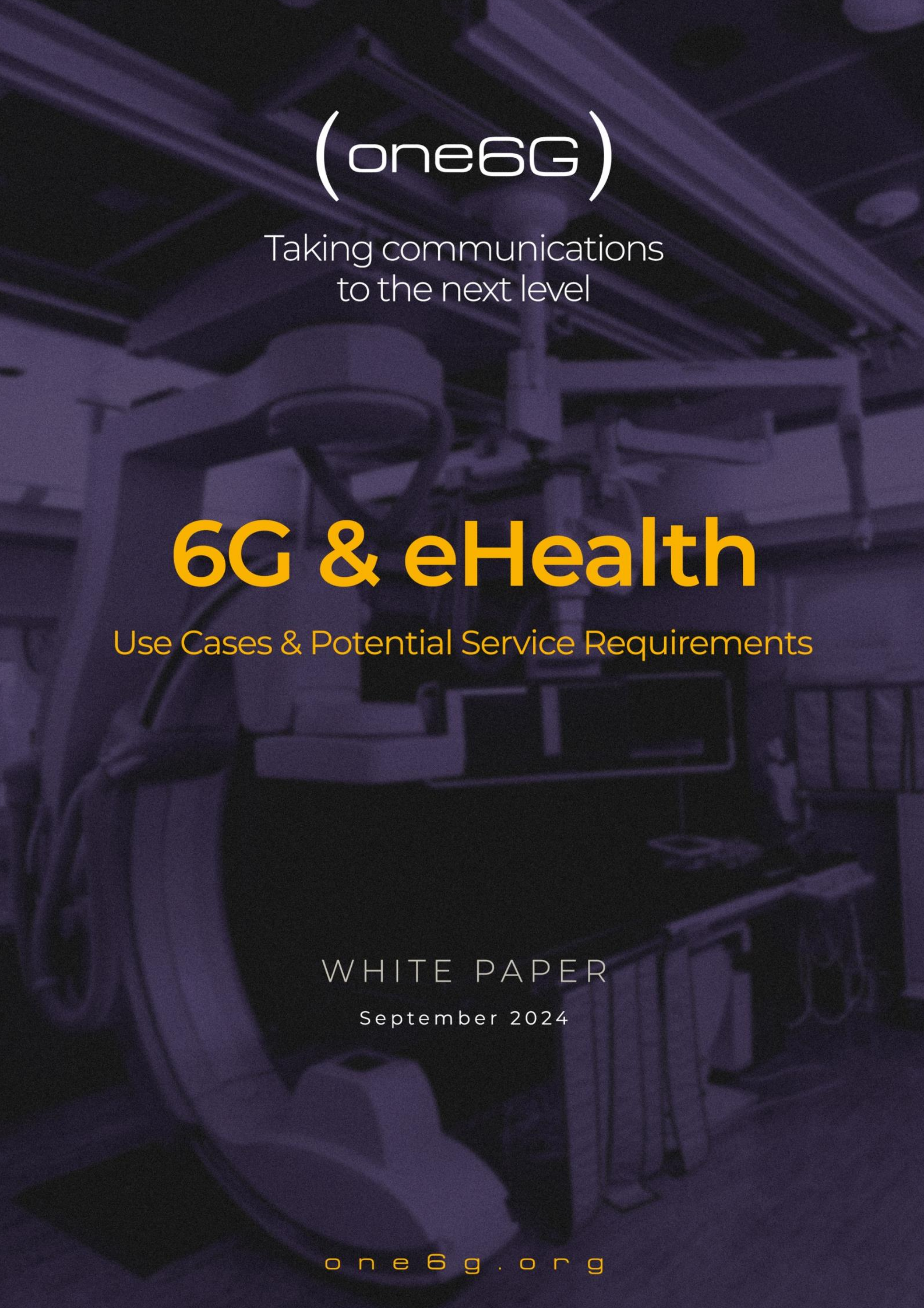


(one6G)

Taking communications
to the next level

6G & eHealth

Use Cases & Potential Service Requirements

WHITE PAPER

September 2024

one6g.org

Scope

The mobile communication industry is identifying system requirements of the healthcare sector to design a future 6G communication system tailored to the requirements of the medical domain. The one6G association recognizes the positive impact of future 6G technology on eHealth applications. Three key trends currently exist in the healthcare sector: 1) increasing aging population (i.e., more healthcare demand), 2) increasing healthcare costs and 3) lack of healthcare personnel to cope with the demand. Moreover, an overarching trend is the need for constant improvement in the quality of healthcare services. Linked to the mentioned challenges, the use of robotic applications in medical applications is regarded as a potential key solution. One6G recognizes that the integration of wireless sensing, communication and computation capabilities in robotic systems as key enablers for increased reliability, capability and operational efficiency at lower complexity and cost. It is therefore envisioned that the future 6G communication system can also significantly empower medical robotic applications. The 6G communication system can also support the precise modeling of individual treatment, enhance the interconnection of different medical data sources and models of all stakeholders (e.g., patients, doctors, devices and robots) and improve the capabilities of mobile robotic systems in the whole treatment process with enhanced sensor, connectivity, and intelligence services. A detailed requirement analysis is necessary to determine precise technical problems and challenges in the medical domain, especially considering the sensitivity, reliability and criticality of the exchange of information in healthcare processes.

The previous whitepapers released by one6G Working Group 1, were focused on robotic use cases enhanced with 6G technology across different verticals such as logistics, automation, healthcare assistance and emergency response [1] [2]. The identified system requirements include highly accurate sensing, high data rate and ultra-low latency communication links, in-network computation support, AI/ML support and a tighter integration between network functionalities such as communication, sensing and computation (including those within network and/or belonging to third-party applications). In a subsequent whitepaper released by one6G [2], we discussed a variety of robotic use cases which consider the functional requirements for supporting multimodal sensing operations (e.g. 3D mapping, object detection and identification, and environment modeling), aspects related to robot autonomy and AI.

The goal of this whitepaper is to overview the potential of 6G technology on the eHealth domain to tackle the key trends in the healthcare sector. To achieve this, we identified and developed use cases together with their functional requirements and key performance indicators in terms of communication, sensing and AI/ML support necessary to realize the use cases. Through discussions with different stakeholders from the medical domain, industry and academic researchers, we have identified 4 clusters of eHealth use cases: Medical Robotic Applications, Vital Sign Wireless Sensing, Medical Data & Model Sharing, and Immersive & Ubiquitous Treatment. The developed use cases per cluster are guided by the model-based medicine vision identified and further developed by members of the medical domain in one6G, where all actors in the healthcare system are mapped with their corresponding digital twin models, and evidence is quickly generated for what-if scenarios in healthcare processes (e.g., health outcome of a patient given medical treatment) in a cost efficient manner. Altogether, the use cases provide different key functional components to enable this vision. Use cases may be realized on its own independent of the model-based vision. We elaborate on initial considerations related to risk mitigation, potential countermeasures, privacy and ethics. Additional use cases will be considered in future volumes of the one6G 6G and eHealth series of white papers.

Table of Contents

1. DEFINITIONS OF TERMS 4

2. MOTIVATION TO EXPLORE EHEALTH APPLICATIONS 6

3. VISION AND EHEALTH FOCUS AREAS 8

4. METHODOLOGY 10

5. SAFETY, ETHICS AND SUSTAINABILITY 11

6. MEDICAL ROBOTIC APPLICATIONS 12

6.1. Telerobotics Diagnostic Examination 12
6.2. Context Aware Mobile Robotic Platforms in Nursing Ward 15
6.3. Dynamic Reconfiguration of Rehabilitation Robotics 18
6.4. Assisted Living with Companion Mobile Robots 21
6.5. Medical Goods Logistics with Robotic Fleets 24

7. VITAL SIGN WIRELESS SENSING 28

7.1. Vital Sign and Occupancy Detection in Hospital Emergency Waiting Room 28
7.2. Vital Sign Sensing in Medical Care Units 30

8. IMMERSIVE & UBIQUITOUS TREATMENT 33

8.1. Immersive XR-based Self Attachment Therapy 33
8.2. Continuous Secure Remote Health Data Collection 36

9. MEDICAL DATA & MODEL SHARING 39

9.1. Exchange of 3GPP sensing model/data associated with Medical Information 39
9.2. Exchange of Medical AI/ML Model 40

10. CONCLUSION, RECOMMENDATIONS AND NEXT STEPS 44

ANNEX A – POTENTIAL RISKS AND COUNTERMEASURES PER USE CASE 45

ANNEX B – POTENTIAL SOCIETAL, ENVIRONMENTAL AND ECONOMIC IMPACTS PER USE CASE CLUSTER 47

11. REFERENCES 49

1. Definitions of terms

In this section, we present a set of definitions for terms related to wireless communication, wireless sensing and AI/ML support services in the context of the eHealth domain.

Communication terms and KPIs

- Communication Direction: refers to who transmits to whom over a wireless channel, i.e., from network to robot (downlink), from robot to network (uplink) and robot to robot (sidelink).
- Communication Mode: refers to the number of involved transmitters and receivers in the wireless communication. Unicast corresponds to one-to-one communication, groupcast corresponds to one-to-many communication, fusion refers to many-to-one and broadcast corresponds to one-to-all communication.
- Communication Availability: refers to the ability of the communication service to perform as required for a given time interval, under given conditions [3].
- Communication Data Rate: refers to the amount of data bits transmitted over a wireless channel during a defined time window [Bits/s] [3].
- Communication Reliability: refers to the proportion of transmitted bits that are correctly decoded by receiver within a given time period (%) [3].
- Communication Latency: refers to the amount of time it takes to transfer a packet from source transmitter to destination receiver, measured at the communication interface [msec] [3].
- Communication Jitter: refers to the variation of communication latency from consecutive packets that have arrived at the receiver [msec].
- Transfer Interval: is the time difference between two consecutive transfers of application data from an application via service interface to network [3].
- Survival Time: survival time refers to the duration for which a network element or system can continue to operate or provide services without failure or interruption.

Wireless sensing terms and KPIs

- Wireless Sensing: is the capability of the 6G communication system to get accurate information about objects within environment (e.g., shape, size, velocity, orientation, location or distances or relative motion between objects) using wireless signals (either reusing communication signals or using dedicated sensing signals) [4].
- Sensing result: processed 3GPP sensing data requested by a service consumer [4].
- 3GPP sensing data: data derived from 3GPP radio signals impacted (e.g. reflected, refracted, diffracted) by an object or environment of interest for sensing purposes, and optionally processed within the 5G system [4].
- non-3GPP sensing data: data provided by non-3GPP sensors (e.g. video, LiDAR, sonar) about an object or environment of interest for sensing purposes.
- Accuracy of Positioning Estimate: describes closeness of measured sensing result (i.e., position) of target object to its true position value [m] [4].

- Accuracy of Velocity Estimate: describes the closeness of the measured sensing result of the target object's velocity to its true velocity [m/s] [4].
- Refresh Rate: is the inverse of the time elapsed between two successive sensing results [1/s] [4].
- Sensing Resolution: describes minimum difference in measured magnitude of target objects (e.g., range, velocity) to be allowed to detect objects in different magnitude [4].
- Human motion rate accuracy: describes the closeness of the measured value of the human body movement frequency caused by part(s) (e.g. chest) of the target object (i.e. human body) to the true value of the human body movement frequency [4].

The following KPIs apply to the definition of the use cases on sensing quantitative requirements:

- Accuracy of positioning estimate describes the closeness of the measured sensing result (i.e. position) of the target object to its true position value. It can be further derived into a horizontal sensing accuracy – referring to the sensing result error in a 2D reference or horizontal plane, and into a vertical sensing accuracy – referring to the sensing result error on the vertical axis or altitude.
- Accuracy of velocity estimate describes the closeness of the measured sensing result (i.e. velocity) of the target object's velocity to its true velocity.
- Confidence level describes the percentage of all the possible measured sensing results that can be expected to include the true sensing result considering the accuracy.
- Missed detection probability denotes the ratio of missing event to acquire a sensing result over all events during any predetermined period when the 5G system attempts to acquire a sensing result. It applies only to binary sensing results.
- False alarm probability denotes the ratio of detecting an event that does not represent the characteristics of a target object or environment over all events during any predetermined period when the 5G system attempts to acquire a sensing result. It applies only to binary sensing results.
- Max sensing service latency: time elapsed between the event triggering the determination of the sensing result and the availability of the sensing result at the sensing system interface.

AI/ML support KPIs

- Max allowed downlink end-to-end latency (Model Transfer): in the context of AI/ML model distribution, is the maximum time a robot may wait to receive an AI/ML model transfer from network [5].
- Max allowed downlink end-to-end latency (AI/ML split inference): in the context of AI/ML split inference, is the maximum time a robot may wait to receive an AI/ML intermediate result from network [5]. Split inference refers to when AI/ML model (e.g., a neural network model) is split among multiple entities during inference.
- Max allowed uplink end-to-end latency (AI/ML split inference): in the context of AI/ML split inference, is the maximum time a network application (e.g., implemented in an edge server) may wait to receive an AI/ML intermediate result from robot [5].

2. Motivation to explore eHealth applications

One6G acknowledges the importance of understanding the evolving societal requirements and market trends in vertical sectors, such as healthcare. Several trends are affecting the development of healthcare systems as a whole. Those trends include increase in aging population and the increasing costs of healthcare (see Fig. 1). The demand of healthcare services is increasing and there is an increasing scarcity of healthcare personnel [6]. Healthcare systems require continuous optimization in order to reduce costs and improve quality of healthcare services. In addition, people that live in remote regions require timely and quality access to healthcare services as well as continuous remote health monitoring. Technological developments are helping improve the quality of healthcare services while reducing costs [7]. Next generation mobile radio networks can potentially play an important role in addressing these issues by delivering enhanced sensing, connectivity and intelligence services tailored for the requirements of the medical domain. One6G foresees the growing demand for eHealth applications and the key role the future 6G system may play in the healthcare sector.

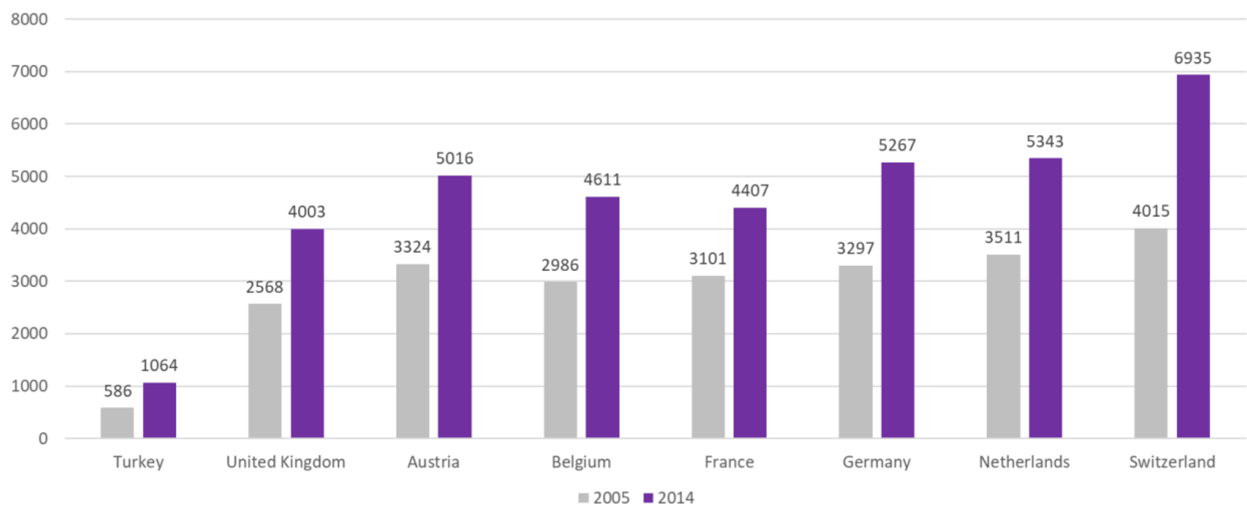


Figure 1. Increasing health care expenditure by a subset of European Countries [Millions of EUR] [6]

From a medical point of view, there have been multiple developments in the healthcare sector to help overcome these issues and to further improve outcomes, such as minimally invasive surgery, multimodal treatment concepts and evidence-based medicine. In evidence-based medicine, medical treatment decisions are made on the basis of treatment results data of a large number of similar patients and based on simplified patient models, which allow for their comparison. This paradigm is prone to generalized treatments that do not account for the individual health particularities of a patient and results from treatment results that are usually obtained with a lengthy and costly process. It is envisioned that the 6G system can address these disadvantages by facilitating the precise record of individual treatments and continuously monitoring patient health states with enhanced connectivity and sensing services with powerful privacy- and security-preserving methods. One promising practical direction is that the future 6G system could provide rich radio sensing information to trusted third-party applications to derive health information with the use of advanced classical signal processing and/or AI/ML methods. Therefore, the generation of evidence can be accelerated and the probability of unnecessary treatments can be reduced. Such outcomes can result in significant cost savings in healthcare systems. In addition, preventive medicine, a medical paradigm that prevents development of diseases or identifies pre-stages of diseases so that treatment can be given before disease further develops [8], can be enhanced by 6G system with enhanced privacy-preserving sensing and intelligence services. The expected shift was already anticipated as moving from “evidence based medicine towards medicine based evidence” [9].

