GRANT AGREEMENT No. 857034

Call: H2020-ICT-2018-2020
Topic: ICT-19-2019
Type of action: RIA

5G HEART

5G HEalth AquacultuRe and Transport validation trials

D2.1: Use Case Description and Scenario Analysis

Revision: v.1.0

Work Package	WP2 5G-HEART Network Architecture and Slice Definition
Task	Task 2.1 Analysis of Use Case and Configuration Scenarios for Network Resource & Slices Planning
Due rate	M07 – 31 Dec 2019
Submission date	31Dec2019
Deliverable lead	OTE
Version	1.0
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Abstract	This report provides the description of the use cases and the scenarios that are going to be demonstrated for each use case. Additionally, it describes the high-level requirements of each scenario from the end-user perspective. There is also an overall network requirement analysis, for satisfying all the scenarios at the same network.

Keywords	healthcare, transport, aquaculture, requirements

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Project co-funded by the European Commission in the H2020 Programme		
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Dissemination Level		
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* R: Document, report (excluding the periodic and final reports)

DEM: Demonstrator, pilot, prototype, plan designs

DEC: Websites, patents filing, press & media actions, videos, etc.

OTHER: Software, technical diagram, etc.

EXECUTIVE SUMMARY

5G-HEART‘s target is to empower three vertical industries - healthcare, transport and aquaculture – by using 5G network. There are many applications/use cases related to these vertical industries. 5G-HEART focuses in the following:

- Healthcare
  - H1: Remote interventional support
  - H2: The PillCam
  - H3: Vital-sign patches with advanced geo-localization
- Transport
  - T1: Platooning
  - T2: Autonomous/assisted driving
  - T3: Support for remote driving
  - T4: Vehicle data services
- Aquaculture
  - A1: Remote monitoring of water and fish quality

These use cases include a number of scenarios and subcases which will be evaluated. Each scenario/subcase has its requirements that should be fulfilled. For instance, Transport scenarios require high downlink throughput while aquaculture require medium. Even though there are same requirements for the verticals, it is clear that there are also some characteristics and requirements that apply only to some of them. A 5G network can offer many advantages and not only offer new opportunities in the industry, but also serve multiple industries with the same infrastructure.

In this document the requirements of each scenario are identified. Additionally, network requirements are presented, since the network should satisfy all the scenarios.

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ABBREVIATIONS

3GPP	Third Generation Partnership Project
4G	fourth generation
4K	3,980x2160 pixel resolution
5G	fifth generation
5G-HEART	5G HEalth AquacultuRe and Transport validation trials
5G NR	5G New Radio
5GTN	5G Test Network
8K	7680x4320 pixel resolution
API	application programming interface
AR	augmented reality
BS	Base Station
CAN	controller area network
CoCA	cooperative collision avoidance
CPU	Central Processing Unit
CT	Computed tomography
D2C	Direct-to-Cloud
DL	downlink
DSLR	Digital single-lens reflex
E2E	end-to-end
ECU	engine control unit
eMBB	enhanced mobile broadband
eNodeB	Evolved Node B (4G)
GBR	Guaranteed Bit Rate
GDPR	General Data Protection Regulation
gNB	next generation NodeB
GPS	global positioning system
GW	gateway
HD	high-definition
HTTP	hypertext transfer protocol
ICMP	Internet Control Message Protocol
ICT	Information and Communications technology
IMS	IP Multimedia Subsystem
IoT	Internet of things
IT	Information Technology
KPI	key performance indicator
LoA	level of automation
LTE	long term evolution
LTE-M	LTE category M1
MEC	multi-access edge computing
mMTC	massive machine type communication
NB-IoT	narrowband IoT
NFV	network functions virtualisation
NR	new radio
OBU	on-board unit
OTA	over-the-air
QoS	quality of service
REM	radio environmental map
ROC	remote operations centre
ROV	remotely operated vehicle
RSU	road side unit
SAE	Society of Automotive Engineers
SDN	software-defined networking
TeSo	tele-operated support
TRP	total radiated power
UDP	user datagram protocol
UE	user equipment

UL	uplink
URLLC	ultra-reliable low latency communication
V2I	vehicle-to-infrastructure
V2N	vehicle-to-network
V2V	vehicle-to-vehicle
V2X	vehicle-to-everything
VNF	Virtual Network Function
VR	virtual reality
WP	work package

1 INTRODUCTION

This deliverable D2.1 "*Use Case Description and Scenario Analysis*" describes at a high-level the use cases, grouped by vertical industry, and the related scenarios that will be demonstrated, from the 5G-HEART project. The overall objective of 5G-HEART is to define and validate the cost efficient 5G converged network concepts, which will enable an intelligent hub supported by multiple vertical industries.

In this deliverable the User Requirements from three distinct Vertical Industries are being collected. More specifically the requirements from the

- Health
- Transport and
- Aquaculture

verticals are gathered and normalized.

Specifically, the requirements from the End-User perspective from 3 use-cases (and 7 scenarios) of the Health Industry, 4 use-cases (and 13 scenarios) of the Transport Industry, and 1 use case (with 7 scenarios) of the Aquaculture Industry are collected.

Since most end users/customers have limited knowledge regarding quantitative network requirements (like Latency, Throughput, Reliability etc.), a more qualitative approach is taken.

Most end-users know the type (e.g., Video, Voice, etc.) and quantity of information they will exchange over the Network. Furthermore, they can understand the importance of the traffic they will receive and/or send, and the impact of lost data or unreliable communication channel(s) can be perceived by them.

Therefore, the users were asked to describe the type and importance of the information that the 5G network will be called to transmit, and not the expected network capabilities. Both the spatial (distribution in space) as well as temporal (distribution in time) of the traffic was requested.

The use cases user requirements are enumerated and explained in Chapter 2 of this report.

Chapter 3 contains the high-level overview description of the *Healthcare*, *Transport* and *Aquaculture* use cases, from the end-user point of view, the related network resources configuration, the required and targeted descriptive requirements for each use case and scenario. Also, it contains the demo location and environment, and the integration needs for a fully working proof of concept. Finally, a narrative of the use case scenario is included.

Chapter 4.1 contains the tables with the user requirements of all the use cases (described in Chapter 3).

Chapter 4.2 contains an overview of the unified infrastructure and the requirements that it should meet in order to support the use cases.

Chapter 5 contains the conclusions drawn from the preceding analysis.

2 USER REQUIREMENTS & DEFINITIONS

The customer or end-user of a service, most of the time does not know (or care) about the Mbps or msec that the Network (they are using) is delivering to them.

They do care about the quality of the Video and Audio in their Video-Conference sessions, or the fast response in their gaming platforms. Furthermore, they do care about their data being transmitted securely, but not about the number of bits used for the encryption of their data.

On the other hand, from the Network Operators and Equipment Manufacturers' point of view the same (one) 5G network has to satisfy all User Requirements. This for instance means that the same network should deliver high-bitrate low-latency data as well as low-bitrate high-latency traffic.

Good knowledge of the user requirements will help Network Operators optimally design and distribute network resources. This will keep Network cost lower and subsequently, make end-user service prices more competitive.

It is also true that a single user requirement (i.e., Real-time Reception of 4K Video) can influence or map in multiple Network Requirements (i.e., Throughput and Latency) and vice versa. An example of the interdependency between user requirements and network requirements is shown in Figure 1 bellow:

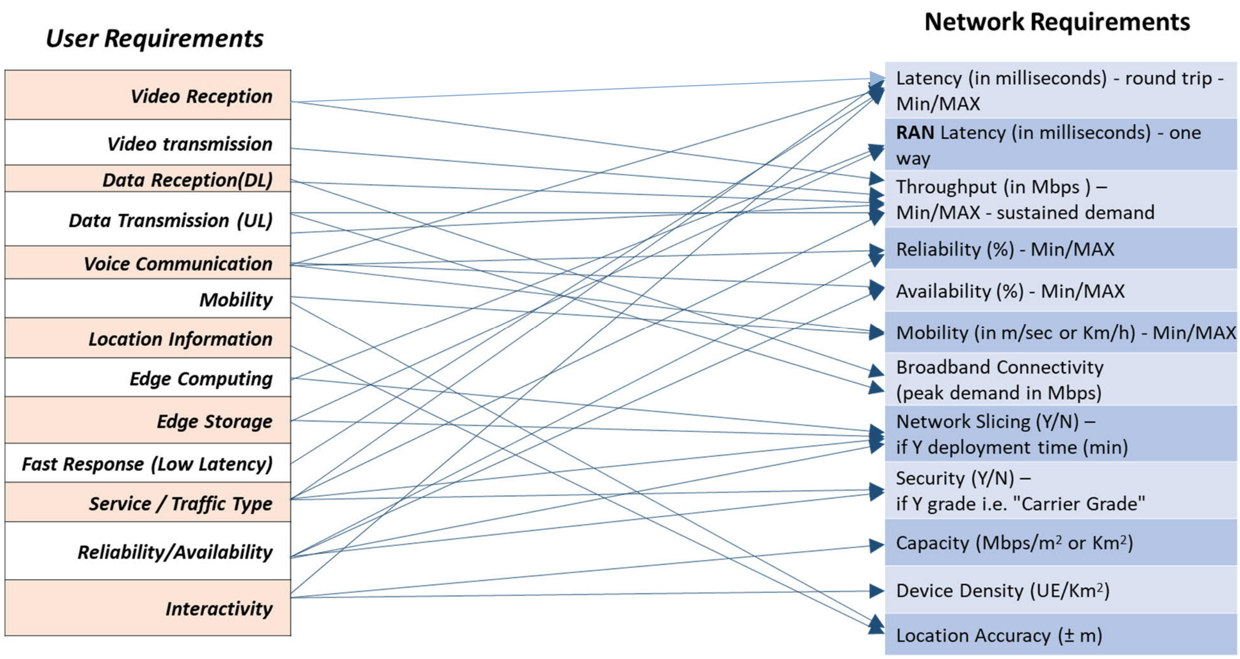

Figure 1: Indicative example of some (not all) dependencies between user-requirements and network requirements.

The user requirements mentioned on the left table in Figure 1 above are explained later in this section of the deliverable. These are the requirements that the end-users (or customers) will need to define in order to ensure seamless and satisfactory delivery of their service.

It should also be noted that user demand for network resources is not uniformly distributed over time and within the coverage of a network. Therefore, the traffic demand has to be defined both in temporal (variability in time) and spatial (variability in the coverage area) terms. An example of time-varying traffic demand is shown in Figure 2. The data/voice traffic in residential areas is high early in the morning and in the evening. In business districts, the traffic peaks during office-working hours (8:00 to 19:00). This is an example of temporal traffic variations during 24 hours. Similar variations can be identified weekly, monthly and yearly. Knowledge of temporal traffic patterns help in optimally designing and distributing network resources.

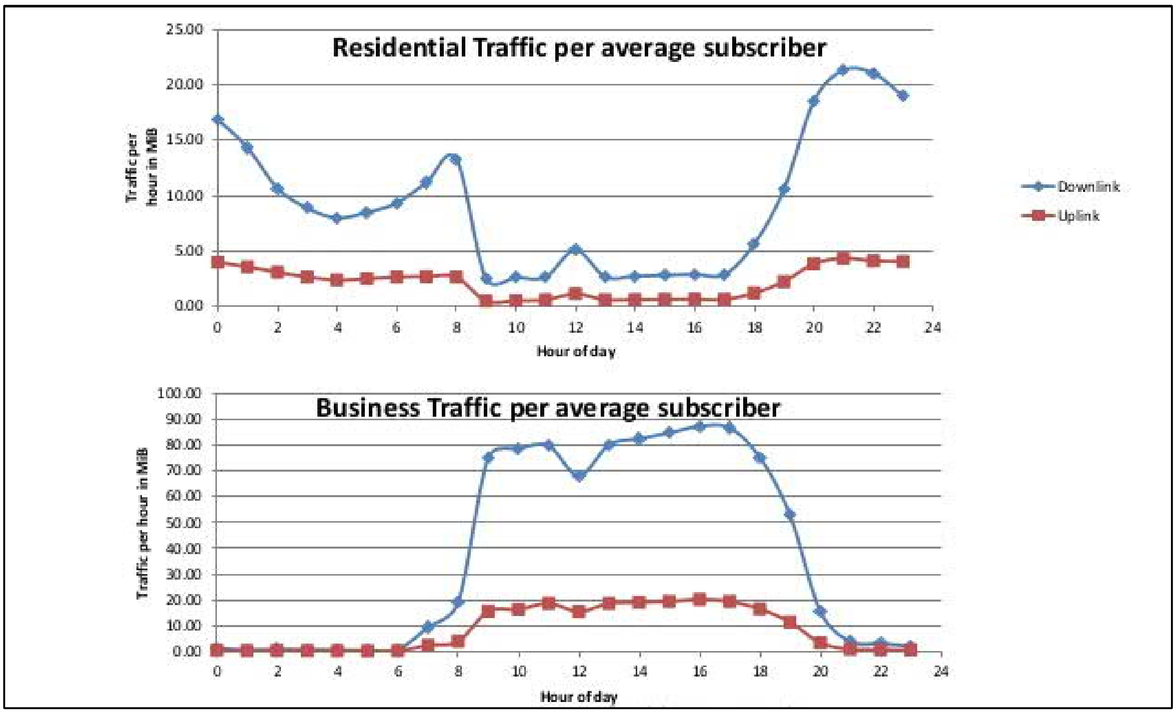

Figure 2: Example of temporal distribution of network traffic demand in residential vs. business areas [1].

Beyond time variation, there is spatial variation of network traffic. The demand or data connections is not uniformly distributed inside the coverage area of a mobile network. An example of spatial distribution of the traffic demand in a dense urban environment, is shown in Figure 3 below. The traffic appears to be concentrated closer to the mobile network BSes.

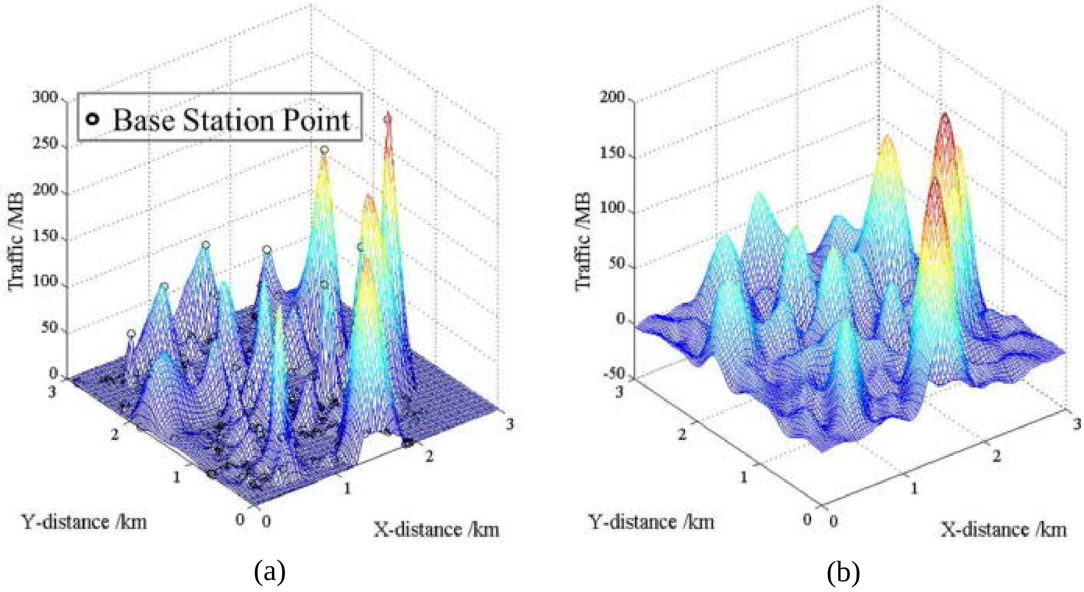

Figure 3: (a) Real traffic distribution in dense urban region (b) Traffic distribution model in dense urban region [2].

Good knowledge of User Traffic Demand both in terms of time and in terms of space will help Network Equipment Manufacturers, Integrators and Network Operators to improve network planning (i.e. location of eNodeB, size of backhauling links, capacity of network elements etc.) and also optimize the distribution of the network resources.

Optimally the Network Operator would like to group together similar user requirements (from different clients and/or use cases but similar services) on shared network resources.

Competing User Requirements (i.e. Fast mobility and High-Positioning-Accuracy) can be split in different network resources and/or 5G network slices.

In certain cases, stringent User Requirements can only partially be satisfied by the network (i.e. transmission of HD-video during a live-concert of a sports' event where the density of the end users is very high also), or network planning should be changed (i.e. extra next generation NodeB (gNB) and or backhauling links).

At the end of the day the Network Operators and Service Providers would like to invest on a single network that will be able to satisfy the majority of the user requirements.

Since knowledge of user requirements a-priori to network design is proven to be very important, the next action is how to gather the user requirements in a coherent and concise procedure.

User Requirements can vary significantly depending on the Vertical Industry. They are also different between the use-cases and scenarios of the same Vertical Industry. In order to analyse the user requirements from all 27 scenarios of the 5G-HEART project a qualitative approach is adopted.

