A 5G Americas White Paper

BECOMING 5G-ADVANCED:

the 3GPP 2025 Roadmap

December 2022

Contents

1. Introduction

Third Generation Partnership Project (3GPP) has standardized features and specifications for 3G through 5G cellular technology generations. Enhancements, advancements, and standardization of 5G technology continue with significant innovation.

This 5G Americas white paper provides an overview of key features and technologies under study and being specified in 3GPP for Release 18 (Rel-18) for implementation and deployment in the 2025-time frame. 3GPP Release 18 is branded as 5G Advanced for its significant improvements as it will include major enhancements in the areas of artificial intelligence (AI) and extended reality XR) that will enable highly intelligent network solutions that can support a wider variety of use cases than ever before. Rel-18 proposes standards for further intelligence into wireless networks by implementing machine-learning-based techniques at different levels of the network.

The various 3GPP security initiatives are discussed in the 5G Americas white papers on "Evolving 5G Security for the Cloud" (September 2022)[1], "Security for 5G" (December 2021)[2], and "Security Considerations for the 5G Era" (July 2020)[3]. Furthermore, 3GPP Technical Specifications for security are contained in the 33.xxx series and security Work Items are listed in the 3GPP work plan.[4]

The white paper material is presented in 3 sections. Section 2 "Background" contains a description of the 3rd Generation Partnership Project (3GPP), 3GPP processes, a review of major enhancements and new vertical applications, an assessment of Global Market Trends and use cases, and a developmental timeline for currently active 3GPP releases. Section 3 "Radio-Access Technologies" highlights 22 new/enhanced RAN features and capabilities. Finally, Section 4 "System Architecture, Core Networks, and Services" presents service and core network developments currently underway in 3GPP.

3GPP Rel-18 sets off the 5G Advanced Evolution. Source**: Qualcomm, Jan 2022.**

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 provides their members with a stable environment to produce the reports and specifications that define 3GPP technologies. 5G Americas is represented at 3GPP as a Market Representative Partner (MRP).

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 (“G’s”) 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 by starting future work well in advance of the completion of the current Release. Although this adds some complexity to the work of the groups, this method ensures that progress is continuous and stable. This white paper provides a summary of the progress of the 3GPP technical features.

2.1 Review of 5G Rel-17

Following the success of 5G Rel-15 and Rel-16, Rel-17 continues to enhance 5G radio access technology in the following areas.

- Enhanced existing 5G applications and use cases
- Introduced new applications, use cases, and services for 5G
- Support new type of devices of 5G

The major enhancements to existing applications are summarized below.

- Further enhancements on MIMO for NR to improve spectrum efficiency and robustness of wireless communications, which is the backbone of 5G. The new techniques introduced in Rel-17 MIMO enhancements include a unified TCI framework to improve beam management, multi-TRP transmission to improve the reliability communications, SRS enhancement to allow more dynamic SRS triggering and enhanced SRS coverage, and optimization for highspeed communications such as high-speed train.
- Improved coverage of uplink control and data channels with techniques such as enhancement repetitions, DMRS time domain bundling, uplink data transport block distribution over multiple slots.
- Enhanced sidelink communications in terms of power saving and Enhanced reliability and reduced latency. Power saving is achieved with partial sensing and DRX enhancement. Reliability of sidelink is improved with inter-UE coordination. Sidelink DRX for broadcast, groupcast, and unicast is supported for sidelink communications. Side link relay is also supported in Rel-17.
- Positioning enhancement includes improved positioning accuracy in both horizontal and vertical, lower latency with shortening request and response, improved efficiency at both network and devices.

- UE Power saving enhancements are therefore vital to the success of 5G/NR. On top of Rel-16 power saving, the enhancement in Rel-17 power saving covers both idle mode and connected mode. For idle mode, PDCCH based PEI is introduced to reduce paging false alarm rate. For connected mode, extension for active BWP with PDCCH skipping by scheduling DCI, and relaxed RLM measurements are introduced.
- For URLLC/IIoT, HARQ-ACK feedback is enhanced to support SPS HARQ-ACK deferral, enhanced type-3 HARQ-ACK, and PUCCH cell switch. Rel-17 also extends URLLC operations in unlicensed band. Multiplexing behavior among HARQ-ACK/SR/CSI and PUSCH for traffic with different priorities are supported. Propagation delay compensation enhancements are introduced for timing sensitive networks.
- IAB enables flexible and dense deployment of NR cells while reducing the need for wireline transport infrastructure. Enhancements to IAB in Rel-17 improve various aspects such as robustness, degree of load-balancing, spectral efficiency, multi-hop latency and end-to-end performance.
- Rel-17 NTN specifies the enhancements identified for issues due to long propagation delays, large Doppler effects, and moving cells in NTN (non-terrestrial networks) especially LEO and GEO with implicit compatibility to support HAPS (high altitude platform station) and ATG (air to ground) scenarios.

New vertical applications introduced in Rel-17 are listed in the following.

- XR study is initiated in Rel-17. XR is an umbrella term for different types of realities, including Augmented Reality (AR), Mixed Reality (MR) and Virtual Reality (VR), and refers to all real-and-virtual combined environments and human-machine interactions generated by computer technology and wearables. Rel-17 studied power, capacity, mobility, and coverage considerations for XR.
- New spectrum 52.6-71GHz is supported in Rel-17. The new spectrum supports both licensed and unlicensed operation. Both the legacy subcarrier space (120Khz) and new subcarrier space (480Khz or 960Khz) are supported.
- IoT over NTN is supported to allow global connectivity via satellite for eMTC and NB-IoT devices anywhere on earth, even in areas beyond terrestrial deployments.
- Rel-17 supports basic functionalities of for broadcast/multicast for UEs in connected mode, and idle/inactive mode. New technologies such as group-based scheduling mechanism, NACK-only based feedback for multicast, HARQ-ACK feedback multiplexing between unicast and multicast, and many other new techniques.

For new types of devices, NR RedCap (reduced capability) device is introduced in Rel-17. Different than the premium 5G NR devices introduced in NR R15/16, Redcap is designed to achieve lower cost, lower complexity, longer battery life and smaller form factor. The introduction of RedCap devices facilitates the expansion of the NR ecosystem to cater to the use cases that are not yet best served by current NR specifications, such as wearables, industrial wireless sensors, and video surveillance cameras. The latency and throughput requirements of use cases earmarked for RedCap devices cannot be met by LTE LPWA (i.e., eMTC and NB-IoT), and there is no overlap in their applications. In summary, Redcap devices can be viewed as a mid-tier device. It is lower than premium devices for eMBB/URLLC services with large throughput/low latency/high reliability. But it is higher than eMTC/NB-IoT devices, which has the lowest complexity, lowest power consumption, and largest delay tolerance.

On system architecture, core networks, and services, 5G Rel-17 supports the following.

- Enhanced Access Traffic Selection Steering (ATSSS-phase 2)
- Drone Identification (ID-UAS)
- Edge computing
- Further enhancements to Network Automation (eNA-phase 2)
- Security enhancement
  - » AKMA TLS protocol profiles
  - » Non-Seamless WLAN offload in 5GS
- Multi-Media/App-enabler enhancements
  - » 5G Multicast-Broadcast Protocols
  - » Edge Extensions to 5GMS
  - » 5GMS AF Event Exposure
  - » Handsets Featuring Non-Traditional Earpieces
  - » 8K Television over 5G
  - » Edge-App
  - » IMS voice enhancements

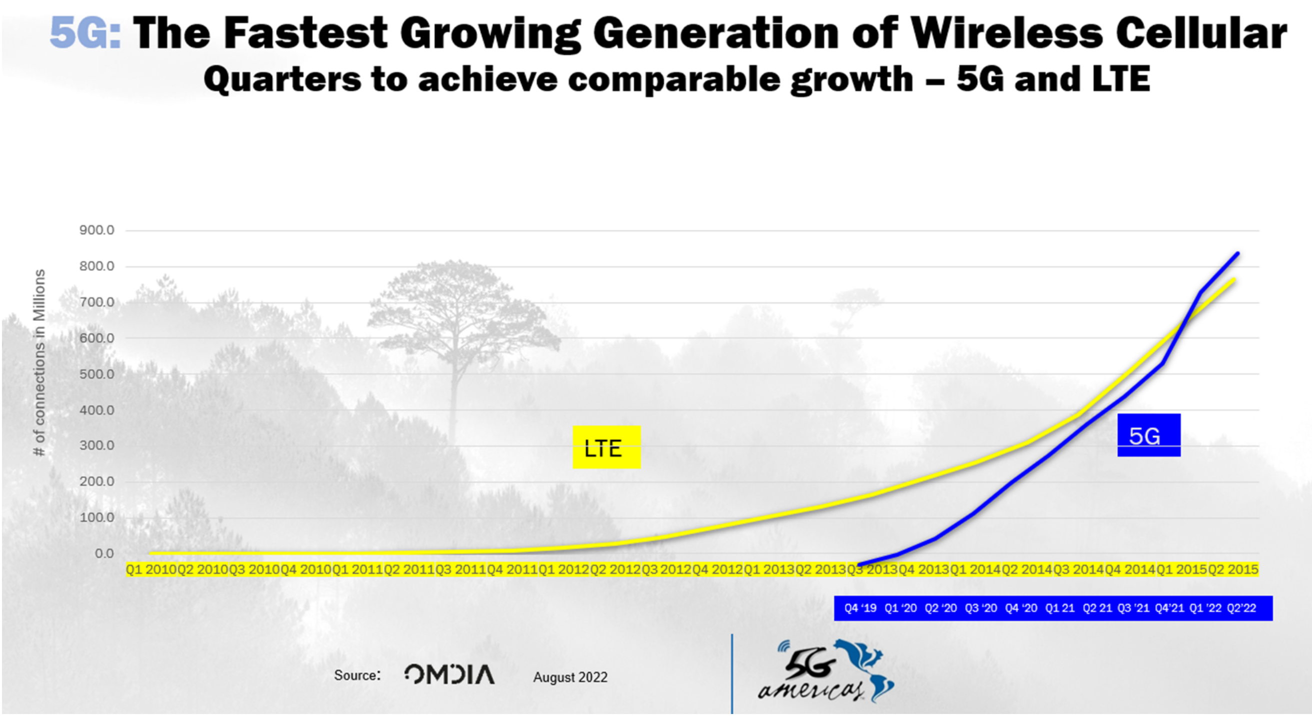
2.2 Global Market Trends towards 5G-Advanced

New mobile technologies profoundly impact economies and societies. 5G or “Fifth Generation” is a commercial reality with approaching two hundred thirty-three deployments worldwide. By supporting new application types and flexible spectrum use, including frequencies never used in cellular systems, 5G provides a communications foundation for a future world—one of extended reality, metaverse, autonomous cars, smart cities, wearable computers, and innovations that are not yet conceived.

5G is already unlocking the potential of technologies like artificial intelligence (AI), edge compute and the Internet of things (IoT). 5G is laying the foundation of Industry 4.0 and becoming instrumental to the success of these new technologies by offering rich bi-directional communications, a potential to support millions of connected devices per squared kilometer with staggering speeds and low latency. The capabilities offered by 5G enable a variety of use cases, paving the way for the economy to realize the cross-industry benefits of magnified and enhanced connectivity.

According to Ericsson Mobility Report (June 2022) 5G is scaling faster than any previous mobile generation and we expect 5G subscriptions to reach 1 billion by the end of 2022 and 4.4 billion by the end of 2027.