Healthcare systems are generating a significantly increasing amount of data. One of the contributing factors is the increase in usage of wearables such as smartwatches and fitness trackers [10]. AI applications for eHealth applications by nature utilize increasing amounts of sensitive data, and therefore the usage of health data and models must satisfy stringent privacy and security requirements. The requirements of methods to exchange health vital sign information and models taking into account security aspects need to be derived [11]. Secure and timely exchange of information from different health sensors and systems will be communicated to high-performance AI compute functions located in-premise, in-network or at trusted/secure third-party providers. Exchanged information could also be communicated semantically to both improve privacy, improve radio performance or facilitate downstream AI medical tasks. The emergence of wireless sensing capabilities of the future 6G system to sense health parameters of patients while maintaining privacy enables multiple novel use cases. Privacy-preserving intelligence services together with highly reliable connectivity services offered by the future 6G system also enables a multitude of novel high-value use cases (e.g., provisioning of immersive services for remote mental health).

The use of technology in medicine is increasing exponentially. Today, technology is prominent in all forms of therapy with interventional methods such as surgery (e.g., robotic arms in surgery rooms) and most prominently in digital data acquisition, communication and digital sensor systems. Western countries have an increasing shortage of staff in the health sector together with a demographic change due to an aging population that will further need medical care [12] (see Figure 2). Technology may play yet another important role in addressing this. The integration of mobile robotic systems with autonomous action and enhanced situational and context awareness capabilities in the whole treatment process could address the staff shortage in the health care sector, especially those processes and tasks that the medical profession considers burdensome. The future 6G system with enhanced connectivity, sensing and intelligence services will play a significant role in facilitating this transition.

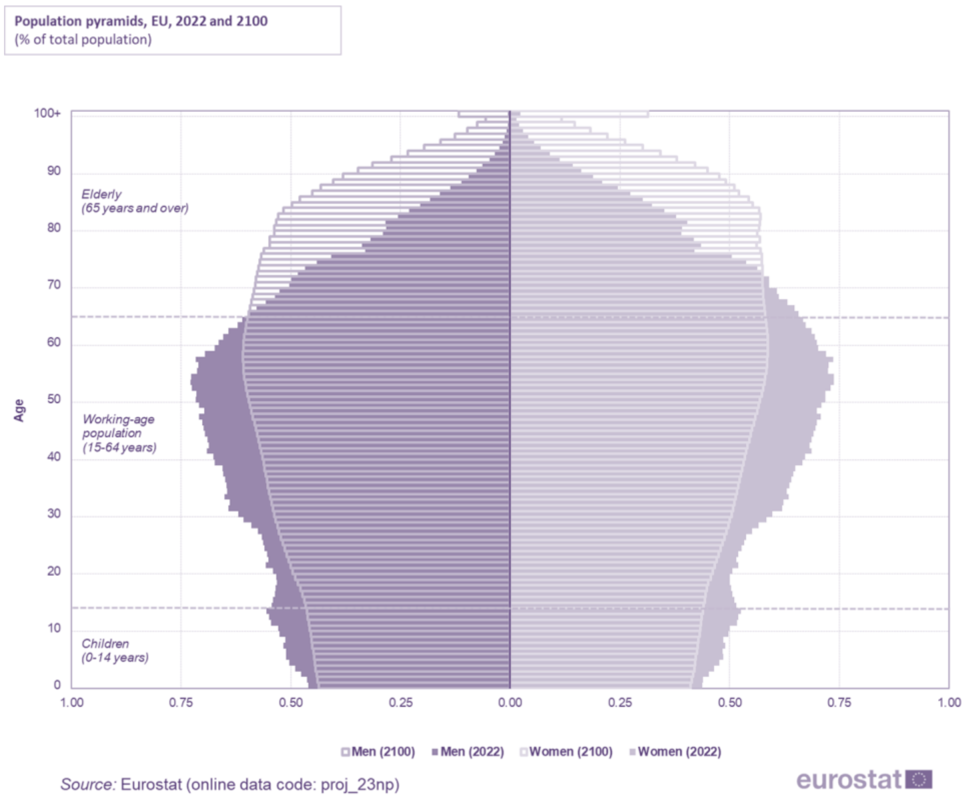


Figure 2. Population pyramid projected to 2100 in the EU [12]

3. Vision and eHealth Focus Areas

Members of the medical domain in the one6G 6GHealth WI have identified and further developed a vision on model-based medicine to address the above challenges in the years to come. In this paradigm, all actors and infrastructure in the healthcare system (e.g., patients, staff, mobile robots) are mapped with their corresponding digital twin models. The adaptation of these models happens dynamically and in real-time as well as taking into account the synchronization time between the involved digital twin models. The models and their interconnections are required to reliably and timely generate medical evidence for what-if scenarios in clinical environments (e.g., outcome given a treatment) as well as generate real-time context awareness to mobile robots so that they perform context-sensitive actions. To truly realize the vision of model-based medicine, the 6G system will provide ubiquitous, massive and reliable connectivity together with reliable sensing combined with powerful AI/ML methods as a service. To enable this vision, we have identified several clusters of eHealth use cases that constitute different components of the model-based medicine vision. The use case clusters are:

- Medical Robotics Applications
- Vital Sign Wireless Sensing
- Medical Data & Model Sharing
- Immersive & Ubiquitous Treatment

The different use cases that fall within these use case clusters are also independent in the sense that they could be realized without a model-based medicine vision. Altogether, they provide different key functional components to enable the model-based medicine vision. In the following, we describe each use case cluster.

Medical Robotics Applications:

To address the increasing staff shortage in the healthcare sector, mobile robotic systems are required to have autonomous action and enhanced situational/context awareness capabilities. The nature of healthcare environments requires the interaction between humans and robots for different collaborative, control and cognition sub-tasks. As outlined in [13], the future 6G communication system will facilitate the process of incorporating new and more performant functions in robotic applications at a reduced cost. The expected key enablers are the integration of communication and sensing capabilities as well as high data rate, high service availability and low-latency wireless access to *data processing* functions and AI/ML services.

Vital Sign Wireless Sensing:

Vital sign monitoring is critical to assess condition of patients. Vital signs are conventionally measured with electrocardiographs (ECG), hemodynamometry (HDM) and photoplethysmography (PPG) which are wired to the patient. Wireless signals can continuously perform remote vital sign sensing in clinical environments. Contactless systems improve the quality of life of the patient (e.g., in palliative care) by not restricting their mobility and avoid distress or agitation [14]. Sensing methods using wireless signals can also be used to monitor contextual information from clinical environment. Contactless vital sign sensing, such as wireless sensing improves quality of life of patients and is one of the key technologies for the realization of preventive medicine.

Medical Data & Model Sharing:

There is an increasing need to integrate multiple sources of health data from different sensor types (e.g., originating from wearable devices) together with electronic health records [15]. Such real-time integration with powerful edge AI/ML methods can enable preventive, continuous and personalized healthcare access. Developments in causal machine learning [16], are enabling the ability to reason about potential effects of interventions at individual and population level. The requirements for standard- and regulatory-compliant real-time [17], exchange of health data and health AI/ML models must be studied. Fast Health Interoperability Resources (FHIR), a standard for exchanging healthcare information among healthcare entities (hospitals, pharmacies or patient's mobile app) [18] is a first step in this direction. Moreover, the reliable and secure communication of AI/ML models to mobile robots will be crucial due to their mobility capabilities and criticality of their tasks.

Immersive & Ubiquitous Treatment:

6G system will have the ability to communicate extremely immersive information to extended reality / virtual reality (XR/VR) systems as well as sense local contextual information useful for XR/VR systems and telemedical applications. Unprecedented levels of immersion together with advanced natural language functionalities (e.g., large language models (LLMs)) positively influence XR/VR-based therapies with self-attachment therapy (SAT) which have shown significant benefits to mental health [19]. In addition, 6G system will have the ability to provide ubiquitous connectivity services with a tighter integration between terrestrial and non-terrestrial networks (e.g., low earth orbit (LEO) satellites). These methods could tackle challenging societal requirements such as mental health at a large scale. There is a need to jointly develop protocols, network functionalities and requirements to enable these use cases.

4. Methodology

To develop the use cases outlined in this whitepaper, we initially identified the use case clusters mentioned above. We then identified use cases that fall under these clusters. Through discussions with different stakeholders from the medical domain, industry and academic researchers, we further specified these use cases and derived potential new requirements and KPIs. The use cases presented in this white paper follow the template used by 3GPP to identify existing features and potential new requirements that would be needed by the 6G system to realize them. The 3GPP template follows the three-stage standardization method as outlined in ITU-T Recommendation I.130. An overview of each section of the use case template is provided below for reference:

Description

Short description of the use case. A couple of paragraphs that defines the background (e.g., necessity), context (e.g., human-in-the-loop) and environment (e.g., nursing ward) of the use case.

Pre-conditions

Necessary capability of the different actors to ensure the realization of the use case.

Service Flows

The flow of events from the moment the use case is triggered to the moment the use case closes. Each step is an action from an actor (e.g., doctor or 3GPP entity). One or two sentences per step.

Post-conditions

Output or outcome once all steps in the service flow have occurred. One or two sentences to describe post-condition.

Existing features partly or fully covering the use case functionality

Identify existing features in current 5G/5G-A system that partially or fully cover required use case functionality

Potential new requirements to support the use case

- Identify new functionality that future 6G system should support to enable the use case
- Functional requirements
- Operational requirements

Key Performance Indicators

Necessary Key Performance Indicators (KPIs) that need to be satisfied to enable the user story defined for the use case.

- e.g., More stringent KPIs in terms of communication (including AI/ML support) and sensing

5. Safety, Ethics and Sustainability

To guarantee and overview safety in the eHealth domain, there exist comprehensive regulations on the design and use of medical devices (e.g., future 6G UE). For example, the Medical device regulation (MDR) is a European Union regulation mandatory for all manufacturers of medical devices in force since May 2021. MDR regulation can be considered as a reference to study the different aspects relevant to the future integration of the upcoming 6G system into the healthcare domain for other regions (e.g., America or Asia). Region-specific considerations will be required to assess risk and potential countermeasures. The underlying goal of the MDR directive is to improve safety, quality and transparency of medical devices [20]. Examples of medical devices include surgical instruments, diagnostic devices (e.g., blood pressure monitors), and implants (e.g., artificial hip joints) which constitute potential UE devices in the future 6G system and which within MDR are assigned to different risk classes.

MDR establishes a risk assessment process that is required to identify and minimize potential risks of patients. The ISO 14971:2019 standard describes methodologies to perform risk management of medical devices. In this whitepaper, we take initial steps by performing an initial risk assessment and potential countermeasures to risk events in the use phase of the medical device life cycle for different use cases based on relevant standards (e.g., ISO/DIN). The wireless communication and sensing requirements of some the use cases described in this whitepaper are derived from MDR regulation. We specify in Appendix A potential risks and their respective potential countermeasures per use case.

To guarantee ethics in the application of technology across multiple verticals including the eHealth domain, there is a P70xx series of standards from the IEEE Standards Association (SA) devoted to govern societally acceptable behaviour of AI and autonomous systems (among other technologies). The P70xx series of standards defines different ethics criteria of AI and autonomous systems. The ethics criteria are algorithmic bias, transparency & explainability, accountability, privacy, responsible governance, fairness, safety, security and dependability [21]. Different vertical sectors have different focus on different ethics criteria. In the eHealth domain the ethics criteria of highest relevance include, but are not limited to: transparency, privacy and responsible governance of AI and autonomous systems. These ethics criteria are partially accounted for in the definition of functional and operations requirements of some of the use cases in this whitepaper (e.g., Sec. 8.1 and 8.2). In future volumes of 6G & eHealth whitepapers, identified use cases will be sub-selected to conduct an ethics profiling in more detail.

To guarantee sustainability in the application of 6G technology in the eHealth domain, analysing the potential societal and environmental impacts according to the Sustainable Developments Goals (SDGs) is key. Different use case-specific sustainability aspects are embedded within the description of the respective use case. We outline initial sustainability considerations related to the potential societal, environmental and economic impacts of the identified use case clusters in Annex B.

6. Medical Robotic Applications

In this section, we outline use cases that fall within the Medical Robotic Applications use case cluster. The identified use cases in this area are Telerobotics Diagnostic Examination use case and Mobile Robotic Platforms in Nursing Ward, Dynamic Reconfiguration of Rehabilitation Robotics, Assisted Living with Companion Mobile Robots and Medical Goods Logistics with Robotic Fleets.

6.1. Telerobotics Diagnostic Examination

Description

The use case is about multiple robotic arms used to provide remote healthcare diagnostic services for different scenarios. A suitable interface which includes joysticks or/and e robotic arms for control is located at the doctor site and many robots and sensors are located at the patient site. Doctors have direct conversation with patients via telepresence and examines patients through robot-assisted inspection with guided tactile contact and audiovisual information. There is bilateral teleoperation (i.e., control information flows in both directions): 1) among robotic arms with haptic feedback. The system enables a medical doctor to achieve three different medical tasks (e.g. auscultation, palpation and ultrasound, 2), without direct human-to-human contact (e.g., avoid direct human contact during pandemics or reach remote communities). The use case is based on prototyping activities from one6G Working Group 4 [22].

Pre-conditions

There is bilateral haptic feedback between the both sides facilitated by the two robotic systems. Additionally, and for suitable processes, robotic arms at the patient side may have full autonomy and feature redundant teleoperation in terms of implemented control modes. The network provides radio access services to the robots at doctor site (leader robots) and the robot(s) at the patient site (follower robots). The doctors switches leader robot to control different follower robot to perform telediagnostics to another patient. Robots are equipped with a multi-instrument medical end-effector that has 3GPP sensing capabilities.

