Large-scale trialing of the B5G technology for eHealth and Emergency domains

Andrea Di Giglio
TIM S.p.A.
andrea.digiglio@telecomitalia.it

Marco Laurino
National Research Council
marco.laurino@cnr.it

Giancarlo Sacco
Ericsson Telecomunicazioni S.p.A.
Giancarlo.sacco@ericsson.com

Gianna Karanasiou
WINGS ICT Solutions
gkaranasiou@wings-ict-solutions.eu

Sergio Berti
Fondazione G. Monasterio
berti@ftgm.it

Elisa Maiettini
Istituto Italiano di Tecnologia
elisa.maiettini@iit.it

Mara Piccinino
Ericsson Telecomunicazioni S.p.A.
mara.piccinino@ericsson.com

Vera Stavroulaki
WINGS ICT Solutions
veras@wings-ict-solutions.eu

Simona Celi
Fondazione G. Monasterio
celi77@ftgm.it

Nicolò Boccardo
Istituto Italiano di Tecnologia
nicolo.boccardo@iit.it

Paola Iovanna
Ericsson Telecomunicazioni S.p.A.
paola.iovanna@ericsson.com

Aruna Prem Bianzino
Universidad Carlos III de Madrid
abianzin@it.uc3m.es

Chiara Benvenuti,
National Research Council
chiara.benvenuti@cnr.it

Lorenzo Natale
Istituto Italiano di Tecnologia
lorenzo.natale@iit.it

Giulio Bottari
Ericsson Telecomunicazioni S.p.A.
giulio.bottari@ericsson.com

***Abstract*— 5G is being deployed and B5G connectivity is under study and standardization. Benefits brought by the 5G/B5G air interface are numerous and 5G is more than just an evolution of radio technology since it consists of innovative concepts: the application of network softwarization and programmability paradigms to the overall network design, the reduced latency promised by edge computing, or the concept of network slicing. These innovations open the door to new vertical-specific services, even capable of saving more lives. The paper describes four use cases to demonstrate the large-scale trialing of the B5G technology specifically devoted to eHealth and Emergency domains, by supporting the B5G applications in large-scale environments (e.g., hospitals) and bringing novel applications (e.g., Remote Proctoring and Smart Ambulance) and on societal benefits in eHealth and Emergency areas through the development of innovative B5G/6G applications. The work is a part of a more complete behavior, TrialsNet project, within SNS JU European Commission Programme, considering other field of application of B5G connectivity.**

Keywords—5G, B5G, eHealth, Emergency, Artificial Intelligence, Machine Learning

I. Introduction

5G technology brings faster and more reliable connectivity. TrialsNet [1] is going to play a role in the context of B5G technology and one of its goals is to demonstrate how B5Gadvancements have the potential to revolutionize healthcare delivery, making it more accessible, efficient, and personalized while improving patient outcomes and experiences. In this work, we consider four fields of applications:

- **Emergency**: 5G/B5G systems open a new possibility to mass causality incidents. In fact, current emergency services are based on predefined Emergency Action Plans, lacking the flexibility to address different dynamic plans and guidelines. Moreover, even though a massive number of sensors and connected devices such as smartphones, tablets, wearables, etc., are available on market, they are not currently used in emergencies. In the emergency context, an issue that remains open is represented by the identification of those who are in most need of medical attention, to prioritize resources. Similar concepts apply when rescuing a patient in a densely crowded area, where it is paramount to achieve very fast reaction times which can substantially improve the survival rate in these contexts.
- **Telemedicine**: 5G/B5G systems allow for medical images and other data to be transmitted quickly and accurately. So, it is possible to transmit data about a patient's health to healthcare professionals in real time, even in mobility situations, permitting pre-hospital identification of the correct diagnosis and management strategy in chest pain patients, which may lead to a better disease outcome.
- **Remote Monitoring**: 5G/B5G systems, together with AR/VR and telepresence technologies, represent a revolution in remote monitoring and proctoring in the interventional cardiology sector. In this way it may be possible, even in areas not equipped with departments for certain medical specializations, to be assisted by the specialized medical doctors', especially in the surgical field.
- **Control of Prosthesis**: A smart prosthesis is an application product that combines cognitive imaging and control technology, enabled by radio connectivity to allow a prosthetic device control system with AI technologies for reducing the need for explicit control by the user and thus their cognitive load for driving it.

