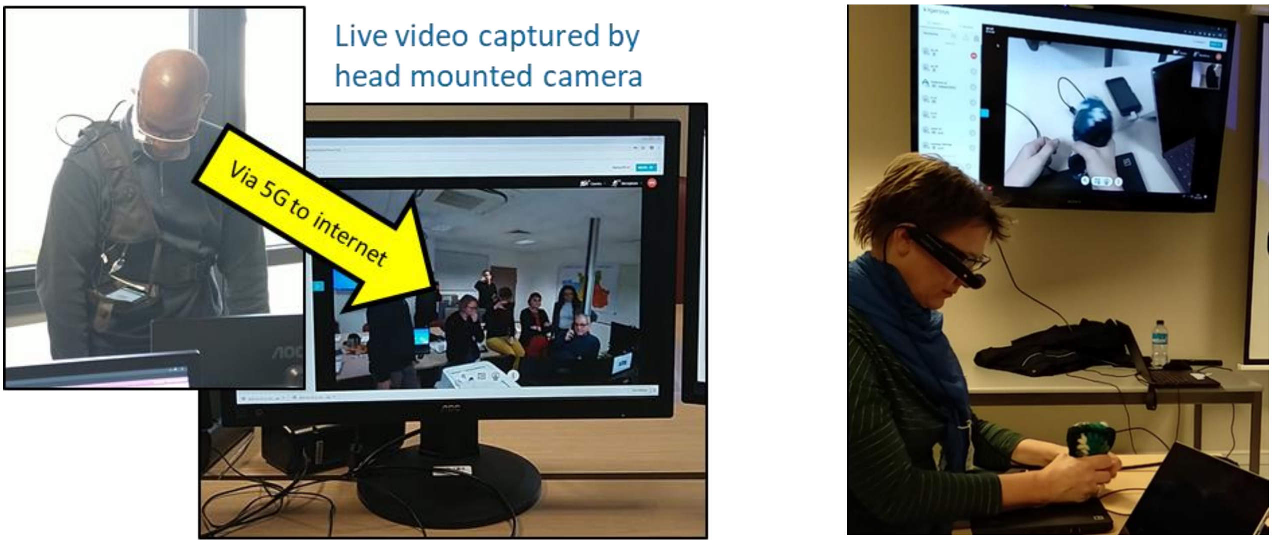


Figure 35. Demonstration of XpertEye assisted reality solution at CHU Rennes.

4.5.2 UX experiment in Dutch context - July 2020

Additional experiments to understand user requirements of a tele guided ultrasound solution were performed in Eindhoven with Dutch healthcare professionals. It was a small-scale experiment aimed to better understand when and how the remote expert needs to see how the probe is positioned on the body of the patient.

In three tele guided ultrasound sessions, an ambulance paramedic was supported by a remote medical manager of the ambulance organization, to perform certain SPOT checks on the patient (an ultrasound abdomen phantom), see Figure 36.

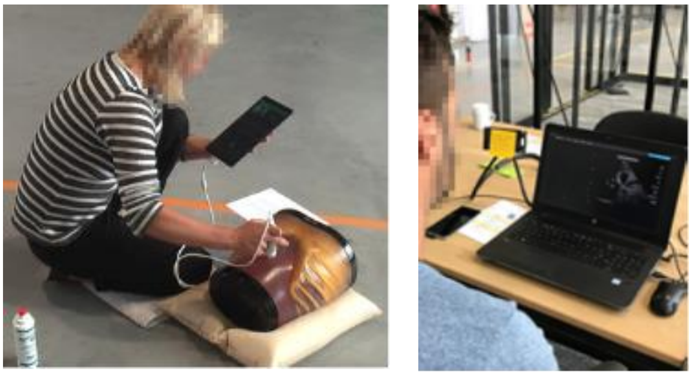


Figure 36. Left: Ambulance paramedic performs ultrasound exam (using Lumify-Reacts plus one of 4 camera solutions). Right: Remote support of a medical manager providing support (using the Reacts application).

The participants in the paramedic role were two experienced ambulance paramedics and one emergency physician who also worked as medical manager at the ambulance organization. Their experience in using ultrasound ranged from “no” to “medium” to “very high” experience. The remote medical manager was also an emergency physician who worked part-time as medical manager at the ambulance organisation.

In this Dutch organization, the medical manager (MM) can be compared to the French SAMU regulator, although the Dutch MM is not located in a dedicated environment for the task. The Dutch MM on call can be busy with other tasks in the hospital, at home or on the go. Ambulance paramedics can call the MM when they need assistance but are not obliged to contact the MM for every patient. Today, they cannot share video or medical device data. In contrast with France there is no emergency doctor part of the Dutch ambulance crew; the ambulance paramedic takes care of the patient together with the (specially trained) driver. Ambulance paramedics are not trained to use ultrasound. However, “rapid responder paramedics” who are sent to accidents to support the ambulance crew can be experienced ultrasound users.

During the session, paramedics performed tasks related to the FAST procedure. These required probe locations at all sides of the abdomen: left & right side of patient (free fluids), front (vena cava & aorta), see Figure 37.

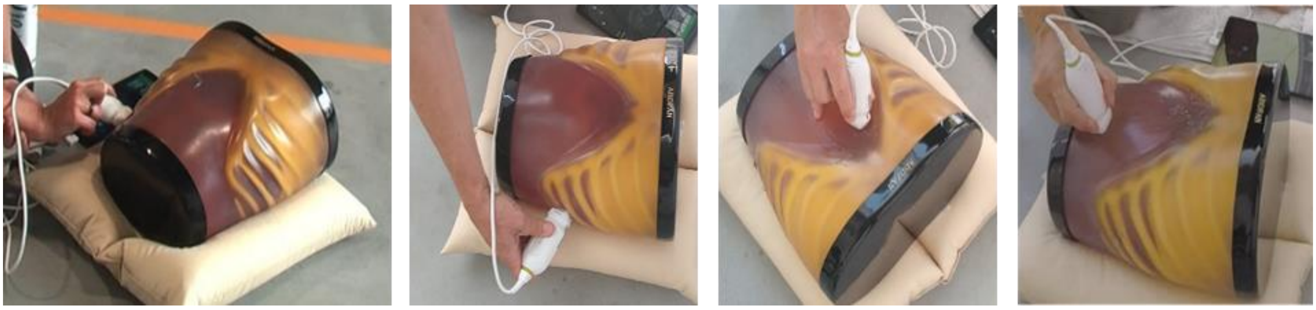


Figure 37. Probe positions required during ultrasound exams.

The major observations are summarized in the following subsections.

[1] The MM does not often have to see the probe position, but it has to be possible sometimes.

During the tele guided ultrasound session, the Medical Manager interprets the shared ultrasound images and instructs which other images to capture. The MM can easily interpret the live ultrasound images without seeing the probe position. Diagnosing is even faster and takes less mental effort when they can talk and/or follow a predetermined scan protocol.

In most cases, the paramedic will know how to position the probe to capture a good ultrasound image. The MM will *only* instruct the paramedic on how to position the probe if the shared ultrasound images are not clear enough for diagnosis. This will happen more often when the paramedic is less experienced in using ultrasound. By looking at the live ultrasound images, the MM can determine the position of the probe, and how to get a better image (content, sharpness). Only if the MM does not manage to give good instructions based on the US images, he will look at the probe video**.** In that case, seeing the probe placed on the patient's body helps the MM to understand the problem and give more effective instructions.

Figure 38 sketches the need of paramedics to be supported in making an ultrasound exam; the need to get support in diagnosing (interpreting the US images) will last longer than the need to get help in placing the probe. After being trained, the paramedic will need to be supervised by an expert, before he/she can pass an accreditation exam. It is not yet clear whether tele guided US will be an acceptable solution to enable remote supervision.

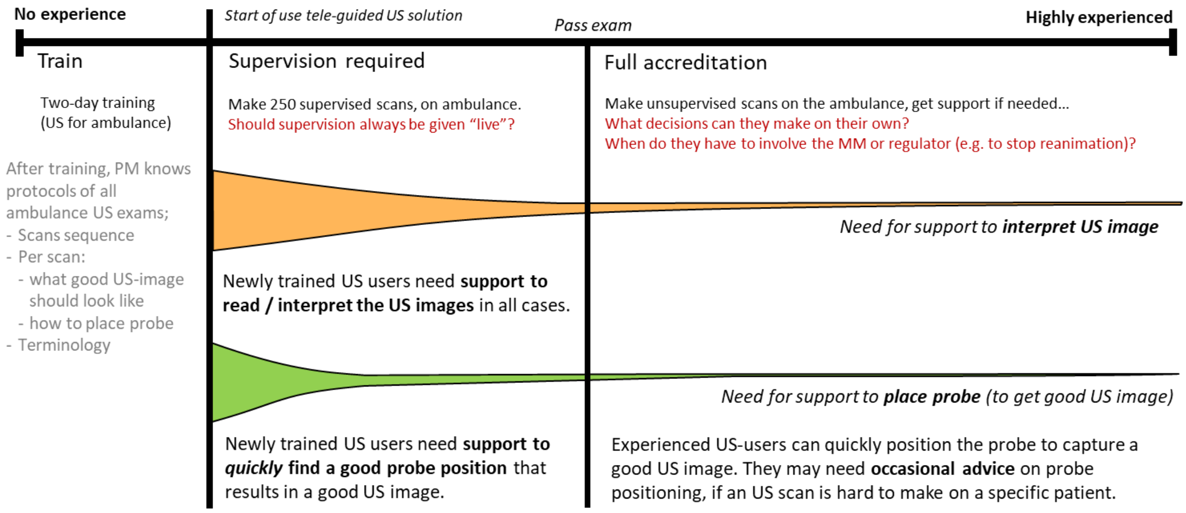


Figure 38. Tele guided ultrasound needs of ambulance paramedic over time (with growing US experience level).

[2] There is not one camera solution that outperforms the others.

During the co-creation several camera solutions were compared: the tablet camera of the Lumify-Reacts tablet, a body worn camera (on chest and head), and a camera that was attached to the (imaginative) ECG device (Figure 39).

