The 5G Evolution:
3GPP Releases 16 — 17

JAN 2020

TABLE OF CONTENTS

1 INTRODUCTION

5G, or "Fifth Generation" mobile wireless technologies, are projected to be a disruptive force central to the development of the Fourth Industrial Revolution. These sets of technologies are expected to be a major driver for a dizzying array of groundbreaking digital services and changes that will sweep across the world over the next decade. The transition to 5G will transform our lives, our economy, our jobs, and our industries as evidence of early signs emerges each day.

For instance, wearables such as cellular smart watches or connected glasses are evolving to become self-contained mobile computing devices. Autonomous vehicles, one of the most highly anticipated 5G technologies, are expected to help us reclaim commute time for new activities in our lives. Healthcare is changing as services like remote monitoring and Telemedicine provide new opportunities for care. Drones will be used for transportation, surveillance and rescue operations. Robots and Artificial Intelligence (AI) will create new dynamics for both humans and machines. Cellular to Everything (C-V2X) connectivity expected to save lives and increase transportation efficiency. Automated end-to-end manufacturing processes enabled by 5G connectivity.

The scale of 5G's impact is expected to be staggering. One glance at industry analyst forecasts provides us with some insight:

- *5 Billion people forecast to be accessing the internet via mobile by 2025*
- *5G coverage will roll out rapidly to cover 40 percent of the global population by 2025*
- *5G will account for almost 1 in 7 connections (14 percent) by 2025*
- *Global penetration rate for all mobile connections will reach 110 percent worldwide by 2025*
- *9 Billion mobile connections by 2025*
- *5.9 Billion unique subscribers in 2025*
- *25 Billion Internet of Things devices globally in 2025*
  (11.4 Billion Consumer Internet of Things (IoT); 13.7 Billion Industrial IoT in 2025)
- *Global Mobile Annual Revenue of $1.1 Trillion in 2025*
- *25 Billion Internet of Things devices globally in 2025*[1]

These are clearly enormous numbers. But while the promise of 5G is high, analysts believe the expected results from 5G technology commercial deployments are just beginning and will take some time. The wireless industry is virtualizing with Multi-Access Edge Computing (MEC) looking to redefine computing itself. The mega-networks of billions of connected things and people of the future will require a major shift in network operations and management.

These changes are being enabled through the Long-Term Evolution (LTE) and 5G specifications created by hundreds of contributing scientists and engineers at the Third Generation Partnership Project (3GPP). This white paper will provide you with some additional background into what 3GPP has in store for future technology releases for LTE and 5G.

2 BACKGROUND

The 3rd Generation Partnership Project (3GPP) unites seven telecommunications standard development organizations (ARIB, ATIS, CCSA, ETSI, TSDSI, TTA, TTC), known as "Organizational Partners" and

[1] *Mobile World Congress Daily*, GSMA Intelligence. 1 March 2018.

provides their members with a stable environment to produce the reports and specifications that define 3GPP technologies.

The project covers cellular telecommunications technologies, including radio-access, core network and service capabilities, which provide a complete system description for mobile telecommunications. These 3GPP specifications also provide hooks for non-radio access to the core network, and for interworking with non-3GPP networks. 3GPP specifications and studies are contribution-driven, by member companies, in Working Groups and at the Technical Specification Group (TSG) level.

The 3GPP technologies from these groups are constantly evolving through Generations of commercial cellular / mobile systems. With LTE, LTE-Advanced, LTE-Advanced Pro and 5G work - 3GPP has become the focal point for most mobile systems beyond 3G.

Although these Generations have become an adequate descriptor for the type of network under discussion, real progress on 3GPP standards is measured by the milestones achieved in particular Releases. New features are 'functionality frozen' and are ready for implementation when a Release is completed. 3GPP works on several Releases in parallel, starting future work well in advance of the completion of the current Release. Although this adds some complexity to the work of the groups, such a way of working ensures that progress is continuous & stable. This white paper provides a summary of the progress of the 3GPP technical features.

2.1 GLOBAL MARKET TRENDS

At of the end of December 2019, there are nine billion mobile connections globally, the vast majority of which are LTE. With 5.22 billion LTE connections, that equates to a global penetration rate of 118% and an LTE penetration rate of 68%[2], based on a world population of 7.7 billion people.

5G network connection numbers are also healthy, currently surging with over 5.2 million 5G subscriptions projected for the end of the year. This number is expected to increase to 1.9 billion at the end of 2024[3], which represents up to 21% of the world's population. The first 5G smartphones were launched in December 2018 to coincide with the launch of 5G networks in South Korea. Smart phones for all three 5G bands (low-band, mid-band and high-band) are expected to be available before the end of 2019.

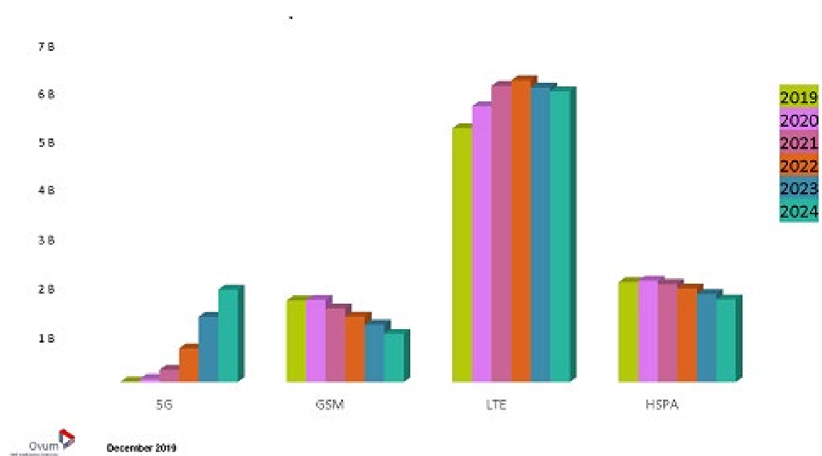

Figure 2.1. Forecasted Connections by Wireless Technology

[2] OVUM (WCIS) September 2019
[3] IBID

Figure 2.1 shows the growth of both LTE and 5G technologies as GSM and HSPA decline over the next six years, with LTE reaching a peak of 6.2 billion connections by 2022 before beginning to slowly decline as 5G gains more popularity.

Overall, 5G network deployment is growing far more rapidly than any other previous generation. A total of 51 commercial 5G networks have already been deployed as of December 18, 2019, with 67 commercial networks forecast by the end of the 2020. This is still a forecast as not all operators have announced their year-end launches as of this printing.

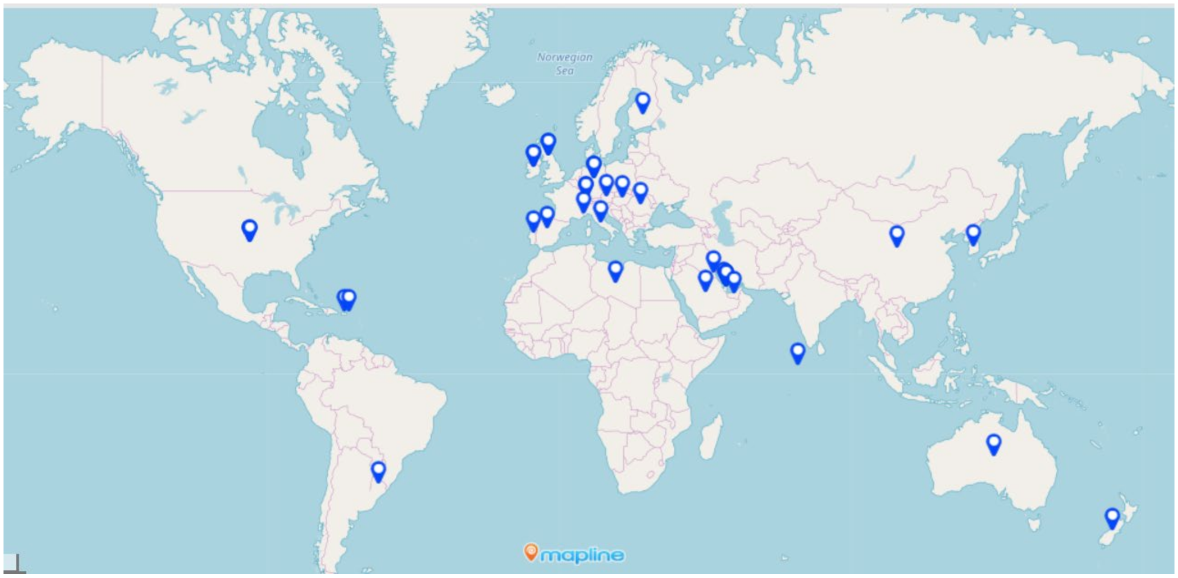

Figure 2.2. Global 5G Commercial Deployments Reported by TeleGeography, Dec 2019[4]

In addition to mobile subscriptions, fixed wireless access (FWA) subscriptions and cellular IoT connections are also increasing. There are currently approximately one billion cellular IoT connections, which is expected to increase to more than four billion in 2024.

Currently, the majority of cellular IoT connections rely on legacy 2G/3G technology. This technology will play a substantial part in 2024, with massive-IoT based on NB-IoT and Cat-M LTE devices predicted to constitute more than 40% of all cellular IoT connections. Broadband IoT is characterized by wide-area use cases requiring higher throughput, lower latency, and larger data volumes. It will contribute nearly 35%, with 4G/LTE connecting the majority of this. Critical-IoT with requirements on extremely low latency and ultra-high reliability will contribute only a small fraction to the total cellular IoT connections even in 2024.

2.2 EXTENSION TO NEW USE CASES

Extending new use cases beyond initial mobile broadband use cases is a main component of not only the wireless access evolution, but also the evolution of LTE and new NR radio-access technology. This includes massive MTC (machine type communication) use cases characterized by requirements on very low device cost and very long device battery life, often also associated with a requirement on very wide-area coverage.

It also includes critical MTC applications, such as industrial process automation and manufacturing, energy distribution and intelligent transport systems. These applications are typically associated with requirements

[4] TeleGeography.

for very high communication reliability and the possibility for very low latency. In the standardization community, both within 3GPP and International Telecommunications Union (ITU), critical MTC applications are often referred to as Ultra-reliable low-latency communication (URLLC).

For information on the plethora of possible new use cases refer to 5G Americas White Paper, 5G Services Innovation, 2019.

2.3 3GPP TIMELINE

3GPP uses a system of parallel "Releases" which provide developers with a stable platform for the implementation of features at a given point and then allow for the addition of new functionality in subsequent Releases. Figure 2.3 illustrates the timeline for the most recent and near-time-future 3GPP Releases.

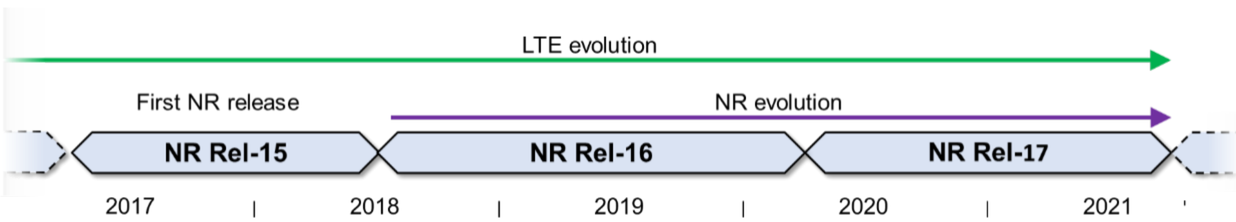

Figure 2.3. 3GPP timeline for Release 15, 16, and 17.

The 3GPP TSG Radio Access Network (TSG RAN) is responsible for the definition of the functions, requirements and involving radio performance, physical layer, and definitions of the operation and maintenance requirements of conformance testing for User Equipment and Base Stations.

Release 15, finalized in June 2018, included the first version of the 5G/NR technology, together with a set of new features as part of the LTE evolution. The current main activity of 3GPP is Release 16. It includes several major enhancements and extensions to NR as part of the first step in the NR evolution, together with additional LTE extensions and enhancements. Release-16 finalization is targeted for March 2020, with the physical layer specifications already finalized in December of 2019. The content of Release 16 is described in more details in Section 3.1.2 and 3.2.2 for LTE and NR respectively.

Release 17 will be the main 3GPP activity during 2020 and 2021, with target finalization in July 2021. Initial discussions on the content of Release 17 were held at RAN #84 (June 2019), with additional discussions taking place at RAN# 85 (September 2019). After RAN#84, email discussions on some possible Release 17 areas were initiated. These were complemented by further email discussions on additional possible Release-17 areas, initiated after RAN #85. The decisions on a set of study/work items for 3GPP Release 17 were made at RAN #86 (December 2019).

Overviews of key Release-17 features are provided in Section 3.1.3 and 3.2.3 for LTE and NR respectively.

2.4 ITU-R AND THE 3GPP IMT-2020 SUBMISSION

The ITU allocates global radio spectrum and satellite orbits, developing the technical standards that ensure that networks and technologies can seamlessly interconnect, and strive to improve access to information and communications technologies to underserved communities worldwide. Since the emergence of 3G mobile communication, each generation of wireless communication has been associated with a specific International Mobile Telecommunications (IMT) technology within ITU-R, the ITU Radiocommunication Sector.

Beginning in 2000, 3G wireless access corresponded to IMT-2000, the global standard for 3G that has opened the way to enabling innovative applications and services (e.g. multimedia entertainment, infotainment and location-based services, among others), while 4G wireless access corresponds to IMT-Advanced. Finalizing the 3GPP submission/proposal for IMT-2020 (the IMT technology corresponding to 5G wireless access) has been a priority throughout 2019.

Figure 2.4 illustrates the ITU timeline for IMT-2020 and the corresponding 3GPP submissions. After the finalization of the IMT-2020 requirements in mid-2017, ITU-R opened up for the submission of IMT-2020 proposals. 3GPP made an initial submission to ITU in December 2017 and a final submission in June 2019.[5]

Figure 2.4. Timeline for IMT-2020 in ITU and 3GPP submission

The overall 3GPP IMT-2020 submission consists of two separate and independent submissions:

- NR submitted by itself as a *Radio Interface Technology* (RIT) proposal for IMT-2020
- NR and E-UTRA/LTE jointly submitted as two *component RITs* of a *Set of Radio Interface Technologies* (SRIT) proposal for IMT-2020.

In both cases, features up to and including 3GPP Release 16 are included in the submission.

The self-evaluation carried out by 3GPP concluded that both the NR-based RIT and the LTE/NR-based SRIT fulfill all IMT-2020 requirements for the three defined usage scenarios (eMBB, mMTC and URLLC) and for all defined test environments.

3 RADIO-ACCESS TECHNOLOGIES

A Radio Access Technology or (RAT) is the underlying physical connection method for a radio-based communication network. Many modern mobile phones support several RATs in one device such as Bluetooth, Wi-Fi, and GSM, UMTS, LTE or 5G NR (New Radio). With respect to this white paper, 3GPP's current areas of focus involve LTE and 5G NR.

3.1 LTE

Long-Term Evolution (LTE) is a standard for wireless broadband communication for mobile devices and data terminals, based on the GSM/EDGE and UMTS/HSPA technologies. It increases the capacity and speed using a different radio interface together with core network improvements.

[5] 3GPP RP-191533, "Draft LTI on 3GPP final technology submission of 3GPP 5G solutions for IMT-2020"

3.1.1 BACKGROUND

Work on the LTE radio-access technology was initiated in 3GPP in November 2004 with the first LTE specifications being finalized in December 2007 as part of 3GPP Release 8. Main characteristics of the first LTE release included:

- Support for wider transmission bandwidths up to 20 MHz
- Support for both frequency division duplex (FDD) and time-division duplex (TDD), enabling operation in both paired and unpaired spectrum within the same radio-access technology
- Orthogonal frequency division multiplexing OFDM-based transmission scheme (conventional OFDM for downlink, DFT-pre-coded OFDM for uplink)
- Integrated support for downlink spatial multiplexing with up to four transmission layers to a single device
- Support for lower radio-access latency compared to earlier 3GPP technologies

The LTE radio-access technology has evolved in many areas with each subsequent release, leading to further enhanced performance and extended capabilities of the technology.

3.1.1.1 SPECTRUM FLEXIBILITY

LTE *carrier aggregation* was introduced in Release 10 as a tool for increasing the overall transmission bandwidth and, consequently, the achievable data rates. Release-10 carrier aggregation supported aggregation of up to five component carriers. This was later extended in Release 13 to up to 32 component carriers, mainly targeting operation in unlicensed spectrum.