In order to demonstrate large-scale trialing of the B5G technology in these fields, four Use Cases have been designed and will be implemented in the context of the TrialsNet project. They are detailed in the following sections.

II. Use cases

A. Mass Casualty Incident (MCI) and Emergency Rescue in Populated Area

The goal of this use case is to provide innovative solutions developed by the project for the most effective coordination operation of first responders (medical personnel, police, rescuers, etc.) in the context of i) triage and coordination of resources at the scene of MCI due to incidents such as

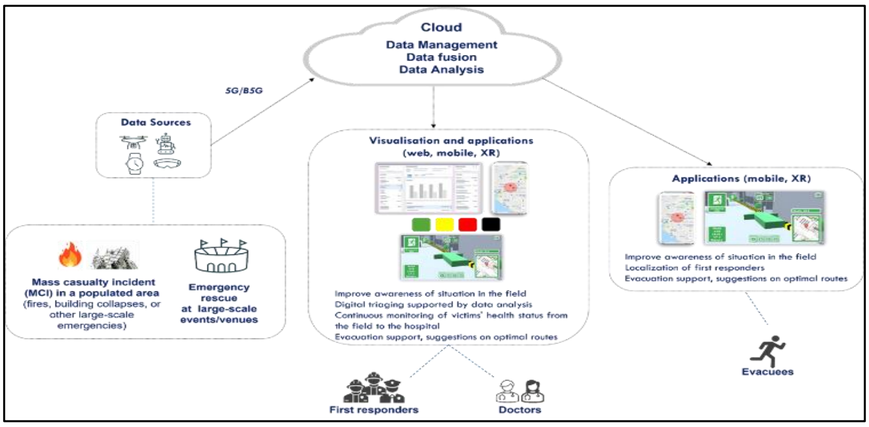

Fig 1. MCI and Emergency Rescue in populated area

earthquakes, fires, building collapses, and ii) emergency evacuation in a large, crowded venue, such as in the case of a sports event. Through this use case, innovative (also 6G-enabled) technologies will be demonstrated in a large-scale field exercise for more efficient communication between first responders and faster and more effective triage and pre-hospital treatment, and they will be compared to the baseline approach using traditional approaches/procedures.

Initially various data from the field are acquired via available data sources (e.g., video-streaming or image capturing from cameras on robots or drones). These data are analyzed to provide insights to first responders on the situation in the field (estimated number and location of victims, support for primary triaging, initial estimation on optimal evacuation routes). Information is displayed to first responders via an appropriate dashboard, while suitable XR applications will also be provided (especially for the evacuation case). For the MCI part, once responders have arrived in the field and have met victims, they can equip victims with wearable devices to collect vital signs. This information will be used, along with the assessment from the first responders, for the secondary triaging and the continuous monitoring of the health status of victims. Data from the scene and health data are transmitted and displayed continuously to remote first responders and medical experts via the dashboard (displaying the appropriate type of information to each user category). In the event of observed abnormalities either in the environment of the incident or in the vital sign values collected, notifications are sent to first responders or medical experts accordingly (remote and in the field) and alarms are raised to trigger the necessary actions, e.g., update the triaging assessment or update the evacuation routes. Notifications/alarms are raised in case something is not yet abnormal, but the data analysis of recorded values show a trend towards a potential problematic situation (e.g., increasing blood pressure which has not yet reached a certain threshold, but may still be worrying). For the MCI case, all data accompanies a victim from the field to the hospital, at which point the system can provide doctors with insights for the final triaging and on the best hospital treatment. In the evacuation scenario, an XR application will be provided for evacuees. This application will provide support on optimal evacuation routes to be followed.

