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

Deliverable D5.1
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List of Acronyms and Abbreviations

AAL	Active Assisted Living
AGV	Automated Guided Vehicle
API	Application Programming Interface
AR	Augmented Reality
CHU	Centre Hospitalier Régional (*University Hospital)*
CO	Carbon dioxide
CoAP	Constrained Application Protocol
CPE	Customer-premises equipment
CT	Computerized Tomography
DB	Database
DICOM	Digital Imaging and Communications in Medicine
ECG/EKG	Electrocardiography
eMBB	enhanced Mobile Broadband
EMR	Electronic Medical Record
FAST	Focused Assessment with Sonography for Trauma
GPRS	General Packet Radio Services
HDFS	Hadoop Distributed File System
GUI	Graphical User Interface
HTML	Hypertext Markup Language
KPI	Key Performance Indicator
LoRa	Long Range
LwM2M	Lightweight Machine to Machine
mMTC	massive Machine Type Communications
MQTT	Message Queuing Telemetry Transport
NB-IoT	Narrow-Band Internet of Things
NR	New Radio
noSQL	Non-Structural Query Language
OR	Operating Room
REST	Representational State Transfer
RF	Radio-Frequency
RGB-D	Red Green Blue - Depth
RTV	Real-Time Video
SMPTE	Society of Motion Picture and Television Engineers
ST	STandard
STARLIT	Smart living platform powered by ArtIficial intelligence & robust IoT connectivity
UC	Use Case
UI	User Interface
URLLC	Ultra-Reliable Low Latency Communications
US	Ultrasound
USRP	Universal Software Radio Peripheral
vEPC	virtualized Evolved Packet Core
WiFi	IEEE 802.11x
XA	X-Ray Angiography

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Executive Summary

In the 5G-TOURS vision, the Safe city use case family demonstrates the ability of 5G to provide services enabling a (possibly fragile) person to have a *safe trip* (e.g., for touristic purposes). A typical scenario is a person (under-age or adult), suffering from a chronic disease implying some risk of health complication. The goal is to provide travellers (but also citizens) with the warranty that, even in case of trouble, they will recover thanks to the proper management of an emergency situation.

This deliverable provides description of all applicative aspects on the use cases (UCs) being developed in the Safe City use cases implementation Work Package (WP5) of the 5G-TOURS project. The document provides a description of the specific use cases addressed for the safe city of the project and the associated trials, which are based on the Rennes node of 5G-TOURS.

The following use cases for safe cities will be covered in this document:

- Use case 6 - Remote health monitoring and emergency situation notification. This use case addresses solutions for remote health monitoring of people, especially when already diagnosed with a critical disease; such a solution includes consultation with remote medical attendants, collaboration between remote and local medical personnel and leveraging advanced technology to detect medical conditions that require immediate attention.
- Use case 7 - Teleguidance for diagnostics and intervention support. This use case aims to improve the quality of first intervention on site in emergency care; to this end, 5G technology is leveraged to provide teleguidance, enabling the on-the-spot, direct treatment of the patient under the guidance of a remote expert so as to prevent further, and potentially irreversible, deterioration of the condition of the patient.
- Use case 8 - Wireless operating room. This use case provides a more flexible and effective operating room (OR) that leverages wireless communications based on 5G to provide the following enhanced medical equipment: i) converstion to and from DICOM-RTV, ii) Mosaic display, iii) AR application, iv) distribution application, and v) tele-mentoring application.
- Use case 9 - Optimal ambulance routing. 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.

For each of the above use cases, this document provides: (i) a use case description from the user perspective, (ii) the application components, i.e., the prototypes, elements that are needed to implement and validate the use cases, (iii) the network component/functions, involving the network elements that need to be supported by the underlying platform, (iv) the trial description, including the setup of the trial, persons and the equipment needed for the trial, (v) the timeline plan and evaluation methodology.

This deliverable further presents an analysis of the requirements that need to be satisfied from the network side in order to enable the realisation of these use cases. This analysis shows that these use cases pose very stringent requirements on the underlying network which could not be possibly met with the legacy 4G technology and can only be satisfied with 5G.

The work performed in this deliverable serves the following purposes: i) it describes all the use cases in detail, motivating their need and the benefits that it brings to the respective vertical players, ii) it identifies the different components that need to be developed by WP5 in order to implement these use cases, including the application and the network level components, iii) it provides a plan for the tasks that need to be performed and their timing, towards the implementation of all the required components, iv) it identifies the required network deployment, to be performed jointly with the 5G-EVE project, and the corresponding 5G architecture, being addressed by WP3, and v) it provides the basis for the testing and the validation of the use cases, which will be aligned with the evaluation methodology being designed by WP7.

1 Introduction

5G technology has the potential to greatly improve safety in the city, by providing means to better assist health related care in all the phases before, during and after an incident. It can be leveraged to improve i) health monitoring for prevention and early detection as well as post operation follow-up, ii) diagnosis and intervention for emergency care in / around the ambulance, and iii) surgery at the wireless operation room in the hospital. Furthermore, 5G can be used to improve monitoring and remote assistance to all citizens and in particular to tourists from their home country, thanks to advance features such as secure communications, slicing and/or ultra-reliable low latency communication. Because of this, 5G is expected to act as a major growth driver for the healthcare sector, leading to lower costs and better outcomes in the transformation from volume-based care to value-based care. This is illustrated in Figure 1, which shows the 5G-TOURS safe city vision involving different aspects related to health and medical assistance.

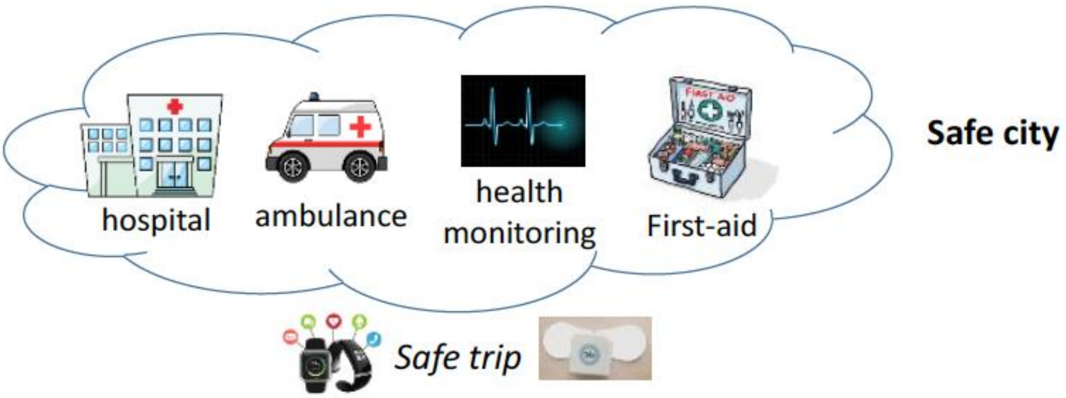

Figure 1: Safe city summary

WP5 contributes to the implementation of the safe city use cases, vertical solutions and trials deployment. This is related to the following objectives identified in the 5G-TOURS project Grant Agreement: objective 3 (Vertical solutions development), objective 4 (Trials deployment) and objective 5 (Use cases deployment).

To achieve the above objectives, the use cases for the safe city will involve real users and healthcare professionals, but they will not involve not real patients (which will be replaced by phantoms). The trials will be performed in real environments (hospital, operating room, ambulance; etc.) with real users, and will rely on phantoms and simulators at the patient level in order to proceed step by step towards a deployment. The use cases will rely on existing prototypes of vertical applications, which will eventually be connected with pre-commercial 5G network infrastructure developed by other 5G TOURS work packages (in particular, in WP3).

The rest of this document is structured as follows. Chapter 2 describes at a high level the vision of 5G-TOURS around the safe city. Chapter 3 describes in detail the envisaged use cases, exposing: i) the description of the use case from the perspective of the vertical end-customers, ii) the different components required from the application side, iii) the network components involved, including the terminal as well as the network side, and iv) the infrastructure deployment required to implement the use case. Chapter 4 identifies the requirements that need to be satisfied by the network for the envisaged use case; this analysis shows that 4G technology would not suffice to support the envisage functionality and 5G is required to this end. Chapter 5 explains the planned timeline to implement the use cases and finally Chapter 6 provides some conclusions and next steps.

The D5.1 deliverable is related with the following 5G-TOURS deliverables:

- It is aligned with the content of D2.1 in terms of use cases, deployment and techno-economic requirements. While this deliverable describes in detail the use cases related to the safe city, D2.1 presents a global view on all the use cases of the 5G-TOURS project.
- It is consistent with D3.1, which focuses on the baseline architecture and deployment objectives. The network architecture described in D3.1 is employed to implement the use cases described here.

- It will provide content to D2.2 (Touristic city use cases, safe city use cases, mobility-efficient city use cases). D2.2 will provide a global view of all the use cases of the project in more detail than D2.1, and will be fed by the use cases details described here.
- Similar to the above, it will provide content to D2.3 (Technical requirement of the use cases, economic and deployment implications).
- It will also provide content to D7.3 (Final integrated 5G-TOURS ecosystem and technical validation results). In particular, D7.3 will validate the use cases based on the objectives identified in this deliverable.
- This deliverables follows the same overall structure as D4.1 and D6.1, which describe the touristic city and the mobility-efficient city use cases, respectively.

2 Overall safe city scenario

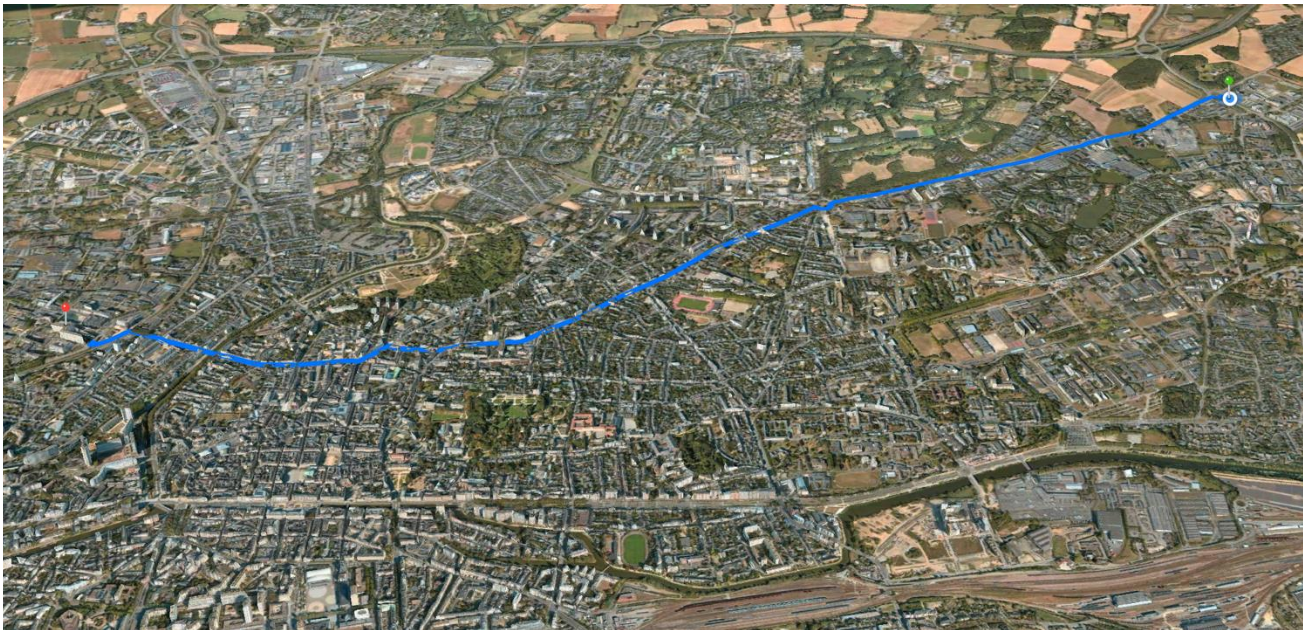

Figure 2: BCOM (green) to CHU (red) itinerary (6 km)

The different use cases in the Safe City WP are interlinked through an overall scenario, which is about a family from Turin visits Rennes, and the go out to the museums and the father is involved in a car accident, while the mother starts feeling breathless. The trials are performed at Rennes, where R&D activities in IT for healthcare (telemedicine, etc.) have been active for more than 30 years. In particular, the scenario involves a car accident and a worsening chronic medical condition respectively, requiring the following medical assistance (the Figure 2 shows the scenario localization, from the accident – in green – to the hospital – in red):

1. (UC6) Wireless monitoring of the chronic patient.
2. (UC7) Tele guidance provided by a medical expert located at the emergency centre to an ambulance doctor who is with the patient in order to perform a medical diagnosis and intervention.
3. (UC8) Minimally invasive surgical intervention in the wireless Operating Room (OR) at the hospital to treat the patient just brought in by the ambulance.
4. (UC9) Optimal ambulance routing for getting medical teams as quickly as possible to the place where medical help is needed and, transporting patients (one of the family members) to the hospital without delays.

More information about the encountered health problems and care needed is provided in the use case descriptions in the following sections. Furthermore, the tables below summarise the various types of communication over the 5G network, as required for each of the Safe City use cases (**Table 1**), and their relative impact on 5G network Key Performance Indicators (KPIs) (**Table 2**).

Table 1: Type of data communications for the Safe City use cases.

