7

5G Communication Systems and Connected Healthcare

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This chapter focuses on 5G mobile systems for ultra-reliable low latency communications applied to two specific healthcare use cases: Wireless Tele Surgery (WTS), using a mobile console and a robotic platform with video, audio and haptic feedback; and Wireless Service Robot (WSR), a companion robot or service robot performing tasks of social caretakers, professional personnel or family members. Cyber-sickness and latency between the robotic platform and a reasoning server are the new technical problems the 5G mobile system is expected to solve, e.g. in hospices, hospitals, homes and campus areas.

In the following sections, we first present the use cases and related technical requirements; then, we describe the 5G reference architecture and key enabling technologies to meet the performance, dependability and security targets for Tele-healthcare. This is followed by a comprehensive analysis of the costs and revenues operators and healthcare providers would encounter to deliver the corresponding services, if a 5G system was deployed.

7.1 Introduction

The next generation of mobile broadband infrastructure or International Mobile Telecommunications (IMT) for 2020 and beyond (5G) will expand and support diverse usage scenarios and applications with respect to previous network generations, purposed primarily for the support of improved voice, mobile Internet and video experience. The main categories of usage scenarios for 5G are [1–3]: *enhanced Mobile Broadband* (eMBB), addressing human-centric use cases for access to multimedia content, services and data; *Ultra-Reliable Low-Latency Communications* (URLLC), with strict requirements, especially in terms of end-to-end latency and reliability; and *massive Machine-Type Communications* (mMTC), for a huge number of connected devices, typically transmitting a relatively low volume of non-delay-sensitive information.

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In this chapter, we focus on URLLC for connecting remote-controlled robots or robotic platforms with intelligence in the edge cloud, i.e. a point of presence (PoP), namely a data centre, close to the robots [4].

The first use case is *Wireless Tele Surgery*, which is considered to be an integral part of the wider field of telemedicine. The aim of telemedicine is to provide specialized healthcare services over long distances to improve the quality of life of patients located in isolated areas, where access to specialized medical services is limited. With 5G, a specialist could examine or operate on a patient at a different geographic location, and the system could potentially remove barriers to healthcare provision in developing countries, in areas of natural disasters, and in war zones, where consistent healthcare services are unavailable or there is no time to transport a patient to a hospital. WTS is primarily about the case where a surgeon in one remote location performs an operation on a patient laid in another room with the aid of a robotic platform [5]. The first successful tele surgery, named "Operation Lindbergh", was performed using a Zeus robotic system in 2001 [6]. Since then, tele surgery has been witnessing tremendous growth [7]. Basically, it consists of a short- or long-distance system that utilizes wired and/or wireless communication networks. A representative paradigm of the short-distance case is the Da Vinci Surgical System. The concept of long-distance tele-robotics is typically exemplified by diagnostic ultrasound scanning systems. In WTS, the aim of introducing 5G technology is to develop Teleoperated surgical systems, which actually was not feasible with the deployment of previous wireless technologies [8]. The target with 5G is to keep latency – the time it takes to successfully deliver an application layer packet or message between wireless communication-rich hospital campuses – below certain thresholds and use robotic surgical devices, which can be operated by an expert surgeon based hundreds miles away from the patient. With the deployment of 5G wireless, the medical doctor may perform remote robotic surgery, or other tasks, e.g. medical ultrasound in a decentralized hospital system at any hospital within such a system; also, using 5G, he or she can be consulted at any time from anywhere. In general, robotic surgery reduces hospitalization time, pain and discomfort and recovery time; it infers smaller incisions, reduced risk of infection, reduced blood loss and transfusions, minimal scarring and better quality, e.g. see [9] and [10]. In order to reach the same "sense of touch" as in conventional interventions, without the remote doctor experiencing *cyber-sickness*, the 5G system must provide the guaranteed low latency and the necessary stability while transmitting *haptic feedback* (tactile and/or kinaesthetic signals), and improved throughput for better visualization, enhanced dexterity, and greater precision, well beyond today's Da Vinci system.

The second use case is about connecting a *Wireless Service Robot*, i.e. a robotic platform with Artificial Intelligence (AI) in the edge cloud [11]. The target is to stay below and above the required latency and throughput, respectively, with a very high degree of reliability between the wireless robot and edge computing servers, and use robotic care devices to assist patients and old people in hospitals, hospices and in their campus areas, and, mostly, at home. The edge cloud (reasoning system) runs computer vision algorithms to interpret human emotions, enable the service robot to interact naturally and perform complex care or household tasks. The main objective is to reduce care costs and, especially, help people to *remain active and independent with a good quality of life*. The 5G wireless connectivity will replace cables, reduce costs, and thus enable a massive adoption and utilization of robotic platforms, globally.

7.2 Use Cases and Technical Requirements

In the following sections, we describe the WTS and WSR use cases in detail and present the corresponding technical requirements 5G wireless is expected to support.

7.2.1 Wireless Tele Surgery

As shown in Figure 7.1, the target is to provide a remote surgeon, who could be located hundreds of kilometres away from patients, with the same sense of touch (essential for localizing hard tissue or nodules) while substituting doctor's hands in interventions with robotic probes (arm or finger). In order to achieve such an experience in remote interventions, delay and stability are the crucial parameters in transmitting haptic feedback (kinaesthetic info, such as force or motion; and/or tactile indicators, such as vibration or heat), in addition to audio/video data, because delays can seriously impair the stability of the feedback process and lead to *cyber-sickness*, which may occur when our eyes observe a movement which is delayed compared to what our vestibular system perceives [12–15].

A reaction time of about 100 ms, 10 ms and 1 ms is required for auditory, visual and manual interaction, respectively [14]. In order to realize these reaction times, so that all human senses can, in principle, interact with machines, and hear and see things far away, the end-to-end Quality of Service (QoS) needs to be guaranteed in terms of reliability (failure rate even below 10^{-7}, i.e. 3.17s of outage per year), speed (30–50 Mb/s encoded bit rate/view, or 1 Gb/s encoded bitrate for holographic rendering) and latency (below 100 ms, 25 ms and 5 ms for audio/video feedback, haptic feedback and interactive live holographic feedback, respectively) [12–15], as depicted in Figure 7.2. The 5G system requires a limited distance between sites, user plane (UP) in local break-out on the edge and a dedicated slice, which isolates traffic and ensures Service Level Agreement (SLA). (Both public and enterprise network options were presented in [4].)

7.2.2 Wireless Service Robots

Service robots for care are being primed to join the labour force in various roles, e.g. logistic, cleaning and monitoring, which can be fully automated. Beyond these simple

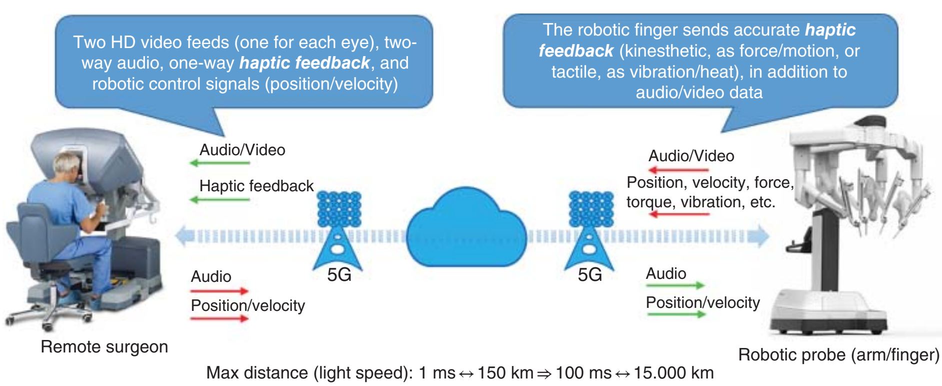

Figure 7.1 WTS: Examples of signals and parameters exchanged between a remote surgeon and a local robotic probe.

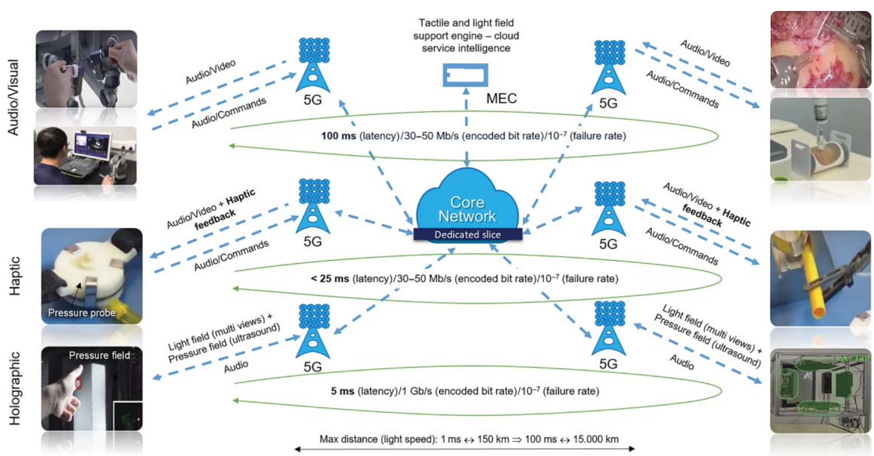

Figure 7.2 WTS: Examples of 5G system and performance requirements [12–15].