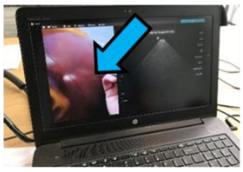
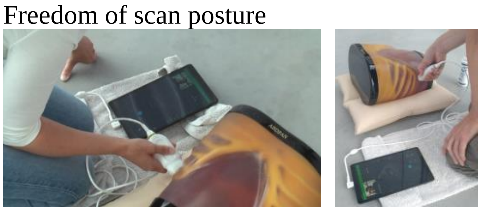
Paramedic		Medical Manager
1 No camera (no video of probe position)	**2 Backside tablet camera** of Lumify/Reacts 	Video via Reacts app 
3 GoPro in chest mount / head mount) 	**4 GoPro on tripod** (ECG device) 	Video via GoPro app on smart phone 

Figure 39. Camera solutions used in the three co-creation sessions.

None of these cameras is ideal for all ultrasound exams. Table 5 lists the strong and weak aspects of each camera solution. (PM = paramedic).

Table 5. Strong and weak aspects of camera solutions.

	Strong	Weak
No camera	- No burden for PM (to aim camera, etc.) - PM has both hands free. Can control tablet or lean on one hand during US scan. - Freedom of scan posture 	- Should be used by paramedic with (a lot of) US-experience.
Tablet camera	- Precise and easy aiming of camera to any probe position on patient body - PM can check easily if probe is visible on video (video window is shown next to US image on tablet screen), but …	- No free hand to lean on or control application - Best tablet position for "aiming tablet camera" is often not best position for looking at US images on tablet screen (viewing distance / angle, reflec-tions). - PM does not notice when probe gets out of sight 
Body cam	- Tablet can be placed on floor: physical com-fort. In that case, the PM has both hands free for scanning. - Tablet can be held in any position to avoid reflections and optimize view an-gle/distance. 	- Extra effort to put on chest band / head strap - Not possible to capture probe at opposite side of patient (or: have to lean over patient)  *Video of chest cam* - If body posture changes, PM has to re-aim camera (during US scan) - Chest band/head strap not in fixed position (stretches / moves when adjusting camera angle)

		- Hard for PM to check video image (on GoPro) - One of 3 PM's disliked to wear body harness.
Head cam	Similar benefits as chest camera. Differences: - A bit more overview for MM, due to higher position of camera	Similar issues as chest camera. Differences: - Impossible for PM to check camera aim (not possible to see GoPro screen). Probe is often out of sight when PM looks at US tablet, and tablet can block line of sight to probe. - One of 3 PM's disliked to wear (sliding) head band with (too heavy/instable) camera.  *Video of head cam*
Camera on tripod	Similar benefits as chest camera. Differences: - 'Helicopter view' gives some contextual information  *Video of tripod cam*	- Camera cannot see opposite (right) side of patient. - Small size of probe in video makes it hard to see small probe movements needed to support fine tuning. (Camera could zoom in to probe, but that increases risk that probe gets out of sight.) - Bystanders might block camera line of sight, or accidentally move the camera

[3] The probe video is not suitable for small movements to fine-tune the probe position.

Fine-tuning the probe position is about millimeters and very small angles. Effects of very small probe movement are clearly visible in the live US images. But these small movements are almost impossible to see in a 2D video because it shows no depth. Also, the GoPro camera was used at a wide view angle to reduce the chance that the probe would get out of sight at the slightest movement of the camera. That resulted in very small size probe in the video window, which made it even harder to see probe movements (Figure 40).

Figure 40. It is not possible to see size of movements directed to/from the camera
(note: images show cropped video stills; the probe looked smaller in the actual video).

[4] Both paramedic and medical manager refuse to be distracted by aiming the camera.

Using a camera (to show the probe to the MM) should NOT distract the PM from making a good quality US scan or taking care of the patient. During the co-creation sessions, the Medical Manager would never warn the paramedic if the camera was not aimed well at the probe. The paramedics disliked having to check whether the camera was (still) aimed well and would not do so while making an ultrasound scan. During the co-creation session (without any real-life pressure), they did check whether the camera was aimed well (by looking at the video if possible) just before beginning the US scan. Anyway, they expected to spend much less time on that in real life, and they preferred not to pay any attention to the camera at all.

Conclusion:

- Medical Managers do not often have to see (the video of) the probe position. They will need it more often when guiding less experienced ultrasound users, or in case of rare or difficult ultrasound exams. Even in those cases, they need to see the probe only if the live US images do not give sufficient information to base "probe positioning" instructions on.
- Generic requirements to the camera of the tele guided ultrasound solution:
  - The camera should require no attention (or as little as possible) of the paramedic. Ideally it should not require any attention to aim the camera to the probe and keep it aimed correctly.
  - Aiming the camera to the probe should not influence the body posture of the paramedic, nor restrict head movements, nor force the paramedic to use one hand to keep aiming the camera.
  - The camera should capture the probe in any position on the patient body, with the right view angle and at the right zoom level to show small probe movements (for fine-tuning) as good as is possible in a 2D video.
- All evaluated camera solutions caused usability issues. The tablet camera seems to be most suitable for the Dutch participants. They expected to use the camera only for a future tele-guided ultrasound solution, not for other remote video support functions (such as looking at the patient or accident context). Because the video of the probe is not often needed, they preferred not to add a second product (reduce cost & maintenance load). Also, they appreciated the ease of aiming the tablet camera closely to the probe anywhere on the body (in the rare cases that the probe really needs to be shown to the MM).

Next step:

Explore the user experience and usability of integrating the ultrasound function as well as the probe-camera function in the XpertEye smart glass solution provided by AMA.

When the paramedic can see the US images in the AMA glasses, he/she does not have to carry or look at the Lumify tablet. This will give them more freedom to find a comfortable body posture while treating the patient (within the limitation of the usage context: sitting on your knees on a rough wet street will never be very comfortable). It also eliminates the need to place the tablet somewhere. During the co-creation, the tablet was often put down on the floor temporarily. But in real life a paramedic can't put the tablet down, then hold it in the hand for a while, before putting it down again, because of hygienic requirements (need to avoid breaking sterility).

5 UC8 - Wireless Operating Room

5.1 UC8 definition

The goal of the use case is to demonstrate the impact of 5G inside the operating room. This use case will face 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 wireless tablet. 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 on 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.

Finally, a HD camera captures the cardiologist's hands to help the scrub nurses to prepare the instruments and to enable students to follow the operation in the amphitheatre close to the TherA-Image room.

All these video or live medical imaging are transferred as wireless video over IP, thanks to the recent DICOM-RTV standard, enabling synchronized real-time communication of video and associated metadata.

The overall architecture was firstly designed as shown in Figure 41. Four video sources (X-Ray, ultrasound, smart glasses and camera) and two displays (augmented reality and mosaic) were considered, all connected over a 5G wireless network.

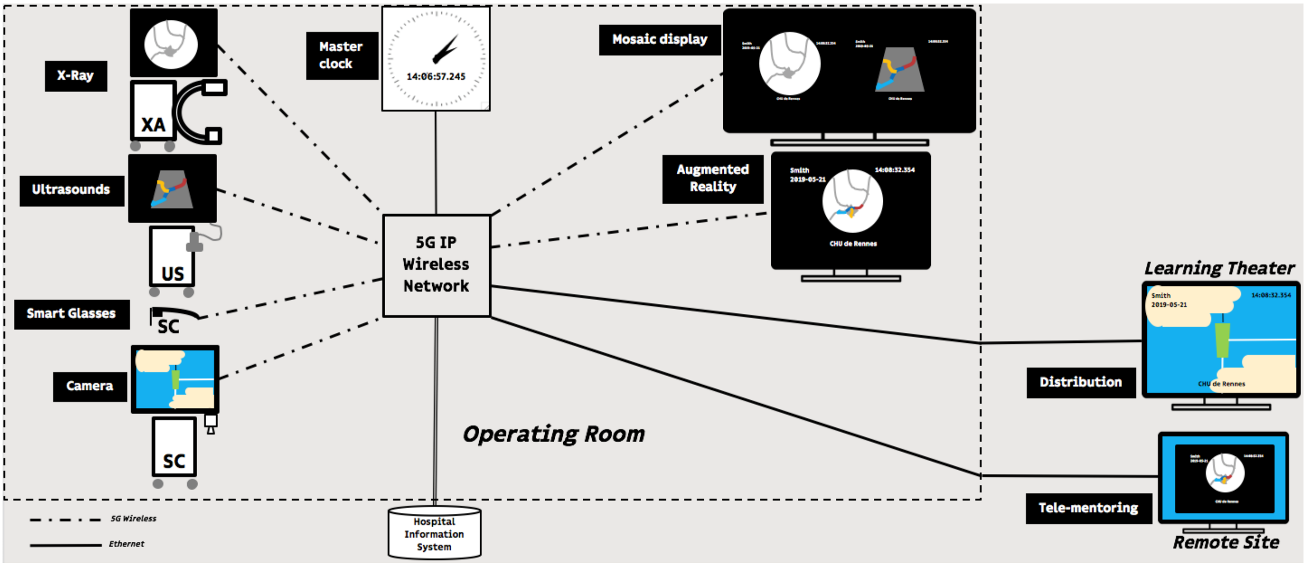


Figure 41. Overall architecture of the Wireless Operating Room.

After a more detailed analysis of the operating room equipment and of the available communication bandwidth, a refined architecture has been proposed (Figure 42). The main components are still involved, however, some adjustments have been made and will be described in the next section.