The proposed application design is based on the STARLIT++ platform (an enhancement of the STARLIT platform [1]) and involves the deployment of devices such as robots or drones with the appropriate equipment (thermal cameras, sensors, etc.). The devices capture images, video, and other data, which are transmitted over 5G networks to a central platform for processing and analysis using AI models and techniques.

For the MCI case, devices will also comprise wearable devices for monitoring of vital signs, such as heart rate, oxygen saturation, body temperature, blood pressure, etc. The platform comprises AI powered mechanisms for providing insights on a range of factors (e.g., estimated number of victims, potential issues for first responders to address in the field, estimated location of users, user's vital signs evolution, forecasting of future issues and health emergencies, etc.). In addition, the routing algorithms to be developed for the calculation of the optimal evacuation routes, will be connected as a service to the STARLIT platform. A direct and continuous transfer of data is to be utilized, to make use of the latest updated information collected and to channel the generated information through the common applications/interfaces to be decided and defined for each scenario (e.g., a smart device or XR glasses, etc.).

Fig. 2. MCI and Emergency Rescue application design

To support the operation of smart service robots, a public 5G network located in Athens will be used, leveraging its high-speed connectivity, low latency, and wide coverage. Specifically, the network will use non-Standalone architecture (NSA) and operate at a frequency of 3.5 GHz. The allocated band for this network is 80-100 MHz. In addition, a private network infrastructure will be utilized prior to the use case implementation on the field. Fig. 3 depicts the architecture in a high-level manner.

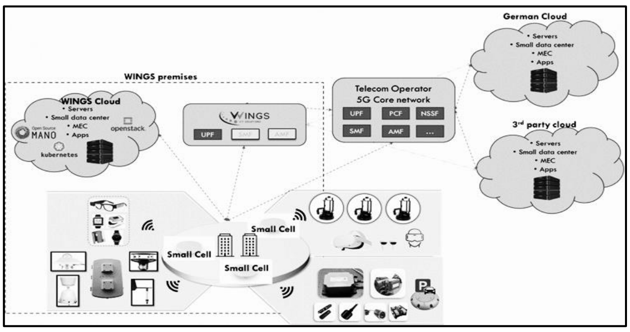

Fig. 3. WINGS architecture for experiments

The test will be also proven in Madrid, in the context of a massive sport event, using a 5G/B5G Ericsson Non-Public Network (NPN). All the experimental devices that will be used for the use case implementation in the venue will connect only to such NPN, while the commercial devices will use the public network. A diagram of the infrastructure is depicted in Fig.4.

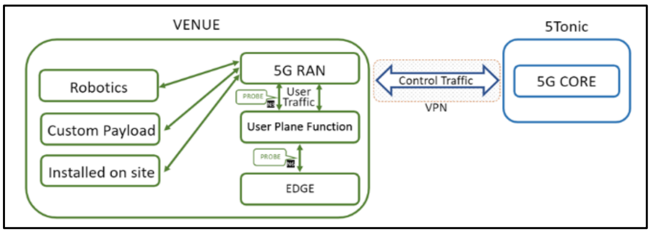

Fig. 4. UC6 NPN infrastructure

The Ericsson 5G NPN infrastructure is a distributed 5G Stand-Alone architecture (SA) network. The 5G SA architecture adopts the new concept of Service-Based interfaces [3]. This means that the Network Functions (NFs) that include logic and functionality for processing signaling flows are not interconnected via point-to-point interfaces but instead exposing and making available services to the rest of NFs. Thus, there is a separation that broadens the range of possible locations in which the network elements can be located. The Radio Access Network (RAN) and the User Plane Function (UPF) are installed at venue premises, while the rest of components of the 5G Core (5GC), the control plane components, are running on the 5Tonic infrastructure (Leganés, Madrid) [4]. This model is interesting because verticals do not need to have their own full 5G deployed, making the service a lot more cost-efficient for them. With this solution, the 5G RAN equipment splits the user plane traffic and the control traffic.