Use Case / Type of data communication	UC6	UC7	UC8	UC9
Real-time medical data / video streams		Ultrasound (US)	X-Ray, US, endoscopy	
Video		Camera, Smart glasses	Camera, Smart glasses	
Physiological signal	ECG?(1)	ECG		
Physiological parameter	Heart rate, breathing rate,	Heart rate		

Use Case / Type of data communication	UC6	UC7	UC8	UC9
	blood pressure, temperature			
Alerts	Heart related event	Medical alerts		Traffic accident and jams, road-works, demon-strations
Voice		Ambulance doc-tor/nurse, sonog-rapher, cardiolo-gist	Surgeon, doctor	

(1) in case heart rate is not sufficient

Table 2: Use case impact on 5G network KPIs.

Impact of 5G	UC6	UC7	UC8	UC9
Prioritisation of flows thanks to slicing technique enabling to ensure that critical communications are reliable	IoT/Narrow	High	High	IoT
Quality of assistance or guidance application due to synchronization thanks to low or ultra-low latency		High	Very-high	
Capacity of multiple simultaneous flow thanks to high or very-high bandwidth communication		High	Very-high	
Capacity of management of high number of simul-taneous sources communication from sensors	High (Patient sensors)			High (Smart city sensors)
Consistent communication infrastructure providing continuous communication based on multiple sup-ports			High (Reliable communication over NR, Wi-Fi, Ethernet)	

3 Use Cases detailed description

3.1 Use Case 6: Remote health monitoring and emergency situation notification

3.1.1 Use Case description

This use case addresses solutions for remote health monitoring of people, especially when already diagnosed with a critical disease (but still compatible with home care, e.g., some form of cardio vascular disease, hypertension, diabetes, etc.), offering them greater freedom of movement away from the home and/or a care facility. Such a solution includes consultation with remote medical attendants, collaboration between remote and local medical personnel and leveraging advanced technology to detect medical conditions that require immediate attention. The main features offered by this use case involve (a) remote health monitoring services leveraging a variety of data sources, including, but not limited to, vital signs, air quality, weather conditions, site waiting times, transportation, traffic and location, 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 use case will leverage wearable devices and patches tracking the tourist's vital signs and having them aggregated inside an IoT-based platform named STARLIT [1], provided by WINGS, where they will be processed in a combined fashion exploiting also various city sources through open APIs (e.g., Rennes Open Data Platform, Google Maps, Dark Sky API). STARLIT's outcome will be the identification or the prediction of a health-related emergency situation, which will be followed by the immediate notification of the nearest emergency care dispatch centre.

The overall story supposes Maria, the mother of the tourist family, to have a family history of chronic cardiac pathology and as such is medically followed by an Italian medical team. We will mainly focus of cardiac signals as well as of physical activity monitoring.

Various parameters related to health/vital signs of a traveller with a health condition are continuously collected from wearables along with other data relevant to the user's health condition. Parameters of interest include blood pressure, heart rate, saturation of oxygen, EKG, echography and CO levels if the patient is intubated. As actual patients/users will not be involved in the trials, measurements will be derived from emulated/users and potentially 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 appropriate dashboards. These dashboards will be implemented as a Web based User Interface (UI) exploiting software technologies such as HTML 5.0, Angular 8.4 with responsive design, etc. Thus, the dashboards 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 are raised (via pop-up windows in the dashboard, SMS and e-mail, depending on the preferences set by the users) to trigger the necessary actions (e.g., if the blood pressure or the heart rate are abnormal and cardiovascular disease is suspected, 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 (see also Use Case 9).

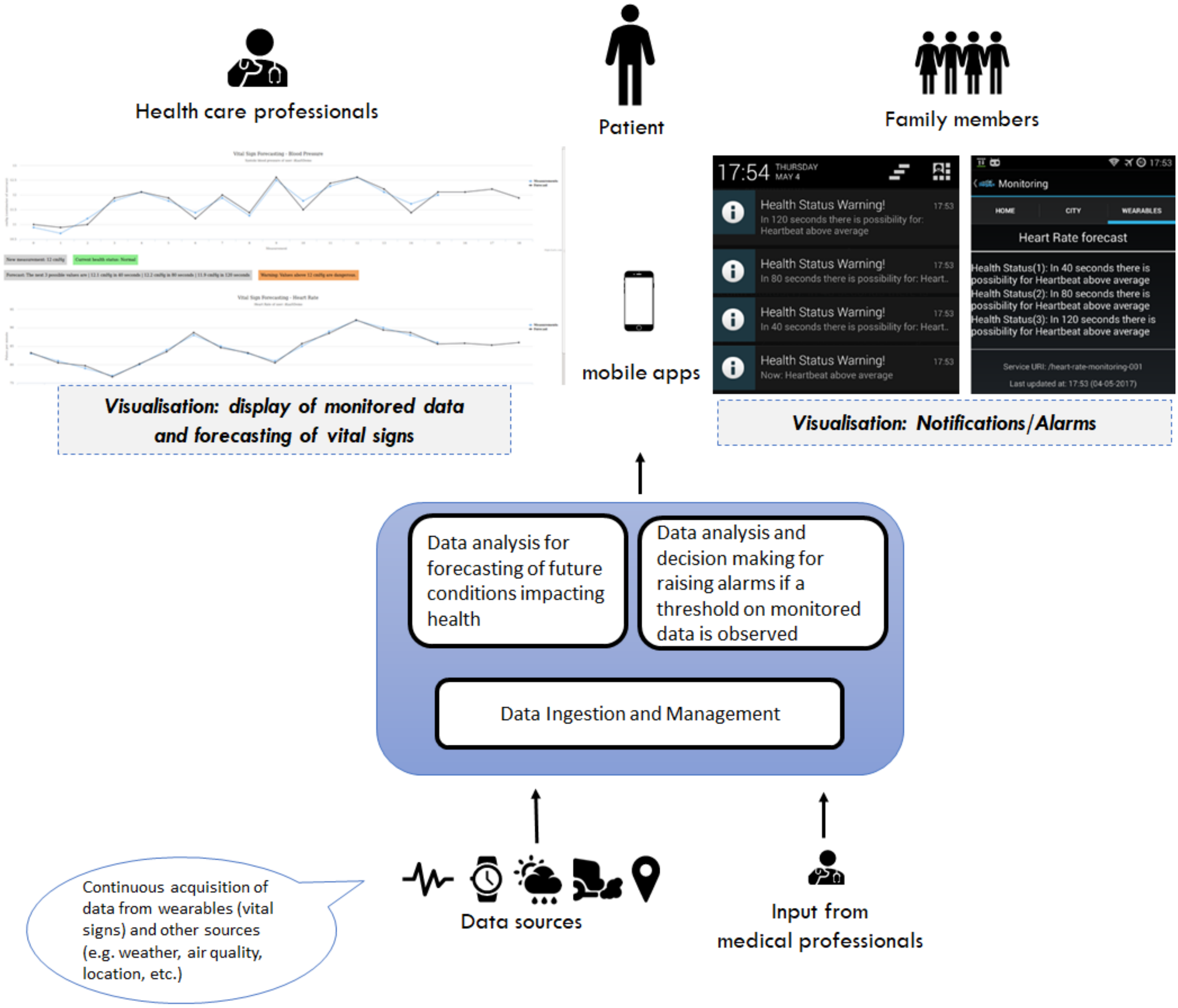

Figure 3: Remote health monitoring and emergency situation notification overview

3.1.2 Application Components

3.1.2.1 Overall architecture

Figure 4 depicts a high-level view of the architecture for remote health monitoring from an application perspective. The key components include:

- various data sources which may be accessed through open APIs (e.g., Dark Sky API [3] for weather) 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, and
- the various dashboards for the visualisation of health monitoring data, notifications and alerts towards the patient, family members, health care professionals and the ambulance dispatch centre.

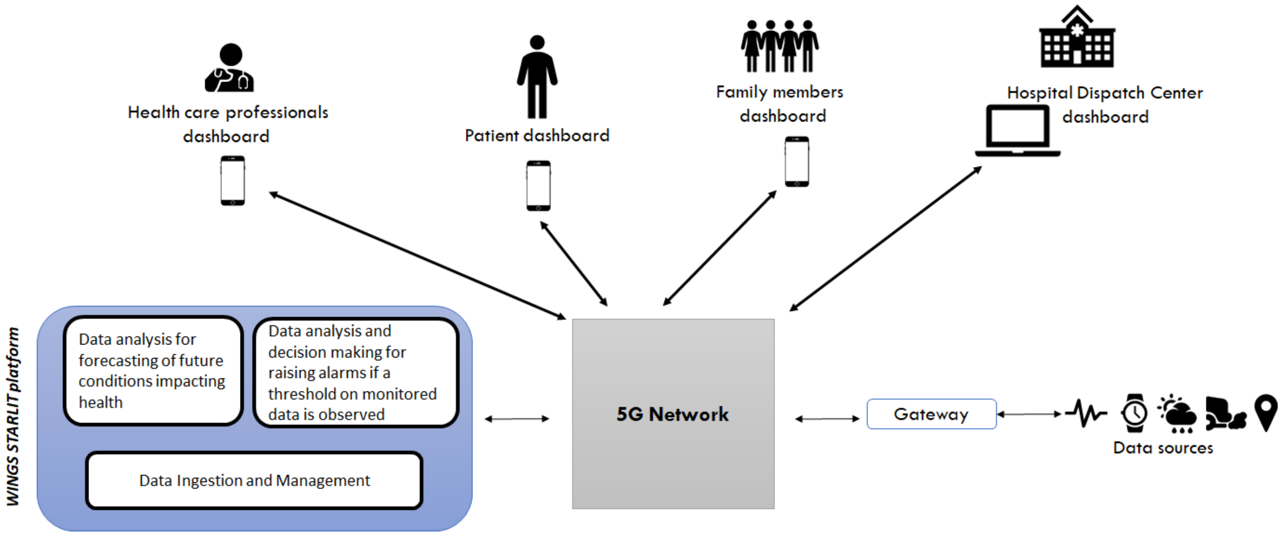

Figure 4: High level architecture for remote health monitoring

3.1.2.2 STARLIT platform

STARLIT is a cloud-based platform that interacts with sensors and actuators and comprises various capabilities. More specifically STARLIT comprises capabilities for self-management of services/application to facilitate greater flexibility, reliability and robustness. STARLIT also contains machine learning functionality (e.g., Bayesian statistics, time series forecasting, self-organising maps) for building knowledge and predicting contextual factors (e.g., traffic, pollution, parking space availability, user's vital signs evolution, etc.), the derived knowledge being exploitable for reliable raising of alarms, efficient recommendations, as well as application and system configuration. Moreover, STARLIT includes decision making capabilities for the autonomous selection of the optimal actions, while taking into account current context, user profiles and knowledge. For example, in the case of remote health monitoring, possible actions include raising an alarm towards patients, family members and designated medical professionals when a monitored vital sign has reached or is approaching a critical threshold. Figure 5 provides a more detailed view of the STARLIT functional architecture. The key components in the remote health monitoring use case are the data ingestion and management, the data analysis and the dashboards.

Overall, STARLIT can combine data from various devices (e.g., wearables for monitoring biometric data, sensors for monitoring temperature, humidity, luminosity, indoor and outdoor air quality, etc.) and also automatically control different types of actuators, such as lights, heating/cooling, but, as well as robots and Automatically Guided Vehicles (AGVs). STARLIT leverages diverse communication technologies and communication protocols. In terms of cloud deployment STARLIT components can be deployed as virtual machines and docker images.

The STARLIT data ingestion and management includes various functionalities for deriving the data from the various devices and delivering them to any other platform components, services and applications as well as triggering actuators.

The data ingested into the system are processed but also stored in a hybrid database system that is comprised of various types of databases (DBs) (e.g., NoSQL, HDFS based, etc.) for various types of information such as raw data from devices, knowledge derived through data analytics and learning mechanisms, or information on available devices and services.

Data analysis, insights and predictions is comprised of functionalities for monitoring, event-detection, forecasting of events and issues, large-scale data processing, image processing and automated decision making. The data analysis mechanisms continuously run, retrieving data from available data sources and applications and updating the inferred data and knowledge stored in the platform databases. These mechanisms also include Artificial Intelligence (AI) and machine learning functionality for building knowledge and predicting contextual factors from data, which can be characterized (at least) by high-velocity/volume/variability. Such mechanisms can be also used to empower decision making and can include Bayesian statistics [4], Time series forecasting [5], Self-Organising Maps (SOMs) [6], Deep Learning [7], Re-enforcement learning [8], and k-Nearest Neighbour(s) (k-NN[9]).