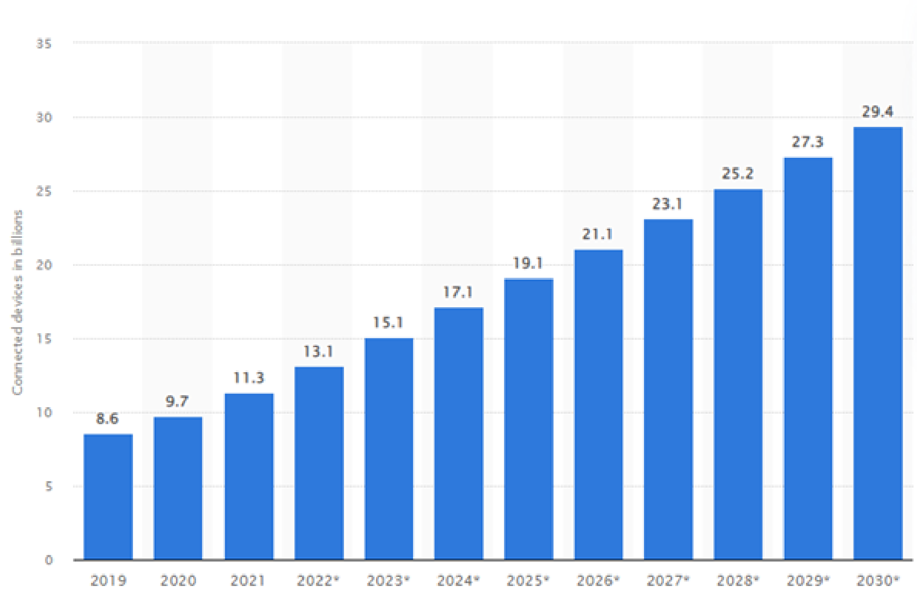
Figure 1: 5G is the fastest growing technology



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

- 7.6 billion people forecast to be accessing the internet via mobile by 2027[5]
- 5G coverage will roll out rapidly to cover71 percent of the global population by 2027[6]
- 5G will account for 46.4 percent of all connections by 2027[7]
- Close to 5.9 billion 5G mobile connections are forecast by 2027[8]
- 29.4 billion Internet of Things (IoT) devices globally in 2030[9]
- The impact of 5G on the U.S. economy will drive up to $2.7 trillion in additional gross output (sales) growth between 2021 and 2025. 5G will add up to $1.5 trillion to the U.S. GDP over the same period.[10]
- 5G has the potential to create or transform up to 16 million jobs across all sectors of the economy between 2021-2025[11]
- 5G will add $2.2 Trillion to the global economy over the next 14 years[12]

Figure 2: Number of Internet of Things (IoT) connected devices worldwide from 2019 to 2030[13]



These are clearly enormous numbers. While the promise of 5G is high, analysts believe the expected results from 5G technology commercial deployments are in the initial development stages and will take time to evolve. The 5G architecture is standardized for today and tomorrow's network evolution. The wireless industry is transformational using technology enablers like Cloud-Native, Software Defined Radio, Network Function Virtuality and Multi-Access Edge Computing (MEC). The mega-networks of billions of connected things and people of the future will require a major shift in network operations and management.

Just as Long-Term Evolution (LTE) continually advanced, 5G will be constantly enhanced in successive versions of the standard, with Release 18 and beyond termed 5G-Advanced. These changes are being enabled through the 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 currently has in store for the more near-term evolution for 5G. It will also touch upon the longer-term evolution of wireless communication into a possible 6G era in the coming decade.

For a more detailed look at what is anticipated for Future Networks here is the 5G Americas White Paper "Mobile Communications Towards 2030". This paper details the global work of conceptualizing anticipated continued enhancements, and the evolution of 5G and beyond into the future. It includes comments as appropriate and presents potential use cases and technologies for the evolution of 5G towards the next Generation.

2.3 New use cases for 5G-Advanced

5G-Advanced technologies will enable many exciting new use cases and applications such as the following:

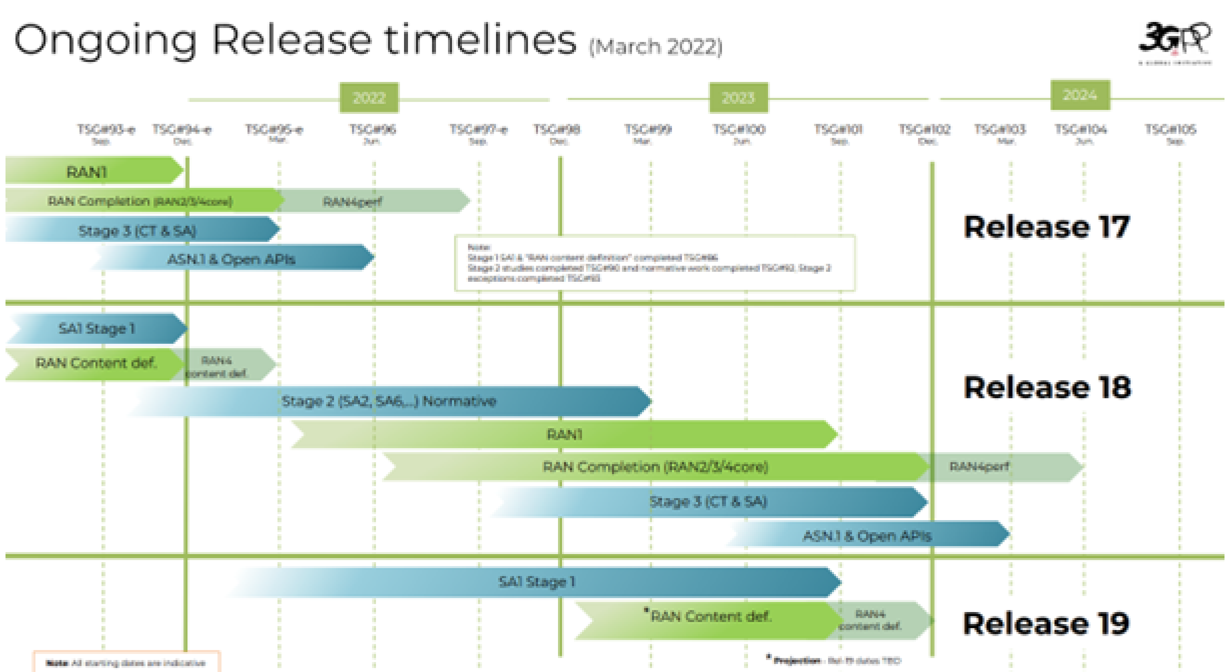
- Framework to apply AI/ML to the air-interface, including the following
  - » CSI feedback enhancement.
  - » Beam management
  - » Positioning accuracy enhancements for different scenarios including NLOS operation
- NR sidelink positioning and relay (coverage extension) enhancements, including the following
  - » V2X
  - » Public safety
  - » Commercial applications and services
  - » IIoT
  - » Positioning integrity for mission critical services
- NR RedCap related use cases, including the following
  - » Wearables (e.g., smart watches, wearable medical devices, AR/VR goggles, etc.)
  - » Industrial wireless sensors
  - » Video surveillance
  - » Smart grid
- UAV NR Improvements for UL and DL interference and Aerial mobility
- Dual Tx/Rx MUSIM for Connected mode on both USIMs (e.g., voice call via one USIM while downloading data on the other USIM)
- Enhancements of NR Multicast and Broadcast Services, including the following
  - » Public safety and mission critical
  - » V2X

    - IPTV
    - Live video
    - Software delivery
    - IoT application
- Mobile IAB (VMR) related use cases, including the following
    - Extending coverage in and around vehicles which follow a certain schedule (e.g., public transport buses, trains etc.
    - Large public events at venues
    - Hot-spot areas
    - Emergency or disaster recovery
- Further enhancement of data collection for SON (Self-Organizing Networks)/MDT (Minimization of Drive Tests) in NR and EN-DC
    - Data collection and utilization
- Enhancements for XR, including the following
    - Real-time media (consumers, enterprise, public institutions etc.)
    - Remote control,
    - Industrial control
    - Mobility automation

2.4 3GPP timeline for 5G-Advanced

3GPP leverages a parallel workflow system for specification release development. That is, multiple releases are under development at any given point in time. For 5G-Advanced, it is envisioned that it will span across multiple releases, including Release 18, Release 19, and perhaps Release 20 and beyond. Scoping in RAN for Release 18, the first target release for 5G-Advanced, began in the 2nd half of 2021 and is scheduled for core specification completion at the end of 2023. This does not include the performance part in RAN4 or UE conformance testing specification work that follows in RAN5. Figure 3 shows the current projections for the 5G-Advanced release timeline. The scope of the following section will focus on the initial RAN 5G-Advanced release cycle (Rel-18).

Figure 3: 5G-Advanced Release Timing, Source: 3GPP



3. Radio-Access Technologies

3.1 MIMO Evolution for Downlink and Uplink

Release-15 NR introduced a flexible framework for massive MIMO solutions, to serve deployments in both sub-6GHz as well as mmWave frequencies.

Releases 16 and 17 focused mainly on various downlink improvements:

Release-16 reduced the overhead for Type II CSI Codebook – to better serve in the Multi-User MIMO scenarios, mainly targeted for FDD frequencies; it also introduced the foundational concepts for multi-TRP operations, with focus on PDSCH.

Release-17 helped further the MIMO operations on FDD, by suggesting partial reciprocity involving concepts such as Angle of Arrival, Angle of Departure, Delay, etc. Given that the commercial deployments had already started around the globe, mainly on TDD utilizing massive MIMO solutions based on channel reciprocity, it was also a good idea to consider extending the SRS capacity and coverage. In terms of mTRP operations, Release-17 started focusing on channels other than PDSCH i.e., PDCCH, PUSCH and PUCCH, proposed a unified TCI framework which now allows a common beam indication for multiple downlink and uplink channels, and added inter-cell operations to the mTRP framework.

Release-18 still brings certain downlink-related enhancements, yet its main focus are the uplink ones. In this way, the first release of 5G-Advanced will not only achieve a symmetry of downlink and uplink capabilities, but it will also prepare for the new emerging applications like AR/VR/XR, which are uplink-heavy. Another aspect of Release-18 worth noting is the increased interest for a diverse set of devices: now that every commercial 5G hand-held device is successfully using massive MIMO solutions to boost the user experience, it is time to extend massive MIMO to CPE, FWA, industrial and vehicular devices. The below paragraphs aim to show the main trends in Release-18 massive MIMO.

The previous releases have built a flexible framework for CSI acquisition and reporting, yet in commercial deployments one may need to prove massive (MU-)MIMO benefits in various high velocity scenarios: high-speed trains, UEs on the highways, UAV, etc. In such scenarios, the CSI information received from the UE can become outdated quickly, causing performance degradation. The existing CSI framework offers workarounds such as transmitting and measuring CSI-RS – respectively reporting CSI – more often. One needs to acknowledge that this approach will generate overhead, drain the uplink resources, and ultimately impact the UE power consumption. It is known that the channel coherence time varies significantly as the velocity increases, hence there is a need to enhance the existing CSI framework with methods that exploit temporal channel correlation, as well as Doppler domain information. Since 5G-Advanced aims to start a paradigm shift and bring an AI-based approach, more and more studies are being conducted to understand how CSI-feedback prediction can help the real-world scenarios.