An effort was undertaken in order to identify the user-perspective requirements that are common in most use-cases and scenarios to be implemented, and demonstrated within the scope of the 5G-HEART project. A brief study of the use-cases from other ICT-19 and ICT-22 projects was also undertaken (as this is summarized in D1.2 of the ICT-17 5G-EVE Project [3]).

2.1 Naming and explanation of most commonly user requirements

For gathering the user requirements from the 27 scenarios of all use cases, a table was given to each-person responsible for implementing each use case (use case "owners"). The first column of the table is the name of the requirement, the second column a brief explanation, and the third is the one to be completed with qualitative values (as described in Section 2.2).

In this section, the explanation/description of the end-user requirements is provided. Beyond the definition, examples are also provided to help with the understanding of what is expected to be provided by the end-user easier. There are 14 user requirements in total. These can be considered to be the least common denominator of the User Requirements from different Vertical Industries. Furthermore, each Vertical Industry and User Service can have additional (more specific) requirements. An example of specific (i.e. QoS or specific MOS score) user requirements can be found in some scenarios of Healthcare (namely H1C and H1D).

The 14 common user requirements for all vertical industries, use-cases and scenarios are:

1. *Video Reception*: Indicates the need to receive high definition Video (4K, 8K) on his/her device, TV/monitor or VR/AR end device. This need can be interpreted into a network requirement for download bandwidth needs depending on the video format (HD, 4K etc.) and also the number of channels that must be simultaneously received (i.e. 2 in the case of a stereoscopic/3D end device).

2. *Video Transmission*: Indicates the user need to transmit video information of different formats and definitions/resolutions and frame rates (i.e. 4K or 8K or even 360^{o}). This user requirement influences the upload bitrates to be provided in the Mobile Access Network. The indicative

bitrates for different video formats are similar to the ones of the previous requirement (Video Reception).

3. *Data Reception (DL)*: Indicates the need to receive any kind of data (Download - DL) from the network at various speeds/bitrates. This requirement together with the nature of the data traffic (mentioned as Service/ Traffic Type requirement) directly influences the dimensioning of the Access Network Capabilities.

4. *Data Transmission (UL)*: Indicated the need to transmit different types of data (Upload - UL) from the user end device to the network and/or other users. Together with the Service/Traffic Type requirement (explained further below), this requirement guides the network planners to correctly size not only the uplink bandwidth but also the backhauling capacity of the network.

5. *Voice Communication*: Indicates the need to have voice interactive communication - real time full duplex between end-users of the network or between end user a Voice Service Platform. This communication can be one-to-one, one-to-many or many-to-many (call-conference).

6. *Mobility*: Indicates the user need to receive and transmit information (any of the previous types, Video, Data and Voice) while moving (at low-walking and/or high speeds-train/car/airplane). Indicated speeds are 5 Km/h for walking, 50-200 km/h for automobile and 200-500 Km/h i.e for Fast Trains. If the end-user or device are stationary there is no mobility requirement and the moving speed is set to 0 km/h. All speeds and speed ranges should be supported by the network, but when planning how to best support a use case it is very useful to know the expected speed of motion of the end-device so as to i.e. define the hand-over specifications accordingly.

7. *Location Information*: Indicates the need to make available and provide location (within certain accuracy) information of the end-device/user. For certain services (i.e. navigation of moving vehicle, autonomous driving, localization of a patient, etc.) it is very important to know the location of the end-device (and therefore the end-user) possibly in 3 dimensions. The accuracy needed, will also depend on the application and can be a few tens of meters to even below 1 meter. Location information can be requested for both outdoor and indoor environments.

8. *Edge Computing*: For certain applications and/or Services there is a need to have computing power / CPU at close proximity with the end device. For example, collision avoidance for a fast moving industrial robot might require complex analysis and calculations to be performed (using the robot sensors and camera input) within a very short time, and then a command to i.e. change course should be given at the shortest possible latency. The simultaneous demand of High CPU power and very low latency can only be achieved by placing Computing Power at close proximity to the end-device (next to the gNB).

9. *Edge Storage*: Similarly, to the previous user requirement, the simultaneous need to store and retrieve large amount of information with the least possible delay for storage and retrieval actions indicates that Edge Storage Capabilities need to be provided. Examples of such situations are surveillance using swarms of drones that need to upload real-time HD-Video, which will quickly dictate emergency actions, or an autonomous vehicle that downloads detailed maps in real time while moving.

10. *Fast Response (Low Latency)*: The time between issuing a request (i.e. change direction) or transmitting a piece of information (i.e. an alarm happened), and receiving a response should be as short as possible. Technology-wise this is the end-to-end Latency of a Telecommunication Network also referred to as round-trip-delay. A simple measurement of this is done via the ICMP protocol with the “ping” command.

11. *Service / Traffic Type*: This user requirement describes the traffic characteristics that the end-users (as a whole) receive and/or generate. It indicates whether there is a need for large volume of traffic to be sustained over long periods of time, or large pieces of information/data to be received or transmitted within a brief period of time (impulses/bursts), or maybe small amount of information must be exchanged at certain (regular or irregular) time intervals (i.e. like in the case of IoT or control signals).

12. *Reliability/Availability*: Indicates whether the Service is to be provided 24/7 (24 hours/day 7days/week continuously) and the level of interruption allowed, which should be specified as a percentage, with values that are usually very close to 100%, e.g., 99.999%. Reliability and Availability are different terms, but for the purpose of this document we will define it as a unified concept that measures from the user point of view the perception of having service everywhere and all the time and how sensitive is the service to communications' brief disruption.

13. *Space/Area Dependent Interactivity*: This user requirement, is a measure of the spatial distribution of the end-users/devices. It indicates the ability to issue commands (or even send data/video) and requests and receive acknowledgement of execution and/or reaction (that can be in the form of data/video) within a very short period of time (in the msec order of magnitude) from a *large number* of "collocated" end user/devices etc. (example is gaming and or guidance for emergency evacuation, transaction stock/financial markets or the more common request for a Web Page).

14. *Security / Privacy*: Last but not least this requirement indicates the need to protect the usability and integrity of user data, equipment and network. Furthermore, it indicates that the *Privacy of User Identity and Information* should be protected. Access also to the User Data & information should be controlled to the degree of security desirable (i.e. public, restricted, confidential, or military/top-secret).

All the above user requirements are summarized in Table 1. This table was given to the use case "owners" in order to fill in their requirements.

Table 1: Brief explanation of *user Requirements*

no	Requirements	Explanation
1	Video Reception	Need to receive high definition Video (4K,8K) on his/her device, TV/monitor or VR/AR end device
2	Video Transmission	Need to transmit high definition (4K or 8K or even 360°) Video
3	Data Reception(DL)	Need to receive data (Download - DL) from the network at various speeds/bitrates)
4	Data Transmission (UL)	Need to transmit data (Upload - UL)
5	Voice Communication	Need to have voice interactive communication - real time full duplex
6	Mobility	Need to receive and transmit information (any of the above types) while moving (at low-walking and/or high speeds-train/car/airplane)
7	Location Information	Need to provide location (within certain accuracy) information of the end-device/user

8	Edge Computing	Need to have computing power / CPU at close proximity since instantaneous responses of complex calculations are needed (i.e. at the end device/car/robot etc.).
9	Edge Storage	Need to store and retrieve large amount of information with the least possible delay for storage and retrieval actions (i.e. surveillance swarms of drones that need to upload real-time HD-Video that will decide emergency actions, or autonomous vehicles to download detailed maps in real time while moving).
10	Fast Response (Low Latency)	The time between issuing a request (i.e., change direction) or transmission of a piece of information (i.e. an alarm happened) and receiving a response should be as short as possible.
11	Service / Traffic Type	Need for large amount of traffic to be sustained over long periods of time, or large pieces of information/data to be received or transmitted within a brief period of time, or small amount of information at certain intervals.
12	Reliability/Availability	Service is to be provided 24/7 (24 hours/day 7days/week continuously) without interruption or small interruptions can be acceptable (i.e. if a communication attempt fails, it can be repeated without consequences after certain amount of time).
13	Space/Area Dependent Interactivity	Need to be able to issue commands and requests and receive acknowledgement of execution and/or reaction within a very short period of time (in the msec range) from a large number of end user/devices etc. (example is gaming and or guidance for emergency evacuation, transaction stock/financial markets or the more common request for a Web Page).
14	Security / Privacy	Need to protect the usability and integrity of user data, equipment and network. Additionally, the privacy of User Identity and information should be protected and access also to the User Data & information should be controlled to the degree of security desirable.

Since most use-case “owners” are not network engineers or technology personnel, a qualitative rather than a quantitative approach was taken to indicate the value or importance of each user requirement.

In the next section the Metrics and Values of the selected user requirement are being presented.

2.2 User Requirements Metrics and Units

For the user requirements presented in Section 2.1 above, there is a metric and value that the end user should define or select. The value indicates the need and/or the level of importance for each requirement. For some of the user requirements a numeric value range is also given in order to provide an indication of the related network parameter/specification for the more technically inclined end-users.

1. *Video Reception*: It is a Boolean value. The expected response is Yes or No. If the answer is yes, then some explanation(s) can be expected in terms of the nature of the video stream (i.e. format) and the number of simultaneous streams/channels that are being received. In case more details can be provided the indicative bitrates for different video formats are:

* HD Video	up to 15 Mbps
* 4K Video low frame rate	15-45 Mbps

* 4K Video high frame rate	45-70 Mbps

2. Video Transmission: Similarly, to the previous user requirement, the expected answer is Yes or No. In the case of a positive answer more details should be given regarding the format of video stream and/or the number of streams.

3. *Data Reception (DL)*: the value of this requirement is provided in a qualitative manner by selecting High/Medium/Low representing values of 1 Gbps / 100 Mbps / 10 Mbps (or less) respectively. If these values are not adequate, the vertical can also indicate Ultra High which represents a data stream of 10 Gbps.

4. *Data Transmission (UL)*: the metrics for this requirement are the same as the one above (High/Medium/Low) with the only difference being the direction of the traffic from the User towards the Network.

5. *Voice Communication*: This is another Boolean requirement whose expected answer is Yes or No. From the Network point of view this means the delivery of Voice Switching Capabilities and the demand for 128 Kbps bidirectional traffic on demand with reasonably short Latency of 50-200 msec. In addition, this value can be used in order to evaluate if the 5G infrastructure providers would need additional components in the Mobile Core, such as IMS VNFs.

6. *Mobility*: The metric of this requirement is the moving speed of the user and/or end-device. Since this can be varying, the range is given as High Speed (300-500 km/h), Medium Speed (50-200 Km/h), Walking/Running Speed (5-10 Km/h) and Stationary (0 Km/h).

7. *Location Information*: Boolean (Yes/No) response is expected. In case of “Yes” approximate accuracy should be given, rated as High / Medium / Low representing accuracies of +/- 0.5 / 4 & 50 meters respectively. The location information can be both for indoor and outdoor environments.

8. *Edge Computing*: It is a Boolean value (Yes or No).

9. *Edge Storage*: It is a Boolean value (Yes or No).

10. *Fast Response (Low Latency)*: The requirement can be defined as Slow/Fast and Very Fast representing network latencies around 100, 25 and 5 ms respectively.

11. *Service / Traffic Type*: According to the description of this requirement, the possible metrics are Sustained (continuous data traffic) / Bursty (traffic in bursts) and Sporadic (at regular or irregular intervals). Each data flow type can then be defined as High/Medium or Low and indicative values are i.e for sustained 1 Gbps / 100 Mbps and 10 Mbps (for high/medium and low) respectively. Similarly, representative values for the other traffic values can be found in Table 2: User Requirements’ Metrics and Indicative Values bellow.

12. *Reliability/Availability*: this requirement can be valued as High/Medium or Low representing reliability of 99.99999% / 99.999% / 99.99% (7 nines, 5 nines and 4 nines).

13. Space/Area Dependent Interactivity: The metric of this requirement is Dense (High Density), Medium Density, Sparse (Low Density) representing >1 UE per m^2 / 1 UE per 25 m^2 / <1 UE per 100 m^2 respectively. For each density, the interaction with the network/service can be characterized as High/Medium and Low representing 1.000 / 100 / 1 transaction per second.

14. Security / Privacy: the metrics for this requirement are Baseline /Medium /High / Ultra-High grade for no security all the way to military type security/encryption levels.

Table 2: User Requirements' Metrics and Indicative Values

no	Requirements	Metric	Values & Units
1	Video Reception	Yes/No no of UEs	Mbps/channel or stream
2	Video Transmission	Yes/No no of Channels	Mbps/channel or stream
3	Data Reception(DL)	High/Medium/Low	100<high<=1.000 / 10<medium<=100 /low<=10 Mbps (Max for Ultra High is 10 Gbps)
4	Data Transmission (UL)	High/Medium/Low	100<high<=1.000 / 10<medium<=100 /low<=10 Mbps (Max for Ultra High is 10 Gbps)
5	Voice Communication	Yes/No	128 Kbps UL/DL full duplex
6	Mobility	High Speed / Medium Speed / Walking-Running Speed / Stationary	200<high speed<=500 / 50<medium speed<=200 / 5<walking-running-cycling speed<=50 / 0 Km/h
7	Location Information	High / Medium / Low Accuracy	high<=1 / 1<medium<=25 / low>25 meters
8	Edge Computing	Yes/No	User Perception (derived from Latency and traffic type)
9	Edge Storage	Yes/No	User Perception (derived from Latency and traffic type)
10	Fast Response (Low Latency)	Slow / Fast / Very Fast	slow>=100 / 25<=fast<100 / very fast<25 msec
11	Service / Traffic Type	Sustained High/medium/Low data rate	Sustained 100<high<=1,000 / 10<medium<=100 /low<=10 Mbps
		Bursty High/medium/Low, burst-size	Bursty 10<high<=1,000 / 0.01<medium<=10 / low<=0.01 MByte bursts
		Sporadic High/medium/Low msg/s	Sporadic 10<high<=1,000 / 0.01<medium<=10 / low<=0.01 packets/sec
12	Reliability/Availability	high / medium / low	99.99999% / 99.999% / 99.99%
13	Space/Area Dependent Interactivity	Dense High/Medium/Low	Dense >1 UE/m^2 and 100<high<=1,000 / 1<medium<=100 / low<=1 transactions/sec
		Medium Density High/Medium/Low	1 UE/25m2<=Medium<1 UE/m2 and 100<high<=1,000 / 1<medium<=100 / low<=1 transactions/sec
		Sparse High/Medium/Low	Sparsity of < 1 UE/25m^2 and 100<high<=1,000 / 1<medium<=100 / low<=1 transactions/sec

14	Security / Privacy	Baseline /Medium /High / Ultra-High grade	Public/restricted/Confidential/top-Secret-Military grade

In total 27 versions (or instances) of Table 2: User Requirements' Metrics and Indicative Values were completed, each representing a different use-case and scenario. A brief description of each use-case and scenario can be found in the chapter that follows. More details of the use cases could be found in deliverables D3.1, D4.1 and D5.1.

Next, an analysis of the combined requirements is being presented. The ultimate goal is to "translate" the user requirements in network requirements (general and specific) and eventually into technical specifications.

Although each use case has its unique requirements, a single 5G network infrastructure will be called upon to successfully implement and deliver them. The grouping of the similar user requirements as well as the identifications of synergies between use-cases (even from different Vertical Industries) is important. It will allow network equipment manufacturers and network operators to optimize their design, define network slices and eventually deliver the service the end-users are expecting and are willing to pay.

3 USE CASES. A HIGH-LEVEL DEFINITION

The high-level use case descriptions, grouped by vertical industries and scenarios will be demonstrated.

3.1 Healthcare

The e-Health sector is identified as a priority in the European Digital Agenda and subsequently in many national digital agendas because of the amount of spending as well as the worrying rise in healthcare costs.

5G will enable a vision, where monitoring, diagnosing and treating patients can take place, anywhere, and anytime, essentially removing the walls of the hospital. The best medical experts can be involved instantly for fast diagnostics & treatment. Optimal care can be offered by keeping care providers, care facilities and patients always connected, also on-the-move, and by having up-to-date patient status and decision support available anytime and anywhere.

The healthcare use cases have been broken down into *subcases*, denoted with ‘A’, ‘B’, etc. Some subcases map to *clinical cases*. This applies especially for the H1 use case. The H2 use case only consists of one subcase, but for consistency the terminology is kept. The H3 use case differs, since this is more concentrated to be a technological development and test, however motivated by clinical cases. The terminology is however not strictly consistent, because some subcases are further granulated into scenarios, while others identify different approaches to address the same challenge.

3.1.1 H1 Remote interventional support

3.1.1.1 Subcase H1A: Educational surgery

Fast mobile network connections today have enabled, not only increased capacity and lowered latency, but also improved reliability. One extra motivation is to reduce physical travel and support ways to reduce CO_2 emissions. Two of the identified ways is remote teaching and distance learning.

In addition to the evolution of mobile connections, high-quality video streaming technology and devices have increased the resolution. 5G, with its increased capacity and throughput, can tackle high-resolution streams, such as 4K and 8K.

One of the interesting video streaming use cases becoming more and more popular nowadays is 360 degree video streaming. Thanks to 360 degree video, the user can select the point of interest (camera angle) to be watched. This can be extremely beneficial for educational surgery where the user (e.g. a student) can select the viewpoint simply by rolling the video image in the client device.