Licensed Assisted Access (LAA) was introduced in Release 13, providing the possibility for LTE transmissions in unlicensed spectrum as well. In the case of LAA and LTE, additional carriers in unlicensed spectrum can complement carriers in licensed spectrum by providing additional capacity and enabling higher data rates.

3.1.1.2 MULTI-ANTENNA ENHANCEMENTS

In Release 10, LTE downlink spatial multiplexing was extended to support up to eight transmission layers. The release also introduced an enhanced reference signal structure, separating the functions of channel estimation and channel-state acquisition. Release 10 also introduced support for LTE uplink spatial multiplexing with up to four transmission layers.

LTE *coordinated multipoint transmission* (CoMP) was introduced in 3GPP Release 11 and was further extended to deployments with less ideal backhaul in Release 12.

3.1.1.3 ENHANCED SUPPORT FOR DENSIFICATION, SMALL CELLS, AND HETEROGENEOUS DEPLOYMENTS

Heterogeneous networks are emerging as a prominent deployment structure. These networks provide full-area coverage with one or multiple dense layers of small cells deployed for capacity and high data rates under a macro layer. Several features specifically targeting small-cell deployments and heterogeneous deployments have been introduced as part of the continuing LTE evolution:

- New means to handle the interference between different cell layers of an heterogenous deployment were introduced in Release 10.

- Enhancements to improve inter-layer mobility were introduced in Release 12.
- LTE *dual connectivity* was introduced in Release 13. With dual-connectivity, a device can be connected to a dense small-cell layer providing high capacity and high data rates and, simultaneously, to an overlaid macro layer providing robust connectivity.
- Compared to a macro layer, the traffic load per cell within a small-cell layer varies more dynamically, with a cell relatively often being completely void of active users. Release 12 therefore introduced the concept of *small-cell on/off* as a mechanism to more dynamically turn-on/turn-off individual cells depending on the traffic situation in order to reduce the average interference level and enhance network energy efficiency.
- *Dynamic TDD* introduced in 3GPP Release 11 allows for more dynamic variation of the downlink/uplink ratio in case of operation in unpaired spectrum. This provides a tool to more dynamically adjust the downlink/uplink capacity ratio to match the instantaneous traffic situation on the different link directions.

3.1.1.4 NEW USE CASES

The first releases of LTE fully focused on the mobile broadband (MBB) use case. However, later 3GPP releases have extended LTE towards several new use cases beyond MBB:

- Enhanced support for so-called massive machine type communication (MTC), targeting applications that typically require very low-cost devices with very long battery life has been in focus for several 3GPP releases and following two different tracks.
    - Release 12 introduced *LTE-MTC*, that is, a set of integrated LTE features specifically targeting enhanced support for massive MTC.
    - Partly in parallel to LTE-MTC, Rlease 13 introduced *Narrowband IoT* (NB-IoT). NB-IoT can be seen as a separate radio-access technology that is very much aligned with LTE, thus enabling, for example, NB-IoT/LTE spectrum coexistence, that is, the deployment of NB-IoT within spectrum already used by an LTE carrier.

Both LTE-MTC and NB-IoT have, since their introduction, been further enhanced and extended in subsequent LTE releases, including Release 16 and also Release 17, see further below.

- *Direct device-to-device* (D2D) communication, targeting both public safety and commercial use cases, was introduced in Release 12 and was further enhanced with device-based relaying functionality in Release 13.
- *V2X* (Vehicular-to-Vehicular, Vehicular-to-Infra-structure, Vehicular-to-Network) communication is seen as an important new use case for cellular networks. Relevant services include, for example, enhanced traffic safety, platooning, and general sharing of information between vehicles as well as between vehicles and the cloud. 3GPP Release 14 first introduced LTE enhancements in this area, including quality of service enhancements and V2V support based on the direct device-to-device feature introduced in Release 12.
- The *short TTI* feature, enabling lower latency by reducing the minimum TTI to less than 0.2 ms was introduced in 3GPP Release 15 as a tool to better serve delay-critical use cases.

3.1.2 LTE EVOLUTION IN RELEASE 16

3GPP Release 16 includes several LTE-related features developed within six different work items: enhancements for LTE-MTC, NB-IoT, DL MIMO efficiency, mobility, performance in high speed scenarios, and 5G terrestrial broadcasts.

3.1.2.1 ENHANCEMENTS FOR LTE-MTC

LTE-MTC is a low-power wide area technology that supports IoT through lower device complexity and provides extended coverage, while allowing the reuse of the LTE installed base.

It was initially introduced in 3GPP Release 12 but has extended in subsequent releases. LTE-based technologies (LTE-MTC and NB-IoT) will provide the foundation for cellular-based massive MTC in the future. The 3GPP Release-16 work item *Additional MTC Enhancements for LTE*[6] introduces several new features:

- Increased spectral efficiency for massive MTC transmissions and reduced energy consumption for massive-MTC devices, enabled by:
  - enhanced mobile-terminated early-data transmission and UE-group wake-up signaling
  - uplink transmission using preconfigured resources in idle mode, allowing the device to avoid time-consuming random-access procedures
  - multi-transport-block scheduling in both the downlink and uplink transmission directions, reducing the control signaling overhead
  - enhanced downlink-quality reporting from the device in both idle and connected mode, enabling improved link adaptation
  - relaxed serving-cell measurement requirements for low-mobility devices
- Performance improvements for ordinary LTE devices that make use of the LTE-MTC coverage enhancements
- Higher efficiency in case of LTE-MTC standalone operation for cells only providing LTE-MTC access but not, for example, LTE-based mobile-broadband access

In the future, operators might migrate from LTE to NR for mobile-broadband services but may need to maintain LTE operations to provide service to legacy massive-MTC devices. In these cases, it is important to enable efficient spectrum co-existence between NR and LTE-MTC. Consequently, the 3GPP Release-16 activities also include performance improvements in terms of NR/LTE-MTC co-existence. The 3GPP Release-16 activities also include features related to the enabling of LTE-MTC devices to connect to the 5G core network (5GC).

3.1.2.2 ENHANCEMENTS FOR NB-IOT

Narrowband Internet of Things (NB-IoT) is a Low Power Wide Area Network (LPWAN) radio technology standard developed by 3GPP to enable a wide range of cellular devices and services. As described above, NB-IoT was introduced as an LTE-based radio-access technology in 3GPP Release 13 with further enhancements introduced in subsequent releases. Similar to LTE-MTC, NB-IoT will be a continually important tool for massive MTC. The continued evolution of NB-IoT is also an important 3GPP activity. In fact, many Release-16 enhancements and extensions of LTE-MTC are also pursued within the context of NB-IoT as part of the Release-16 work item *Additional Enhancements for NB-IoT*[7]. More specifically, the work item includes:

- Increased spectral efficiency for NB-IoT transmissions and reduced energy consumption for NB-IoT devices enabled by:
  - enhanced mobile-terminated early-data transmission and UE-group wake-up signaling

[6] 3GPP RP-11356 “Additional MTC Enhancements for LTE” (Work-item description)
[7] 3GPP RP-191576 “Additional Enhancements for NB-IoT” (Work-item description)

    - uplink transmission using preconfigured resources in idle mode, allowing the device to avoid time-consuming random-access procedures
    - multi-transport-block scheduling in both the downlink and uplink transmission directions, reducing the control-signaling overhead
    - enhanced downlink-quality reporting from the device in both idle and connected mode, enabling improved link adaptation
- Enhanced support for network management, including SON support for reporting of Cell Global Identity and random-access performance
- Mobility enhancements by means of new system information to assist idle-mode inter-RAT cell selection for NB-IoT to and from LTE, LTE-MTC and GERAN

Similar to LTE-MTC, the 3GPP Release-16 activities on NB-IoT also include performance improvements in terms of NR/NB-IoT co-existence, as well as the support for connecting NB-IoT devices to 5GC.

3.1.2.3 DL MIMO EFFICIENCY ENHANCEMENTS

One of the important enabling features of LTE-Advanced to meet IMT-Advanced downlink performance requirements is multi-user MIMO, where a transmitter serves multiple users simultaneously on the same frequency resource, primarily relying on spatial separation. DL MIMO refers to MIMO focused on downlink performance.

By means of the *Enhanced Beam forming/Full-Dimension*-MIMO (EB/FD-MIMO) feature of 3GPP Release 13 and Release 14, LTE already includes support for efficient massive MIMO. However, in order to enable the full potential of LTE EB/FD-MIMO, additional enhancements are introduced as part of 3GPP Release 16. More specifically, the Release-16 work item *DL MIMO Efficiency Enhancements for LTE*[8] aims to enhance the capacity and coverage of SRS (Sounding Reference Signal) transmission targeting massive MIMO for LTE TDD. This includes:

- Allowing for SRS transmission over more than one uplink symbol per subframe. This enables improved SRS capacity (SRS transmission of different UEs in different symbols) as well as extended SRS coverage (SRS transmission of a single UE over multiple symbols, that is, over longer time).
- Introducing the concept of *virtual cell ID* for SRS. This enables further improved SRS capacity by allowing different UEs within the same physical cell to occupy the same SRS time-frequency resource and instead be separated in the code domain by the use of different SRS sequences.

3.1.2.4 MOBILITY ENHANCEMENTS

A random-access channel (RACH) is a shared channel used by wireless terminals to access the mobile network for call setup and bursty data transmission. Whenever mobile wants to make an MO (Mobile Originating) call it schedules the RACH.

As part of 3GPP Release 14, LTE handover latency was improved/reduced by introducing *RACH-less* handover and *Make-Before-Break* handover solutions. However, RACH-less handover is only applicable when the current uplink timing can be reused in the target cell. Furthermore, the Release-14 make-before-break handover is only applicable for UEs with dual receiver chains. Thus, even with the Release-14 enhancements, a non-negligible handover interruption time still exists in many important scenarios.

[8] 3GPP RP-182901 “DL MIMO Efficiency Enhancements for LTE” (Work-item description)

For these reasons, additional LTE mobility enhancements were introduced in 3GPP Release 16 as part of the work item *Even further Mobility enhancement in E-UTRAN*[9] with the following objectives:

- To further reduce user data interruption during handover, with a target to reach as close as possible to 0 ms interruption time
- To further improve the handover robustness

An improved handover procedure known as *"enhanced make-before-break handover*" or "*Dual active protocol stack solution"* (DAPS) has been specified to reduce handover interruption time. DAPS reduces interruption during handover close to 0 ms, that is, in line with the target, by maintaining the source cell radio link (including data flow) while establishing the target cell radio link.

A *conditional handover* procedure has also been specified as part of Release 16 to improve handover robustness. At conditional handover, the handover command is transmitted with a triggering condition in advance to avoid poor cell-edge radio conditions. The handover command may include more than one potential target cell. When the triggering condition for a potential target cell is fulfilled, the UE executes the handover to that particular target cell.

3.1.2.5 FURTHER PERFORMANCE ENHANCEMENTS IN HIGH-SPEED SCENARIO

The 3GPP Release-14 work item *Performance enhancements for high speed scenario in LTE* improved the mobility and throughput performance under high speed up to and above 350km/h, by enhancing the requirements for UE Radio Resource Management (RRM), UE demodulation, and base station (PRACH) demodulation.

The Release-16 work item *Further performance enhancement for LTE in high speed scenario*[10] extends the enhancements relative to Release 14 including:

- Extending to even higher speed (up to 500 km/h), targeting, for example, very-high-speed trains
- Extending the enhanced RRM/demodulation requirements to the carrier aggregation scenario (Release 14 only considered the non-carrier aggregation (CA) scenario).

3.1.2.6 LTE-BASED 5G TERRESTRIAL BROADCAST

Multimedia Broadcast Multicast Services (MBMS) is a point-to-multipoint interface specification for existing and upcoming 3GPP cellular networks, which is designed to provide efficient delivery of broadcast and multicast services, both within a cell as well as within the core network. For broadcast transmission across multiple cells, it defines transmission via single-frequency network configurations. The specification is referred to as Evolved Multimedia Broadcast Multicast Services (eMBMS) when transmissions are delivered through an LTE (Long-Term Evolution) network. eMBMS is also known as LTE Broadcast.

Based on studies on to what extent the 3GPP Release-14 LTE MBMS meets the 5G requirements for dedicated broadcast, 3GPP is currently carrying out a Release-16 work item *LTE-based 5G terrestrial broadcast*[11] with the objective to define additional numerologies for the PMCH (Physical Multicast Channel). This includes:

[9] 3GPP RP-190921 "Even further Mobility Enhancements in E_UTRAN" (Work-item description)
[10] 3GPP RP-181482 "Performance enhancements for high-speed scenario in LTE" (Work-item description)
[11] 3GPP RP-190731 "LTE-based 5G Terrestrial Broadcast" (Work-item description)

- New numerology for PMCH targeting rooftop reception in MPMT (Medium-Power/ Medium-Tower) and HPHT (High-Power/High-Tower) scenarios. The new numerology will have a cyclic prefix length of at least 300μs and a core OFDM symbol duration of at least 2.4ms. This is anticipated to enable SNR gains in the range 5-15 dB and spectral efficiency gains of 100-500%.
- New numerology with 100 μs cyclic prefix and 400 μs core symbol duration for support of mobility up to 250km/h.

3.1.3 FURTHER LTE EVOLUTION IN RELEASE 17

With regards to LTE, the Release-17 activities will be relatively limited due to the growing maturity of the LTE radio-access technology. Currently, the only agreed-upon Release-17 work item on LTE will focus on further enhancements in the areas of LTE-MTC and NB-IoT, in line with the expected long-term use of LTE-based technology to serve massive-MTC applications.[12] The aim is for further broadening of the use cases for cellular LPWA and to address lessons drawn from existing deployments and trials. The work item will include 16-QAM modulation for NB-IoT and the possibility for 14 HARQ processes for half-duplex LTE-MTC where, in both cases, the aim is to enable higher peak data rates. The work item will also include the support for faster recovery from radio link failures and enhanced NB-IoT carrier selection.

Separately, 3GPP will carry out a study on the possibility and required specification updates to support NB-IoT and LTE-MTC.[13] The aim of this possible specification would be to provide IoT connectivity in very remote areas with low or no cellular connectivity.

3.2 NEW RADIO (NR)

5G New Radio (NR) is the global standard for a unified, more capable 5G wireless air interface. It will deliver significantly faster and more responsive mobile broadband experiences and extend mobile technology to connect and redefine a multitude of new industries.

3.2.1 NR - CURRENT STATUS

Technical work on the NR radio-access technology was initiated in 3GPP in the spring of 2016 based on a kick-off workshop in the fall of 2015. The first NR specifications—limited to non-stand-alone operation where the NR carrier always operates together with an LTE carrier—was finalized in December 2018, with stand-alone operation supported in the June-2018 version of Release 15.

A main characteristic of NR is the substantial expansion in terms of the range of spectrum in which the radio-access technology can be deployed, with operation from below 1 GHz up to more than 40 GHz supported already in the first NR release.[14] This spectrum flexibility is enabled by a scalable OFDM numerology and inherent support for massive beamforming.

Other key features of NR include:

- Further reduced latency (compared to, for example, LTE), enabled by:
  - Shorter slots
  - Possibility for transmission over part of a slot, sometimes referred to as "mini-slot" transmission

[12] 3GPP RP-193264 "Rel-17 enhancements for NB-IoT and LTE-MTC" (work-item description)
[13] 3GPP RP-193235 "Study on NB-IoT/eMTC support for Non-Terrestrial Network" (study-item description)
[14] Formally, the core specification supports operation up to 52.6 GHz.

    - Faster Hybrid ARQ retransmissions
- Significantly more “lean” transmission, for example, due to significantly less always-on signals, leading to higher spectral efficiency as well as enabling higher network energy performance
- Possibility for tight interworking with LTE including LTE/NR dual-connectivity (simultaneous connectivity via LTE and NR) as well as spectrum co-existence (the possibility to deploy NR on top of LTE in the same spectrum). The latter is enabled by the OFDM-based transmission scheme with an LTE-compatible (15 kHz-based) numerology

3.2.2 NR EVOLUTION IN RELEASE 16

Release 15 was revolutionary for introducing a brand-new air interface but Release 16 is an evolutionary development targeting new verticals by improving the capacity and operation of existing features.

The features being developed for NR Release 16 can be roughly divided into two groups, as seen in Table 3.1:

- Features that expand NR to new verticals such as the transport industry, industrial IoT, manufacturing, enterprise, automobile, etc.
- Features that enhance capacity and improve the operation efficiency of the wireless networks

Vertical Expansion		Capacity and Operational Efficiency Enhancement	
• IIoT (Industrial IoT) • URLLC • 2-Step RACH	• NR Positioning • NR Unlicensed • V2X	• MIMO Enhancements • MR-DC • Integrated Access and Backhaul (IAB)	• Mobility Enhancements • cross link interference (CLI)/remote interference management (RIM) • UE Power Savings

Table 3.1. Main Features of NR Release 16

Release-16 NR started in the RAN working groups in early 2018 with the study item phase and the work item phase following in early 2019. It is expected that the physical layer aspects will be complete by the end of 2019. The higher layer aspects and ASN.1 of NR Release 16 are expected to be completed during the first half of 2020. Figure 3.1 shows the Release-16 NR timeline.