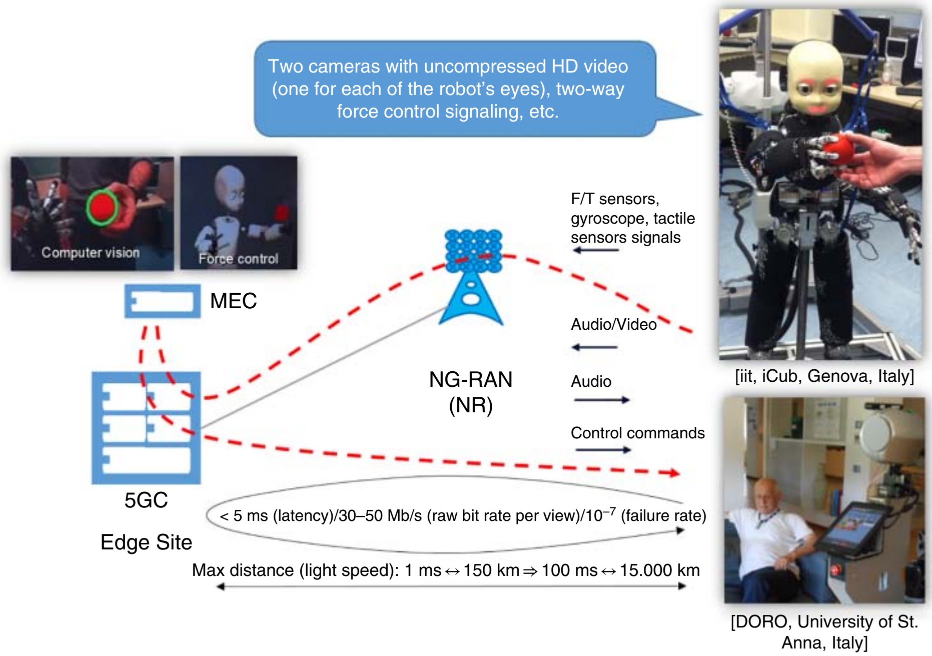

Figure 7.3 WSR: Examples of signals exchanged between the MEC server and robot and performance requirements [19, 20].

tasks, androgynous robots are anticipated to interpret human emotions, to interact naturally with people and perform complex care or household jobs, as well as to assist patients and old people in hospital and hospice campus areas, and at home to reduce care costs, and to help ageing people to remain active and independent with good quality of life as long as possible [16–20].

The target with 5G wireless is to meet the required latency and throughput with ultra-high reliability, between a wireless robot and a *Multi-access Edge Computing* (MEC) server (reasoning system) [21], where most of the intelligence is located, e.g. for object tracking, recognition and related applications [19, 20], as illustrated in Figure 7.3.

Examples of data rates and estimated bandwidth for robot sensors and control signals are reported in Table 7.1. Particular attention should be paid to the control loops,

Table 7.1 Requirements for robot sensors and signals [19].

Sensor name	Specs	Bandwidth
Cameras	2×, 640×480, 30 fps, 8/24 bit	147–441 Mb/s uncompressed
Microphones	2×, 44 kHz, 16 bit	1.4 Mb/s
F/T sensors	6×, 1k Hz, 8 bit	48 kb/s
Gyroscopes	12×, 100 Hz, 16 bit	19.2 kb/s
Tactile sensors	4000×, 50 Hz, 8 bit	1.6 Mb/s
Control commands	53DoF × 2–4 commands, 100 Hz/1 kHz, 16 bit	3.3 Mb/s (worst case), 170 kb/s (typical)

which cannot be executed locally. For instance, visual processing cannot be handled locally, because of the computational load/amount of data, and therefore is managed by a reasoning server remotely. This means a 5G wireless connectivity between peer points of Gb/s throughput, extremely low latency (< 5 ms) for force and motion control, and with failure rates below 10^{-7}, i.e. max 3.17s of outage per year. Also, for fully autonomous robots, to meet the required performance, it is very important to decide where and what to compute and how to transfer data and signals at a given transmission bandwidth [19].

7.3 5G Communication System

The 5G network architecture enabling the verticals was described in Chapter 1. This section presents the architecture, technology and security aspects of 5G that would cater for the Tele-healthcare use cases and applications presented in Section 7.2. The reader may find more information about 5G network domains, architectures and slicing in [22] and [23], respectively.

7.3.1 3GPP Technology Roadmap

The completion of the first phase (Phase 1 or Release 15, R15) of New Radio (NR) technology was in June 2018, in its Non-Standalone (NSA) Option 3 configuration. The Standalone (SA) Option 2 and 5 were finalized in September 2018. The remaining 3GPP NSA architecture options (4 and 7) will be specified in 2019. A high-level 3GPP content roadmap for 5G systems is depicted in Figure 7.4 [24].

The 3GPP R15 supports eMBB and some aspects of URLLC, such as: fast terminal processing time; front-loaded Demodulation Reference Signal (DMRS); mini-slot scheduling; uplink "grant-free" transmission; downlink pre-emption and flexible frame structure for low latency; downlink control channels with a high level of aggregation; data

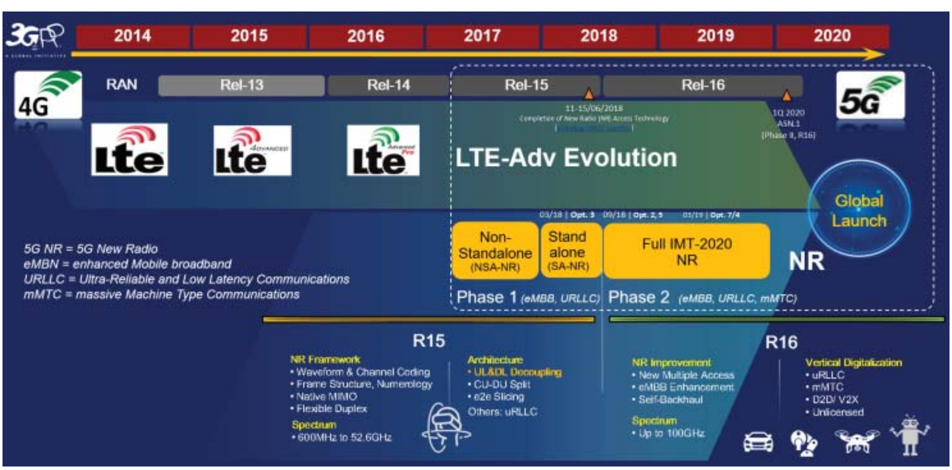

Figure 7.4 5G definition and 3GPP 5G content roadmap [24].

channel slot aggregation; and data (packet) duplication for high reliability. Some of those features are explained in Section 7.3.5.

The second phase (Phase 2 or Release 16, R16) of 5G will be frozen in 2020, and will support all usage scenarios: eMBB, URLLC and mMTC. Examples of features that will be standardized for further improving the reliability and latency performances are: Compact Downlink Control Information (DCI) and Physical Downlink Control Channel (PDCCH) repetition; Uplink Control Information (UCI) enhancements, such as Hybrid Automatic Repeat reQuest (HARQ) and Channel State Information (CSI) feedback improvements; Physical Uplink Shared Channel (PUSCH) enhancements, such as mini-slot level hopping, retransmission and repetition; scheduling, HARQ and CSI processing timeline enhancements; terminals multiplexing and prioritization for different latency and reliability requirements; enhanced UL configured grant transmissions (grant-free); multi-Tx/Rx Point (TRP) transmission; mobility and beam management improvements; uplink/downlink (UL/DL) intra-User Equipment (UE) prioritization and multiplexing. Some of the most important features to cater for Tele-healthcare use cases are described in Section 7.3.5.

7.3.2 5G Spectrum

The LTE operates always in the low band, i.e. below 6 GHz [24]. 5G NR is expected to support contiguous, non-contiguous and much broader channel bandwidths than available to current mobile systems. Also, 5G new radio will be the most flexible way to benefit from all available spectrum options from 400 MHz to 90 GHz, including licensed, shared access and licence-exempt bands, *Frequency Division Duplex* (FDD) and *Time Division Duplex* (TDD) modes, including *Supplementary Uplink* (SUL), Long-Term Evolution (LTE)/NR *uplink frequency sharing*, and narrowband and wide-band *Carrier Components* (CC). Operating band combinations for SUL are reported in [25]. More information on Dual Connectivity (DC) with and without SUL including UL sharing from terminal perspective – Output power dynamics for E-UTRA/NR DC (EN-DC) with UL sharing from UE perspective – may be found in [26].

A multi-layer spectrum approach is required to address such a wide range of usage scenarios and requirements [27]:

- The *Coverage and Capacity Layer* relies on spectrum in the 2 to 6 GHz range (e.g. C-band) to deliver the best compromise between capacity and coverage.
- The *Super Data Layer* relies on spectrum above 6 GHz (e.g. 24.25–29.5 and 37–43.5 GHz) to address specific use cases requiring extremely high data rates.
- The *Coverage Layer* exploits spectrum below 2 GHz (e.g. 700 MHz) providing wide area and deep indoor coverage.

5G networks will leverage the availability of spectrum from these three layers at the same time, and regulators are expected to make available contiguous spectrum in all layers in parallel, to the greatest extent possible.