Another ambition of advanced NR releases is to extend the focus to other than the usual hand-held smartphones – CPE, FWA, vehicular, industrial, etc. Since all these types of devices will use the next generation networks, Release-18 aims to find means to accommodate these needs of increased capacity. The first step would be to extend the number of orthogonal Demodulation Reference Signals to 24 – in this way, more users with more layers can take benefit of the network simultaneously. Since the new devices aim to use 8 Tx, the CSI framework will also need to adopt some enhancements in terms of Sounding Reference Signals (SRS), SRS Resource Indication (SRI), TPMI codebooks. For downlink, these enhancements will add to the existing SRS Antenna Switching operation, currently used in many commercial networks. For uplink, the scope would be to extend the support to 4 or more data layers, potentially sent from more than one UE panel, by using multi-panel UEs.

Releases 16 and 17 set the stage for mTRP and continued evolving its framework, yet their main scope was the downlink operations. Release-18 will shift the focus onto the uplink operations, to again accommodate a more diverse set of devices. The previous releases allowed for a UE with multiple Rx panels to simultaneously receive data from two TRPs. This release will now allow for a UE with multiple Tx panels to simultaneously transmit data to multiple TRPs. Obviously, transmitting from two UE panels also involves studying the potential enhancements required by the timing advance and power control operations. If the previous releases focused on mTRP Non-Coherent Joint Transmission (NC-JT), suitable for eMBB applications which can work with a non-ideal backhaul, Release-18 studies the improvements needed for Coherent Joint Transmissions (C-JT), especially in terms of CSI feedback. In such scenarios, the tight synchronization between TRPs is important, since accurate CSI is a key enabler for C-JT. Yet a C-JT solution will be able to improve the coverage, as well as the average throughput. Finally, Release-18 will extend the existing mTRP framework to accommodate larger collaboration sets – more than 2 TRPs – to mainly benefit mobility and URLCC.

Although the main theme of Release-18 is its focus on uplink operations, with a few additions to enhance the downlink ones, there are several leitmotifs worth mentioning: its increased interest to create an environment for a diverse set of devices including CPE, FWA, vehicular, industrial and the trend to use AI/ML algorithms more and more – especially in predicting CSI feedback and in Beam Management operations.

Overall, Release-18 massive MIMO brings a vast range of enhancements to reduce the overhead and increase the spectral efficiency, to offer more stable connections for all types of scenarios – even the high velocity ones, and to accommodate the emerging applications requiring low-latency.

3.2 Study on Artificial Intelligence (AI)/ Machine Learning (ML) for NR Air Interface and NG-RAN

With the introduction of 5G, mobile networks are becoming increasingly complex from resource management perspective with wide variety of combinations for hardware, software, deployment architecture and use cases that need to be handled by the network. Having an appropriately dimensioned, efficient, and reliable network configuration is of paramount importance. It is well understood that traditional method design, deployment and operation may not be able to provide efficiencies in many cases.

There is a trend towards leveraging Artificial Intelligence (AI) and Machine Learning (ML) for automating both repetitive and complex tasks by using large amounts of data collected by the system. Applied correctly, AI/ML techniques have the potential to provide significant efficiency in the network.

Wireless networks inherently collect large amounts of data as part of normal operation. This data centric approach is the foundation for AI/ML in RAN.

At the same time, mobile devices have become increasingly more powerful in its compute capability. Fueled by the increased compute and expanded data availability, various implementations for radio functionalities based on AI/ ML techniques are already in place at the mobile devices. The compute capability, including both AI/ML training and inference, at the mobile devices is expected to increase multiple folds in the upcoming decade.

3GPP standards for 5G-Advanced is aimed to address means to optimize the standardized interfaces for data collection, while leaving the automation function up to proprietary implementation to ensure vendor incentives in terms of innovation and competitiveness.

In 3GPP Rel 15 study, a network functionality NWDAF (Network Data Analytics Function) was introduced and has been enhanced in Rel-16 and Rel-17 [14]. Three uses cases were identified in the release 17 study item for AI/ML RAN performance enhancement: 1) Network energy savings; 2) load balancing; 3) mobility optimization.

Up until Rel-17, the AI/ML functionalities at the network side and at the device side have been developed separately, with the interaction between the two sides having been largely limited to data collection. One of the visions of the 5G-Advanced, beginning from the Rel-18 AI/ML study, is to bring synergy between AI/ML functionalities at the two sides by introducing various levels of collaborations through the air-interface. Specifically, Rel-18 study aims to explore the benefits of augmenting the air-interface with features enabling improved support of AI/ML through studying few carefully selected use cases and assessing their performance in comparison with traditional methods. It would lay the foundation for future air interface use cases leveraging AI/ML techniques.

The initial three use cases listed below are aimed to focus on the formulation of a framework to apply AI/ML to the air-interface.

- CSI feedback enhancement. e.g., overhead reduction, improved accuracy, prediction
- Beam management. e.g., Beam prediction in time and/ or spatial domain for overhead reduction and accuracy improvement
- Positioning accuracy enhancements for different scenarios including NLOS operation

For the use cases under consideration, Rel-18 study aims to achieve the following objectives:

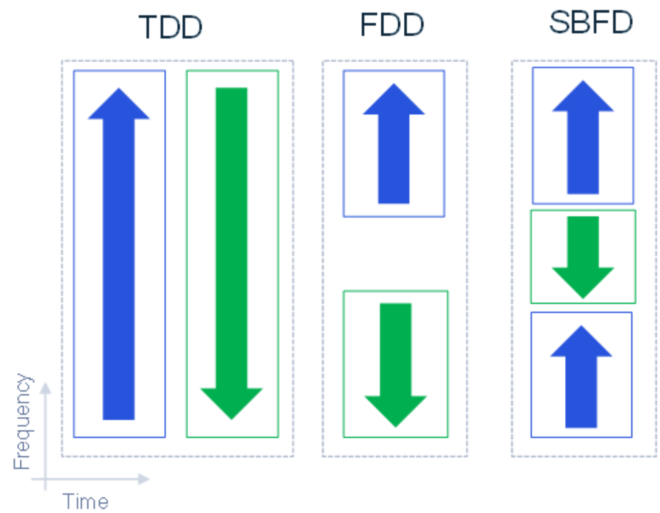
- Evaluate performance benefits of AI/ML based algorithms.
  - » Methodology based on statistical models for link and system level simulations
  - » Determine the common KPIs and corresponding requirements for the AI/ML operations
- Assess potential specification impact specifically for the agreed use cases
  - » PHY layer aspects
  - » Protocol aspects
  - » Interoperability and testability aspects

The Rel-18 and subsequent studies and specification efforts are expected to bring synergies of 5G and AI/ML, connecting intelligent edge of smart devices and RAN and to enable data-driven and adaptive air interface, RAN, and device optimization.

3.3 Study on Evolution of NR Duplex Operation

Current NR operation is based on either paired spectrum or unpaired spectrum. Frequency division duplexing (FDD) is the duplexing mode for paired spectrum in which UL and downlink transmission occur simultaneously using dedicated UL and DL channels sufficiently separated by a frequency gap. Time division duplexing (TDD) is the duplexing mode for the unpaired spectrum in which UL and DL transmission occur at same channel using different time resources.

Figure 4: Illustration of the concept of SBFD comparing with FDD/TDD

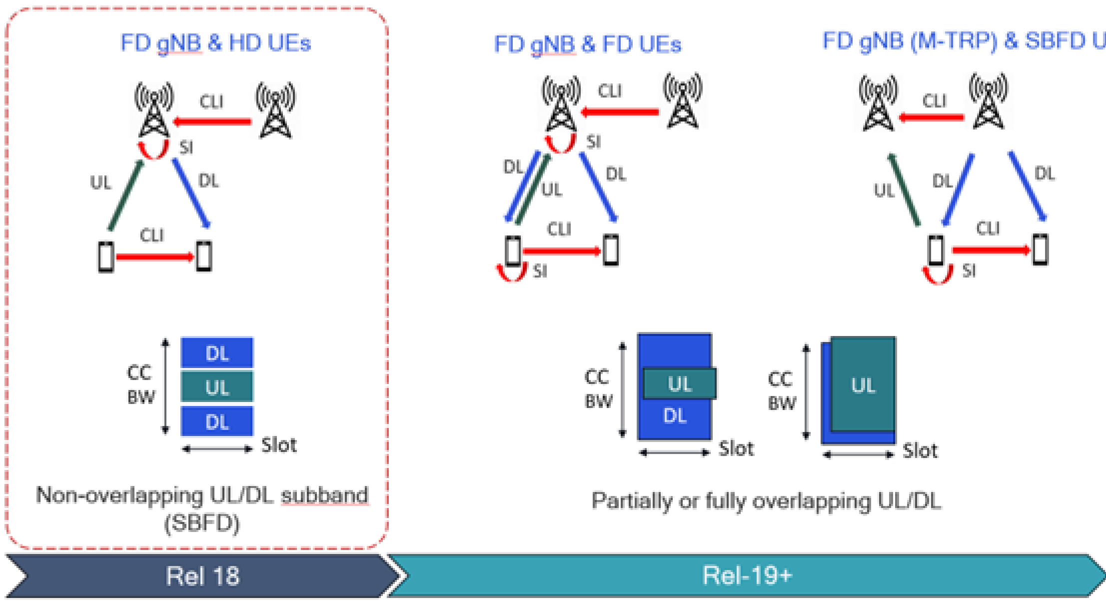


Full duplex technology is a promising duplexing scheme that leverages the benefits of both TDD/FDD enabling lower latency, improved coverage, and flexible UL/DL scheduling. 3GPP is studying in Release 18 the evolution of NR duplexing through full duplex operation at gNB in TDD band using non-overlapping UL and DL sub-bands while the UEs are still operating in half-duplex mode. Future NR release (Rel-19+) may consider more advanced duplexing schemes, e.g., partially or fully overlapping UL/DL sub-bands at the gNB and/or full duplex operation at the UE.

There are many challenges to enable full duplex technology. The major challenge is the self-interference mitigation at the full duplex node. For SBFD gNB, although DL and UL are separated in different sub-bands with narrow guard band in between each DL and UL sub-bands, the direct leakage may cause blocking or saturation of the gNB RF receiver and/ or reduce the dynamic range while the unwanted emissions caused by Tx non-linearly may jam the reception of the UL in the UL sub-band and reduce the SINR. In addition to the direct leakage, clutter echo from nearby reflectors may be of comparable signal strengths to the direct and cause similar effects of blocking and jamming. The other challenge is the cross-link interference (CLI) between gNBs and between UEs. In addition, coexistence with legacy operation is another major challenge. The coexistence refers to both co-channel (intra-operator) with legacy (TDD) gNB and legacy UE that not aware of full duplex gNB and adjacent-channel (inter-operator) coexistence.

The management of various types of interference may require additional considerations on existing 3GPP techniques. For example, the exiting CLI and RIM framework

Figure 5: Road map to evolution of full duplex technologies



may be extended to spatial domain to optimize the beam selection between UEs and gNBs and expanded to L1/L2 CLI framework to increase flexibility and reduce reporting latency compared to Rel-16 L3 based CLI framework. DL/UL power control may need to be revisited for better handing of SI and CLI. Tx/Rx timing alignment at the full duplex node could be another aspect for special treatment. Issues may also arise for scheduling and multiplexing various DL/UL channels to fully exploit the benefits of full duplex. In addition, implementation-based techniques can be leveraged to handle some of these interferences. For example, direct self-interference may be handled by having separate Tx/Rx panels that improves spatial isolation, frequency separation by having UL and DL in separate sub-bands and means of interference cancellation. The clutter reflection can be mitigated by means of Tx and Rx beamform nulling and proper selection of Tx/Rx beam pairs.