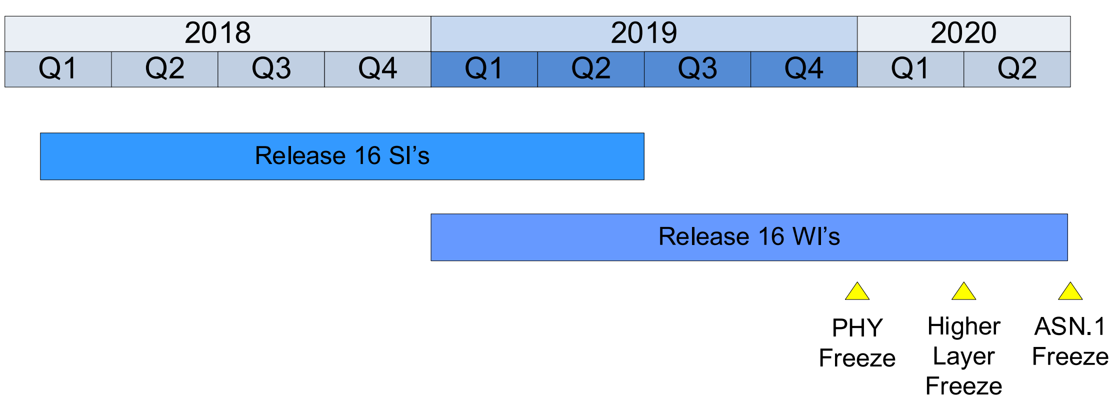

Figure 3.1. NR Release 16 timeline.

3.2.2.1 MIMO ENHANCEMENTS

Release-15 NR introduced a scalable and very flexible MIMO framework that can be further enhanced in later releases. The Release-15 MIMO framework supports MIMO across sub-6GHz frequencies and mmWave frequencies, with a plethora of antenna elements and different transceiver architectures supporting digital, hybrid, and analog transceivers. The Release-15 MIMO framework introduced the following capabilities:

- Support of beam-based operation, which is required for mmWaves
- Scalable and flexible CSI codebook with up to 32 ports and an RS design including CSI-RS, DMRS and SRS.
- CSI type I codebook providing basic closed-loop MIMO support
- CSI type II (high resolution) codebook which brings significant gain (at least 30%) over LTE and fits Multi-User-MIMO (MU-MIMO) operation.

Despite the performance, coverage and efficiency improvements of the Release-15 MIMO framework, its limitations are being addressed by the Release-16 work item *Enhancements on MIMO for NR*.[15] The work item includes the following enhancements/extensions:

- Enhancements to CSI type II codebook for MU-MIMO support
    - Overhead reduction by compressing the CSI report in the frequency domain.
    - Extending the CSI type II codebook to rank larger than two.
- Multi-TRP/Multi-Panel transmission enhancements for different backhaul assumption (ideal and non-ideal) and for both inter-cell and intra-cell multi-TRP transmission. This includes:
    - Downlink control signaling for non-coherent joint transmission. Two designs are considered; single PDCCH from one TRP scheduling PDSCH transmissions from multiple TRPs, and multiple PDCCH with each TRP having one PDCCH transmission scheduling the corresponding PDSCH transmission, see Figure 3.2
    - Uplink control signaling for supporting non-coherent joint transmission.
    - Multi-TRP for URLLC. Figure 3.3 shows an example of how multiple TRPs can enhance reliability by replicating transmissions, if one TRP is blocked the signal can still be received from the other TRP.
    - At most two TRPs/panels can be used for simultaneous multi-TRP/panel reception in Release 16
- Multi-beam operation enhancements primarily targeting FR2 (mmWaves). This includes:
    - Reduced latency and overhead, by avoiding beam tracking via RRC
    - Beam failure recovery for Scell
    - Measurement and reporting of L1-SINR
- Uplink full-Tx-power transmissions with multiple power amplifiers
- Definition of new low-PAPR reference signals
    - New sequences for PDSCH and PUSCH DMRS
    - New DMRS sequences for PI/2-BPSK-based PUSCH and PUCCH.

[15] 3GPP RP-182863 "Enhancements on MIMO for NR" (Work-item description)

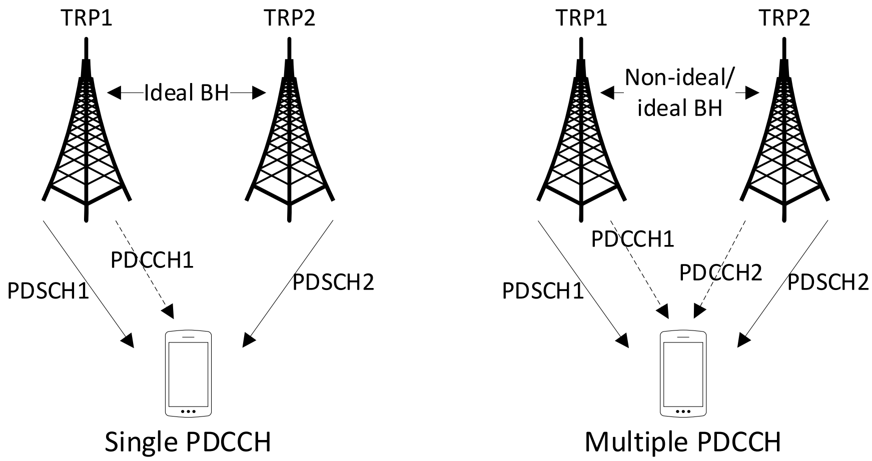

Figure 3.2. Support of single PDCCH and multiple PDCCH for Multi-TRP transmission.

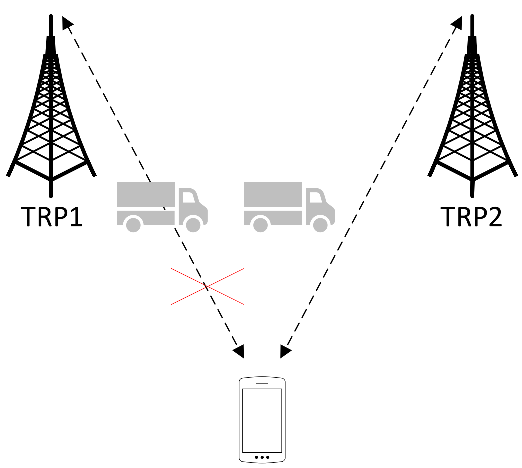

Figure 3.3. Multi-TRP for enhancing URLLC operation.

3.2.2.2 INTEGRATED ACCESS AND BACKHAUL

Integrated Access and Backhaul[16] supports wireless backhaul and relay links in-band or out-of-band with access links, as shown in Figure 3.4. Significant NR bandwidth can be split between access and backhaul links, especially in mmWaves.

[16] 3GPP RP-191558 "Integrated Access and Backhaul for NR" (Work-item description)

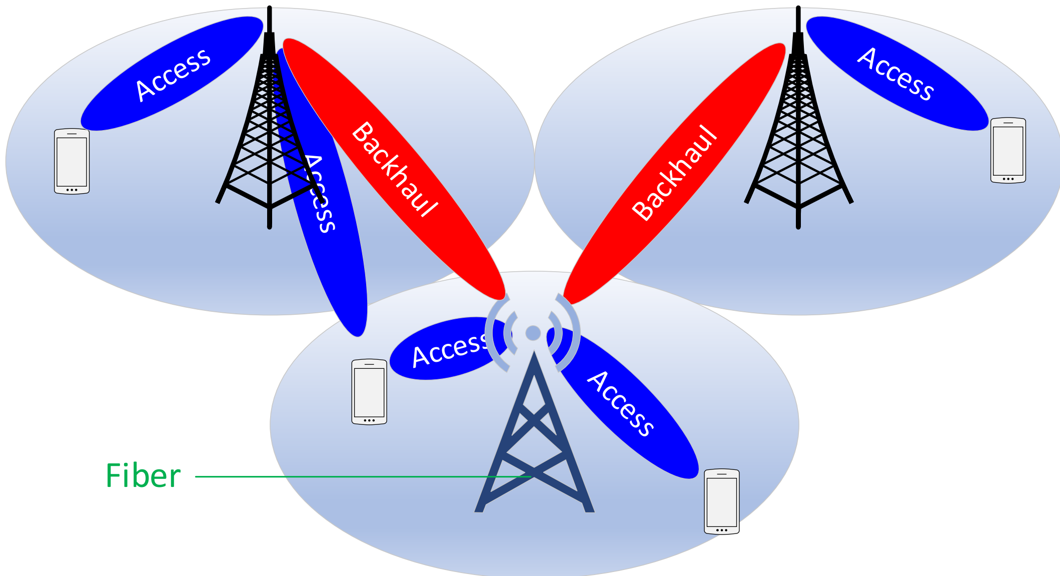

Figure 3.4. IAB.

The primary goal of IAB is to:

- Improve capacity by supporting networks with a higher density of access points in areas with only sparse fiber availability.
- Improve coverage by extending the range of the wireless network and by providing coverage for isolated coverage gaps. For example, if the UE is behind a building (as shown in Figure 3.5), an access point can provide coverage to that UE with the access point being connected wirelessly to the donor cell.
- Provide indoor coverage, for example, with an IAB access point on top of a building that serves users within the building.

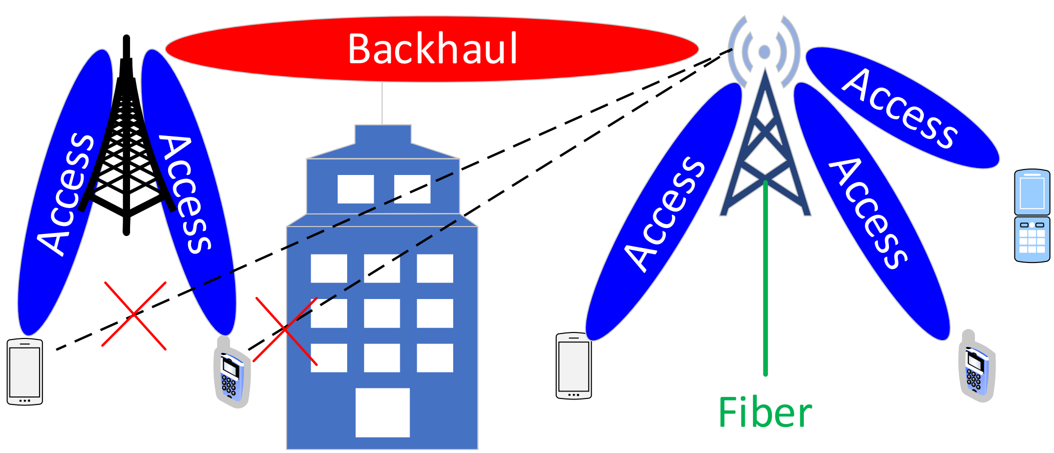

Figure 3.5. IAB can provide coverage to isolated coverage gaps.

The scope of the IAB feature in Release 16 includes:

- Multi-hop backhauling for flexible range extension for both FR1 (sub-6 GHz) and FR2 (mmWaves)
- Topology adaptation including redundant connectivity to optimize backhauling performance and to respond to backhaul link failure.
- Mapping of UE bearers to backhaul RLC channels and QoS enforcement over backhaul RLC channels to meet E2E QoS requirements.
- Scalability to a large number of UEs
- Flexible deployment allowing IAB node operation in EN-DC mode with EPC or in SA-mode with 5GC.
- Support for NR-NR DC for UE and IAB-nodes
- Efficient operation for both in-band and out-of-band relaying
- OTA synchronization across IAB topology
- Backwards compatibility, i.e. a Release-15 UE can access the network via a Release-16 IAB node

3.2.2.3 CROSS LINK INTERFERENCE/REMOTE INTERFERENCE MANAGEMENT

Release 16 extends NR with new features for *CLI* mitigation and *remote interference management* (RIM).[17]

CLI mitigation is intended to allow more flexible and adaptable resource sharing in unpaired spectrum. This is enabled by means of:

- CLI measurements, for example, CLI-RSSI and CLI RSRP, and associated reporting
- Network coordination mechanisms by exchanging UL/DL configuration

Remote interference management deals with mitigation of interference caused by base stations hundreds of kilometers away. This interference is caused by a phenomenon known as ducting. Higher layers of the atmosphere have lower density and therefore a lower refractive index. This reflects electromagnetic waves, ultimately sending the signal much farther (see Figure 3.6).

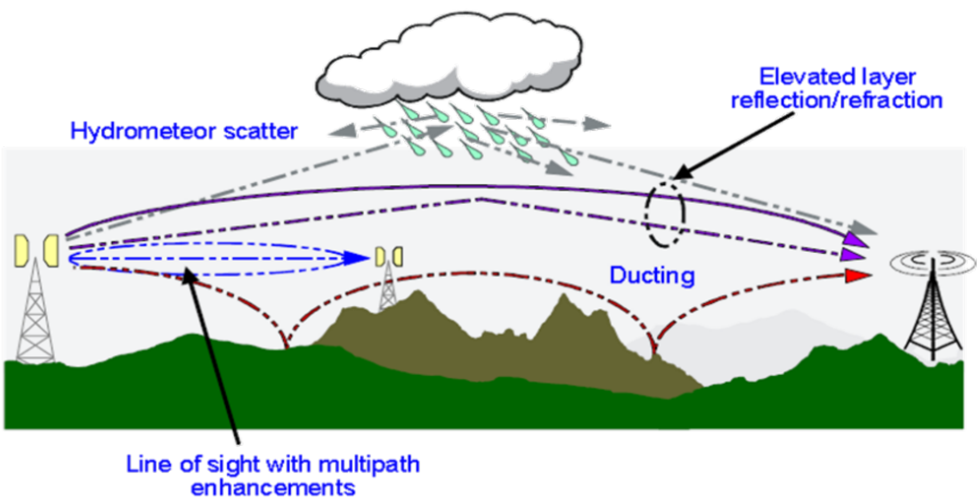

Figure 3.6. Remote interference 100's of kms away caused by ducting.

[17] 3GPP RP-191546, "Cross-Link Interference (CLI) / Remote Interference Management (RIM) for NR" (Work-item description)

The propagation delay also delays the interfering signal due to the large propagation distance and may exceed the guard period. Consequently, the downlink transmission of the aggressor may severely interfere with the uplink reception at the victim, see Figure 3.7.

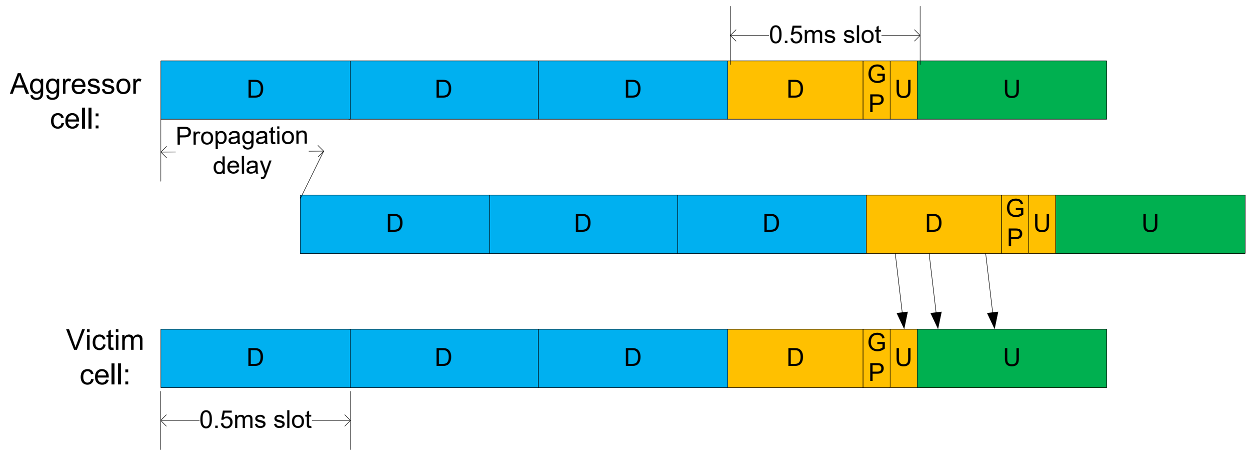

Figure 3.7. Single of aggressor cell arriving delayed at victim cell such that downlink of aggressor cell interferes with uplink of victim cell.