One interesting use case is where the sensor data is transferred alongside the video stream and therefore, it provides additional information of the situation.

The storyboard for flexible video focus is the following

- Video link (with 360-degree camera) is initialized and teaching session is started by the teacher.
- Students join the class through their chosen end-devices (phones/computers/tablets/...).
- During the educational session, the teacher asks the assistant to bring the secondary camera for a close-up shot of the wound of the patient. The assistant starts the secondary camera stream, which can be viewed, either automatically or by an interaction on the student side, and moves into position.

- Through high-quality secondary video, students get an accurate picture on the details of specific treatment method or state of the patient.

The subcase H1A tests will be performed in Oulu, Finland.

Table 3: Scenario H1A user requirements

Requirements	Metric	Values & Units
Video Reception	Yes	15 Mbps/channel or stream
Video Transmission	Yes	200 Mb/s
Data Reception(DL)	High	< 1Gb/s
Data Transmission (UL)	High	< 200 Mb/s
Voice Communication	Yes	128 Kbps UL/DL
Mobility	Stationary	
Location Information	Low accuracy	Location not used
Edge Computing	Yes	4K transcoding capabilities
Edge Storage	Yes	4K transcoding capabilities
Fast Response (Low Latency)	Slow	>100 ms
Service / Traffic Type	Sustained High	< 1 Gb/s
Reliability/Availability	Low	< 99%
Space/Area Dependent Interactivity	Dense low	1-20 UE/m^2 and < 1 transaction/sec
Security / Privacy	High	Confidential (GDPR)

3.1.1.2 Subcase H1B: Remote ultrasound examination

Ultrasound enables rapid imaging of internal body structures such as tendons, muscles, joints, blood vessels, internal organs and soft tissue that do not show up well on X-ray. It has no known harmful effects compared to X-rays and CT scans and it is very compact in size as an imaging device. Furthermore, ultrasound is a non-invasive, affordable, portable and versatile imaging technique suitable for Point of Care, including obstetrics, gynaecology and general medical emergencies. A variety of organs can be examined quantitatively, including the heart, lungs and abdomen, using different types of ultrasound imaging techniques that show 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.

However, capturing a quality ultrasound image and interpreting it is hard and requires a lot of practice. This means that an expert sonographer may not be available on-site when needed. Upcoming communication technologies will enable expert (cardiac) sonographers to perform remote ultrasound diagnostics of complex cases, even on patients from rural areas. Such tele-sonography solutions will enable an expert to guide a remote doctor or paramedic in performing ultrasound exams and ultrasound guided interventions.

Three different approaches have been identified initially:

1. Remote diagnosis with B-mode / Color-Doppler ultrasound (with video) is essentially a Skype-like session to be set-up between a remote expert and a local doctor. The Skype-like session will include audio/video (2-way) and streaming ultrasound, all planar (i.e. 2D).
2. Augmented reality guided ultrasound diagnostics enables a remote expert and a local doctor to step into the same augmented reality space (i.e. 3D) by wearing AR/VR headsets (glasses), coordinating the exam of the patient together.

3. Robot-guided ultrasound examination (with fixed video) brings the remote doctor into the driving seat of the examination by remotely controlling a robot arm with haptic feedback, manipulating the ultrasound probe touching the patient.

The subcase H1B tests will be performed in Oslo, Norway.

Table 4: Scenario H1B user requirements

Requirements	Metric	Values & Units
Video Reception	Yes 3-4 channels	15 Mbps/channel or stream
Video Transmission	Yes 3-4 channels	45 Mbps/channel or stream
Data Reception(DL)	Medium	< 100 Mb/s
Data Transmission (UL)	Low	< 10 Mb/s
Voice Communication	Yes	128 Kbps UL/DL
Mobility	Stationary	
Location Information	Low Accuracy	
Edge Computing	Yes	Derived from latency
Edge Storage	Yes	Derived from latency
Fast Response (Low Latency)	Fast	<50 ms
Service / Traffic Type	Sustained High	Sustained 100 Mb/s
Reliability/Availability	Low	<99.9 %
Space/Area Dependent Interactivity	Dense medium	> 1UE m/2 and <100 transactions/sec
Security / Privacy	High	Confidential (GDPR)

3.1.1.3 Subcase H1C: Paramedic support

The 5G system can be used to connect a healthcare professional responding to medical emergencies (e.g. ambulance paramedic, nurse, emergency medical technician or other first responder) with remote senior support. This remote senior support will be the medical supervisor of the ambulance service, or a medical expert located at a hospital, first responder call centre or other medical facility. This helps in making the optimal triage decisions with respect to diagnosis, treatment and selection of the most appropriate destination hospital for the patient. Triage is a method used by healthcare professionals in an emergency setting to sort the incoming cases in three categories, according to how severe the trauma is, and how the prognoses are.

In 5G-HEART, the priority will be to validate the usage of 5G for two remote imaging functions which are expected to have the most demanding requirements on wireless connectivity in terms of data throughput and latency:

1. Wearable video on glasses or on a headset worn by a health professional (e.g. paramedic) at the scene of the emergency. The built-in HD video system enables a senior medical specialist, located remotely, to see the patient being assessed by the health professional. Simplex video and duplex audio virtually embeds the remote senior specialist at the scene of a pre-hospital patient event.
2. Ultrasound has the potential to significantly improve the management of pre-hospital care (first diagnosis, intervention, triage) and in particular it helps to reduce the “door to diagnosis and therapy time”, which is one of the most important factors in improving medical assistance and survival. The first two approaches listed for H1B (Section 3.1.1.2) apply here as well.

Storyboard for wearable video use cases

- A patient event happens and the ambulance is called and arrives.
- The paramedic, nurse or ambulance technician assesses the patient situation. Being approximately 10,000 events per year (30/day), they require additional medical support from the medical supervisor. The medical supervisor is trained in pre-hospital emergencies.
- The paramedic, nurse or ambulance technician wears the video headset and sends point-of-view video back to the medical supervisor. The medical supervisor may be in the ambulance office, on the road or at home.
- The medical supervisor can see the point of view video of the pre-hospital event and is immersed in the scene visually.
- The supervisor has a higher situational awareness regarding severity and volume of the situation compared to voice-only description. He/she can make more accurate decisions for patient treatment.

The subcase H1C tests will be performed in Groningen, the Netherlands.

Table 5: Scenario H1C user requirements

Requirements	Explanation	Metric	Values & Units
Video Reception	Need to receive high definition Video (4K,8K) on his/her device, TV/monitor or VR/AR end device	Yes	15 Mbps/channel or stream
Video Reception Wearable	Need to receive 'Good' quality video (640x480, 720p 1080p 25/30 frames per second) on a mobile tablet in the supervisor vehicle	Yes	>2Mbps per stream
Video Reception MOS	Should have a Mean Opinion Score of 4 and 5	High	MOS = 5 (or 4)
Video Transmission	Need to transmit high definition (4K or 8K or even 360o) Video	Yes	15 Mbps/channel or stream
Video Transmission from Weareable	Need to transmit Good quality video (640x480, 720p 1080p 25/30 frames per second) from an Android access device	Yes	>2mbps per stream
Audio MOS	Need duplex audio to accompany video. MOS should be 5	High	MOS = 5
Data Reception(DL)		Low	
Data Transmission (UL)		Low	

Voice Communication		Yes	128 Kbps UL/DL
Mobility		Medium	
Location Information		Low Accuracy	
Edge Computing		No	
Edge Storage		No	
Fast Response (Low Latency)		Fast	<100 ms
Audio/Video latency		Slow	<200 ms
Service / Traffic Type		Sustained medium	Sustained 10 Mb/s
Reliability/Availability		High	>99.99999%
QoS Event	IT should be possible to trigger a QoS Event with GBR uplink requirements of 2mbps for a time window of 10-20 minutes for a medical emergency event		GBR or QCI2/QCI4 with >2Mbps UL
Space/Area Dependent Interactivity		Dense low	Dense: >2-3 devices $/m^2$
Security / Privacy		High	Confidential (GDPR)

3.1.1.4 Subcase H1D: Critical health event

Four distinct clinical cases were identified, with different types of pain points which could potentially be solved using paramedic wearable video:

1. Mass casualty supervisor support

This use case is based on *wearable video for the supervisor* at a mass casualty event in Oslo. The motivation for this use case is to provide video to enable higher situational awareness for mass casualty supervisors and scene commanders. The paramedic supervisor manages the event for the ambulance service and wears the video headset and *sends point of view video back to the supervisor* in the call centre. In this way, the call centre supervisor can see the point of view video of the mass casualty event and is immersed in the scene. The call centre supervisor has higher situational awareness regarding severity and volume of the situation and can make more accurate decisions for resource allocation and dispatch to resolve the situation with best medical outcome.

2. Chronically ill child; chronic disease with child known to hospital

This clinical case is based on *wearable video for the paramedic* visiting a chronically ill child and *connecting the video back to the paediatric doctor* who knows the child. The motivation for this use case is to empower the paramedic to make decisions which include the senior doctor who knows the child in question and can make more accurate decisions because of the contextual information. The paramedic has limited knowledge of the baseline condition (e.g. language, motion, etc.) and the situation makes him/her concerned.

3. Cancer drug follow-up at home

This clinical case relates to cancer patients that stay temporarily at home, also because treatment in a hospital with chemotherapy leaves a patient vulnerable to infections. Chemotherapy can create a shock in the body as the body has to also deal with the drug which is focused on the cancer tumour. If the patient becomes very ill, this can be very demanding for the paramedic to deal with, due to lack of the necessary skills. They currently have a direct telephone number to call, but it is better to have an expert with a personal relationship to the patient involved. The *paramedic wears the video headset and sends point of view video back to the oncologist* who is treating the patient. The oncologist doctor may be in the hospital or at home. The oncologist knows the cancer patient, but the paramedic has low contextual information about the patient when she/he arrives.

4. Paramedic to paramedic for drug delivery support

This clinical case is about the pain treatment in an ambulance by introducing a new, powerful drug, like fentanyl, to pre-hospital care. It has not been earlier available for paramedics and a pilot is in plan in Oslo. This drug is used after trauma as it has a quicker onset. A range of drugs in different clinical pilots are considered. These are naloxone and fentanyl, as well as a range of intraosseously delivered drugs.

The question of the fentanyl drug trial relates to the security mechanism. What is the right indication for the right patient? Is the drug dose correct and documented correctly? Are adverse effects manageable? There are risks of sedation and loss of respiration; are these manageable? The paramedic needs to act accordingly if adverse events happen. *The pilot will be an evaluation of these issues.* The paramedic doesn’t necessarily need to be fully experienced with all possibilities. Consultation with another paramedic is seen important, i.e. peer to peer consultation. The more senior paramedic may be on duty in the field or in a call centre or at the hospital waiting for calls. Numeric grading will be used, for example: what is the pain level on scale 1 to 10? Another question is: who in the healthcare service has the ultimate responsibility? Yet another question is the progression of pain over time.

The key question is the quality improvement in the clinical trial project. Is there better pain relief at the end of the treatment with fentanyl in the ambulance?

The subcase H1D tests will be performed in Groningen, the Netherlands, and possibly in Oslo, Norway.

Table 6: Scenario H1D user requirements

Requirements	Explanation	Metric	Values & Units
Video Reception	A need to receive high definition Video (4K,8K) on his/her device, TV/monitor or VR/AR end device	Yes	15 Mbps/channel or stream
Video Receiption Wearable	A need to receive 'Good' quality video (640x480, 720p 1080p 25/30 frames per second) on a mobile tablet in the supervisor vehicle	Yes	>2mbps per stream
Video Reception MOS	Should have a Mean Opinion Score of 4 and 5	High	MOS = 5 (or 4)
Video Transmission	User need to transmit high definition (4K or 8K or even 360o) Video	Yes	15 Mbps/channel or stream
Video Transmission from Weareable	A need to transmit Good quality video (640x480, 720p 1080p 25/30 frames per second) from an Android access device	Yes	>2mbps per stream
Audio MOS	Need duplex audio to accompany video. MOS should be 5	High	MOS = 5
Data Reception(DL)		Low	<10 Mb/s
Data Transmission (UL)		Low	<10 Mb/s
Voice Communication		Yes	128 Kbps UL/DL
Mobility		Walking-running speed	<10 km/h
Location Information		Medium	> 25 m
Edge Computing		No	
Edge Storage		No	
Fast Response (Low Latency)		Fast	<100 ms
Audio/Video latency		Slow	<200 ms

Service / Traffic Type		Sustained High	Sustained >100 Mb/s
Reliability/Availability		High	>99.99999 %
QoS Event		High	GBR or QCI2/QCI4 with >2Mbps UL
Space/Area Dependent Interactivity		Dense high	Dense > 1UE/m2 and >100 transactions/sec
Security / Privacy		High	Confidential (GDPR)

3.1.2 H2 The PillCam

3.1.2.1 Subcase H2A: The Pillcam

Colon cancer is the second most common cause of cancer mortality for both men and women. It is a cancer where early detection is of clear value. The finding and removal of subclinical polyps in the colon may prevent later cancer, and early detection increases the chance of curative resection.

Capsule video endoscopy (Pill Camera) has been available for small bowel visualization for more than ten years. More recently, a colon capsule has been introduced for selective colon visualization. This may be an alternative to colonoscopy and, in recent studies, has compared favourably in terms of automatic polyp detection using algorithms in recent studies. In this way, one can reduce or avoid viewing long video sequences of several hours. In other words, an easy-to-use solution with an effective infrastructure that can automatically transmit videos from the pill camera recorders to a secure cloud will be useful. Use of this method would avoid patients going to the hospital, as it is assumed that the patient purchases the pill and necessary equipment at the local pharmacy and can perform this procedure at home.

In this project we aim to test real-time transmission with feedback control of the pill to improve diagnosis. The goal is to design, implement and test an infrastructure that will use pill cameras where the recorders can transmit videos to an access point or a gateway that can upload the data and user ID in a secure manner to a cloud server at OUS.

The subcase H2A tests will be performed in Oslo, Norway.

Table 7: Scenario H2A user requirements

Requirements	Metric	Values & Units
Video Reception	No	
Video Transmission	Yes	>10 Mb/s, single channel

Data Reception(DL)	No	
Data Transmission (UL)	Low	<10 Mb/s
Voice Communication	No	
Mobility	Walking-running speed	<3 m/s
Location Information	No	
Edge Computing	Yes	Based on latency
Edge Storage	Yes	Base don latency
Fast Response (Low Latency)	Very fast	1-3 ms
Service / Traffic Type	Sustained low	Sustained 10 Mb/s
Reliability/Availability	High	>99.99999 %
Space/Area Dependent Interactivity	Sparse Low	Sparse < 1UE/m2 and < 1 transaction/sec
Security / Privacy	High	Confidential (GDPR)

3.1.3 H3 Vital-sign patches with advanced geo-localization

Taking NB-IoT, LTE-M, Cellular IoT developments further enables single-use vital-sign patches, making continuous monitoring of ambulatory patients, anytime and anywhere, a reality. As these patches connect direct-to-cloud (D2C), a gateway or smartphone in the middle is avoided, enabling hassle-free, out-of-the-box connectivity.

This serves the quadruple aim in healthcare (enhancing the patient experience, improving health outcomes, lowering the cost of care, and improving the work life of care providers), for example, when using a patch to continuously monitor the heart rate and breathing rate of post-surgery patients. Patients can be sent home earlier from the hospital, reducing costs and improving patient experience. Whenever a deterioration of the patient is detected, immediate action is possible, improving patient outcomes.

3.1.3.1 Subcase H3A: Vital-sign patch prototype

Single-use vital-sign patches form an interesting class of devices putting extreme – and often conflicting – requirements on e.g. cost, wearability (i.e. form factor), energy consumption, (peak) power consumption, antenna performance and global roaming. Exploring this class within 5G-HEART will help generate requirements for future 3GPP standardization (i.e. Release 17 and beyond) and for future mMTC deployments (i.e. Release 14 and beyond), through understanding which network features will have most impact on the feasibility of the concept and which network features are still missing (i.e. gap analysis).

Direct-to-cloud vital-sign patch will be used measuring heart rate and breathing rate, which is already addressing the abovementioned post-surgery monitoring use case. Using cellular technology will help to enable truly global connectivity.

Single-use, direct-to-cloud, vital-sign patches are tiny devices (< 4x3x1 cm) that are worn directly on the human torso. Consequently, these devices will need to contain a tiny battery and a single, tiny antenna to connect to the cellular network. Good coverage is required, also indoors, but deep indoor coverage -- e.g. in basements -- is generally not required. So, for now let's assume coverage on-par with cell phones.

The battery size constraints imply that peak power must be limited to ~40 mA which means Powerclass 6 (+14 dBm) or lower. The antenna size constraints -- plus its < 1 cm distance to the human torso -- imply a total antenna efficiency of -14 dBm or worse in the 700-800 MHz range, i.e. a TRP around 0 dBm.

For our first target use case -- post-surgery monitoring at home -- the total amount of data sent during the lifetime of the device is very limited: for a ~1 kB upload message the maximum energy usage should be now more than a few mWh. Observe that given the above TRP constraint, it is likely that enhanced coverage modes involving many repetitions may be needed. However, for more demanding use cases this number would even be lower.