3.4 NR sidelink evolution

In Rel-16, sidelink communication was developed in RAN, primarily to support advanced V2X (Intelligent Transportation Systems – ITS) applications by providing direct communication between two UEs without the need for the participation of a base station (e.g., gNB). In Rel-17, SA2 also studied and standardized Proximity-based services (ProSe), including public safety and commercial related services[15]. As part of Rel-17, power saving solutions (e.g., partial sensing, DRX) and inter-UE coordination have been developed in RAN1 and RAN2 to improve power consumption for battery-limited terminals and increased reliability of sidelink transmissions. Although NR sidelink was initially developed for V2X applications, there is growing interest in the industry to expand the applicability of NR sidelink to commercial use cases. With this in mind, at 3GPP RAN#95, the RAN plenary approved a Rel-18 work item entitled: NR sidelink evolution[16].

For 5G-advanced sidelink applications, two key requirements have been identified and will be addressed by this work item:

- Increased sidelink data rate
- Support of new carrier frequencies for sidelink (FR2 and Unlicensed spectrum)

Increased sidelink data rate is motivated by applications such as sensor information and video sharing between vehicles with high degree of driving automation. Commercial use cases could require data rates in excess of what is possible in Rel-17. Increased data rate can be achieved with the support of sidelink carrier aggregation and sidelink over unlicensed spectrum. One of the key objectives is to study a mechanism to support NR sidelink CA operation based on existing LTE sidelink CA operation. Furthermore, by enhancing the FR2 sidelink operation, increased data rate can be more efficiently supported on FR2. While the support of new carrier frequencies and larger bandwidths would also allow to improve data rates, the main benefit would come from making sidelink more applicable for a wider range of 5G applications and verticals, e.g., public safety, IoT, commercial, etc.

More specifically, with the support of unlicensed spectrum and the enhancements in FR2, sidelink will be in a better position to be implemented in commercial devices since utilization of the ITS band is limited to ITS safety related applications.

Another aspect that this work item will study and specify is to consider the V2X deployment scenario where both LTE V2X and NR V2X devices are to coexist in the same frequency channel. For the two different types of devices to coexist while using a common carrier frequency, it is important that there is a mechanism to efficiently utilize resource allocation by the two technologies without negatively impacting the operation of each technology.

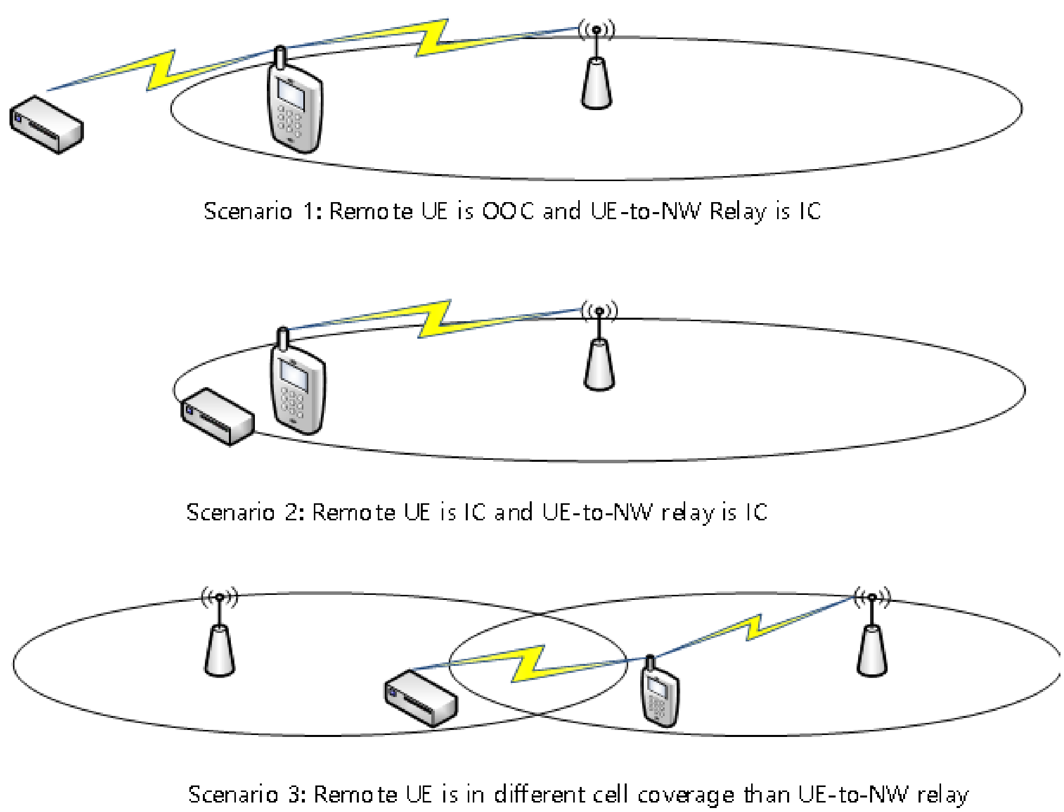
3.5 NR sidelink relay enhancements

3GPP RAN approved a study item “Study on NR sidelink Relay” in Rel-17 to cover the enhancements and solutions necessary to support the UE-to-network Relay and UE-to-UE Relay coverage extension, considering a wider range of use cases including V2X, Public Safety and commercial applications and services. The study outcome was documented in 3GPP TR 38.836, and it contains potential technical solutions for the sidelink relay with a conclusion that both Layer-2 based Relay architecture and Layer-3 based Relay architecture are feasible and a recommendation for their normative work. However, the follow-up Rel-17 work item “NR sidelink Relay” included only limited features due to the lack of time. It supports only UE-to-Network relay, and its service continuity solution is limited to intra-gNB direct-to-indirect and indirect-to-direct path switching in Layer-2 relay17. Figure 6 shows the three scenarios that are considered in TR 38.836.

Additionally, a study item for ProSe phase 2 was approved in SA in order to investigate further 5G system enhancements to support Proximity Services in Rel-18. RAN-side enhancements for sidelink relay are necessary in accordance with the SA work.

For better support of the use cases requiring sidelink relay, further enhancements are necessary in order to introduce the potential solutions identified during the Rel-17 study item. To be specific, support of UE-to-UE relay is essential for the sidelink coverage extension without relying on the use of uplink and downlink. Service continuity enhancements in UE-to-Network relay are also necessary to cover the mobility scenarios that are not supported in Release 17.

Figure 6: Scenarios for UE-to-Network Relay



In addition, support of multi-path with relay, where a remote UE is connected to network via direct and indirect paths, has a potential to improve the reliability/robustness as well as throughput, so it needs to be considered as an enhancement area in Rel-18. This multi-path relay solution can also be utilized to for UE aggregation where a UE is connected to the network via direct path and via another UE using a non-standardized UE-UE interconnection. UE aggregation aims to provide applications requiring high UL bitrates on 5G terminals, in cases when normal UEs are too limited by UL UE transmission power to achieve required bitrate, especially at the edge of a cell. Additionally, UE aggregation can improve the reliability, stability and reduce delay of services as well, that is, if the channel condition of a terminal is deteriorating, another terminal can be used to make up for the traffic performance unsteadiness caused by channel condition variation.

3.6 Study on expanded and improved NR positioning

Since Rel-15, 3GPP NR specifications have supported some level of 5G positioning. 3GPP positioning specifies the mechanisms to support or assist in the calculation of the geographical position of a UE[18]. UE position knowledge can be used, for example, in support of Radio Resource Management functions, as well as location-based services for operators, subscribers, emergency services and third-party service providers. In Release 17, 3GPP RAN conducted a study on "Scenarios and requirements of in-coverage, partial coverage, and out-of-coverage NR positioning use cases" focusing on V2X and public safety use cases, with the outcome being captured in TR 38.845[19]. As NR specifications have evolved, also positioning enhancements have been identified to address not only various coverage scenarios, but also higher accuracy, lower latency location, high integrity and reliability requirements resulting from new applications and industry verticals for 5G.

Given the current market needs and expanding requirements, 3GPP has approved a new Rel-18 Study Item on expanded and improved NR positioning[20]. The primary objectives are to build on the conclusions from TR 38.845 and study sidelink positioning solutions to meet V2X and public safety requirements, and also expanding into commercial and IIoT use cases. 3GPP will evaluate performance and feasibility of potential solutions for sidelink positioning over licensed/ITS spectrum, considering relative positioning, ranging, and absolute positioning in the following areas:

- Positioning methods (e.g., TDOA, RTT, AOA/D) including combination of SL positioning measurements with other network-dependent positioning measurements (e.g., Uu interface-based measurements)
- sidelink reference signals for positioning purposes from physical layer perspective, including signal design, resource allocation, measurements, and associated procedures, etc.
- Positioning architecture and signaling procedures (e.g., configuration, measurement reporting, etc.) to enable sidelink positioning covering both UE-based and network-based positioning.

In addition to sidelink positioning, two promising positioning techniques that have been identified in previous 3GPP studies will be considered in Rel-18. One technique is to take the advantage of the rich 5G spectrum to increase the bandwidth for the transmission and reception of the positioning reference signals (PRS) based on bandwidth aggregation for intra-band carriers. In Release-17, this technique was briefly studied and so far, the Release-18 work will focus on intra-band carriers. The second enhancement is to use the NR carrier phase measurements. NR carrier phase positioning has the potential for significant performance improvements for indoor and outdoor deployments, which includes concepts already used today for GNSS carrier phase positioning in outdoor environments. This method is motivated from Real Time Kinematic GNSS (RTK-GNSS) techniques, which relies on phase measurements.

Another area that will be addressed in Rel-18 is positioning integrity. Positioning integrity is a measure of the trust in the accuracy of the position-related data and the ability to provide timely warnings based on positioning assistance data provided by the network. In Rel-17, 3GPP addressed this concept for GNSS integrity, and for Rel-18 it is natural to extend these solutions to address other 3GPP positioning techniques as well as there are relevant integrity aspects of mission critical use cases that rely on positioning estimates and corresponding uncertainty estimates. Integrity enables applications to make the correct decisions based on the reported position, inclusive of some measure of positioning integrity.

Another area is to improve the power efficiency for IIoT scenarios such as massive asset tracking. The work will focus on the UEs in RRC_INACTIVE and/or RRC_IDLE state with a target of 6 -12 months battery lifetime. Along with evaluating the power consumption of the Release-17 positioning techniques for RRC_INACTIVE UEs, various aspects for the improvement of power efficiency will be investigated including DRX cycle, sleeping mode, configuration and update for downlink and uplink reference signals, and the UE behavior for reference signal measurement and reporting.

Lastly, Release-17 has specified support for RedCap (Reduced Capability) UEs with reduced bandwidth support and reduced complexity, including reduced number of receive chains. Such UEs could support NR positioning functionality. However, there is a gap in that the core and performance requirements have not been specified for the positioning related measurements performed by RedCap UEs, and no evaluation has been performed to see how the reduced capabilities of RedCap UEs might impact eventual position accuracy. This study item will address these gaps by evaluating the performance of existing positioning procedures and measurements with RedCap UEs and define potential enhancements as necessary. Different solutions may be studied to overcome the limited capability including frequency hopping and stitching of the downlink and uplink positioning reference signals.