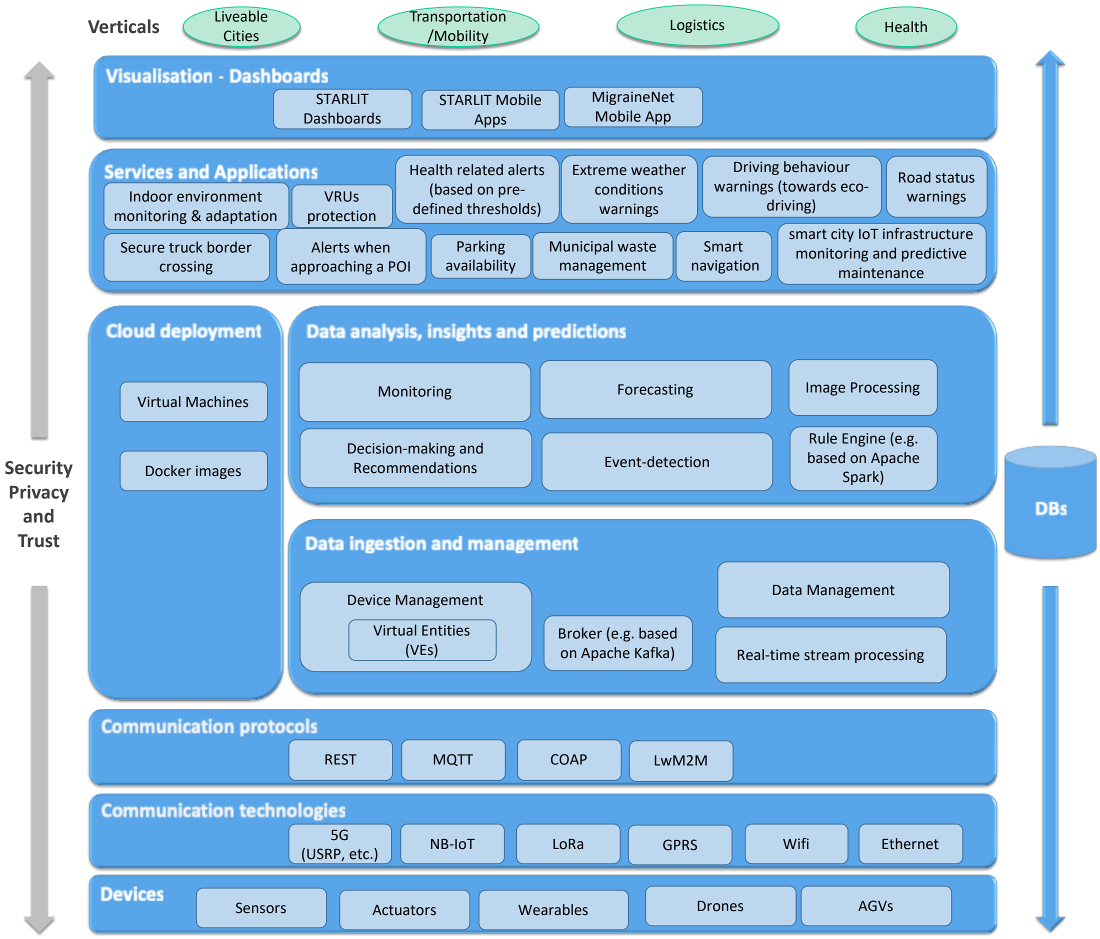

Figure 5: STARLIT functional architecture

As part of the STARLIT applications, dashboards are provided for visualization of measurements on interactive graphs, notifications and alerts. Real-time and historical data as well as forecasts/predictions can be depicted. Dashboards are provided as web-based UIs that can run from any tablet, smartphone or PC.

Finally, the STARLIT platform integrates an OpenStack software module, namely Keystone, to ensure data security and privacy both at the data and system level. Specifically, OpenStack Keystone is a security module complemented with a REST API that allows the access control of users, applications, etc. and is used to control the access on the data, ensuring at the same time their privacy. In addition to the above, the platform communications among the services/applications/user interactions are secured and the data are transferred as encrypted payloads based on trusted certificates. While no actual medical data will be used, rules for medical data and GDPR policies will be followed [20].

3.1.2.3 Devices and gateways

In the scope of health monitoring, it is envisaged to have a set of physical devices connected either via a 4G/5G smartphone (Samsung) through Bluetooth, a 5G CPE through Wi-Fi, or directly via a LTE-M / 5G-mMTC modem (Sequans chipsets), to showcase connectivity aspects. In the latter case, a gateway as depicted in Figure 4 and detailed in Figure 7 is required to connect the devices with the rest of the system (server at the edge or cloud platform). This gateway will be installed in close proximity to the devices and will be responsible i) for connecting the devices to the analysis platform, ii) for acquiring data (measurements) from the devices, iii) for performing some lightweight processing of these data and finally, iv) for transmitting them to the dedicated servers, using available communication technologies and protocols. Figure 6 presents an indicative version of the gateway, as well as its main specifications. As depicted in the figure, the gateway is included in a small box and is comprised of a digital board, a connectivity chipset, a battery and an RF antenna. The gateway in this use case will be smaller than the depicted one and light enough to be carried by a human without being a nuisance. The gateway will be connected to as many devices as required to obtain the parameters of interest (i.e. blood pressure, heart rate and oxygen saturation).

IoT gateway specifications
Protection Class: IP66/68,Flame Proof, Water Proof
Recommended Storage Temperature: + 30°C
Operating temperature: Min: -40C Max: +85C
Reading Methods: flexible to support different devices' protocols
Power source: Primary lithium battery
Input Voltage (Battery): Min: 3.2V Max: 4V
Current Consumption On Sleeping Mode: 5uA
Battery Main Characteristics: Voltage: 3.7V, Nominal capacity: 17.0 Ah, Maximum continuous current: 250 mA
Dimensions: H: 69mm L:125mm W:92mm
Typical weight: <700g
Relevant Certifications: CE, ISO9001:2015

Figure 6: Gateway (device and specifications)

Moreover, the gateway can apply consistency control techniques to the data, assuring their credibility and identifying/detecting potential errors. In summary, the gateway will read data from any connected device, will build the corresponding message with all the data, will perform basic calculations and/or complex computations if required (e.g., data transformation). Data will be transmitted to the edge server with the STARLIT platform intelligence in constant time intervals. Furthermore, data transmission will occur in cases of specific events (e.g., every time a value change more than % or an absolute value), using suitable technologies and protocols. The correct sequence of data will be guaranteed, as it won't be possible to transmit duplicate messages. Due to limited hardware capabilities, only short-term buffering will be supported. However, wide buffering of the data will be offered by the server at the edge.

These actual devices will be combined with emulated data (it was decided not to use data of actual patients given the complexity and legal issue of doing so) in order to carry out detailed evaluations, as well as to showcase also aspects such as scalability of the use case solutions. In other words, devices that are connected via precursor 5G technologies (NB-IoT, LTE-M), will send realistic (emulated) vitals in a network-technically realistic way, thus allowing the observation of real-world timings between physiological changes without the involvement of actual patients. Once 5G enabled devices are available they will be exploited as well.

3.1.3 Network Component/functions

An ultra-reliability / high availability / high coverage slice is required to ensure that the transmission of the measurements to STARLIT's intelligence is guaranteed, and triggers the appropriate notification actions (towards the user's family and designated medical professionals). An eMBB slice may also be required to enable live streaming of the user's condition (e.g., until an ambulance arrives).

3.1.4 Trial description

An overview of the trial architecture is depicted in Figure 7. In high-level terms the trial will evolve as follows. First, an ultra-reliability slice will be instantiated by the 5G-TOURS network orchestration and management to support remote health monitoring, as described in Deliverable D3.1. Measurements from the user's devices and other data sources will be sent to the STARLIT platform, through this slice, and the platform will process the measurements and will generate forecasts of the user's health status. The current and predicted values of the user's vital signs will be displayed on the various dashboards. If a monitored or forecasted value (e.g., heart rate or blood pressure) is outside the normal value ranges, an alert will be generated, and the appropriate health care professional will be notified. If deemed necessary by this health care professional then a notification will also be sent to the Ambulance Dispatch centre in order to send an ambulance to where the patient is located (see also section 3.4 Use Case 9: Optimal ambulance routing). In critical situations, the camera on the user's mobile phone (or one of his family members) can be activated for live video streaming until the ambulance arrives. During the whole flow of the scenario, network related KPIs will be displayed and recorded through the corresponding GUIs.

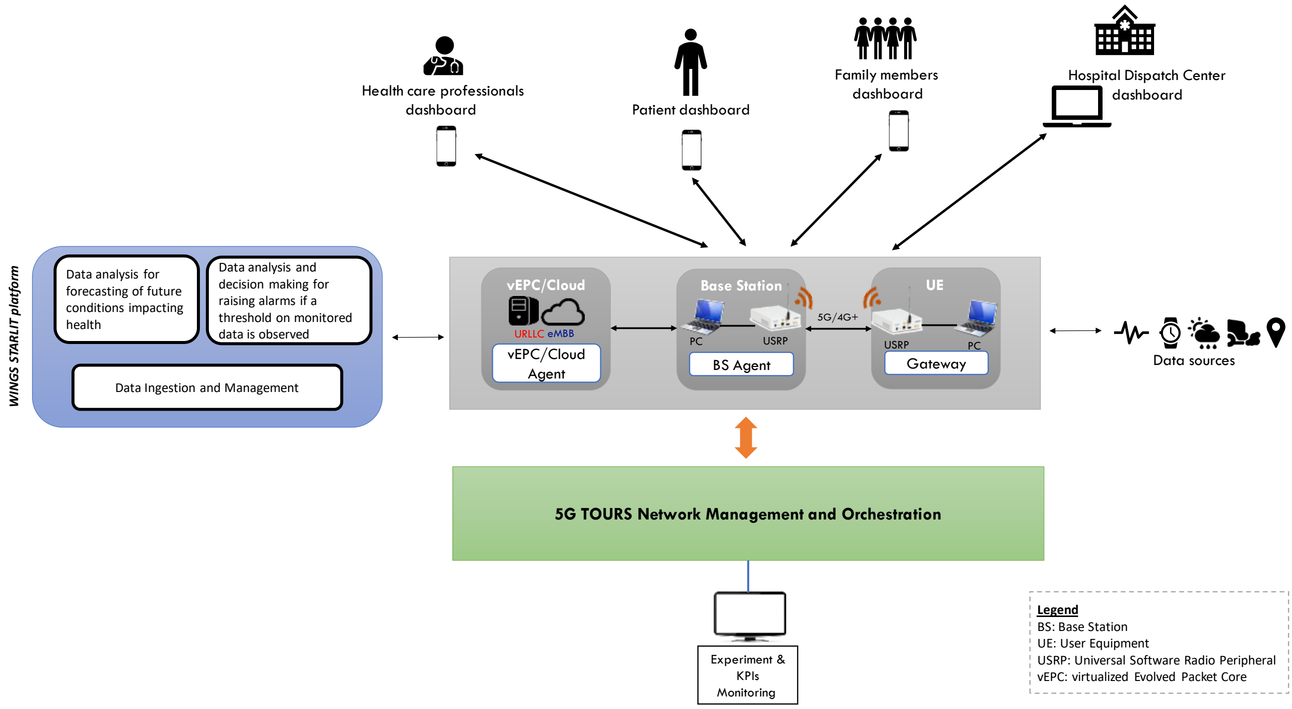

Figure 7: Health monitoring and incident-driven communications prioritisation trial architecture

Until an actual 5G network becomes available, 4G and Universal Software Radio Peripherals (USRPs) will be exploited for initial testing. The trial does not present increased in terms of bandwidth for the transmitted data. More important requirements include reliability (99.999%), availability (99.99%), coverage (99.99%), mobility (Up tp100Km/h) and location accuracy (≤200 m).

3.2 Use Case 7: Teleguidance for diagnostics and intervention support

3.2.1 Use Case Description

This use case aims to improve the quality of first intervention on site in emergency care, thanks to teleguidance.

In France, protocols for emergency care require the presence of at least one doctor in the ambulance, who is required to make a call to a regulator in the emergency care centre to discuss patient status and decide on clinical interventions. In addition, a medical specialist such as a cardiologist may be consulted in specific cases. These are the main roles in the scenarios described below, tied to three assumed locations (which are commonly under the responsibility of the Regional University Hospital, like CHU de Rennes for example):

- **The Regulator** is an experienced emergency care doctor, responsible for taking clinical decisions and selecting the most suitable hospital for the patient. There might be multiple remote experts involved, but for simplicity we assume a single Regulator role in these scenarios. The Regulator is assumed to work on the emergency ward of a hospital, and has the regular facilities of the ward at his disposal, but may also be burdened or limited by additional tasks he is performing there.
- **The Ambulance Doctor** is typically less experienced than the regulator, but may have some sonography skills. He can usually do basic ultrasound exams such as FAST: he judges whether the images are acquired correctly and communicates the result verbally to the Regulator. Emergency response teams may include additional staff, but again, for simplicity we condense the communication only to the Ambulance Doctor. The Ambulance Doctor who is assumed to be at a remote site. The Ambulance Doctor is assumed to work in the interior of the ambulance, but also at the location where the emergency is taking place.
- **The Medical Specialist** is a specialised doctor who may be asked for advice in difficult cases, e.g., cardiology related cases that may require tele-guidance for the acquisition of an echocardiogram and interpretation by a cardiologist. The medical specialist is typically located at the hospital.

For the interpretation of complex echocardiograms extensive study and practice is required for correct interpretation. The Ambulance Doctor may be able to correctly position the probe to acquire echocardiograms of sufficient diagnostic quality. However, he will still be dependent on the Regulator or an additional Medical Specialist (Cardiologist) to assist in diagnosing the data properly. Diagnosis and decision making can be considerably improved if the Regulator can see the patient through a live video stream, guide the Ambulance Doctor to perform an ultrasound exam (via a second live video stream from the Regulator / Cardiologist to the Ambulance Doctor) and watch the ultrasound stream in real time to make an accurate diagnosis. Such teleguidance is visualized in Figure 8.