The subcase H3A tests will be performed in Eindhoven, the Netherlands and in Oslo, Norway.

Note that, unless stated otherwise, the requirements below will relate to the post-surgery monitoring case.

Table 8: Scenario H3A user requirements

Requirements	Metric	Values & Units
Video Reception	No	
Video Transmission	No	
Data Reception(DL)	no	
Data Transmission (UL)	Low	< 100 kb/s
Voice Communication	no	
Mobility	Walking-running speed	<3 m/s
Location Information	No	
Edge Computing	No	
Edge Storage	No	
Fast Response (Low Latency)	Slow	~5 minutes
Service / Traffic Type	Sporadic Low	Sporadic, >0.01 packet/sec (one transaction every two hours)
Reliability/Availability	Medium	>99.999 %
Space/Area Dependent Interactivity	Medium Density low	< 1 UE/25 m2 and < 1 transaction/sec (500 devices/cell)
Security / Privacy	High	Confidential (GDPR)
Coverage	Medium	Indoor/outdoor, on-par with cellphones @ 0 dBm TRP
Energy	Very low	~1 mWh per ~1kb upload message

3.1.3.2 Subcase H3B: Localizable tag

Wearable health monitoring has emerged as an effective way for improving the performance of patient remote diagnoses and monitoring. A patch can be designed for patients suffering from conditions that require immediate help in case of an emergency, examples include heart, diabetic, epilepsy or pregnancy risk monitoring. For this, a patch would generate an alert when an emergency is detected. As the patient may be incapacitated, there is also a strong requirement to localize the patient. Localization is an essential piece of information for the emergency centre to effectively assign resources at the right location.

The purpose of the field tests is to validate the narrowband radio-localization approach with real signals and in a realistic environment (outdoor/indoor, rural/urban). The accuracy of the localization and the associated range should be evaluated for different propagation conditions. The test plan is articulated in three steps: laboratory tests, field tests with a first version of the radio-localization process and a last step which will consist of validation of the final localization proposal in the field.

The subcase H3B tests will be performed in Grenoble, France.

Table 9: Scenario H3B user requirements

Requirements	Metric	Values & Units
Video Reception	No	
Video Transmission	No	
Data Reception(DL)	Low	<50 kbps
Data Transmission (UL)	Low	<50 kbps
Voice Communication	No	
Mobility	Medium (for ping)	130 km/h
Location Information	Medium accuracy	10 meter radius (indoor) and a floor-accurate
Edge Computing	No	
Edge Storage	No	
Fast Response (Low Latency)	Slow	Localization information has to be available in < 1 min
Service / Traffic Type	Sporadic Low	Sporadic 0,005 messages/sec
Reliability/Availability	medium	99.999%
Space/Area Dependent Interactivity	Sparse Low	Sparsity of < 1 UE/100m2 and 0,005 transaction/sec
Security / Privacy	High	Confidential (GDPR)

3.2 Transport

5G connected transport will drive transformational changes while bringing social, economic and industrial benefits to the economies that take the lead in its adoption. Communication between vehicles, infrastructure, the cloud and other road users is crucial to increase the safety of future automated vehicles and their full integration in the overall transport system. Cooperation, connectivity, vehicle digitisation and automation are not only complementary technologies; they reinforce each other and will merge completely over time.

3.2.1 T1 Platooning

Platooning allows vehicles to form a tightly coordinated "train" with significantly reduced inter-vehicle distance, thus increasing road capacity and efficiency. The vehicles in a platoon receive periodic data from the platoon leader (i.e., first vehicle) to carry on platoon operations. This information allows the distance between vehicles to become extremely small, i.e., the gap distance translated to time can be very low (i.e., an order of magnitude of sub-second). Platoon members (i.e., vehicles following the leader) can be autonomously driven, which improves fuel efficiency, reduces accident rate and enhances productivity by freeing up drivers to perform other tasks.

3.2.1.1 Scenario T1S1 & T1S2 - High bandwidth in-vehicle situational awareness and see-through for Platooning

This scenario involves support for high bandwidth in-vehicle streaming serving situational awareness/collision warning and see-through applications for platooning scenarios. When driving in a platoon with very close distances between vehicles, the passengers will most likely feel more secure when they can see what is happening ahead of the platoon leader. One way of facilitating this is by providing an augmented reality (AR) video stream from the platoon leader to the other members. This can also extend the object and event detection to the trailing vehicles for increased safety (via redundancy) or comfort by anticipating manoeuvres of the lead vehicle in response to the driving conditions. For instance, the identified objects ahead and/or real-time video representing the front scene could be used as a visual alert that a given platoon is about to be split for safety and/or efficiency reasons, thus keeping the anxiety levels of the drivers low and increasing their readiness to take over the control of the vehicle whenever needed.

The trials will be conducted on the Surrey node of the 5GENESIS project located on the campus of the University of Surrey. The trail building blocks include object and event detection capabilities through on-board sensors together with vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) communications over 5G. The effectiveness of the considered functionalities (i.e., see-through and situational awareness) in supporting platooning will be assessed with a focus on the resulting driving experience and smoothness of switching between platooning and individual driving modes.

Table 10: Scenarios T1S1 & T1S2 user requirements

Requirements	Metric	Values & Units
Video Reception	Yes (platoon members)	15 Mbps/channel or stream (HD video)
Video Transmission	Yes (platoon leader)	15 Mbps/channel or stream (HD video)
Data Reception(DL)	Medium	10 to 100 Mbps
Data Transmission (UL)	Medium	10 to 100 Mbps
Voice Communication	No	n/a
Mobility	Medium Speed	50-200 Km/h
Location Information	High Accuracy	±0.5 meters
Edge Computing	Yes	User Perception (derived from Latency and traffic type)
Edge Storage	No	n/a
Fast Response (Low Latency)	Very Fast	5 msec
Service / Traffic Type	Sustained Medium	Sustained 100 Mbps
Reliability/Availability	High	99.99999%
Space/Area Dependent Interactivity	Medium density and Medium interaction	Density of >1 UE/10 m2 and 100 transactions/sec
Security/Privacy	Baseline	Public

3.2.1.2 Scenario T1S3 – Dynamic channel management for traffic progression

This scenario proposes to optimize the assignment of radio channels to the V2I and V2V links used by the platoons operating in a given area. To this end, a centralized architecture is considered, where a V2X application analyses the speed, location and destination of the platoons before assigning the best radio channels to each of them. Based on this analysis, a radio environmental map (REM) combining geolocation information with the best radio channels is generated and continuously updated. The area of interest may cover a single (e.g., junctions) or multiple (e.g., highways) road side units (RSUs). Distributed architectures may also be considered in scenarios where cooperative sensing (i.e., with other vehicles and/or RSUs) is more appropriate to determine the best radio channels in a given neighborhood.

The trials will be conducted on the Surrey node of the 5GENESIS project located on the campus of the University of Surrey. Both centralized and distributed architectures will be explored. In the centralized solution, the various platoon members report through the 5G network their speed, location and destination to their serving RSUs. In a given area possibly spanning various RSUs, a V2X application will gather and combine all received inputs to determine the optimum channel assignment for each of the active platoons. A hierarchical optimisation is considered where a local REM combining geo-location information with the best radio channels is generated and continuously updated in each neighbourhood. Note that a form of collaboration between the local REMs is required to minimise the border effects (e.g., facilitate handovers and minimise co-channel interference). In the distributed solution, the best radio channels are directly determined based on a collaborative sensing jointly performed by the various platoon members.

Table 11: Scenario T1S3 user requirements

Requirements	Metric	Values & Units
Video Reception	No	n/a
Video Transmission	No	n/a
Data Reception(DL)	Low	10 Mbps
Data Transmission (UL)	Low	10 Mbps
Voice Communication	No	n/a
Mobility	Medium Speed	50-200 Km/h
Location Information	Medium Accuracy	±4 meters
Edge Computing	Yes	User Perception (derived from Latency and traffic type)
Edge Storage	No	n/a
Fast Response (Low Latency)	Very Fast	5 msec
Service / Traffic Type	Sustained Low	Sustained 10 Mbps
Reliability/Availability	High	99.99999%
Space/Area Dependent Interactivity	Medium density and Medium interaction	Density of >1 UE/10 m2 and 100 transactions/sec
Security/Privacy	High	Confidential

3.2.2 T2 Autonomous / Assisted driving

Advanced Driving enables semi-automated or fully-automated driving. Longer inter-vehicle distance is assumed. Each vehicle and/or RSU shares data obtained from its local sensors with vehicles in proximity, thus allowing vehicles to coordinate their trajectories or manoeuvres. In addition, each vehicle shares its driving intention with vehicles in proximity. The benefits of this use case group are safer traveling, collision avoidance, and improved traffic efficiency.

3.2.2.1 Scenario T2S1 & T2S2 –Smart junctions and network assisted & cooperative collision avoidance (CoCA)

A high percentage of all traffic accidents occur at intersections, where there is a high density of vehicles and vulnerable road users (e.g. cyclists and pedestrians). The "*Intersection Safety Information Provisioning*" scenario as described within 3GPP [4] (i.e. smart junctions) provides network assisted safety information towards vehicles to prevent traffic accidents and assist cooperative automated driving functions when the vehicles pass through an intersection. This safety information may involve the exchange of precise digital maps of intersections, the status of traffic signals and locations of vehicles and vulnerable road users. Besides intersections, such network-assisted collision warning and avoidance services can also be beneficial on other road segments, e.g. highways. This scenario is part of a trial at the 5Groningen site together with H1C Remote Paramedic Support in order optimize the ambulance path from an emergency event location to a hospital.

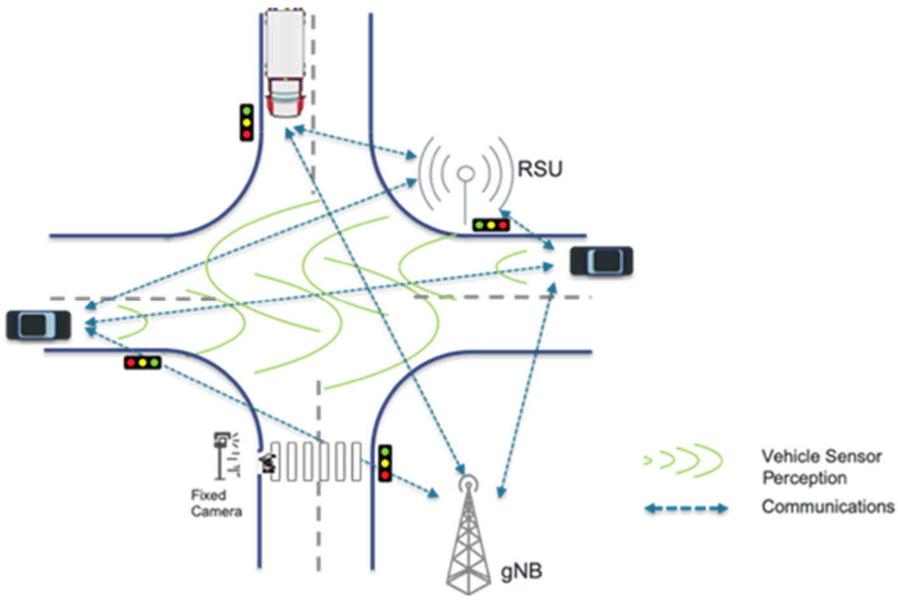

Figure 4: Example of a smart junction with traffic lights.

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Table 12: Scenarios T2S1 & T2S2 user requirements

Requirements	Metric	Values & Units
Video Reception	No	n/a
Video Transmission	No	n/a
Data Reception(DL)	Low	10 Mbps
Data Transmission (UL)	Low	10 Mbps
Voice Communication	No	n/a
Mobility	Medium speed	Maximum 160 km/h
Location Information	High Accuracy	±0,5 meters
Edge Computing	Yes	User Perception (derived from Latency and traffic type)
Edge Storage	Yes	User Perception (derived from Latency and traffic type)
Fast Response (Low Latency)	Very Fast	5 msec
Service / Traffic Type	Mixture of Sustained Low data rate and Bursty medium burst-size	Mixture of Sustained 10 Mbps and Bursty 10 MByte bursts
Reliability/Availability	Medium	99.999%
Space/Area Dependent Interactivity	Medium density and High interaction	Density of 1 UE / 10 m2 and 1.000 transactions/sec
Security/Privacy	Baseline	Public

3.2.2.3 Scenario T2S3 – QoS for advanced driving

This scenario involves the QoS-aware switch of driving modes based on the context at-hand. This involves the dynamic selection of the most appropriate level of automation (LoA) among the following options [5]:

0 – No Automation,

1 – Driver Assistance,

2 – Partial Automation,

3 – Conditional Automation,

4 – High Automation,

5 – Full Automation.

While each driving mode has its own merits and advantages, there exist non-trivial traffic scenarios where using an inappropriate driving mode may result in traffic hazards and/or accidents. As such, the best LoA for a given environment should be selected based on all the relevant factors (e.g., the operating conditions of the vehicle, design decisions made by manufacturers and regulation in-force).

The trials will be conducted on the Surrey node of the 5GENESIS project located on the campus of the University of Surrey. A V2X application dynamically selects the most appropriate LoA for a given trip. Depending on the capabilities of the vehicle, features of the network and constraints imposed by the vehicle manufacturer, the V2X application may be hosted in the vehicle, edge or cloud. This decision-making entity initially determines the target trajectory based on the current location and destination of the vehicle. Based on that, it negotiates the connectivity and QoS levels that can be provided by the network for each segment of the trip. Prior to this negotiation, an authentication procedure is performed on the network side to authorise only trustworthy accesses.

Table 13: Scenario T2S3 user requirements

Requirements	Metric	Values & Units
Video Reception	No	n/a
Video Transmission	No	n/a
Data Reception(DL)	Low	10 Mbps
Data Transmission (UL)	Low	10 Mbps
Voice Communication	No	n/a
Mobility	Medium Speed	50-200 Km/h
Location Information	Medium (low SAE automation levels) to High (high SAE automation levels) Accuracy	±4 meters (low SAE automation levels) to ±0.5 meters (high SAE automation levels)
Edge Computing	Yes	User Perception (derived from Latency and traffic type)
Edge Storage	No	n/a
Fast Response (Low Latency)	Slow (low SAE automation levels) to Very Fast (high SAE automation levels)	100 msec (low SAE automation levels) to 5 msec (high SAE automation levels)
Service / Traffic Type	Sustained Low	Sustained 10 Mbps
Reliability/Availability	High	99.99999%
Space/Area Dependent Interactivity	Sparse and Medium interaction	Sparsity of < 1 UE/100m2 and 100 transactions/sec
Security/Privacy	High	Confidential

3.2.2.4 Scenario T2S4 – Human tachograph

This scenario focuses on a wearables-based human tachograph, which provides a direct measurement/assessment method and technology to assess the driver's physiological status. Wearable sensor devices are typically worn continuously, thus also providing important information from time spent outside the vehicle. The driver's alertness and fitness-to-drive can be determined from sleep history, recovery status, stress levels and physical activity or lack thereof during the day. In addition, wearable sensors can provide real-time status information about the driver in the car while driving.

Wearables-based driver condition monitoring can provide useful data for the active safety systems utilised in cars and other vehicles, such as trucks and engines. However, this information will be especially useful for future connected automated vehicles where accident prevention can be aided by sharing information between vehicles and other systems. If the monitoring data, typically restricted to the current state of the driver, is extended to include the potential risk factors identified from the driver's history data (e.g. sleep deprivation, high stress, etc.), more proactive- measures can be taken to improve the safety of driver, passengers and other road users. Wearables, when coupled with high-performance connectivity and service platforms, can furthermore provide driver condition monitoring capabilities to vehicles, which do not have an on-board system installed or function as part of network-assisted warning and safety systems.

The trials in this scenario will be built around wearable sensor devices with short-range connectivity and standard-compliant 4G/5G network components. Smartphones will act as links/gateways between the sensor devices and 5G network, as well as perform data fusion tasks. Alternatively, data fusion can take place at the network edge or in the cloud. The test cases will start with simple connectivity and performance tests, and then evolve to include more processing in the network and assess the delays related to MEC and cloud architectures. In the end, the integrate service and network architectures will be validated from an end-to-end perspective. The required trialling infrastructure as well as measurement and testing tools for the 5G network will be provided by the VTT's 5GTN Oulu trial facility. In addition, trialling cooperation with other sites (i.e., 5GENESIS and/or 5Groningen) could be done in the later phases of the project.

The storyboard for the trials is as follows:

- Wearable devices send sensor data to the gateway (GW) node (e.g. smartphone) or vehicle on-board system in Vehicle A via a Bluetooth low energy (BLE) or WiFi link.
- The GW node or vehicle on-board systems sends sensor data from Vehicle A to the network via a 5G NR link.
- Vehicle A receives additional information and feedback messages based on the sensor data (processed in the network) via a 5G NR link or V2X broadcast service.
- The 5G GW device utilises the additional information received from the network and combines it with the live measurement data from the wearable devices.
- Vehicle B receives information/warning messages based on the sensor data from Vehicle A (processed in the network) via a 5G NR link or V2X broadcast service.
- Wearable devices or vehicle on-board systems display suggestions/warnings to the drivers of Vehicle A and Vehicle B based on the messages received from the network.