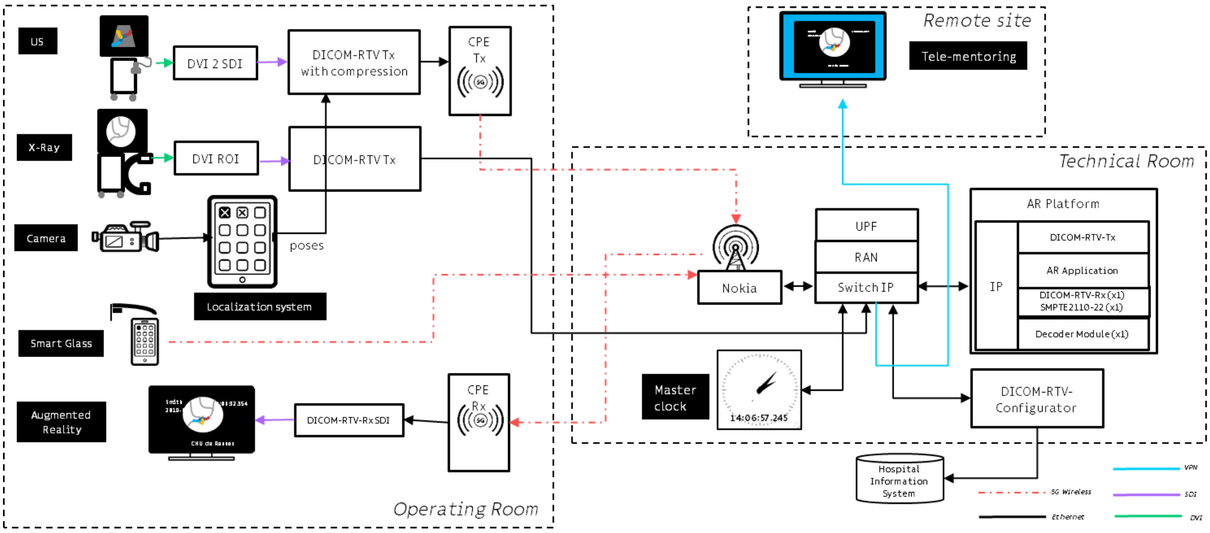


Figure 42. Revisited architecture of the Wireless Operating Room.

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 will operate 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 need to be 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 must be setup. This platform will receive the two incoming streams, perform the different calculation and video processing and send the resulting view over a 5G downlink. It might be necessary to downgrade the video resolution or framerate to fit in the available downlink bandwidth. The AR platform will need to embed a video decoding board to decompress the signal coming from the ultrasound with the minimum possible latency. The two DICOM-RTV-Tx (Transmitter) will be located in the operating room, close to the medical equipment, and the AR platform will be settled in the technical room, just next to the TheraImage room (Figure 43).

To receive the results of the AR platform, a DICOM-RTV-Rx (Receiver) must be placed in the OR next to a secondary monitor. The Mosaic display, initially envisioned in Figure 41, was eventually removed. Indeed, this would have implied another 1.5 or 3 Gbps video stream, which is not compatible with the available bandwidth. As for the fluoroscopy stream, compression could have been used, but would have required another quite expensive coding module. The distribution to the learning theatre also initially envisioned is still possible but does not imply any communication over 5G, so it is not shown in Figure 42 to simplify the general architecture.

The overall end to end latency should not exceed 150 ms not to impact the cardiac procedure. Indeed, above this latency, surgeon's gesture and concentration are disturbed and can alter the intervention. Obtaining this latency is today quite challenging knowing the different phases of the transfer to be performed.

Figure 43. TheraImage technical room.

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 44. 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 45). To prevent the loss of tracking, first tests were conducted by adding a 3D marker on top of the probe. Results are encouraging (Figure 46) and further work will be performed to try to reduce the size of the marker.

Figure 45. Ultrasound probe to be tracked.

Figure 46. First test of localization of US probe using depth camera and marker.

Next step is to transport the poses calculated by the localization system 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 47.

Figure 47. 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 (Figure 48). 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. These calibrations are currently under investigation and will require a dedicated phantom. Main ideas are presented here.

Since the position of the RGB-D camera is fixed, the World coordinate system [33] 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 could be estimated using a phantom with metal landmarks, via a dedicated calibration procedure that will be developed later in the project.

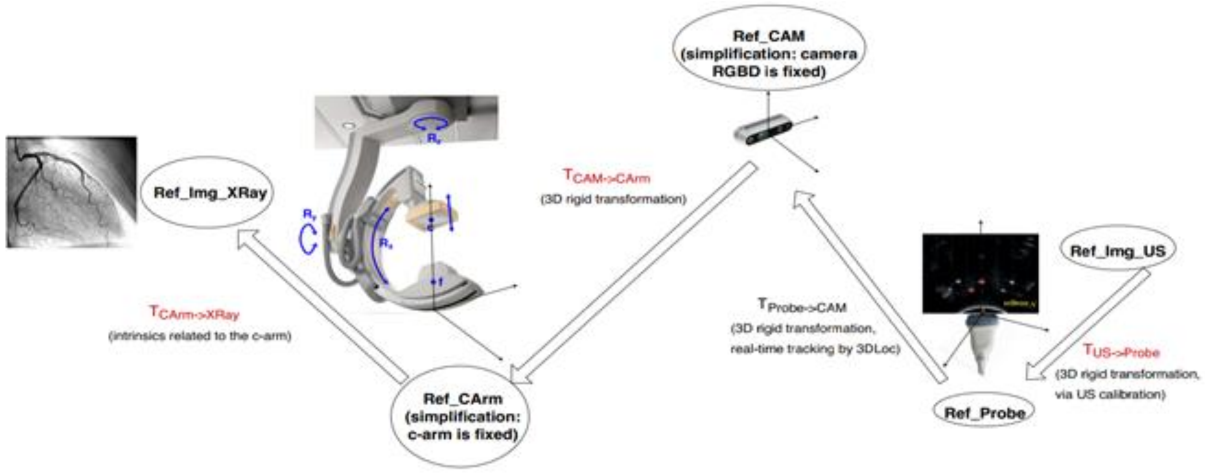


Figure 48. Multiple references involved.

5.2.2 Terminal Equipment components

The ultrasound-imaging device **GE Vivid E95** [46] will be used in the project, allowing real-time 2D/3D imaging of both cardiac structures and blood flow with a relatively high spatial resolution. The 3D+t imaging framerate is about 10-15 fps. The video signal can be directly retrieved on the ultrasound using a DVI connector.

The **C-arm Angiography/Fluoroscopy** machine present in TheraImage 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 will rely on the **AMA XpertEye** solution, comprising smart glasses and a smartphone as gateway, as shown in Figure 49. The XpertEye solution is implemented over WebRTC and the video flow coming from the smart glasses' camera will be potentially converted in DICOM-RTV in AMA's smartphone, using a prototype implementation of DICOM-RTV on Android, based on BCOM's DICOM-RTV Converter solution. Finally, it will be converted in the network in WebRTC to reach the remote user. This transition through DICOM-RTV enables the harmonization of all video flows. If the performance is too weak, the original solution will be used, which implements a WebRTC end-to-end flow.

Figure 49. AMA XpertEye solution.

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

A secondary monitor, provided by CHU Rennes, will be placed inside the OR to display the view of the AR application.

As mentioned earlier, DICOM-RTV-Tx and DICOM-RTV-Rx will be provided to operate DICOM-RTV transfers. Work is in progress to reduce the form factor of these modules, currently available as standard desktop computers. Several CPEs are required to connect the equipment but the model to be used has not been determined yet. Inside the technical room, several equipment components will also be installed:

- On the networking side, the WEF User Plane Function PNF will be deployed a described in section 2.2.2.2;
- The AR platform is under construction. It should be provided as a rackable server, with high computational resources and dedicated hardware to perform video compression/decompression if necessary. Another computer might be necessary to deploy a configuration application, called DICOM-RTV-Configurator, which allows configuring the DICOM-RTV transfers, and communicates with the Hospital Information System to retrieve patient information;
- Finally, a grandmaster, a precise time reference equipment, will be necessary to communicate a precise clock to all device components based on PTP protocol (Precision time Protocol).

5.2.3 Interfaces

The interfaces between the different devices are presented in Figure 50. 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 mini-ITX PC and a COTS hardware switch. Both CPE 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. As such, it is physically located in the Hospital technical room.

It is also remotely connected to the virtual Core Network of the Wireless Edge Factory (WEF) 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 also connected to the Core Network and both follow the 5G NSA (Non Stand Alone) connectivity standard. The WEF 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 test in labs

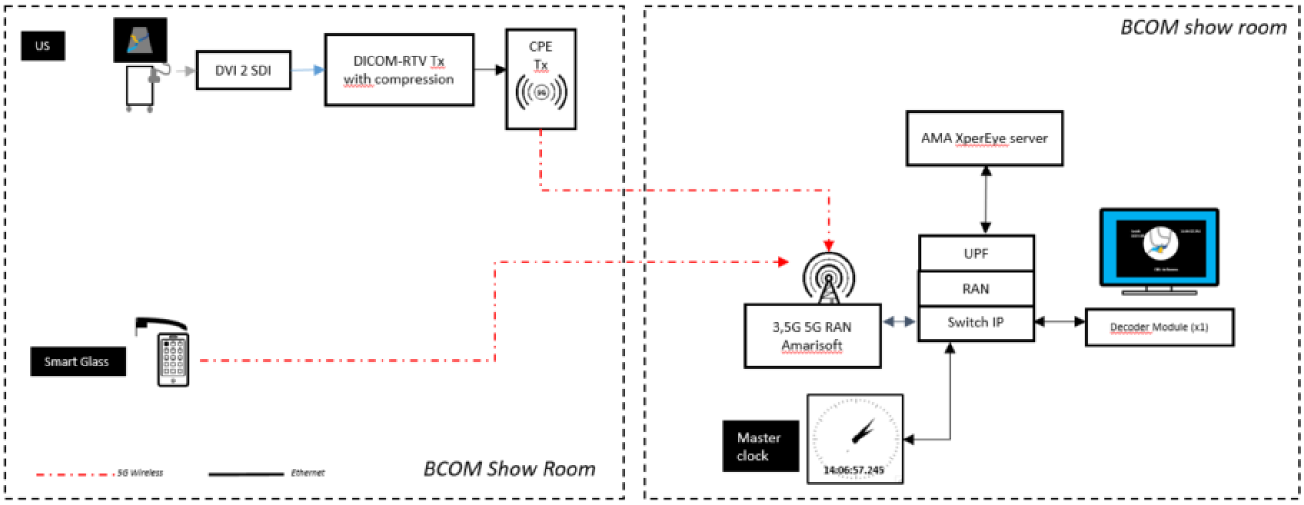


Figure 50. Test in lab architecture.

The first tests in lab consisted in two uplink 5G transmissions, one for the ultrasound stream and one for the **AMA XpertEye** solution, see Figure 50.

The ultrasound was using the DICOM-RTV Tx module to compress the video signal to 30Mbps. The output of the compression module was then connected to the 5G CPE Router.

During a joint UC7 and UC8 workshop in October, the full setup was demonstrated at BCOM premises. Photographs of this setup were taken while using 5G transmission, see Figure 51 and Figure 52.