To mitigate remote interference, *RIM-reference signals* are introduced to indicate and detect the presence of remote interference. Various implementation schemes can then be used to mitigate the effect of remote interference when detected such as:

- Time-domain solutions:
  - The victim can avoid scheduling on UL symbols suffering from remote interference.
  - The aggressor can mute/back-off or avoid scheduling on DL symbols that cause remote interference to the victim.
- Frequency domain solutions
  - The aggressor DL and the victim UL can be statically or semi-statically configured to transmit on mutually orthogonal frequency resources
- Spatial domain solutions
  - Mounting antennas at the aggressor at lower height
  - The victim/aggressor gNB adjust the antenna down-tilt
- Power-domain solutions
  - The victim gNB increases the UL transmission power
  - The aggressor gNB reduces the DL transmission power on DL symbols potentially causing remote interference

3.2.2.4 UE POWER SAVINGS

The goal of UE power saving is to improve the UE battery life. NR devices may dissipate more power than LTE devices given NR's flexibility and its high bandwidth and data rates. It is natural to investigate schemes for reducing UE power consumption to improve the UE's battery life and ultimately make NR more power efficient than LTE.

3GPP undertook a study item to develop a power consumption model and evaluate different power saving schemes that showed substantial power-saving possibilities, some of which are part of the Release-16 work item *UE Power Savings in NR*.[18] This includes:

- PDCCH-based power-saving signal/channel triggering UE adaptation in RRC-Connected state.
- Enhancements to cross-slot scheduling.
- Adaptation of the number of MIMO layers.
- UE indication to transition out of the RRC-connected state.
- UE power saving assistance information.
- Intra-frequency and inter-frequency RRM-measurement relaxation in IDLE and INACTIVE modes.

3.2.2.5 MOBILITY ENHANCEMENTS

Release-15 NR supports basic handover based on UE measurement reporting.

- The source gNB triggers handover by sending a handover request to the target gNB.
- After receiving ACK from the target gNB, the source gNB initiates handover by sending a handover command with target-cell configuration.
- After RRC reconfiguration with target-cell configuration applied, the UE sends a random-access to the target cell.

In NR high-frequency range with beamforming, the handover interruption time can be larger than that of LTE due to beam sweeping. Furthermore, this may lead to more radio-link failures and hence less reliability. To reduce the handover interruption time and reliability, a set of mechanisms are being specified as part of the Release-16 work item *NR Mobility Enhancements*[19]:

- Mechanisms to reduce interruption time during Handover/SCG change, considering schemes by dual active protocol stack-based solution:
- Mechanisms to improve Handover/SCG change reliability, considering schemes such as:
    - Conditional Handover for NR Pcell change;
    - Conditional handover-based NR PScell addition/change for any architecture option with NR PScell;
    - T312-based fast failure recovery (similar to LTE).

3.2.2.6 MULTI-RAT DUAL CONNECTIVITY AND CA ENHANCEMENTS

Release-15 NR supports E-UTRAN/NR Dual Connectivity, NR/E-UTRAN Dual Connectivity (NE-DC) and NR-NR Dual Connectivity. EN-DC and NE-DC are called Multi-Radio DC (MR-DC). Release 16 considers additional mechanism to enhance the performance of dual connectivity (DC) and CA[20].

- Release 15 supported NR-NR DC between FR1 and FR2 for the synchronous case. Release 16 extends the support to the asynchronous case and other carrier combinations, for example, MCG and SCG with serving cells in same frequency range
- Early measurement reporting from neighbor and serving cells to reduce the delay when setting up dual connectivity and/or carrier aggregation.

[18] 3GPP RP-191607, "UE Power Savings in NR" (Work-item description)
[19] 3GPP RP-190489, "NR Mobility Enhancements" (Work-item description)
[20] 3GPP RP-191608, "LT-NR & NR-NR Dual connectivity and CA Enhancements" (Work-item description)

- Efficient and low-latency serving-cell configuration/activation/setup by minimizing the signaling overhead and latency needed for cell setup and cell activation.
- Fast recovery of MCG link when the SCG link is still operational, for example, by utilizing the SCG link and split SRBs for recovery during MCG failure.
- Cross-carrier scheduling of CA cells with different numerologies. In Release 15, cross-carrier scheduling is supported only when all cells have the same numerologies.
- Enable the Release-15 behavior of “DL HARQ timing for FDD Scell for LTE TDD-FDD CA with TDD Pcell, applied to FDD Pcell” to apply to dual uplink EN-DC.
- Support for aperiodic CSI-RS triggering with different numerology between CSI-RS and triggering PDCCH
- Inter-band CA support with unaligned frame boundary but with slot alignment and partial SFN alignment

3.2.2.7 INDUSTRIAL IOT (IIOT)

The motivation for the Release-16 work item *Support of NR Industrial Internet of Things* [21] is to extend the applicability of NR to various verticals, such as further improvements for AR/VR and new uses cases like factory automation, transport industry and electrical power distribution. This is achieved by increasing the reliability of the Uu interface, increasing resource efficiency with duplication, better handling of high-priority traffic multiplexed with low-priority traffic in the same UE, and more efficient support of TSC.

To achieve this the following mechanisms are considered:

- PDCP duplication enhancements
    - Duplication with up to four copies over up to four legs.
    - Enhanced control of PDCP duplication activation/deactivation.
- Intra-UE prioritization/multiplexing
- TSC-related enhancements like reference-timing delivery from gNB to UE and Ethernet header compression

3.2.2.8 ULTRA-RELIABLE LOW LATENCY COMMUNICATIONS (URLLC)

Release 15 provided basic URLLC functionality:

- Lower latency by supporting:
    - Higher subcarrier spacing, with shorter transmission durations.
    - Mini-slots with fewer number of symbols.
    - Frequent PDCCH monitoring reducing the latency of the layer-1 control information.
    - Configured-grant, which allows the UE to autonomously transmit uplink data without having to send a scheduling request and wait for the uplink grant.
    - Downlink preemption.
- Higher reliability by supporting;
    - Multi-slot repetition.
    - Low spectral efficiency MCS/CQI tables.
    - PDCP duplication.

[21] 3GPP RP-191561, “Support of NR Industrial Internet of Things” (Work-item description)

Release 16 further enhances the NR support for URLLC services by enabling latency in the range of 0.5 to 1 ms and improved reliability with a target error rate of 10^{-6}. This allows the support of new use cases, such as factory automation and transport industry as well as improving the performance of Release-15 use cases such as AR/VR and gaming.

To achieve this, the Release-16 work item *Physical Layer Enhancements for NR Ultra-Reliable and Low-Latency Communication (URLLC)* [22] focuses on the following areas of improvements:

- PDCCH enhancements focusing on:
  - Configurable field sizes for downlink control information for improved reliability.
  - Increased PDCCH monitoring capability to minimize scheduling block/delay.
- UCI enhancements focusing on:
  - Support of multiple HARQ-ACK feedback occasions per slot to reduce latency.
  - Construction of multiple HARQ-ACK codebooks with different treatment intended for different services.
- PUSCH enhancements by supporting cross-slot-boundary scheduling for both dynamic PUSCH grant and configured PUSCH grant.
- Scheduling and HARQ enhancements including the support of:
  - Out-of-order HARQ-ACK allowing the HARQ-ACK of a more recently scheduled low-latency transmission to be transmitted before the HARQ-ACK of regular transmission that was scheduled earlier.
  - Out-of-order PUSCH scheduling allowing a low-latency PUSCH that has been scheduled after a normal PUSCH to be transmitted before the normal PUSCH.
  - Overlapping dynamic PDSCHs.
- Inter-UE prioritization and multiplexing focusing on:
  - UL preemption by allowing the gNB to interrupt data transmission from one user to accommodate higher-priority data from another user.
  - Enhanced UL power control to enable power boosting for URLLC UL transmissions overlapping with some eMBB transmission.
- Configured-grant enhancements by supporting multiple active configurations, to accommodate different service flows and to reduce the alignment time for URLLC UL transmissions.

3.2.2.9 V2X (VEHICLE-TO-EVERYTHING)

V2X extends the 3GPP platform to the automotive industry by providing vehicle-to-everything support to vehicles, pedestrians, infra-structure units, the network. The V2X messages can be transferred over the Uu interface (the normal uplink/downlink interface between the base station and the UE) or directly between UEs on a sidelink interface (also known as PC5).

V2X was introduced to 3GPP in Release 14 by extending LTE to provide support for the automotive industry. Release-14 V2X supports basic road safety features by exchanging messages regarding position, speed and direction with the surrounding vehicles, infra-structure units and pedestrians. The second phase of V2X in LTE Release-15 enhanced V2X by introducing features such as carrier aggregation on the sidelink interface, 64QAM, reduced latency, and a feasibility study on transmission diversity and short TTI for the sidelink.

[22] 3GPP RP-191584, "Physical Layer Enhancements for NR Ultra-Reliable and Low-Latency Communication (URLLC)" (Work-item description)

3GPP started Release-16 NR V2X with a study item on the evaluation methodology of the new V2X cases. For this purpose, RAN WG1 considered the evaluation methodology for developing technical solutions supporting the 5G V2X use cases. This methodology encompasses simulation models as well as performance metrics.

The simulation models include:

- Channel models covering a larger range of frequencies both below and above 6 GHz. The new sidelink channel models (used for vehicle-to-vehicle or V2V, vehicle-to-pedestrian or V2P, etcetera.) extend those in LTE with additional modelling components such as blocking and moving scatterers. For uplink and downlink evaluations in vehicle-to-network (V2N), the channel models in TR 38.901 are reused
- Deployment models including urban and highway scenarios with new vehicle dropping models (compared to Rel 14), including a clustered UE dropping model for platooning
- Traffic models with a large degree of variation in terms of packet arrivals (including periodic and aperiodic), data rates, and packet sizes. In addition, MBB traffic is also considered

Packet Reception Radion (PRR) serves as a performance metric for reliability and latency used since Rel 14, but has been redefined to cover broadcast, multicast and unicast transmissions. Additional performance metrics such as Packet Inter-Reception (PIR) and absolute/relative positioning error have been introduced to evaluate persistent collisions as well as the accuracy of positioning-related features. RP-171093 was a study item for developing the evaluation methodology for 5G V2X and ended in June 2018.

A new Release-16 study item on enhancing NR to support V2X was started in June 2018 and completed in March 2019 following the study on the evaluation methodology for V2X. This study item was followed by a Release-16 work item for normative 3GPP NR specifications to support V2X. NR V2X is designed to complement and interwork with LTE V2X by supporting more advanced use cases. The advanced V2X use cases have been defined by the SA working groups. There are 25 advanced V2X use cases, grouped into four areas:

- *Vehicle platooning* is the ability of a group of vehicles traveling together to organize into a platoon, with a lead vehicle providing messages to other vehicles in the platoon allowing for smaller inter-vehicle distances
- *Extended sensors* allow for exchange of sensor data and live video between vehicles, pedestrians, infra-structure units, and V2X application servers to extend the UE’s perception of the surrounding environment.
- *Advanced driving* allows for autonomous or semi-autonomous driving by exchanging sensor data and driving intention which enables vehicles to coordinate their trajectories
- *Remote driving* allows for a remote driver or V2X application to remotely drive a vehicle for passengers who can’t drive themselves, or vehicles driven in dangerous environments. The main requirement for remote driving is low-latency communication.

NR V2X targets lower latency, higher reliability, higher capacity, and better coverage than LTE V2X, and is intended to be future proof for future development of advanced V2X services. To achieve these objectives, several enhancements are part of the NR Release-16 V2X work item[23].

[23] 3GPP RP-190984, “5F V2X with NR Sidelink” (Work-item description)

New NR sidelink design should be considered future proof for further enhancements in upcoming releases, and that considers in-network coverage, out-of-network coverage as well as partial network coverage. The sidelink design in Release 16 includes:

- Sidelink Physical Channels:
  - Physical Sidelink Shared Channel (PSSCH) used for the actual data transmission
  - Physical Sidelink Control Channel (PSCCH) used for conveying Sidelink Control Information (SCI)
  - Physical Sidelink Feedback Channel (PSFCH) used for Hybrid ARQ (HARQ) feedback information
  - Physical Sidelink Broadcast Channel (PSBCH) ent in the Sidelink-SSB (S-SSB)
- Operation on dedicated carrier(s) or on carrier(s) shared with NR Uu and/or LTE Uu in licensed spectrum. When operating on shared carrier(s) the sidelink channels and the Uu interface channels can be in the same channel or adjacent channels
- Operation in FR1 (sub-6 GHz) and FR2 (mmWaves) spectrum. The primary focus of Release 16 is FR1 with no FR2-specific optimization except for support of PTRS.
- Support of sidelink unicast, sidelink groupcast and sidelink broadcast.
- Support of two resource allocation modes, that can be configured separately or simultaneously
  - Mode 1 which supports scheduling by NR Uu or LTE Uu.
  - Mode 2 which supports autonomous UE operation, where the UE senses and selects resources on the sidelink based on network configuration.
- Support of different synchronization mechanisms including sidelink synchronization channel, with the ability to select the synchronization reference
- Support of TDM-based and FDM-based mechanisms for the “not co-channel” in-device coexistence between LTE and NR sidelinks.
- Support of link adaptation with up two-antenna ports. The sidelink CSI information is conveyed across the Physical Sidelink Shared Channel (PSSCH).
- Cross-RAT Control: DCI-based activation/deactivation of LTE sidelink using the NR Uu interface.
- UE reports to assist with gNB scheduling
- QoS management of the radio interface including.

As mentioned earlier, NR V2X is designed to coexist and internetwork with LTE V2X. Figure 3.8 is an example of an LTE-NR dual connectivity network with V2X support. The UE’s V2X communication on the LTE sidelink and the NR sidelink is controlled and configured by the LTE or NR Uu interface, while the UE is configured in EN-DC mode. On the other hand, Figure 3.9 is an example of an NR standalone network with V2X support. The UE’s V2X communication on the LTE sidelink and the NR sidelink is controlled and configured by the gNb through the NR Uu interface.

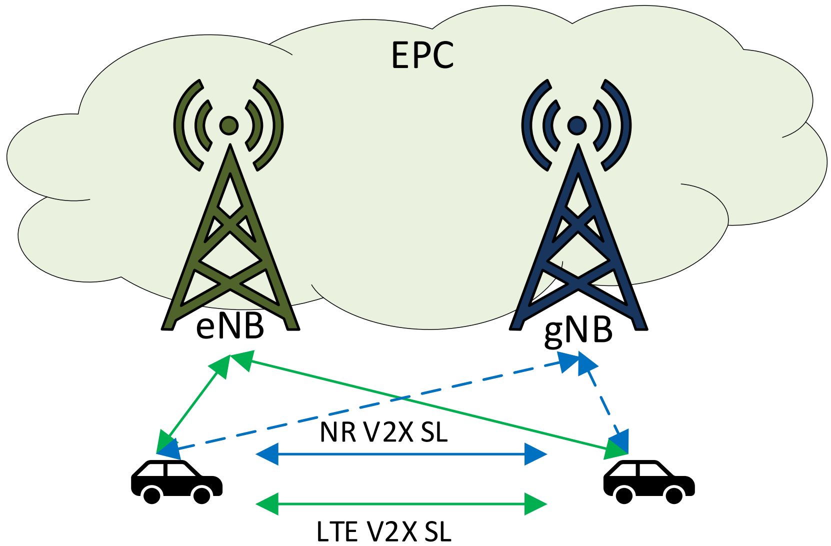

Figure 3.8. LTE-NR Dual Connectivity with V2X support.

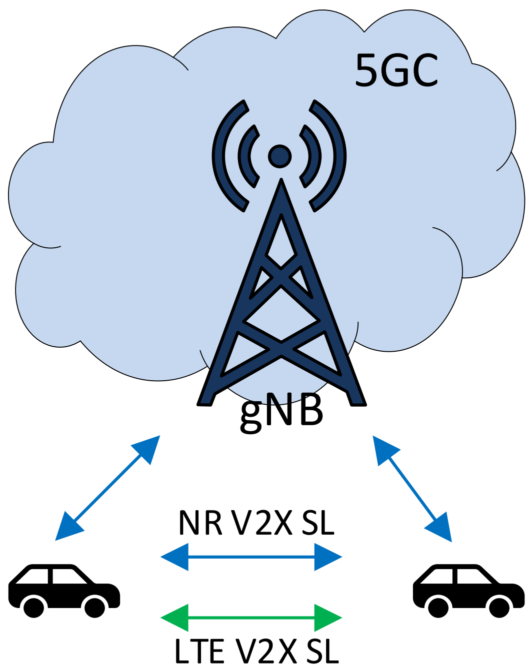

Figure 3.9. Standalone NR with V2X support.