[1] *Unilateral teleoperation means that control information flows in one direction from teleoperator to actuator.*

[2] *Auscultation refers to action of listening to sounds from organs such as the heart with a stethoscope. Palpation refers to a method of sensing with fingers or hands during a physical examination to examine characteristics of an organ or body part. Ultrasounds refers to a procedure that uses high-energy sound waves to sense tissues and organs inside body.*

Service flow

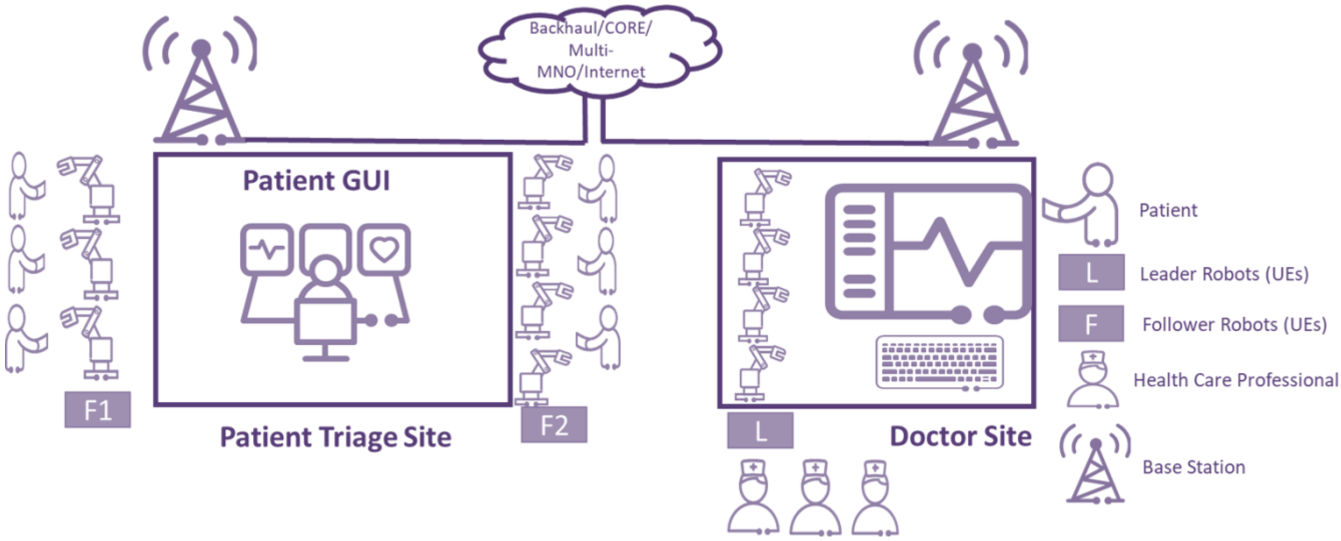


Figure 3. Illustration for Telerobotic Diagnostic Examination for Triage during Pandemics

1. Multiple patients arrive to robot-assisted telediagnostics center (patient site) (e.g. during a pandemic or in rural areas). Depending on their/the physicians requirements patients will receive a comprehensive or directed examination which might include palpation ,auscultation, ultrasonography and other procedures.
2. Doctors are prompted by a network notification to perform telediagnosis. The doctors via the application at doctor site sends a request to the network for a reliable multi-modal end-to-end communication service.
3. Network configures an end-to-end quality of service policy across network nodes (e.g., base stations) spanning multiple network domains (e.g., core network/UPF/public network). In addition, network configures sensing service to guarantee safety proximity between robots and patients/doctors for the telediagnosis.
4. Doctors use joystick-like controls of leader robots (L) that teleoperate a multi-instrument medical end-effector (follower robots F1 and F2) at patient site. The force control of follower robots at patient site corresponds to that of the leader robots operated by the doctor with bilateral teleoperation at doctor site to safely perform physical contact with patient.
5. Doctors receive audio-visual and haptic feedback from follower robot F1 and F2 and the examination cabinet when performing palpation and auscultation to patients. Follower robots F1 and F2 communicate multi-modal information to base station deployed in the vicinity of patient site.
6. Base station at patient site communicates multi-modal information from the multiple follower robots via the backhaul and intermediate network domains to the doctor site. The intermediate network domains may include CORE network functions in multi-operator domains as well as different UPFs along route to patient site.
7. Base station at doctor site receives multi-modal information and communicates information reliably to robot-mounted UE at leader robots L.
8. Patients receive audio visual instructions in real-time from doctors with audio-visual equipment.

Post-conditions

Doctors perform a tele-diagnosis to patient without risk of viral infection as well as enable comprehensive diagnostics for patients in remote locations in commercial network.

Existing features partly or fully covering the use case functionality

Integrated Sensing and Communication Use cases: 3GPP TR.22.837

- Clause 5.17 Use case on health monitoring at home
- Clause 5.29 Use case on Coarse Gesture Recognition for Application Navigation and Immersive Interaction

Robotic aided surgery and diagnosis: 3GPP TS22.104

- Clause A.6.2 Robotic aided surgery
- Clause A.6.3 Robotic aided diagnosis

KPIs for tactile and multi-modal communication service: 3GPP TS22.261 Clause 7.11

Other relevant KPIs and functionalities are defined under: IEEE 1918.1, 3GPP TACMM (SA1), Cyber-CAV (SA1) and XRM (SA2) features describe main techniques to enable collaborative operation including Low latency and reliable communication over local/national and regional service coverage, Multimodality synchronisation, and Service availability [Tables 4.3.1, 4.3.2, Table 4.3.3 KPIs]

Potential New requirements:

To enable protective stop of follower robots (when trespassing protective stop space of robot according to DIN EN ISO 13482 [23]), 3GPP system shall have the capability to timely compute and deliver 3GPP sensing result of human state (e.g., position, range) to application located at follower robot or at an edge application server that triggers a protective stop.

Key Performance Indicators:

The 3GPP system should meet the following communication KPIs extended from Tele-surgery use cases for Robo-Telediagnosis in 3GPP 22.104 use cases:

Scenario	Availability: target value [%]	Reliability: Mean Time btw Failure	e2e latency	Bit rate	Message Size [byte]	Transfer Interval	# of active UEs	Service Area
Robo Tele-diagnosis	> 99.999	>> 1 month (< 1 year)	< 20 ms	2 Mbit/s to 16 Mbit/s	~80	< 20 ms / 100 km^2	< 20 per 1 km^2 NOTE1	regional

NOTE1: Triage during pandemics require the capacity to attend a significant density of patients due to infections peaks during pandemics. Multiple follower robots are required to meet the patient demand.

The sensing KPIs to enable collision avoidance during human-robot interaction are:

Scenario	Sensing service area	Confidence level [%]	Accuracy of positioning estimate by sensing (for a target confidence level)		Accuracy of velocity estimate by sensing (for a target confidence level)		Sensing resolution		Max sensing service latency [ms]	Refreshing rate [s]	Missed detection [%]	False alarm [%]
			Horizontal [m]	Vertical [m]	Horizontal [m/s]	Vertical [m/s]	Range resolution [m]	Velocity resolution (horizontal/ vertical) [m/s x m/s]				
Collision avoidance during human-robot interaction (e.g., medical palpation)	indoor/ outdoor	99	≤1 NOTE1	≤1	≤0.833	≤0.833	<0.5	0.1 NOTE2	< 100	<1	<1	<1

NOTE1: Follower robot must accurately sense position of safety-related objects (i.e., humans).

NOTE2: Humans can move hands up to 3 m/s vertically during a short period of time. High velocity resolution in order to properly adjust physical reaction of follower.

6.2. Context Aware Mobile Robotic Platforms in Nursing Ward

Description

Mobile robotic platforms will be widely used in healthcare sector to take over a subset of caregiving tasks [24] and the surveillance of patients. The prevention of complications and serious illnesses is a critical area that is particularly affected by staff shortages. In this use case, mobile robots monitor, communicate and interact with patients at ward level utilizing timely and context-aware actions to support care-giving tasks. Mobile robots require context-awareness of the health situation of patients so that said mobile robots can adapt their actions accordingly to perform context-sensitive actions when interacting with them (e.g., interact with mindful dialogue and move patient with extreme care as soon as possible to emergency room).

Pre-conditions

Mobile robots have autonomous navigation and manipulation capabilities. Mobile robots can perform 3GPP sensing as well as employ AI/ML methods to classify objects in environment with visual input data from mounted cameras. Infrastructure sensors (cameras and smalls base stations as customer premise equipment) are deployed in nursing ward detect and localize patients. Small base stations sense average vital health parameters of patients. In addition, patients are equipped with health wearable sensors. Applications server (deployed in network or robot) has sensor fusion capabilities. Robotic systems have dialogue capabilities (e.g., with LLM/VLM).

Service Flows

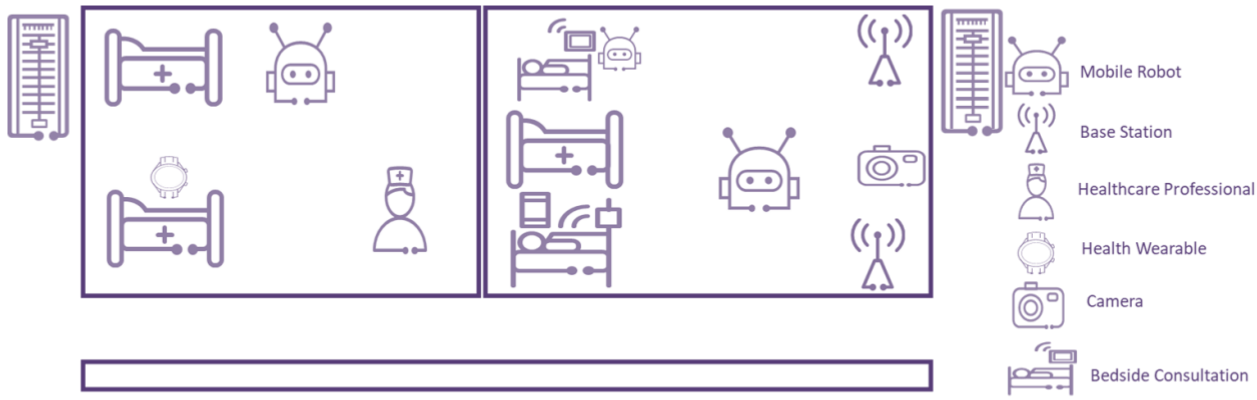


Figure 4. Illustration for Mobile Robotic Platforms in Nursing Ward Use Case

1. Patient in nursing ward starts to have critical medical situation and is at risk.
2. An alarm associated to the patient at risk is triggered by pre-installed legacy medical sensors. Human caretaker is not able to respond to alarm due to conflicting critical task with another patient.
3. Infrastructure sensors (e.g., health wearable, small base station with 3GPP sensing, cameras) and also sensors mounted in mobile robots sense different information related to the environment and situation of the patient at risk.
4. Mobile robot in vicinity reliably receives alarm notification from network including related sensing information (e.g., 3GPP sensing data/result, visual data of patient, biometric data points from wearable). In addition, relevant electronic health record (EHR) of patient is communicated by application server via the network to mobile robot.
5. Mobile robot performs sensor fusion of the different data modalities related to the patient at risk.
6. Mobile robot fuses information and acquires awareness of the current context/situation in a timely manner. Application server or mobile robot performs sensor fusion of the different modalities to compute a context encoding. Alternatively, application server located in hospital premises may provide context-awareness as a service to mobile robots.
7. Mobile robots perform context-aware actions (e.g., move patient with extreme care to emergency room and mindful dialogue) and bring patient back to stable state. The context-aware actions belong to two spaces: the physical one, related to motion; the medical one, related to determining the actual state of the patient and the actions to solve the medical situation.
8. In the meantime, another patient in another room requires consultation with doctor. All human healthcare professionals are busy with other tasks. Mobile robot moves towards patient and provides a bedside consultation with remote doctor via an HD screen.
9. Bedside consultation is provided with remote doctor at remote location in hospital.

Post-conditions

Mobile Robots provide assistance to overloaded healthcare professionals to prevent complications and serious illnesses of increasing amount of patients with context-aware actions (sensitive to disease or distress of patient). Mobile robots by consuming context-awareness services perform context-aware interactions to interact with patients in the nursing ward. Mobile robots will become of high value especially during night-time and in areas with complicated conditions (e.g. isolated patients).

Existing features partly or fully covering the use case functionality

Positioning: 3GPP TS 22.261

- Clause 6.27.2 Positioning services requirements

5G wireless sensing service functional requirements: 3GPP TS 22.137

Enhanced Multimedia Broadcast Multicast Services (MBMS) ETSI TS 103 720

5G Service Requirements for the 5G System TS 22.261 Clause 6.13 Flexible broadcast/multicast service

Critical Medical Applications: 3GPP TS 22.261 Clause 6.34

Potential New requirements:

3GPP system should enable sensor fusion of multi-modal health data (e.g., 3GPP sensing data, Electronic Health Records and wearable health information) in local data network (e.g., hospital network) or in-network (privacy-preserving computing) to compute context encoding and provide it as a service to mobile robot in a timely manner.

Subject to operator’s regulation and user’s consent, 3GPP system shall multicast/unicast 3GPP sensing data, pre-processed information or results in target service sensing area or configured multicast service area to authorized UEs (e.g., mobile robots in nursing ward).

Key Performance Indicators

The communication KPIs to support medical monitoring and forwarding of processed information are:

Profile	Characteristic parameter					Influence quantity					
	Communication service availability: target value in %	Communication service reliability (Mean Time Between Failure)	End-to-end latency: maximum	Bit rate	Direction	Message Size [byte]	Transfer Interval	Survival Time	**UE speed (km/h)**	**# of UEs connection**	**Service Area**
Medical monitoring (note 2)	> 99,9999	>> 6 month, < 2 year	< 100 ms	~ 1-30 Mbit/s NOTE 2	Uplink	>10000 – Note 2	50 ms	Transfer Interval	< 20	1000/km2	Indoor environments including Deep Indoor. (NOTE 1)
Forwarding of Medical Processed Information to Mobile Robots	> 99,9999	>> 6 month, < 2 year	< 100 ms	~ 50 Mbit/s	Downlink/Sidelink	~ 100000 Note 2 -	50 ms	Transfer Interval	< 20	1000/km2	Indoor environments including Deep Indoor. (NOTE 1)

NOTE 1: “deep indoor” term is meant to be places like e.g. elevators, building’s basement, underground laboratories of hospital, …

NOTE 2: Dependent on the representation of the communicated e.g., point cloud) 3GPP sensing data, as well as non-3GPP sensing data and contextual information and other sensing information.

6.3. Dynamic Reconfiguration of Rehabilitation Robotics

Description

After a serious medical incident (e.g., accident or stroke), frequent rehabilitation therapies (e.g., 45 minutes a day) are required to restore pre-incident mobility. Typically, this requirement is not met due to lack of rehabilitation services. Additionally, training results might require a continues adaptation of training conditions (e.g. readjustment of the range of motion). Bringing rehabilitation to the home with the use of rehabilitation robotics is key to tackle this issue [25]. State-of-the-art rehabilitation exoskeleton robot prototypes or products (e.g. commercial lower limb rehabilitation systems such as Erigo, Lokomat, LOPES, ReWalk) are currently used [26]. Accurate human gait[3] information is key for lower limb exoskeleton rehabilitation robotics. The wider adoption of rehabilitation robotics is constrained by the lack of reconfigurability and customisability of the exoskeletons. Moreover, there are insufficient levels of robotic intelligence for automated recovery progress evaluation as well as lack of effective personalised treatment methods. An ideal dynamic and reconfigurable exoskeleton is capable of being structurally/mechanically adjusted to the patient's needs. To achieve the latter, the exoskeleton requires an accurate model of human lower limb mechanics, sensing of patients biomechanics (flexibility, strength, etc.) and the accurate recording of vital signs (e.g., heart rate measurements). The future 6G system can tackle these issues by potentially enabling a real-time 'human-in-the-loop' (closed-loop) rehabilitation system with the generation of optimal patient-specific adaptation of the exoskeleton, which is versatile, mobile and safe [27].

Pre-conditions

The exoskeleton lower-limb rehabilitation robotic system is equipped with multiple motors that enable it to switch between structures with different degrees of freedom and torque characteristics. In addition, the exoskeleton system is equipped with a UE with ISAC sensing capabilities and there is a CPE deployed indoors. The patient utilizes the exoskeleton in an indoor environment. An outdoor macro BS deployed outdoor provides communication service to exoskeleton-type UE. Application server is located at hospital premises and an edge application server is deployed at BS. Controllers are deployed at the application servers to compute optimal control and adaptation actions. Application server in hospital premises hosts a digital twin model of the human gait motion.

Service Flows

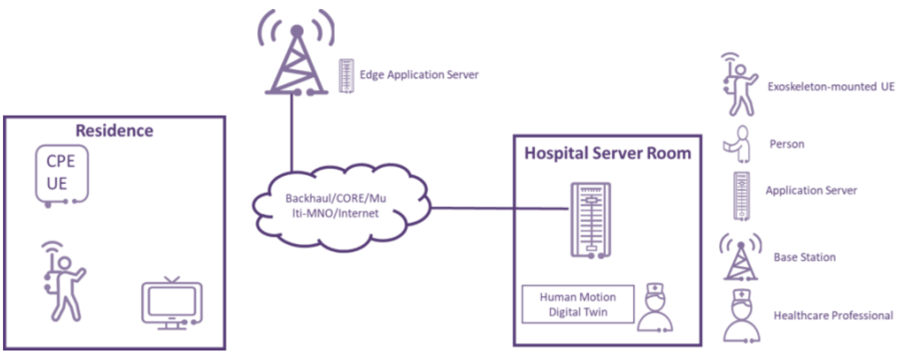


Figure 5. Illustration for Dynamic Reconfiguration of Rehabilitation Robotics Use Case

---

[3] *A gait refers to a manner of limb movements made during locomotion. Human gait refers to bipedal forward propulsion of the center of gravity of the human body.*

Step 1. Bob had an accident years ago and will start his daily rehabilitation therapy at home to restore mobility using a robotic exoskeleton. Bob wears robotic exoskeleton and the UE mounted on the robotic exoskeleton sends a communication and sensing request to the 3GPP network.