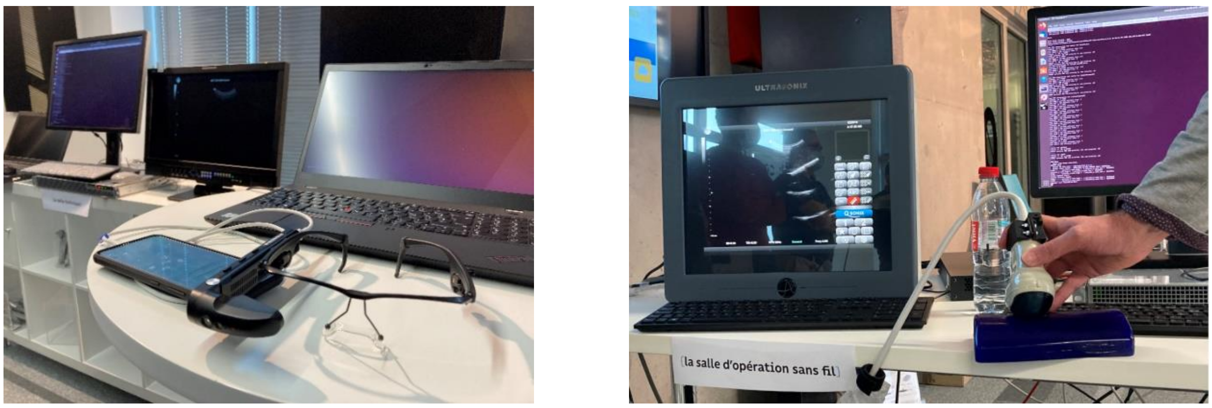
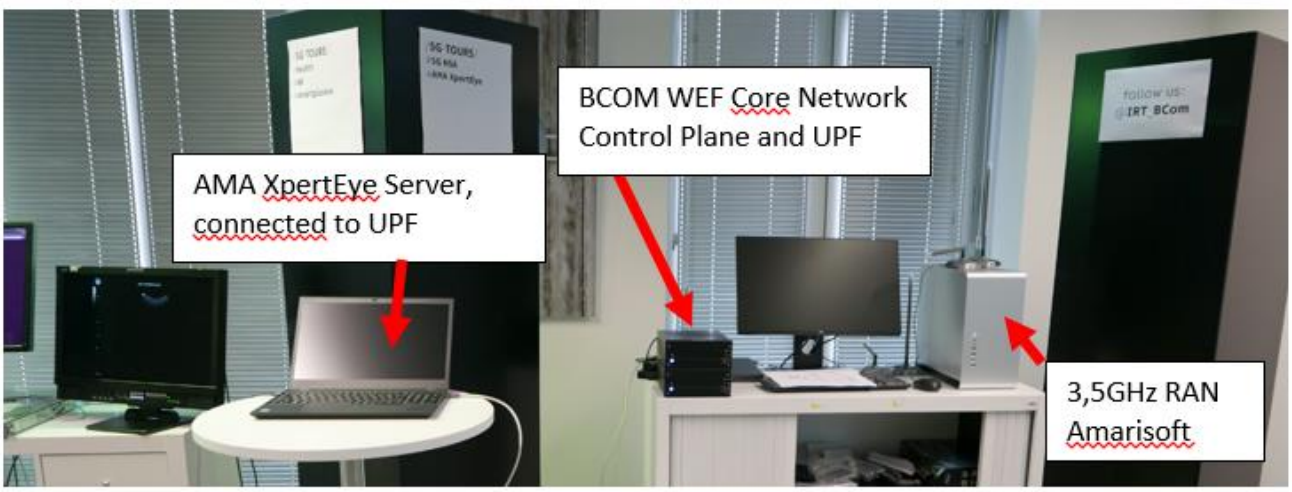


Figure 51. AMA XpertEye solution and ultrasound view after a 5G transmission during workshop in October 2020.



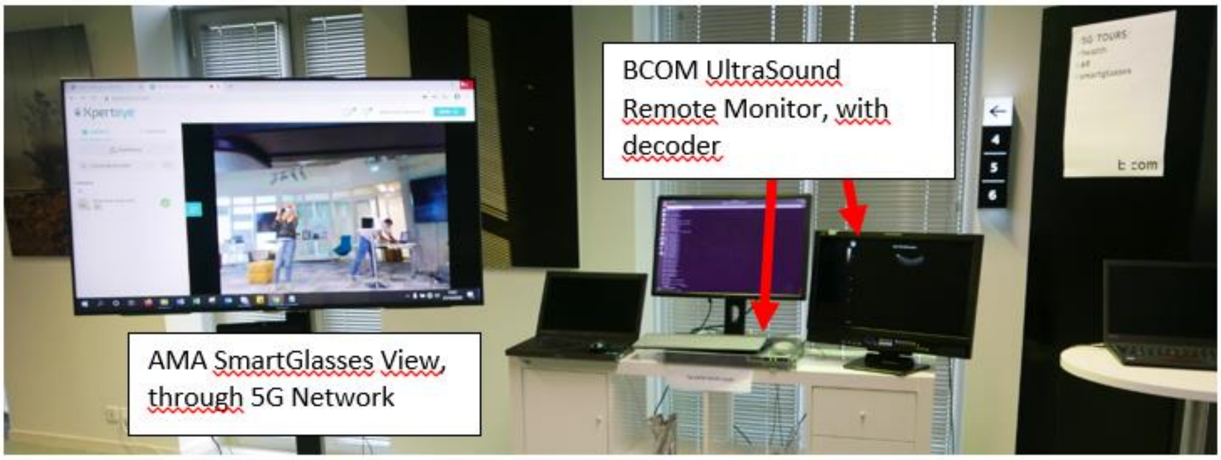


Figure 52. 5G NSA network equipment, AMA Server and remote monitors for Smart Glasses and UltraSound device.

5.3.1 Network Architecture

For the lab test phase, all user components of the use case were located in the BCOM showroom. The UPF and WEF Control Plane were also located in the showroom. Each was hosted on a dedicated mini-ITX PC. The UPF used a 1Gb/s switch and network interfaces on the PC. The gNodeB component was an Amarisoft Callbox Classic [34]. It supports up to 600 Mbps downlink and 150 Mbps uplink as well as a 10m range when used at full power. During the testing phase, the power settings of the Amarisoft Callbox Classic were set to minimal, so the bit rate and range were lower. The architecture of the test setup to show case UC8, is shown in Figure 53.

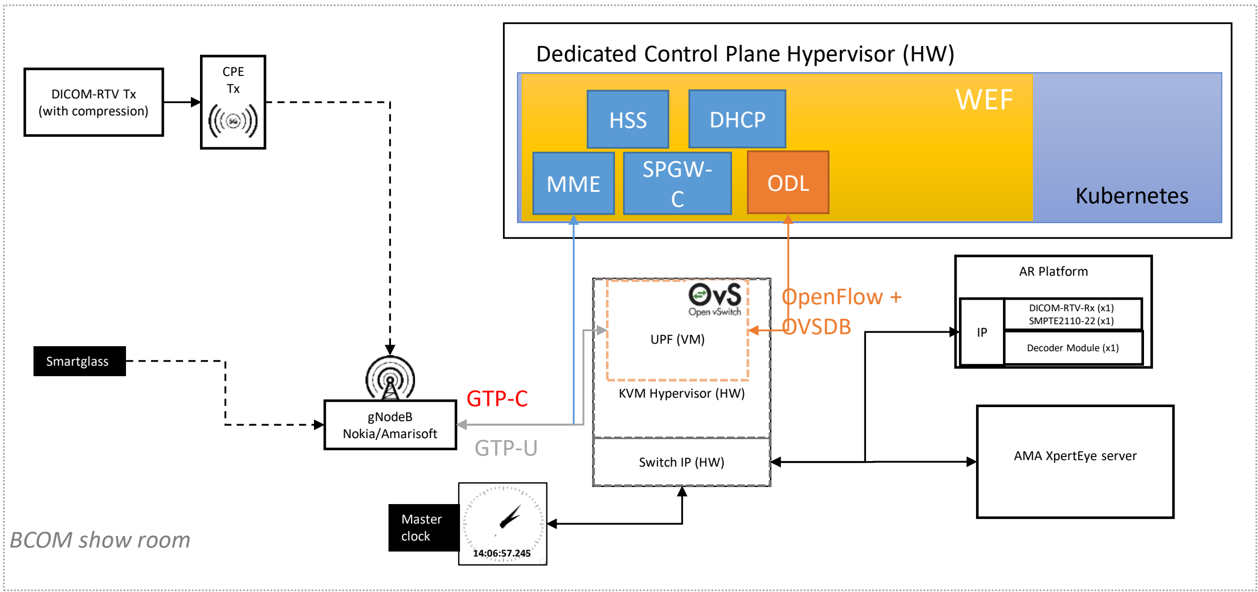


Figure 53. UC8 Network architecture (Demo target).

5.3.2 Lab test results

The first lab tests were conducted at BCOM in October 2020. These tests used the architecture depicted in Figure 50, involving several elements. We first tested the network components alone to determine the bitrate supported by our experimental 5G networks and then we ran functional tests that involved a first version of the AR use case and the smart glasses provided by AMA.

Networking tests

In terms of bitrate, we achieved an average downlink rate of 100 Mbps and an average uplink rate of 43 Mbps with the Huawei CPE set 5m from the RAN antenna**.** With the CPE set 1m from the antenna, we reached 180 Mbps downlink and 70 Mbps uplink. 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 tested the network latency and found that it varied greatly. We used the ping tool to evaluate the round-trip-time between a laptop connected to the Huawei CPE through a wired connection and the UPF component. We found that the RTT could vary randomly between 30ms and 200ms.

Functional tests

For the functional tests, we used the setup described in section 5.3.1. The DICOM-RTV TX component was configured to encode its video flow at a bit rate of 30Mbps. The tests showed that the flow could be transmitted to DICOM-RTV decoder through the 5G network successfully for several hours without interruption.

On the reception side, the output of the decoder module was connected to a monitor to visualize the ultrasound and estimate the latency in the uplink transmission. After some measurements, the overall latency was estimated around 120ms, 60ms for coding and decoding the video signal, and 60ms for the 5G operations. Knowing the processed video signal will need to be transferred back to the operating room, we will investigate to find ways to reduce this latency, so that the surgeon can perform his intervention in good conditions.