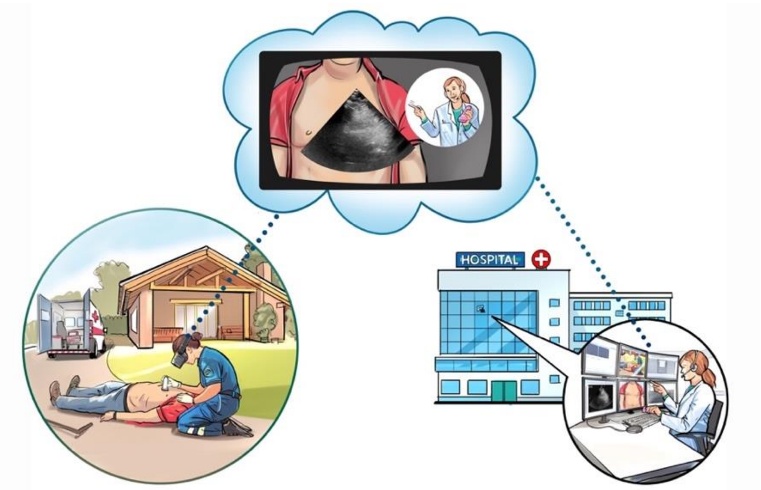

Figure 8: Teleguidance for echocardiography of by the Ambulance Doctor to the hospital-based Regulator.

In emergency care, teleguidance is especially important in case a patient is critically ill and will not survive transportation to the hospital, while it is difficult to diagnose the causes of this condition and not clear what to do. An example is the case where a patient is suffering from a cardiac arrest where immediate resuscitation is required. If the patient has no shockable rhythm, cardiopulmonary resuscitation (CPR) must be performed directly. At the same time, it must be diagnosed if there are any reversible causes of the arrest such as a pulmonary embolism, pulmonary oedema, a tension pneumothorax or a cardiac tamponade caused by a pericardial effusion must be diagnosed. Point of Care (PoC) ultrasound is an excellent tool for diagnosing such conditions. Together with the guidance and advanced interpretation skills delivered by the Regulator, has the potential to improve the quality of care for the patient.

Teleguidance can be done with 2D camera images, but it can be substantially improved by applying Augmented Reality. With advanced computer vision and 360° cameras, richer contextual information of the situation in the ambulance can be conveyed back to the Regulator at the hospital. Conversely, the guidance from the Regulator can be fed back into an augmentation for the Ambulance Doctor, enabling him to consume the feedback in a graphical fashion, and hands-free. The choice of technology for the Ambulance Doctor and Regulator depends on personal preferences, but also on the exact context and requirements of their work setting.

The scenario consists of a family from Turin who are doing a touristic tour in Brittany, thereby paying a visit to Rennes.

During the visit, one parent is involved in an accident and as a result is suffering from respiratory distress related to a pneumothorax and reduced heart function due to pericardial effusion.

The other parent who is staying at the hotel is suffering from breathlessness, related to aortic valve stenosis.

At the accident scene**:**

- A bystander discovers an accident on the road; a man alone in the car shows signs of **thoracic traumatism;**
- The bystander calls the emergency service;
- The Regulator starts handling the call and sends him an SMS (or an email) containing a WebRTC link that enables his smartphone camera to directly start streaming video to the Regulator's screen (via XpertEye's real time and secured communication services provided by AMA [25]);
- The Regulator sees through this secured real time video streaming session, signs of **respiratory distress** and therefore directly sends the medical team to the patient's location;
- The car accident generated a traffic jam and thus the 5G antenna is overloaded;
- When the Ambulance Doctor arrives at the scene, he is equipped with smart glasses that allows him to dodo live and secure video conferencing (using an advanced version of the same XpertEye), and he performs an ultrasound exam with a handheld ultrasound device. The Regulator provides guidance so that he holds the probe at the correct position. At the same time, the Regulator watches both the video of the probe position on the patient's chest and the live ultrasound image stream; All data transfer from the emergency team shall be treated as high priority and thus should not suffer on the overloaded 5G antenna.
- The Regulator now diagnoses a **tension pneumothorax** as well as pericardial effusion, which could lead to a **cardiac tamponade**.

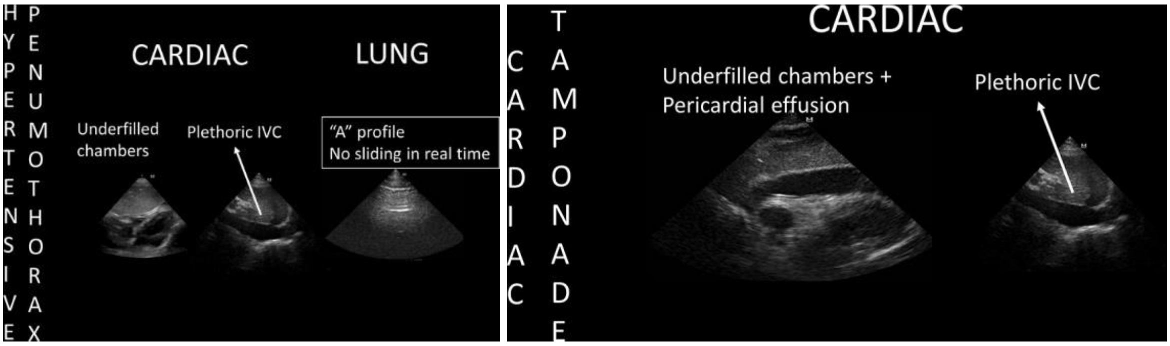

Figure 9: US B-Mode images of Hypertension pneumothorax a Cardiac tamponade [15]

- The Regulator and the Ambulance Doctor discuss the situation via a video conference;
- The Regulator decides that the situation is too critical and must be treated directly. The treatment is to directly **drain the tension pneumothorax**, which is done via an instrument - a needle that is handled by the Ambulance Doctor. The Regulator **guides the needle insertion based on the live ultrasound feed**. The Ambulance Doctor gets verbal and graphical instructions (displayed on the smart glasses screen) that show where he should put the ultrasound probe and where to insert the needle;
- By carefully watching the tip of the needle the Regulator gives immediate feedback on how to move and when to stop. At the same time, the immersive telepresence allows the Regulator to stay informed of the state of the patient without needing the Ambulance Doctor to explicitly provide feedback;
- After completion of the draining procedure, the patient must be transported as fast as possible to the hospital for surgery.
- The patient is monitored for the whole duration of the transportation, with particular focus on the heart;
- The **draining of cardiac tamponade can be done at any time if needed**, which becomes important in cases of e.g., a cardiac arrest. If so, this is again done with the assistance by teleguidance of the Regulator (or an additional cardiology expert).

Hotel scene**:**

- A woman wakes up suddenly in the middle of her nap. She had been bit sick for the past days but now she now experiences **breathlessness** and she feels **extremely uncomfortable**. She is anxious - looking for fresh air - but minute by minute she finds it even more difficult to breathe;
- Her daughter calls the emergency service and explains the situation;
- The Regulator sends an SMS (or an email) with a WebRTC link to start video communication with the patient's daughter and asks her to point the camera at her mother;
- The Regulator now gets a first impression of the condition and also shares the video in real-time with the ambulance team;
- The ambulance arrives in about 15 minutes, by which time, the patient is so stressed that it is impossible to communicate with her and get her back to a calm condition;
- With some difficulty, the Ambulance Doctor gets the patient to sit down in the ambulance with some oxygen. The Ambulance Doctor starts trying to understand the reason for this acute situation. At the same time, another member of the ambulance team, wearing AMA's smart glasses streams live video of the examination to the Regulator;
- The physical exam is difficult and there is a doubt about a murmur heard that might be linked to a severe aortic valve stenosis. This is something that might have a **significant importance for guiding the treatment** and the type of medication to be **administered in this emergency,** before that the patient and the ambulance reach an intensive care unit;
- An **echoscopy** is then performed, the **blood pressure** is measured and the **physical aspect of the patient** is shared through connected glasses with the cardiologist from the intensive care unit (Figure 10).

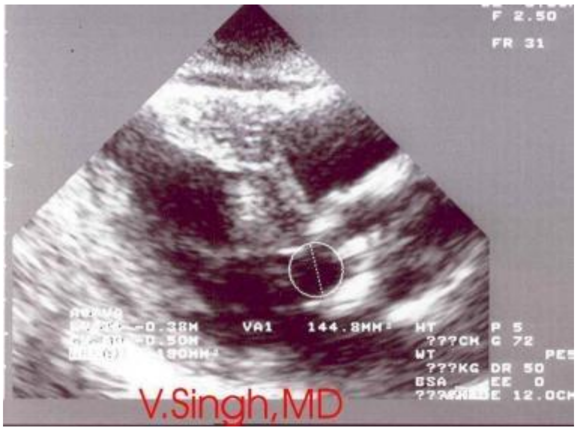

Figure 10: Aortic stenosis US B-Mode image [16]

- The Regulator now decides to switch the acquisition to continuous wave Doppler ultrasound, which provides a reliable estimate of the valvular gradient in most patients with aortic stenosis [17]. However, this is difficult to diagnose by untrained physicians. Therefore, the Regulator guides the Ambulance Doctor to appropriately place the ultrasound probe, and then remotely sets the acquisition to continuous wave Doppler (the Figure 11 shows a measurement of maximum velocity and tracing of the velocity curve to calculate mean pressure gradient).

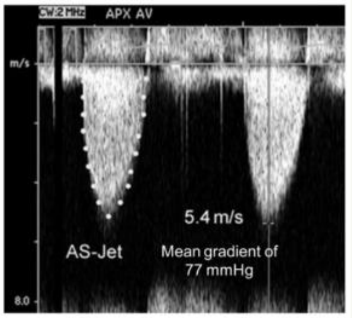

Figure 11: Continuous-wave Doppler of severe aortic stenosis [18]

- The **diagnosis of a highly calcified aortic valve stenosis** is made in the patient in combination with a low blood pressure and very high degree of pulmonary hypertension;
- A diuretic treatment is started directly to provide temporary symptom relief [19] while the blood pressure must be monitored continuously due to the potential for reduced LV diastolic filling, which may reduce cardiac output. All this data is directly shared with the Regulator and the Medical specialist (Cardiologist).

3.2.2 Application Components

3.2.2.1 Overall architecture

To enable effective teleguidance of emergency response staff for point of care emergency diagnostics and intervention, high bandwidth and reliable communication is required between the local Ambulance Doctor and the Regulator who resides in the hospital or in the emergency call centre. In particular, different types of data must be exchanged at high speed, including high resolution real-time audio, video and ultrasound streams, Electronic Medical Records (EMR) and vitals data such as EKGs. Figure 12 shows this in more detail (during the project, the expert cam will be limited to HD, contrary that the figure shows).

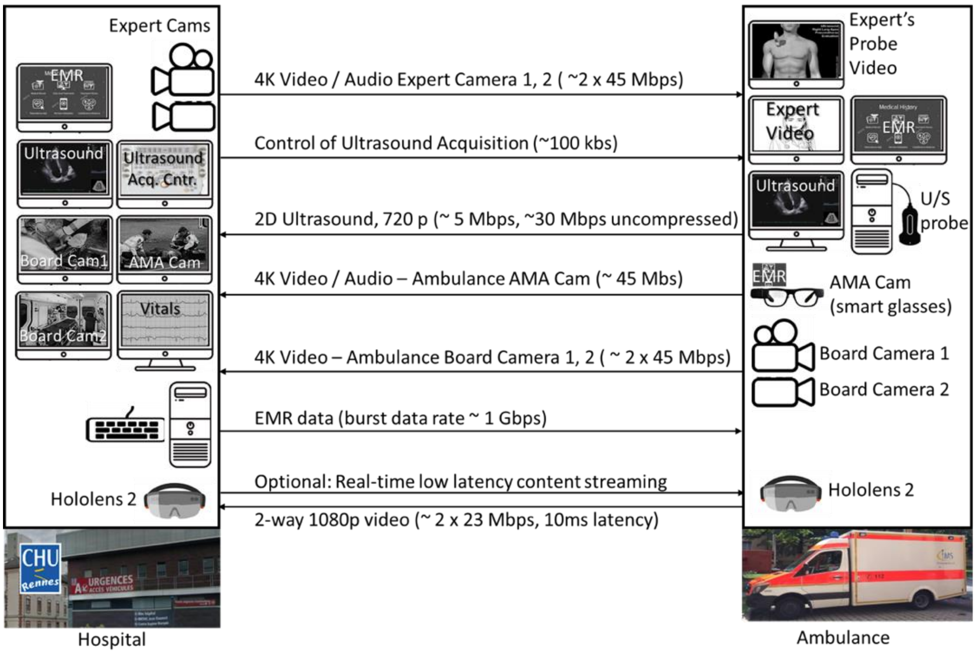

Figure 12: Solution components for tele-guided diagnosis and intervention for emergency care

3.2.3 Network Component/functions

With respect to the 5G infrastructure that is responsible for reliable exchange of the aforementioned data at sufficient quality and speed, it is expected that only the ambulance connects to a nearby 5G base station, while the hospital and/or emergency call centre directly connects to a high capacity backbone (Figure 13). In the circumstance that the hospital infrastructure turns out to be too slow or not reliable enough to guarantee the required Quality of Service (QoS), it may be considered to directly connect from the hospital to a 5G base station, via a 5G hospital network or CPE. This way QoS can be guaranteed by the 5G mobile network operator.

In the car accident, the objective is to also simulate a crowded antenna, such as a car accident is likely to create a big traffic jam generating a lot of data transfer to a specific antenna. All data transmitted by the ambulance and the first responder team shall be treated as priority and shall not suffer from the surrounding data traffic on this same antenna. Today, 4G networks in France are not able to provide such service, but this is a key requirement for all emergency services.