7.3.3 5G Reference Architecture

The performance requirements of Section 7.2.1 and Section 7.2.2, especially in terms of reliability and end-to-end latency, cannot be entirely supported by 4G and/or Wi-Fi systems [1]. Superior wireless performance may be achieved with the deployment of a

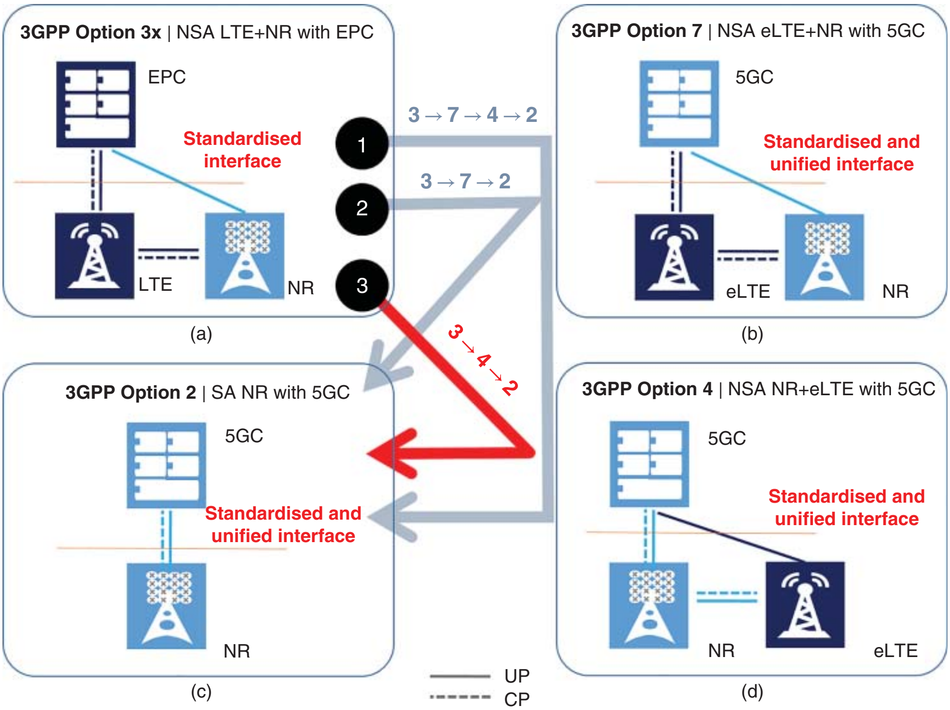

Figure 7.5 3GPP 5G architecture options and network migration strategies.

new generation of radio access networks with wireless access based on NR and (evolved) LTE (R15 LTE or eLTE of later releases). The most likely initial deployment options are illustrated in Figure 7.5 a) and c) (see e.g. [22] and [23]).

- *3GPP Option 3x* (NSA LTE plus NR with Evolved Packet Core, EPC) is the configuration that most carriers (network operators) will adopt, due to minor investments for their 5G launch. It supports eMBB and Fixed Wireless Access (FWA) usage scenarios and Voice over IP (VoIP) over LTE (VoLTE) or Circuit Switch Fall Back (CSFB) to earlier network releases (2G or 3G).
- *3GPP Option 2* (SA NR with 5G Core, 5GC) is initially adopted by only a few carriers globally. For taking full advantage from it, a wide coverage rollout is needed, as the interoperation with 4G/Evolved Packet System (EPS) is less efficient. Initial partial coverage rollouts may be more suitable for enterprise or overlay deployments. In the long run, it will support all usage scenarios (eMBB, URLLC, mMTC), plus other functionalities than Option 3x, such as Network Slicing and Voice over NR (VoNR).

The medium-/long-term migration path of 5G networks is also depicted in Figure 7.5, and, ultimately, all networks will converge to a 3GPP Option 2 architecture configuration (SA NR with 5GC). The medium-term migration strategies are basically two, depending on the carriers' spectrum availability for deploying the NR:

1. *From 3GPP Option 3x (NSA LTE + NR with EPC) to 3GPP Option 4 (NSA NR + eLTE with 5GC).* This choice is driven by the availability of low band NR (<3 GHz, <1 GHz for rural). The 5G services are launched with LTE+NR NSA on EPC, the NR and 5GC

rollout are driven by needs of 5G coverage; outside the NR coverage, 5G services may be provided by 3GPP LTE NSA Option 4 with 3GPP Option 5 (SA eLTE with 5GC). The interworking between eLTE and NR is also required.

2. *From 3GPP Option 3x (NSA LTE + NR with EPC) to 3GPP Option 7 (NSA eLTE + NR with 5GC)*. The reasons to go for that are: Leverage 4G (LTE/EPC) installed base; NR rollout driven by better service (not coverage); and eLTE for all wide area coverage and all use cases. The drawbacks are: Full Dual Stack eNB/ng-eNB in LTE RAN to EPC/5GC; LTE RAN upgrades to eLTE; and required Interworking between LTE and NR. UE availability is also, currently, questionable.

As in previous mobile system generations, 3GPP defines a clear functional split between the NG-RAN and 5GC with the overall 5G System architecture defined in [28–30] and a more convenient overview of the Access Network (AN) and Core Network (CN) functions in [31]. The two network domains (AN–CN) are separated by a standardized interface (N2 and N3) defined in a set of specifications that enable multi-vendor RAN–CN deployments [29]. Also, this interface has been now unified, meaning that all next generation accesses (trusted/untrusted fixed/mobile 3GPP access points) must support this interface.

The 5GC is responsible for Non-Access Stratum (NAS) security and idle state mobility handling; UE internet protocol (IP) address allocation and protocol data unit (PDU) control; and mobility anchoring and PDU session management.

The NG-RAN is responsible for inter-cell Radio Resource Management (RRM), Radio Bearer (RB) control, connection mobility control, radio admission control, measurements configuration and provisioning, and dynamic resources allocation. As introduced in Chapter 1, and illustrated in Figure 7.6, the NG-RAN supports only two possible configurations:

- *Central Unit (CU)-Distributed Unit (DU) Split*: The RAN non-real-time protocol (NRT) stack is implemented in the CU and the functions more sensitive to delays in the DU close to the antennas.

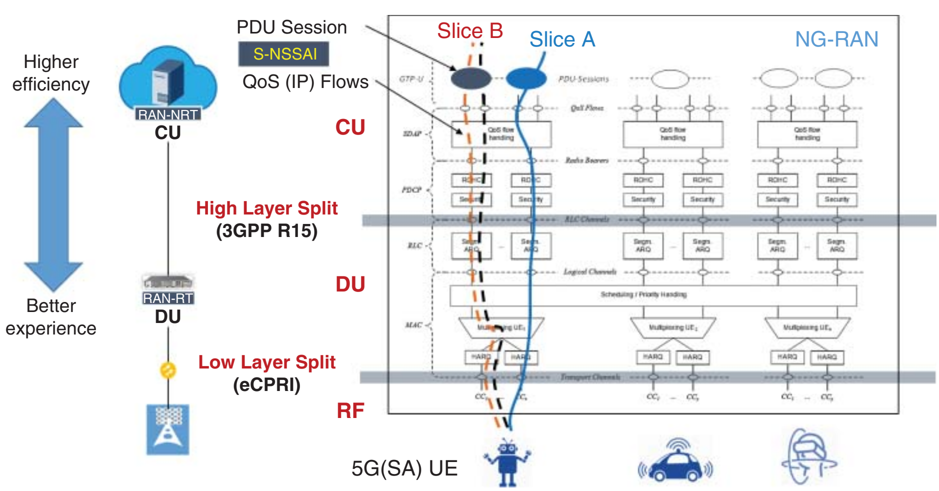

Figure 7.6 NG-RAN CU-DU and high layer and low layer protocols split.

- *CU-DU Co-Located at the Edge of the Network*: All RAN base band functionalities are running into one box placed closed to the antenna units.

The CU-DU split architecture can provide on-demand deployment [22, 23]: The CU may run on a cloud platform and can be deployed in different locations to meet the *efficiency-latency trade-off* for offering different type of services, e.g. the latency in regional, local and access data centre deployment scenarios is below 50 ms, 20 ms and 5 ms, respectively. Moreover, the cloud RAN architecture supports *multi-connectivity* and avoids data transmission detour, which reduces delays in user plane (UP) data transmission across the Multi-Radio Access Technologies (LTE-NR RATs). As further clarified in the following sections, multi-connectivity is critical for radio connection redundancy, and five uncorrelated links could already achieve an outage of less than 10^{-7}, which is the required hard-bound reliability for tactile applications [14].

In other words, in 5G, the radio interface protocol stack has been optimized for cloud and distributed computing with a flexible fronthaul split, between high layer protocols, i.e. Packet Data Convergence Protocol (PDCP) and Radio Link Control protocol (RLC), and low layer (L1) peer entities, using the enhanced Common Public Radio Interface (eCPRI). This will also allow access providers to relax the transmission capacity and the utilization of Ethernet. For example – assuming 100 MHz band, a three-sector site with 64Tx/Rx mMIMO and 16 layers – the interface between the radio unit (RU) and edge cloud (radio access unit, RAU) would require: 1 Tb/s with no split, using a CPRI interface; 150 Gb/s with low layer split and enhanced CPRI (eCPRI) interface; and 1–10 Gb/s with high layer split. The latency with low layer split is expected to be below 0.1 ms, as with CPRI; and 5 ms with high layer split, which is still satisfactory for supporting the WTS and WSR use cases described in Section 7.2 [23].

Additional benefits will come with the introduction of the 5GC, which supports many new enabling network technologies. Among other fundamental technology components, as depicted in Figure 7.7, the 5GC is characterized by a layered and

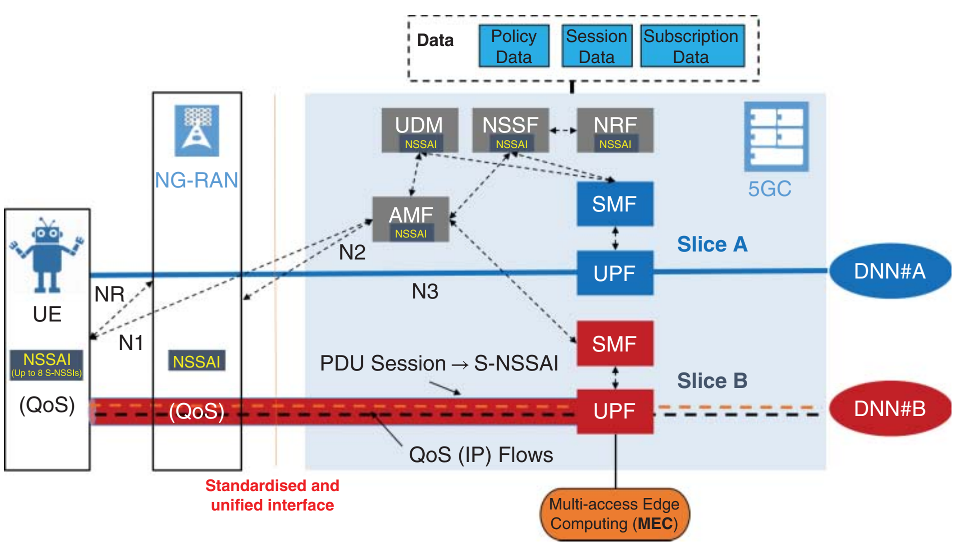

Figure 7.7 5GC and end-to-end network slicing [23].

service oriented architecture, with Control Plane (CP) and UP split and *Shared Data Layer (SDL)*, for subscription, state and policy data. It also supports: user plane session continuity when the terminal moves across different access points; interworking with untrusted non-3GPP access systems; a comprehensive policy framework for access traffic steering, switching and splitting; and wireless-wireline convergence [23].