3.2.2.10 NR UNLICENSED

Licensed spectrum may be the cornerstone of wireless mobile service to meet the service requirements for coverage, spectral efficiency, and reliability but unlicensed spectrum plays an important role in complementing licensed spectrum by boosting capacity and, in some cases, improving data connectivity.

As discussed in Section 3.1.1, operation of a 3GPP-based system in unlicensed spectrum was first introduced in Release 13 in the form of license assisted access (LAA).

The NR Unlicensed (NR-U) study and work items in Release 16[24] introduce NR to unlicensed frequency bands in the 5GHz and 6GHz frequency ranges of FR1, see Figure 3.10. The 5 GHz band is used by existing technologies such as Wi-Fi and LTE-based LAA. In this band, the impact of NR-U on WiFi should not exceed that of an additional Wi-Fi network of the same generation on the same carrier. The 6GHz band is a greenfield band but lack regulatory requirements ar. In the US, the 6 GHz band extends between 5925 – 7125 MHz while, in Europe, it extends between 5925 – 6425 MHz. In the 6 GHz band, the channel-access mechanism for NR-U will use energy detection for coexistence with other RATs sharing the same band, regulations permitting.

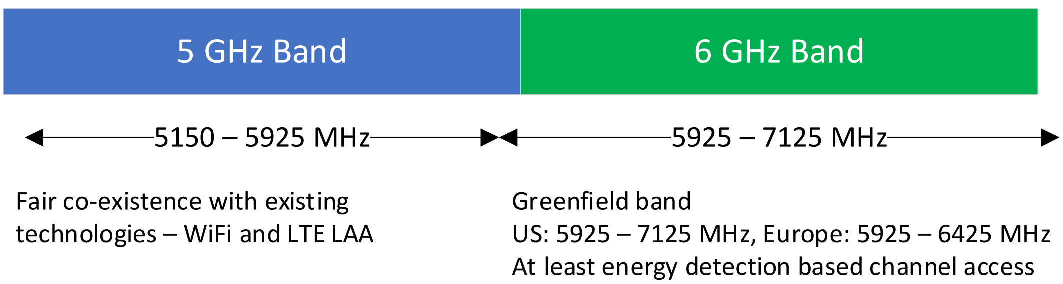

Figure 3.10. Spectrum priorities for NR-U.

NR-U can operate in one of two modes:

- Standalone unlicensed access, where NR operates in an unlicensed band with no assistance from a carrier in a licensed band,
- License assisted access (LAA), where the operation of NR in the unlicensed band makes use of a carrier in the licensed band for assistance, e.g. for control signaling.

The NR-U work item supports the following scenarios:

- Scenario A: Carrier aggregation in NR between licensed band (Pcell) and NR-U (Scell). The NR-U Scell may have both DL and UL or just DL. The NR Pcell is connected to 5GC. This scenario improves NR capacity by adding more spectrum to NR.
- Scenario B: Dual connectivity between LTE in licensed band (Pcell) and NR-U (PSCell). This scenario improves the capacity of LTE deployments.
- Scenario C: Standalone-NR-U connected to 5GC. This scenario targets standalone deployments such as non-public networks.
- Scenario D: Standalone cell in unlicensed band connected to 5GC and UL in licensed band.
- Scenario E: Dual connectivity between NR in licensed band and NR-U, with the Pcell connected to 5G-CN. This scenario improves NR capacity by adding more spectrum to NR.

The channel-access procedure for NR-U is largely inherited from LTE LAA, except that the NR-U design is mostly based on NR Release 15 with additional enhancements for operation in unlicensed spectrum. The enhancements are necessary to fulfill regulatory requirements—like *Power Spectral Density* (PSD)

[24] 3GPP RP-191575, "NR-based Access to Unlicensed Spectrum" (Work-item description)

limitations and *Occupied Channel Bandwidth* (OCB) in Europe—and also to compensate for reduced transmission opportunities due to LBT failure. The main enhancements are:

- Inclusion of RMSI-CORESET(s)+PDSCH(s) (carrying RMSI) associated with SS/PBCH block(s) in addition to the SS/PBCH burst set in one contiguous burst (referred to as the NR-U DRS) to limit the required number of channel-access and for short channel occupancy.
- Support of new UL resource allocation (block- interlaced waveform) to satisfy the OCB requirements and PSD requirements of the 5GHz unlicensed bands in Europe.
- Multiple techniques to handle reduced HARQ A/N transmission opportunities due to LBT failure, including the support of gNB-triggering retransmission of HARQ-Ack/Nack feedback.
- Enhancements to UL scheduling, such as scheduling multiple slots for PUSCH(s) using a single UL grant.
- Removing dependencies of HARQ process information to the timing for configured UL transmissions. In NR-U configured UL, UE selects HARQ ID, RV, and NDI and report that as part of UCI in every configured UL PUSCH.
- Support of DL type-B PDSCH length from 2 to 13 symbols.

NR-U study item concluded that it is feasible for NR-U to achieve fair coexistence with Wi-Fi, and for NR-U to coexist with itself.

3.2.2.11 NR POSITIONING

Release-15 NR provides support for RAT-independent positioning techniques and Observed Time Difference Of Arrival (OTDOA) on LTE carriers. Release 16 extends NR to provide native positioning support by introducing RAT-dependent positioning schemes. These support regulatory and commercial use cases with more stringent requirements on latency and accuracy of positioning.[25] NR enhanced capabilities provide valuable, enhanced location capabilities. Location accuracy and latency of positioning schemes improve by using wide signal bandwidth in FR1 and FR2. Furthermore, new schemes based on angular/spatial domain are developed to mitigate synchronization errors by exploiting massive antenna systems.

The positioning requirements for regulatory (e.g. E911) and commercial applications are described in 3GPP TR 38.855. For regulatory use cases, the following are the minimum performance requirements:

- Horizontal positioning accuracy better than 50 meters for 80% of the UEs.
- Vertical positioning accuracy better than 5 meters for 80% of the UEs.
- End-to-end latency less than 30 seconds.

For commercial use cases, for which the positioning requirements are more stringent, the following are the starting-point performance targets

- Horizontal positioning accuracy better than 3 meters (indoors) and 10 meters (outdoors) for 80% of the UEs.
- Vertical positioning accuracy better than 3 meters (indoors and outdoors) for 80% of the UEs.
- End-to-end latency less than 1 second.

[25] 3GPP RP-191156, "NR Positioning Support" (Work-item description)

Figure 3.11 shows the RAT-dependent NR positioning schemes being considered for standardization in Release 16:

- *Downlink time difference of arrival* (DL-TDOA): A new reference signal known as the positioning reference signal (PRS) is introduced in Release 16 for the UE to perform downlink reference signal time difference (DL RSTD) measurements for each base station's PRSs. These measurements are reported to the location server.
- *Uplink time difference of arrival* (UL-TDOA): The Release-16 sounding reference signal (SRS) is enhanced to allow each base station to measure the uplink relative time of arrival (UL-RTOA) and report the measurements to the location server.
- *Downlink angle-of-departure* (DL-AoD): The UE measures the downlink reference signal receive power (DL RSRP) per beam/gNB. Measurement reports are used to determine the AoD based on UE beam location for each gNB. The location server then uses the AoDs to estimate the UE position.
- *Uplink angle-of-arrival* (UL-AOA): The gNB measures the angle-of-arrival based on the beam the UE is located in. Measurement reports are sent to the location server.
- *Multi-cell round trip time* (RTT): The gNB and UE perform Rx-Tx time difference measurement for the signal of each cell. The measurement reports from the UE and gNBs are sent to the location server to determine the round trip time of each cell and derive the UE position.
- *Enhanced cell ID* (E-CID). This is based on RRM measurements (e.g. DL RSRP) of each gNB at the UE. The measurement reports are sent to the location server.

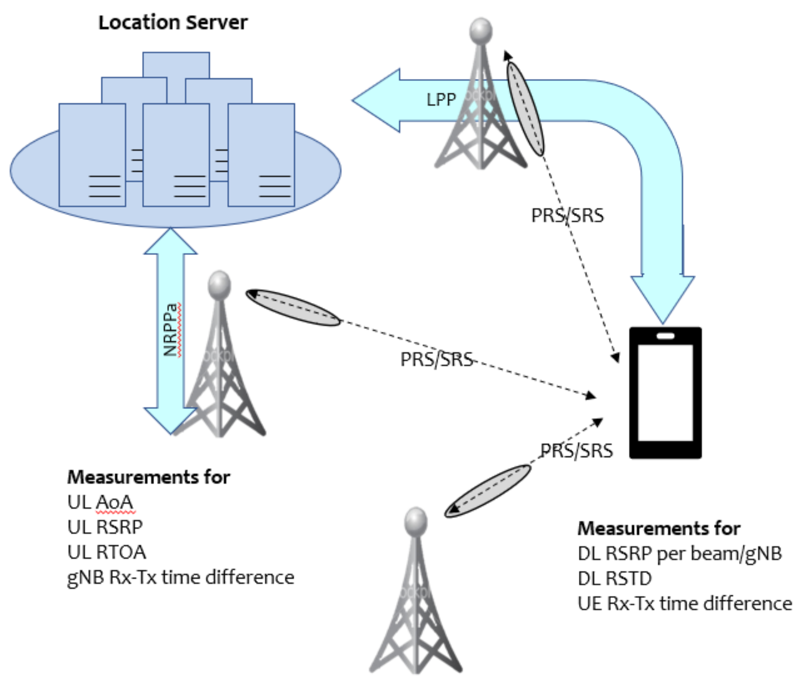

Figure 3.11. NR RAT-dependent positioning schemes.

UE-based measurement reports for positioning:

- Downlink reference signal reference power (DL RSRP) per beam/gNB
- Downlink reference signal time difference (DL RSTD)
- UE RX-TX time difference

gNB-based measurement reports for positioning:

- Uplink angle-of-arrival (UL-AoA)
- Uplink reference-signal receive power (UL-RSRP)
- UL relative time of arrival (UL-RTOA)
- gNB RX-TX time difference

NR adopts a solution similar to that of LTE LPPa for Broadcast Assistance Data Delivery, which provides support for A-GNSS, RTK and OTDOA positioning methods. PPP-PTK positioning will extend LPP A-GNSS assistance data message based on compact "SSR messages" from QZSS interface specifications. UE-based RAT-dependent DL-only positioning techniques are supported, where the positioning estimation will be done at the UE-based on assistance data provided by the location server.

3.2.2.12 2-STEP RACH[26]

RACH stands for Random Access Channel, which is the first message from UE to eNB when it is powered on. In terms of Radio Access Network implementation, handling RACH design can be one of the most important / critical portions.

The contention-based random-access procedure from Release 15 is a four-step procedure, as shown in Figure 3.12. The UE transmits a contention-based PRACH preamble, also known as Msg1. After detecting the preamble, the gNB responds with a random-access response (RAR), also known as Msg2. The RAR includes the detected preamble ID, a time-advance command, a temporary C-RNTI (TC-RNTI), and an uplink grant for scheduling a PUSCH transmission from the UE known as Msg3. The UE transmits Msg3 in response to the RAR including an ID for contention resolution. Upon receiving Msg3, the network transmits the contention resolution message, also known as Msg4, with the contention resolution ID. The UE receives Msg4, and if it finds its contention-resolution ID it sends an acknowledgement on a PUCCH, which completes the 4-step random access procedure.

[26] 3GPP RP-190711, "2-step RACH for NR" (Work-item description)

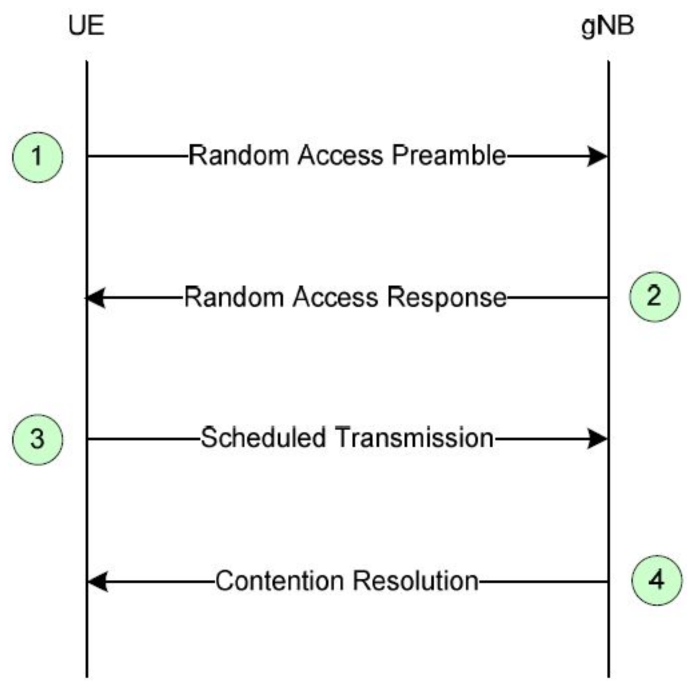

Figure 3.12. 4-step contention-based Random Access Procedure [TS 38.300].

The four-step random-access procedure requires two round-trip cycles between the UE and the base station, which not only increases the latency but also incurs additional control-signaling overhead. The motivation of two-step RACH is to reduce latency and control-signaling overhead by having a single round trip cycle between the UE and the base station. This is achieved by combining the preamble (Msg1) and the scheduled PUSCH transmission (Msg3) into a single message (MsgA) from the UE, known as MsgA. Then by combining the random-access respond (Msg2) and the contention resolution message (Msg4) into a single message (MsgB) from the gNB to UE, see Figure 3.13. Furthermore, for unlicensed spectrum, reducing the number of messages transmitted from the UE and the gNB, reduces the number of LBT attempts.

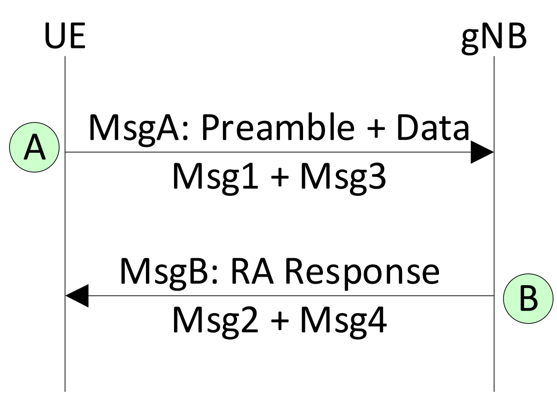

Figure 3.13. Two-step contention-based Random Access Procedure.

Design targets for two-step RACH:

- A common design for the three main uses of 5G, i.e. eMBB, URLLC and mMTC in licensed and unlicensed spectrum.
- Operation in any cell size supported in Release 15, and with or without a valid uplink time alignment (TA).
- Applicable to different RRC states, i.e. RRC_INACTIVE, RRC_CONNECTED and RRC_IDLE states.
- All triggers for four-step RACH apply to two-step RACH including, Msg3-based SI request and contention-based beam failure recovery (CB BFR).

As described earlier, MsgA consists of a PRACH preamble and a PUSCH transmission, known as MsgA PRACH and MsgA PUSCH respectively. The MsgA PRACH preambles are separate from the four-step RACH preambles, but can be transmitted in the same PRACH Occasions (ROs) as the preambles of four-step RACH, or in separate ROs. The PUSCH transmissions are organized into PUSCH Occasions (POs) which span multiple symbols and PRBs with optional guard periods and guard bands between consecutive POs. Each PO consists of multiple DMRS ports and DMRS sequences, with each DMRS port/DMRS sequence pair known as PUSCH resource unit (PRU). two-step RACH supports at least one-to-one and multiple-to-one mapping between the preambles and PRUs.

After the UE transmits MsgA, it waits for the MsgB response from the gNB. There are three possible outcomes:

1. gNB doesn't detect the MsgA PRACH ➔ No response is sent back to the UE ➔ The UE retransmits MsgA or falls back to four-step RACH starting with a Msg1 transmission.
2. gNB detects MsgA preamble but fails to successful decode MsgA PUSCH ➔ gNB sends back a fallbackRAR to the UE with the RAPID (random-access preamble ID) and an uplink grant for the MsgA PUSCH retransmission ➔ The UE upon receiving the fallbackRAR, falls back to four-step RACH with a transmission of Msg3 (retransmission of the MsgA PUSCH).
3. gNB detects MsgA and successfully decodes MsgA PUSCH ➔ gNB sends back a successRAR to the UE with the contention resolution ID of MsgA ➔ The reception of the successRAR successfully completes the two-step RACH procedure.