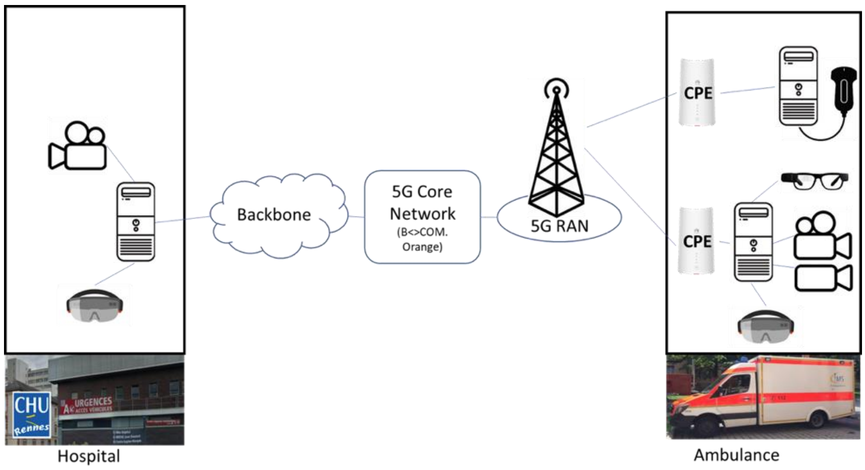

Figure 13: 5G network connectivity for tele-guided diagnosis and intervention for emergency care

Next, it needs to be determined whether there is a need for a single or several CPE devices or not, which may depend on the type (speed, reliability, latency) of required communication that is required. Another consideration is the integration of a base station into the ambulance (small cell), which would provide guaranteed coverages in the area of the ambulance.

3.2.4 Trial description

For the trial, equipment will be installed both in the ambulance and at the hospital. As Figure 12 and Figure 13 illustrate, this consists of the following hardware:

- Hospital:
  - Multiple high-resolution monitors (and racks to mount them), and computers that they connect to;
  - 4K cameras (one pointed at the medical expert / regulator and another one pointed at the probe that the medical expert is holding);
  - Ultrasound probe (possibly dummy probe) and ultrasound acquisition control software;
  - *Optional: Hololens 2 with associated equipment and software, or equivalent AR/VR headset;*
- Ambulance:
  - To show vitals, EMR data, expert videos, ultrasound: (either one of these options or combinations):
    - Multiple high-resolution monitors (with mounting rack) and computers that they connect to, or
    - AMA smart glasses (with cameras) with necessary equipment and software;
  - Lumify probe(s) with necessary computer hardware and software;
  - Fixed cameras (4K) in ambulance and AMA smart glasses with cameras (1080p));
  - *Optional: Hololens 2 with associated equipment and software, or equivalent AR/VR headset.*

With respect to software and (cloud / edge) services, the following must be in place:

- Real time communication services for all real-time data (WebRTC services);
- EMR access or simulator (due to security reasons connection to the real CHU de Rennes EMR is not feasible) & storage service;
- Ultrasound image quality assessment software;
- Simulator software services to generate appropriate ultrasound images related to cardiac problems.

3.3 Use Case 8: Wireless operating room

3.3.1 Use case description

This use case addresses a more flexible operating room (OR) thanks to the use of wireless communications based on 5G.
The driver with a severe headache and vision loss, origin of a car accident has been admitted at the CHU de Rennes by ambulance and directly transferred in the TherA-Image operating room [11] from the neuro and cardiovascular department, equipped with the most recent technologies, as shown in Figure 14.

Figure 14: TherA-Image Operating Room at the CHU de Rennes

The accident was in fact due to a stroke happening to the tourist patient secondary to a rupture from a cerebral aneurysm. The interventional procedure starts with a 3D Angiography X-Ray acquisition enabling to obtain the 3D volume of the aneurysm. Then, a cerebral aneurysm embolization is performed, guided by fluoroscopy, complemented by ultrasounds estimating the blood flow, and superimposed on the fluoroscopy image, using advanced segmentation and matching algorithms with an Augmented Reality application generating guidance image displayed on the wireless tablet. The use of complementary imaging sources, shown on the Figure 15 and Figure 16, is justified to limit the use of X-Ray and contrast product at the minimum.

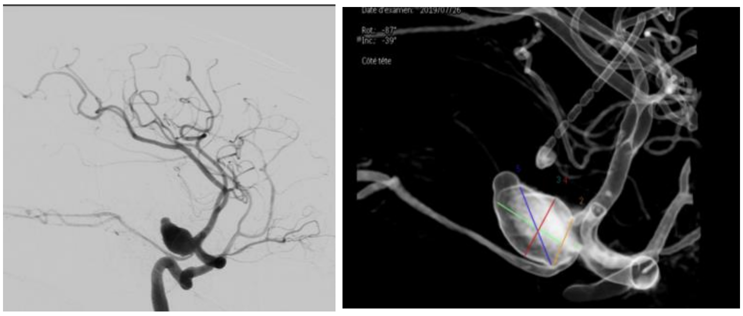

Figure 15: X-Ray Angiography and fluoroscopy

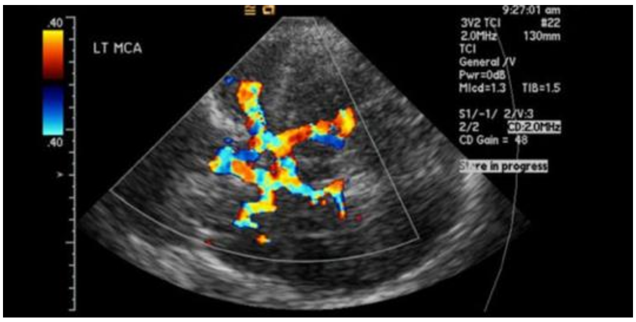

Figure 16: Transcranial ultrasounds

The cerebral embolization consists in inserting micro-catheter and placing many soft platinum coils into the aneurysm, as shown on the Figure 17.

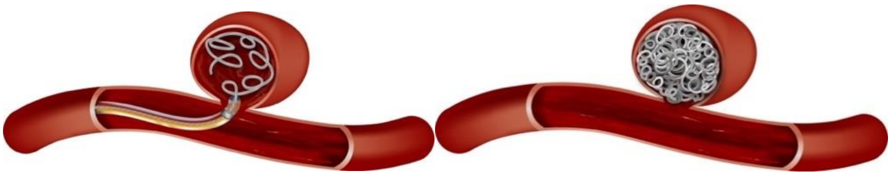

Figure 17: Aneurysm embolization

Note: the extension or replacement of the use case, in italic below, will be implemented only if possible.

In case it replaces the neuro use case (it the "neuro" phantom supporting ultrasounds are not available), the text above would be the following:

The accident 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.

Afterwards, the patient was treat, and while recovering from the heart failure, it was observed that he was suffering from breathlessness. However, he was actually suffering from a chronic heart failure, mainly right heart failure in a context of persistent atrial arrhythmia that was neglected for years.

The patient is symptomatic and it prevents him from recovering from his heart failure. It is thus required that he is examined echocardiography. A severe tricuspid regurgitation due to a severe atrial enlargement was observed. The medical treatment (diuretics) is optimized but the patient remains symptomatic and starts to get some degree of function renal dysfunction. Therefore, it is decided among the "heart team" to consider the correction of the tricuspid regurgitation [12]. *This procedure could require a surgical tricuspid valve replacement which is a problem for a patient initially hospitalized for an acute stroke. Then, a percutaneous treatment using clips is decided. This procedure requires the intervention of an invasive cardiologist, a surgeon, a cardiac imager for implanting the clips using the echocardiography guidance in addition to the use of the X-ray and some per-operative evaluations that are been done by cardiac CT and echocardiography (Figure 18).*

The tricuspid repair using clips is a new treatment that is quite challenging and not practiced by many surgeons across the world. It requires a collaboration among experts that are not necessarily onsite for the clips' implantation.

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, as shown on Figure 19.

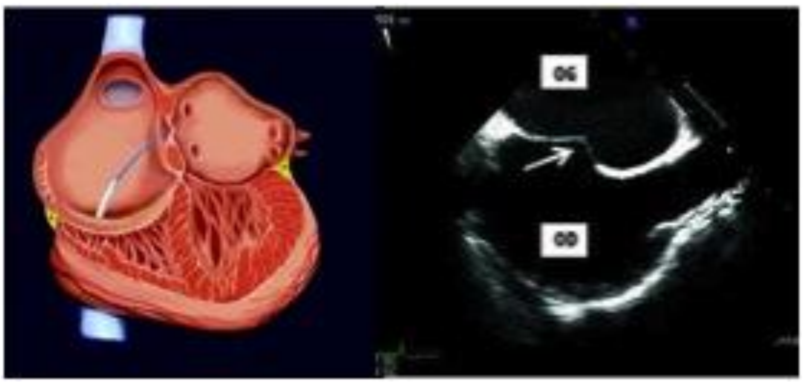

Figure 18: Transoesophagian ultrasounds

Figure 19: 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 [2] enabling synchronized real-time communication of video and associated metadata.

After the operation is performed, the patient is transferred to the hospital ward for a few days post-surgery.

3.3.2 Application Components

3.3.2.1 Overall architecture

As shown on the Figure 20, the following four devices are producing live video or medical imaging flows:

- C-Arm Interventional X-Ray producing fluoroscopy and angiography (XA X-Ray Angiography);
- Transcranial ultrasounds equipment (US Ultra-Sounds);
- Smart glasses (SC Secondary Capture), worn by the cardiologist;
- Overhead camera (SC) filming cardiologist's hands.

These video flows are received by four devices (only the two first ones are in the OR):

- Mosaic display system that enables to display two flows among the four flows;
- Augmented Reality application that combines XA and US flows;
- Distribution system that displays the camera image (SC) to the learning theatre close to the OR;
- Teleconference system that displays the smart glass video (SC) to a remote user.

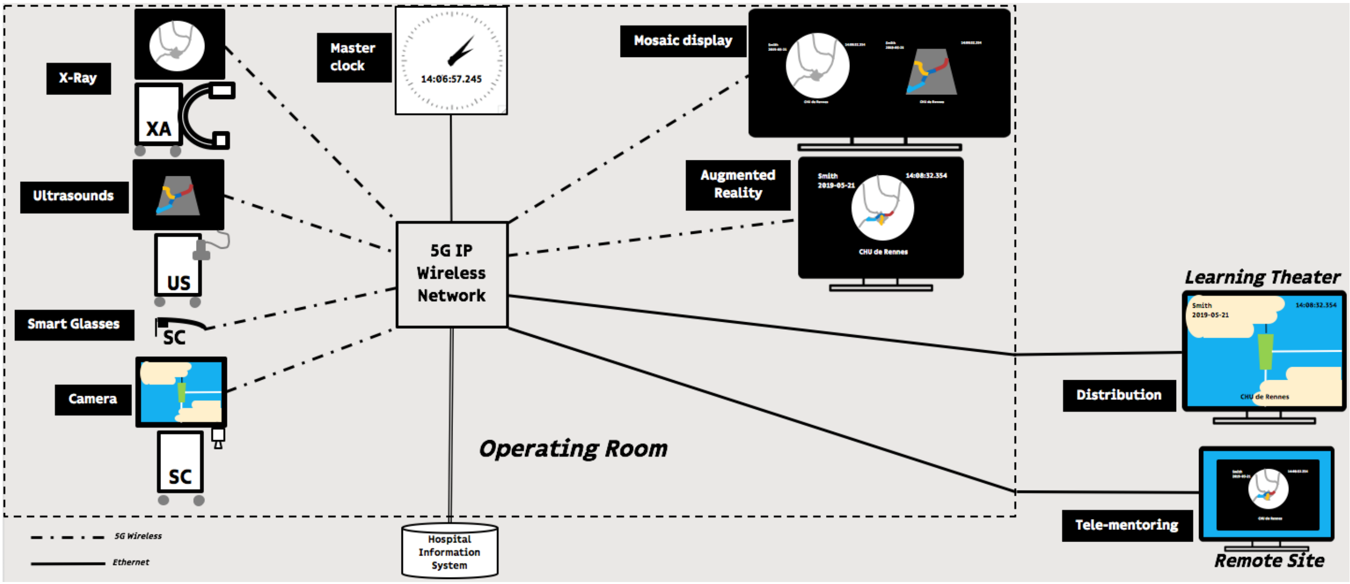

Figure 20: Overall architecture of the Wireless Operating Room

3.3.2.2 Conversion to and from DICOM-RTV

A general overview of the management of the video and live medical imaging inside the OR, using the recent DICOM-RTV standard [2], is shown in Figure 21. The basic principle is to manage all the visual information through video monitors that are installed in the OR in order to ensure that the relevant participants at the procedure are properly informed about what happens, in order to take the best possible decisions and make the appropriate actions with regards to the quality of care. As in several situations, an adverse event may cause dramatic damage, the patient's safety is the highest priority. Therefore, having the right information at the right place and at the right instant is a key requirement. Note that there are 50 million annual procedures in the US generating around 300,000 severe but preventable adverse events. It is often considered that three quarter of them are due to other reasons that the surgeon gesture, i.e. non-respect of procedures, miss-communication among participants or human stress [21].