Step 2. Upon reception of the request, the 3GPP network configures the CPE UE and the exoskeleton-mounted UE to perform an ISAC sensing operation. The sensing information that can be derived with 3GPP sensing includes real-time vital signs and motion/posture recognition necessary to perform an initial automatic disability assessment based on patient-specific evidence.

Step 3. Bob is prompted to start a test motion (e.g., walk a few meters back and forth). The exoskeleton-mounted UE and CPE UE transmit ISAC sensing signals with Bob as a sensing target. The sensors on the exoskeleton-mounted UE also communicate their measurements.

Step 4. ISAC sensing result is computed in 3GPP network (e.g., Base Station) or at an edge application server, and is communicated to trusted 3rd party application deployed at application server in hospital. Based on previous collected information, a motion digital twin of Bob is updated based on an accurate kinematics model, center of gravity calculations, heart rate measurements, and other relevant information to derive a disability assessment. ISAC sensing results from Bob are continuously computed and updated based on data from ISAC sensing signals.

Step 5. Based on the disability/motion assessment, a networked control system[4] closed over a 3GPP network is initiated with the configuration of the end-to-end communication path between hospital server room and residence to meet a specific QoS. In order for the rehabilitation to work as intended, and conduce to the desired levels of patient comfort and safety, the center of motion of the patient's ankle complex and that of the exoskeleton should be perfectly aligned.

Step 6. The sensor measurements associated with the multiple actuators in the different joints on the robotic exoskeleton (e.g., motor encoders, inertial measurement unit (IMU), etc…) together with the vital sign measurements are communicated in real-time to the motion controller deployed at the application server in hospital premises via the uplink. Alternatively, the controller may be deployed in an edge application server collocated with Base Station.

Step 7. Upon reception of the measurements and based on the target reference signal, controller computes optimal control actions (e.g., torques, directions) to minimize the control error between the actuation and reference signal to achieve equilibrium (e.g., alignment of center of motion of patient's ankle complex with that of exoskeleton).

Step 8. The optimal control actions adapted to patients' state and needs are communicated to the exoskeleton via the downlink of the 3GPP network.

Step 9. Upon reception of the referential, optimal control actions, the motors/actuators mounted on the exoskeleton attempt to execute these optimal control actions. Once the resulting motions have been performed, new measurements are generated that need to be communicated to the controller to stabilize the networked control system. The feedback control loop is constantly executed (repeat from step 6).

Post-conditions

Bob takes part in his daily rehabilitation therapy by wearing a reconfigurable exoskeleton tailored to his needs. The networked control system closed over the 3GPP network facilitates the operation of an optimal, patient-specific reconfigurable exoskeleton for an effective rehabilitation therapy.

[4] *Feedback control loops closed over a communication network.*

Existing features partly or fully covering the use case functionality

Integrated Sensing and Communication Use cases: 3GPP TR.22.837

- Clause 5.29 Use Case on Immersive Interaction Service with Gesture Recognition
- Clause 5.17 Use case on health monitoring at home

Robotic aided diagnosis: 3GPP TS22.104

- Clause A.6.3 Robot-aided diagnosis

Potential new requirements needed to support the use-case

There are no new functional requirements to enable the use case. New requirements are in the form of new communication and sensing KPIs.

Key Performance Indicators

The Sensing KPIs for posture recognition and vital sign sensing is:

Scenario	Sensing service area	Confidence level [%]	Human motion rate accuracy [Hz]	Accuracy of positioning estimate by sensing (for a target confidence level)		Accuracy of velocity estimate by sensing (for a target confidence level)		Sensing resolution		Max sensing service latency[ms]	Refreshing rate [s]	Missed detection [%]	False alarm [%]
				Horizontal [m]	Vertical [m]	Horizontal [m/s]	Vertical [m/s]	Range resolution [m]	Velocity resolution (horizontal/ vertical) [m/s x m/s]				
Posture Recognition and Vital Sign Sensing for Rehabilitation	Indoor	99	0.0317 NOTE1	0.05 NOTE2	0.05 NOTE2	N/A	N/A	0.01 NOTE2	Dependent on Sampling Time	100 ms	< 0.1 s	< 1%	< 1%

NOTE1: (Average Heart Rate Measurement) Norm DIN EN 60601 defines the requirement of the measurement of a heartbeat within +/- 75ms around the actual heartbeat (i.e., 0.0317 Hz considering heart rates as low as 40 bpm) [28].

NOTE2: (Posture/Motion Recognition) IEC 80601 establishes the rehabilitation robot might have a very close contact to patient for an extended period of time. Physical interactive control depends on the sensor input from patient. High range resolution required to guarantee safety [28].

The Communication KPIs for sensor feedback from rehabilitation robotics are and dynamic reconfiguration of rehabilitation robotics are:

Scenario	Availability: target value [%]	Reliability: Mean Time btw Failure	Direction	e2e latency	Bit rate	Message Size [byte]	Transfer Interval	UE speed	# of active UEs	Service Area
Sensor Feedback from Rehabilitation Robotics	> 99.999	>> 1 month (< 1 year)	Uplink	50 ms NOTE2	Up to 78.6 Mbit s NOTE3	< 9830400 NOTE3	< 20 ms / 100 km²	< 12.8 km/h NOTE1	< 20 per 100 km²	regional
Dynamic Reconfiguration (Control) of Rehabilitation Robotics	> 99.999	>> 1 month (< 1 year)	Downlink	50 ms NOTE2	2 Mbit/s NOTE2	~80 NOTE2	< 20 ms / 100 km²	< 12.8 km/h NOTE1	< 20 per 100 km²	regional

NOTE1: The average human running speed is approximately 12.8 km/h.

NOTE2: Determined by the "slowest" exteroreceptive feedback[5] hardware used in the control loop (e.g., 50 ms for depth cameras). Ideal and efficient, (hard) real-time control on a networked system is based on 1 ms control loops.

NOTE3: If point-cloud data (constructed from different sensors) is used, message size can be up to 9830400 bytes.

6.4. Assisted Living with Companion Mobile Robots

Description

Due to the current demographic change in terms of aging population [12], a significant portion of older adult population lives in households or care homes [29]. Home-assisted living with mobile robots is a promising solution to address the increasing demand of companionship and assistance tasks. The increasing aging population call for solutions that scale and improve the quality of life and safety of adults in complex environments. Mobile robots can perform essential companionship tasks such as exchange items with human (e.g., exchange groceries, furniture, cooking tools, etc…) as well as engaging in personalized dialogues. Mobile robots will provide safe physical contact during human-robot interaction as well as provide personalized assistance to older adults based on their current health situation or preferences with the help of more enhanced connectivity, sensing and intelligence services provided by the 6G system. Furthermore, companion mobile robots can take over monitoring and medical assessment services of the supported being, enabling prevention and continuous observation in order to avoid serious events.

Pre-conditions

Mobile robots are mobile servant robots (as defined by DIN EN ISO 13482 [23]) that have autonomous navigation and manipulation capabilities. Mobile robots can perform 3GPP sensing. A CPE deployed at home has 3GPP communication and sensing capabilities. An infrastructure base station provides connectivity to mobile robots if they perform assistance tasks outdoors. An edge application server is collocated with the base station for computational offloading services. Mobile robots have dialogue capabilities (e.g., with LLM/VLM). A mobile robot management system

---

[5] *Exteroceptive feedback refers to the outcome of the movement through the exoskeleton's sensors.*

is deployed within the premises of hospital or care center and manages mobility of robot in indoor and outdoor scenarios.

Service Flows

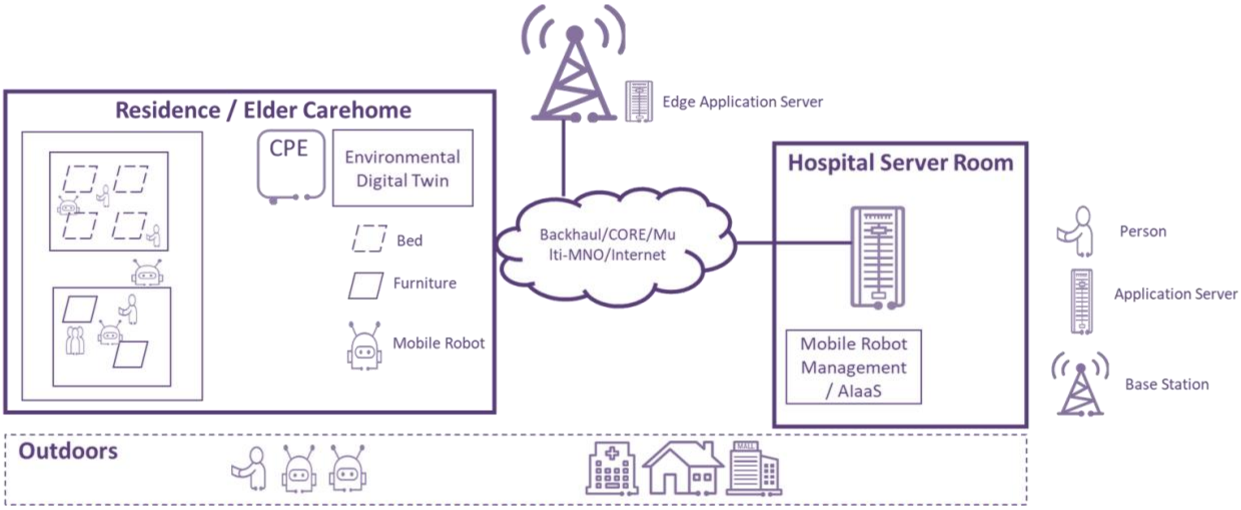


Figure 6. Assisted Living with Companion Mobile Robots

Step 1. Bob wakes up at his residence. Mobile robot servants A and B receive wake-up signal from CPE in order to start home-assistance tasks.

Step 2. Bob prefers to prepare his breakfast by himself. Therefore, Bob requests mobile robot servant A to only provide him assistance by giving him the necessary ingredients and household appliances as he requests them.

Step 3. Upon verbal requests from Bob, mobile robot servant A exchanges household appliances as well as ingredients. Bob prepares his breakfast.

Step 4. In the meantime, mobile robot servant B receives the task from Bob to take his wife Susan to a language school at the city centre. During their trajectory to the college, mobile robot servant B requests personalized AI/ML services from 6G system (in-network or edge application server collocated with BS) to quiz wife Susan on recent Spanish topics Susan has been taking at the language school.

Step 5. During their way to the language school by foot, mobile robot servant B at a walking distance from Susan engages in personalized conversational dialogue with her. Susan successfully reviews her Spanish course topics with the help of mobile robot servant B.

Step 6. After leaving Susan at the language school, mobile robot servant B goes to grocery store and buys groceries.

Step 7. Upon finalization of the Spanish language course, mobile robot servant B waits Susan outside the language school carrying the bought groceries.

Step 8. Susan requests mobile robot servant B to give her the grocery bags to carry back home herself. Susan safely receives said grocery bags from mobile robot servant B.

Step 9. Back at home, Bob enjoys a nutritious breakfast and welcomes Susan and mobile robot servant B returning home.

Step 10. While servicing Bob, robot servant A realizes walk shakiness and a slight tremor in Bobs movements for which reason it contacts the family doctor for aid.

Post-conditions

Bob and Susan are safely assisted and supported with tasks such as cooking, carrying groceries as well as personalized conversational dialogues.

Existing features partly or fully covering the use case functionality

Service continuity: 3GPP TS 22.263

- clause 5.5 Service continuity

5G wireless sensing service functional requirements: 3GPP TS 22.137

- Clause 5.1 Description
- Clause 5.2 Requirements

Use case on AMR collision avoidance in smart factories: 3GPP TR22.837 Clause 5.23

Use case on Coarse Gesture Recognition for Application Navigation and Immersive Interaction: 3GPP TR22.837 Clause 5.29.

Potential new requirements needed to support the use-case

To enable protective stop of mobile robot servant (when trespassing protective stop space of robot according to DIN EN ISO 13482 [23]), 3GPP system shall have the capability to timely compute and deliver 3GPP sensing result of human state (e.g., position, range) to application located at mobile robot servant or at an edge application server that triggers a protective stop.

To enable safe physical contact during human-robot interaction according to DIN EN ISO 13482 [23], the 3GPP system shall provide 3GPP sensing information/result (e.g., material, micro-deformation information of exchanged object, velocity of human) to the mobile servant robot so that said robot can apply the properly adjusted physical reaction (e.g., contact force and velocity of end-effector).

Depending on the necessary dialogue tasks, the 3GPP system shall provide wireless communication capabilities to timely deliver dialogue output, AI/ML split inference and/or AI/ML model to mobile robot servants in arbitrary outdoor environments.

Key Performance Indicators

The sensing KPIs for the Safe Physical contact during human-robot interaction (e.g., item exchange) are:

Scenario	Sensing service area	Confidence level [%]	Accuracy of positioning estimate by sensing (for a target confidence level)		Accuracy of velocity estimate by sensing (for a target confidence level)		Sensing resolution		Max sensing service latency [ms]	Refreshing rate [s]	Missed detection [%]	False alarm [%]
			Horizontal [m]	Vertical [m]	Horizontal [m/s]	Vertical [m/s]	Range resolution [m]	Velocity resolution (horizontal/ vertical) [m/s x m/s]				
Safe Physical contact during human-robot interaction (e.g., item exchange)	indoor/ outdoor	99	≤1 NOTE1	≤1	≤0.833	≤0.833	0.5	0.1 NOTE2	< 100	<1	<1	<1

NOTE1: Mobile robot servant must accurately sense position of safety-related objects (i.e., humans).

NOTE2: Humans can move hands up to 3 m/s vertically during a short period of time. High velocity resolution in order to properly adjust physical reaction of mobile robot servant.

The communication KPIs for the Personalized Interaction with Human (i.e., AI/ML model transfer/output/split inference) are:

Scenario	Availability: target value [%]	Reliability: Mean Time btw Failure	Direction	e2e latency	Bit rate	Message Size [byte]	Transfer Interval	UE speed	# of active UEs	Service Area
Personalized Interaction with Human (i.e., AI/ML model transfer/output/split inference)	> 99.99	>> 1 month (< 1 year)	Downlink	100 ms	Up to [5.6] Gbits/s NOTE1	Depends on size of communicated AI/ML model/output/split0inference. NOTE 3	< 20 ms / 100 km2	< 12.8 km/h NOTE2	< 20 per 100 km2	regional

NOTE1: If AI/ML model is communicated to mobile servant robot (e.g., LLM), we assuming 10x model compression for 7 Billion parameter Med-Alpaca LLM model [30].
NOTE2: The average human running speed is approximately 12.8 km/h. Mobile serving robot accompanies human.