As described earlier, MsgB consists of the random-access response and the contention-resolution message. The random-access response is sent when the gNB detects a preamble but cannot successfully decode the corresponding PUSCH transmission. The contention resolution message is sent after the gNB successfully decodes the PUSCH transmission. MsgB can contain backoff indication, fallbackRAR and/or successRAR. A single MsgB can contain the successRAR of one or more UEs. The fallbackRAR consists of the RAPID: an uplink grant to retransmit the MsgA PUSCH payload and time-advance command. The successRAR consists of at least the contention resolution ID, the C-RNTI and the TA command.

3.2.3 FURTHER EVOLUTION IN RELEASE 17

Initial discussions on the content of 3GPP Release 17 began at RAN #84 in June 2019 with the final decisions on Release 17 having occurred in December of 2019. Release 17 will consist of enhancements to Release-16 features, including MIMO, unlicensed access and IAB as well an extension of operating spectrum beyond 52.6 GHz. Release 17 will also introduce support for new use cases, for example the support of reduced capability devices for specific IoT use cases.

3.2.3.1 NR BEYOND 52.6 GHZ

NR Release 15/16 support operation in spectrum up to 52.6 GHz. As part of 3GPP Release 17, spectrum support will be extended to up to 71 GHz.[27] This extension will cover the original 60 GHz band (57-66 GHz) as well as the recently identified 66-71 GHz frequency band. The extension to higher frequency bands will include the introduction of new numerology/numerologies with higher subcarrier spacing and related timing aspects. It will also, for example, include any physical-layer procedures and protocol aspects required for operation in unlicensed bands between 52.6 GHz and 71 GHz.

3.2.3.2 IAB ENHANCEMENTS

Integrated Access and Backhaul networks reduce deployment costs by obviating the need to provide wired backhaul to each cellular base station. Several extensions to Release-16 IAB will be covered by a Release-17 work item on IAB enhancements.[28] The aim of this work item is to enhance Release-16 IAB in terms of robustness, spectral efficiency, latency, and end-to-end performance.

The IAB work item will include extended possibilities for multiplexing transmissions between the backhaul and access links, that is, simultaneous DU and MT operation within an IAB node, including:

- Simultaneous MT-RX/DU-TX and/or simultaneous DU-RX/MT-TX, often referred to as IAB-node full duplex
- Simultaneous MT-RX/DU-RX and/or simultaneous MT-TX/DU-TX, sometimes referred to as SDM (if DU/MT separation in the spatial domain, for example, by the use of different antenna panels) or FDM (if DU/MT separation in the frequency domain by transmitting over separate resource blocks)

These multiplexing options, which can improve IAB efficiency and reduced latency, are at least partly already possible with Release-16 IAB. However, some additional features—like new timing relations between the DU and MT part of an IAB node—will further extend the applicability of these multiplexing combinations.

The work item will also include extended means for topology adaptation to enable enhanced backhaul robustness as well as more general topology, routing and transport enhancements for improved efficiency of deployments utilizing IAB.

3.2.3.3 REDUCED CAPABILITY NR DEVICES (NR-LIGHT)

As already discussed, the basic massive MTC use cases, characterized by requirements on very low device cost and very low device energy consumption in combination with wide-area coverage, are assumed to be provided by means of LTE-based LTE-MTC and NB-IoT also in the 5G era. However, there are use cases that require lower device complexity and reduced energy consumption compared what can be provided by NR Release 15/16 and which, at the same time, has higher requirements in terms of data rates and latency compared to what can be provided with LTE-MTC and NB-IoT. To address such use cases, 3GPP has initiated Release-17 activities on *reduced-capability NR devices* (sometimes referred to as NR Light).[29] The work will initially be carried out as a study item to be concluded at RAN #88 (June 2020), with an expected work item to follow.

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[27] 3GPP RP-193229 “New WID on Extending current NR operation to 71 GHz” (work-item description)
[28] 3GPP RP-193251 “New WID on Enhancements to Integrated Access and Backhaul” (work-item description)
[29] 3GPP RP-193238, ” New SID on support of reduced-capability devices””

In terms of reduced device complexity, at least to following will be considered:

- Support for reduced number of TX/RX antennas at the device side
- Reduction of the minimum required device bandwidth
- Support for devices only capable of half-duplex operation (no simultaneous TX/RX) in paired spectrum

In terms of reduced device energy consumption, at least the following will be considered:

- Reduced complexity in PDCCH monitoring by reducing the number of required blind decoding
- Extended DRX functionality

The aim is to achieve the reduced device complexity and energy consumption without compromising the achievable coverage. This Release-17 technology capability is not intended to replace mMTC low-power wide-area devices (i.e. eMTC/NB-IoT devices), but to enhance NR to address the following use cases in Industrial IoT and other verticals:

- Industrial wireless sensors with low latency (5-10ms) and medium data rate (<2 Mbps)
- Medium to high data rate (2-25 Mbps) video transmission
- High data-rate wearables (5-50 Mbps) with long battery life (1-2 weeks)

These use cases have higher requirements than mMTC but lower than eMBB and URLLC. The objective is to first study and identify solutions for:

- Reducing UE complexity, for example, reduced number of antennas, reduced UE bandwidth, half-duplex FDD, etc.
- Mitigating impact from UE complexity reduction, for example, coverage compensation
- UE power saving and battery life enhancements, for example, extended DRX, reduced control channel monitoring, etc.

3.2.3.4 SMALLDATA ENHANCEMENTS

NR Release 15/16 does not allow for the transmission of user data in inactive state. As a consequence, even for the transmission of very small amount of data the device has to resume the connection, something that has a negative impact on signaling overhead as well as device energy consumption. For this reason, Release 17 will introduce the possibility for transmission of small data payloads in inactive state.[30] This will be partly based on the already existing mechanisms of 2/4-step RACH (Section 3.2.2.12), including an extension of the payload size supported for these (currently used only for control signaling),

In addition, the work item aims at enabling uplink transmission using configured PUSCH resources, based on the Release-15/16 configured-grant framework, also in inactive state.

3.2.3.5 SIDELINK ENHANCEMENTS

As described above (Section 3.2.2.9), the Release-16 work item on NR V2X introduced the possibility for sidelink (direct device-to-device) communication in NR. Although focusing on the V2X scenario, the Release-16 sidelink can also be used for, for example, public safety.

[30] RP-193252 “Work Item on NR small data transmission in INACTIVE state” (work-item description)

Further enhancements and extensions to NR sidelink communication will be introduced as part of Release 17.[31] The aim of these enhancements/extensions is to

- Enhance sidelink communication for V2X and public-safety use cases in order to support requirements and operation scenarios not fully covered by Release-16 sidelink
- Extend sidelink communication to new commercial use cases

Key areas of enhancements include reduced device energy consumption during sidelink operation and enhanced reliability and reduced latency for sidelink communication for URLLC-type applications.

In parallel to the work item on sidelink enhancements as outlined above, 3GPP will also carry out studies on sidelink-based relaying, that is, the use of device-to-device communication as a way to extend the network coverage outside the area directly covered by the network infra-structure.[32]

Release 17 recognizes the market demand for mission critical national security and public safety services. The 3GPP system architecture and radio network working groups are discussing the requirements of more general NR proximity services (ProSe). Release 17 can advantageously reuse the high-reliability and low-latency features of the NR cellular (Uu) interface and the advanced features of the PC5 interface developed for V2X applications. For ProSe, there is an inherent need to provide reliable out-of-coverage services, support communications among emergency rescue personnel, and quickly connect out-of-coverage areas to infrastructure nodes. To meet the requirements of ProSe, 3GPP plans to extend the capabilities of the Release 16 NR PC5 interface by enabling UE-based relaying. UE-based relaying can be useful in both partial (spotty) coverage and out-of-coverage situations by establishing multi-hop communication paths, such as in UE-UE-UE or NW-UE-UE relaying situations. These relaying features may require some new solutions in network control, resource allocation, end-to-end QoS management and UE/relay discovery. At physical-layer and MAC level, it is expected to reuse the release-16 features, incorporating changes to reduce energy consumption critical for handheld devices.

3.2.3.6 POSITIONING ENHANCEMENTS

The native positioning support introduced in NR Release 16 (section 3.2.2.11) targeted both regulatory and commercial use cases with positioning accuracy down to at least 3 meters and end-to-end latency less than 1 second as the ¨performance target for commercial use cases.

The Release-17 study item on enhanced positioning[33] focuses on more high-accuracy positioning targeting commercial IoT use cases such as location of assets and moving objects within factories, with sub-meter-lever accuracy and end-to-end latency less than 100 ms,

The aim of the study item is to

1. Evaluate the achievable accuracy and latency with the Release-16 positioning features
2. If needed, identify and evaluate enhanced positioning techniques that can be used to reach the targets for high-accuracy positioning as outlined above.

[31] 3GPP RP-133231 "New WID on NR sidelink enhancements" (work-item description)
[32] 3GPP RP-193253 "New SID: Study on NR sidelink relays" (study-item description)
[33] 3GPP RP 133237 "New SID on NR positioning Enhancements" (study-item description)

3.2.3.7 DYNAMIC SPECTRUM SHARING

The Release-17 work item on dynamic spectrum sharing focuses on further enhancements in terms of spectrum sharing between NR and LTE.[34] More specifically, the work item aims at enhanced scheduling capacity for NR UEs on a shared (LTE+NR) carrier by extending cross-carrier scheduling (separate carrier for PDCCH carrying scheduling assignment/grant and actual downlink/uplink data transmission on PDSCU/PUSCH) to also support PDCCH on SCcell scheduling PDSCH/PUSCH on P(S)Cell. The work item will also consider scheduling PDSCH on multiple carriers using a single DCI.

3.2.3.8 MIMO ENHANCEMENTS

As described above (Section 3.2.2.1), Release 16 included a set of new features to enhance NR MIMO operation. Further MIMO enhancements, including beam management enhancements, will be introduced as part of NR Release 17.[35] This, for example, includes enhancements within the following areas/scenarios:

- High speed vehicular scenarios, especially at higher frequencies, where further reduction in overhead and latency, as well as a reduction in beam failure, is desired
- Extension of multi-TRP transmission to additional physical channels in both the downlink and uplink transmission directions
- Enhancements to SRS (Sounding Reference Signal) transmissions to extend capacity and coverage
- Further enhanced Type II CSI-RS, for example, multi-TRP/panel transmission in case of non-coherent joint transmission and utilization of partial reciprocity (for example reciprocity in terms of angle-of arrival/departure and delay) in case of FDD deployments

3.2.3.9 UE POWER SAVING ENHANCEMENTS

As described in Section 3.2.2.4, means for reduced NR UE energy consumption for devices in connected state were introduced already as part of NR Release 16. Release 17 will consider additional UE power-saving features specifically targeting devices in idle/inactive mode.[36] This will include means to reduce unnecessary UE paging receptions and means to make TRS/CSI-RS occasions currently available only for connected state available also to devices in idle/inactive state.

Release 17 will also consider extensions to the Release-16 UE PDCCH-based power saving adaptation including PDCCH monitoring reduction when C-DRX is configured.

3.2.3.10 NON-TERRESTRIAL NETWORK

During Release 15 and Release 16, 3GPP studied the feasibility and standard adaptations needed to enable NR communication over satellite systems referred to as *Non-terrestrial Networks* (NTN).[37] For Release 17, a work item will be carried out along the lines of the preceding studies. The focus will be on transparent (non-regenerative) payload satellite systems for both Low Earth Orbit (LEO) and Geostationary Orbit (GEO) scenarios, including systems with and without GNSS capability. [38]

[34] 3GPP RP-193260 "New WID on NR Dynamic spectrum sharing" (work-item description)
[35] 3GPP RP-193133 "New WID: Further enhancements on MIMO for NR"
[36] 3GPP RP-193239 "New WID: UE Power Saving Enhancements" (work-item description)
[37] 3GPP TR 38.811, "Study on New Radio (NR) to support non-terrestrial networks"
[38] 3GPP RP-193234 "Solutions for NR to support non-terrestrial networks (NTN" (work-item description)

Key technical areas include:

- Means to handle the very large propagation delay experienced in the satellite scenario (especially for the GEO scenario), something which will impact, for example, random-access procedures, HARQ operation, and RRC procedures
- Extended/enhanced beam management and cell selection/re-selection, especially for the LEO case where the satellite will move rapidly relative to the corresponding devices.

3.2.3.11 NR BROADCAST/MULTICAST

Broadcast/Multicast (BC/MC) functionality for NR will be introduced in Release 17.[39] Some of the intended use cases are Public Safety, V2X applications, IP4/IP6 multicast delivery, IPTV, software delivery over wireless, group communication IoT.

In more details the work item will, for example, include the specification of

- Group-scheduling mechanisms
- Dynamic change between multicast and unicast delivery
- Means for improved reliability of broadcast/multicast services.

The broadcast/multicast mode of operation is targeted to be available to devices in connected state as well as idle/inactive state.

3.2.3.12 SUPPORT FOR MULTI-SIM DEVICES

Multi-SIM devices enable use of multiple subscriptions, potentially for different networks, in one device. As of today, multi-.SIM devices are supported with no specific support within the 3GPP specifications. The Release-17 work item on *Support for Multi-SIM Devices* aims to introduce such support, thereby enabling enhanced performance and user experience in case of a multi-SIM device.[40]

One objective of the work item is to address the issue of collision of paging messages from two different networks for multi-SIM devices. Another objective is to specify mechanisms that a multi-SM device can use to notify the current network when it, for some reason, switches to another network associated with a different SIM.

4 SYSTEM ARCHITECTURE AND NETWORK-RELATED FEATURES

Upcoming 3GPP releases will also include enhancements and specifications relating to 5G and LTE system architecture and network-related features. Areas of focus include 5G deployment options and migration, as well as newly introduced 5G radio access and core network key features.

4.1 5G DEPLOYMENT OPTIONS AND MIGRATION

The 5G eco-system currently invests in and plans to roll out two variants of 5G (Figure 4.1), both initially based on 3GPP Release 15. Option 1 depicts Non-standalone (NSA) NR, also referred to as connectivity. Option 3 displays how NR boosts the throughput of a device connected to LTE/EPC (for example, 4G RAT and 4G Core). This is done using E-UTRAN - NR Dual Connectivity (EN-DC). The second variant of 5G to

[39] 3GPP RP-193248 "New work Item on NR support of Multicast and Broadcast Services" (work-item description"
[40] 3GPP RP-193250 "New WID: Support for Multi-SIM devices in Rel-17" (work-item description)

be rolled out is Standalone (SA) NR (Option 2), where the UE connects using only 5G technologies (NR and 5GC). The target architecture for the 5G migration is to use SA NR and 5GC as far as possible, even though LTE/EPC will need to remain for a long time to handle legacy devices.

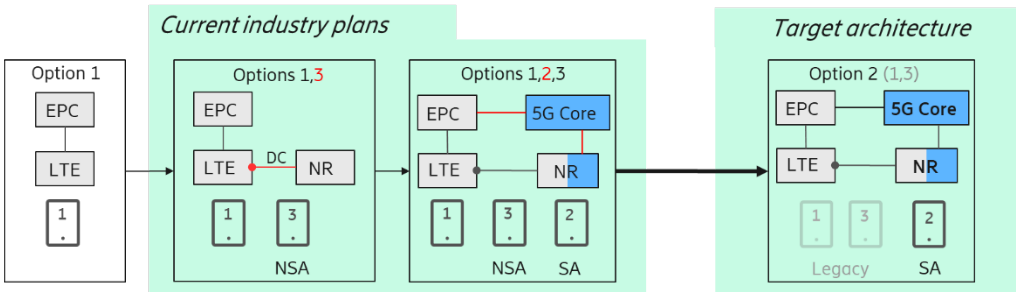

Figure 4.1. Migration towards 5G target architecture.

We acknowledge that there are other Options defined in 3GPP, involving variants to upgrade LTE to 5G, but 5G Americas believes the benefit of focusing on the currently planned Options (3 and 2) will allow the industry to scale the 5G eco-system.

Figure 4.2 summarizes how to migrate to 5G using a combination of Options 1, 3, and 2, that is, LTE, NSA NR, and SA NR. The focus here is on wide-area services, where the area rollout of NR will expand gradually, both on new TDD spectrum (mmW or sub-6 GHz) and in lower bands (spectrum sharing). Figure 4.2 also illustrates a 5GC-capable device using different connectivity options depending on the current NR spectrum coverage. When NR is available with good coverage and wide bandwidth, SA NR Option 2 is used. Where NR is only available on partial spectrum, NSA NR Option 3 can be used. Outside NR coverage, plain LTE Option 1 is used.