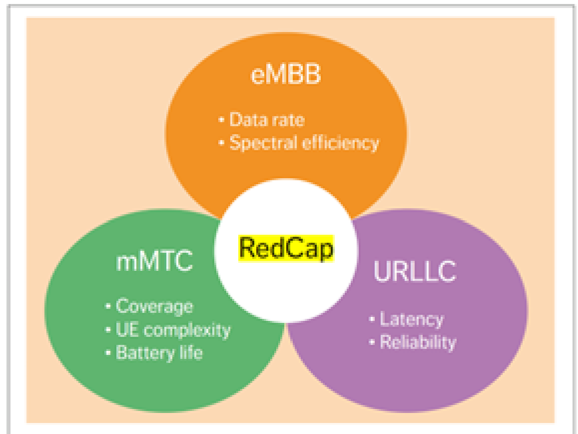
3.7 Study on further NR RedCap UE complexity/cost reduction

The 3GPP-based global cellular networks are connecting things-to-things and things-to-persons across borders. Many industries are experiencing the benefits of cellular IoT, for example in the consumer electronics, automotive, railway, mining, utilities, healthcare, agriculture, manufacturing, and transportation sectors. The flexibility and scalability of 5G NR makes it possible to introduce timely enhancements to address new use cases to help expand the 5G ecosystem and connect an ever-greater number of devices to the network.

To further accelerate the industrial transformation and digitalization 3GPP release 17 introduced the support of reduced capability (RedCap) NR devices. The aim is to facilitate the expansion of the NR device ecosystem to cater to the use cases that are not yet best served by current NR specifications. Generally speaking, RedCap is positioned to address use cases that are today not best served using eMBB, ultra-reliable low-latency communications (URLLC) or massive Machine Type Communication (mMTC) solutions as depicted by Figure 7[21.]

The use cases that motivate the specification work on NR RedCap include wearables (e.g., smart watches, wearable medical devices, AR/VR goggles, etc.), industrial wireless sensors, and video surveillance. These three use cases put some generic requirements on the system such as: reduced device complexity; compact form factor; support

Figure 7: Release 17 RedCap targets the requirement space between eMBB, URLLC and mMTC



for FR1 and FR2. Table 1 specifies the use case specific requirements[22.]

The scope of 3GP Release 17 specifications for RedCap includes: half duplex operation with a single transmits and receive branch; maximum bandwidth support of 20MHz in FR1 and maximum 100 MHz operational bandwidth for FR2; support for eXtended Discontinuous Reception (eDRX) in RRC Idle and RRC Inactive states, which allows a RedCap device to power down for long periods and save power. Longer eDRX cycles for RRC Inactive state and Wake-up signal (WUS) are expected to be supported in 5G-Advanced. WUS is a compact signal tailored to indicate a coming paging message. The aim is to reduce the power a device spends on monitoring paging occasions.

Enhancements planned in 3GPP release Release-18 are to improve the support of three use cases identified in release 17 as well as expand into a new range of use cases such as smart grid. 5G-Advanced will also introduce positioning support in RedCap, with detailed description in Section 3.6. The Release-18 RedCap device is intended to be a lower-tier device with capabilities between LPWA (eMTC and NB-IoT) device and Release-17 RedCap device. Table 2 is showing the detailed capabilities of different types of devices. These enhancements are to be introduced keeping in mind the integrity of RedCap ecosystem to maximize the economies of scale.

Table 1: Requirements of wearables, industrial wireless sensors, and video surveillance use cases

	Data Rate	Latency	Availability/ Reliability	Battery lifetime	Device size
Wearables	5 - 50 Mbps DL, 2 - 5 Mbps UL	Relaxed	N/A	up to 1 - 2 weeks	Compact form factor
Industrial wireless sensors	< 2 Mbps	< 100 ms	99.99%	At least a few years	N/A
Video surveillance	2 - 4 Mbps for economic video, 7.5 - 25 Mbps for high-end video	< 500 ms	99% - 99.9%	N/A	N/A

Table 2: Comparison of device capabilities

	R15/16 NR eMBB	R17 NR RedCap	R18 NR RedCap (Expected)	LTE-M (Cat M1)	NB-IoT (Cat NB1)
UE BW	100 MHz (FR1) 200 MHz (FR2)	200 MHz (FR1) 100 MHz (FR2)	20 MHz or 5 MHz (FR1 only)	1.4 MHz	180 KHz
Duplex	FD-FDD, TDD	FD/HD-FDD, TDD	FD/HD-FDD, TDD	FD/HD-FDD, TDD	HD-FDD, TDD
UE Antenna	1T2R (FDD)/ 1T4R (TDD)	1T1R/1T2R	1T1R/1T2R	1T1R	1T1R
Max Modulation Order	256QAM for DL, 64QAM for UL	64QAM (256QAM optional)	64QAM (256QAM optional)	16QAM	QPSK
Peak Data Rate - DL	2.3 Gbps	220 Mbps	10 Mbps	588 kbps	26 Kbps
Peak Data Rate - UL	468 Mbps	120 Mbps	10 Mbps	1119 kbps	66 Kbps

The scope of study on further reduction of NR RedCap complexity in Release 18 includes the following[23]:

- The supported peak data rate for Rel-18 RedCap targets to 10Mbps.
- UE bandwidth reduction to 5MHz in FR1
- Reduced UE peak data rate in FR1
- UE processing timeline relaxation
- Reuse of Release 15 SSB and minimize changes to L1
- Operation in BWP with/without SSB and without/with RF retuning should be considered

Note that the study is only for FR1, but some solutions may also be applied to FR2.

3.8 Study on network energy savings

Mobile data traffic is expected to grow 5 times in the next 5 years (reference Ericsson Mobility Report). If network deployment and operation is performed in the same way as 3G and 4G days, energy consumption of mobile network is also expected to grow significantly. This is neither sustainable nor is it morally responsible. As 5G becomes ubiquitous across society, with requirements to handle advanced services and applications requiring very high data rates (e.g., XR), networks are being denser, use more antennas, larger bandwidths and more frequency bands. The environmental impact of 5G needs to stay under control, and novel solutions to improve network energy savings need to be developed (reference – Breaking the energy curve).

According to GSMA report, energy cost for mobile operator account for ~ 23% of OPEX [24]. Most of the energy cost comes from radio access network and in particular from the Advanced Antenna Units (AAU). Power consumption of radio can be categorized into two types: dynamic and static. Dynamic energy consumption happens when radio transmits and receives data. Static consumption happens all the time to maintain necessary operation of the radio network.

Therefore, there is a need to initiate a study and develop an energy consumption model for the radio network. While reduction in energy saving is important for radio network, it should also be evaluated holistically by assessing the impact on network and end user performance looking at KPIs such as spectral efficiency, user throughput, latency, capacity, UE power consumption and other key KPIs such as accessibility, retainability. Basically, energy saving solution should not negatively impact these KPIs.

Scope of the study would be as follows[25]:

- Definition of a base station energy consumption model
- Definition of an evaluation methodology and KPIs
- Study and identify techniques on the gNB and UE side to improve network energy savings in terms of Base Station transmission and reception

The study would prioritize idle and low load scenarios and different loads among carriers and neighbor cells are allowed.

The following example scenarios are listed under the scope of study in no particular order.

- Urban micro in FR1, including TDD massive MIMO
- FR2 active antenna scenarios
- Urban/Rural macro in FR1 with/without Dynamic Spectrum Sharing
- EN-DC/NR-DC macro with FDD PCell and TDD/Massive MIMO on higher FR1/FR2 frequency

3.9 Study on NR Network-Controlled Repeaters aka smart repeaters

In mobile telecommunication system, a good quality network design/consistent RF coverage deployment between base stations and end user devices is very important. Mobile operators rely on different types of network nodes such as picocell, femtocell, microcell, macrocell etc. To offer a unified signal coverage in their network deployments. However, due to the different terrain types in rural, suburban, and dense urban environments, signal coverage problems still occur and there might be locations where a network coverage from base stations may not be adequate. It may bring network performance limitations and not to align with planned network design by an operator. Examples of these areas could be coverage holes - a shadow area caused by terrain or buildings, edge areas of the existing cellular coverage, tunnels, etc. This coverage problem could be resolved by densifying or relocating base stations, but it may be not always be an ideal solution due to backhaul availability limitations, longer deployment times or it may not economically viable.

Due to these limitations, demand occurs in telecom industry to explore a new types of network nodes which potentially help to increase a mobile operators' flexibility for their network deployments and coverage quality enhancements. A Network-Controlled repeater is an example of a network node, which does not require a wired backhaul, that can help to expand the network coverage area and signal dead zone elimination, etc. In general, a Radio Frequency

(RF) repeater is an amplifier system which amplifies-and-forwards received signals. The repeater then beams the amplified signals into targeted areas such as coverage hole, tunnels, valleys etc[26].

RF repeaters have been used in 2G,3G and 4G commercial deployments to extend the network coverage. In Rel-17, 3GPP RAN4 specified requirements for RF repeaters for 5G New Radio (NR) targeting both frequency ranges FR1 (i.e., includes sub-6GHz frequency bands) and FR2 (i.e., frequency bands range from 24.25 GHz to 52.6 GHz).

An RF repeater presents a cost-effective solution for extending network coverage; however, it has limitations as it does not take into consideration various factors that could improve performance. Such factors may include information on semi-static and/or dynamic downlink/uplink configuration, adaptive transmitter/receiver spatial beamforming, etc.

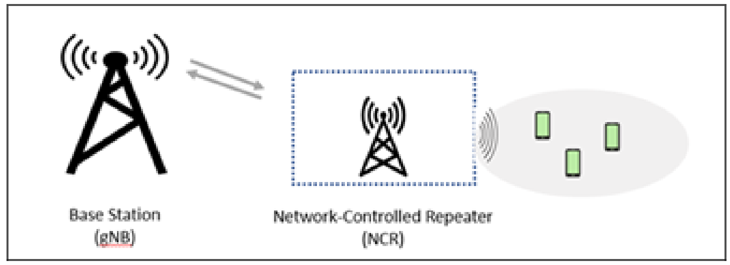
A network-controlled repeater is an enhancement over conventional RF repeaters which receive side control information from the network base station. Side control information could allow a network-controlled repeater to perform it's amplify-and-forward operation in a more efficient manner. Potential benefits include mitigation of unnecessary noise amplification, transmissions and receptions with better spatial directivity, and simplified network integration. Cost-efficiency would be a key consideration point.

3GPP Release 18 will study NR network-controlled repeaters with single hop and stationary architecture[27]. The TR will include study on side control information such as beamforming information, Uplink-Downlink TDD configurations, timing information to align transmission/reception boundaries, On-Off information to improve energy efficiency, power control information for interference management, etc. The study will help to define which side control information is necessary and a look into how to identify and authorize such network-controlled repeaters.

Table 3: 3GPP Frequency Range Definition

NR Frequency Range Designation	Corresponding Frequency Range
FR1	410 MHz - 7125 MHz
FR2	24250 MHz - 52600 MHz

Figure 8: Illustration of Network Repeater Concept



3.10 Enhancement of NR Dynamic spectrum sharing (DSS)

LTE-NR spectrum sharing emerges as a technology that allows service providers to deploy LTE and NR in the same carriers and bands. DSS dynamically assigns time-frequency resources to either LTE or NR according to their respective traffic demands, enables the coexistence of multiple radio access technologies in frequency range 1 (FR1) for NR without new dedicated spectrum allocation for 5G.