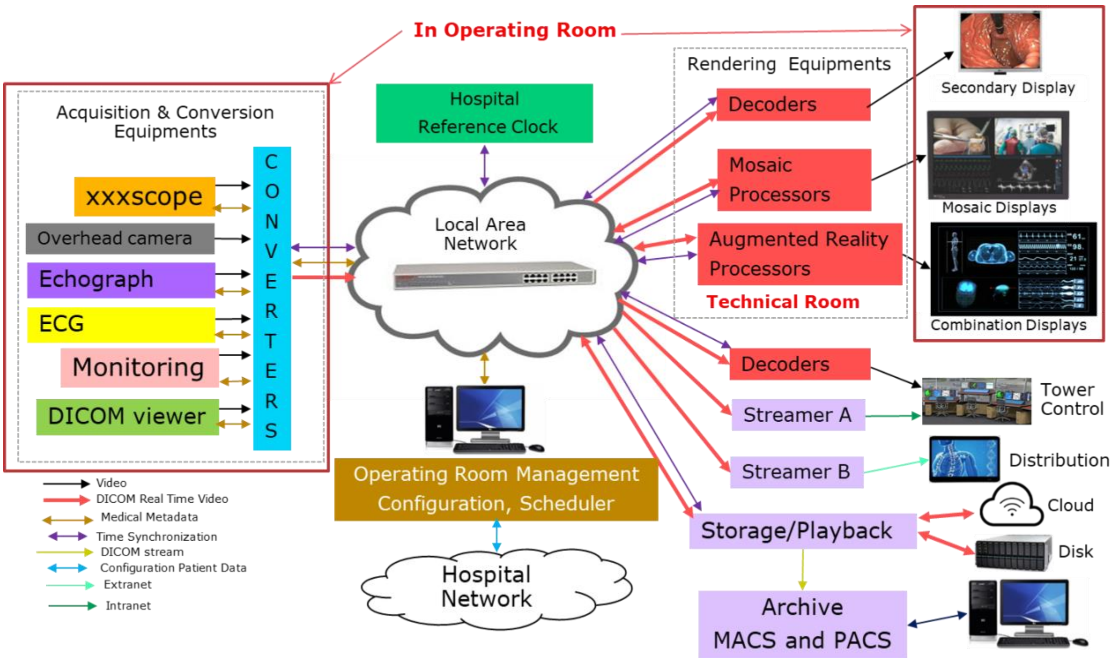

Figure 21: Management of video in the OR, using DICOM-RTV

Given the above, the impact of the replacement of the majority of wired connections by wireless, enabled by indoor 5G, is huge, considering that every cable can potentially cause damages (e.g., fall, infection, obstacle to equipment motion) and disconnecting/reconnecting it is always a challenge.
A generic summary of this architecture is shown in
Figure 22, where every DICOM-RTV compliant communication is either performed thanks to an separate equipment connected to the source or destination via a converter, or integrated natively inside the equipment itself.

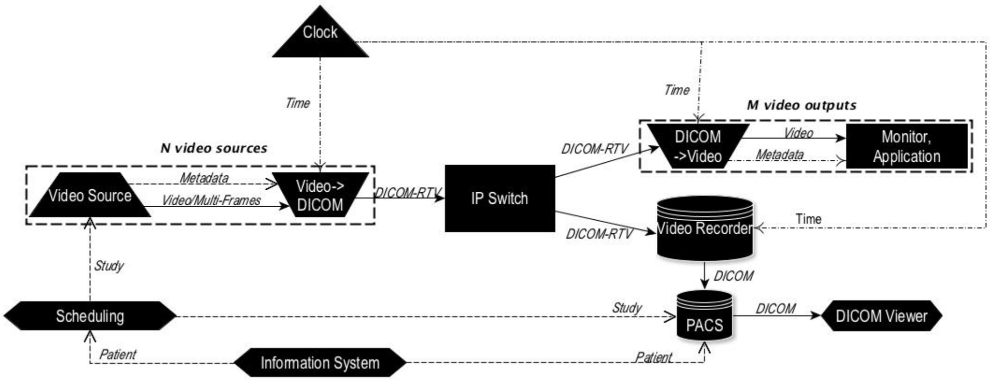

Figure 22: Generic architecture of DICOM-RTV based OR

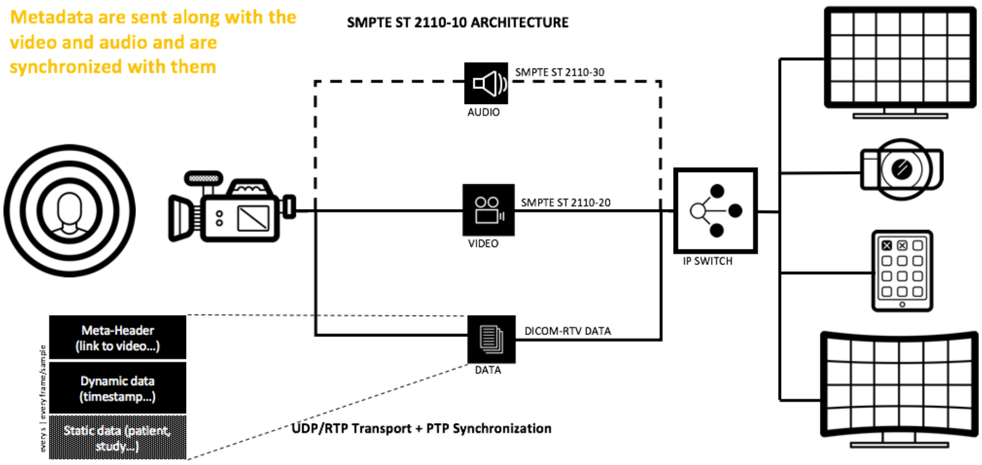

Figure 23: DICOM-RTV Principles

DICOM-RTV relies on the SMPTE ST 2110 family of standards, which conveys multimedia information along with metadata without multiplexing the different “essences” (e.g., audio, video, ancillary data) but instead by transferring them in parallel using the intrinsic multiplexing capability of IP, as shown in Figure 23. This parallel transmission requires all the streams to be perfectly synchronised, which is done through the Precision Time Protocol (PTP), where every communicating device is connected to the “Grand Master” delivery the very accurate clock (nanosecond level), and all “grains” of communication (i.e., frame, audio sample) are timestamped, and a mechanism of “time alignment” ensures that they are properly synchronized (resulting sometimes by a frame skip or duplication) to compensate a delay.

Because DICOM-RTV has been recently finalized, on September 2019, and only for endoscopy and photography at the moment, no commercial equipment is DICOM-RTV compliant, yet. Therefore, DICOM-RTV converters will be provided in two forms: SDI-DICOM-RTV (or vice-versa) gateways on PC hardware, or software stacks integrated into device (R&D versions).

The implementation of DICOM-RTV will rely on the prototype of BCOM which has been successfully deployed in experimental contexts.

3.3.2.3 Mosaic Display

Mosaic display will be performed using BCOM's DICOM-RTV Converter, achieving similar results to what BCOM produced for its World premiere on January 16th, 2019 at CHU de Rennes, as shown in Figure 24.

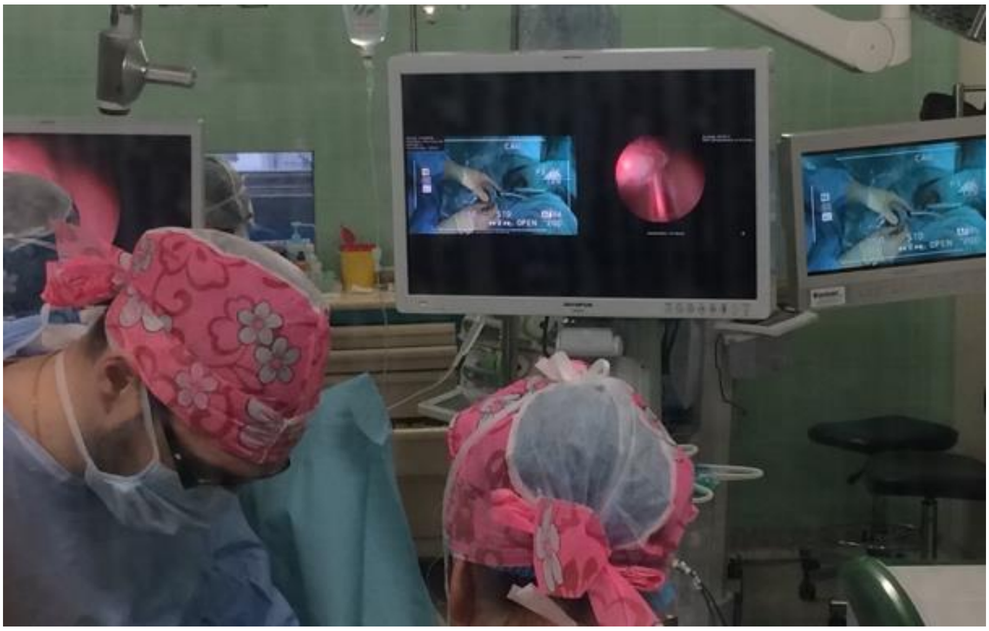

Figure 24: World premiere of DICOM-RTV at CHU de Rennes

3.3.2.4 AR Application

The AR Applications provides an original live image that combines two live sources, originating, for example, from X-Ray fluoroscopy and ultrasounds for example, in order to help the physician (radiologist, cardiologist, surgeon) to better understand the patient anatomy. For example, it adds the coloured pixels issued from the ultrasound and to represent the blood flow on the fluoroscopy image.

This AR application requires four sources of information:

- Fluoroscopy stream;
- 3D position of the X-Ray sensor;
- Ultrasound streams;
- 3D position of the ultrasound probe.

The 3D position is conveyed as DICOM-RTV metadata, and so it is perfectly synchronized with the medical imaging stream, giving the position of the sensor at every frame. However, as the X-Ray and ultrasounds devices are not able to export such 3D position and so it is necessary to generate this information using other equipment. Such object/organ localization will therefore be performed using one of the three following devices, shown in Figure 25:

- NDI Polaris based on small lighted spheres trackers;
- NDI Aurora based on magnetic sensor trackers;
- RGD-B camera providing point cloud enabling to find known objects.

Figure 25: NDI [22] Polaris, NDI Aurora and Intel [23] RGB-D camera

The two first are classical, very accurate devices that use off-the-shelf software but require long calibration. The third one is based on a prototype product developed by BCOM.

3.3.2.5 Distribution Application

The distribution application will rely on a prototype developed by BCOM and is provided for the project. It is based on BCOM's DICOM-RTV Converter, which is interfaced with Web-RTC. Two implementations have been made, one using GStreamer [13], and the second one using the Janus WebRTC Server.

3.3.2.6 Tele-mentoring Application

Figure 26: AMA XpertEye solution

The tele-mentoring application will rely on the AMA XpertEye solution, provided for the project, comprising smart glasses and a smartphone as gateway, as shown in Figure 26. 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 the smartphone used as 5G gateway, using a prototype of implementation of DICOM-RTV on Android, based on BCOM's DICOM-RTV Converter, and then converted in the network in WebRTC to reach the remote user. This transition through DICOM-RTV enables the harmonization of all video flows, and makes it possible to display the smart glass flow in the mosaic monitor. If the performance is too weak, the original solution will be used, which implements a WebRTC end-to-end flow.

3.3.3 Network Component/functions

The network infrastructure has to support simultaneous video flows on wireless connections, preferably in multicast to enable multiple receivers to consume the video flows without increasing the bandwidth.

Because the medical imaging flows (i.e. fluoroscopy and ultrasounds) are more important than the video flows (smart glasses and overhead camera), the network will be able to manage priority among the communication channels, with at least two ranges of services (slices). Ideally, a separate slice would be useful, as the X-Ray fluoroscopy flow is more important that the ultrasound one, and the mosaic display may be considered more important than the AR application.