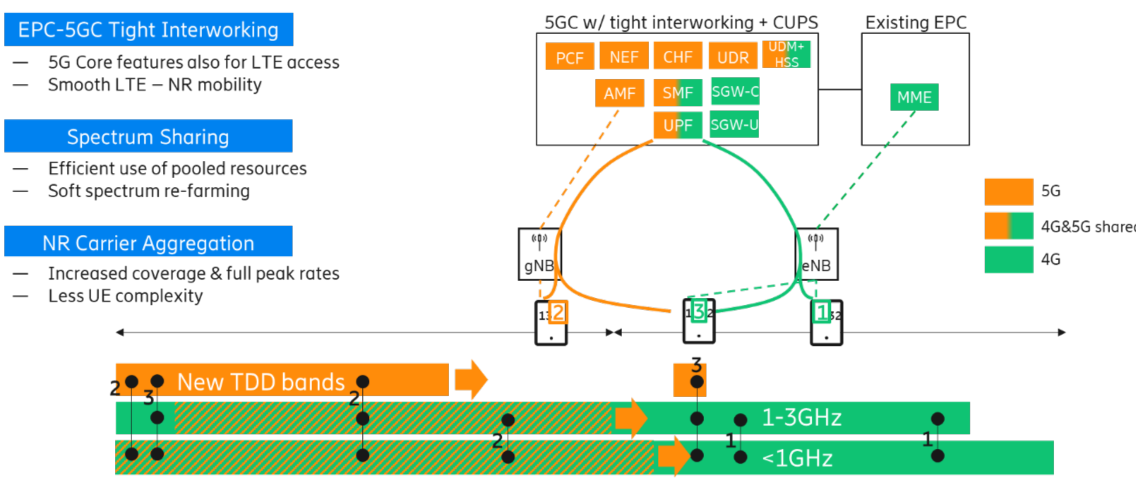

Figure 4.2. Migration to 5G using Options 1, 3 and 2.

There are three key technology enablers for this migration to 5G:

1. **EPC-5GC Tight Interworking** is used to handle areas with insufficient NR coverage during the 5G migration. It can be used with different deployment cases - illustrated in Figure 4.2 is a new 5GC with embedded EPC functions which interworks with an existing EPC that serves legacy LTE/EPC devices. This solution is based on 3GPP-specified EPC-5GC Tight Interworking and 3GPP-specified EPC CUPS (Control-User Plane Separation). In this way, a 5GC-connected device that

moves out of NR (Option 2) coverage will be supported on LTE (Option 1 or Option 3) while still being anchored in the same 5GC gateway. Key 5GC features will be retained as well as smooth LTE-NR mobility.

2. **Dynamic spectrum sharing**, as supported by Release 15, will enable quick NR deployment on existing LTE bands, with efficient pooling of the resources between LTE and NR.
3. **NR Carrier aggregation** is a key motivator to deploy NR on lower (FDD) bands, and to move to SA NR. Carrier aggregation provides best coverage performance, increased downlink usage of the new 5G TDD spectrum, best data rate aggregation performance and less UE complexity within sub-6-GHz bands compared to the dual transmitters needed for dual connectivity solutions.

4.2 5G RAN/CN ARCHITECTURE AND KEY FEATURES

The influence from vertical industries such as automotive, industrial IoT (e.g. factory automation), Cellular IoT, Transport and Satellite industry and Wireless/Wireline convergence will drive many of the new features development for 3GPP's next rounds of releases. Additionally, requirements on deployment flexibility and roaming improved overall architecture for better automation and virtualization are leading to improvements of the architecture.

4.2.1 5G RAN AND CN ARCHITECTURE AND KEY FEATURES FOR RELEASE 16

In Release 16, 3GPP has continued enriching the 5G system with new features like cellular IoT support, Ultra-reliable low latency architecture support, 5G LAN services, Time Sensitive Networking for Industrial IoT, Non-Public Networks and Integrated Access and Backhaul (relaying). In addition, Release 16 enhances the base architecture of Release 15 with features like enhancing the Service Based Architecture, improving flexible deployments of Session Management Control Function (SMF) and User Plane Function (UPF), support for commercial services using location based service architecture, enhancements to UE capability signaling, RAN Self-Organizing Networks, Dual Connectivity and Carrier Aggregation enhancements.

Some of the key features as identified by 3GPP SA2 and RAN work items are listed here, in no particular order:

Table 4.1. Key Features for Release 16

Enhancement of URLLC supporting in 5G	5G_URLLC
5GS Enhanced support of Vertical and LAN services, Private Network Support for NG-RAN, and Support of NR Industrial Internet of Things (IoT)	Vertical LAN, NG_RAN_PRN, NR_IIOT
Cellular IoT support and evolution for the 5G System	5G_CIoT
Architecture enhancements for 3GPP support of advanced V2X services	eV2XARC
Enhancement to the 5GC Location Services	5G_eLCS

Optimizations on UE radio capability signaling	RACS
Study on architecture aspects for using satellite access in 5G	FS_5GSAT_ARCH, FS_NR_NTN_solutions
Enablers for Network Automation for 5G	eNA
Wireless and Wireline Convergence for the 5G system architecture	5WWC
Enhancing Topology of SMF and UPF in 5G Networks	ETSUN
Access Traffic Steering, Switch and Splitting support in the 5G system architecture	ATSSS
Enhancements to Service Based Architecture	5G_eSBA
Enhanced IMS for 5G	eIMS5G
User Data Interworking, Coexistence and Migration	UDICOM
Enhancements for Background Data Transfer	xBDT
System enhancements for Provision of Access to Restricted Local Operator Services by Unauthenticated UEs	PARLOS
Enhancement of Network Slicing	eNS
Architecture enhancements for the support of Integrated Access and Backhaul	IABARC, NR_IAB
(Self-Organizing Networks) and MDT (Minimization of Drive Tests) support for NR	NR_SON_MDT SON
LTE-NR & NR-NR Dual Connectivity and NR Carrier Aggregation enhancements	LTE_NR_DC_CA_enh
NR mobility enhancements	NR_Mob_enh

These key enhancements in 3GPP SA2 and RAN work items warrant further discussion. For instance, the study on integration of satellite access based on NR in 5G architecture continues beyond Release 16 and requires close cooperation between CN and RAN lead work in the same area.

The enhancements for Service Based Architecture (eSBA) in 5GC enables indirect communication and delegated discovery through Service Communication Proxy. This allows flexible architecture and NF communication via Network Repository Function (NRF) and Service Communication Proxy (SCP). By defining NF Service Set and NF Set, the network functions and services defined can be deployed and selected modularly and provide redundancy for the NF services.

The enhancement of Location Services (LCS) uses Release-15 baseline architecture and then adds support for roaming for location services. Some of the additional functions include: NEF enabled exposure of location (at GMLC and AMF/UDM (Cell Identity)), control plane positioning for non-3GPP accesses, Location privacy subscription, temporary blocking of positioning consent from the UE or from Application Function, low powered devices optimized location reporting using CIoT operations for LTE and bulk location reporting operation.

The network slicing function is being further improved with interworking support with EPS to 5GS mobility. It introduces a new procedure for reallocation of AMF and V-SMF as part of topology enhancement work in Connected mode, and also by reallocation to a new AMF during Idle mode mobility. Another added feature known as Network Slice Specific Authentication and Authorization (NSSAA) enables separate authentication and authorization per Network Slice. The trigger of NSSAA is based on subscription information from UDM and operator policy and may be performed when UE indicates support for the feature.

Another feature provided is Radio Capabilities Signaling Optimization (RACS) via optimized OTA signaling of UE Radio capabilities by introducing mapping of RACS ID to UE Radio Capability in the network. A RACS ID uniquely maps to a set of UE Radio Capabilities and is fixed once established. Multiple UEs can share a common RACS ID, while mapping between RACS ID to UE Radio capabilities will be stored in the network as a new NF UE (radio) Capability Management Function (UCMF), as well as cached in RAN nodes and AMF. Two types of RACS ID are standardized, Manufacturer allocated RACS ID and PLMN allocated RACS ID where a PLMN may support either type - or both types.

Enhancements to the Network Automation (eNA) architecture compared to Release 15 adds data collection and network analytics exposure features. Network Analytics ID allows specific analytics data collection based on the source and type of information to Network Data Analytics Function (NWDAF). It defines the output analytics information based on statistics and prediction from the data collected. Some examples of Analytics ID include: Slice Load Level information, Network Performance Information, UE Mobility Information, QoS sustainability, etcetera. A network may deploy multiple NWDAFs, so Analytics ID type support are available either via NRF or via local configuration.

Topology enhancement for flexible deployment of SMFs and UPFs includes the possibility of supporting deployments where a SMF cannot control UPFs in the whole PLMN (examples include mobility between regions within a PLMN, inter-PLMN mobility and Corporate UPF access). It also includes enhancements to better support deployments where a UPF is controlled by multiple SMFs. The feature introduces an Intermediate SMF (I-SMF) entity, with I-SMF supporting selection of Intermediate UPF and selection of other UPF with breakout function. Multiple SMFs control one UPF and possible UP IP address allocation may then be performed in the UPF instead of SMF, as instructed by SMF.

In Release 16, 3GPP took some additional steps to enhance IMS and 5GC to better suit the 5G architecture and some of its features for IMS. These include: P-CSCF registration for discovery via NRF, SMF discovery of P-CSCF via NRF, providing SBA services for Cx and Sh with equivalent functionality, HSS registration in NRF, discovery of HSS instances and their capabilities (legacy vs SBA) to handle gradual migration and co-existence of Rx and N5 for policy and charging control (PCC). In addition, an enhancement was introduced to support Single Radio Voice Call Continuity (SRVCC) from 5G IMS to 3G.

Release 16 provides architectural enhancement in the form of a new Service Based Interface for interaction between HSS and UDM for user data interworking, migration and coexistence between EPS and 5GS. In addition, a 3GPP 9xx series technical report provides additional deployment options for the operators for the coexistence and migration without any changes to the 3GPP standards themselves.

5G_CIoT introduces support for CIoT (similar to EPS) in 5GS for NB-IoT and LTE-M devices with 5GS support. The following features are included: Support for infrequent small data transmission (DoNAS), Frequent small data communication (UP optimization), High latency communication, Power saving functions, Management of Enhanced Coverage, Support of common north-bound APIs for EPC-5GC interworking, Monitoring, Network parameter configuration API via NEF, Overload Control for small data, Inter-RAT mobility support to/from NB-IoT, Support for Expected UE behavior, QoS Support for NB-IoT, Core Network selection for Cellular IoT, Group communication and messaging, Support of the Reliable Data Service and MSISDN-less MO SMS.

Vertical LAN and services for 5GS require several enhancements and additions to the architecture. Within this work area, three key components were addressed: 5G LAN services (5G_LAN), Time Sensitive Networking (TSN) and Non-Public Networks (NPN).

5G_LAN services provide group management services enabling 3rd parties (AF) to create, update and remove groups (may also be done via operator's O&M), as well as handle 5G Virtual Network (VN) configuration data in the network and configuration of group member's UE. For 5G LAN session management, the feature session establishment towards 5G VN group and for user plane handling it enables support for private communication within a 5G VN group with enablement of on UE-to-UE communication.

3GPP Release 16 introduces Non-Public Network (NPN) support that enables the 5G architecture to deliver two types of NPNs: Stand-Alone Non-Public Networks – SNPN or access to a non-public network through a separate logical access network, and Public Network Integrated NPN – PNI NPN or access through an operators public access network. The architecture also provides support for service continuity and support access of NPN services via PLMN and vice versa. SNPN has certain restrictions such as no roaming between SNPNs, no interworking with EPS and UEs supporting SNPN need to be configured with specific data such as PLMN and Network ID (NID). PNI NPN operation may optionally make use of the concept known as Closed Access Group (CAG) which enables the control of UEs' access to PNI NPN on a per cell basis (CAG cells). A UE may be configured with CAG information on a per PLMN basis.

Further enhancements to support NPNs are studied for subsequent releases including enabling support for UE onboarding and provisioning for an NPN, enabling support for SNPN along with subscription/credentials owned by an entity separate from the SNPN.

Time Sensitive Networking architecture enables 5GS to provide time synchronization of packet delivery in each hop, to support Time Sensitive Networking and industrial control via 5GS. For Release 16, the 5G System is integrated with an external network providing TSN services as a TSN bridge. Currently, the release is supporting a centralized TSN model and with specific subset of IEEE specifications with support enabled for the integration. These areas of support include: periodic QoS flows, hold and forward buffer and 5GS logical TSN bridge management & QoS parameter mapping. The TSN time synchronization support includes single and multiple working clock domains via single architecture where:

- gNBs provide only sync for UEs for 5G-clock (sent OTA) and RAN remains agnostic to external time domains;
- UPFs time-synced to the gNB/RAN clock;
- External clocks synced via user-plane path with time stamping in TSN translators at the edge (at the UPF and the UE);
- All 3GPP user-plane nodes are synced to one common clock (3GPP 5G clock).

The entire 5G system can be considered as an 802.1AS "time-aware system". Only the network elements at the edges of the 5G system (translator/adaptor) need to support the IEEE 802.1AS operations.

Architecture enhancements were done in the 5G system for redundant transmission support to enable better reliability for services that require URLLC communications support. Three different variants of solutions are available in Release 16. Operators can choose any or multiple mechanisms depending on the deployment and applications requiring URLLC services.

These variants are: dual connectivity based end to end redundant PDU sessions for the service associated with URLLC profile; redundant user planes between NG-RAN and UPF (redundant N3/N9 interfaces) for the same PDU session where only that link is considered need to be redundant; underlying transport network redundancy where UPF transmits packets utilizing two different redundant transport link and NG-RAN eliminates redundant packets and vice versa. This requires redundant packet handling in UPF and NG-RAN. Additional enhancements have been made to improve handover performance and URLLC QoS monitoring features were introduced to react to any performance degradation. One method uses QoS flow end to end monitoring and the other uses existing GTP-U path monitoring function provided by OAM.

Enhanced V2X architecture developed an end to end architecture for delivering V2X services using either network connectivity (Uu interface) or sidelink communication between the UEs directly using PC5 interface or a combination of both. The core network for 5G enables UE configuration via PCF (UE policy configuration capabilities in 5GS) as well as via V2X AF for both NR and LTE access. The key enhancements in NR compared to LTE PC5 include enhanced support of PC5 QoS aligned with QoS over Uu interface and support for three modes of PC5 operation, unicast, groupcast and broadcast. PC5 NR support is applicable to both stand-alone (5GS) and non-stand-alone (EPS with NR as secondary node). Using Network Analytics, QoS prediction statistical information is provided to V2X AF via NWDAF. Enhancement of Uu QoS with alternative QoS profiles for RAN will be able to adapt to V2X service conditions (this function is not limited to V2X only). A V2X dedicated slice may be used in roaming environments and could be beneficial for OEMs. Specific 5QIs for V2X services has been defined as well.

Access Traffic Steering, Switch and Splitting support in the 5G system architecture (ATSSS) are defined as:

- Access Traffic Steering: Selects an access network for a new data flow
- Access Traffic Switching: Moves all traffic of a data flow from one access network to another access network (“per-flow scheduling”)
- Access Traffic Splitting: Splits the traffic of a single data flow across multiple access networks (“per-packet scheduling”).

Key concepts supported in Release 16 include the following:

- Multi-access PDU Session = PDU Session with simultaneous user-plane ”legs” in 3GPP and non-3GPP access;
- Delegated user-plane decisions:
  - PCF provides ATSSS policy to SMF, and SMF provides corresponding rules to UE and UPF
  - Uplink steering/switching/splitting decided by UE, based on ATSSS rules received from the SMF
  - Downlink steering/switching/splitting decided by UPF, based on N4 rules received by SMF.
- Two aggregation methods supported:
  - Multi-path TCP (MPTCP), for TCP traffic, with MPTCP proxy in UPF;
  - Lower Layer (ATSSS-LL) function below IP, for any traffic.
- Basic measurements between UE and UPF to assist access selection
  - UE and UPF make RTT measurements per access;
  - UE reports access availability/unavailability to UPF.

ATSSS is currently not supported when moving to EPC from 5GC, except for the specific case with wireline access integrated to EPC/5GC with 5G-RG; ATSSS with one User Plane leg in E-UTRA/EPC and one User Plane leg in wireline/5GC is supported.

By collaborating with Broadband Forum (BBF) for convergence of wireline access using 5GS, 3GPP has developed the integrated architecture enabling wireline access connectivity towards 5GC via 3GPP interfaces and protocols. The connectivity options include 5G-RG (RG enhanced with 5G capabilities) connecting via wireline access, 5G-RG using 3GPP access (Hybrid access) and legacy RG (FN-RG) using wireline access.