Table 14: Scenario T2S4 user requirements

Requirements	Metric	Values & Units
Video Reception	No	n/a
Video Transmission	No	n/a
Data Reception(DL)	Low	<10 Mbps
Data Transmission (UL)	Low	<10 Mbps
Voice Communication	No	n/a

Mobility	Medium	50-200 Km/h
Location Information	High Accuracy	±0,5 meters
Edge Computing	Yes	User Perception (derived from Latency and traffic type)
Edge Storage	Yes	User Perception (derived from Latency and traffic type)
Fast Response (Low Latency)	Very fast	5 msec
Service / Traffic Type	Sustained Low data rate (wearables data) Bursty Medium burst-size (history data) Sporadic Medium msg/s (synchronisation)	Sustained: 10 Mbps (wearables data) Bursty: 10 MByte bursts (history data) Sporadic: 1 msg/sec (synchronisation)
Reliability/Availability	Low	99.99%
Space/Area Dependent Interactivity	Medium density and High interaction	Density of 1 UE / 10 m2 and 1.000 transactions/sec
Security/Privacy	High	Confidential

3.2.3 T3 Support for remote driving

Remote driving enables a remote human operator or a cloud-based application to operate a remote vehicle, in cases the passengers of the vehicle cannot drive themselves, or a vehicle is sent driverless to its destination, e.g., driving through a dangerous environment. For a case where variation is limited and routes are predictable, such as public transportation, remote driving based on a cloud-based application can be employed. In addition, access to cloud-based back-end service platform can be considered for these scenarios.

3.2.3.1 Scenario T3S1 – Tele-operated support (TeSo)

Remote driving is a concept in which a vehicle is controlled remotely by either a human operator or a Cloud-based computing software. While autonomous driving needs a lot of sensors and sophisticated algorithms like object identification, path planning and vehicle control, remote driving with human operators can be realised using less of them, provided that ambient information is properly transferred and visualised to the remote vehicle operator. In the current use-case, the envisioned scenario is that of a vehicle traveling in urban or suburban streets, or in a highway, bearing high-definition (HD) video cameras (front, right-left side and rear) and perhaps various sets of sensors, such as radars/lidars. With the aid of vehicle's instrumental data and video streaming, a remote human operator (or a cloud-based application) can track the car and control its course and speed. Tele-operation may be considered throughout the vehicle course, or on-demand after the request of the driver for remote assistance.

All instrumental data and video streams are communicated to the remote location of the human operator, namely the remote operations centre (ROC) that is either accessed through the core or located at the edge of the network. The instrumental data and video feed represent sufficient ambient information that will allow the accurate creation of situation awareness, which in turn will allow prompt reaction to emerging hazards (e.g., collision avoidance, efficient driving, etc.), without the need for sophisticated/expensive artificial intelligence (AI) computing. Furthermore, such TeSo capability enables a single human operator to potentially control remotely more than one vehicle, thus providing additional levels of protection and efficiency, e.g., allow an operator to monitor the driving of three vehicles and prevent hazardous situations.

In the deployment scenario, TeSo is enabled by a V2N connection between in-vehicle UE, defined as an on-board unit (OBU), a remote server hosting V2N applications, and in particular by the TeSo application used by the remote human operator. OBU is connected to the 5G network through a V2N connection. The V2N connection transfers the instrumental sensor data feed (high resolution perception data) from the vehicle to the remote human operator (through the uplink connection). The instrumental sensor data provides the human operator the "driver's view" in that particular vehicle and allows the human operator to send appropriate command messages (e.g., command trajectories and possibly voice commands/voice communication between tele-operator and actual human driver) back to the vehicle (through the downlink connection). More specifically, the vehicle needs to share not only driving information, such as speed, position and videos from cameras (front, right and left side, and rear), but also vehicle status information, such as steering angle, gear position, throttle pedal position, handbrake position, turn and alarm signals, lights and fuel consumption with remote operator. In addition, sensory data from radar and lidar, can be optionally used, especially considering the case of a remote driving cloud application that constitutes a use case evolution. At the same time, specific effectors are used so as for the remote driving service to be able to control the different actuators of the car, such as steering wheel, brake, handbrake, gear, throttle, turn and alarm signals and lights to manoeuvre the vehicle.

To manoeuvre a vehicle, data from multiple vehicle instruments should stream their information in real time (synchronised and with low-latency) to the operator and at the same time achieve low-latency in the control task (manoeuvring the vehicle in real time). Any significant constraints or disruptions in the sensory data or video transfer would not be tolerable in a remote driving scenario. For instance, limits on the uplink throughput of the V2N link would limit data feeds in terms of achievable resolution, frame (or refresh) rates and compression applied (contributing compression latency). These throughput limits become more severe in road environments with multiple vehicles contenting for the same mobile network resources for V2N communications. The constraints posed by legacy 4G networks in achievable uplink throughput and area capacity would make a wide-scale adoption of the solution challenging. At the same time, the downlink channel has to comply with ultra-low latency constraints to stream the control data generated by human operator at the ROC. The end-to-end delay would result accumulatively from: instrumental sensors reading, instrumental data processing, uplink, data visualisation, manual control, control signal reading, downlink, and control signal processing.

5G needs to provide the increased availability of connectivity, reduced latency and offer additional benefits including service discovery and security, as well as advanced localisation of the vehicle. Specifically, the 5G eMBB service should be used to stream raw sensor and high definition video data from the vehicle to the ROC, while the 5G URLLC service is needed to exchange safety critical messages.

Table 15: Scenario T3S1 user requirements

Requirements	Metric	Values & Units
Video Reception	No	n/a
Video Transmission	Yes, one channel or stream	15 Mbps/channel or stream (HD video)
Data Reception(DL)	Low	1-5 Mbps
Data Transmission (UL)	Low	1-5 Mbps
Voice Communication	Optional	128 Kbps UL/DL
Mobility	Running Speed (urban environments) Running to Medium Speed (sub-urban environments) Running to High Speed (highways)	0-50 Km/h (urban environments) 0-100 Km/h (sub-urban environments) 0-250 Km/h (highways)
Location Information	High (urban environments) to Medium (sub-urban	±0.5 meters (urban environments) to ±4 meters (sub-urban environments and highways)

	environments and highways) Accuracy	
Edge Computing	Optional	User Perception (derived from Latency and traffic type)
Edge Storage	Optional	User Perception (derived from Latency and traffic type)
Fast Response (Low Latency)	Very Fast	5 to 20 msec
Service / Traffic Type	Sustained Medium data rate	Sustained 15-20 Mbps
Reliability/Availability	Medium	99.999%
Space/Area Dependent Interactivity	Medium density and High interaction	Density of 1 UE/15 m2 and 200 transactions/sec
Security/Privacy	High	Confidential

3.2.4 T4 Vehicle Data Services

Under the vehicle data services use case, the trial scenarios focus on interconnecting the third-party data sources, be it a centralised online database or a distributed sensor network, and the connected automated vehicles via the available 5G infrastructure.

3.2.4.1 Scenario T4S1 – Vehicle prognostics

A Road Side Unit (RSU) application, having the capability to access the Internet, will enable any passing vehicle to report its current functional state to a local/remote diagnosis service and receive a "Just in time repair notification". A vehicle service application linked to local repair centres needs to obtain and analyse data from the vehicle periodically. An RSU application can provide this data by collecting in from the passing cars on the road. Based on the analysis outcome, the repair centre will notify to the vehicle owner with any identified issues.

The trials in this scenario will be built around RSU devices with short-range connectivity and standard-compliant 4G/5G network components. Specifically, it is assumed that an RSU, located on the roadside and having the capability to access the Internet, provides connectivity support to approaching vehicles. The approaching vehicles have the appropriate hardware for recording the current functional state (e.g. engine control unit (ECU)) and the connectivity enabled. The RSU unit receives the appropriate information from the passing vehicles and transmits it to the local repair centre. The data is processed in the cloud. The analysis can be assisted with additional data associated with the same vehicle. The additional data can be gathered from other RSUs along the vehicle route. The data is analysed and a respective warning message is sent to the vehicle. At the end, the driver verifies the analysis made from the repair centre and takes the necessary actions accordingly.

The required trialling infrastructure as well as measurement and testing tools for the 5G network will be provided by 5GENESIS/UNIS trial facility in collaboration with partners.

Table 16: Scenario T4S1 user requirements

Requirements	Metric	Values & Units
Video Reception	No	n/a
Video Transmission	No	n/a

Data Reception(DL)	High	1.000 Mbps
Data Transmission (UL)	Medium	100 Mbps
Voice Communication	No	n/a
Mobility	Medium Speed	50-200 Km/h
Location Information	Medium Accuracy	±4 meters
Edge Computing	No	n/a
Edge Storage	Yes	User Perception (derived from Latency and traffic type)
Fast Response (Low Latency)	Slow	>100 msec
Service / Traffic Type	Bursty High burst-size	Bursty 1.000 MByte bursts
Reliability/Availability	Medium	99.999%
Space/Area Dependent Interactivity	Medium density with Medium interaction	1 UE/25m2<density<1 UE/m2 with < 100 transactions/sec
Security/Privacy	Medium	Restricted

3.2.4.2 Scenario T4S2 – OTA (over the air) updates

Engine Control Unit (ECU) is a generic term for a hardware module with corresponding software in a car that controls some electronic functions within the vehicle system. It controls anything from the steering wheel to the brakes and with automated driving. The ECU is a key part of the vehicle, and will possibly need regular software updates. Over-the-air updates will provide significant cost-savings, as the vehicles will not need to be recalled by a manufacturer or service centre. Note that such an update mechanism requires significant security protection measures.

As in the previous scenario, the trials will be built around RSU devices with short-range connectivity and standard-compliant 4G/5G network components. Specifically, it is assumed that an ECU unit is installed on the vehicle along with the respective software to analyse the electronic functions and condition of the vehicle. Connectivity is established with the service that processes the data acquired from the ECU unit. At the start of the trip, the collected data are transmitted through the network and the appropriate processing takes place in the cloud. In order to be fully taken into consideration, the processed data is shared with an automated driving service (if such a service is running in parallel). The analysis of the vehicle's software status is transmitted back to the vehicle. The procedure repeats after a predefined time-step so that the driver is kept up-to-date with respect to the status of the vehicle electronic functionalities during the entire trip. Finally, the driver is fully aware of the status of the vehicle functionalities and can plan his future trips and vehicle service accordingly.

The required trialling infrastructure as well as measurement and testing tools for the 5G network will be provided by 5GENESIS/UNIS trial facility in collaboration with partners.

Table 17: Scenario T4S2 user requirements

Requirements	Metric	Values & Units
Video Reception	No	n/a
Video Transmission	No	n/a
Data Reception(DL)	High	1.000 Mbps
Data Transmission (UL)	Medium	100 Mbps
Voice Communication	No	n/a
Mobility	Medium Speed	50-200 Km/h

Location Information	Medium Accuracy	±4 meters
Edge Computing	No	n/a
Edge Storage	Yes	User Perception (derived from Latency and traffic type)
Fast Response (Low Latency)	Slow	>100 msec
Service / Traffic Type	Bursty High burst-size	Bursty 1.000 MByte bursts
Reliability/Availability	Medium	99.999%
Space/Area Dependent Interactivity	Medium density with Medium interaction	1 UE/25m2<density<1 UE/m2 with < 100 transactions/sec
Security/Privacy	High	Confidential

3.2.4.3 Scenario T4S3 – Smart Traffic Corridors

The current scenario focuses on how to utilize real time air quality and traffic information as well as the emission profile of the vehicle to provide the optimal routing to the selected destination, taking into account environmental and congestion principles.

Vehicles will utilize selected routes in order to reduce pollution or congestion. This scenario uses historical and real-time data from vehicles to intelligently control the routes that a vehicle is recommended or mandated to take in any given journey.

For instance, individual (or groups of) vehicles will be monitored and routed based on locally implemented emissions corridors. Vehicles, such as lorries or older vehicles with high emissions, will be guided through a high emissions corridor, whilst low emissions or electric vehicles will be given more flexibility on the routes they take to their destination. Logistics and delivery vehicles will be routed based on time-of-day to reduce congestion.

In particular, IoT infrastructure that provides traffic as well as air-quality information is installed. Moreover, a cloud service is provided which supports the analysis of the incoming data in real time. The driver asks for recommendation for a selected destination. The server located on the Cloud analyses the profile of the vehicle and the current situation of the area of interest based on the information received from the sensors and provides the optimal route in real time. The test cases will start with some simple performance tests, and then evolve to include more processing in the network and assess the delays related to MEC and cloud architectures. In the end, the integrated service and network architectures will be validated from an end-to-end perspective. The required trialling infrastructure as well as measurement and testing tools for the 5G network will be provided by 5GENESIS/UNIS trial facility in collaboration with partners.

Table 18: Scenario T4S3 user requirements

Requirements	Metric	Values & Units
Video Reception	No	n/a
Video Transmission	No	n/a
Data Reception(DL)	Low	10 Mbps
Data Transmission (UL)	Low	10 Mbps
Voice Communication	No	n/a
Mobility	Medium Speed	50-200 Km/h
Location Information	Medium Accuracy	±4 meters
Edge Computing	No	n/a
Edge Storage	Yes	User Perception (derived from Latency and traffic type)
Fast Response (Low Latency)	Fast	~25 msec

Service / Traffic Type	Bursty Medium burst-size	Bursty 10 MByte bursts
Reliability/Availability	Medium	99.999%
Space/Area Dependent Interactivity	Medium density with Medium interaction	1 UE/25m2<density<1 UE/m2 with < 100 transactions/sec
Security/Privacy	Baseline	Public

3.2.4.4 Scenario T4S4 – Location based advertising

Vehicle and passenger information are readily available. Location-based servers will be implemented to stream content (upon request, if required) as well as local advertising or traffic guidance to vehicles and road users. This becomes especially useful in car-sharing models where vehicles are not owned, and the origin and destination of each journey may vary depending on the passengers.

The demo plans to use 5GENESIS facility located in the University of Surrey. Access to vehicle GPS coordinates will be required so that current vehicle location can be understood. This data will be transmitted to a cloud-based application over the network. Depending on the vehicle location, multimedia advertisement content will be served to the vehicle, to be decoded and displayed to the user.

Table 19: Scenario T4S4 user requirements

Requirements	Metric	Values & Units
Video Reception	Yes	15 Mbps/channel or stream (HD video)
Video Transmission	No	n/a
Data Reception(DL)	High	1.000 Mbps
Data Transmission (UL)	Medium	100 Mbps
Voice Communication	No	n/a
Mobility	Running to Medium Speed	0-200 Km/h
Location Information	High Accuracy	±0,5 meters
Edge Computing	No	n/a
Edge Storage	No	n/a
Fast Response (Low Latency)	Very Fast	5 msec
Service / Traffic Type	Sustained High data rate	Sustained 1.000 Mbps
Reliability/Availability	Medium	99.999%
Space/Area Dependent Interactivity	Medium density with High interaction	1 UE/25m2<density<1 UE/m2 with 1.000 transactions/sec
Security/Privacy	Medium	Restricted

3.2.4.5 Scenario T4S5 – End to End (E2E) slicing

The multiplicity of use case scenarios that may run simultaneously inside the same vehicle calls for a form of customisation to simultaneously support the diverse and often conflicting requirements of each of them. With the recent introduction of softwarisation enablers (e.g., network function virtualisation (NFV) and software-defined network (SDN)) into mobile networks, network slicing has emerged as an efficient tool to create customised logical network instances on the same physical infrastructure. In this respect, different E2E slices can be used to simultaneously support the various V2X applications running inside the same vehicle. For instance, passengers can watch a HD movie, while a collision awareness application detects a road hazard and triggers an emergency message for the cars behind to slow down or stop to prevent an accident. In such scenarios, a minimum level of isolation is needed to ensure that the operation of one slice does not affect the others e.g., the QoS of safety-related V2X applications is not impacted by other applications running on the same network.

The trials will be conducted on the Surrey node of the 5GENESIS project located on the campus of the University of Surrey. 5GENESIS will provide an open API through which the slice consumer (e.g., V2X application) can request and/or negotiate the creation of tailored network slices to meet its needs according to a predefined template. The open API allows to interact with the test facility in a transparent way (i.e., making abstraction of the underlying implementation details) with the possibility to access it through a user-friendly web portal.

It is worth pointing out that this scenario can be applied to support any of the other Transport scenarios. As such, it is not associated with a specific table of user requirements.

3.2.4.6 Scenario T4S6 – Vehicle sourced HD mapping

Collect and maintain up-to-date data via crowdsourcing of HD maps of roads and infrastructure information through on-board cameras and sensors which would stream back to a regional or central service, firstly to establish baseline maps and subsequently to manage change detection. Autonomous vehicles will utilise high-definition maps to aid their decision making.

The demo plans to use 5GENESIS facility located in the University of Surrey. HD image data from vehicle cameras will be streamed to cloud based server which will run algorithms to generate geo spatial data, to be used later to aid autonomous driving.