The separation of control and user planes provides deployment flexibility and independence. The distribution of core functionality, especially user plane, closer to the radio, i.e. to the edge cloud, enables the placement of applications closer to the end user with improved throughput, reducing the transport network load, and latency, decreasing the physical distance and number of transport hops. The service-based architecture – including the related Network Repository Function (NRF) for 5GC control plane functions – allows flexible addition and extension of functions including the proprietary ones. The SDL, between all network functions (and micro-services within the functions), enables common session resiliency and geo-redundancy models, and a shared interface for accessing all session data (e.g. for analytics). The 5GC is also agile to deploy new or updated functions in a "DevOps" style. The Network Exposure Function (NEF) enables the integration of Telco functions with service providers, enterprises and operator's own IT systems to create new use cases and opportunities to monetize. The core slicing and related Network Slice Selection Function (NSSF) enable a flexible assignment of users to different network slice instances that are tailored to the different use cases. The 5GC also supports a unified subscriber management, authorization and authentication solution [23].

Other fundamental 5G enabling technologies, end to end, are: *Flow-based QoS*, with a much higher level of granularity than LTE, which is currently limited to the bearer service concept; multi-connectivity, where the robot could be connected simultaneously to 5G, LTE and Wi-Fi, offering a higher user data rate and a more reliable connection; terminal assisted Network Slicing, and E2E network management and orchestration, with in-built support for cloud implementation and edge computing [23].

The 5G flow-based QoS concept is illustrated in Figure 7.8. The NAS packet filters associate IP Flows with QoS Flows in the UE (robot) and User Plane Function (UPF). The Service Data Adaptation Protocol (SDAP) provides mapping between QoS flows and Data Radio Bearers (DRBs) and marking QoS Flow Identifier (QFI) in both DL and UL packets. There is a single SDAP entity for each PDU session (GTP Tunnel). The QFI uniquely identifies the QoS flow and consists of the following parameters [29]:

- 5G QoS Identifier (5QI): Resource Type (Guaranteed Bit Rare (GBR) and Non- GBR), Priority Level, Packet Delay Budget (PDB) UE ↔ UPF, and Packet Error Rate (PER);
- Allocation Retention Priority (ARP);
- Guaranteed (GFBR) and Max Flow Bitrate (MFBR) for GBR flows (UL and DL).

In the DL, each UPF uses policies from Policy Control Function (PCF)/Session Management Function (SMF) to identify flows and adds QFI tags, enforces Session-AMBR (Aggregated) and counts packets for charging. Each UPF sets Reflective QoS (RQI) to activate Reflective QoS in the UE (robot). The NG-RAN uses QFI tags and policies to map flows to one or more DRBs, and enforces the Max Bit Rate (UE-AMBR) limit per UE (robot) for non-GBR QoS flows.

In the UL, the UE (robot) uses either signalling or "reflective" learning approach to derive the QFI policies to map QoS flows onto DRBs, and performs UL rate limitation on

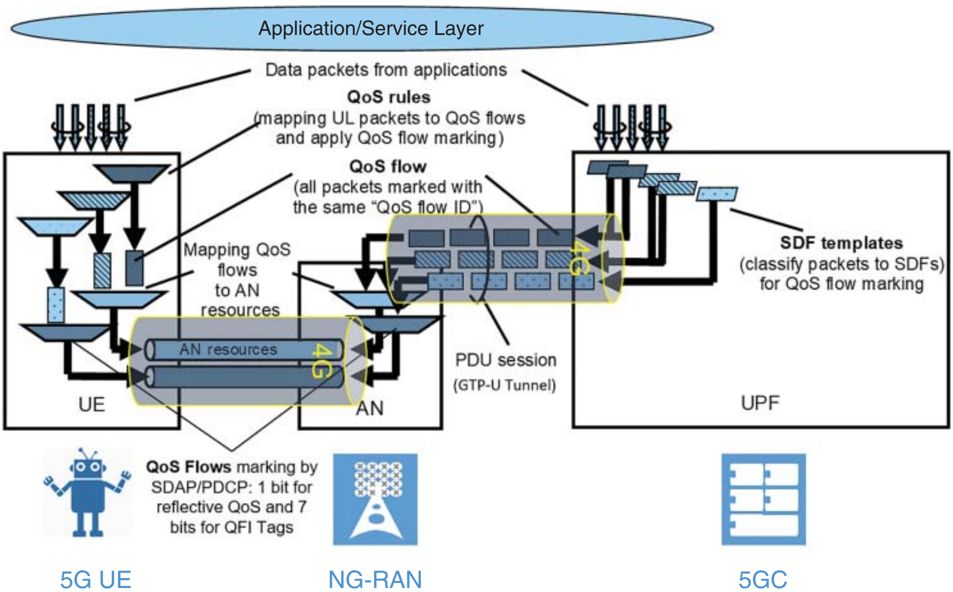

Figure 7.8 5G QoS Concept [29].

a PDU Session basis for non-GBR traffic, based on Session-AMBR value. The NG-RAN and UPF police QFI usage and enforce Max Bit Rate (UE-AMBR) and Session-AMBR, respectively. The UPF counts the packets for charging.

The transport network layer QoS treats packets based on 5QI tags (e.g. using DiffServ). The mapping is based on Software Defined Networking (SDN) policies.

IP Flows are mapped onto QoS Flows, which are mapped onto one or more DRBs. Data radio bearers are associated to one PDU Session, which is mapped onto one S-NSSAI. The S-NSSAI is mapped onto one Network Slice Instance (NSI), i.e. one Network Slice; and the NSI is mapped onto a single Data Network Name (DNN). However, the vice versa is not valid, as described in the following paragraphs. This is how 5G handles the flow-based QoS within a given NSI [23].

3GPP for terminal assisted network slicing defines a new parameter denoted as *Single-Network Slice Selection Assistance Information* (S-NSSAI). Each S-NSSAI assists the network in selecting a network slice instance. The S-NSSAI is composed by the following attributes [29, 30]:

- *Slice/Service Type (SST)*: Where 1 (eMBB), 2 (URLLC), 3 (mMTC) are the standardized values for roaming; operator-specific settings are also possible;
- A *Slice Differentiator (SD)*: Tenant ID, optional, for further differentiation during the NSI selection.

The Network Slice Selection Assistance Information (NSSAI) consists of a collection of S-NSSAIs. In 3GPP R15, a maximum of eight S-NSSAIs may be sent in signalling messages between the UE (robot) and the Network.

The NSSAI is configured (Configured NSSAI) in the UE (robot) per Public Land Mobile Network (PLMN) by the Home PLMN (HPLMN). The robot uses the Requested NSSAI during the Registration Procedure and the Allowed NSSAI, received from the

Access and Mobility Function (AMF), within its Registration Area (RA). The RA allocated by AMF to the robot has homogeneous support for network slices [29].

The 5GC supports AMF-level slicing per terminal type, and SMF- and UPF-level slicing per service or per tenant based on S-NSSAI and DNN. An example of two network slices for one terminal is illustrated in Figure 7.7.

The NG-RAN is aware of the slice at PDU Session level, because the S-NSSAI is included in any signalling message containing PDU Session info. Pre-configured slice enabling in terms of NG-RAN functions is implementation-dependent. An example of NG-RAN slicing is depicted in Figure 7.6. The Medium Access Control (MAC) scheduling – based on RRM policies related to the SLA in place for the supported slice and QoS differentiation within the slice – is vendor-dependent [29].

Details on how the NSSAI is exchanged between the terminal and network entities during the Registration and PDU Session establishment procedure, as well as how the NSI is instantiated end-to-end, may be found in [23].

7.3.4 5G Security Aspects

5G System security is based on the well-established and proven 4G/EPS security, which has been further enhanced [32, 33]. The 5GS keying hierarchy is comparable to 4G for the functionality towards the RAN, i.e. all keys for the *Access Stratum* (AS) are derived from the NAS security parameters inside the Core Network and signalled the RAN. The main new model of the 5GS is on how the security functionality is decomposed and distributed inside the core network. This also enables the globally unique 5G *Subscription Permanent Identifier* (SUPI, which is comparable to the IMSI of earlier system generations) to always be signalled encrypted via the RAN towards the CN. It is decrypted by the Home PLMN and delivered from there to the serving Core Network for any user service, management and regulatory purposes. In contrast to earlier system generations, where the International Mobile Subscriber Identity (IMSI) was used in the RAN for recovering from network failures and thereby enabled certain attacks, the 5G System never exposes the SUPI to the RAN nor does it transfer it in clear via the radio. Further, 3GPP 5G Release 15 adds an option to perform user plane integrity protection between UE (robot) and gNB. In 3GPP Release 16, security algorithms use up to 256-bit keys [32] (see Figure 7.9).

Also, the transport network layer within and between RAN and core network domains is protected using IPSec tunnels. Examples of security deployment scenarios for 3GPP NSA Option 3x and Option 2 configurations are illustrated in Figures 7.10 and 7.11, respectively. As shown in the figures, the 3GPP Option 2 has the same level of security as 3GPP Option 3x. Hence, if 4G is proved to be an isolated network, 5G results even more robust, and meets all security requirements to connect robotic platforms. More information on 5G security aspects and deployment scenarios may be found in [34].