The Integrated Access and Backhaul feature adds support for wireless backhauling of base stations using the NR radio interface. It is seen as an enabler for further network densification without requiring fiber implementation in every base station. The solution is designed to allow flexible deployment of NR base stations (called IAB nodes) utilizing the larger bandwidth on higher frequencies bands for wireless backhaul. The architecture is based on the gNB split architecture where the gNB-DU functionality is terminated in the IAB node, while the gNB-CU functionality is terminated in a donor node. The IAB node re-uses existing procedures defined for the UE to connect to the donor node. The solution has minimum impacts to the core network.

The work in Release 16 on Self-Organizing Networks and Minimization of Drive Tests adds NR support the SON features specified in LTE, as well as some NR specific enhancements for instance related to NR RRC inactive state.

The work on LTE-NR & NR-NR Dual Connectivity and NR Carrier Aggregation enhancements in Release 16 adds improvements to various carried aggregation and dual connectivity solutions within NR and between NR and LTE. For example, reducing the setup latency for UEs to enter dual connectivity or CA in order to fully utilize the available bandwidth.

Release 16 also included work in the RAN working groups to improve the NR mobility with new solutions to improvise robustness and end user performance, such as reducing service interruptions at handover. One such solution included a mechanism for conditional handover, where the network can configure the UE with multiple handover candidates as well as the conditions for triggering handover towards the candidates. This improves robustness since the UE can trigger handover by itself in case the link to the source cell would suddenly be blocked.

4.2.1.1 5G CN ARCHITECTURE AND KEY FEATURES FOR RELEASE 17

Release-17 core-network-standard features will be built on Release 15 and Release 16 specifications. It will provide further system enhancements and some additional features that were not included in the previous releases. Current schedule for Release 17 complete (code freeze) date is targeted at 3Q 2021.

There are multiple studies and work items that are being proposed, approved, or progressing, in various stages and working groups in 3GPP as of this writing. This section will introduce some of these study or work items with some high-level descriptions. Effort is being made to highlight new important features with emphasis on architectural work (stage 2, SA2) but it is not a comprehensive overview of Release 17.

Some system enhancements and support for new services were added for Release 17. Example of the works involve asset tracking, audio-visual service production, Communication Service Requirements for Critical Medical Applications, 5G enhancement for UAVs (Unmanned Aerial Systems), service requirements on enhancements for cyber-physical control applications in vertical domains, multimedia priority services (phase 2), Support for Multi-USIM Devices, enhanced relays for energy efficiency and extensive coverage, and others. The details of these use case and requirements can be found in 3GPP SA1 working group's web links.

The 5G core network is designed to be modular with network slicing and Service Based Architecture, so multiple use cases can be supported. The system architecture working group (SA2) in Release 17 will continue to develop system enhancements and new features to support existing and new use cases and requirements.

Table 4.2 shows the current list of Release-17 SA2 study/work items. Due to the timeline and resources constraints, this list will be prioritized in the September 2020 SA plenary meeting and it is possible some of these study/work item may not be included in Release-17 features. Two noticeable features that are possible in Release 17 are multicast and broadcast capabilities for 5G and proximity services support for 5G. Both new features are essential in supporting mission critical services and other commercial services.

Table 4.2. List of work items in system architecture group for Release 17 (to be updated once the SA plenary agreed on a final priority list).

Acronym	Definition
5G_AIS	5G System Enhancement for Advanced Interactive Services
5G_MCIoT	Cellular IoT enhancement for the 5G System
5G_ProSe	System enhancement for Proximity based Services in 5GS
5GLAN_enh	Enhancement of support for 5G LAN-type service
5GSAT_ARCH	Integration of Satellite in 5G Systems
5MBS	Architectural enhancements for 5G multicast-broadcast services

Acronym	Definition
5WWC_enh	Study on enhancement of support for 5WWC
AAI_LTE_NR	Application Awareness Interworking between LTE and NR
eATSSS	Extended Access Traffic Steering, Switch and Splitting support in the 5G system architecture
eIMS5G	Enhanced IMS to 5GC Integration
eLCS_ph2	Enhancement to the 5GC Location Services-Phase 2
eNA_Ph2	Enablers for Network Automation for 5G - phase 2
enh_EC	enhancement of support for Edge Computing in 5GC
eNPN	enhanced support of Non-Public Networks
eNS_Ph2	Enhancement of Network Slicing Phase 2
eUEPO	enhancement of 5G UE Policy
eV2XARC_Ph2	Architecture enhancements for 3GPP support of advanced V2X services - Phase 2
FLADN	Supporting Flexible Local Area Data Network
ID-UAS	Supporting Unmanned Aerial Systems Connectivity, Identification, and Tracking
IIoT	Enhanced support of Industrial IoT - TSC/URLLC enhancements
MPS2	Multimedia Priority Service (MPS) Phase 2
MUSIM	Support for Multi-USIM Devices
NG_RTC	System architecture for next generation real time communication services
SB_SMS	service-based support for SMS in 5GC

Acronym	Definition
SUP	Smarter User Plane
UPCAS	UPF enhancement for control and SBA
UUI5	the Usage of User Identifiers in the 5G System

SA2 Release-17 study on architectural enhancements for 5G multicast-broadcast services (5MBS): Multicast and broadcast features were defined for LTE but the services using those standards have not been widely deployed. However, this feature is important for multiple use cases in 5G such as CIoT, V2X, mission critical services, and others. In addition, with 5G service-based architecture, there is an opportunity to define a modular and simpler architecture. This study will be coordinated with corresponding RAN work. There are two sets of goals for this study item, one is to define a framework for multicast and broadcast service, the other is to "support broadcast architecture for TV Video and Radio Services in 5G system".

SA2 Release-17 study on System enhancement for Proximity based Services in 5GS: proximity services (also referred to as D2D direct communications) was also defined in LTE and is an important feature for public safety, V2X, and other commercial services for 5G services. This study will define a framework in coordination with the corresponding RAN work for supporting such features in 5G. There are two sets of objectives for this framework: one is to support public safety use cases, and the other is to support commercial use cases.

In addition to SA2 work, these are some other important works going on in other 3GPP working groups that provide complete system support and they also provide additional features that deem to be critical to the future 5G services. For example, CODEC working group (SA4)' 5GXR work to support AR/VR/XR applications.

5 CONCLUSION

3GPP is in its final stage of completing Release 16 while simultaneously engaging in detailed discussions and decisions on Release 17.

In Release 16, the current 5G NR capabilities are enhanced from Release 15, improving the operational efficiency of the radio-access technology. In parallel, Release 16 introduces new capabilities extending NR towards new verticals. Some key features of NR Release 16 are:

- Support for Integrated Access/Backhaul (IAB) extending NR to support also the wireless backhaul, thereby enabling, for example, rapid deployment of NR cells and new ways to provide NR coverage in areas with sparse fiber density
- Support for NR operation in unlicensed spectrum, both in form of license assisted access where an NR carrier in unlicensed spectrum complement and operates jointly with a carrier (NR or LTE) in licensed spectrum, and stand-alone operation,
- Enhanced support for V2X, URLLC, and Industrial IoT, thereby extending/enhancing the applicability of NR to new usage scenarios including factory automation and transport industry

Decisions by 3GPP were made on Release 17 in December of 2019 to improve network capacity, latency, coverage, power efficiency and mobility. In Release 17addition to general enhancements of current features, several new Release 17 features have been outlined in this paper including:

- Extending the operation of NR to spectrum above 52.6 GHz to 71 GHZ
- Introducing Reduced Capability NR devices (NR-Light, i.e. enabling services with a UE complexity/capability trade-off in-between the conventional high-quality eMBB services and the low-complexity services enabled LTE-MTC and NB-IoT).
- Enhanced Dynamic Spectrum Sharing
- Multi-Sim devices
- More advanced Sidelink communications
- Small data capabilities
- Enabling broadcast/multicast services within NR
- Support for non-terrestrial networks (i.e. a satellite component of NR)

For LTE, the extensions and enhancements in Release 16, and even more for Release 17, are much limited, reflecting the maturity of the LTE technology. A key focus for Release 16, and possibly also for Release 17, is further enhancements of the support for massive-MTC applications by means of enhancements to both LTE-MTC and NB-IoT. In parallel, there are Release-16 enhancements, for example, in terms of mobility and performance for high-speed scenarios such as very-high-speed trains.

Overall, the mobile wireless industry continues to make great strides in research, development, standardization and deployment of 5G technologies. The evolution and revolution in wireless continues with new standardized technical features at 3GPP as the mobile wireless industry connects more people and things in new markets.

APPENDIX

ACRONYMS

3GPP	3rd Generation Partnership Project
4G	Fourth Generation
5G	Fifth Generation Mobile Networks
5GC	Fifth Generation Core
AI	Artificial Intelligence
AMF	Access and Mobility Management Function
AoA	Angle-of-Arrival
AoD	Angle-of-Departure
BC	BroadCast
BF	Beamforming
CA	Carrier Aggregation
CAG	Closed Access Group
CAGR	Compound Annual Growth Rate
CAPEX	Capital Expenses
CIoT	Cellular IoT
CLI	Cross-Link Interference
cMTC	Critical Machine Type Communications
CN	Core Network
CoMP	Coordinated Multi-Point Transmission and Reception
CORESET	Control Resource set
CP	Control Plane / Cyclic Prefix
CQI	Channel Quality Indicator
C-RNTI	Cell RNTI
CS	Circuit Switched
CSI	Channel-State Information
CSI-RS	Channel-State Information Reference Symbol
CU	Control/ User Plane OR Central Unit
D2D	Device-to-Device
DC	Dual Connectivity
DCI	Downlink Control Indicator
DL	Downlink

DMRS	Demodulation Reference Signal
DoNAS	Data over NAS
DU	Distributed Unit
E2E	End-to-End
EB	Enhanced Beam forming
eMBB	Enhanced Mobile Broadband
EN-DC	E-UTRAN New Radio Dual Connectivity
eNodeB	Evolved NodeB
EPC	Evolved Packet Core also known as System Architecture Evolution (SAE)
EPC/SAE	Evolved Packet Core/System Architecture Evolutions
ePDG	Evolved Packet Data Gateway
EPS	Evolved Packet System
ETSI	European Telecommunications Standards Institute
E-UTRA	Evolved Universal Terrestrial Radio Access
E-UTRAN	Evolved Universal Terrestrial Radio Access Network
FCC	Federal Communications Commission
FD	Frequency Division
FD	Full Dimension as in FD-MIMO
FDD	Frequency Division Duplex
FDM	Frequency-Division Multiplexing
FR1	Frequency Range 1 (410 MHz – 7125 MHz)
FR2	Frequency Range 2 (24250 MHz – 52600 MHz)
FWA	Fixed Wireless Access
GEO	Geosynchronous (Satellite) Orbit
GERAN	GSM EDGE Radio Access Network
GMLC	Global Mobile Location Center
GNSS	Global Navigation Satellite System
GPRS	General Packet Radio Service
HARQ	Hybrid Automatic Repeat Request
HPHT	High-Power/High-Tower (broadcast scenario)
HSS	Home Subscriber Server
IAB	Integrated Access Backhaul
ID	Identity

IEEE	Institute of Electrical and Electronics Engineers
IMS	Internet Protocol Multimedia Subsystem
IMT	International Mobile Telecommunications
IIoT	Industrial Internet of Things
IoT	Internet of Things
IP	Internet Protocol
I-SMF	Intermediate SMF
ITU	International Telecommunications Union
LAA	License Assisted Access
LBT	Listen-Before-Talk
LCS	Location Services
LCM	Life Cycle Management
LEO	Low Earth (Satellite) Orbit (400 km to 2000 km)
LPWA	Low Power Wide Area
LTE	Long Term Evolution
MBMS	Multimedia Broadcast Multicast Services
MBSFN	Multicast-Broadcast Single Frequency Networks
MC	MultiCast
MCG	MeNB Cell Group
MCS	Modulation and Coding Scheme
MDT	Minimization of Drive Tests
MEC	Multi-access Edge Computing
MEO	Medium-Earth (Satellite) Orbit (2000 km to just below geosynchronous orbit)
MIMO	Multiple-Input Multiple-Output
MME	Mobility Management Entity
mMTC	Massive Machine Type Communications
mmWave	Millimeter Wave
MPTCP	Multi-Path TCP
MPMT	Medium-Power/Medium-Tower (broadcast scenario)
MR-DC	Multi-Radio Dual Connectivity
MSISDN	Mobile Station International Subscriber Identity Number
MT	Mobile-Terminated (also used to indicate the north-bound part of an IAB node)

MTC	Machine Type Communications
MU-MIMO	Multi-User Multiple-Input Multiple-Output
NA	Network Automation
NB-IoT	Narrowband IoT
NE-DC	NR E-UTRA Dual Connectivity
NEF	Network Exposure Function
NF	Network Functionality
NG	Next Generation
NID	Network ID
NPN	Non-Public Network
NR	New Radio
NRF	Network Repository Function
NR-U	NR Unlicensed
NSA	Non-Standalone
NSSAA	Network Slice-Specific Authentication and Authorization
OCB	Occupied Channel Bandwidth
OFDM	Orthogonal Frequency Division Multiplexing
OPEX	Operating Expenses
OTA	Over-The-Air
OTDOA	Observed Time Difference of Arrival
PAPR	Peak-to-Average-Power Ratio
PCC	Policy and Charging Control
Pcell	Primary cell
P-CSCF	Proxy Call Session Control Function
PDCCH	Physical Downlink Control Channel
PDCP	Packet Data Convergence Protocol
PDSCH	Physical Downlink Shared Channel
PLMN	Public Land Mobile Network
PMCH	Physical Multicast Channel
PNI NPN	Public Network Indicated NPN
PRACH	Physical Random-Access Channel
ProSe	Proximity Services
PS	Packet Switched
PSBCH	Physical Sidelink Broadcast Channel

PSCCH	Physical Sidelink Control Channel
PSFCH	Physical Feedback Control Channel
PScell	Primary Scell
PSSCH	Physical Sidelink Shared Channel
PTRS	Phase-Tracking Reference Signal
PUCCH	Physical Uplink Control Channel
PUSCH	Physical Uplink Shared Channel
QoS	Quality-of-Service
RACH	Random Access Channel
RACS	Radio Capabilities Signaling Optimization
RAN	Radio Access Network
RIM	Remote Interference Management
RIT	Radio Interface Technology (IMT-2020 proposal)
RMSI	Remaining Minimum System Information
RNTI	Radio Network Temporary Identity
ROHC	Robust Header Compression
RRC	Radio Resource Control
RRM	Radio Resource Management
RSRP	Reference Signal Received Power
RSRQ	Reference Signal Received Quality
RSSI	Received Signal Strength Indication
RSTD	Received Signal Time Differenfce
RTOA	Relative Time of Arrival
RTT	Round Trip Time
Rx	Receive
SA	Stand-Alone
SBA	Service-Based Architecture
Scell	Secondary cell
SCI	Sidelink Control Indicator
SCG	SeNB Cell Group
SCG	Secondary Cell Group
SCP	Service Communication Proxy
SC-PTM	Single-Cell Point-to-Multipoint

SFN	Single Frequency Network
SIM	Subscriber Identity Module
SINR	Signal-to-Interfance-and-Noise Ratio
SL	Sidelink
SMF	Session Management Control Function
SNPN	Stand-Alone NPN
SON	Self-Optimizing or Self-Organizing Network
SRIT	Set of Radio Interface Technologie(s)
SRS	Sounding Reference Signal
SRVCC	Single Radio Voice Call Continuity
TA	Time Alignment
TDD	Time-Division Duplex
TDM	Time-Division Multiplexing
TDOA	Time Difference Of Arrival
TSC	Time Sensitive Communication
TTI	Transmit Time Travel
Tx	Transmit
UAV	Unmanned Ariel Vehicles
UC	UniCast
UCI	Uplink Control Indicator
UCMF	UE (radio) Capability Management Function
UDM	Unified Data Management
UE	User Equipment
UL	Uplink
UPF	User-Plane Function
URLLC	Ultra-Reliable Low Latency Communications
V2P	Vehicular-to-Pedestrian
V2V	Vehicular-to-Vehicular
V2X	Vehicle-to-Everything
VN	Virtual Network
WG	(3GPP) Working Group
WI	Work Item
WID	Work Item Description

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The mission of 5G Americas is to advocate for and facilitate the advancement of 5G and the transformation of LTE networks throughout the Americas region. 5G Americas is invested in developing a connected wireless community for the many economic and social benefits this will bring to all those living in the region.

5G Americas' Board of Governors members include AT&T, Cable & Wireless, Ciena, Cisco, CommScope, Ericsson, Intel, Mavenir, Nokia, Qualcomm Incorporated, Samsung, Shaw Communications Inc., Sprint, T-Mobile USA, Inc., Telefónica and WOM.

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