Table 20: Scenario T4S6 user requirements

Requirements	Metric	Values & Units
Video Reception	No	n/a
Video Transmission	Yes	15 Mbps/channel or stream
Data Reception(DL)	Low	10 Mbps
Data Transmission (UL)	High	1.000 Mbps
Voice Communication	No	n/a
Mobility	Running to Medium Speed	0-200 Km/h
Location Information	High Accuracy	±0,5 meters
Edge Computing	No	n/a
Edge Storage	No	n/a
Fast Response (Low Latency)	Slow	100 msec
Service / Traffic Type	Sustained High data rate	Sustained 1.000 Mbps
Reliability/Availability	Low	99.99%
Space/Area Dependent Interactivity	Medium density with High interaction	1 UE/25m2<density<1 UE/m2 with 1.000 transactions/sec
Security/Privacy	Baseline	Public

3.2.4.7 Scenario T4S7 – Environmental Services

Local, Regional and National weather offices source their data through satellite earth observation maps and local weather stations. These are generally used for weather forecasts. Vehicles will provide a rich and real time source of weather and environmental information through existing on-board sensors. Light sensors will detect external light conditions such as cloud cover and fog, wiper data for intensity of rain and suspension data for monitoring road conditions such as potholes. These will be consolidated to create hyper local weather maps aiding drivers and automated vehicles in day-to-day driving but also to assist local authorities to improve road maintenance.

The demo plans to use 5GENESIS facility located in University of Surrey. Access to vehicle network like controller area network (CAN) will be required so that various sensor data like that of wipers can be read. This data will be transmitted to a cloud-based application over the network for consolidation.

Table 21: Scenario T4S7 user requirements

Requirements	Metric	Values & Units
Video Reception	No	n/a
Video Transmission	No	n/a
Data Reception(DL)	Low	10 Mbps
Data Transmission (UL)	Low	10 Mbps
Voice Communication	No	n/a
Mobility	Running to Medium Speed	0-200 Km/h
Location Information	Medium Accuracy	±4 meters
Edge Computing	No	n/a
Edge Storage	No	n/a
Fast Response (Low Latency)	Slow	100 msec
Service / Traffic Type	Sustained Low data rate	Sustained 10 Mbps
Reliability/Availability	low	99.99%
Space/Area Dependent Interactivity	Medium density with Low interaction	1 UE/25m2<density<1 UE/m2 with 1 transaction/sec
Security/Privacy	Baseline	Public

3.3 Aquaculture

Aquaculture is the controlled process of cultivating aquatic organisms, particularly for human consumption. It is a similar concept to land-based agriculture, and is often referred to as fish farming but can also include the farming of crustaceans (e.g. shrimp, crayfish), molluscs (e.g. mussels, oysters) and plants (seaweed species). Aquaculture activities take place throughout the world, in a variety of environments from coastal ocean waters, freshwater ponds and rivers or on land-based facilities in flow-through or recirculation tanks.

With an anticipated 10 billion people expected to inhabit the planet by 2050, the demand for animal protein will increase by 52 percent. Sustainable and healthy approaches to feeding the world are more critical than ever before. In order to sustainably feed the world’s growing population with a healthy, lean protein, aquaculture’s role is of the utmost importance. The primary responsibility of aquaculture is to efficiently complement wild-caught fish options to increase the amount of seafood available worldwide. This is of increasing importance given the fact that production from wild capture fisheries has not increased over the last two decades, therefore there is more reliance on aquaculture to meet the growing demand for healthy seafood. As the EU is a net importer of seafood produce, the EU Commission has provided strategic guidelines for the sustainable development of aquaculture in the EU and is actively promoting the development of the industry through the *Farmed in the EU* campaign.

To that respect, the aquaculture sector aims to maximize the growth rate and minimize the production costs, through the optimization of production systems, while ensuring fish/seafood product quality, optimal resource use and minimisation of environmental impact. There are currently research and implementation actions (and corresponding investments from public and private domain) for the development of autonomous data acquisition and communication systems as well as the development of intelligent management systems able to facilitate the complex operations of aquaculture sites. Implementing and applying new/emerging technologies and innovations in monitoring and management systems can enable economic, environmentally and socially sustainable aquaculture development throughout the EU and generate enhanced public and investor confidence in EU aquaculture.

3.3.1 A1 Remote monitoring of water and fish quality

The use case includes the implementation of a cross-border aquaculture platform in two pilot sites: a) in Greece (SKIRONIS), supported by the 5G-EVE node in Athens and b) in Norway (SEALAB), supported by 5G-VINNI. Furthermore, use case requirements and expertise will be offered by the Marine Institute in Ireland, in order to make the use case as far representative as possible, as well as cross-border.

Various equipment will be installed on site including underwater cameras (HD, 4K), IoT sensors (oxygen, salinity, temperature, weather stations) and autonomous sensor carriers (underwater drone) to test various data transportation levels with 5G technology. Testing involves real-time remote monitoring and operations; controlling cameras, winches, lights, sensors, multiple streams, a large real-time data gathering of images and sensor data, and of course remote drone/ROV (Remotely Operated Vehicle) operation. The relevant KPIs are bitrate levels, latency measures, network stability, thus giving better understanding of the possibilities and constraints of using the 5G technology.

Ubiquitous coverage is very important for both sites. The network should be able to cover both Internet needs for personnel, data transfer from monitoring stations and sensors, and most importantly video/image transfer. 5G can provide all of this. Additionally, 5G can be a powerful infrastructure enabling/encompassing advanced technology like Artificial Intelligence, in order to support an intelligent management system offering automation and intelligence in the aquaculture sector.

The Aquaculture use case aims to cover the different functionalities required by aquaculture sites during their day-to-day operations. In order to do that, a series of test cases will be executed including data collected by water quality sensors as well as camera footage from cameras both underwater and security ones. Additionally, remote and autonomous operations including drone and/or ROV controlling will be investigated, as well as edge computing and on-site communication needs. All the above are described in detail in the context of 5 different scenarios that are going to be included in the final trials on the two pilots. These have been defined through the test cases that are going to be executed during the trials. In the context of this deliverable we group these test cases into the following scenarios in order to further analyze their requirements:

- A1S1: Sensory data monitoring
- A1S2: Camera data monitoring
- A1S3: Automation and actuation functionalities
- A1S4: Edge and cloud-based computing
- A1S5: Cage to cage – on site communication

The installations that are going to take place for the implementation of the scenarios include sensors, cameras (underwater and security), a remotely operated drone, an edge computing node and cage-to-cage communication equipment. Additional equipment will also be investigated during the execution of the trials. The architecture that is going to be used is described briefly in Figure 5.

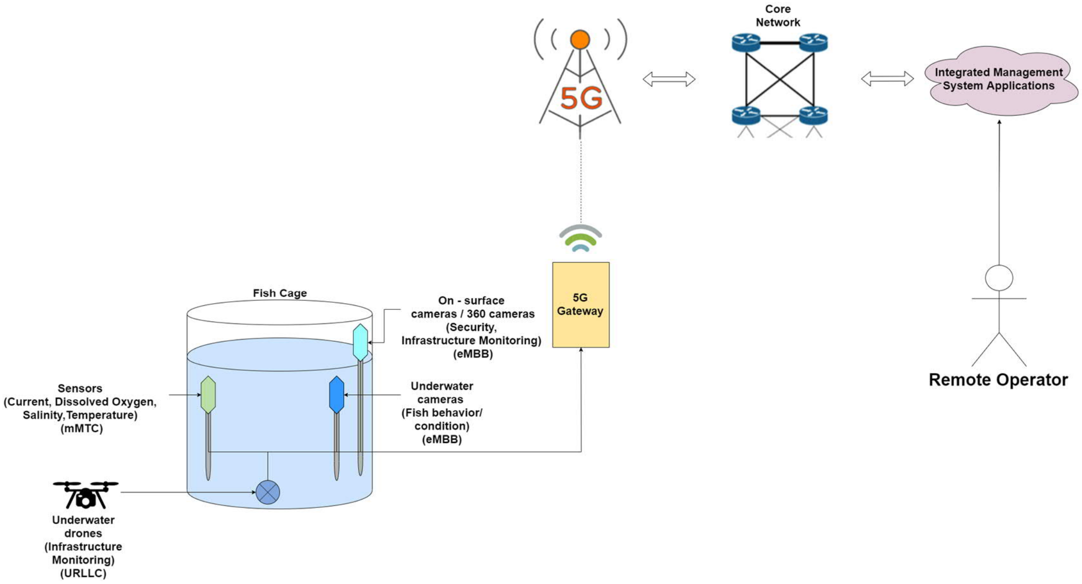

Figure 5: Aquaculture scenario architecture.

Providing the installation of the equipment described, the connection to the 5G network is going to be implemented through a set of 5G gateways, able to upload the incoming traffic. The connection depends on the availability of a network base station that will provide the access point to the network. For the measurement of the different requirements that are considered, a set of probes will be placed across the network infrastructure to cover the points of interest.

For the execution of the tests, a software cloud platform will be used, obtaining sensory and camera data from the equipment (through the 5G infrastructure) and running real-time machine learning and analytics algorithms to analyse the data and produce valuable observations facilitating the monitoring of the site. Additionally, a series of site management functionalities will be tested, allowing the transfer of operational data to the cloud as well as remote operations for the drone or other actuation systems (feeding systems, lights and camera operations, etc.).

3.3.1.1 Scenario A1S1: Sensory data monitoring

This scenario, which will be implemented on both sites, focuses on the continuous sensory data collection monitoring of the site. More and more fish farms use to gather big amounts of data to monitor and analyse the performance of the farm. Parameters like oxygen, temperature, salinity, current and meteorological data are frequently obtained to evaluate water quality and guarantee the life quality of the site in general. Thus, it is essential for the implemented platforms to provide these kinds of functionalities, support data collection from multiple data sources and import the collected data into the management system. Additionally, the systematic recording and scheduling of the different actions performed by its operators (e.g. management of the feed quantities, mortalities reporting, management of cage transfers, time sharing and personnel management) as well as the reporting of manual observations made on site, is a very important aspect that increases the data load that is required.

Table 22: Scenario A1S1 user requirements

Requirements	Metric	Values & Units
Video Reception	No	-
Video Transmission	No	-
Data Reception(DL)	Low	<= 10 Mbps

Data Transmission (UL)	Low	<= 10 Mbps
Voice Communication	No	-
Mobility	Stationary	0 Km/h
Location Information	Low Accuracy	>25 meters
Edge Computing	No	User Perception (derived from Latency and traffic type)
Edge Storage	Yes	User Perception (derived from Latency and traffic type)
Fast Response (Low Latency)	Slow	>= 100 msec
Service / Traffic Type	Sustained low	Sustained <= 10 Mbps
Reliability/Availability	High	99.99999%
Space/Area Dependent Interactivity	Dense low	Dense >1 UE/m2 and 1 transaction/sec
Security/Privacy	Medium	-

3.3.1.2 Scenario A1S2: Camera data monitoring

This scenario, which will be implemented on both sites, is about the evaluation of the network infrastructure in terms of supporting a big portion of the data transfers that are required for the operation of the fish farming sites regarding camera footage. Specifically, data from security footage obtained from cameras located on-site will be considered, as well as image and real-time video footage from underwater cameras for monitoring purposes like fish health, feed waste management, behavior analysis or other techniques that use image processing algorithms to extract more sophisticated information from the data and guide the management activities. A major requirement from the user's perspective in this case is that these kinds of data loads should be supported by the available network infrastructure to cover the needs of such functionalities.

Table 23: Scenario A1S2 user requirements

Requirements	Metric	Values & Units
Video Reception	No	-
Video Transmission	Yes	15 Mbps/channel or stream
Data Reception(DL)	Low	<10 Mbps
Data Transmission (UL)	High	1.000 Mbps
Voice Communication	No	-
Mobility	Stationary	0 Km/h
Location Information	Low Accuracy	>25 meters
Edge Computing	No	User Perception (derived from Latency and traffic type)
Edge Storage	Yes	User Perception (derived from Latency and traffic type)
Fast Response (Low Latency)	Very Fast	5 msec
Service / Traffice Type	Sustained high	Sustained 1.000 Mbps
Reliability/Availability	High	99.99999%
Space/Area Dependent Interactivity	Dense Medium	Density of >1 UE/m2 and 100 transactions/sec
Security/Privacy	Medium	-

3.3.1.3 Scenario A1S3: Automation and actuation functionalities

This scenario, which will be implemented in the Greek site, concerns the implementation of a low-latency network infrastructure which will be able to support automations in ROVs and deliver commands in minimal time allowing the remote operation of such devices. In the case of an aquaculture site, automatic feeding, maintenance or other systems precisely activating the corresponding mechanisms according to the needs of the farm stands as a major requirement for its smooth operation. Additionally, the management of ROVs or underwater drones (in a harsh environment like the cage infrastructure which includes multiple obstacles) requires instant confrontation and resolution. Thus, the network on-site should support such operations at real-time. Furthermore, the navigation and positioning of underwater cameras and the controlling of lights for optimal footage latency as well as bandwidth and throughput will be examined in this scenario.

Table 24: Scenario A1S3 user requirements

Requirements	Metric	Values & Units
Video Reception	No	-
Video Transmission	Yes	15 Mbps/channel or stream
Data Reception(DL)	Low	<10 Mbps
Data Transmission (UL)	High	1.000 Mbps
Voice Communication	No	-
Mobility	Walking speed	5 Km/h
Location Information	Medium	±4 meters
Edge Computing	Yes	User Perception (derived from Latency and traffic type)
Edge Storage	Yes	User Perception (derived from Latency and traffic type)
Fast Response (Low Latency)	Fast	5 msec
Service / Traffice Type	Sustained medium	Sustained 100 Mbps
Reliability/Availability	High	99.99999%
Space/Area Dependent Interactivity	Dense medium	Density of >1 UE/m2 and 100 transactions/sec
Security/Privacy	High	-

3.3.1.4 Scenario A1S4: Edge and cloud-based computing

This scenario, which will be implemented in the Norwegian site, concerns the implementation of a data network infrastructure in order to support high speed, high resolution cameras, real time image/data processing algorithms and generally to support the payloads of such functionalities. The benefits of such functionalities when enabled by edge and cloud-based computing are of great interest for the user and the tests will focus on bandwidth, throughput and latency.

Table 25: Scenario A1S4 user requirements

Requirements	Metric	Values & Units
Video Reception	No	-
Video Transmission	Yes	15 Mbps/channel or stream
Data Reception(DL)	Medium	100 Mbps
Data Transmission (UL)	Medium	100 Mbps
Voice Communication	No	-
Mobility	No	0 Km/h

Location Information	Low accuracy	±50 meters
Edge Computing	Yes	User Perception (derived from Latency and traffic type)
Edge Storage	Yes	User Perception (derived from Latency and traffic type)
Fast Response (Low Latency)	Fast	5 msec
Service / Traffice Type	Sustained medium	Sustained 100 Mbps
Reliability/Availability	High	99.99999%
Space/Area Dependent Interactivity	Dense medium	Density of >1 UE/m2 and 100 transactions/sec
Security/Privacy	High	-

3.3.1.5 Scenario A1S5: Cage to cage – on site communication

This scenario, which will be implemented in the Norwegian site, concerns the implementation of various service and maintenance operations at the aquaculture site such as well boats for transport and delousing, handling mortalities, net inspections etc. This process greatly benefits access to sensor and video data from the cage, as well as, data from management systems to conduct their operations. Additionally, the real-time operation and navigation underwater cameras require the network to support low latency. By moving the 5G connection point from the centralized feed barge at the site to connection points at each cage this test will also identify the benefits of 5G technologies in comparison with cabled networks (e.g. fiber optics, Ethernet) and wireless networks (4G, RoIP) which are most frequently used today. Bandwidth, latency and coverage will be measured in this test.

Table 26: Scenario A1S5 user requirements

Requirements	Metric	Values & Units
Video Reception	Yes	15 Mbps/channel or stream
Video Transmission	Yes	15 Mbps/channel or stream
Data Reception(DL)	Medium	100 Mbps
Data Transmission (UL)	Medium	100 Mbps
Voice Communication	No	-
Mobility	Walking speed	5 Km/h
Location Information	Medium	±0,4 meters
Edge Computing	No	User Perception (derived from Latency and traffic type)
Edge Storage	Yes	User Perception (derived from Latency and traffic type)
Fast Response (Low Latency)	Very Fast	5 msec
Service / Traffice Type	Sustained high	Sustained 1.000 Mbps
Reliability/Availability	High	99.99999%
Space/Area Dependent Interactivity	Dense medium	Density of >1 UE/m2 and 100 transactions/sec
Security/Privacy	High	-

4 USE CASES REQUIREMENTS ANALYSIS

In this section, we provide a description of the general requirements emerging from each use-case in each vertical, accompanied by a short description of the importance of each general requirement for the corresponding vertical. The employed approach for obtaining the general requirements was based on the content of the previous section. The most stringent user requirements of each use-case/scenario were cumulatively collected per vertical and were cross-examined across the three verticals. The goal was to identify the upper bounds across verticals for the identified requirements by users in each scenario/use-case of the verticals.

In the following, we first provide the cumulative general requirements for each vertical, to point out the most stringent ones, and then based on them, we provide the overall general requirements for the 5G-HEART system.