6.5. Medical Goods Logistics with Robotic Fleets

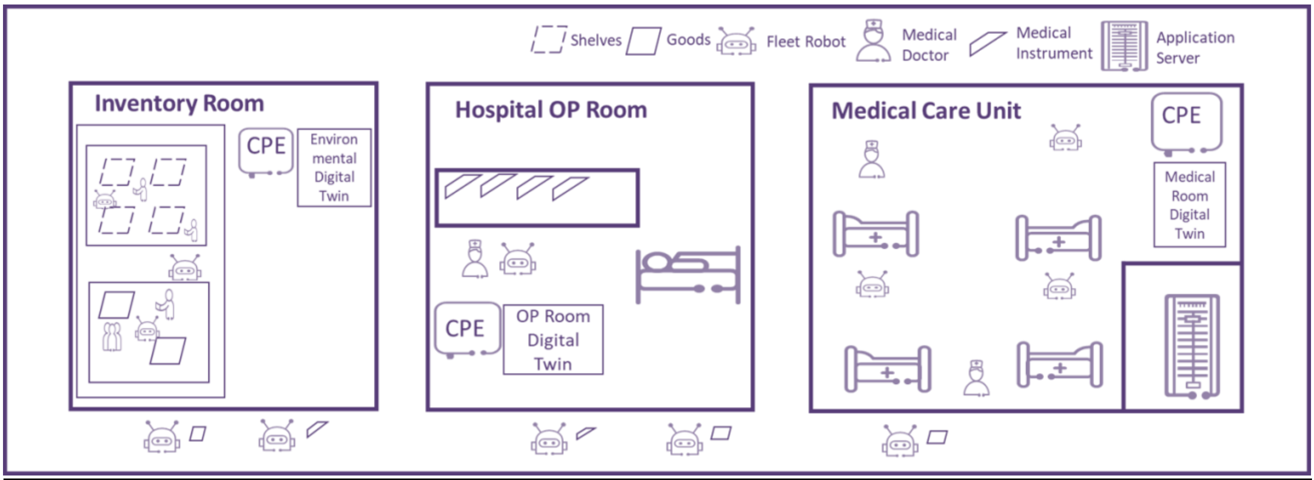
Description

Robotic fleets for logistics of medical goods help automate tasks and boosts efficiency of the healthcare system. With their advanced capabilities in inventory tracking, stock replenishment, medical good picking, sorting, and packing, robotic fleets offer unprecedented benefits that reduce costs, and enhance overall operational efficiency of healthcare services. Said benefits can significantly help overcome the staff shortage in healthcare sector, especially in those tasks where the healthcare staff considers burdensome. The human personnel can be relieved from tasks like transportation of heavy objects (e.g., patient beds, medical devices, or instrumentation containers) or collection of packaged materials for upcoming surgeries [31]. The formation of robotic fleets can handle higher workloads and have a centralized context-dependent management of fleet resources (e.g., adapted to the number of humans in hospital room, adapted to hospital section where transportation of heavy objects is needed the most). The robotic fleet allows to reorganize work so to free human workforce for more critical and mentally demanding tasks.

Pre-conditions

Fleet robots have manipulation and grasping capabilities and their fleet movement is managed by a centralized robot fleet management system deployed in an application server. Fleet robots are equipped with a UE with 3GPP communication and sensing capabilities. The application server is located in the premises of the hospital and computes the joint trajectory of fleet robots adapted to the environment and workload requirements. A customer premise equipment (CPE) is deployed indoors and has 3GPP communication and sensing capabilities. CPEs host an environmental digital twin that is derived with 3GPP sensing and other contextual information. The environmental digital twin provides real-time environment information to the application server. Fleet robots track inventory items and provide real-time medical good quantities and location updates.

Service Flows



Step 1. Hospital A is currently experiencing high demand of healthcare services. The operation (OP) room(s) requires multiple surgical instruments and medical devices located in the hospital inventory room. At the same time, the medical care unit (e.g., palliative care unit) also requires multiple medical goods (e.g., medicines, instruments) to be carried to the medical care unit as soon as possible.

Step 2. Healthcare professionals input different workload requests in an application interface (GUI) to the robotic fleet management system. The application server processes the requests and itself requests the CPEs deployed in the different hospital rooms to provide real-time environmental information.

Step 3. The CPEs located at the different rooms perform 3GPP sensing to sense environmental objects in the hospital environmental (e.g., human occupancy of the different rooms, obstacles, space limitations, surfaces). Based on 3GPP sensing and other contextual information, CPEs construct an environment map, referred to as environmental digital twin.

Step 4. Based on the different workload requirements inputted by the healthcare professionals and the current environmental situation at the different hospital rooms, the robotic fleet management system hosted at the application server orchestrates the robotic fleet (e.g., compute robotic fleet size and composition). Based on the target location where medical goods have to be moved to, the robotic fleet management system computes the trajectory of all robots to reach an optimal movement efficiency at the hospital adapted to the contextual situation at each hospital room.

Step 5. The global trajectory is communicated to the fleet robots via the different CPEs. Fleet robots select and pick items from inventory room to transport them to target location using 3GPP sensing.

Step 6. Based on the current real-time situation, the CPEs and fleet robots report the current traffic efficiency in the hospital environmental as well as object and event detection information. Based on said information and 3GPP sensing information from CPEs, robotic fleet management system recomputes the trajectory of fleet robots.

Step 7. Fleet robots arrive to their respective hospital room with their transported medical goods.

Post-conditions

Fleet robotic resources are efficiently used to support different workloads in the hospital environment adapted to the environment and needs. Healthcare professional perform caregiving tasks efficiently with the support of fleet robotic systems.

Existing features partly or fully covering the use case functionality

Positioning: 3GPP TS 22.261

- Clause 6.27.2 Positioning services requirements

5G wireless sensing service functional requirements: 3GPP TS 22.137

- Use case on AMR collision avoidance in smart factories 3GPP TR 22.837
- Use case of integrated sensing and positioning in factory hall 3GPP TR 22.837

Critical Medical Applications: 3GPP TS 22.261 Clause 6.34

Potential new requirements needed to support the use-case

There are no new functional requirements to enable the use case. New requirements are in the form of new communication and sensing KPIs.

Key Performance Indicators

The sensing KPIs are extended from the use case on AMR collision avoidance in smart factories and the use case of integrated sensing and positioning in factory hall in the 3GPP report TR 22.837:

Scenario	Sensing service area	Confidence level [%]	Accuracy of positioning estimate by sensing (for a target confidence level)		Accuracy of velocity estimate by sensing (for a target confidence level)		Sensing resolution		Max sensing service latency [ms]	Refreshing rate [s]	Missed detection [%]	False alarm [%]
			Horizontal [m]	Vertical [m]	Horizontal [m/s]	Vertical [m/s]	Range resolution [m]	Velocity resolution (horizontal/ vertical) [m/s x m/s]				
Fleet robot collision avoidance in hospital	indoor/outdoor	99	[≤0.5] NOTE1	N/A	0.5	N/A	[0.5]	[0.1] NOTE2	<100	0.05	N/A	0.1% NOTE 3

NOTE1: High accuracy needed for hospital environment since it is highly safety-critical due to moving persons, sensitive equipment, sterile zones, (e.g., referenced in DIN EN ISO 3691–4 [32])

NOTE2: Simulations of robotic fleets in hospital environments indicate velocity of 1.2 m/s (relatively high) is promising to achieve reduced fleet size and minimum total duration of transportation tasks in hospital environments [31].

NOTE3: Minimum false alarms so that healthcare professionals can trust the robotic fleet system.

NOTE4: The action of grasping medical goods with the help of 3GPP sensing is not considered in this use case.

The communication KPIs for the trajectory path(s) to each fleet robot as well as the sensing and traffic information to the fleet management system is:

Profile	Characteristic parameter					Influence quantity					
	Communication service availability: target value in %	Communication service reliability (Mean Time Between Failure)	End-to-end latency: maximum	Bit rate	Direction	Message Size [byte]	Transfer Interval	Survival Time	UE speed (km/h)	# of UEs connection	Service Area
Communication of trajectory path(s) to each fleet robots	> 99,9999	>> 6 month, < 2 year	< 100 ms	~ 1-10 Mbit/s NOTE 2	Downlink	~ 100000 Note 2 -	50 ms	Transfer Interval	< 5	1000/km 2	Indoor environments including Deep Indoor. (NOTE 1)
Communication of real-time sensing and traffic information to fleet management system	> 99,9999	>> 6 month, < 2 year	< 100 ms	~ 1 Mbit/s NOTE 3	Uplink	>10000 – Note 2	50 ms	Transfer Interval	< 5	1000/km 2	Indoor environments including Deep Indoor. (NOTE 1)

NOTE 1: "deep indoor" term is meant to be places like e.g. elevators, building's basement, underground laboratories of hospital, …

NOTE 2: Dependent on the representation of the communicated global path trajectory plan to fleet robots.

NOTE 3: Dependent on the coarse representation of the 3GPP sensing information and the current traffic state information (e.g., Cooperative awareness messages).

7. Vital Sign Wireless Sensing

In this section, we outline use cases that fall within the Vital Sign Wireless Sensing use case cluster. The identified use cases in this area are Vital Sign and Occupancy Detection in Hospital Emergency Waiting Room and Vital Sign Sensing in Medical Care Units.

7.1. Vital Sign and Occupancy Detection in Hospital Emergency Waiting Room

Description

Patients in emergency waiting rooms within hospitals have different medical conditions. The continuous monitoring of average heart rate, temperature and oxygen saturation information of patients at hospital waiting rooms help trigger medical personnel perform timely and cost effective actions in nursing ward/emergency waiting rooms. In addition, contactless monitoring does not add distress by measuring probes with direct contact [33]. Vital sign monitoring with wireless signals is based on measuring the relative distance changes between the transmitter and the skin of a person due to cardiac activity or respiration [34]. Spectral analysis of video data allows for the assessment of additional features such as oxygen saturation or temperature.

Pre-conditions

Base station (e.g., a customer premise equipment) is an indoor small cell with the capability to perform 3GPP sensing. Local health personnel has an agreement with owner of base station to provide 3GPP sensing to support activities of caregivers in hospital.

Service Flows

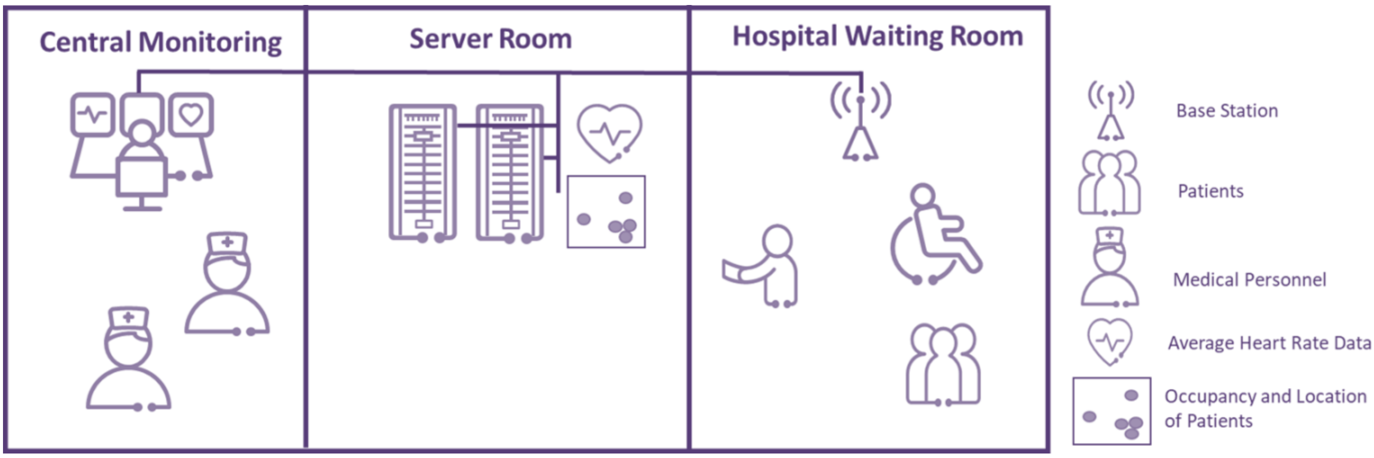


Figure 7. Illustration for Vital Sign and Occupancy Detection in Hospital Waiting Room

Step 1. New patients are arriving to the hospital waiting room with different states. To appropriately manage incoming load of patients, hospital management personnel requests a 3GPP sensing service to perform vital sign and occupancy detection in a hospital emergency waiting room.

Step 2. Base station receives request and configures its resources to transmit wireless signals.

Step 3. Base station transmits wireless signals in target sensing service area within the hospital waiting room. Wireless signals are used to sense the average heart rate of any patient in waiting room and sense the occupancy rate of the hospital waiting room. The relative distance changes between the transmitter and the skin of the patients due to cardiac activity are measured with wireless signals.

Step 4. Base station receives 3GPP sensing data and communicates information to a sensing function located at the network or at a trusted 3rd-party application. Sensing Function computes vital health parameters. Result is forwarded to application server within hospital premise.

Step 5. Medical personnel receive average health sensing information per patient in waiting room as well as the occupancy rate of the waiting room. These information helps medical personnel promptly and cost effectively react to incoming load of patients.

Step 6. By continuously monitoring the respective vital signs of any patient, health related changes are immediately recognized and prompted to the personnel allowing them to react accordingly.

Post-conditions

A medical personnel manages the incoming load of patients and takes according actions based on the average heart rate of patients.

Existing features partly or fully covering the use case functionality

3GPP system can position equipped patients (i.e., patients with a UE) with 3GPP positioning.

Integrated Sensing and Communication Use cases: 3GPP TR.22.837

- Clause 5.17 Use case on health monitoring at home
- Clause 5.29 Use case on Coarse Gesture Recognition for Application Navigation and Immersive Interaction

Potential new requirements needed to support the use-case

There are no new functional requirements to enable the use case.

Key Performance Indicators

The sensing KPIs are:

Scenario	Sensing service area	Confidence level [%]	Human motion rate accuracy [Hz]	Accuracy of positioning estimate by sensing (for a target confidence level)		Accuracy of velocity estimate by sensing (for a target confidence level)		Sensing resolution		Max sensing service latency[ms]	Refreshing rate [s]	Missed detection [%]	False alarm [%]
				Horizontal [m]	Vertical [m]	Horizontal [m/s]	Vertical [m/s]	Range resolution [m]	Velocity resolution (horizontal/ vertical) [m/s x m/s]				
Hospital Emergency waiting room	Indoor	99	0.0317 NOTE 1	N/A	N/A	N/A	N/A	N/A	N/A	100 ms	1 s	< 0.1%	<0.1 % NOTE2

NOTE1: Norm DIN EN 60601 defines the requirement of the measurement of a heartbeat within +/- 75ms around the actual heartbeat (i.e., 0.0317 Hz considering heart rates as low as 40 bpm) [28].

NOTE2: Low amount of false alarms are required so that healthcare professionals trust the continuous contactless heart rate monitoring system in emergency waiting room. [3]

7.2. Vital Sign Sensing in Medical Care Units

Description

Medical care units (such as nursing wards) have different requirements in terms of vital sign measurements and patient freedom. Most care units prioritize the comfort of their patients and only in serious conditions, such as found on an intensive care unit, a more invasive and patient-contact monitoring deems necessary. Traditional wired sensors, such as the electrocardiograph (ECG), restrict movements, limiting a patient's ability to have walks and engage in activities. Hence, contact-based monitoring should be avoided. However, tracking medical relevant information (synchronous and continuous heart rate/respiration measurement) of vital signs is crucial to monitor health status, assess the effectiveness of medications, and ensure appropriate treatments. Currently, nurses measure these vital signs regularly, but the need for less intrusive and more continuous monitoring solutions is evident. Such advancements would support patient comfort while maintaining the essential oversight of their health conditions [4].

NOTE1: Average vital sign measurements are not sufficient to track patients current status and to register adverse events (or similar hospital environments).

Pre-conditions

Transmit Receive Points (TRPs) are indoor small base station with the capability to perform 3GPP sensing (acting as sensing transmitter and/or sensing receiver)) and are fixed on the floor (or roof) in the palliative care unit. UEs can also act as a sensing transmitter and/or receiver and are carried by nurse or mobile robot in the palliative care unit. Local health personnel have an agreement with owner of TRPs/UEs to provide 3GPP sensing to sense medical relevant data and support healthcare professionals in the palliative care unit.

Service Flows

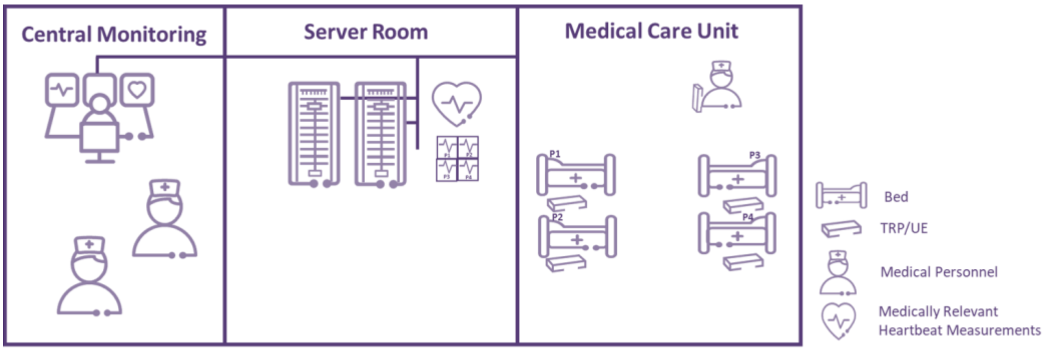


Figure 8. Illustration for Vital Sign Sensing in Medical Care Unit

Step 1. Health care professionals receive multiple new patients in the care unit.