NR adopted the orthogonal frequency division multiplexing (OFDM) waveform as its baseline, with the basic numerology of 15 kHz sub-carrier spacing (SCS) support, which was compatible with the waveform and numerology of LTE. This enabled a highly aligned resource grid structure between LTE and NR, providing a fundamental basis to support LTE-NR co-existence.

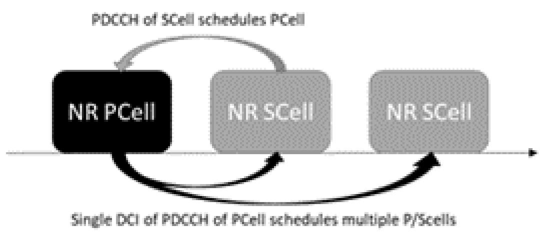
In NR Release 15 and Release 16, the following functions build the solid foundation of LTE-NR co-existence in FDD bands.

- NR 100 kHz channel raster for FDD bands
- Optional NR UL 7.5kHz shift for FDD bands
- NR PDSCH with rate matching of LTE CRS
- NR PDSCH alternative additional DMRS symbol location
- NR flexible CORESET/PDCCH resource configuration
- Multiple CRS rate matching patterns in an NR carrier
- Enhancement of PDSCH mapping type B

It enables the basic operation (Rel.15) and performance enhancement (Rel.16) in terms of channel alignment, interference elimination and resource mapping. However, as the number of NR devices increases there are not enough NR scheduling resources in the shared carriers, particularly limited by PDCCH resource. To avoid interference to the LTE system, NR scheduling is not expected to overlap with the LTE PDCCH region and symbol with LTE CRS. In this case, the available resources for NR PDCCH and NR PDSCH are pretty constrained.

In Release 17, when carrier aggregation (CA) is activated, 3GPP specification would allow cross-carrier scheduling, which overcomes the PDCCH resource constraint of NR PCell with the help of SCell, PDCCH of SCell schedules PDSCH or PUSCH on PCell. In case of DSS, PDSCH resource of PCell can be scheduled via NR SCell PDCCH without utilizing constrained DSS cell PDCCH resource, consequently uplift the DSS cell capacity. Moreover, release 17 allows PCell/SCell scheduling multi-PDSCH with single downlink control information (DCI) instead of multi-DCI, without adding PDCCH overhead when allocating SCell PDSCH resources in resource constrained DSS cell[28].

Figure 9: Cross-carrier scheduling of DSS[29]



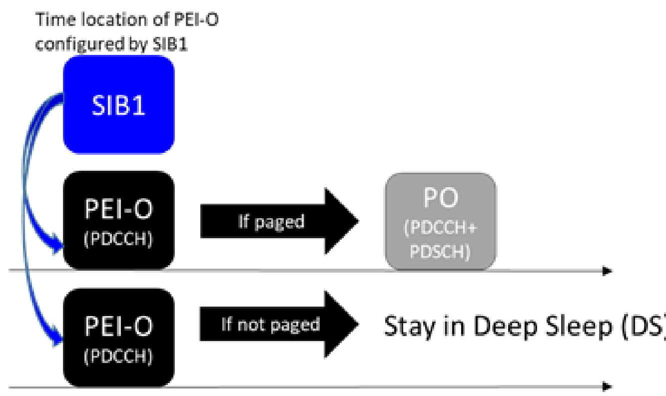
3.11 Study on low-power Wake-up Signal and Receiver for NR to enhance non-smartphone type devices

In the past decades, the Internet of Things (IoT) has become ubiquitous and connected people around the world. Cellular IoT is considered one of the most attractive contributions to the IoT industry, these devices are categorized as low power devices featuring lower consumption and offering a long battery life. Reducing power consumption in a low power device and its interaction with the network has gained a significant area of focus.

In early 3GPP releases, DRX and eDRX were introduced, UE is allowed to stop monitoring the radio channel, and enters the low power consumption mode or sleep mode for a certain period. In Release 16 Wake-Up Signal (WUS) was introduced, it indicates whether the next DRX On Duration will contain any scheduling grants or not. Because UE consumes less power when detecting WUS than monitoring the entire DRX On duration, therefore extends the batter life. Furthermore, UE-Group WUS (GWUS) allows gNB to configure multi WUS group, only one group of UEs paged at a time. This allows the UE to skip the paging procedures if UE is not configured in the paging group, therefore lowers the group paging rate and paging false alarm rate.

Release 16 features relaxed measurement in RRC connect mode, however, lower power devices designed to stay in idle/inactive mode most of the time to extend its battery life. Paging Early Indication (PEI) feature introduced in release 17, focuses on lowering energy consumption in idle and inactive mode UE[30]. UE only needs to detect PEI at the time location configured by SIB, where PEI notifies the UE whether to receive the next Paging Occasion (PO)[31], illustrated in the Figure 10. If UE is paged, then it continues to monitor its associated PO; if UE is not paged, UE may stay in deep sleep (DS) mode without consuming power of PO detection. In the illustrated Figure 10, PEI is signaled via DCI format 2-7, or optionally via TRS. Similarly, UE group PEI can be used for PEI, further reducing the power consumption in idle/inactive mode.

Figure 10: Paging early indication in RRC idle state



To further prolong the battery life and improve the user experience, Release 18 studies on a new wake-up signal to trigger the main radio and a separate receiver which can monitor wake-up signal with ultra-low power consumption. Main radio works for data transmission and reception, which can be turned off or set to deep sleep unless it is turned on[32].

3.12 Multi-carrier enhancements for NR

There are two major multi-carrier enhancements for 5G-advanced, as listed below

- Multi-cell scheduling with a single DCI
- UL Tx switching among more than two bands

The first enhancement supports multi-cell scheduling with a single DCI.

In the 5G-Advanced era, it is expected that more spectrum will be made available. This includes re-faming from previous generations and expansion of mmW bands. These spectra can be aggregated for a UE to increase data throughput for downlink and/or uplink. There are two modes in legacy carrier aggregation – self-scheduling and cross-carrier scheduling. For self-scheduling, downlink control information (DCI) that indicates scheduling information (resource allocation, link adaptation, etc.) of DL data (PDSCH) or UL data (PUSCH) on each carrier is delivered by a PDCCH on the same cell as for the scheduled data. For cross-carrier scheduling, a PDCCH and the scheduled DL or UL data can be transmitted/received on different cells. Cross-carrier scheduling further enables to transmit/receive PDCCH carrying multiple DCIs on a scheduling cell for DL data and/or UL data on multiple different cells.

When the number of cells in the carrier aggregation operation is small, cross-carrier scheduling would enable UE power efficient operation since the UE monitors PDCCH only on the scheduling cell. However, with the increased number of cells, it would be difficult to achieve the benefit of cross-carrier scheduling due to the following reasons:

- Many DCIs for multiple scheduled cells for the UE must be carried by a PDCCH of one scheduling cell. This consumes a lot of resources in the DL control of the cell and hence would block other UE's scheduling opportunities.
- The UE has to monitor a lot of PDCCH candidates in the scheduling cell, which consumes a lot of UE power.

To address the issues of DL control overhead and UE power consumption, it was agreed to support multi-cell PUSCH/PDSCH scheduling by a single DCI. Unlike legacy carrier aggregation, single DCI provides scheduling information of DL data or UL data for multiple scheduled cells. For this feature, the most important open issue is how to design a DCI for multi-cell scheduling. Since the payload of a DCI is limited (e.g., up to 120 bits excluding CRC), it is not possible to simply concatenate all the existing indication fields of legacy DCIs for multiple scheduled cells to form a DCI for multi-cell scheduling. Moreover, large payload of a DCI degrades coverage performance of the PDCCH. On the other hand, reducing the number of bits of a DCI field loses scheduling flexibility in general. As such, the trade-off between DCI payload size and scheduling flexibility has to be carefully considered.

The second multi-carrier enhancement is supporting UL Tx switching among more than two bands. 3GPP specified two bands switching in Rel-16 and Rel-17, while Rel-16 is on 1Tx-2Tx switching and Rel-17 is on 2Tx-2Tx switching. As 5G deployment expands, operators plan to re-farm more 3G/4G spectrum for 5G and further ask the flexible switching among more than 2 bands.

Figure 12 is an illustrative figure on more than 2 bands switch. Each band may be with 1 or 2Tx which depends on the supported antenna numbers. The Tx chain(s) could dynamically switch among different bands according to scheduling or configuration.

Figure 11: Self-scheduling, cross-carrier scheduling, and multi-cell scheduling

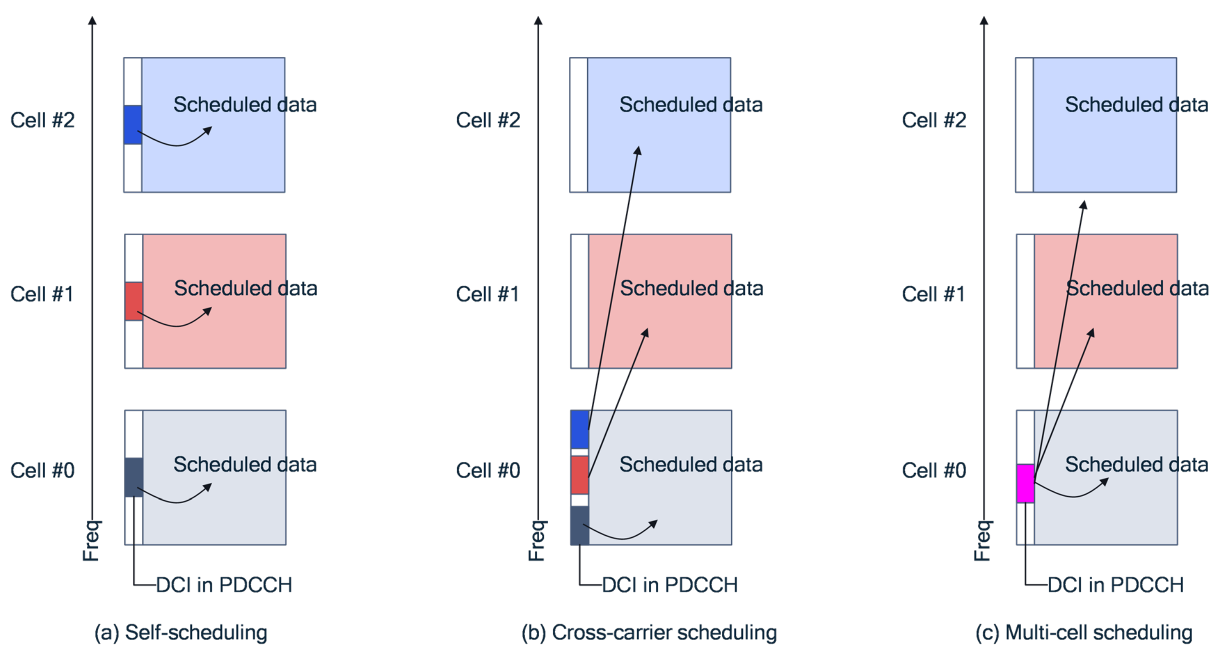
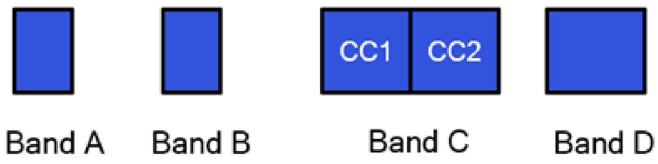


Figure 12: Switching band combination with more than 2 bands



Compared with switching between 2 bands, more than 2 bands switching would result to more complicated switching band pair and RF combination. For example, without restriction, the switching could be from any of band list and to another random band in the list. The overall band pair combination would be around ten, which is not affordable for UE implementation. Therefore, the design should target the switching complexity reduction as the first priority. One possible way to reduce the complexity is to define the anchor band among the switching band pairs, and only allow the switching between anchor band and another non-anchor band.