B. Remote Proctoring

Today, new cutting-edge technologies for telepresence can make remote proctorship just as effective as conventional proctor support to safely direct the surgery. In line with this, the final aim of the remote proctoring use case will be to demonstrate the possibility of ensuring a telepresence support in surgical field based on 5G wireless network and not by fully wired connection as currently done.

This use case will implement the remote proctoring activities in the field of interventional cardiology that will take place in two Italian hospitals located in Pisa and Massa (Italy) respectively. This use case will develop an E2E solution based on a telepresence platform that will enable a remote expert cardiologist in Pisa to efficiently join a proctored interventional session in Massa. In the trial, the expert proctor will be located at a central hospital hub site in CNR campus in Pisa. The remote hospital site in Massa will host the interventional catheterization training room where new trained clinicians will perform under the remote observation of the expert proctor. As illustrated in Fig.5, this use case aims to specifically deploy an indoor in-field cellular coverage network, based on a dedicated 5G network, for real-time remote proctoring applications to offer the best quality of connectivity. The remote proctor in central hospital hub will be equipped with a telepresence station to monitor and support the surgeons in surgery training room in the remote hospital via the telepresence system. This will enable the experienced proctors to supervise many surgical operations and, by means of wireless connectivity instead of cable one, has the advantage of being location-independent and, in a more general application, enables it to be a truly portable tool that expert proctors can use even outside of a specific hospital.

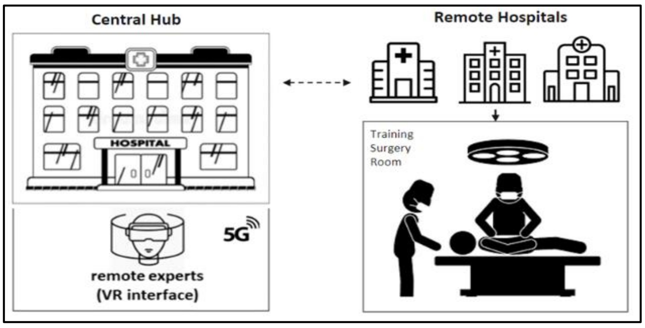

Fig. 5. Remote proctoring use case concept

The experiment implements two operational macro-modules, one operating in a remote hospital and the second one in the central hospital.

The macro-module in the remote hospital for surgery operating room will be constituted by i) a clinical-certified commercial telepresence system, constituted by acquisition tools and connection hub installed in the surgical room, and ii) a local wired LAN provided by the hospital IT service and related gateway. The acquisition tools of the telepresence system will be formed by smart glasses for the same view as the surgeon, a 360-degree camera for the view of the operating room, and a hub for video streaming of clinical monitors to obtain complete monitoring of surgical operations. All the acquisition tools will be wirelessly connected to the connection hub, which will be wired-connected to the hospital network. The connection hub will be equipped with specific software (commercial software of telepresence system) to securely broadcast multiple live videos from the acquisition tools in operating room to the remote expert.

The macro-module in central hospital for remote expert will be composed by i) a telepresence platform (i.e., a workstation with High Definition (HD) monitors and control interfaces), ii) a VR headset for an immersive telepresence experience, and iii) a 5G indoor network infrastructure. The workstation of telepresence platform will be equipped with the software of telepresence system with a dashboard that will give the remote expert the surgeon's view of the operational room, the complete view of entire operating room, and the view of clinical monitors. The software will also permit the remote expert to communicate directly through audio and chat with the surgeon. In the trial, the possibility of using as interface of remote expert a VR headset will be explored and tested. In this case, the VR headset will be connected to the workstation, and it will be used to give to the expert an immersive surgeon's view. Fig. 6 describes the infrastructure scheme of remote proctoring use cases (the lower left box depicts the smart ambulance, threated in Section II.C). The Telepresence System's local hub and the related workstation are both located in "Central Hospital Hub". This system is connected to the 5G network via a Customer Premise Equipment (CPE), which uses a SIM card provided by TIM to ensure access to the network. The CPE can be directly connected to the Telepresence System or can act as a dedicated Wi-Fi hotspot, where the Telepresence System can be connected using the best available Wi-Fi technology. The RAN, which is based on Ericsson systems, consists of two main components.