Step 2. Hospital management personnel request a 3GPP sensing service to perform 3GPP sensing of medical relevant data. The request includes the periodicity and sensing requirements of the service.

Step 3. Network configures TRPs/UEs with wireless resources to perform 3GPP sensing according to requirements to compute medical relevant vital sensing information.

Step 4. Once 3GPP system is configured to perform 3GPP sensing as per request, patients are introduced in the care unit and laid on the beds.

Step 5. TRPs perform initial human detection and start performing 3GPP sensing with a given periodicity to perform synchronous heartbeat measurement of patients lying on bed. 3GPP sensing data is forwarded to a sensing function (located at the TRP/UE, an in-network application function or a 3rd-party trusted application).

Step 6. Application Server or 3rd Party trusted application receives 3GPP sensing data of all TRPs/UEs and compute sensing result in the form of medically relevant measurements of heartbeat. Alternatively, TRPs/UEs may independently compute heartbeat measurements.

Step 7. Accurate and continuous 3GPP sensing results are received at the central monitoring center.

Post-conditions

Medically relevant vital sign information of patients in care units are continuously and accurately sensed and timely provided to central monitoring system. Reliability of contactless system with 3GPP sensing avoids false alarms since there are no probes to manipulate by distressed patients. Distress of patients is significantly reduced by enabling mobility.

Existing features partly or fully covering the use case functionality

There are no 5G/5G-A system features that partially or fully cover required use case functionality.

Potential new requirements needed to support the use-case

3GPP system should identify/detect number of relevant patients and orientation of patients to perform beamforming if needed to each patient and sense medically relevant data of heartbeat measurements with 3GPP sensing. Alternative, this information can be received by a 3rd party application server.

Key Performance Indicators

The 3GPP system shall be able to provide 3GPP sensing service with the following KPIs:

Scenario	Sensing service area	Confidence level [%]	Human motion rate accuracy [Hz]	Accuracy of positioning estimate by sensing (for a target confidence level)		Accuracy of velocity estimate by sensing (for a target confidence level)		Sensing resolution		Max sensing service latency[ms]	Refreshing rate [s]	Missed detection [%]	False alarm [%]
				Horizontal [m]	Vertical [m]	Horizontal [m/s]	Vertical [m/s]	Range resolution [m]	Velocity resolution (horizontal/ vertical) [m/s x m/s]				
Synchronous Heartbeat Measurements in Medical Care Units	Indoor	99.9	0.003 NOTE 1	N/A	N/A	N/A	N/A	N/A	N/A	100 ms	1 s	< 0.01 % NOTE 2	< 0.01 % NOTE 2

NOTE1: Norm DIN EN 60601 defines the requirement of the measurement of a heartbeat within +/- 75ms around the actual heartbeat (i.e., 0.0317 Hz considering heart rates as low as 40 bpm) [28] . To be competitive with ECG measurements, human motion rate accuracy should be significantly more precise in medical care units (assuming a factor of 10).

NOTE2: Minimum false alarms are required so that healthcare professionals trust the continuous contactless heart rate monitoring system in the palliative care unit, where patients may suddenly be in critical situation [3] .

8. Immersive & Ubiquitous Treatment

In this section, we outline use cases that fall within the Immersive & Ubiquitous Treatment use case cluster. The identified use cases in this area are Immersive XR-based Self Attachment Therapy and Continuous Secure Remote Health Data Collection.

8.1. Immersive XR-based Self Attachment Therapy

Description

According to the 2022 Global Burden of Disease survey, mental diseases have been one of the top 10 main causes of burden1 globally since 1990 [35]. With the onset of the COVID-19 pandemic, there has been a significant negative impact on the global population's mental health condition due to a variety of environmental stimuli [36], with the effect in the UK being most severe among the 18-34 demographic group but visible in all age the population [37]. One approach that has shown promise in treating mental health issues in pilot study is the Self-Attachment Technique (SAT) [38]. Immersive Virtual Reality has been explored to enhance the efficacy of this psychotherapeutic treatments [39] [5,6,7]. Within this framework, disorders such as chronic anxiety and depression are traced back to quality of individual's attachment with primary caregiver during childhood. XR user's capacity for self-regulation of emotion are enhanced by means of simulating a photo-realistic version of the user's childhood avatar and rich interactions with said avatar. XR user interacts positively with childhood avatar and improves secure attachment by repetitive secure interactions.

Pre-conditions

Base station is an outdoor macro cell. XR Headset is a UE with ISAC sensing capabilities to record sensing data of user and environment. XR Headset is not a rendering device. Application server is a rendering device.

Service Flows

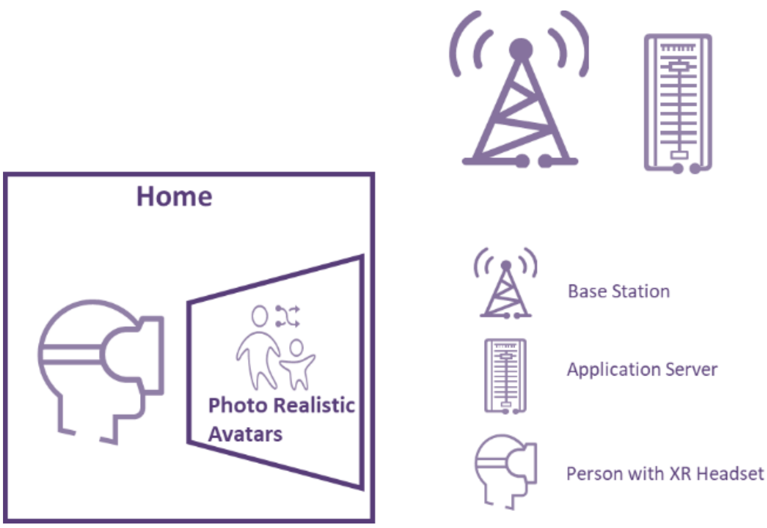


Figure 9. Illustration for Immersive XR-based Self Attachment Therapy Use Case

Step 1. XR user will start self-attachment therapy from home. XR device sends request to Base Station to initiate an immersive treatment service.

Step 2. Base station receives request and configures XR device to sense XR user facial expression and local environment with 3GPP sensing in a privacy preserving way.

Step 3. XR transmits wireless signals to produce sensing data of the facial expression and relevant environment information of XR user.

Step 4. XR device computes a facial encoding of the XR user and communicates it to Base Station. Base station communicates facial encoding to application server. Application server may be located in-network or may be a 3rd Party Trusted application.

Step 5. Based on the received facial encoding, application server computes a photorealistic childhood avatar version of user together with additional information to simulate a desired environment. Additional information (such as audio) help application server build/train a customized large language model tailored for the user.

Step 6. Base station communicates detailed real-time rendering of photorealistic avatar to XR user as well as real-time prompt responses from the customized large language model in application server.

Step 7. Changes of emotional (e.g., voice tone, facial expressions, motion gestures) of XR user are encoded and communicated to base station, and thereafter forwarded to application server.

Step 8. Application server computes respective nuanced emotional responses from childhood avatar and are communicated to XR user. It also includes photorealistic simulation of the desired environment of the user.

Post-conditions

XR user is involved in a protocol that describes patterns of interaction between adult-self (XR user) and inner-child (childhood avatar version of XR user) that foster secure attachment [40].

Existing features partly or fully covering the use case functionality

- Mobile Metaverse Services requirements in TS 22.156.
- Use case on Gesture Recognition for Application Navigation and Immersive Interation in TR 22.837.

Potential new requirements needed to support the use-case

The network shall be able to provide 3GPP sensing data to trusted 3rd-party applications.

Based on operator policy, the 3GPP network shall support the provision of predicted quality of service/link quality information for a requested area based on 3GPP and non-3GPP sensing data.

Key Performance Indicators

The sensing KPIs for the Gesture Recognition for Immersive XR-based Self Attachment Therapy are:

Scenario	Sensing service area	Confidence level [%]	Motion Rate Accuracy [Hz]	Accuracy of positioning estimate by sensing (for a target confidence level)		Accuracy of velocity estimate by sensing (for a target confidence level)		Sensing resolution		Max sensing service latency[ms]	Refreshing rate [s]	Missed detection [%]	False alarm [%]
				Horizontal [m]	Vertical [m]	Horizontal [m/s]	Vertical [m/s]	Range resolution [m]	Velocity resolution (horizontal/ vertical) [m/s x m/s]				
Facial Gesture Recognition for Immersive XR-based Self Attachment Therapy	Indoor/ Outdoor	N/A	N/A	FFS	FFS	0.1	0.1	0.001 NOTE2	[0.3]	<100	< 0.1	FFS	FFS

NOTE1: Sensing requirements are extended based on use case on Gesture Recognition for Application Navigation and Immersive Interation in TR 22.837 [4].

NOTE2: To properly characterize user's facial gestures, 3GPP sensing should at least have similar sensing resolution as pixel camera. Assuming a 1920x1080 pixel camera is hypothetically placed 1 meter right in front of the user, the horizontal width is 2 × (1m × tan(90/2)) = 2m, the range resolution ≈ 2m / 1920p ≈0.00104 m/p.

The communications KPIs for the Immersive XR-based Self Attachment Therapy are:

Scenario	Availability: target value [%]	Reliability: Mean Time btw Failure	Direction	e2e latency	Bit rate (Uplink)	Bit rate (Downlink)	Message Size [byte]	Transfer Interval	UE speed	# of active UEs	Service Area
Immersive XR-based Self Attachment Therapy	99.9	>> 1 month (< 1 year)	Downlink	10 ms NOTE3	[500] Mbits/s NOTE1	[200-2000] Mbits/s NOTE1	FFS NOTE4	< 20 ms / 100 km^2	< 12.8 km/h NOTE2	< 100 per 1-10 km^2	Residential

NOTE1: KPIs extended from Mobile Metaverse Services (Viewports streaming from rendering device to AR glasses through direct device connection) in TS 22.156

[41]. For Uplink, >500 Mbits/s may be expected. The assumption is that XR device does not have rendering capabilities. Application server performs rendering and hosts personalized intelligence of user avatar.

NOTE2: The average human running speed is approximately 12.8 km/h.

NOTE3: Includes uplink and downlink delay between XR device and application.

NOTE4: Dependent on the video/audio resolution and 3GPP sensing representation

8.2. Continuous Secure Remote Health Data Collection

Description

Currently, medical treatment decisions are made based on treatment results on a large number of similar patients (i.e., evidence-based medicine). The limitations of said approach are twofold: a) the process of generating medical evidence is lengthy and costly, b) generalized treatments may not account for individual health characteristics of a patient. The proliferation of eHealth wearables such as fitness trackers and smartwartches together with ubiquituous connectivity by future 6G system provides the opportunity to collect continuous data points associated to the health state of patients with a common known health state (e.g., a specific disease). Said health information is fed to patient digital twin models in real-time with powerful secure- and privacy-preserving AI/ML methods.

Pre-conditions

Base station A is an outdoor macro cell deployed in a rural environment. Constellation of NTN nodes (low-earth orbit satellites, UAVs or a high-altitude platform station) provides connectivity services to remote regions where connectivity of terrestrial network is limited (e.g., mountains/forest. Bob and Ellen are persons with a common pre-existing medical condition (e.g., diabetes) which use eHealth wearables. Infrastructure at hospital collects medical states of Bob and Ellen in real-time. Bob and Ellen health state is twinned by digital twin models residing in hospital.

Service Flows

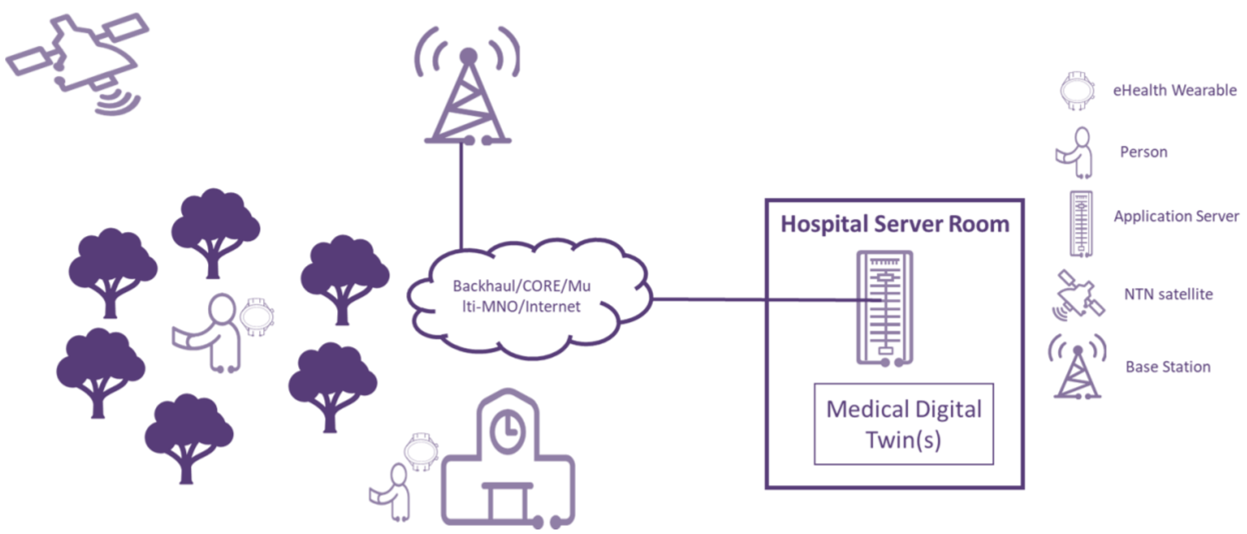


Figure 10. Illustration for Continuous Secure Remote Health Data Collection

Step 1. Bob does a hike near his hometown and Ellen takes a walk in her local town. Both Bob and Ellen are connected to terrestrial network (i.e., base stations).

Step 2. eHealth wearable worn by Bob and Ellen transmits continuous health data points to Base Station. Said application data traverses to the application server at hospital via the 3GPP network.

Step 3. Additionally to health realted data, environmental data alike are transmitted which provide contextual information for the analysis of health data (e.g. slope of a way, altitude, temperature, etc.)

Step 4. Upon reception of medical information from Bob and Ellen, patient digital twin model(s) deployed at application server are adapted to replicate Bob and Ellens real-time health state.

Step 5. As Bob walks deeper into the forest, connectivity is completely lost due to a coverage hole of the terrestrial network as there are mountains in the vicinity. A connection reestablishment/handover procedure is established.

Step 6. NTN satellite(s) belonging to given constellation act as a base station to provide complete or partial direct radio access to eHealth wearable worn by Bob.

Step 7. eHealth wearable timely transmits continuous health data points to NTN satellite(s) belonging to a given constellation (acting as a independent base station). NTN satellite also acts as a backhaul and forwards information to application server via the terrestrial mobile network.

Step 8. Upon reception of continuous health data points, application server at hospital (where the medical digital twins are deployed) triggers an accurate proactive action (e.g., walk at a slower pace) to be delivered to Bob.

Step 9. Application server communicates proactive action via the network. At the last mile, NTN satellite(s) reliabily communicate accurate proactive action to Bob.

Post-conditions

Information relevant to medical state of Bob and Ellen are continuously collected without interruption by application server residing at hospital. Digital twin models are updated to replicate health state of Bob and Ellen. Proactive action is timely and reliably communicated to Bob wherever he is located.

Existing features partly or fully covering the use case functionality

NR NTN supports downlink coverage enhancements both at FR1 and FR2 (with transparent and regenerative satellite) TR 22.822,

TS 38.101-5 “NR; User Equipment (UE) radio transmission and reception; Part 5 Satellite Access Radio Frequency (RF) and performance requirements”.

Potential new requirements needed to support the use-case

3GPP system should have enhanced mobility management capabilities between NTN-TN and NTN-TN mobility coordination including redundancy to improve service continuity.

The 6G system shall enable reduced capability UEs (RedCap) access 3GPP network through NTN nodes (e.g., LEO satellites) with global roaming and coverage.