Finally, we conducted tests with the smart glasses provided by AMA to test whether it was possible to transport the video stream from the smart glasses to another phone connected on the 5G network while simultaneously streaming the video encoded by the DICOM-RTV module. The test was successful and showed that there was enough bandwidth for both video streams to be transmitted at the same time.

5.4 Test in the network

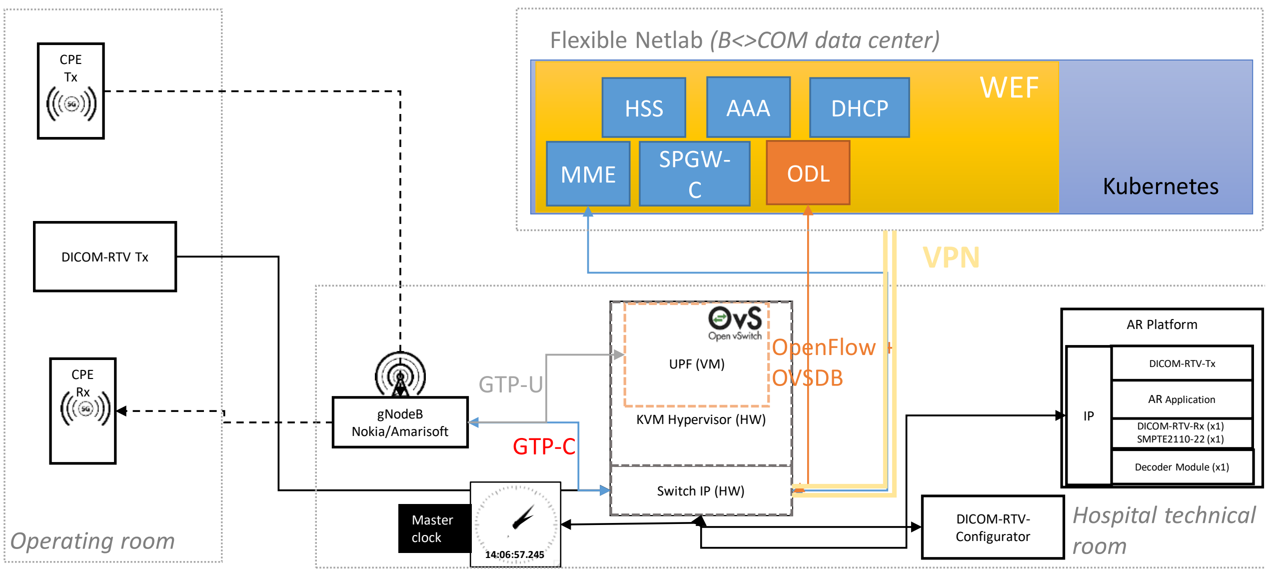


Figure 54 UC8 Network Architecture (Final Target).

For the final test, the user components will be deployed in the Rennes Hospital Operating Room and Technical Room. The UPF will be deployed in the Technical Room as well. The UPF will use a 10Gb/s switch and network interfaces on the PC. The connection to the Core Network deployed in the BCOM datacenter will be ensured through a VPN between the Hospital and BCOM. The gNodeB component will be provided by Nokia and will allow much higher data rate, as required by the various video streams of the use case.

In terms of 5G-TOURS network innovation aspects, the plan for the wireless operating room use case is outlined in Table 6.

Table 6. Network related innovation aspects for UC8.

	Network Innovation		
Use cases	**Service layer**	**Enhanced orchestration**	**Other**
Wireless operating room	The service layer is used to provide a friendly interface to the hospital in order to reserve a slice satisfying the desired reliability requirements.	Network Services Core Network deployment through 5G EVE.	An interface is provided between the devices in the operating room and the network.

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's platform, STARLIT, is exploited in order 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, will be leveraged for comprehensive decision-making. Real-time route updates will be performed as new information arrives.

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 will roughly evolve 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 will be tested under various conditions (traffic incidents, areas that do not support 5G). Aspects of the trial may be emulated such as the ambulance on route, the traffic conditions, the 5G coverage, etc.

Two key novelties that 5G brings to this use case are (i) the acquisition of information through sensors developed throughout the city with mMTC, and (ii) the prioritization of the routing information of the ambulance over other traffic flows, due to its criticality.

6.2 UC9 implementation

6.2.1 Application Components

Figure 55 and Figure 56 depict a high-level view of the architecture for optimal ambulance routing from an application perspective.

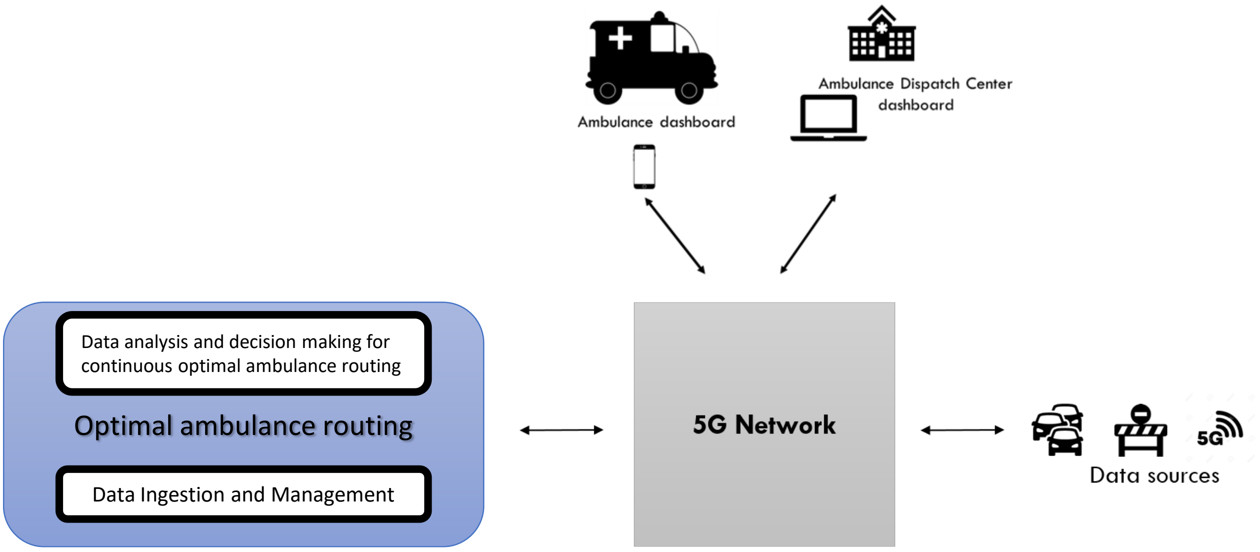


Figure 55. Optimal ambulance routing use case.

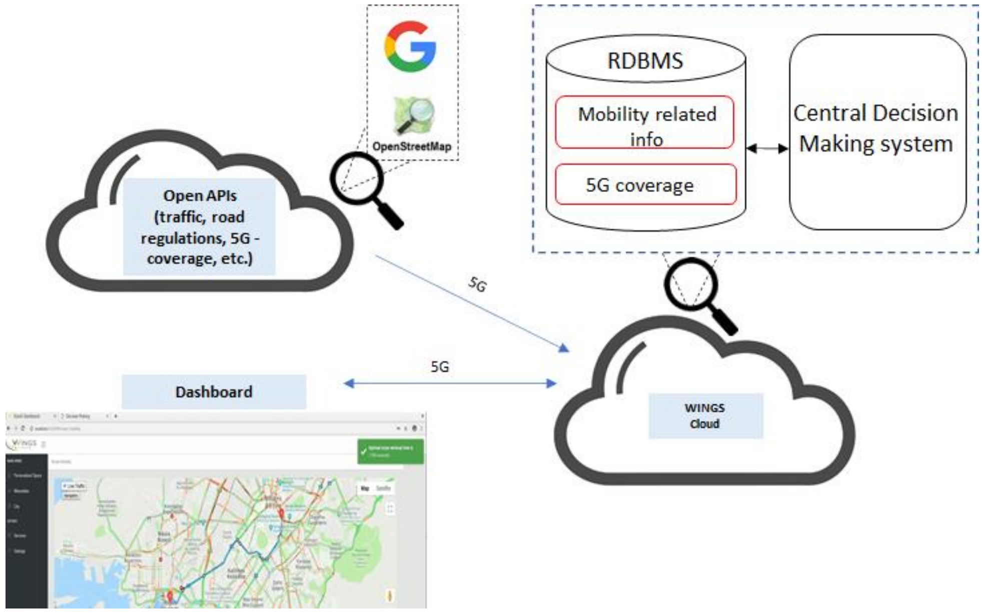


Figure 56. Optimal ambulance routing use case trial architecture.

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, for each of 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 user'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 [43] was leveraged. In particular, 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 will be 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 57.

- **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.).

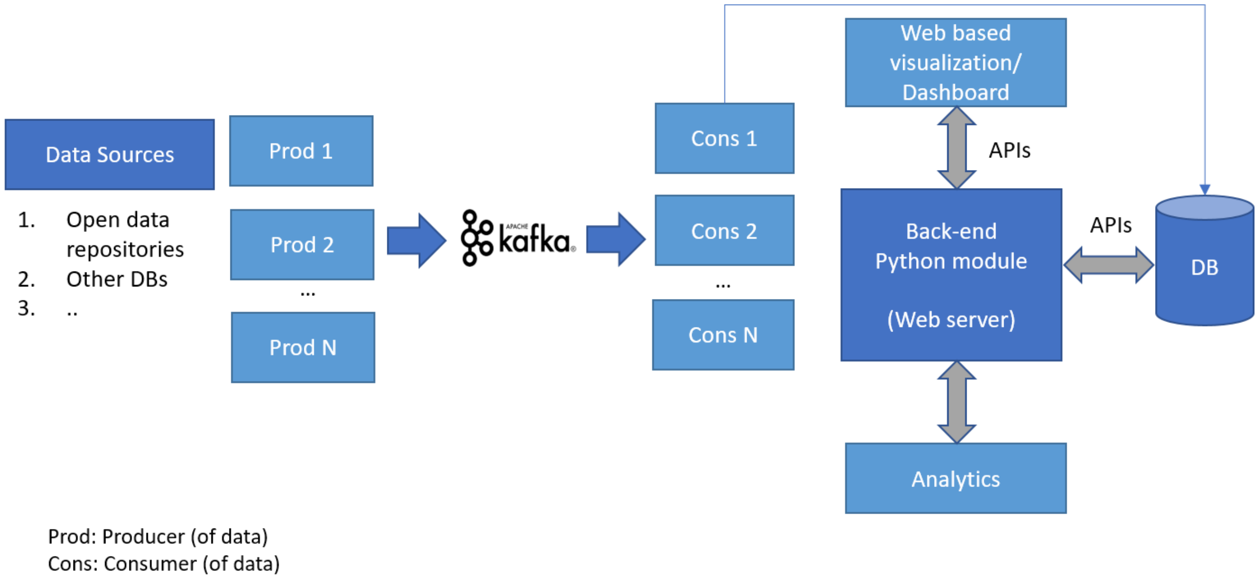


Figure 57. Functional architecture of the provided system.