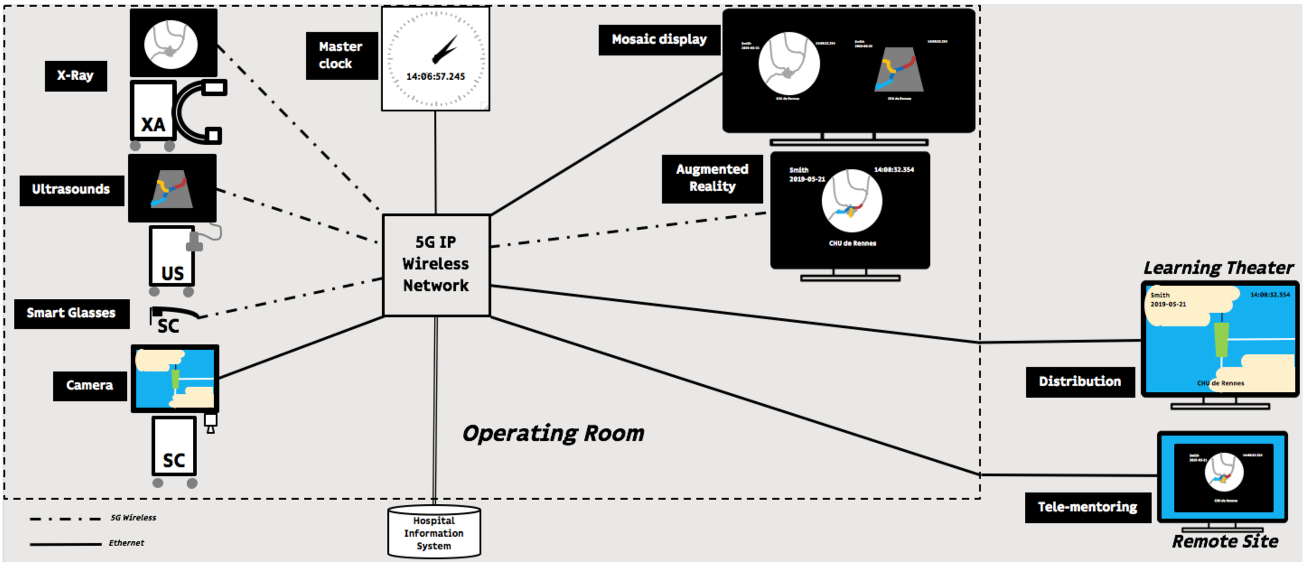

Figure 27: Overall architecture of the minimal solution

The multimedia streams to be transferred by wireless indoor 5G will be the following (*italic items are optional*):

- Two sources of medical imaging as input for the AR application (end-to-end latency <150ms but precision of synchronization <15ms requiring a latency <5ms for time transmission):
  - X-Ray, 1024x1024x10bits at 2 to 4fps (potentially 4 to 10fps), so from 20 to 100 Mbps (uncompressed);
  - Ultrasounds 512x512x8bits or 10bits or 1024x1024x8bits or 10bits at 30fps for neurovascular and 75fps for cardiac (if a phantom is confirmed as being available), so from 60 to 786 Mbps (uncompressed);
- AR application:
  - 1920x1080x8bitsx3colors at 60Hz, so 3 Gbps (uncompressed) or 150 Mbps (compressed);
- Additional videos:
  - Smart glasses video for report to remote physician: 1280x720x3colorsx8bits at 30 Hz, so 664 Mbps (uncompressed) to 30 Mbps (compressed);
  - *External camera for showing physician's hands: 1920x1080x8bitsx3colors at 60Hz, so 3 Gbps (uncompressed) or 150 Mbps (compressed);*
- *Mosaic display:*
  - *1920x1080x8bitsx3colors at 60Hz, so 3 Gbps (uncompressed) or 150 Mbps (compressed).*

The wireless network has to cover the OR but not more, in order to avoid to disturb the environment (other equipment, pacemakers, etc.). The wireless network has to be connected to a fast local (wired) backbone network to allow the display of the video in the neighbouring learning amphitheatre as well as to stream video to a physician located at Turin to support tele-mentoring via the 5G-TOURS platform. A minimal version of the wireless communication network in the OR consists of four channels, i.e. X-Ray, Ultrasound, smart glass video and AR data, as shown in Figure 27. The architecture of the network infrastructure to be deployed is described in the deliverable D3.1 [26].

3.3.4 Trial description

All the trials will be performed with the TherA-Image platform at the CHU de Rennes, comprising an OR, a technical room and a data centre, as shown in Figure 28.

Figure 28: TherA-Image Platform

In the context of the trials, actual CHU de Rennes cardiologists (and optionally other cardiologists), assisted by scrub nurses, will perform the procedures on phantoms reproducing blood flow, with a medical 3D printer, as shown in Figure 29.

Figure 29: Auriculum phantom

The patient being supposed to have a CT scan before the intervention, an actual CT exam will be used. In fact, the phantom corresponds to the same patient and the study is anonymized and used for feeding the AR application. The phantom is placed in the X-Ray C-Arm. The ultrasound probe is placed in a fixed position enabled to get a live image of the blood flow, or an assistant manipulates it. One or two localization devices (see Figure 25) are positioned close to the phantom. The artificial circulation of blood is activated in the phantom and the cardiologist acquires X-Ray angiographies feeding the AR application. The AR application will be prepared, calibrated, and launched. The overhead camera is properly placed in order to capture the neuro-radiologist/*cardiologist*'s hands. A wireless tablet, supporting the AR application, is placed in front of the neuro-radiologist/*cardiologist* without hiding the catheter insertion area. Then the procedure starts. The neuro-radiologist/*cardiologist*, wearing the smart glasses, establishes a session with the remote Italian physician (mimicked by a French colleague in France in a first phase) and performs the interventional procedure, during which he is able to verify the blood flow distribution thanks to the AR application. Other participants inside the OR can see the X-Ray and ultrasounds images on the mosaic screen. Observers or students can see the videos produced in the OR including the neuro-radiologist/*cardiologist*'s hands view. The remote physician can see what is seen by the neuro-radiologist/*cardiologist* on his 5G tablet, and, for example, the tablet supporting the AR application.

3.4 Use Case 9: Optimal ambulance routing

3.4.1 Use case description

This use case essentially acts as the step following the health monitoring described in the previous section. 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. While optimal ambulance positioning and routing has been addressed extensively from a decision-making perspective and a more theoretical aspect [27], the emergence of technologies such as 5G actually enable the fast and reliable acquisition of data on changing factors of an urban or sub-urban 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 (e.g., a patient with severe wounds may be best transferred in the most stable possible way, thus avoiding major potholes, etc.). Information taken into consideration, in this respect refers to current traffic status, real-time road closures (due to demonstrations or concerts), etc. Open data APIs, such as the ones offered by the city of Rennes [10], 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.

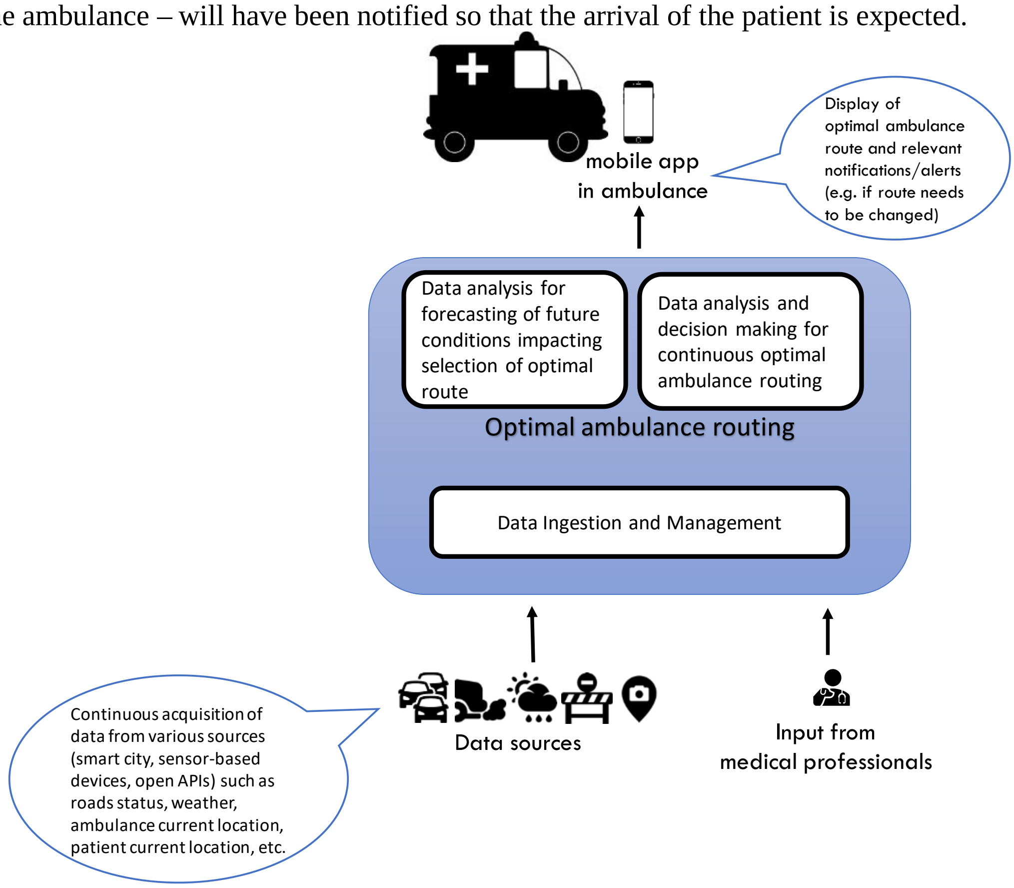

Figure 30: High-level view of optimal ambulance routing use case [14]

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 flow, weather conditions (if applicable), city events (e.g., road closures). 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 under various conditions (traffic, weather, appropriateness of hospital) aspects of the trial may be emulated such as the ambulance on route, the traffic conditions, the weather conditions, etc.

3.4.2 Application Components

Figure 31 depicts a high-level view of the architecture for optimal ambulance routing from an application perspective. The key components include:

- various data sources which may be open APIs (e.g., Dark Sky API [3] for weather) 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 and;
- 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 (described in more details in section3.1.2.2) for optimal ambulance routing takes into account traffic, city events (e.g., protests, concerts), weather, pollution, etc. 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 estimated time to reach the specified destination is calculated, taking into account the aforementioned information. For each candidate route an optimality "score" is calculated considering also pollution conditions if relevant to the user health status. 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 pollution and other potentially hazardous situations (e.g., avoiding an area where an accident has occurred), and taking into account the user's health condition. Multi-criteria decision making methods are used for this purpose.

3.4.3 Network Component/functions

It is expected that devices for collecting various information and data from medical experts, the STARLIT platform and the ambulance (on board device) communicate via 5G as depicted in Figure 31. The ambulance and devices of medical experts are assumed to connect to a nearby 5G base station. An mMTC slice is required to support this service for the measurements from the various data sources to be continuously send to the STARLIT platform for the dynamic calculation and update of the optimal ambulance route.

3.4.4 Trial description

An overview of the trial architecture is depicted Figure 31. In high-level terms, the trial will evolve as follows. First, an mMTC slice will be instantiated by the 5G-TOURS network management and network orchestration. Measurements from the various devices and other data sources are sent to the STARLIT platform, through the mMTC slice, and the platform processes the measurements and generates forecasts on the status of various parameters affecting the available routes and calculates the optimal one. During the scenario, network related KPIs will be displayed through the corresponding GUI.

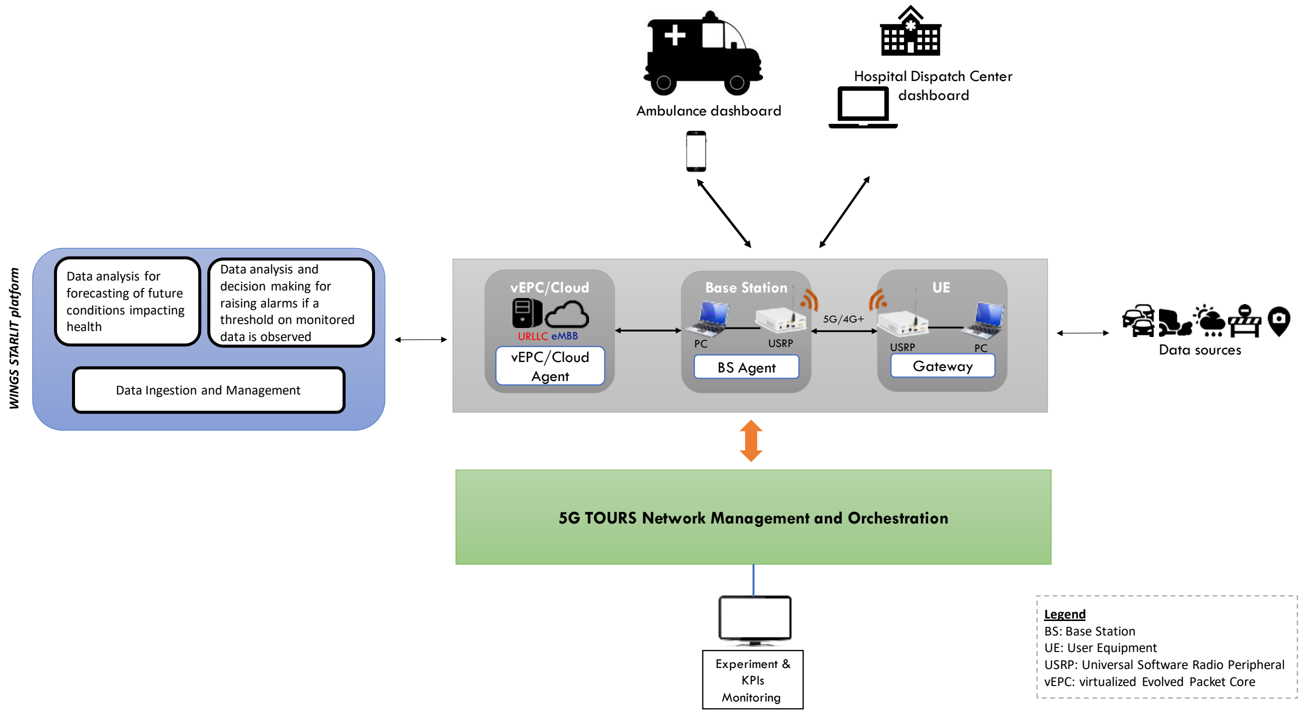

Figure 31: Optimal ambulance routing trial architecture

Until an actual 5G network becomes available 4G and USRPs will be exploited for initial testing. The optimal ambulance routing does not require much in terms of bandwidth for the data transmitted. More important requirements include reliability (99.999%), availability (99.99%), coverage (99.99%), mobility (>100Km/h) and location accuracy (≤200 m).

4 Network Requirements

4.1 Network Requirements summary

Network requirements will be refined in the further deliverables depending on the available infrastructure as studied in WP3. However, **Table 3** gives a first overview of the Safe City use cases network requirements. Following sections are summarizing these requirements via radars comparing requirements to 4G and 5G capabilities.