Key Performance Indicators

Scenario	Availability: target value [%]	Reliability: Mean Time btw Failure	e2e latency	Direction	Bit rate	Message Size [byte]	Transfer Interval	UE speed	# of active UEs	Service Area
Continuous Secure Remote Health Data Collection	> 99.9999 NOTE1	>> 1 month (< 1 year)	< 100 ms	Uplink/Downlink	<1 Mbit/s NOTE2	~80 NOTE2	< 20 ms 100 km^2	< 12.8 km/h NOTE3	< 1000 per 10 km^2	Regional

NOTE1: Significant reliability is required to capture continuous and real-time changes in health states of users independent of their location. The requirements point into the direction of global coverage with 3GPP connectivity (terrestrial and/or non-terrestrial.

NOTE2: Narrowband service such as continuous measurements of vital sign measurements (e.g., heart rate) and emergency call are covered with requirements.

NOTE3: The average human running speed is approximately 12.8 km/h.

9. Medical Data & Model Sharing

In this section, we outline use cases that fall within the Medical Data & Model Sharing use case cluster. The identified use cases in this area are Exchange of 3GPP sensing model/data associated with Medical Information and Exchange of Medical AI/ML Model.

9.1. Exchange of 3GPP sensing model/data associated with Medical Information

Description

3GPP system is expected to sense states (e.g., position, velocity and orientation) of passive objects (e.g., unequipped/equipped patient) as well as provide remote sensing data to compute medical relevant health of persons especially in mobile environments. Such health sensitive information is relevant for healthcare entities such as hospital and/or health ministries. The provisioning of 3GPP sensing data associated to health information is useful to support healthcare personnel in hospital environments or pandemics. 3GPP sensing data associated to health information belonging to real patients would be used by a trusted healthcare entity to compute relevant health parameters. The communication of 3GPP sensing data associated to health information of persons should be communicated to trusted healthcare entities in a secure and in a privacy preserving way.

Pre-conditions

3GPP system has the capability to perform 3GPP sensing with UE-based and gNB-based sensing. Sensing Function to compute 3GPP sensing result (e.g., medically relevant health information) with 3GPP sensing data associated to health information can be located at trusted application server in hospital premises or 3GPP system. Local health personnel have an agreement with owner of TRPs/UEs to provide 3GPP sensing to sense medical relevant data.

Service Flows

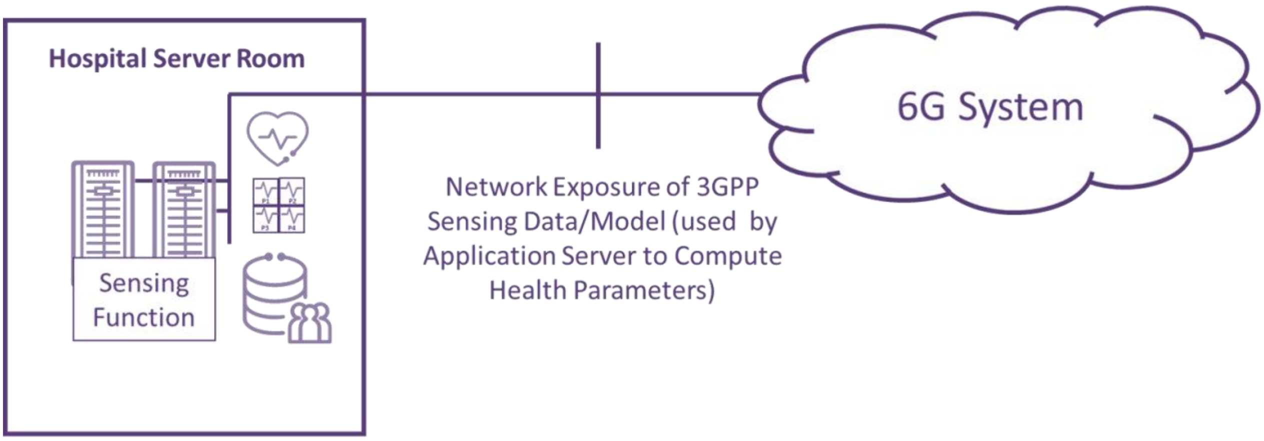


Figure 11. Illustration for Exchange of 3GPP sensing model/data associated with Medical Information Use Case

Step 1. Sensing Function deployed in application server in hospital server room requests a 3GPP sensing sensing service associated to medical data of people (i.e., with a specific set of requirements in the sensing request).

Step 2. 3GPP system performs 3GPP sensing to derive raw sensing data associated with medical data.

Step 3. Subject to service request, 3GPP system exposes pre-processed/postprocessed sensing data (or sensing result) via an interface with a predefined set of rules, service discovery, authentication and security procedures.

Step 4. Novel interface between healthcare entity and 3GPP system invokes relevant network procedures for authentication, security, privacy and service discovery.

Step 5. Once network procedures that guarantee security of the 3GPP sensing data/result associated to medical data are executed, 3GPP system communicates 3GPP sensing data/result to healthcare entity. Optionally, if 3GPP system communicated pre-processed sensing data, 3GPP system may communicate a sensing function/model allowing third-party 3rd party application (e.g., healthcare entity) compute relevant health parameters on-premise.

Post-conditions

3GPP sensing data associated to medical data is exposed to trusted health entity in a secure, privacy-preserving way.

Existing features partly or fully covering the use case functionality

There are no 5G/5G-A system features that partially or fully cover required use case functionality.

Potential new requirements needed to support the use-case

Subject to operator or service request and user's consent, 3GPP system shall provide mechanisms to protect identifiable information of 3GPP sensing results (e.g., related to medical information of users) from eavesdropping.

Subject to operator or service request, 3GPP system shall provide sensing function/model (e.g., AI-ML model) to trusted 3rd-party application (e.g., healthcare entity) to compute sensing result based on pre-processed/post-processed 3GPP sensing data, contextual information and/or non-3GPP sensing data.

Subject to operator or service request, 3GPP system shall provide mechanisms to support encryption, integrity protection, privacy of sensing function/model communicated to 3rd-party application.

9.2. Exchange of Medical AI/ML Model

Description

The mobility of mobile robots implies medical AI/ML models will have to be communicated wirelessly. The reliable and secure wireless communication of medical AI/ML models to mobile robots will be crucial due to the criticality of their tasks and improved mobility capabilities. In response to task and environment change, mobile robots might need to switch medical AI/ML model. The importance of having a medical task-specific model cannot be highlighted enough, since generation of inaccurate or misleading health predictions in a healthcare context is unacceptable. Moreover, in scenarios, where the infrastructure connectivity may become unavailable or a significantly lower communication latency is required, a mobile robot (or, medical IoT device) will have to communicate AI/ML models with direct communication (i.e., sidelink) to another mobile robot. The wireless exchange of medical AI/ML models should be real-time, standard- and regulatory-compliant. There exist application layer protocols that facilitate the exchange of medical data or models. One example is the Fast Health Interoperability Resources (FHIR) [18], a standard for exchanging healthcare information among healthcare entities (hospitals, mobile robots or patient's mobile app). Lower layers will have to provide a communication service that complies with such application layer protocols. The exchange of medical AI/ML model should also abide to regional regulation on AI [42].

Pre-conditions

Mobile robots have autonomous navigation and manipulation capabilities. Mobile robots have direct and network communication capabilities. Local healthcare entity has an agreement with owner of TRP/UEs to provide communication. Mobile Robots have positioning and 3GPP sensing capabilities. A customer premise equipment (CPE) is deployed indoors and a macro Base station is deployed outdoors. The macro Base Station can provide configuration to CPE.

Service Flows

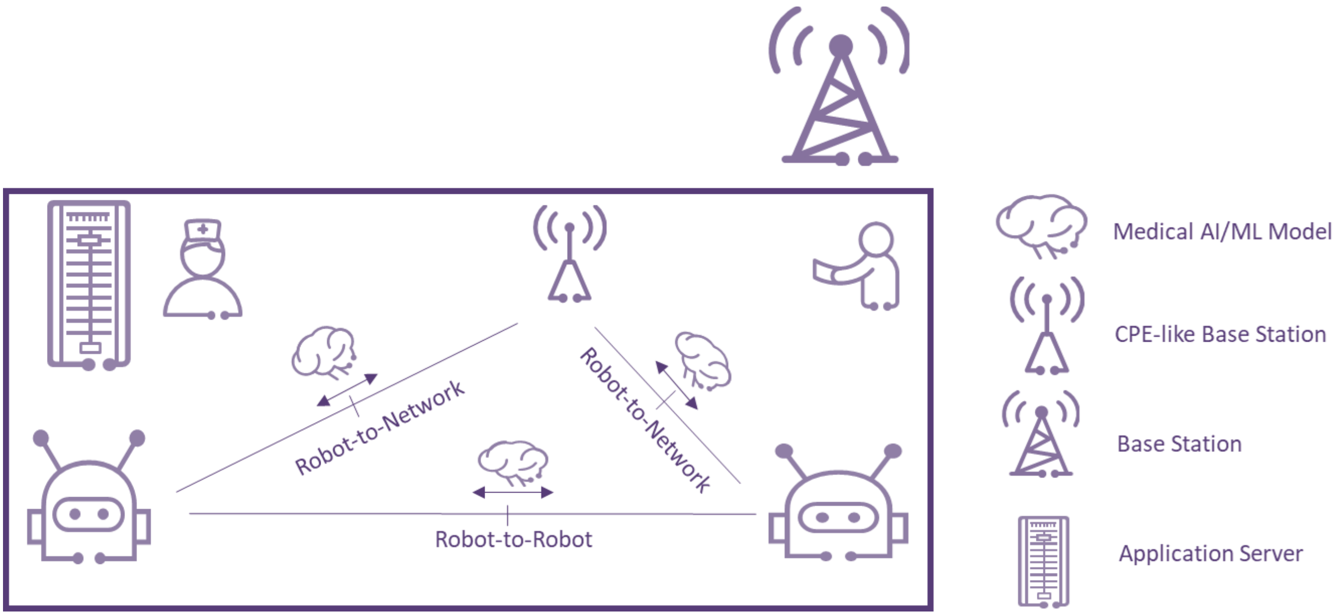


Figure 12. Illustration for Exchange of Medical AI/ML Model Use Case

Step 1. Mobile Robot X has a specific medical AI/ML model (e.g, an LLM fine-tuned for the medical domain) and moves to room A.

Step 2. Mobile Robot Y in room A requires the medical AI/ML model X to perform caregiving task with a patient Bob. Mobile Robot Y becomes aware of the mobile robot X and has limited connectivity with the infrastructure.

Step 3. Mobile Robot Y upon becoming aware of Mobile Robot X, sends a communication service request to Mobile Robot X to initiate an extremely high data rate and reliable communication in the sidelink (i.e., robot to robot communication). The wireless communication should be resilient against eavesdropping with powerful security methods.

Step 4. Mobile Robot X acknowledges request and provides the communication service to communicate the medical AI/ML model through the sidelink communication interface to Mobile Robot Y. Alternatively, if the wireless infrastructure is available and latency requirement is not restrictive, the BS may provide the wireless communication service with a first hop in the uplink and another hop in the downlink.

Step 5. Upon reception, Mobile Robot Y acknowledges the secure reception of medical AI/ML model.

Post-conditions

Mobile Robot Y using its medical AI/ML model executes its caregiving task successfully with patient Bob.

Existing features partly or fully covering the use case functionality

TS 22.261 Clause 6.40 requirements on AI/ML model transfer.

Potential new requirements needed to support the use-case

Subject to operator policy, user's consent and national or regulatory requirements, the 3GPP system shall provide the capability of exposing configuration and/or performance information about a medical AI/ML model (e.g., model accuracy, complexity and supported medical caregiving tasks and applications) to UEs (i.e., mobile robots).

Subject to operator policy, user's consent and national or regulatory requirements, the 3GPP system shall support a dedicated security and privacy-preserving encription method for extremely sensitive information such as medical AI/ML model communication through the radio communication interface (uplink, downlink (Uu) or sidelink (PC5)).

Subject to operator policy, user's consent and national or regulatory requirements, the 3GPP system shall support the means to support the configuration of QoS (e.g., latency, reliability, data rate) of the communication path using either direct device-to-device or network infrastructure communication, and select dynamically based on expected QoS performance.

Subject to operator policy, user's consent and national or regulatory requirements, the 3GPP system shall support the means to support the configuration the communication KPIs across the service area or a target "information shower" service area (intended to communicate an extreme amount of information in a short amount of time).

Key Performance Indicators

The communication KPIs to support the use case are:

Profile	Characteristic parameter									
	Communication service availability: target value in %	End-to-end latency: maximum	Bit rate	Direction	Message Size [byte]	Reliability Model Weight Factors	Reliability Model Information (e.g., Model Topology, performance on tasks, prompt)	UE speed (km/h)	# of UEs connection	Service Area
Exchange of Medical AI/ML Model (NOTE 2)	> 99,999	1 s	~ [5.6] Gbit s/s NOTE 1	Sidelink/Downlink NOTE 2	Depends on size of medical AI/ML model. NOTE 3	99.9%	99.999%	< 20	1000/km^2	Indoor environments including Deep Indoor. NOTE 4

NOTE 1: Assuming 10x model compression for 7 Billion parameter Med-Alpaca LLM model [30].

NOTE 2: Also applicable for uplink (using network infrastructure as relay).

NOTE 3: Open source eHealth LLMs such as Med-Alpaca and ClinicalCamel require 7 Billion parameters and 70 Billion parameters respectively [30] .

NOTE 4: "deep indoor" term is meant to be places like e.g. elevators, building's basement, underground laboratories of hospital

10. Conclusion, recommendations and next steps

The present whitepaper elaborates on the potential of the future 6G system in the healthcare domain. After outlining the healthcare sector's challenges, a vision based on model-based medicine is described as a key potential paradigm to tackle said challenges. Through discussions with different stakeholders from the medical domain, industry and academia, we describe a series of use cases that can enable the model-based vision. The use cases belong to the following use case clusters: Medical Robotic Applications, Vital Sign Wireless Sensing, Immersive & Ubiquitous Treatment and Medical Data & Model Sharing. For each use case, functional and key performance indicators in terms of communication, sensing and AI/ML support are identified. From this analysis of use cases, we provide initial guidance for the technology development of the upcoming 6G system to deliver enhanced sensing, connectivity and intelligence services tailored for the requirements of the medical domain. Future instalments of one6G whitepapers will consider further one6G eHealth use cases.

The recommendations from the analysis in this white paper are two-fold: firstly, the use cases presented in this document should continue to be refined with the aim of submitting said eHealth related use cases to SDOs, such as 3GPP SA1 or ETSI. Secondly, there are other considerations related to ethics, sustainability and safety that need to be further analysed for identified eHealth use cases with the different stakeholders from the medical domain. In this direction, we performed an initial analysis of the risks and countermeasures per use case. We also considered sustainability aspects such as environmental and societal impact per use case cluster. Relevant stakeholders from the medical domain, industry and academia shall further collaborate to determine the depth of ethical requirements for 6G.

The different technology features of the future 6G system will be able to flexibly meet identified performance requirements in terms of communication, sensing and computation. Beyond performance requirements, a detailed analysis of risks and countermeasures compliant to medical device regulation and relevant standards will benefit the potential societal value that future robust network medical devices (including medical robotics) and network infrastructure can bring. In summary, it is recommended that future work can consider and build upon this whitepaper to work towards clear enhancements of the 6G system for the healthcare sector of the future.

To effectively understand the intersection of medical and mental health with Information and Communications Technology (ICT), we recommend collaborative projects and platforms that bring together diverse stakeholders from healthcare, academia and industry. This collaborative approach fosters cross-disciplinary knowledge exchange, enabling medical and mental health experts to leverage the innovative potential of ICT research, while simultaneously providing ICT researchers with valuable insights into the complexities of healthcare needs. Collaborative platforms such as the one6G association accelerate the development of impactful solutions that address critical challenges in both fields.

Annex A – Potential Risks and Countermeasures per Use Case

In the present annex, we describe a potential risk and potential countermeasures for undesirable what-if scenarios in the described use cases. Some of the risks are described as specified by DIN/ISO 13482 [23] and IEC 80601 [28] standard documents.