7.3.5 5G Enabling Technologies

This section summarizes key contributions of researchers from industry and academia that address the technical challenges reported in Section 7.2 and sheds light on some fundamental 5G technologies for URLLC, and especially those suitable for Tele-healthcare applications. More information on the subject may be found in [35].

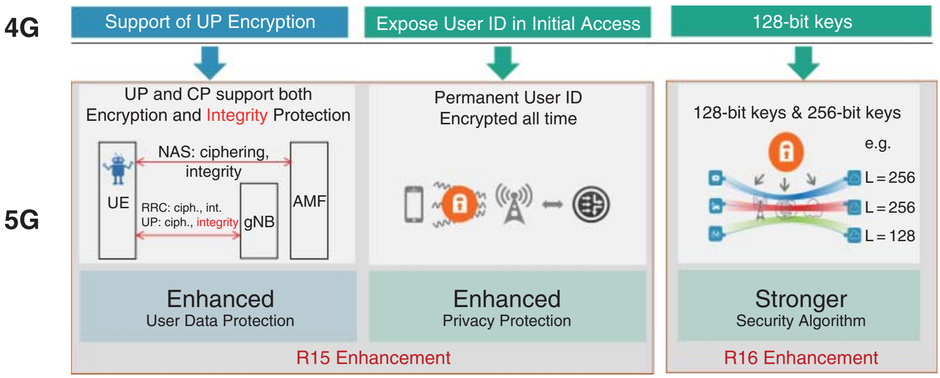

Figure 7.9 3GPP 5G security enhancements [32].

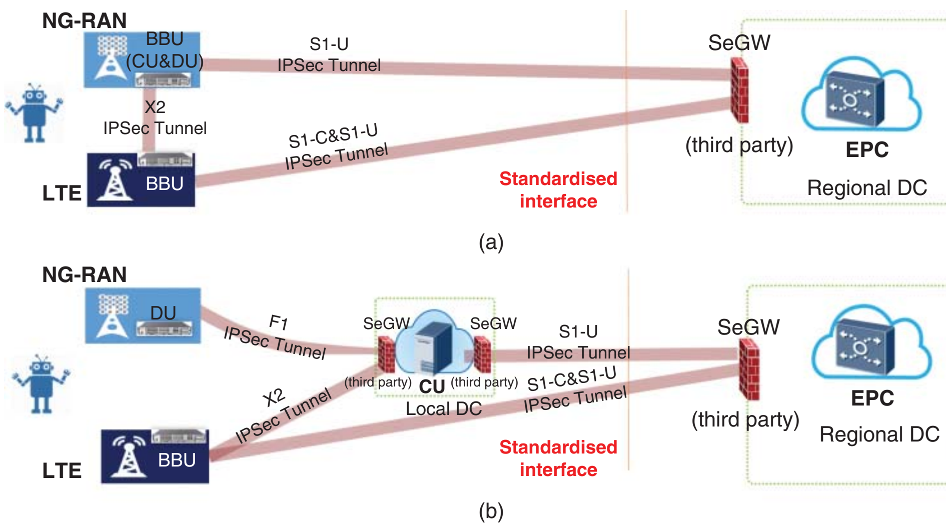

Figure 7.10 3GPP NSA Option 3x security deployment: a) without CU-DU split; b) with CU-DU split.

7.3.5.1 5G Design for Low-Latency Transmission

In 3GPP R15, and later releases, both NR (TDD and FDD) and LTE (TDD) are designed to fulfil the requirements on latency reported in Section 7.2.

LTE and NR use orthogonal frequency division multiplexing (OFDM) as the waveform. A Cyclic Prefix (CP) is used to cope with a time-dispersive propagation channel, i.e. only delay-spread of signals that exceeds the CP length introduces inter-symbol interference. In the UL, LTE uses discrete Fourier transform (DFT) precoding to reduce the peak-to-average-power ratio at the transmitter, and DFT precoding is also available for NR uplink [36].

LTE uses a fixed numerology of 15 kHz sub-carrier spacing and operates below 6 GHz. The NR has been designed for all spectrum options and supports a *flexible numerology*, which consists of different Sub-Carrier Spacing (SCS), nominal Cyclic Prefix (nCP) and Transmission Time Interval (TTI), or scheduling interval, depending on bandwidth and latency requirements. Sub-carrier spacing of 15 kHz to 120 kHz, and the corresponding

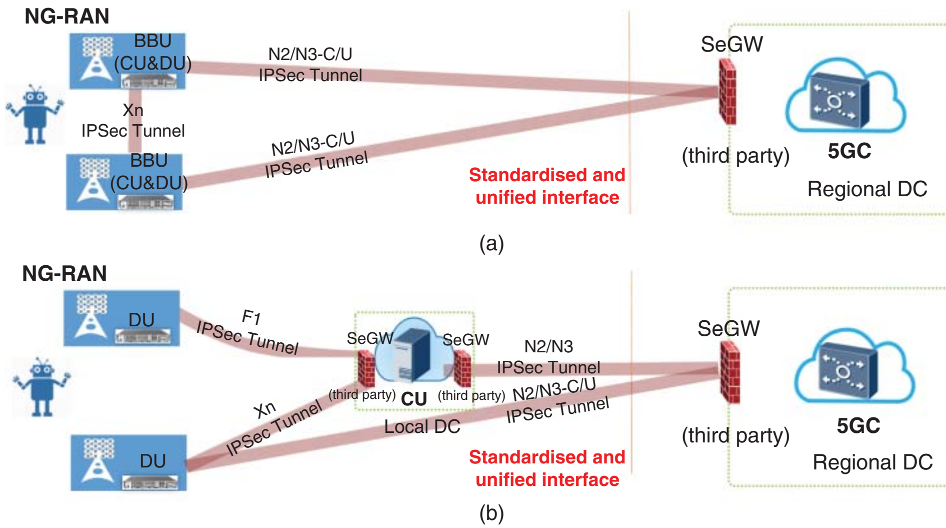

Figure 7.11 3GPP SA Option 2 security deployment: a) without CU-DU split; b) with CU-DU split.

cyclic prefix of 4.7 to 0.6 μs and scheduling interval of 1 ms to 0.125 ms, are defined for different Carrier Components (CC), which may vary from 5 MHz to 100MHz, below 6GHz, and from 50 to 400MHz, above 6GHz [23]. Examples of OFDM numerology options are illustrated in Figure 7.12.

For optimal radio performance, the higher the carrier frequency, the higher the allowed carrier component and sub-carrier spacing, the lower the corresponding cyclic

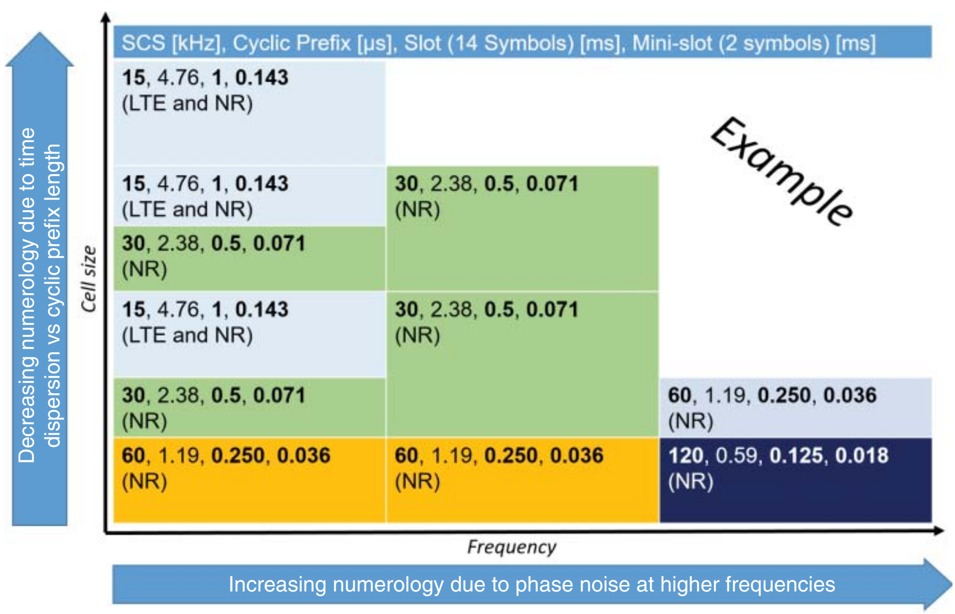

Figure 7.12 Examples of feasible OFDM numerology options for different spectrum ranges and cell deployments [36].

prefix and scheduling interval. At higher frequencies (e.g., millimetre-wave, or spectrum above 20 GHz), the phase noise increases and numerologies with larger sub-carrier spacing provide better robustness. This is because at higher SCS the symbol duration decreases, and hence also the length of a *slot*, which is the basic frame structure at which most physical channels and signals repeat. In LTE and NR (R15) a slot comprises 14 OFDM symbols (OFDMS), which leads to a slot length of 1 ms at 15 kHz SCS. In NR, by using higher numerologies, the slot duration decreases from 1 ms to 0.125 ms, which is beneficial to achieving lower latencies [36].

In NR, beyond numerology scaling, the concept of *non-slot-based transmission* has been introduced, which is also referred to as *mini-slot*. A mini-slot in NR can start at any OFDM symbol and can have a variable length of 2, 4, or 7 symbols [37]. This provides fast transmission opportunities for URLLC traffic, because it is not restricted to any particular slot boundary. Thus, the mini-slot provides a viable solution to low-latency transmissions irrespective of sub-carrier spacing, while the usage of wider sub-carrier spacing for low latency is mostly limited to small cells deployment [36].

Similarly for LTE FDD spectrum allocations, the *short TTI* (sTTI) enables fast transmission opportunities of 2, 3 or 7 OFDMS duration. The sTTIs can be embedded into the existing LTE frame structure, around existing control channels and reference symbols, and are independently scheduled with new in-band control elements, thereby allowing lower scheduling delay at the expense of increased overhead [36].