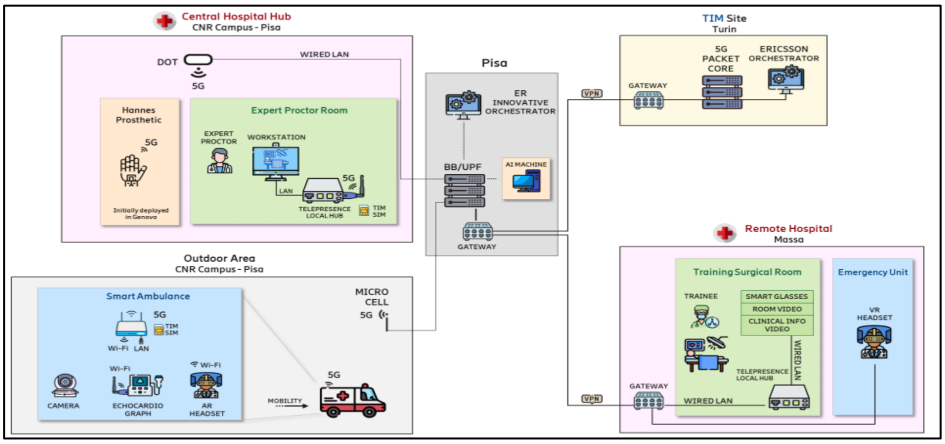

Fig. 6. Infrastructure scheme

The first component is the baseband unit, which is responsible for processing baseband signals. The second component is an indoor radio antenna that covers the experimental area. Part of the CN is hosted in Pisa and part in Turin. More specifically:

- Unified Data Management (UDM) module (hosted in the TIM Innovation site, Turin). It is responsible for managing the user data and profile information that is needed for authentication, authorization, and accounting purposes.
- User Plane Function (UPF) module (hosted in Pisa). It is responsible for handling the user data flowing between the 5G network ensuring that it is delivered efficiently and reliably.

Turin and Pisa are connected through a VPN which is active between two specific packet gateways. The overall 5G infrastructure is supported by the commercial Ericsson Orchestrator [6], located at TIM's premises in Turin. Additionally, a second orchestration module, specifically designed to manage vertical use cases that require more challenging handling of end-to-end QoS with optimal usage of the underlying infrastructure resources, has been deployed by Ericsson Research in Pisa within 5Growth project [7]. This provides further support for the overall 5G infrastructure.

C. Smart ambulance

The prognosis of acute coronary syndromes is strongly depending on the time between the onset of the symptoms and the reperfusion of the coronary artery responsible for the ischemic event. Any delay in therapeutical actions increases the patient's mortality or loss of myocardial muscle with consequent cardiac dysfunction. In this scenario, ambulances are not only a mere tool for quick transportation of a patient’s living area to a hospital equipped with facilities for coronary intervention, but they also offer early pre-hospital evaluation for a precise diagnosis and preliminary therapeutic support.