Cluster	Use Case	Potential Risks & Hazards	Potential Countermeasures
Medical Robotic Applications	Telerobotic Diagnostic Examination	Unintended robot motion	- A protective stop may be proactively triggered by 6G system with the assistance of 3GPP infrastructure sensing
	Context-sensitive Mobile Robots in a Nursing Ward	Incorrect autonomous decisions and actions	- Trustworthiness (or level of uncertainty) of different decisions/actions shall be quantified by a network entity. If uncertainty above acceptable levels, additional information/alternative approaches shall be used to resolve decision (e.g., another sensing modality to perform sensor fusion) and execute decision
	Dynamic Reconfiguration of Rehabilitation Robotics	Unforeseen/unmodelled interference/s between different components of the exoskeleton during self-reconfiguration, causing obstruction during mode-switching (i.e. between dynamic and static rehabilitation) and potentially having a pernicious effect on the robots' joints/actuators and the user's safety. (i) low (ii) med	- Develop a simulation model of the exoskeleton based on its URDF file, which will enable one to exhaust all the different configuration-switching possibilities, ensuring that none of these transitions induce undesirable joint interference and, potentially, unsafe operation.
	Assisted Living with Companion Mobile Robots	Lack of awareness of robots by humans	- Warning lights or wireless signal to werable devices shall be provided to alert users and third parties about the presence of the personal care robot (e.g., for visual/hear impaired human)
	Medical Goods Logistics with Robotic Fleets	Localization and navigation errors	- Constant monitoring of confidence of localization/positioning results, 6GS trigger robot to safe state in case of unreliable localization services or trigger sensor fusion as well as increased refresh rate
Vital Sign Wireless Sensing	Vital Sign and Occupancy Detection in Hospital Emergency Waiting Room	Electromagnetic interference	- Mobile robot and infrastructure sensing shall have robust sensing interference cancellation algorithms
	Vital Sign Detection in medical care units	Electromagnetic interference	- Mobile robot and infrastructure sensing shall have tight coordination between sensing transmitters to minimize interference

Cluster	Use Case	Potential Risks & Hazards	Potential Countermeasures
Immersive & Ubiquitous Treatment	Immersive XR-based Self Attachment Therapy	QoE insatisfaction (e.g., dizziness)	- 6GS shall objectively monitor/predict QoE for the immersive treatment service and adapts its communications service
	Continuous Secure Remote Health Data Collection	Lack of service continuity	- 6GS shall notify the application the absence of acceptable service at a specific geographical area or coordinate radio access nodes to provide service in said area
Medical Data & Model Sharing	Exchange of sensing model/data associated with Medical Information	Eavesdropper of medical information	- 6GS shall provide means to detect eavesdropper and potentially adapt its service based on the eavesdropper characteristics
	Exchange of Medical AI/ML Model	Interruption of service continuity	- 6GS shall use 3GPP sensing service to assist the proactive adaption of the communication service and avoid interruption

Annex B – Potential societal, environmental and economic impacts per Use Case Cluster

In the present annex, we describe initial potential societal, environmental and economic impacts of the identified 6G use case clusters.

<table>
<tr><th colspan="2">Potential societal, environmental and economic impacts</th></tr>
<tr><td>Societal and Environmental impact including energy consumption</td><td>
Medical Robotic Applications:
Societal Impact:
• Address the staff shortage by complementing healthcare personnel with performant and cost-effective medical robotics
• Increase working efficiency of tasks that medical domain considers burdensome
• Improve access to healthcare diagnostic services
• Personalized and adaptive rehabilitation robotics improve rehabilitation therapies post-accident of patients
• Ultimately, reduce treatment costs and improve quality of healthcare services.
Environmental Impact:
• Mobile robots reduce energy consumption by performing computational offloading to infrastructure
• Infrastructure and mobile robots perform 3GPP radio-based sensing reusing hardware for 3GPP communication. Need to study energy efficiency of the integrated communication and sensing operation to assess carbon footprint.
Vital Sign Wireless Sensing:
Societal Impact:
• Increase human safety (by increasing health monitoring) and improve quality of life of patients by enabling free movement while keep essential vital sign overwatch
Environmental Impact:
• Infrastructure or mobile robot perform vital sign wireless sensing reusing hardware for communication. Need to study energy efficiency of the integrated communication and sensing operation
Immersive & Ubiquitous Treatment:
Societal Impact:
• Address global mental health challenges, where immersive treatment (e.g., self-attachment therapy) may be provided ubiquitously.
• Continuous monitoring of vital health parameters potentially everywhere.
Environmental Impact:
• More XR and health monitoring devices widely deployed. Need to optimize energy efficient communication to reduce carbon footprint.
Medical Data & Model Sharing:
Societal Impact:
• Increase human safety (by increasing health monitoring) and improve quality of life of patients by enabling free movement while keep essential vital sign overwatch
• Medical robotics applications tailored for the caregiving tasks/patients.
• Need to guarantee stringent privacy requirements of 3GPP sensing data, sensing results, medical AI/ML model.
Environmental Impact:
• Extreme data rates required for the exchange of medical AI/ML models may increase energy consumption of devices. Energy efficient methods are necessary to reduce said increase.
</td></tr>
</table>

Potential societal, environmental and economic impacts	
Technology gap relative to 5G	• 3GPP radio-based situational awareness sensing • Vital sign sensing with 3GPP radio-based sensing • Enhanced AI/ML support (split inference and model transfer), • More granular QoS differentiation for multi-modal data • Extreme rates and extreme service availability Sensing-assisted Communication • Tighter NTN and TN integration towards ubiquitous connectivity
Impact on existing network infrastructure	Extreme data rates, hyper-reliable and low latency communication, extremely high service availability, high-precision positioning and detailed sensing capabilities from environment, privacy, sustainability requirements are main requirements that are driving technology development
Feasibility relative to physical and economic constraints.	The services may arise in 5-10 years, therefore a long-term use case.
Industry growth opportunity [< 10% (low), <50% (mid) >50% (high)]	>50% (low in short term and high in long term)
Disruptive impact on 6GS	Medical Robotic Applications: Increased network load as well as reduced user terminal energy consumption Vital Sign Wireless Sensing: Enhanced 3GPP sensing functionality as well as new interfaces that guarantee security and privacy Immersive & Ubiquitous Treatment: Increased network capacity with terrestrial and non-terrestrial networks Medical Data & Model Sharing: implementation of new protocols and algorithms to guarantee security and privacy (especially in post-quantum age)
SDO's related features and activities	ITU-T, 3GPP, ETSI, ISO/DIN, IEEE SA

11. References

[1] one6G, “6G & Robotics: A Methodology to identify Potential Service Requirements for 6G-empowered Robotic Use Cases,” Nov 2023.

[2] one6G, “6G & Robotics: Identifying Use Cases and Potential Service Requirements - Methodology and Examples,” June 2024.

[3] 3GPP, “TR. 22.104 "Service Requirements for cyber-physical control applications in vertical domains",” 2023.

[4] 3GPP, “TR 22.837: Feasibility Study on Integrated Sensing and Communication (Release 19),” 2023.

[5] 3GPP, “TR 38.852, Release 18 Study on traffic characteristics and performance requirements for AI/ML model transfer in 5G Systems (5GS),” 2023.

[6] “Sharelock in Health: How artificial intelligence may improve quality and efficieny, whilst reducing healthcare costs in Europe,” PwC, 2017. [Online]. Available: http://stats.oecd.org/index.aspx?DataSetCode=HEALTH_STAT#.

[7] PwC, “Digitalization in hospitals,” 2022.

[8] L. a. n. S. F. Hood, “Predictive, personalized, preventive, participatory (P4) cancer,” Nature Reviews Clinical Oncology, pp. 184-187, 2011.

[9] R. Horwitz, A. Hayes-Conroy, R. Caricchio and B. Singer, “ From evidence based medicine to medicine based evidence.,” The American journal of medicine, vol. 130, no. 11, pp. 1246-1250, 2017.

[10] I. M. D. &. Insights, “Leveraging wearables and the Internet of Things to disrupt, transform and unlock value - Predictions on the future of wearables,” 2017. [Online].

[11] M. Ghassemian, M. Smith-Creasey and M. Nekovee, “Secure Non-Public Health Enterprise Networks,” in IEEE International Conference on Communications Workshops (ICC Workshops), 2020 .

[12] E. Commision, “Population projections in the EU,” March 2023. [Online]. Available: https://ec.europa.eu/eurostat/statistics-explained/index.php?oldid=497115.

[13] one6G, “6G & Robotics: A Methodology to Identify Potential Service Requirements for 6G-empowered Robotic Use Cases,” one6G, 2023.

[14] K. S. e. al., “A Contactless System for Continuous Vital Sign Monitoring in Palliative and Intensive Care,” in 2018 Annual IEEE International Systems Conference (SysCon), 2018.

[15] R. P. Ana Koren, “Standardizing Personal Medical Data in 5G and 6G Era,” in International Symposium on Wireless Personal Multimedia Communications (WPMC), 2023.

[16] S. F. e. al., “Causal machine learning for predicting treatment outcomes,” Nature Medicine, vol. 30, pp. 958-968, 2024.

[17] “Health Information Privacy,” [Online]. Available: https://www.hhs.gov/hipaa/index.html.

[18] H. L. S. I. (. Standard, “Fast Health Interoperability Resources (FHIR),” [Online]. Available: https://hl7.org/fhir/2020Sep/index.html.

[19] T. K. A. M. T. M. a. T. I. T. Ito, “Virtual Reality Course Based on the SAT Counseling Method for Self-Guided Mental Healthcare,” in IEEE International Conference on Healthcare Informatics (ICHI), 2018.

[20] TUVSud. [Online]. Available: https://www.tuvsud.com/de-de/branchen/gesundheit-und-medizintechnik/marktzulassung-und-zertifizierung-von-medizinprodukten/mdr-medizinprodukteverordnung-eu.

[21] I. S. S. Association, “The Ethics Certification Program for Autonomous and Intelligent Systems (ECPAIS),” [Online]. Available: https://standards.ieee.org/industry-connections/ecpais/.

[22] one6G, “Prototying in 2023: Working Group 4,” 2023.

[23] D. E. ISO, “Robots and robotic devices –Safety requirements for personal care robots (ISO 13482:2014),” 2014.

[24] B. L., P. Schwingenschlogl, J. Hofmann, D. Wilhelm and A. Knoll, “Boosting the hospital by integrating mobile robotic assistance systems: a comprehensive classification of the risks to be addressed,” in Autonomous Robots, 2024.

[25] T. Wang, Y. H. Lin, E. Spyrakos-Papastavridis, S. Q. Xie and J. S. Dai, “Stiffness Evaluation of a novel ankle rehabilitation exoskeleton with a type-variable constraint,” in Mechanism and Machine Theory, 2023.

[26] NHS, “summitmedsci.co.uk,” [Online]. Available: https://summitmedsci.co.uk/2023/02/14/university-hospitals-dorset-pioneering-the-nhs-rehab-revolution-with-robotics/ .

[27] G. Durandau et al., “Voluntary Control of wearable robotic exoskeletons by patients with paresis via neuromechanical modeling,” Journal Neuroengineering Rehabilitation, vol. 16, p. 91, 2019.

[28] DIN, “Norm DIN 60601-1 DIN EN 60601-1 - Medical Electrical Equipment - VDE 0750-1:2022-11,” 2022.

[29] U. Nations, “World Population Ageing 2020 Highlights - Living arrangements of older persons,” Social Affairs PD, 2020.

[30] Y. Kim, X. Xu, D. McDuff, C. Breazeal and H. Park, “Health-LLM: Large Language Models for Health Prediction via Wearable Sensor Data,” in arxViv:2401.06866v1, 2024.

[31] L. Bernhard, A. F. Amalanesan, O. Baumann, F. Rothmeyer, Y. Hafner, M. Berlet, D. Wilhelm and A. Knoll, “Mobile service robots for the operating room wing - balancing cost and performance by optimizing robotic fleet size and composition,” International Journal of Computer Assisted Radiology and Surgery, vol. 18, pp. 195-204, 2023.

[32] D. E. ISO, “DIN EN ISO 3691-4 Industrial Trucks - Safety Requirements and Verification Part 4 - Driverless industrial trucks and their systems,” ISO, 2020.

[33] K. Shi, C. Will, T. Steigleder, F. Michler, R. Weigel, C. Ostgathe and A. Koelpin, “A Contactless System for Continuous Vital Sign Monitoring in Palliative and Intensive Care,” in Annual IEEE International Systems Conference (SysCon), 2018.

[34] C. Lhi, V. M. Lubecke, O. Boric-Lubecke and J. Lin, “A Review on Recent Advances in Doppler Radar Sensors for Noncontact Healthcare Monitoring,” IEEE Transactions on Microwave Theory and Techniques, vol. 61, no. 5, pp. 2046-2060, 2013.

[35] “Global, regional, and national burden of 12 mental disorders in 204 countries and territories,” The Lancet Psychiatry, vol. 9, no. (2), pp. 137-150, 2022.

[36] B. &. N. C. Pfefferbaum, “Mental health and the COVID-19 pandemic,” New England Journal of Medicine, vol. 383, no. (6), pp. 510-512, 2020.

[37] D. M., M. Daly, A. R. Sutin and E. Robinson, “Longitutidanl changes in mental health and the COVID-19 pandemic: evidence from the UK Household Longitudinal Study,” Psychological Medicine, vol. 52, no. (13), pp. 2549-2558, 2020.

[38] A. Edalat, “Computational Neurology and Psychiatry,” Self-Attachment: A Holistic Approach to Computational Psychiatry, vol. 6, pp. 273-314, 2017.

[39] I. Ghaznavi, U. Jehanzeb and A. Edalat, “Usability evaluation of an immersive virtual reality platform for self-attachment psycotherapy,” }.

[40] D. Cittern, A. Edalat and I. Ghaznavi, “An Immersive Virtual Reality Mobile Platform for Self-Attachment,” 2020.

[41] 3GPP, “TS 22.156 "Mobile Metaverse Service:Stage 1 (Release 19)",” 2024.

[42] IEEE, “IEEE SA ' AI in Mental Health for Today and Tomorrow: the IEEE Regulating AI in Digital Mental Health Forum,” [Online]. Available: https://standards.ieee.org/beyond-standards/ai-mental-health-forum-london/.

[43] A. Edalat, N. Polydorou, F. Ryan, B. J. Gilbert and D. Nicholls, “Proof of Concept for Efficacy of VR-based Self-Attachment Intervention in a Non-clinical Population,” 2022.

[44] J. Fuchtmann and B. R. Krumpholz, “COVID-19 and beyond: Development of a comprehensive telemedical diagnostic framework,” International Journal of Computer Assisted Radiology and Surgery, pp. 1403-1412, 2021.

Abbreviations

5G	5G Communication System
5G-A	5G-Advanced Communication System
6G	6G Communication System
AI	Artificial Intelligence
3GPP	3rd Generation Partnership Project
5GS	5G System
6GS	6G System
DIN	Deutsches Institut für Normung
FFS	For Further Study
ICT	Information Communications and Technology
ID	Identification
IEEE	Institute of Electrical and Electronics Engineers
ISO	International Organization for Standardization
ITU	International Telecommunications Union
KPI	Key Performance Indicators
LIDAR	Light Detection and Ranging
LLM	Large Language Model
ML	Machine Learning
NA	Not Applicable
NLP	Natural Language Processing
NR	New Radio
PC5	Sidelink communication interface
RRC	Radio Resource Control
SDO	Standardization Organization
SLAM	Simultaneous Localization and Mapping
SOBOT	Service Robot
TR	Technical Report
TS	Technical Specification
UC	Use Case
Uu	Uplink/Downlink communication interface
URDF	Unified Robot Description Format
WG	Working Group
WI	Working Item
VLM	Visual Language Model
XR	Extended Reality
XRM	XR and Media Services

Contributors

- Mohammad Shikh-Bahaei, Emmanouil Spyrakos-Papastavridis, *King's College London*
- Dirk Wilhelm, *Klinikum Rechts der Isar Technische Universität München*
- Fabian Michler, *Sykno GmbH*
- Abbas Edalat, Ye Xinyan, *Imperial College London*
- Thomas Neumuth, Tobias Pabst, *Innovation Center Computer Assisted Surgery, Universität Leipzig*
- Jesús Fernández Lozano, *University of Malaga*
- Ali Hessami, *Vega Global Systems*
- Fatih Cogen, *Turkcell*
- Gereon Hinz, *STTech GmbH*
- Albena Dimitrova Mihovska, *RDIC*
- Periklis Chatzimisios, *International Hellenic University*
- Jose Mauricio Perdomo, Mona Ghassemian, Daniel Gordon, *Huawei Technologies Duesseldorf*

info@one6g.org

@One6GGlobal

one6g.org