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 58.

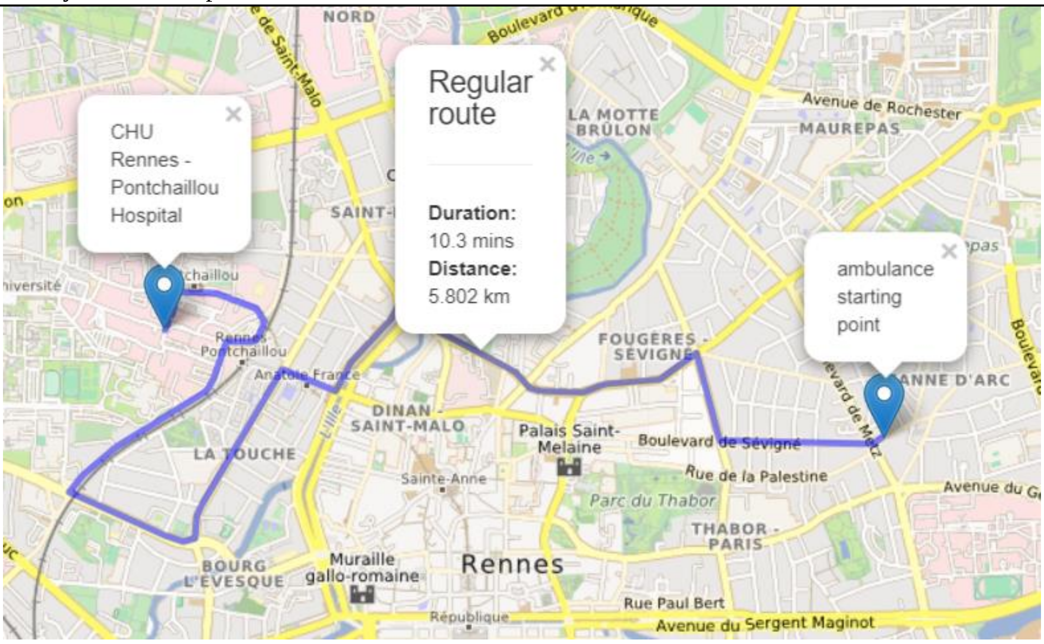


Figure 58. Regular routing of the ambulance asking for directions towards the optimal medical centre.

In another scenario, at the same time when the ambulance is requesting a route to the selected medical centre, a traffic incident has been recorded in "Rue de Vincennes". The cloud service, incorporating this information, provides the fastest alternative which avoids the respective street segment and responds to the end user with the alternative route, along with the corresponding distance and estimated time, as shown in Figure 59.

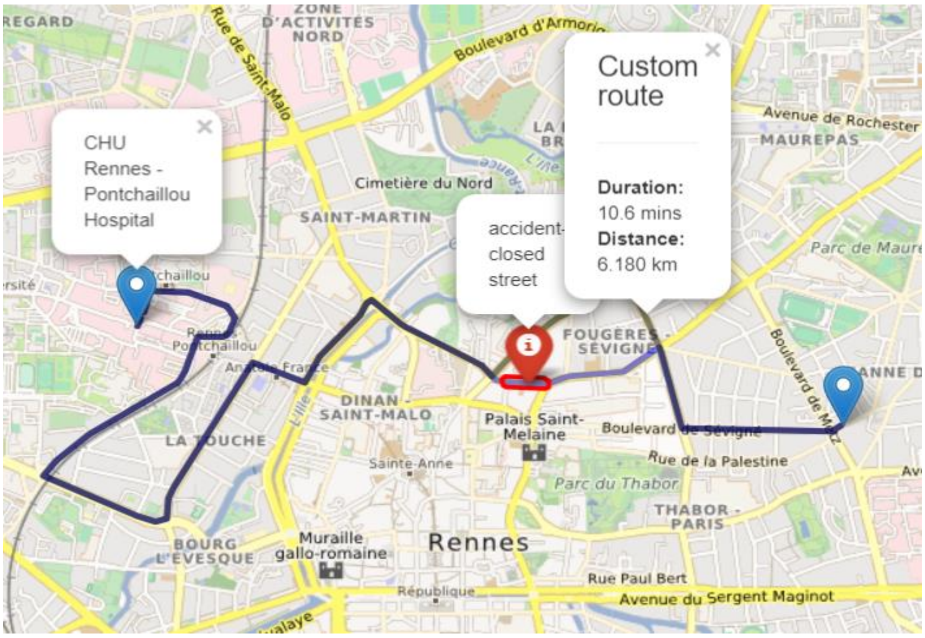


Figure 59. Custom routing of the ambulance, taking into account the information for accident and avoiding the respective street segment.

In the final 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 a video streaming, it will be crucial to maintain 5G connectivity throughout the journey. As shown below, from scattered point - measurements, a spatial 'heatmap' is created, representing the coverage of 5G in the area. The algorithm specifies the zones in the 'heatmap' that indicate low/no 5G connectivity based on a configurable threshold and provides the end user the fastest available route that avoids the specified zones as shown below. In the left part of the figure Yellow/light green colours represent areas with no/low 5G coverage while on the right: the alternative route is shown instead of the fastest one, avoiding the zones defined as 'no - 5G coverage', as shown in Figure 60.

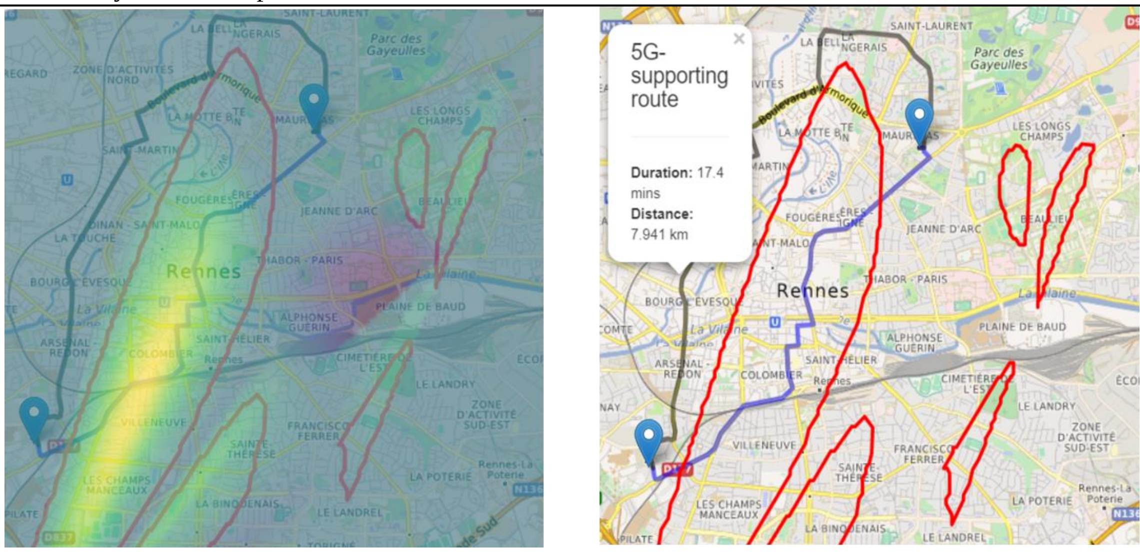


Figure 60. A 5G - 'heatmap' based on simulation data.

Furthermore, to illustrate the decision-making system of the algorithm, further elaboration of the aforementioned scenario is examined. In particular, assuming a patient condition in which flawless high-quality video streaming and transporting the patient to the hospital as fast as possible are of equal importance, a decision needs to be made regarding the route to be chosen. As illustrated in Figure 61 and Figure 62, the algorithm takes into account the extend of the intersection of the shortest route with the areas that do not provide 5G coverage and the gain in terms of time of the shortest route compared to the route that provides constant 5G coverage and balances the costs, to output its final decision. Figure 61 depicts in the left side the shortest route in blue, the route ensuring 5G coverage in black, and the area with no/low 5G coverage in red. In the right part of Figure 60 the part of the shortest route intersecting with the area with no/low 5G coverage is shown in yellow. The length of these segments is the weight for the cost of the route – the longer the part with no 5G-coverage, the less likely it is for the route to be selected.