4.1.1 Healthcare use-case scenarios

Table 27: Most stringent user requirements for the Healthcare vertical

No	Requirements	Metric	Use-cases scenarios
1	***Video Reception***	**Yes**	Several
2	***Video Transmission***	**Yes**	Several
3	***Data Reception (DL)***	**High**	H1A
4	***Data Transmission (UL)***	**High**	Several
5	***Voice Communication***	**Yes**	Several
6	***Mobility***	**Medium**	H3B
7	***Location Information***	**Medium**	Several
8	***Edge Computing***	**Yes**	Several
9	***Edge Storage***	**Yes**	Several
10	***Fast Response (Low Latency)***	**Very fast**	H2A

11	***Service / Traffic Type***	**Sustained high Sporadic low**	**1)** Several **2)** H3A, H3B
12	***Reliability/ Availability***	**High**	Several
13	***Space/Area Dependent Interactivity***	**Dense / high**	H1D
14	***Security/Privacy***	**High**	Several

Regarding the Healthcare vertical, the user requirements from all use-case scenarios were compared and the most stringent ones in terms of implementation were identified as presented in Table 27. More specifically, use-case scenarios of H1A "Educational surgery", H1B "Remote ultrasound Examination", and H1C "Paramedic support" determined the higher demands for video and data transmission and reception. For the purposes of the scenario H1B, 3-4 channels of 15 Mbps each for HD video reception and transmission are needed. The scenario H1A poses further needs for streaming of 4K-8K video or even 360-degrees video, leading up to 200 Mbps throughput in the uplink. In addition, H1A sets the higher limits of data transmission to medium, while for the data reception the higher limit is set to medium by the scenario H1B. As far as the voice communication is concerned, most of the Healthcare use-case scenarios need to have real-time full-duplex voice communication to supplement the video and data perception, due to the urgency and criticality of such scenarios. Considering scenarios H1C and H1D "Critical health event", there is a need to receive high definition Video (4K, 8K) on his/her device, TV/monitor or VR/AR end device, as well as, a need to receive 'Good' quality video (640x480, 720p - 1080p, 25/30 frames per second) on a mobile tablet in the supervisor vehicle (Wearable) and a requirement for a Mean Opinion Score (MOS) of 4 and 5. Furthermore, regarding video transmission for H1C and H1D apart from the need to transmit high definition (4K or 8K or even 360-degree video) Video once again there is need to transmit Good quality video (640x480, 720p - 1080p, 25/30 frames per second) from an Android access device (Wearable). These scenarios also demand duplex audio to accompany video with a MOS value of 5.

Although, for most of the use-case scenarios the need for mobility is restricted to stationary and walking-running speed, the H3B "Localizable Patch" scenario requires a medium speed up to 130 km/h. On the other hand, there is always significant need to provide accurate location of the end device, and thus, a medium location information requirement is imposed from scenarios H1D and H3B. In order to perform complex calculations and retrieve a large amount of information with the least possible delay, several of the scenarios pose the need for (either combined or not) edge computing and storage. This need can be further justified by considering the stringent fast response requirement of 1-2 msec defined by H2A "The Pillcam" use-case scenario.

Regarding the traffic type resulting from the Healthcare services, it can be characterized as sustained high for the majority of the scenarios, while a value of 100 Mbps sustained traffic is especially defined for the H1B scenario. At the same time, the scenarios of H3B and H3A "Vital-sign patch prototype" constitute an exception to other healthcare services, resulting to a sporadic low traffic type. In addition, the space/area interactivity is considered as dense high due to H1D. Finally, a high reliability is needed by all scenarios besides H1A and H1B, whereas a high-medical degree security is required for the purposes of the whole Healthcare vertical, in order to provide services without interruptions and protect the usability and integrity of user data.

4.1.2 Transport use-case scenarios

Table 28: Most stringent user requirements for the Transport vertical

No	Requirements	Metric	Use-cases scenarios
1	***Video Reception***	**Yes**	Several
2	***Video Transmission***	**Yes**	Several
3	***Data Reception (DL)***	**High**	Several
4	***Data Transmission (UL)***	**High**	T4S6
5	***Voice Communication***	**Yes**	T3S1
6	***Mobility***	**High**	Several
7	***Location Information***	**High**	Several
8	***Edge Computing***	**Yes**	Several
9	***Edge Storage***	**Yes**	Several
10	***Fast Response (Low Latency)***	**Very fast**	Several
11	***Service / Traffic Type***	**Sustained high** **Bursty high** **Sporadic medium**	Sustained high: T4S4 Bursty high: several Sporadic medium: T2S4
12	***Reliability/ Availability***	**High**	Several
13	***Space/Area Dependent Interactivity***	**Medium Dense / High**	Several
14	***Security/Privacy***	**High**	Several

Table 28, presents the cumulative user requirements for the Transport Vertical, pointing out the most stringent ones. Considering reception and/or transmission of HD video, several transport use-case scenarios, require at least 15 Mbps per channel/stream, both for reception and transmission. Specifically, T1S1 and T1S2 "High bandwidth in-vehicle situational awareness and See-through for platooning" demand both reception and transmission of HD video, for platoon members and platoon leader, accordingly. On the other hand, T3S1 "Tele-operated support" and T4S6 "Vehicle sourced HD mapping" demand only video transmission, while, T4S4 "Location based advertising" demands only video reception.

Considering high data rate reception and/or transmission, equivalent or higher than 100Mbps, T3S1, T4S1 "Vehicle prognostics", T4S2 "OTA Updates" and T4S4, require data reception (related to the downlink channel), while T4S6 "Vehicle sourced HD mapping" requires data transmission (related to the uplink channel). Considering voice communication (128 kbps), only scenario T3S1 requires this feature, optionally, to support the feature of transferring and/or receiving voice commands with the Remote Operational Centre.

Considering high mobility support (equivalent or higher than 300 km/h), several transport use case scenarios are related to this feature, and specifically spanning all scenarios related to use case 3 "Support for remote driving" and T4 "Vehicle data services". Considering high-precision location information (up to 0.5 meters), almost all transport use case scenarios are related to this feature, as it is essential for the proper functionality of most 5G vehicular services.

Considering edge computing and/or edge storage support, T1S1 & T1S2 and T2S3 "QoS for advanced driving" require edge computing, while, T4S1 and T4S2 require edge storage, T2S4 "Human tachograph", T3S1 and T4S3 "Smart traffic corridors" require both edge computing and edge storage support.

Considering fast response, related to low latency support (equivalent to 5 msec), T1S1 & T1S2, T2S4, T2S1, T2S2, and T4S4 require very fast response, in all cases T3S1 and T2S3 require fast to very fast response, depending on the specific options.

Considering service / traffic type, high sustained traffic rate (up to 1000 Mbps) is related to scenario T4S4, high bursty traffic rate (up to 1000 MB bursts) is related to several scenarios, while medium sporadic rate (up to 1 msg/sec) is related to scenario T2S4. Considering high reliability 99.999% reliability index), almost all transport use case scenarios are related to this feature, as it is essential for the proper functionality of most 5G vehicular services.

Considering space/area dependent Interactivity, medium density combined with high interactivity is related to several transport use case scenarios, i.e., T2S1, T2S2, T4S4 and T4S6. Lastly, a high grade of security/privacy is required especially for T1S3 "Dynamic channel management for traffic progression", T2S3, T2S4, T3S1 and T4S2 to ensure integrity of sensitive user and/or operator data.

4.1.3 Aquaculture use-case scenarios

Table 29: Most stringent user requirements for the Aquaculture vertical

No	Requirements	Metric	Use-cases
1	***Video Reception***	**Yes**	A1S5
2	***Video Transmission***	**Yes**	Several
3	***Data Reception (DL)***	**Medium**	Several

4	***Data Transmission (UL)***	**High**	Several
5	***Voice Communication***	**No**	-
6	***Mobility***	**Walking speed**	A1S5, A1S3
7	***Location Information***	**Medium**	A1S3, A1S5
8	***Edge Computing***	**Yes**	Several
9	***Edge Storage***	**Yes**	Several
10	***Fast Response (Low Latency)***	**Very fast**	Several
11	***Service / Traffic Type***	**Sustained high**	Several
12	***Reliability/ Availability***	**Very fast**	Several
13	***Space/Area Dependent Interactivity***	**Dense / medium**	Several
14	***Security/Privacy***	**High**	Several

Regarding the Aquaculture vertical, Table 29 presents the unified vertical user requirements over all the involved use-case scenarios. In particular, the requirement for Video Reception is imposed by use-case scenario A1S5 “Cage to cage – on site communication”, where several 5G communication devices will be installed on cages and vessels supporting the site. Video transmission is required for all use-case scenarios besides A1S1 “Sensory data monitoring”. The need to transmit HD video for the monitoring of the fish behaviour and the infrastructure maintenance is present in all the rest use-cases. Video/image data will be transmitted by the ROV/drone, the underwater cameras, a 360-degrees camera and a CCTV system. Both aforementioned requirements are assumed to demand 15 Mbps/channel or stream.

The need for medium data reception (DL) comes from use-case scenarios A1S4 “Edge and cloud-based computing” and A1S5, whereas high data transmission (UL) is required in use-case scenarios A1S2 “Camera data monitoring” and A1S3 “Automation and actuation functionalities”. Voice communication is not required by any of the Aquaculture use-case scenarios. The mobility requirement is present in two use-case scenarios, namely A1S3 where the drone is expected to move at walking speed and A1S5 because of the involved well boats. Considering the medium location information accuracy requirement, it is once again imposed by use-case scenarios A1S3 and A1S5 due to the operations of transport and delousing from well boats, as well as net inspections and other maintenance functions. Edge computing is required by use-case scenarios A1S3 and A1S4, whereas edge storage is needed for all use-case scenarios since the capability of storing and retrieving large amount of information with the least possible delay benefits their functionalities.

Very fast response (or equivalently low latency) is needed for all use case scenarios apart from A1S1, since they involve real-time monitoring operations. Furthermore, scenario A1S3 includes the remote operation and navigation of the drone which amplifies the need for low latency. The sustained high traffic type is originating from use-case scenarios A1S2 and A1S5, whereas the rest of the use case scenarios have the lower requirement of sustained medium traffic, besides A1S1, where the small payloads of the sensor packets indicate a sustained low traffic. No other type of traffic (sporadic, bursty) is relevant for the examined scenarios. High reliability/availability is a common requirement for all use-case scenarios, since uninterrupted (24/7) service is essential for all monitoring functionalities.

All use-case scenarios have a dense space/area requirement because of the large-number of co-located end user/devices and sensors. Regarding interactivity, however, use-case scenario A1S1 has a low requirement given that no bidirectional communication is expected, whereas the remaining use-case scenarios require medium interactions involving the transmission and reception of data, the issue of commands and requests and the reception of acknowledgements. Finally, the need to protect the usability and integrity of data, equipment and network, as well as guaranteeing privacy is present in all use-case scenarios, but to a different degree. In particular, the high Security/Privacy requirement is common in use-case scenarios A1S3, A1S4 and A1S5, whereas the remaining two use-case scenarios have the lower demand of medium.

4.1.1 General requirements for the use-case scenarios

With respect the each of the identified user requirements, the following comments considering the cumulative user requirements across all 5G-HEART verticals are applicable:

1. **Video reception:** As far as the video reception is concerned, where 15 Mbps/channel or stream (serving HD video) are considered, the H1B "Remote ultrasound examination" scenario of the Healthcare vertical is the strictest, requiring 3-4 such channels for proper operation.
2. **Video transmission:** Similarly, to video reception, video transmission assumes channels of 15 Mbps/channel or stream, or channels of more than 200 Mbps/channel. Both relevant scenarios belong to the Healthcare vertical, and more specifically, H1B "Remote ultrasound examination" requires 15 Mbps, while H1A "Educational surgery" requires more than 200 Mbps. Such demanding scenario assumes 4K-8K video stream and possibly a demanding 360-degrees video.
3. **Data reception (DL):** High data rate reception, i.e., greater than 100 Mbps, at the downlink has emerged as a user requirement for several scenarios across the verticals, mainly for those in transport and aquaculture domains. This indicates the importance of fulfilling this metric for these scenarios, as well as the emerging requirement to simultaneously serve two or more of such scenarios. This will be one of the major challenges for the 5G-HEART architecture and 5G in general.
4. **Data transmission (UL):** Similarly, high data rate, greater than 100 Mbps, at the uplink has been identified as a user requirement across verticals, again mainly for scenarios in the transport and aquaculture domains. As with data reception in the downlink this user requirement will pose a significant challenge, especially when multiple scenarios will be required to be simultaneously served.
5. **Voice communication:** A voice communication requirement of 128 kbps both for uplink/downlink has emerged for several scenarios in Healthcare and Transport verticals. The gravity of this requirement is not expected to pose significant challenges to the infrastructure. However, it will be needed to investigate whether serving of other more challenging requirements has an impact on the final quality of the voice communication experienced by the users.
6. **Mobility:** Regarding mobility there is a clear grading of user requirements across verticals. Several Transport vertical scenarios pose high mobility requirements with speeds above 200 Km/h, the H1C "Paramedic support" scenario of the Healthcare vertical poses a medium speed requirement of maximum 160 Km/h and the Aquaculture scenarios have low mobility requirements. Thus, different challenges will emerge for each different vertical. However, the simultaneous service of such diverse scenarios regarding mobility requirements will be a challenging task.
7. **Location information:** Several scenarios across verticals will require a high location accuracy information, i.e. in the order of ±0.5m. Other scenarios across verticals will require an average location information accuracy in the order of ±4-5m. This user requirement seems to be rather

homogeneous across verticals, namely that the same diversity from medium to high accuracy values will be required for all verticals, the eventual requirement depending on the specific scenario/application.

8. **Edge computing:** The requirement for edge computing is relatively flat across verticals, where several scenarios demonstrate a positive requirement for the existence of support for edge computing.
9. **Edge storage:** Similarly, various of the above scenarios with a positive requirement for edge computing will also demand edge storage. This is a holistic requirement as well, employed by many scenarios across verticals.
10. **Fast response (low latency):** As with location information, similar diversity is exhibited by all three verticals, where there are several scenarios requiring very fast response with latencies as low as 1-2 msec, i.e., scenarios H2A "The Pillcam", several in Transport and all in Aquaculture besides A1S1, while others require slower responses in the order of 25 msec or even lower in the order of 100 msec. It will be a major challenge for the infrastructure to meet the fast response requirement of 1-2 msec, especially when concurrent scenarios will be needed across verticals.
11. **Service/traffic type:** The service/traffic type emerges as the more diverse user requirement across scenarios across verticals. Sustained high types of traffic requiring 100 Mbps bitrate will be required by Healthcare and Aquaculture scenarios (H1A "Educational surgery, H1B "Remote ultrasound examination", and several in Aquaculture), while all three types of sustained high (T4S4 "Location based advertising"), bursty high (T4S1 "Vehicle prognostics") and sporadic medium (T2S4 "Human tachograph") will be needed in the Transport vertical. The diversity of traffic type emerging across scenarios in all verticals will be a major challenge for the infrastructure and the definition of the slices that will be serving the corresponding scenarios.
12. **Reliability/availability:** The reliability/availability requirement is also expected to impose significant challenges to the infrastructure. Most of scenarios across verticals demand a rather high value, i.e., above 99.999%, up to 99.99999% for some rather sensitive scenarios in Healthcare and Transport verticals.
13. **Space/area dependent interactivity:** Regarding the space/area interactivity, the stricter requirements across vertical come from the Healthcare and Transport verticals, requiring support of high density, mainly in scenarios H1D "Critical health event", T4S4 "Location based advertising", T4S6 "Vehicle sourced HD mapping".
14. **Security/privacy:** With respect to security and privacy several scenarios have a high security requirement at the level of High level. Naturally, this involves most of the scenarios in the Healthcare and Transport verticals, where life-critical data will be required to be transferred (i.e., in the health-related scenarios and in the automotive scenarios, where accuracy and responsiveness is needed to serve autonomous and tele-operated driving).

4.2 Requirement clustering

In the previous section, we identified the most stringent user requirements of each use-case/scenario, cumulatively collected per vertical and cross-examined across the three verticals. The goal was to identify the upper bounds across vertical for the identified requirements by users in each vertical use-case.

In this section, we provide the infrastructure unified requirements considering all the scenarios from the three verticals, demonstrating the whole range of each requirement and not only the most stringent value, in order to highlight the different flavours of each service type, which as a next step will be mapped to the respective slices definition. The infrastructure unified requirements are presented in Table 31. In particular, for some specific requirements (the number 1, 2, 5, 8 and 9 mentioned at the end of Section 4.1.4), the answer is simply yes or not, while for the rest a different and granular level of demand needs to be filled, which can be classified as low, medium and high. For each requirement, the respective scenarios are listed in the respective cases, using a colour code according to the related vertical (i.e., red for Healthcare, green for Transport and blue for Aquaculture).

As it can be observed, a number of requirements, such as video reception and transmission and edge computing/ storage are involved with scenarios from all verticals. On the contrary, the voice communication requirement is related only to specific scenarios from Healthcare and Transport.

On the other hand, most requirements are divided into classes, some of which concern all the three verticals, whereas others are more concentrated to one or two verticals. In more detail, a list of the features required by scenarios across all verticals are: low data reception/transmission, medium location information accuracy, low and high fast response, all classes of sustained traffic type, high reliability/availability, as well as high level of security/privacy. Furthermore, medium fast response, low sporadic traffic type, high dense and low sparse space/area dependent interactivity are required exclusively by scenarios of the Healthcare vertical. Similarly, medium and high bursty traffic type, medium sporadic traffic type, medium and high semi-dense and medium sparse space/area dependent interactivity, and low security/privacy are only present in Transport scenarios. The remaining requirement classes are involved in a combination of two verticals.