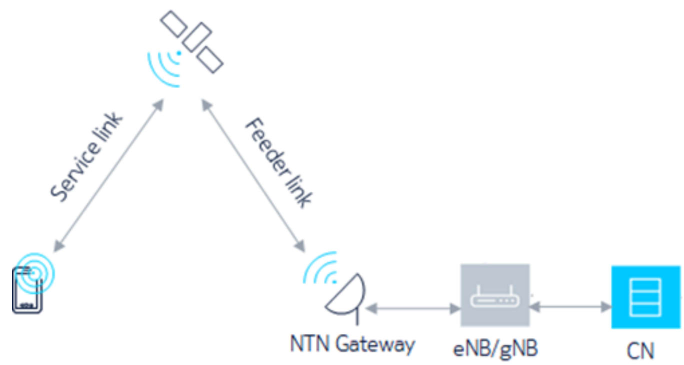
3.13 NR NTN (Non-Terrestrial Networks) enhancements

Prior to 3GPP Rel-17, LTE and NR standards have been developed for land-based cellular networks. Rel-17 is the first release of LTE and NR that supports using NTN (non-terrestrial networks) to provide link access for NB-IoT/eMTC devices and NR UE. NTN can be a constellation of LEO, MEO, GEO satellites[33], or a network of HAPS (High Altitude Platform Stations). The NTN node (LEO, MEO, GEO, HAPS) acts as a repeater, performing frequency conversion and power amplification, and is transparent to the UE. The eNB/gNB is located on the ground and connected to the NTN node via an NTN gateway as shown in Figure 13.

This NTN feature is only available in FDD operation due to the round-trip delay of signal via satellite. In Rel-17, NTN is applicable in FR1 using S band or L band. Handheld devices, IoT devices, or VSAT terminals (with directive antenna and higher transmit power) can be the UE connecting to NTN. An NTN capable UE must compensate the time and frequency offsets caused by propagation delay and satellite motion in the uplink transmission. GNSS positioning capability is required for the UE to calculate the time and frequency compensations together with the satellite position and velocity in system information broadcast.

For non-geostationary satellites, cells on the ground supported by satellite beams may be moving (earth-moving) or fixed (earth-fixed), depending on whether the satellite beam is steered toward a fixed target area. In either case, the tracking areas for paging are earth-fixed. That means the tracking area to cell mapping has to be updated as the satellite moves to serve a new geographic area.

Figure 13: Transparent NTN architecture



Some enhancements are expected for NR over NTN and NB-IoT/eMTC (in LTE) over NTN in Rel-18. As in Rel-17, only transparent NTN architecture (i.e., eNB/gNB functionality is not on the NTN node) is considered and UE is required to have GNSS capability and perform time and frequency compensations in the uplink.

Rel-18 enhancements in NR to support NTN connectivity have been decided[34] in these areas:

- Extend NR (FDD mode) NTN to >10 GHz frequency bands, e.g., Ka band, for VSAT devices. A VSAT terminal has a higher antenna gain and transmit power and can be installed on airborne, maritime, or land-based vehicles for broadband data services. These frequency bands will not be accessible for handheld UE and IoT devices because of the large path loss at high frequencies.
- Coverage enhancement for low-data rate and VoIP services via commercial smart phone in NTN scenarios. VoIP is only applicable for LEO due to the latency associated with propagation distance, while low-data rate service can be provided by all satellites (LEO, MEO, GEO) by sufficient repetitions of transmission.
- Improve UE mobility in NTN earth-fixed and earth-moving cells, as well as mobility between NTN and TN, for service continuity through enhanced procedures of measurements, cell re-selection, and handover. Tracking areas will be earth-fixed as in Rel-17.
- Network verification of UE location report to meet regulatory requirements in terms of accuracy, latency, reliability, etc. for various purposes (e.g., emergency call, lawful intercept, public warning, charging/billing).

3.14 IoT NTN enhancements

For NTN access, lower complexity IoT devices generally impose additional constraints, including support of half-duplex in FDD bands, and GNSS and radio modules not operating at the same time. In addition, synchronization must be maintained during a longer transmission time with repetitions, and UE power consumption needs to kept low for a long battery life. Expected Rel-18 enhancements for IoT over NTN are in the following areas[35]:

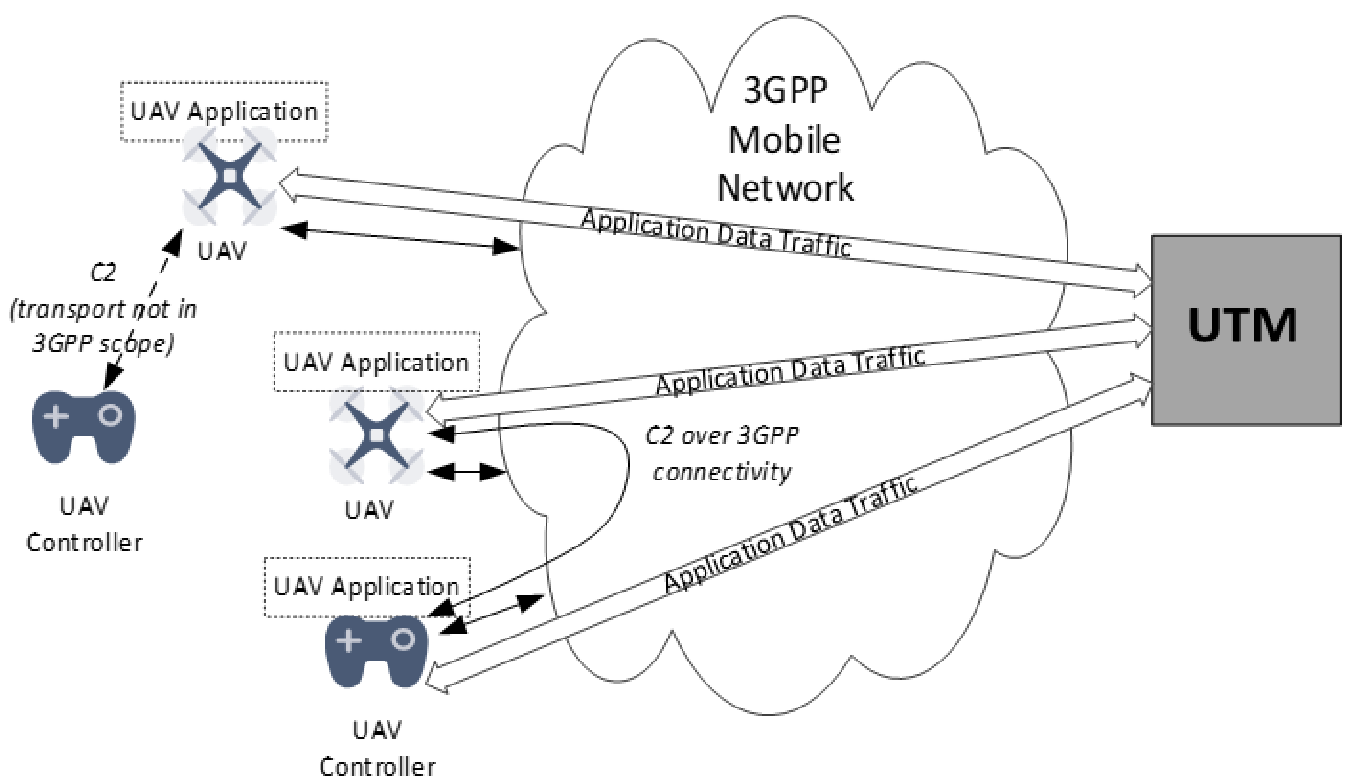
- Support of discontinuous coverage. In a sparse constellation of satellites, NTN coverage may only be available at specific times and places. Enhancements will ensure IoT devices can be reached and can transmit/receive data when NTN coverage is available while UE energy is conserved when NTN is out of coverage.
- Mobility enhancements. Neighboring cell measurements and cell measurements triggering before radio link failure will be supported in NTN scenarios. NR NTN mobility enhancements introduced in Rel-17 will be considered for eMTC adoption.
- IoT NTN performance improvement in terms of throughput. HARQ stalling can be severe for NB-IoT and eMTC over NTN, given that the round-trip-time is long and the number of HARQ processes for IoT devices may be few. Disabling HARQ feedback for downlink data transmission will be worked on to mitigate the HARQ stalling and improve throughput.
- Optimization of GNSS operation with sparse use of GNSS and with a good power efficiency for long-term connection. IoT over NTN in Rel-17 is designed for short and sporadic connections where a new GNSS fix is not required. Rel-18 will improve GNSS operation to allow UE to update its location for maintaining synchronization in a long connection time and to reduce power consumption.

Core and performance requirements[36]. The RF, RRM, and demodulation requirements for NB-IoT and eMTC operations over NTN have not been specified in Rel-17 timeframe. These requirements will be completed in Rel-18.

3.15 NR Support for UAV

To address the needs of a quickly emerging vertical, there has been a lot of activity over the last few years within the 3GPP to ensure that the 3GPP networks and systems will meet the connectivity needs of Uncrewed (or Unmanned) Aerial Systems (UAS). UAS, consist of Uncrewed Aerial Vehicles (drones) and UAV controllers, and along with a UTM (UAV Traffic Management) entity, supports a wide range of commercial, public safety and law enforcement applications. Figure 14 shows the UAS architecture model within the 3GPP eco-system to enable various C2 (Command and Control) procedures.

Figure 14: 3GPP UAS reference architecture[37]



However, from the 3GPP RAN perspective, to date, up to and including Release 17, only LTE enhancements have addressed UAV/UAS requirements. At 3GPP RAN#94 in December 2021, 3GPP agreed to begin work on a Release 18 5G (NR) work item for the second half of 2022[38]. This work item will align NR solutions with the existing LTE UAV solutions and specify NR-specific enhancements. The four general objectives of this work will include the following:

- Specify enhancements to measurement reports as follows: UAV-triggered measurement report based on configured height thresholds, reporting of height, location and speed in measurement report, flight path reporting, measurement reporting based on a configured number of cells (i.e., larger than one) fulfilling the triggering criteria simultaneously
- Specify the signaling to support subscription-based UAV identification
- Study and specify, if needed, enhancements for UAV identification broadcast
- Study UE capability signaling to indicate UAV beamforming capabilities and, if necessary, RRC signaling, e.g., FR1 with directional antenna at the UE side.

While the Rel-17 NR features improve UE and network performance with respect to LTE, further improvements are needed in Rel-18 to address UAV use cases, since the NR system didn't take aerial vehicles (and UAS) into account when it was initially designed. In terms of UL and DL interference as well as mobility, these and other issues will need to be studied with UAV limitations kept in mind, such as higher latency, reduced MIMO capabilities. Moreover, the interference issues that may be generated by UAVs should be considered in order not to disrupt the operation of a network that was intended for terrestrial UEs[39].

3.16 Dual Tx/Rx MUSIM

In many cellular markets, the usage of a phone with multiple subscriptions has become increasingly common. Here, each subscription of the phone is associated with one USIM and has an independent connection to the network. This implies that the resources of a single UE or mobile equipment have to be shared between these multiple connections. In the past deployments including HSPA and LTE, this was handled mainly by UE implementations. The drawback of this approach was that there were not uniform or consistent behaviors across UEs in the deployments. In addition, not having network awareness and support and relying on the UE side only has limited the extent of optimizations and thus better performance.