Currently, ambulances are not equipped with instruments that allow HD real-time patient vision and echocardiographic video to allow an efficient real-time visualization of patient heath information for the remote expert in the hospitals. This use case will propose a 5G-connected smart ambulance operating outdoor in the hospitals area in Pisa and connected to the hospital in Massa. The use case will develop an infrastructure that will enable ambulances (or small Emergency centers) to share diagnostic information with the main center, adopting a “hub and spoke” strategy. The proposed infrastructure will be designed and implemented to equip the ambulance with diagnostic tools for cardiological pathology and smart devices to guarantee an efficient and fast 5G connection in remote locations and mobility conditions. The ambulance will be equipped with modern diagnostic tool (echocardiography) and a 5G hub to ensure a reliable connection in all conditions, including emergency high-speed transport through congested urban areas (Fig.7). Synergies with “remote proctoring” will be carried out for what concerns slices orchestration.

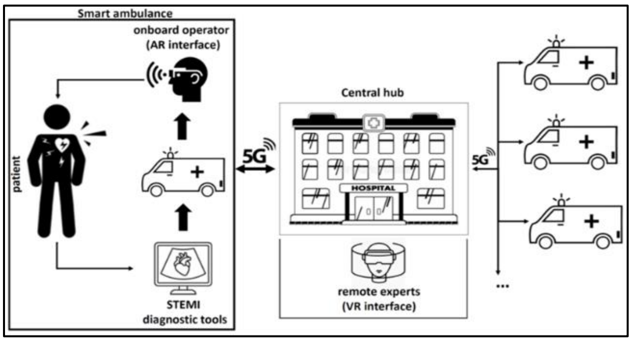

Fig 7. Smart ambulance use case concept

From the implementation point of view, a bi-directional audio/video communication network from and to the central hub (hospital for primary PCI) will be deployed. In this way, the onboard emergency operator can send information and big data batches (such as real-time video and 3D imaging, like in echo-cardiography) to a central hub with low latency and the central hub will provide real-time information to local operators to maximize early intervention. To have more specific information about the clinical status of the patient and the emergency setting, the remote experts in the central hub will get information from ambulances and onboard operators via VR headsets. The emergency operator onboard the ambulance will be equipped with an AR headset with cameras to receive information from the central hub and to send the video of emergency setting to the central hub. To send data and a HD video in real-time between the ambulance in mobility and the hospital hub, low latency 5G is essential. In addition, video from onboard emergency operator cameras can be transmitted live via the very high throughput provided by 5G without any quality loss or buffering.

The 5G infrastructure serving smart ambulance shares most of its components with the infrastructure for remote proctoring (Fig. 6). The main difference is related to the use of an outdoor antenna (micro cell) to provide coverage in the outdoor area where the smart ambulance is planned to operate. A second difference is related to the CPE that will be used in the ambulance. It is expected that the best option is to cover the interior of the ambulance with a Wi-Fi network originated from a 5G modem. Two installation options will be considered:

- Option 1: Installing a specific 5G modem and router inside the ambulance and connecting them to an external antenna through an Ethernet cable. The antenna is shaped like a "hockey puck" and magnetically anchored to the top roof of the ambulance. This solution has the advantage that the Wi-Fi hotspot is completely indoors, and the 5GHz bandwidth can be used for better wireless network performance.
- Option 2: Mounting the 5G modem, antennas, and router on the exterior of the ambulance in a single, aerodynamic, and ruggedized "shark fin" casing. This simplified form factor reduces installation complexity and cost, but the Wi-Fi hotspot is outside the ambulance, and the 5GHz bandwidth cannot be used.

A Wi-Fi connection provide by the 5G modem, would also allow commercially available AR headsets and portable echocardiographs to be connected. In the future, such devices could be directly equipped with embedded cellular modems for direct access to 5G and its evolutions.

The high throughput and low latency required by this use case will be achieved through 5G network slicing, for which a dedicated slice of the network resources that is optimized for real-time communication and emergency services can be assigned to the ambulance. This slice allocation will provide high throughput connectivity and low latency communication, allowing medical personnel to remotely diagnose and treat patients in real-time, even while the ambulance is in motion. To achieve this, an Orchestrator (see Fig. 6) will configure the slice with strict QoS requirements, which would ensure that the ambulance's connection to the hospital is prioritized over other network traffic. This would help preventing delays or interruptions in the ambulance's communication with the hospital, even if the network is congested.