The NR supports both *static and dynamic UL/DL TDD configuration options*. The TDD latency is largely determined by the worst case timing; for example, a DL packet arrives exactly at the beginning of an UL allocation or vice versa. A suitable TDD configuration for URLLC is when UL (mini-)slots alternate with DL (mini-)slots. However, mini-slots shorter than 7 OFDM symbols are not considered for TDD, as the UL-DL switching overhead would become dominant in too-short time slots [36].

Furthermore, for the UL, a significant part of delay is due to the lengthy time it takes while exchanging scheduling requests and UL grant transmissions between the BS and the UE (robot). Also, for a reliable communication this signalling bears the risk that both messages need to be correctly decoded in order to start an UL transmission. Many "grant-free" multiple access techniques that eliminate the dynamic request and grant signalling overhead have been investigated. For instance, as a remedy for both the delay and robustness issues, a *periodic grant* can be configured in the UE (robot). Both LTE and NR support a Semi-Persistent Scheduling (SPS) framework, in which the terminal is given a periodic grant that it uses only when it has UL data to transmit. Necessarily, these URLLC resources are tied up for the UE (robot), but by assigning overlapping grants to multiple UEs the resource waste is reduced, and at lower rates the impact on reliability due to collisions can be managed. This method of periodic grants reduces the latency by one feedback round-trip time and thereby enables low-latency UL data transmission [36].

A significant part of the delay budget relates to the *processing time for decoding in the DL*. The usage of Low-Density Parity Check (LDPC) codes for 5G NR eMBB services has the promise of reducing it. However, the effective benefits of such codes for URLLC services are still disputed in 3GPP. To further reduce the processing time for HARQ retransmissions, it is proposed to *predict whether the decoding will be successful or not*; this enables the UE (robot) to anticipate its feedback transmission while running the decoding in its pipeline. False positives, which occur when an early ACK is generated for a transport block that is not going to be correctly decoded, are considered more critical than false negative, because they may trigger a higher layer retransmission. Prediction techniques with improved reliability are currently for further study. Improved prediction techniques with sensitive tolerance to false negatives will most probably cope with the Tele-healthcare targets [38].

A resource- and latency-efficient scheduling solution is to multiplex data with different TTI lengths (i.e., mini-slots and slots) and, if needed, let the high-priority data use resources of lower-priority data. This type of multiplexing is also referred to as *pre-emption*. For example, in NR DL, a mini-slot carrying high-priority or delay-sensitive data can pre-empt an already ongoing slot-based transmission on the first available OFDM symbols, without waiting until the next free transmission resource. A similar concept is also considered for the UL, and in general for LTE. At the cost of degrading the longer transmission, no additional resources would need to be reserved in advance for the low-latency communication. The damaged longer transmission is then swiftly repaired with a transmission containing a subset of the Code Block Groups (CBGs) in a later TTI, after providing the essential information to clean the contaminated soft values in the receive buffer from the pre-empted data [36].

Massive Multiple-Input Multiple-Output (mMIMO) is an integral part of the 5G NR features from day one. With mMIMO the number of transmitting antenna elements is much higher than the number of MIMO streams (layers). In practice, mMIMO means that the number of controllable antenna elements is more than eight. 5G NR supports 8 Layer Single User (SU)-MIMO or 16 Layer Multi-User (MU)-MIMO in DL, and 4 Layer SU-MIMO in UL, with the possibility of dynamic switching in both directions. MU-MIMO means that parallel MIMO data streams (or layers) are transmitted to different robots at the same time-frequency resources.

Beamforming (BF) offers the advantages that the same resources can be reused for multiple robots in a cell. It allows *Space Division Multiple Access* (SDMA), maximizing the number of supported robotic platforms within that sector. Also, it minimizes interference, increases the cell capacity, enhances link performance and increases the coverage area. 5G radio design is fully optimized for mMIMO using three basic techniques for forming and steering beams [23]:

- *Digital Beamforming*, where each antenna element has a transceiver unit with the adaptive Tx/Rx weights in the baseband, enabling frequency-selective beamforming. Digital beamforming boosts capacity and flexibility and is mostly suited to bands below 6 GHz.
- *Analogue Beamforming* implements only one transceiver unit and one RF beam per polarization. Adaptive Tx/Rx weighting on the RF is used to form a beam. This is best suited for coverage at higher mmWave bands and offers low cost and complexity.
- *Hybrid Beamforming* is a combination of analogue and digital beamforming. When some beamforming is in the analogue domain, the number of transceivers is typically much lower than the number of physical antennas, which can simplify implementation, particularly at high frequency bands. This technique is suited to bands above 6 GHz.

In NR, all physical control and data channels support beamforming. The many radiating dipoles allow narrower beams in the zenith (vertical plane) and azimuth (horizontal

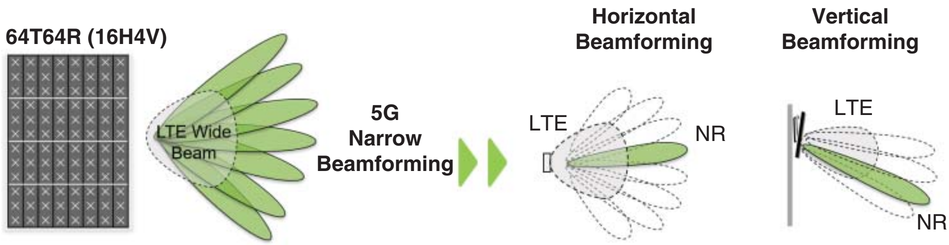

Figure 7.13 5G Massive MIMO narrow beam design for 3D shaping.

plane) directions, as depicted in Figure 7.13. The coverage for common and shared channels may be thus improved, e.g. the coverage gain of 64T64R vs. 2T2R may be up to 10 dB, and the interference can be also mitigated, yielding a higher Signal to Interference plus Noise Ratio (SINR), meaning better throughput and more cell capacity.

Multi-Access Edge Computing provides efficient transport and low latency to hosted applications in the operator trusted domain, close to the robot's access point (edge). As shown in Figures 7.3 and 7.7, the MEC enables access to applications deployed near the robotic platform [21]. In 5G, the local break-out (UPF of 5GC) could be flexibly deployed in other locations too, leveraging Network Function Virtualisation (NFV) and End-to-End Service Orchestration (E2E SO) capabilities, i.e. algorithms within the different domains (RAN, Core, Transport etc.) that enable the right flexibility and trade-offs for the network administrator to efficiently place VNFs and exploit slicing [23].

7.3.5.2 5G Design for Higher-Reliability Transmission

The definition of reliability and related performance targets for the WTS and WSR use cases were presented in Section 7.2. In the following, we review the key disruptive innovations that enable a reliable connection for robotics control and beyond.

The first disruptive innovation is about a more flexible design of *control channels*, specified in earlier 3GPP releases to support all service applications and now tailored to an individual service. Examples of specific control channel enhancements are [38]:

- *Link Adaptation for Control Channels*: In LTE, the Physical Downlink Control Channel (PDCCH) already supports link adaptation by adjusting the *aggregation level* (i.e., repetition coding rate) in accordance with radio conditions. The maximum supported aggregation level is 8, which provides a PDCCH decoding error rate of 1% for an SINR of –5 dB. For 5G, with larger aggregation levels (e.g., 16), more robust coding schemes would be required to achieve much lower error rates. A similar approach should be applied to other critical control channels, such as the Physical Uplink Control Channel (PUCCH), carrying the channel quality indicator (CQI) and HARQ feedback. Besides varying the coding rate, *power control techniques* could be also applied to boost or reduce the transmit power on a per-terminal basis and achieve the required error performance.
- *Asymmetric Signal Detection for ACK/NACK*: For URLLC, the reliability of detecting NACK signals is more important than the trustworthiness of detecting ACK signals. Therefore, the asymmetric signal detection can be utilized to reduce the probability of

missing a NACK signal at the cost of increasing a wrong ACK detection (i.e., decoding an ACK as a NACK).

- *Compact Downlink Control Information (DCI)*: URLLC services are typically associated with smaller packet sizes compared to eMBB. Hence, the number of bits that are used to indicate the number of Physical Resource Blocks (PRBs) can be reduced. For 5G NR, the DCI content is still under discussion, and two DCI sizes have been agreed for the purpose of performance evaluation: 20 bits and 60 bits. The compact DCI formats allow more robust transmission of the control channel information without increasing the control overhead.
- *CQI Enhancements*: The CQI report is utilized for performing the downlink MCS adaptation by indicating to the Base Station (BS) the highest MCS that the terminal (robot) estimates it can decode at a certain BLER level. The following three enhancements for the CQI measuring and reporting procedure are proposed. First, the CQI report must be estimated at the UE (robot) targeting different Block Error Rate (BLER) targets compared to the fixed 10% target in LTE. Second, the BLER target for DL data transmission should be configurable according to the TTI duration, HARQ round-trip time (RTT) and control channel reliability. Third, the CQI report should effectively reduce the link adaptation mismatches due to the rapid and unpredictable SINR variations.

In *multi-connectivity*, a robot is connected to the network via multiple radio links. Several flavours of multi-connectivity have been defined in 3GPP for LTE and NR to improve user throughput and transmission reliability by aggregating signals of different access points. For instance:

- In R10, 3GPP introduced *Carrier Aggregation* (CA) as a method for the device to connect via multiple carriers to a single base station. In CA, the aggregation point is the MAC entity, allowing a centralized scheduler to distribute packets and allocate resources among all carriers, e.g. based on propagation channels knowledge, with a tight integration of the radio interface protocols involved.
- In R12, *Dual Connectivity* (DC) was specified for LTE, where the aggregation point was moved up to the PDCP layer. This way, two MAC protocols with their separate scheduling entities can be executed in two distinct nodes, without strict requirements on their interconnection.
- In R15, both architecture concepts of CA and DC are reused in both LTE and NR to improve the transmission reliability on upper protocol layers, beyond reliability improvements intended on the physical layer (PHY). This is achieved by *Packet Duplication* (PD) at PDCP layer. An incoming packet, for example, of a URLLC service, is thereby duplicated on the PDCP level, and each duplicate undergoes procedures on the lower layer protocols, RLC and MAC, and hence individually benefits from retransmission reliability schemes on RLC, MAC and PHY. Eventually, the data packet is transmitted via different frequency carriers to the robot, which ensures uncorrelated transmissions due to frequency diversity and even macro diversity, in DC from different sites. The method is illustrated in Figure 7.14 for both CA and DC [36, 38].