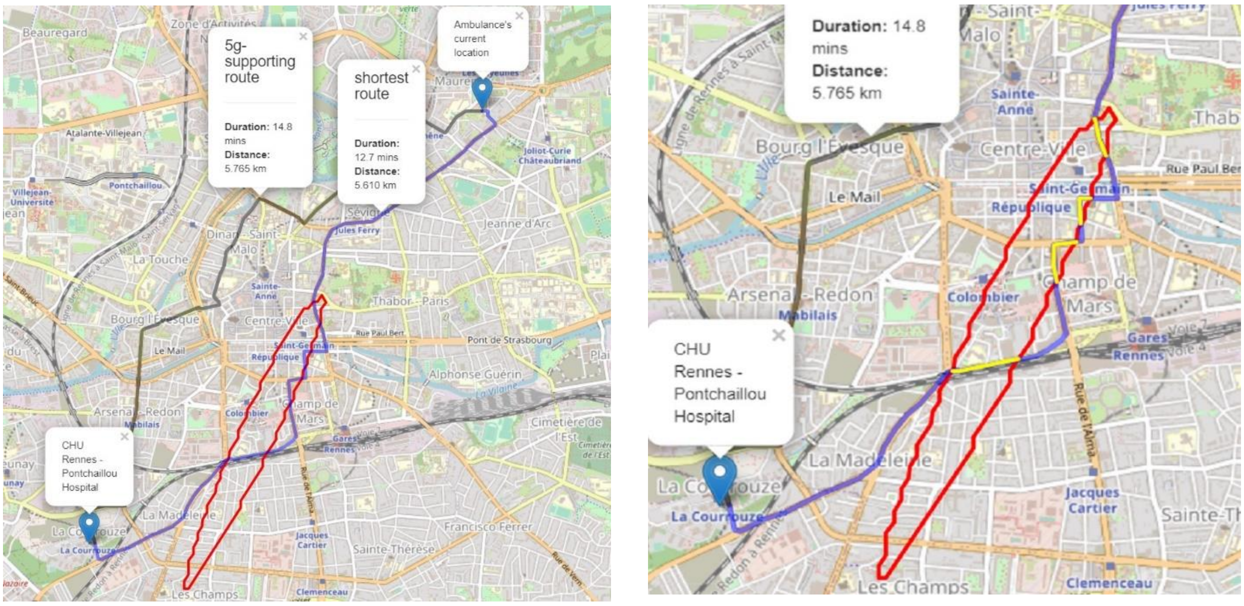


Figure 61. Left: Shortest route (blue) and route ensuring 5G coverage (black). Right: Part of the shortest route intersecting with the area with no/low 5G-coverage shown with yellow.

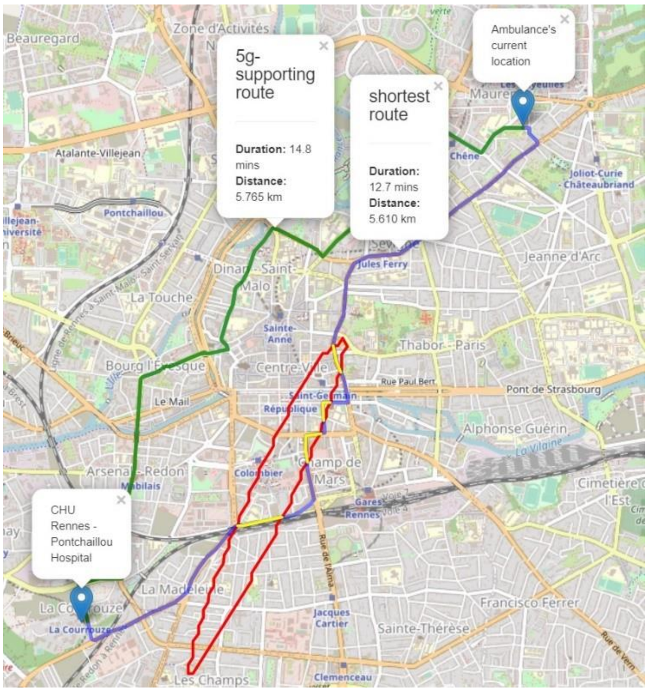


Figure 62. Selected route ensuring 5G coverage (green)

Figure 62 displays the selected route that ensures 5G coverage. This is selected as the cost of the shortest route due to the parts not providing 5G-coverage is considered bigger than the gain in terms of time. The implementation of the algorithm offers configurable factors. Figure 63 and Figure 64 show two possible visualizations of the ambulance dashboard incorporating this functionality.

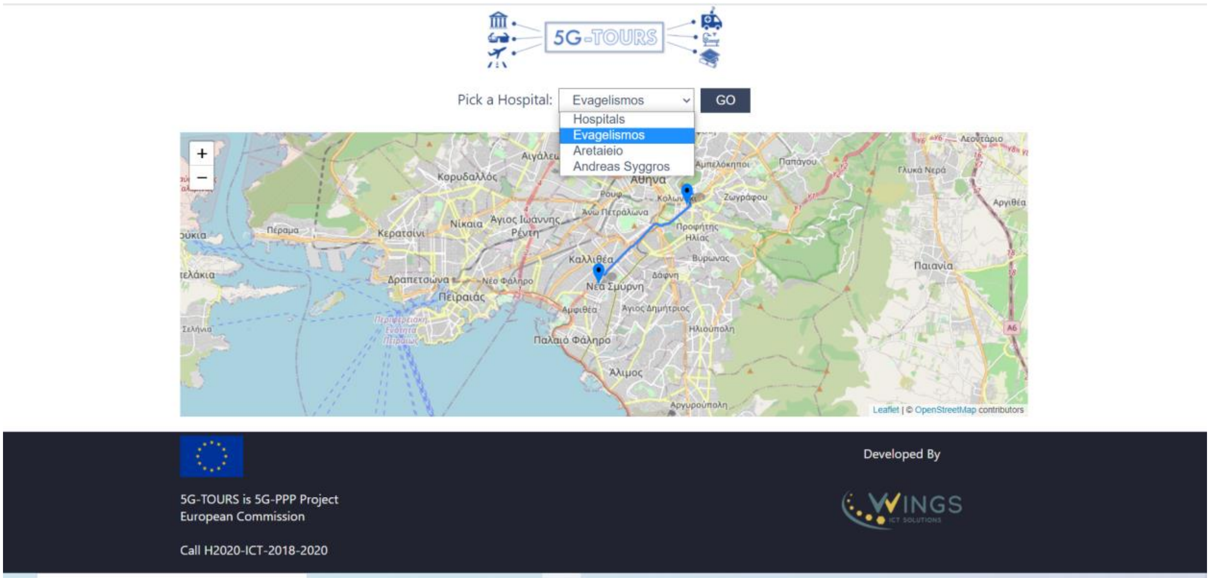


Figure 63. Ambulance dashboard view: Dispatch Centre / hospital selection.

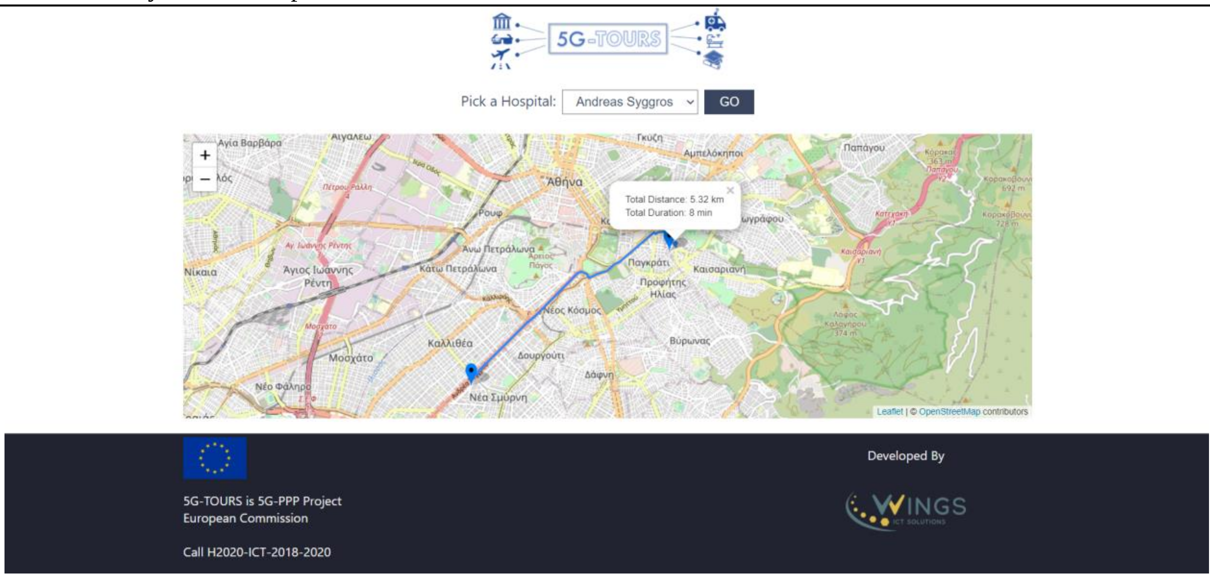


Figure 64. Ambulance dashboard view: optimal route visualisation.

6.4 Test in the network

Testing options in Rennes are slightly restricted because only a commercial LTE-M network is available in Rennes. In a future phase where there may be a deployment of 5G technology, tests are planned related to the collection of information and the prioritization of ambulance routing traffic. Initial testing will also be performed via the Athens site. The KPIs that will be collected are latency (round trip time) and throughput.

In terms of 5G-TOURS network innovation aspects, the plan for the optimal ambulance routing use case is outlined in Table 7. As in case of use case 6 these will be tested only on the Greek node as this is connected to additional work performed in the scope of WP3 and WP7, which cannot be supported by the Rennes site. This work on AI enhanced MANO and diagnostics is implemented using OSM whereas in the Rennes site ONAP for VNF management is used. Moreover, the connected performance diagnosis tools require additional metrics and KPIs (e.g. VM/Container metrics, link metrics, application level metrics etc) that are not offered by the Rennes site.

Table 7. Network related innovation aspects for UC9.

	Network Innovation		
Use cases	**Service layer**	**Enhanced orchestration**	**Other**
Optimal ambulance routing	Active Performance Measurement while the Service is Running (on the Greek node). This is shown to the customer through the service layer interface.	Resource allocation, deployment and migration of Network Services in an automatic and optimized way using various metrics (infrastructure, VNFs, Applications, etc) and verticals' requirements. (5G EVE OSM upgrade, Greek node)	Correlation of user QoE (WP7) with Active Service KPIs to identify relation between network performance, Quantitative Service KPIs and QoE.

7 WP Workplan

7.1 Milestone description

The overall planning of deliverable work and milestones – as described in D5.1 [24] – is depicted inFigure 65. The planned deliverables of these milestones are the following:

- M1: use case overall design, network and application requirements analysis;
- M2: use case first implementation tested in lab environment;
- M3: use case first implementation tested on initial network infrastructure;
- M4: use case first implementation evaluated on initial network infrastructure;
- M5: use case second implementation evaluated on pre-commercial network infrastructure.