D. Adaptive Control of Hannes Prosthetic Device

Upper limb prosthetic systems have the potential to be life changing devices for amputees. In recent years, shared autonomy frameworks have been used to mitigate the cognitive load of users driving prostheses, since a semi-autonomous control system reduces explicit user inputs, by using sensory information. Following this direction, the aim of this use case is to introduce sensor-driven autonomous behaviour to reduce the need of explicit control by the user during a prosthetic object grasping. Therefore, in the target efficient shared autonomy control system, AI methods are used to control arm’s joints using the sensory information from the prosthesis (EMG as well as images from an embedded camera).

The main purpose is to demonstrate that it is possible to improve the user experience using a prosthetic arm, leveraging on radio connectivity to provide sufficient computing power to deploy recent AI methods on the prosthesis with high reliability and minimal latency. The system will be validated with experiments on the field with the Hannes prosthetic arm. The system performance will be verified in both laboratory and field tests, in terms of accuracy, reliability and efficiency. The AI methods that will be employed are based on Deep Neural Networks and require powerful and specialized hardware for both training and deployment. At the same time the control system is requested to be reactive to user’s intention changes and modifications of the surrounding environment. For this reason, the required computation will be de-localized at the edge of the Network and an ultra-reliable low latency connection will allow the continuous interaction between the sensors, the device and the AI machine that will be located outside the prosthesis (refer to Fig. 8 for a representation of the proposed architecture). The system will control a part of the Degrees of Freedom (DoFs) of the prosthesis while the user is driving it and controls the remaining ones.

The application developed in this use case reconfigures some of the DoFs of the Hannes prosthetic hand during a grasping movement. The aim is to automatically adapt (pre-shape) the hand to the intended grasp movement by the human, which can be inferred by the type of object to grab and the approach direction to it. The application will follow the framework of the shared autonomy splitting the control between the human and the AI based system. The different elements that will compose this application’s architecture are reported in Fig .8. The Hannes prosthetic arm will be equipped with different sensors, such as EMG, IMU and a video camera. Specifically, this latter will be mounted either on the wrist or on the palm of the prosthesis and it will be wired connected to an embedded electronic board (e.g., through Universal Serial Bus – USB – connection). This latter will be equipped with 5G network devices that will allow to stream the data via radio from the sensors to a server (the “AI Machine” in Fig. 8) where the AI method, based on Deep Neural Networks, is running. The data from the sensors mounted on the prosthesis are used by the AI method to gather information about the surrounding environment (like, e.g., the object to grasp and the direction of approach) and predict the correct configuration of the prosthetic arm joints that would allow to perfectly grab the object while adapting to the user’s movements.

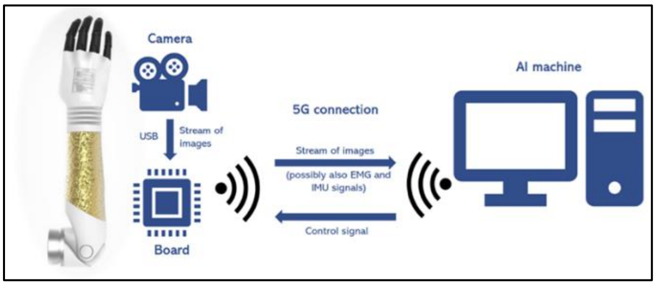

Fig. 8. Architecture of the application for the Adaptive Control of Hannes Prosthetic Device use case

The developed AI method will be based on previous work [8]. Specifically, an eye-in-hand learning-based approach Will be used for hand pre-shape classification from RGB image sequences. The system is designed to support the possibility to grasp each object part with a different grasp type. The learning architecture relies on a well-established model with the following architecture: (i) Convolutional Neural Network (CNN) based feature extraction (CNN backbone), followed by (ii) a pre-shape classifier. The first block encodes each image into a convolutional feature vector which is then taken as input by the classifier to predict a pre-shape for each image. The Mobilnet V2 [9] is used as CNN backbone for its efficiency at inference time, using pre-trained weights on the ImageNet dataset [8]. Instead, two stacked fully connected layers are adopted for the hand pre-shape classification.