Furthermore, multi-connectivity based on dual connectivity has the potential to achieve zero *Mobility Interruption Time* (MIT) and zero *Handover Failure Rate* (HFR), i.e. *Mobility 0-0*, for user plane data and signalling messages. The handover is made

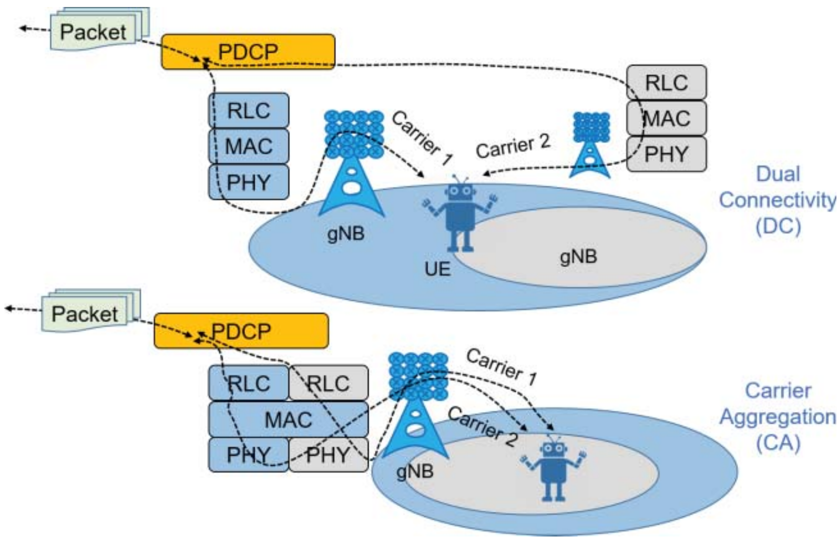

Figure 7.14 Packet duplication in DC and CA; conceptually applicable to LTE and NR [36, 39].

in two steps and during the procedure packet duplication may be also employed [40, 41]:

- *Make before break and RACH-less handover:* In R14, with a single transceiver (TRX), simultaneous transmission and reception is not possible, hence the device disconnects from the Serving Cell (SC) after receiving a Handover Command (HO CMD) and resumes only when it receives the first packet from the Target Cell (TC). The Random Access (RA) procedure can be avoided if the Time Advance (TA) is null or the same for both source and target cells, and an UL grant is sent to the device in an HO CMD, or the terminal receives it on the PDCCH from the target node (T-gNB). Using this technique, the Radio Link Failure (RLF) occurs frequently, due to interference, and the device stops transmitting packets. The improvements range from 40 ms to 5 ms, but only under certain circumstances.
- *DC-based handover:* In R15, and later releases, the device with multiple (two) TRXs can be simultaneously connected to the source and target cell. The source is removed only if the signal falls more than an additional threshold (offset) below the currently best configured gNB; the master role is swapped before the source gNB is removed from the active set; and the signalling radio bearer (SRB), i.e. control plane messages carrying uplink measurement reports and downlink reconfigurations, is established and duplicated via both master node (MN) and secondary node (SN). The NR RLF detection reuses the same mechanism as with LTE; it could be extended with a feature for "SN survival", reporting the failure of the MN via the SN and swapping the MN. If this solution was in place, the MIT and HFR would reduce to 0-0.

7.3.6 5G Deployment Scenarios

The 5G deployment scenarios using a 3GPP NSA/SA architecture configuration is depicted in Figure 7.15. All network domains, including some functionality of the RAN, may run on cloud infrastructures.

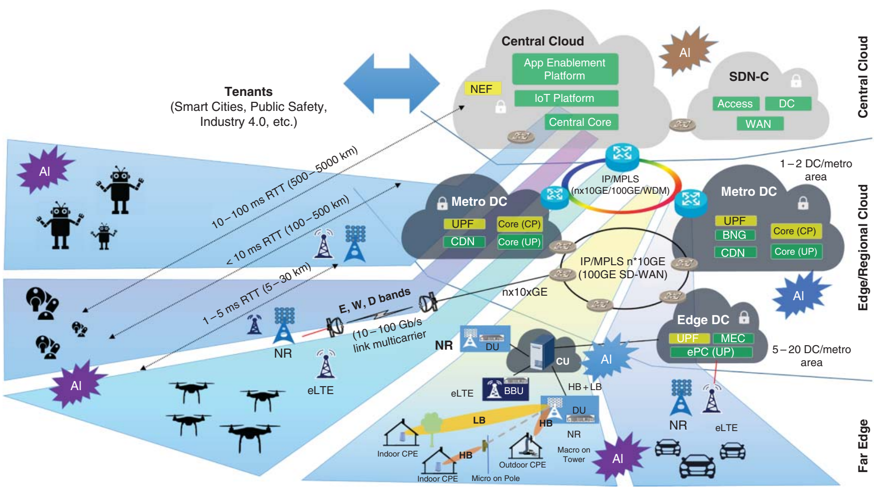

Figure 7.15 Example of 5G deployment scenario on EPC/5GC with end-to-end network slicing.

The *far edge* data centre, or point of presence (PoP), may host CU functions, as illustrated in Figure 7.6. This is the area where radio equipment (antennas, radio and base band units) are deployed.

The *edge/regional* cloud is separated from the far edge zone by a standardized (NSA Option 3x) and unified (SA Option 2/5, NSA Option 4/7) interface, see Figures 7.5 and 7.7, leaving a clear division between radio and core domains. The local break-out to a MEC server (see Figure 7.7) may be located in an edge/regional PoP.

The core network functionalities may be placed in the edge/regional and *central* clouds. The IoT and application enablement platforms reside in the central cloud, where the SDN controller of the transport network layer are also located.

The introduction of the 5G core will be based on software upgrades of the core functions instantiated in the edge/regional cloud, namely in the metro and edge data centres, as shown in Figure 7.15.

The utilization of network slices – five in Figure 7.15, with different service level agreements between tenants and Communication Service Providers (CSPs), e.g. in terms of *throughput*, *reliability*, *latency* and *mobility* – will allow the infrastructure to support a number of use cases – five in Figure 7.15, i.e. 5G for WSR; 5G for WTS; 5G for Augmented Reality (AR), Virtual Reality (VR) and Mixed Reality (MR); 5G FWA; and 5G for connected cars – over a single physical infrastructure.

In the case of Tele-healthcare, this partitioning will make the 5G business case positive for the CSP and tenants, as discussed in Section 7.4.

The expected delays between robots and far/edge (5–30 km), edge/regional (100–500 km) and central cloud (500–5000 km) are 1–5 ms, below 10 ms and 10–100 ms, respectively, as shown in Figure 7.15. Based on this, the CSP may decide the optimal location of network functions and MEC servers to meet the requirements summarized in Section 7.2 for WTS (see Figure 7.2) and WSR (Figure 7.3).

Artificial intelligence, e.g. algorithms for descriptive, predictive, prescriptive and cognitive analytics; deep learning; reasoning etc. will find application mostly in the following equipment, domain and functions, but not limited to those [23]:

- Self-Organizing Network (SON): Key capabilities, algorithms and architecture attributes within the different domains (RAN, Core, Transport etc.);
- data and application enablement platforms, i.e. big data analytics (structured data analytics, text analytics, web analytics, multimedia analytics, network analytics, mobile analytics, etc.);
- platforms for IoT and Customer Experience Management (CEM); and
- robotic platforms, vehicles, Customer Premise Equipment (CPE) and next generation devices.

7.4 Value Chain, Business Model and Business Case Calculation

In this section, we qualify and quantify the impact of robotics globally, and present an example of business model for Tele-healthcare and the corresponding business case calculation for the communication service provider and care service organization. More information on the topic may be found in [4].

7.4.1 Market Uptake for Robotic Platforms

In 2014, more than 1000 robotic platforms were sold for medical applications, primarily (about 80%) for remote-assisted surgery. Ten times more medical units have been forecast to be sold by the end of 2019 [42]. In the future, safety, better clinical outcomes and especially reduced labour costs will lead to exponential growth in demand not only for robot-assisted surgery, but in other segments of healthcare as well, such as sanitation, sterilization, lab processing and materials handling.

The presence of service robots is currently insignificant at the global level, but sales of robotic platforms to assist elderly and disabled persons will exceed 12,000 units by end of 2018 [42]. This market is expected to increase substantially over the next 20 years. In fact, looking into the future, we are likely to see hospitals, nursing homes and hospices, as well as private houses for the elderly, in developed and emerging economies, as key drivers for the widespread use and demand for wireless service robots.

By 2030, 16% of the world population will be over 60 years of age [17]. The speed of growth of ageing population is much more dramatic in developed countries. For example, in Japan, it is anticipated that by 2050, 39% of all Japanese will be above 65 years old. Under such conditions, the need of service robots for elderly care, such as physical and preventive care, as well as companionship will rapidly surge. In Australia, health also dominates public expenditure and employment. Australia spends more than 10% of GDP ($AU170.4 billion) on health, making it a prime candidate for innovation to both reduce costs of healthcare and improve outcomes [43].

As a result, the global market of personal robots, including "care-bots", driven by rapidly ageing populations, could reach up to €14.4 billion by 2022 [42]. The global total sales revenue of household and personal service robots is forecast to grow by 23.5% per annum in the 2015–2020 period. Personal care robots, priced US$1500–US$4700, could enter our personal lives, commercializing the market by 2020.