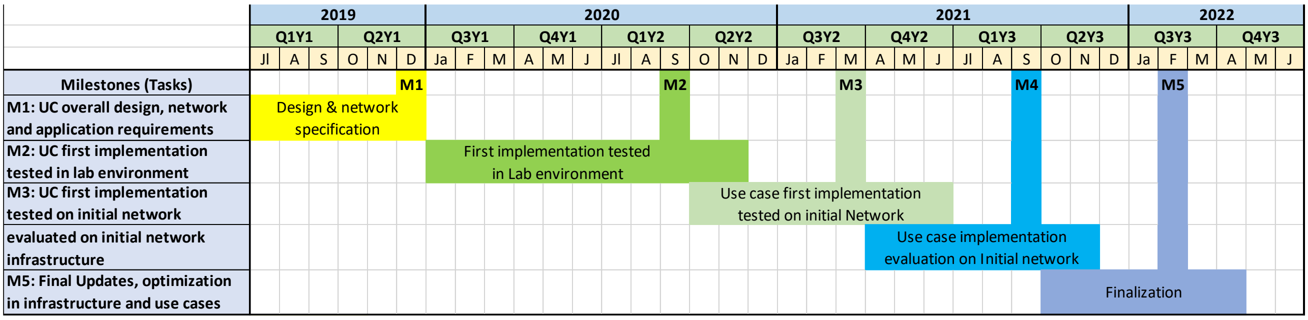


Figure 65. Overall planning of milestones and associated work.

The different tasks that are associated with these milestones are typically overlapping. For example, testing of use case implementations on (initial) network infrastructure is done while use case implementation work is still in progress. This is illustrated in Figure 65.

7.2 Deviation from work plan, risks and mitigation actions

All partners in WP5 have already passed milestone M1 and have thus finalized the overall design of network and application requirements analysis. With respect to the other milestones, some deviation has occurred, mainly related to COVID-19 lockdown measures and the recent change of available frequencies for experimental 5G networks in France as decided by French authorities. Because of this, the original planning for UC7 and UC8 has shifted more than 3 months. The updated time plan for the implementation of WP5 [24] is illustrated in Figure 66. As shown, a slight delay is expected but it is still expected that the project goals are achieved by the end of the project.

Year	2020					2021												2022				
Quarter	Q1Y2		Q2Y2			Q3Y2			Q4Y2			Q1Y3			Q2Y3			Q3Y3			Q4Y3	
Project Month	M15	M16	M17	M18	M19	M20	M21	M22	M23	M24	M25	M26	M27	M28	M29	M30	M31	M32	M33	M34	M35	M36
Original Milestone		M2						M3						M4					M5			
Month-Year	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M
UC6		M2						M3							M4					M5		
UC7					M2						M3						M4				M5	
UC8						M2						M3					M4				M5	
UC9		M2						M3							M4					M5		

Figure 66. Time plan for the implementation of WP5.

Notably, the COVID-19 crisis has caused considerable delay and it will continue to have impact on WP5 progress and our way of working in 2021. In particular the following issues need to be addressed:

- Travel restrictions make it impossible for all UC7 partners to meet and do joint integrations on site.

  We plan to address this through more frequent online meetings and regular exchange of software and hardware equipment to enable development and test at multiple sites.

- Most company office spaces and test labs have been inaccessible and continue to be so during the second lock down in December 2020 – January 2021. This causes delay in the installation of equipment, network infrastructure and prototyping / testing. In particular, the Rennes University Hospital

(CHU) has been and still is only accessible to medical personnel and patients. This has a big impact on UC8, since it needs to setup the Wireless Operating Room: the space designated as the wireless operating room is completely locked down, so no equipment installations are possible.

We plan to address this issue by changing the location of the WOR from the real medical environment at the hospital to a test lab area at BCOM. This means that some of the medical equipment cannot be integrated into the test setup but must be emulated instead.

- The delivery of medical ultrasound probes to CHU and AMA was delayed for three months, because these were needed elsewhere, in particular to diagnose patients with COVID-19.

  Three probes have now been delivered to the Rennes University Hospital. These are the Lumify S4-1 broadband phased array probe, the Lumify C5-2 broadband curved array transducer and the Lumify L12-4 broadband linear array transducer [13]. One of these probes will be used by AMA for integration and test.

- The Rennes University hospital was and still is fully overloaded with COVID-19 patients, leaving no time for doing project related work.

  We address this in the project by doing usability tests on teleguided ultrasound diagnostics (UC7) on site at the High-Tech Campus in Eindhoven with real doctors and paramedics, see section 4.5. The chosen area is the 5GHUB test lab of Ericsson and Vodafone and contains an indoor 5G RAN.

- AMA has been fully overloaded for several months with requests to deploy their remote video communication solution for medical tele-consultation purposes to prevent physical contact between (COVID-19) patients and healthcare providers – such as GPs – as much as possible. Therefore, AMA could not work on 5G-TOURS related tasks.

  This issue has now been handled by AMA. This has resulted in a first working demonstrator of remote ultrasound at BCOM in October 2020 over a 5G network, see section 4.2.

Other issues are related to the recent change of available frequencies for experimental 5G networks in France and the absence of an experimental mMTC 5G network:

- The delivery of network equipment is delayed, because production factories were temporarily closed (due to COVID-19), but more important, the recent change of available frequencies require significant equipment updates.

  The commercial offer between Nokia (Bell-labs and Business) and BCOM has been issued and accepted. The integration of the equipment and the WEF started in Dec 2020 and should be continued in early 2021. This lab staging is important before a field trial. Meanwhile, NOKIA is working on a delivery of new release of the Remote Radio Head (RRH). In parallel, we are also working on a test setup based on the Amarisoft 5G RAN in the 3,5GHz band, but this option has some limitations in terms of throughput and latency.

- There is still no experimental 5G mMTC network available in Rennes that connects to 5G EVE. So there is no possibility to use the new network technologies being developed in 5G EVE and 5G-TOURS, such as the service layer that will enable slice creation. This has impact on UC6 and UC9. To make sure that new 5G releases can be used and tested for the mMTC related use cases UC6 and UC9, the Greek 5G node in Athens is used instead.

8 Conclusion

This deliverable report describes the work progress in the “Safe City” work package (WP5). It provides a detailed description of the current status of the design and implementation for the four use cases in WP5 (UC6, UC7, UC8, UC9) that will be demonstrated in Rennes. For each UC, this document presented the status of the architecture design, the network design and respective equipment to be deployed for the implementation of the pilots, the terminal equipment to be used as well as the application development progress for each one of the trials for the evaluation of the solutions according to the expected KPIs. Furthermore, a new WP5 time plan has been created for the second period of the 5G-TOURS project, taking into account delays suffered so far and new ways of working due to current and future COVID-19 measures that restrict social interactions and travel.

With respect to UC6, the current version of the application and application dashboard has been shaped based on feedback from the Rennes University Hospital (CHU Rennes). This concerns the vital signs to be monitored and the corresponding types of devices to be used. Further improvements of the dashboard are also based on close cooperation with CHU, e.g. support for concurrent monitoring of multiple patients on one screen and at multiple locations. The dashboard’s main functionality is completed, i.e. presentation of the monitored data in a user-friendly format as well as the display of alarms in case an anomaly is detected. Multiple wearable devices have been integrated, while work is ongoing to integrate additional Sequans devices.

Concerning UC7, considerable progress has been made to integrate the XpertEye video communication solution of AMA with the Lumify ultra-portable ultrasound solution of Philips. Also, it has been demonstrated that AMA’s video communication services can be deployed as virtual network functions in a virtual user plane running on a 5G edge node at BCOM, while user equipment communicate through a 5G base station that connects to the edge node. In parallel, various user test were performed to assess the medical relevance and user friendliness. To mention are the user tests performed in Eindhoven with real doctors and paramedics on how to use a variety of cameras and camera positions to improve tele-guided ultrasound diagnostics. Major conclusion is that all the evaluated camera solutions caused usability issues, where the tablet camera seemed to be the most suitable to avoid blocking the view on the ultrasound probe. Detailed conclusions are described in in this report (section 4.5.2). Based on these results, new experiments in 2021 will address the user experience and usability of integrating the ultrasound function as well as the probe-camera function in the XpertEye smart glass solution provided by AMA.

The setup of equipment in the operating room for UC8 has been hampered because CHU has been inaccessible for most of 2020 to non-medical staff due to COVID-19 measures imposed nationally and locally. This has been countered by installing the equipment at a different location, i.e. at BCOM premises. Although not all radiology equipment could be available at BCOM, real-time ultrasound and DICOM real-time video communication has been demonstrated using a 5G base station with a local virtual UPF running the required algorithms as virtual network functions.

With respect to UC9, the solution has been reshaped to clearly showcase the use of 5G technology and 5G-TOURS network innovations such as the service layer and enhanced orchestration mechanisms. To this purpose, the application will now also support video communication through the ambulance dashboard – if the patient status requires it – and if there is sufficient 5G coverage on the available routes. A new version of the optimal ambulance routing algorithm and ambulance dashboard – displaying information on the route – has been implemented.

Testing options in Rennes are restricted for UC6 and UC9, as currently, only the commercial network in Rennes can be used. Therefore, in 2021 testing will also be performed via the Athens site. The next steps for UC6 and UC9 include testing, measurement collections and analysis as well as integration with key 5G-TOURS network innovations such as Service layer, Enhanced orchestration, and diagnostics.

The integration of UC7 and UC8 conducted recently in October 2020 was successful. This milestone helped the use-case owners to integrate for the first time the different and heterogeneous buildings blocks at network and application levels. The 5G-CORE has been validated. At the application level, the transmission of the videos streams has been tested in the uplink. This first lab trial has validated the use-case in terms of connecting all the components (PNFs and VNFs) and running the first end-to-end transmission. It was the opportunity to show the results to CHU medical doctors (who attended the workshop) and get their feedback on the relevance of the use-case and the need to ease the usage for a non-telecom user. At the performance level, this trial showed us clearly the need to improve the monitoring framework to collect the targeted KPIs for the forthcoming milestones. Also, the optimisation of different networking parameters (throughput, multicast, latency) has been identified as another area to investigate further for next milestones and to meet the use-case requirements.

With the above, this document has clearly identified the functionality already implemented by the different UCs, as well as the different pieces that still need to be realized to achieve these objectives. Furthermore, this deliverable document serves as a reference for the evaluation of the progress made in comparison to the agreed UC implementation time plan as presented in the deliverable D5.1[24]and internal report IR5.1 [50]. It will be updated in due time, to capture further UCs implementation progress.

It is noteworthy that the content in this document is strictly aligned, on several levels, with 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 level.

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