Table 3 – Safe City UCs preliminary technical requirements

Use-case	Name	Slice	Preliminary Technical Requirements				
			Density	Speed	Throughput	Latency	Reliability
Use-case 6	Remote health monitoring and emergency situation notification	mMTC, URLLC	-	5km/h to 100 km/h	10 Mbps to 50 Mbps UL per device	≤ 50ms E2E	99.9999%
Use-case 7	Teleguidance for diagnostics and intervention support	eMBB, URLLC	5 to 30 per 1km^2	≤ 120km/h	150 Mbps to 1Gbps UL/DL	10 to 25ms E2E	99.999%
Use-case 8	Wireless operating room	eMBB, mMTC ,URLLC	-	-	600 Mbps to 7Gbps UL/DL	10 to 30ms E2E	99.99999%
Use-case 9	Optimal ambulance routing	mMTC	-	≥ 100km/h	200 Mbps DL and ≥ 20 Mbps UL per device	≤ 50ms E2E	99.9999%

4.2 UC6 Network Requirements

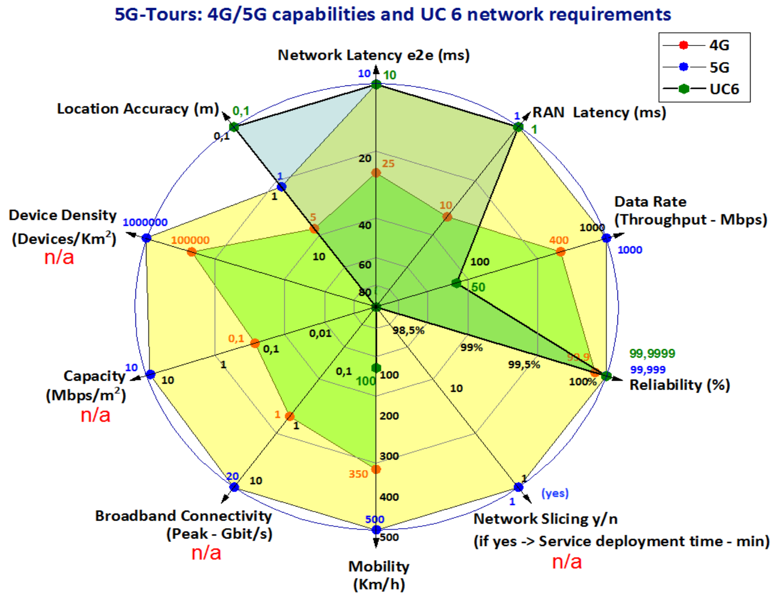

Figure 32: UC6 Network Requirements

Compared to the 4G capabilities, the main requirements addressed by the UC6 are better location accuracy, higher reliability as well as lower latency.

4.3 UC7 Network Requirements

Compared to the 4G capabilities, the main requirements addressed by the UC7 are slicing, higher location accuracy, capacity, broadband connectivity, data rate and reliability as well as lower latency.

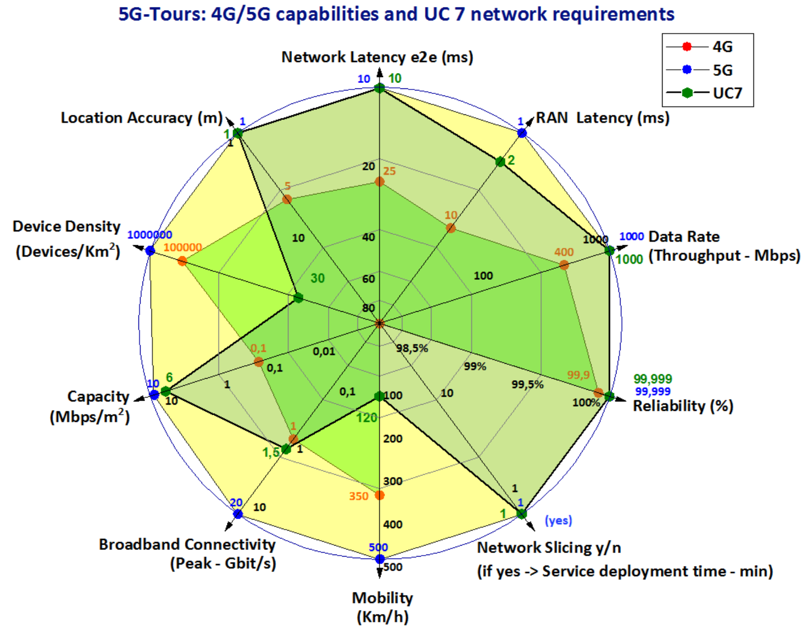

Figure 33: UC7 Network Requirements

4.4 UC8 Network Requirements

Compared to the 4G capabilities, the main requirements addressed by the UC8 are slicing, higher data rate and reliability as well as lower latency.

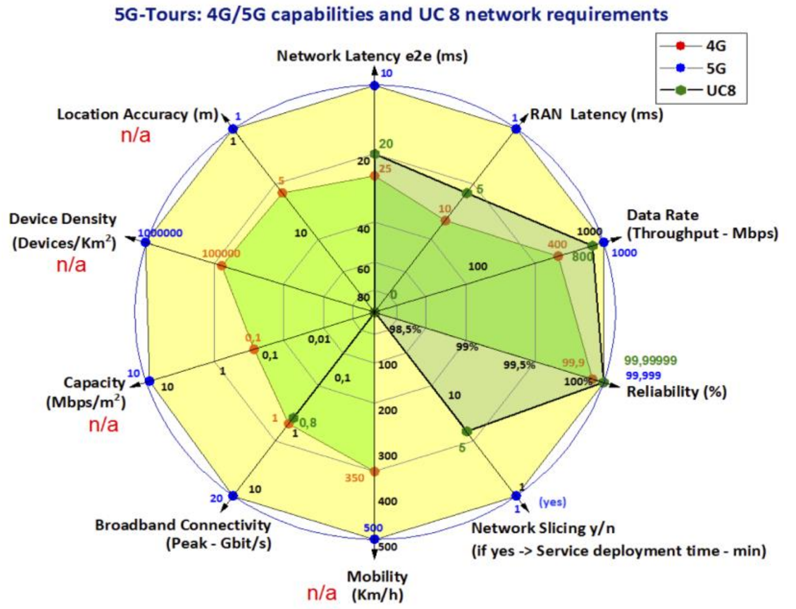

Figure 34: UC8 Network Requirements

4.5 UC9 Network Requirements

Compared to the 4G capabilities, the main requirements addressed by the UC9 are slicing, higher location accuracy and reliability as well as lower latency.

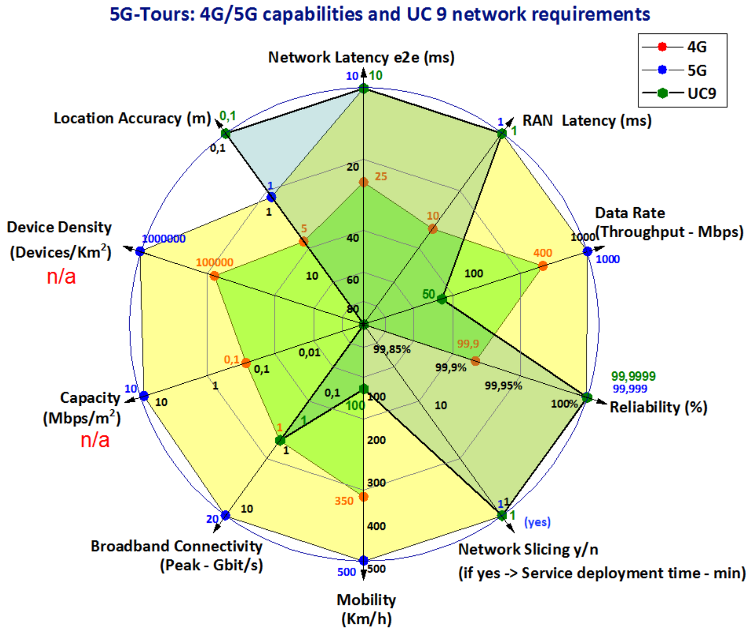

Figure 35: UC9 Network Requirements

5 Time plan and evaluation methodology

5.1 Milestones description

The **Table 4** provides the time schedule of the use cases implementation, to be refined in the context of WP5 (application development), WP3 (network deployment) and WP7 (integration and evaluation).

Table 4: Trials summary Time Plan

	2019		2020				2021				2022	
	Q1 Y1	Q2 Y1	Q3 Y1	Q4 Y1	Q1 Y2	Q2 Y2	Q3 Y2	Q4 Y2	Q1 Y3	Q2 Y3	Q3 Y3	Q4 Y3
UC6		Mil1			Mil2		Mil3		Mil4		Mil5	
UC7		Mil1			Mil2		Mil3		Mil4		Mil5	
UC8		Mil1			Mil2		Mil3		Mil4		Mil5	
UC9		Mil1			Mil2		Mil3		Mil4		Mil5	

The achievements of the milestones are the following:

- Mil1: use case overall design, network and application requirements analysis;
- Mil2: use case first implementation tested in lab environment;
- Mil3: use case first implementation tested on initial network infrastructure;
- Mil4: use case first implementation evaluated on initial network infrastructure;
- Mil5: use case second implementation evaluated on pre-commercial network infrastructure.

5.2 Trials evaluation methodology

The evaluation of the success of the use cases involves a complex interaction of the verification of the technical requirements and the validation of the final use cases. While the final evaluation methodology followed by the project will be defined in WP7 in its forthcoming deliverables, in this section the discussion is about the input variables and the output metrics that will be considered for the evaluation methodology.

5.2.1 Verification of the technical KPIs.

All the use cases listed in this document have very specific requirements in terms of maximum latency, minimum throughput or area capacity. All of these KPIs are currently listed by relevant fora such as 5G PPP as the main metrics that have to be evaluated.

In fact, 5G-EVE provides a thorough testing methodology that takes as input detailed information about relevant metrics such as the network topology, the number of devices or the configuration of the radio access to deliver compelling results in terms of e.g., the experienced delay, the available throughput or higher-level indicators such as the service creation time.

While the testing methodology provided by 5G-EVE targets pure network KPI in a non-standalone mode, the verification methodology put in place by 5G-TOURS for the evaluation methodology shall necessarily be extended to take into account the additional requirements that are imposed to the network. Being the one envisioned for the safe city enhanced use cases that involve also more heterogeneous inputs such as the kind of devices (e.g. medical imaging sources) or their mobility (e.g. for the case of the ambulance routing). All these new metrics will be used to devise a KPI evaluation methodology that extends the one introduced by 5G-EVE to take into account the 5G-TOURS specificity.

5.2.2 Validation of the services.

Besides the verification of the technical KPIs (i.e., if the network can provide a certain KPI needed by the service) the extent of the use cases proposed by 5G-TOURS in the safe city and the other trials also imposes the validation of the services from very different viewpoints: technical, business and societal. By leveraging on the KPIs verification activities described before, the 5G-TOURS partners will evaluate the impact of the proposed use cases by adopting methodologies that aim to get feedback from the relevant stakeholder. For instance, the participation in relevant innovation fora on 5G for the healthcare or the direct discussion (through detailed questionnaires) with the end-users of the technology may be a possible path to follow in this activity.

The detailed methodology will be discussed in close cooperation with WP7 and WP8.

6 Conclusion

In this document, several use cases based on the safe city have been described both from the user and the network perspective. Anticipating on the actual implementation and evaluation of these use cases, this deliverable has analysed and highlighted the different requirements related to the use cases. In general, the health related use cases impose very stringent requirements that could not possibly be met by legacy 5G technology and thus explore the limits of the network capabilities. In particular, we can highlight the following network requirements:

- As these use cases impact people's life, involving e.g. even emergency care, very high reliability is extremely important and need to be provided at levels that could not be attained by current mobile networks.
- In many cases, the applications involved have a very high level of interactivity and require very high quality, leading to extreme latency requirements much beyond those provided by current networks.
- Depending on the nature of the information to transfer and the type of devices used, data rate or device density are also important issues which can pose quite extreme requirements on the network.

In addition to the analysis of the use cases, this deliverable has also addressed the implementation of the corresponding trials. These use cases require very sophisticated medical equipment that currently does not rely on network communication or relies on current technologies which suffer from very severe limitations. This deliverable has analysed the configurations, implementations and evolutions required by these devices in order be leverage 5G communication to improve the corresponding medical applications. In this way, this delivered has served to anticipate the actual implementations required for these use cases, which will be documented in the future deliverables.

In terms of network deployment, we have identified the functional requirements that need to be imposed on the 5G architecture side, which will be fed into WP3 in order to make sure that the 5G-TOURS architecture meets the requirements of the safe city use cases. We have also identified the infrastructure required in order to provide the needed coverage and deployment requirements, which will be provided as input to the 5G-EVE project, responsible for providing the network infrastructure together with the network operator and manufacturers involved in the 5G-TOURS projects.

In summary, this deliverable has provided the basis upon which WP5 will implement the safe city use cases along the project duration:

- We have described in detail a set of use cases of practical interest that are valuable for the vertical partners involved in this WP; these descriptions identify the goal that will be pursued by this WP.
- We have identified the application-layer components that are required to run the use cases and their interface with the network; one of the major tasks within WP5 will be to develop all this components.
- We have identified the requirements on the network side, which will be provided as input to WP3 and 5G-EVE in order to ensure that the mobile network infrastructure deployed in Rennes satisfies the needs of the use cases that need to be implemented.
- We have set the basis upon which we will be able to validate the use cases and make sure that they satisfy the project objectives both in terms of network technologies as well as the functionality need by the end-customers.
- We have defined a timeline for the implementation, integration and validation of the use cases.

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