The use case will be first implemented and tested in the Ericsson R&D laboratory in Genoa, where a 5G network infrastructure based on 3GPP Rel-15.0 5G NSA is provided. The 5G Ericsson deployment is supported by the Ericsson Radio System and Evolved Packet Core (EPC) solutions. The main components of the laboratory 5G network solution are summarized below:

- RAN: Radio Access Network composed of LTE and NR radios and basebands (Digital Unit) connected to the transport layer.
- Transport network: routers to implement fronthaul and backhaul to implement optimized baseband/radio interconnection.
- Core solution: the main components are the Home Subscriber Server (HSS), the MME, the Evolved Packet Gateway (EPG)

Along the project this laboratory network will evolve in an Ericsson Stand Alone architecture to support the advanced applications of the use case.

In the second phase in Pisa, the Adaptive Control of Hannes Prosthetic trial will be served by a 5G network covering an indoor area located in the CNR campus in Pisa and connected via a 5G dongle, which uses a SIM card provided by TIM to ensure access to the network. The 5G infrastructure is composed by a RAN and a CN. The RAN, which is based on Ericsson systems, consists of two main components: the first component is the baseband unit, which is responsible for processing baseband signals that have not yet been modulated to the radio frequency (RF) domain; the second component is an indoor radio antenna that covers the experimental area. Regarding the CN, part will be hosted in Pisa and part in Turin as already described for the remote proctoring use case.

III. Conclusions

In conclusion, this paper has explored the application of B5G connectivity in the context of Emergency and eHealth, to be demonstrated during TrialsNet project lifetime. The advanced capabilities offered by B5G, including ultra-low latency, high bandwidth, massive device connectivity, and network slicing, have a transformative impact on emergency services and eHealth applications. Through the integration of B5G technology, emergency responders can benefit from enhanced situational awareness, real-time communication, and efficient coordination during critical situations. The low latency and high data rates enable rapid transmission of multimedia data, such as high-resolution images, videos, and vital signs, empowering emergency medical professionals with the necessary information for making informed decisions promptly. Specifically, through the describing Emergency use case, cutting-edge (and 5G/B5G/6G) technologies will be shown off in a large-scale field exercise for more effective first responder communication, quicker and more efficient triage, and pre-hospital treatment, and they will be compared to the baseline approach using conventional approaches.

The seamless and reliable connectivity provided by B5G enables continuous monitoring of patients in real-time, improving healthcare access, reducing hospital visits, and enhancing patient outcomes. The use case of remote proctoring in the field of interventional cardiology, is a unique innovative solution based on smart tools for telepresence in the surgical field to connect expert proctors and remote hospitals and the use case of smart ambulance demonstrates the possibility to provide consultations, allowing healthcare providers to remotely diagnose and treat patients with greater precision and efficiency, even in mobility.

These technologies open the door to the Internet of Medical Things (IoMT), i.e., the network of Internet-connected medical devices, hardware infrastructure, and software applications in eHealth. The IoMT ecosystem expands, incorporating a wide range of connected medical devices and wearables, including the control of advanced control capabilities for prostheses.

The benefits of B5G connectivity in Emergency and eHealth are not limited to the selected use cases which, covering a wide range of examples and going to be deeply tested, but extend to numerous other use cases and scenarios. However, it is important to recognize the challenges associated with the deployment and adoption of B5G technology, including infrastructure requirements, privacy concerns, and regulatory considerations. Addressing these challenges will be crucial in realizing the full potential of B5G in emergency and eHealth domains.

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