7.4.2 Business Model and Value Chain

Traditional operators will not likely offer WTS or WSR services as standalone providers. Given the required level of specialization, understanding of professionals' specific needs, an operator will need to partner with specialized sectors in healthcare, either with clinic/medical centres or suppliers of robotic platforms. Suppliers of medical robots include accessories and services, and provide leasing contracts for their robots. The operator will essentially guarantee connectivity in strict SLA with WTS/WSR providers, where the latter may be a medical centre (custom application) or a separate third party, who can provide services to multiple medical centres/clinics. The connectivity provider could adopt new tariff models by selling guaranteed URLLC services to enable new revenue models on top of only bandwidth being sold.

In our model, the value chain consists of: *third-party robot provider/operator ↔ medical clinic centre ↔ specific department ↔ patient*. The contribution of an insurance company for monetization and flow can be either through patients or directly to department in the medical centre or the medical centre itself.

7.4.3 Business Case for Service Providers

The proposed business model reflects the financial impact on a) a Mobile Network Operator to build-up a 5G Indoor Infrastructure (ID); and b) a Care Provider to deliver "robot care" services.

7.4.3.1 Assumptions

For the operator business case calculation, we assume the 5G indoor infrastructure (small cells) is deployed in hospices, residential areas and private buildings, under an existing macro coverage, e.g. LTE services. The operator's costs consist of CAPEX and related OPEX for ID deployment and backend servers. The revenue is estimated based on ARPU per robot connectivity (€50/month).

In the operator case, the Present Value (PV) of the cash flow is derived over 10 years – from 2020, when the 5G mobile system 3GPP R15 is launched to 2029 – assuming a Discount Rate (PV) of 8%, an Earnings Before Interest, Taxes, Depreciation and Amortization (EBIDTA) margin of 33%, an ARPU decline multiplier of 2%, an equipment price erosion multiplier of 8%, and an OPEX erosion multiplier of 1%.

The number of service robots and deployed indoor cells for connecting them to the backend server are reported in Table 7.2. From 2020 to 2029, the number of service robots in hospices (H), residential floors (R) and private homes (P) is expected to grow year on year by 12%, 10% and 33%, respectively.

In the case of a Care Provider, the corresponding cash flow (PV) in 2020–29 is derived assuming a Discount Rate (PV) of 8% and an EBIDTA Margin of 40%.

Other relevant parameters for the Care Provider business case calculation are reported in Table 7.3.

7.4.3.2 Business Cases Calculation

In the period 2020–29, the cash flow (PV) for the Connectivity Service Provider (Operator) and for the Care Provider, under the assumptions summarized in Section 7.4.3.1, are depicted in Figures 7.16 and 7.17, respectively.

Figure 7.16 shows an immediate Return on Investment (RoI) for the Operator: The cumulative value of the Net Present Value (NPV) of cash flow remains flat during the first year; it then soars proportional to the increase of the number of deployed service robots year on year till 2029.

The business case for the Care Provider is different, and the breakeven point proves to be in 2024, i.e. four years after the "Robot Care" launch in 2020. Then, the cumulative value of the cash flow (NPV) becomes positive and keeps rising steadily till 2029, where it reaches €2.636 million.

Although not shown in Figure 7.17, it is worth noting that the cumulative value of the cash flow (NPV) for the Care Service Provider is truly sensitive to the CAPEX per robot; e.g. if the price of each robot was set to €2500, i.e. 25% more expensive than the value reported in Table 7.3, and used for the business case calculation, the breakeven point would be in 2026, i.e. two years later!

Table 7.2 Number of service robots and indoor (ID) cells per location in 2020 [4].

Parameter	Hospices (H)	Residential floors (R)	Private homes (P)
Robots	500 (H)	200 (R)	100 (P)
ID Cells	H/20	R/10	P

Table 7.3 Assumptions for the care provider business case calculation [4].

Parameters	Value
Useful time of deployment per day [h]	12
Number of visitations, hospice, per day [#]	12
Number of visitations, residential type, per day [#]	6
Robot replacement every Nth year [#]	5
Backend servers per robot [#]	0.05
Costs	
CAPEX per robot [€]	**2,000**
OPEX per robot [€/y]	2,443
CAPEX backend server [€]	5,000
OPEX backend server [€/y]	2,500
Connectivity [€/month]	**50**
Maintenance [€/month]	75
Insurance [€/month]	75
Electricity consumption [kW/h]	65
Electricity cost [€/kWh]	0.15
Revenues	
Hospice robot, shared [€/month]	90
Residential robot, shared [€/month]	150
Private robot [€/month]	900

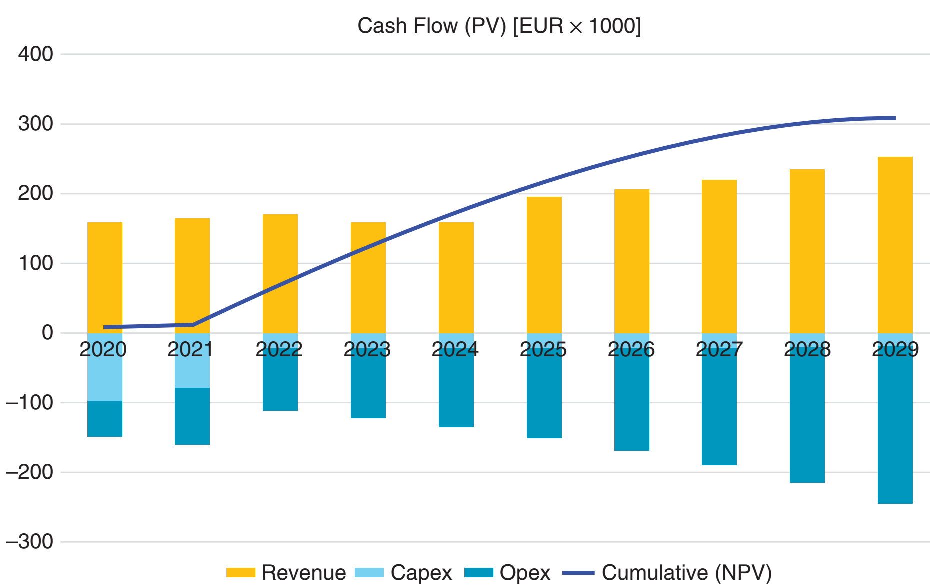

Figure 7.16 Cumulative cash flow (Net Present Value) for Connectivity Service Provider.

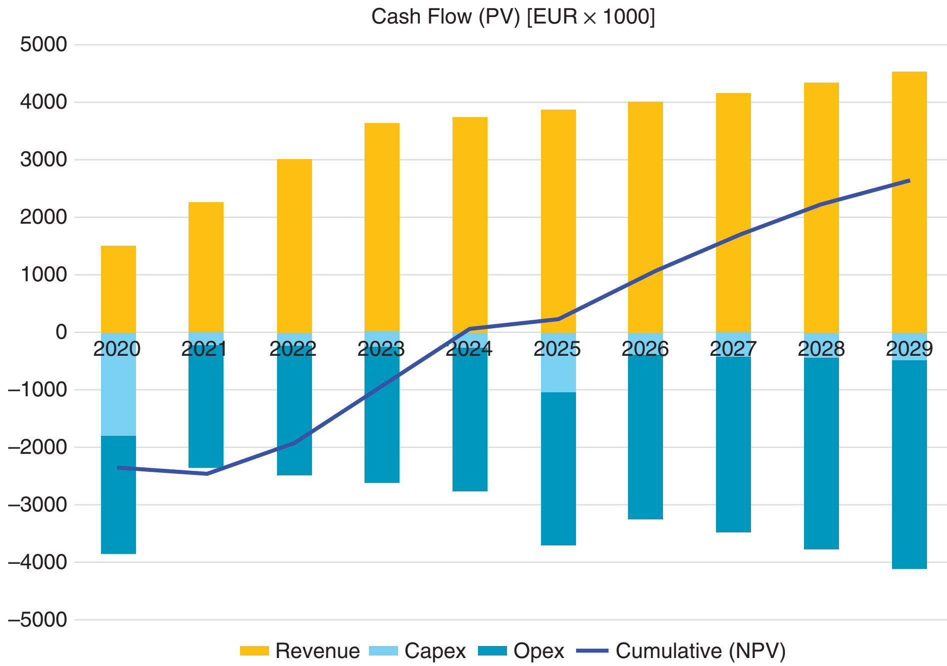

Figure 7.17 Cumulative cash flow (Net Present Value) for Robot Care Service Provider.

7.5 Conclusions

In this chapter, we have presented two examples of use cases for healthcare using robotic platforms enabled by ultra-reliable low-latency communications, which require the deployment of 5G wireless.

It should be noted that the proposed 5G wireless solutions to Wireless Tele Surgery and Wireless Service Robots, for Tele-health and Tele-care services, are applicable to many more use cases and scenarios, because the *haptic control* is inherent to a number of tactile applications, and *control loops* between reasoning servers and machines are needed for handling traffic of connected vehicles, robots for industrial processes automation, etc. [43].

As a part of this framework, we have analysed the business case for a Connectivity Provider and for a Care Provider using WSR in hospitals, hospices and related campus areas and, especially, at home (private buildings).

A more attractive business case for operators would require to support other use cases using the same physical infrastructure, in order to cover costs (especially OPEX) of a dedicated 5G system to Tele-healthcare. Network slicing could be a fundamental enabling technology to this end.

For Care Providers, the business case is quite sensitive to rising OPEX and CAPEX per robot, including its replacement. The business case will unquestionably fly when more powerful robotic platforms will help save more costs of care, and their price will be much more accessible to consumers. Business to Business (B2B) is where a RoI business would be easily made, as long as the price per month to lease the robot was much cheaper than hiring people, as confirmed in [44].

Ultimately, we want to state clearly that the assumptions and views reported herein are solely those of the authors, and do not necessarily represent those of their affiliates.

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