Another kind of limitations that needs to be considered involves the combination of specific requirements, which results to a trade-off. For example, high reliability involves high energy consumption, which impacts the battery lifetime of wearable devices, as in Scenarios H1C, H1D. Furthermore, the combination of high mobility with high location information, as required in T3S1, T4S4, T4S6, and with high UL/DL data rate as in T4S4, T4S6, would pose high implementation difficulty.

Finally, it should be noted that Table 31 displays the largest common set of requirements that are present to all use cases. However, there are some use case scenarios with a more elaborate list of requirements that applies only within their scope. A representative example is scenario H3A that involves the requirements of medium indoor/outdoor coverage and very low energy, which can be seen as specific challenges to the mMTC mode of 5G.

Table 30 Requirement clustering

No	Requirements	Metric		
		Low	Medium	High
1	Video Reception	H1A-D, T1S1-2, T4S4, A1S5		
2	Video Transmission	H1A-D, H2A, T1S1-2, T3S1, T4S6, A1S2-5		
3	Data Reception (DL)	H1C, H3B, T1S3, T2S1-4, T3S1, T4S3, T4S6-7, A1S1-3	H1B, T1S1-2, A1S4-5	H1A, H1D, T4S1, T4S2, T4S4
4	Data Transmission (UL)	H1B, H1C, H1D, H2A, H3A-B, T1S3, T2S1-4,T3S1, T4S3, T4S7, A1S1	T1S1-2, T4S1, T4S2, T4S4, A1S4-5	H1A, T4S6, A1S2-3
5	Voice Communication	H1A-D, T3S1		

6	Mobility		H1D, H2A, H3A, A1S3, A1S5	H1C, H3B, T1S1-3, T2S1-4, T4S1-3, T4S7	T3S1, T4S4-6
7	Location Information		H1A, H1B, H1C A1S1, A1S2, A1S4	H1D, H3B, T1S3, T4S1-3, T4S7, A1S3, A1S5	T1S1-2, T2S1-4, T3S1, T4S4, T4S6
8	Edge Computing		H1A, H1B, H2A, T1S1-3, T2S1-4, T3S1, A1S3, A1S4		
9	Edge Storage		H1A, H1B, H2A, T2S1-2, T2S4, T3S1, T4S1-3, A1S1-5		
10	Fast Response (Low Latency)		H1A, H3A, H3B, T4S1-2, T4S6, T4S7, A1S1	H1C	H1B, H1D, H2A, T1S1-3, T2S1-4, T3S1, T4S3-4, A1S2-5
11	Service / Traffic type	Sustained	H2A, T1S3, T2S1-4, T4S7, A1S1	H1C, T1S1-2, T3S1, A1S3, A1S4	H1A, H1B, H1D, T4S4, T4S6, A1S2, A1S5
		Bursty	-	T2S1-2, T2S4, T4S3	T4S1, T4S2
		Sporadic	H3A, H3B	T2S4	-
12	Reliability / Availability		H1A, H1B, T2S4, T4S6, T4S7	H3A, H3B, T2S1-2, T3S1, T4S1-4	H1C-D, H2A, T1S1-3, T2S3, A1S1-5
13	Space / Area Dependent Interactivity	Dense	H1A, H1C, A1S1	H1B, A1S2-5	H1D
		Medium-Dense	H3A, T4S7	T1S1-3, T4S1-3	T2S1-2, T2S4, T3S1, T4S4, T4S6
		Sparse	H2A, H3B	T2S3	-
14	Security / Privacy		T1S1-2, T2S1-2, T4S3, T4S6, T4S7	T4S1, T4S4, A1S1, A1S2	H1A-D, H2A, H3A-B, T1S3, T2S3-4, T3S1, T4S2, A1S3-5

Table 32 lists the network service types / slices requirements on a per use case scenario basis. As it can be observed, most scenarios require one of the available service types (i.e., URLLC, mMTC, and eMBB), while others require a combination. More precisely, Aquaculture use-case scenarios A1S2 “Camera data monitoring”, A1S4 “Edge and cloud-based computing”, and A1S5 “Cage to cage - on site communication” require the combination of mMTC and eMBB. Healthcare scenarios H1B “Remote ultrasound examination” and H2A “The Pillcam” and Transport scenarios in use case T1 “Platooning” and T3 “Support for remote driving” require the combination of URLLC and eMBB. All three URLLC, mMTC and eMBB are needed only by one Aquaculture use-case, namely A1C “Automation and actuation functionalities”.

The contents of Table 31 in a graphical form, where the number of Use Cases that specify the need of a particular requirement, are shown below:

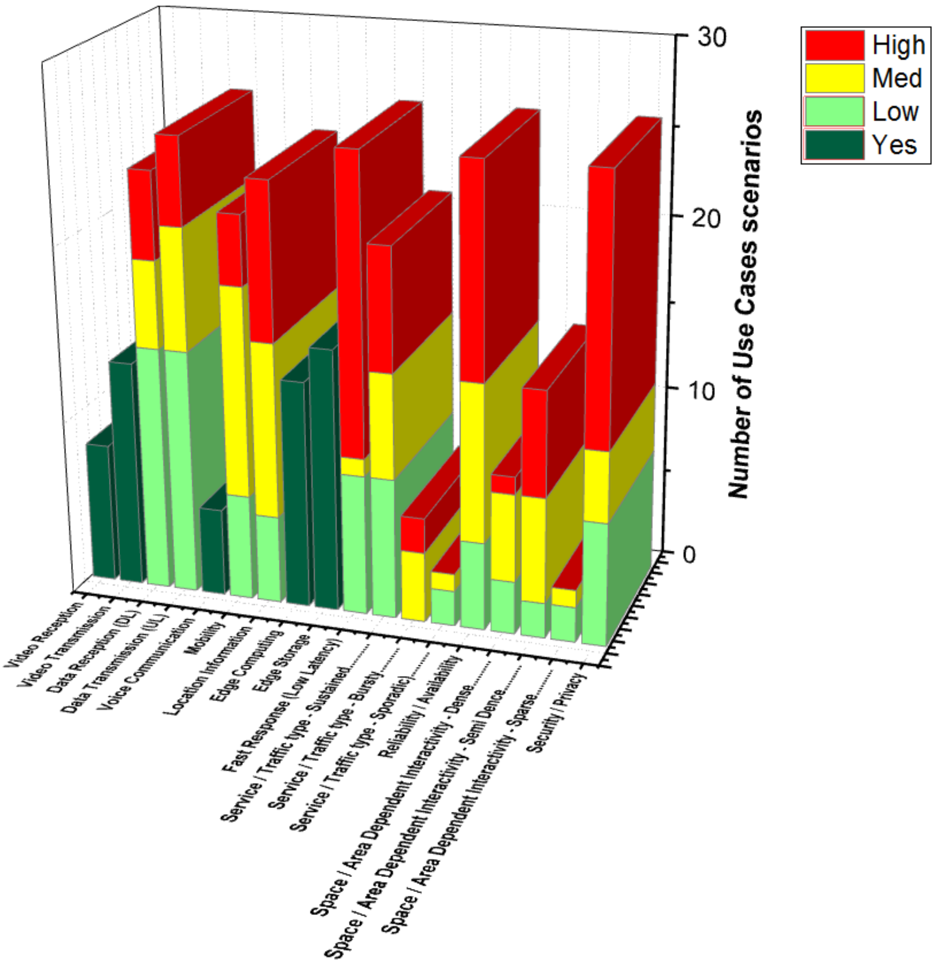

Figure 6: Requirements classification.

Based on the above, it is evident that all the aforementioned combinations should be considered during the slice definition phase since a single slice per service type may not be sufficient for some scenarios or a single slice may also serve multiple scenarios. Taking into account Table 31 and the presented requirement classification, it is obvious that many inputs need to be considered during slice definition. More details on the slice definition will be provided in 5G-HEART deliverable D2.2 “User Requirements Specification, Network KPIs Definition and Analysis”.

Table 31 Service types / slices

Use Case	Sub Use Case	URLLC	mMTC	eMBB
Remote Interventional Support	H1A: Educational Surgery			√
	H1B: Remote Ultrasound examination	√		√
	H1C: Paramedic Support			√
	H1D: Critical Health Event			√
The PillCam	H2A: The PillCam	√		√
Vital-sign patches with advanced geolocation	H3A: Vital-sign prototype		√	
	H3B: Localizable tag		√	

Platooning	T1S1&T1S2: High bandwidth in-vehicle situational awareness and see-through for platooning	√		√
	T1S3: Dynamic channel management for traffic progression.	√		√
Autonomous/Assisted driving	T2S1&T2S2: Smart junctions and network assisted & cooperative collision avoidance (CoCA)	√		
	T2S3: QoS for advanced driving	√		
	T2S4: Human tachograph	√		
Support for remote driving	T3S1: Support for remote driving	√		√
Vehicle data services	T4S1: Vehicle prognostics.		√	
	T4S2: Over-The-Air (OTA) updates		√	
	T4S3: Smart traffic corridors		√	
	T4S4: Location based advertising		√	
	T4S5: End to End (E2E) slicing		√	
	T4S6: Vehicle sourced HD mapping		√	
	T4S7: Environmental services		√	
Remote monitoring of water and fish quality	A1S1: Sensory data monitoring		√	
	A1S2: Camera remote monitoring		√	√
	A1S3: Automation and actuation functionalities	√	√	√
	A1S4: Edge and cloud-based computing		√	√
	A1S5: Cage to cage – on site communication		√	√

The above table in Graphical Form is shown in the following graph:

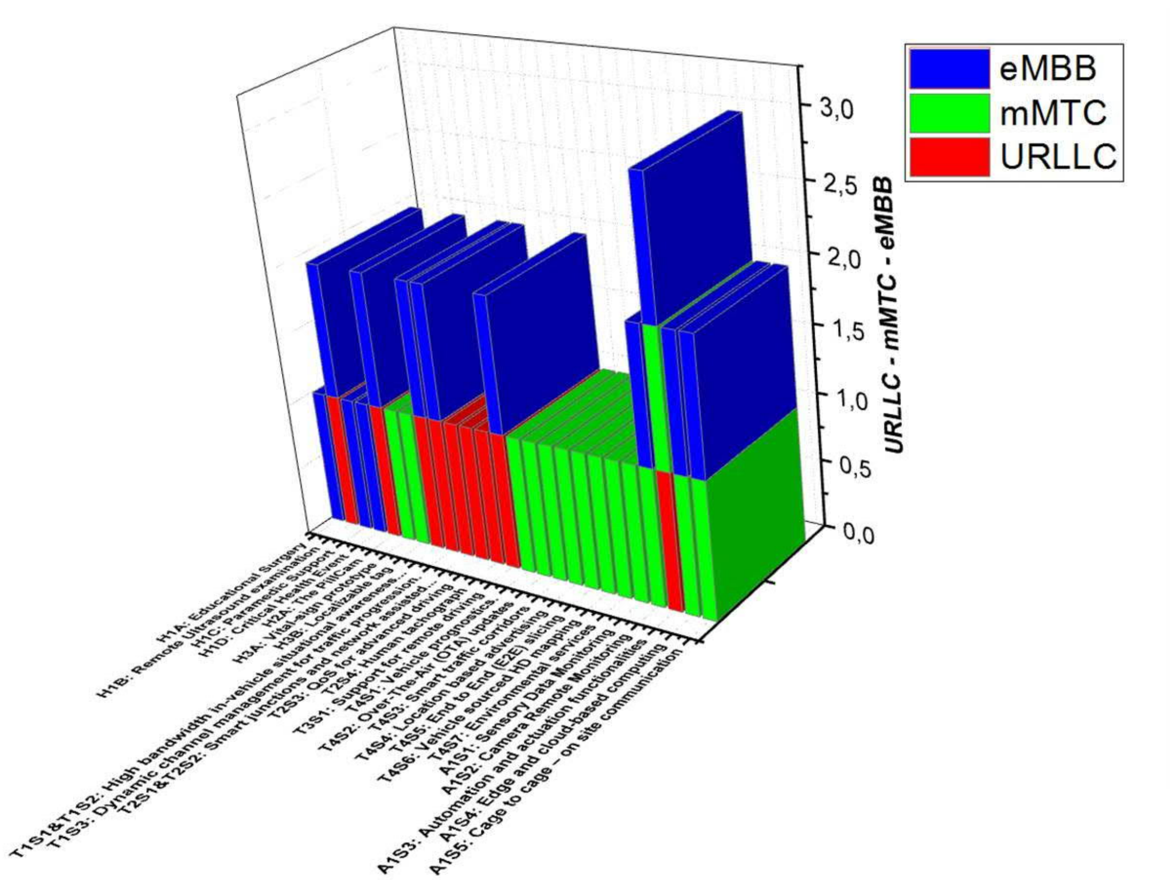

Figure 7: Service types/slices requirements per use case scenario.

From the data it appears that the highest demand is for mMTC service type, followed by eMBB and the lowest demand (from only 9 use-cases) is URLLC.

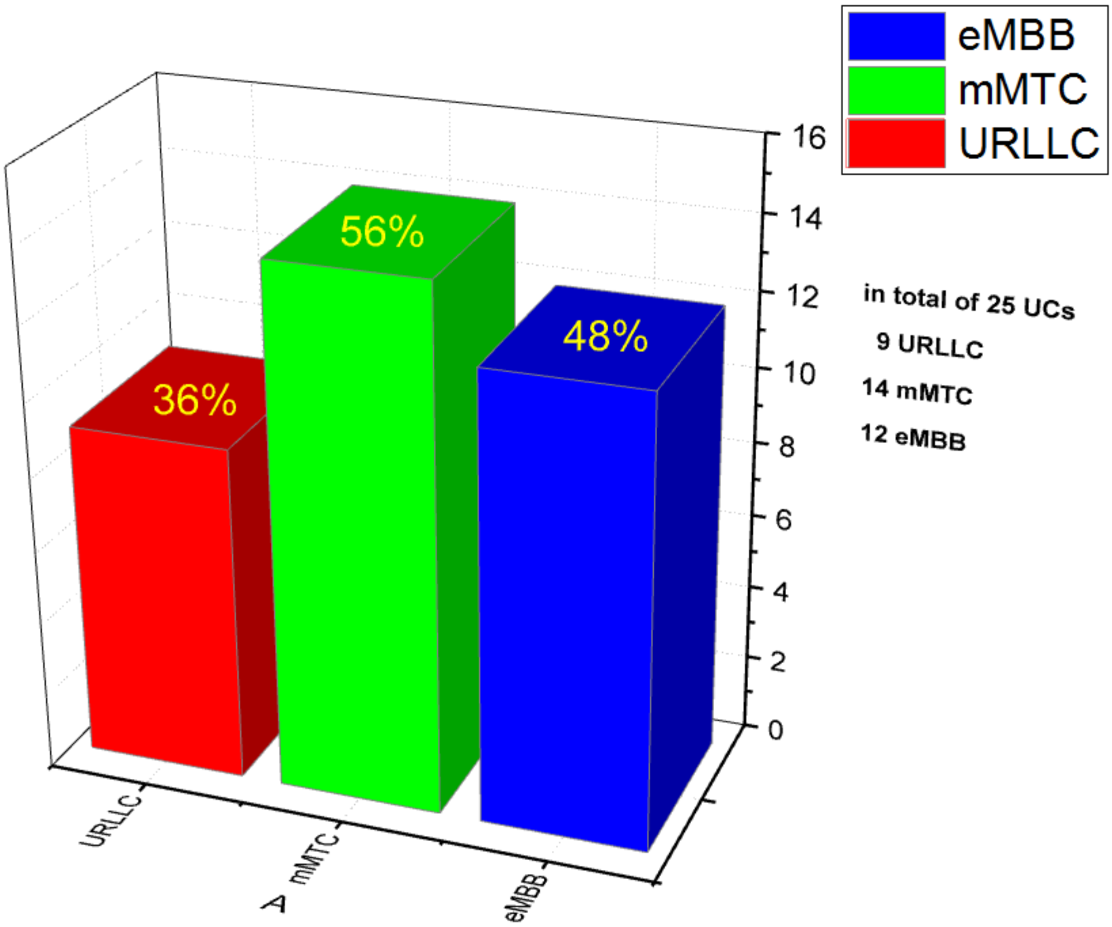

Figure 8: Service types/slices requirements demand.

5 CONCLUSIONS

In this document the use cases separated in scenarios were presented. More specifically, the healthcare vertical includes three use cases, the transport vertical includes four use cases and the aquaculture includes one use case. These use cases are separated in twenty seven scenarios in total.

The requirements of each scenario were identified from the perspective of the end-user. There are requirements that apply to all the scenarios and others that characterize some of them. More specifically, there were presented 14 user requirements in total. These could be considered to be the least common denominator of the User Requirements from different Vertical Industries. Furthermore, each Vertical Industry and User Service could have additional requirements (more specific).

Finally, the requirements of the network had to be evaluated, taking into account that it should be unified and able to serve all the scenarios.

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