3GPP has decided to standardize some aspects of Multiple-USIM (or MUSIM) UE behavior in order to address the shortcomings of reliance on pure UE implementations. To that end, in Rel-17, several features were introduced. The use case scenario for Rel-17 was when the UE is active only at most for one USIM. In other words, only a single connection or link is allowed to be in Connected mode while the other one will be in Idle or Inactive mode. The activity on Idle/Inactive mode is relatively rare; therefore, 3GPP has focused on where the UE switches between the two connections via using "gaps" in the active connection.

In practical use cases, the UE may need to be in Connected mode on both USIMs. For example, the user may be on a voice call via one USIM while downloading data on the other USIM. In such scenarios, sharing of UE resources is more challenging compared to the Rel-17 assumptions of a single active connection since the UE will be receiving and transmitting in both connections.

The main challenge in using UE resources across multiple active links is sharing the RF and other resources dynamically without major disruption to the ongoing transmissions. As a first step, the network should be aware of any changes in the UE resources. It is important to note that the network becomes aware of UE resources via the UE capability reporting at the initial connection. Several methods have been introduced by 3GPP to update this capability when the UE resources change, for example due to overheating or power saving purposes. However, MUSIM will require a more comprehensive and streamlined approach to changes in UE capabilities due to simultaneous active links which can change more dynamically.

In Rel-17, 3GPP has also not considered Dual Connectivity (DC). Given that the majority of NR deployments are currently based on EN-DC (LTE + NR DC) and also evolving towards NR-DC (NR + NR), it is essential to study the case of each USIM being in DC mode. Thus, the changes in UE capability can also impact either or both connections to the primary and secondary gNBs in DC.

Another approach to sharing UE resources could be alternating between the two links in a time-division manner. This can give better performance, especially for uplink where dividing the limited UE power between simultaneous transmissions may not be optimal. This will require signaling between the UE and the network to determine an appropriate time-division across two links, which can also need to consider the multiple legs of a DC connection.

In all possible UE resource sharing and capability update options, the signaling between the UE and the network should be agile to adapt to the changes on the links and at the same time should have low overhead.

MUSIM operation may also need to consider the impact of cooperation between multiple UEs, multi-path operation via relay, and In-Device-Coexistence problems, which are all being studied in 3GPP Rel-18.

3.17 Enhancements of NR Multicast and Broadcast Services

Functionality explicitly targeting the NR support for Multicast and Broadcast Services (MBS) was first introduced as part of 3GPP Release 17 with focus on use cases such as public safety and mission critical, V2X applications, IPTV, live video, software delivery over wireless and IoT applications, etc. Release 17 included two delivery modes for MBS

- Multicast (delivery mode 1): Delivery only to UEs in RRC connected state that has joined an MBS session and addressing higher QoS services
- Broadcast (delivery mode 2): Delivery to all MBS UEs in a service area regardless of the RRC state and addressing lower QoS services

Further enhancements to the NR support for MBS are pursued as part of 3GPP release 18, initially in form of a study item.[40] The release-18 work on enhanced MBS support focuses on the following areas:

- The possibility for multicast reception also in RRC inactive state, enabling a larger number of multicast receiving UEs in a cell and reduced UE energy consumption
- Joint reception of unicast transmissions and broadcast transmissions within a UE
- More efficient provisioning of multicast/broadcast services when the same service is provided by multiple operators in a shared-network scenario

3.18 Mobile IAB (VMR)

The introduction and evolution of 5G technology in the telecom industry has not only created new radio (NR) access standard but also facilitated integration of networks for vertical markets with diverse applications such as Augmented Reality (AR), Virtual Reality (VR), Internet of things (IoT), Vehicle to everything (V2X), Smart cities etc.

5G applications and related services are diverse which bring up the demands for advanced cellular networks in terms of higher data rate, lower latency, enhanced cellular coverage and connectivity. This may be challenging and can have performance limitations in outdoor and mobility scenarios.

Traditional cellular network deployments are mainly on fixed macro base stations (BS). In certain environments e.g., dense urban environments, there might be locations where a network performance from base stations may not be adequate, and that area can have a signal coverage problem. Densifying network sites by installation of additional base stations on buildings and/or other infrastructure sites or relocating cell sites can resolve these coverage problems. However, it may not always be an ideal solution and may bring challenges to the operators such as costs in site installation, power sourcing, backhaul availability, real estate permissions, and regulations approval etc. which may also require significant efforts and time.

3GPP Rel 16 has introduced a multi-hop NR (New Radio) based Integrated Access and Backhaul (IAB) solution which aims to reuse the existing 5G radio air interface for wireless backhaul purposes and is expected to provide a more cost-efficient and faster network deployment solution. As an alternative to fiber backhaul it can facilitate faster deployment of mobile networks. In general, an IAB is a node serving UEs using a wireless backhaul from a fiber connected node- called a donor node.

3GPP Release 16 and Release 17 mainly focus IAB use cases and requirements as a stationary network node. 3GPP Release 18 continues to enhance NR IAB solution, focusing on the scenario where Mobile-IAB nodes are mounted on vehicles. This node will use a wireless backhaul from a 5G core connected stationary donor node and provide 5G NR coverage and connectivity to UEs located inside or surrounding to it. This node is also called a Vehicle Mounted Relay (VMR)[41].

There is a surge in demand for use of wireless broadband on-board in public/private vehicles in urban areas. For mobile service providers, the demands to serve these mobile users with a better user experience and a seamless signal coverage while traveling on their network is a challenge. Mobile-IAB node could be useful in urban environments such as mounted on vehicles which follow a certain schedule (e.g., public transport buses, trains etc.). It could provide opportunities to improve network coverage and capacity enhancements e.g., better user experience to users located inside or surrounding to these mobile-IAB nodes. Other scenarios such as during the large public events at venues, hot-spot areas, Mobile-IAB could also serve the users or devices that are surrounding the vehicle and it could improve a user experience. Also, the Mobile-IAB could be useful in emergency or, disaster recovery scenarios where there is little or no network coverage and the use of Mobile-IAB node can enable 5G coverage and connectivity in a timely manner.

In addition to network coverage and capacity enhancements, Mobile-IAB nodes could provide benefits to network operators by minimizing the network related capital and operational expenditures (CAPEX and OPEX) e.g., time and efforts to invest in real-estate lease and permissions, monthly operating cost of wired backhaul etc.

A 3GPP release 18 study is investigating a potential single hop architecture. It will also include system level enhancements for 5G systems to support IAB nodes mounted on vehicles using NR for wireless access toward the UE and for backhaul to the 5GC. It is targeted for both frequency ranges FR1 (sub-6GHz frequency bands) and FR2 (24.25 GHz to 52.6 GHz) including In-band and Out-band scenarios. The Study will help to explore several areas such as[42],

- support of mobile IAB nodes operation, provisioning, control, and configuration
- Service continuity (including mobility of the UE and/or mobile-IAB nodes)
- UE network access control, policy charging, Quality of Service (QoS), Multi-PLMN RAN sharing
- Multi-link connectivity (i.e., between the donor node and mobile-IAB node, between the mobile-IAB nodes)
- support for regulatory requirements (e.g., first responders, priority services, public safety), and support for location services for UEs accessing mobile-IAB nodes etc.

Figure 15: Illustration of Mobile IAB node (VMR) Concept

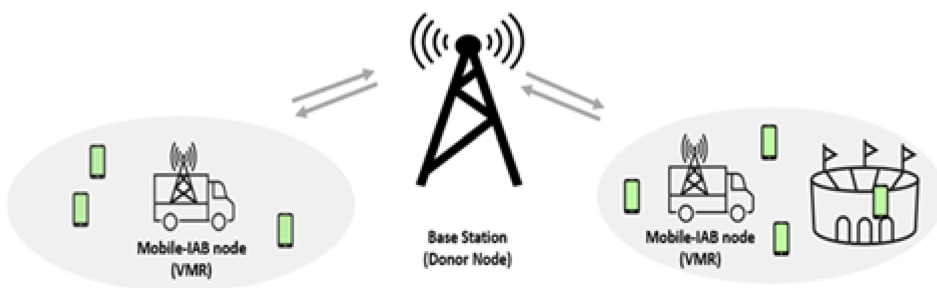


Table 4: 3GPP Frequency Range Definition

NR Frequency Range Designation	Corresponding Frequency Range
FR1	410 MHz - 7125 MHz
FR2	24250 MHz - 52600 MHz

3.19 Further enhancement of data collection for SON (Self-Organizing Networks)/MDT (Minimization of Drive Tests) in NR and EN-DC

Self-Organizing Networks (SON) is an automation technology that is designed to plan, configure, manage, optimize, and repair Radio Access Networks (RAN) efficiently and effectively. The 3GPP SON-related work to date encompasses solutions for network self-configuration and self-optimization, which was first introduced in LTE to support deployment of the system and network performance optimization. The first SON features, PCI allocation and Automatic Neighbor Relations (ANR) were introduced in Rel-8. Success of these two features encouraged further study on the topic and resulted in a Rel-9 work item that eventually enabled 3 SON features: Mobility Robustness Optimization (MRO), Mobility Load Balancing (MLB) and RACH optimization. The two first features, MRO and MLB, turned out to be key enablers of LTE and they were further enhanced in following releases to match increasing LTE complexity. Besides ANR, MRO, MLB and RACH optimization, other features enabling particular aspects of network self-optimization were discussed and enabled in separate SIs/WIs: Minimization of Drive Tests (MDT), Energy Saving (ES), interference cancelation (ICIC, eICIC), TDD UL/DL traffic adaptation (eIMTA), collaborative multi-point operation (CoMP), etc.

In Rel-16, the Study Item "Study on RAN-centric Data Collection and Utilization for LTE and NR" studied use cases of SON/MDT and other use cases related to data collection and utilization and identified potential solutions for these use cases. The Study Item used LTE solutions as a baseline and take the NR architectures and features into account, e.g., MR-DC, CU-DU split architecture, beam, inactive state, etc.[43] However, due to limited time, only a subset of potential SON/MDT functions and initial considerations were studied and specified in the Rel-16. The Rel-17 follow-on work item introduced enhancement of SON and MDT features to support in NR standalone and MR-DC, including CCO (Coverage and Capacity Optimization), inter-system inter-RAT energy saving, inter-system load balancing, 2-step RACH optimization, mobility enhancement optimization, PCI selection, energy efficiency (OAM requirements), Successful Handovers Reports, UE history information in EN-DC, load balancing enhancement, MRO for SN change failure, RACH optimization enhancements, MDT enhancement and L2 measurements.

Moreover, further enhancement of SON/MDT was identified as necessary in Rel-18 to specify additional data collection techniques and features in NR. The 3GPP RAN plenary has approved a new work item entitled "Further enhancement of data collection for SON (Self-Organizing Networks)/MDT (Minimization of Drive Tests) in NR standalone and MR-DC (Multi-Radio Dual Connectivity)" which is to commence in the second half of 2022[44]. This work will specify additional support of data collection for SON features, including, MRO for MR-DC SCG failure scenario, and MRO enhancement for inter-system handover voice fallback, including specification of the UE reporting necessary to enhance the mobility parameter tuning and inter-node information exchange, including possible enhancements to interfaces. Additional enhancements of SON/MDT for the following will also be addressed in 5G-Advanced: MR-DC CPAC, successful PScell change report, successful Handover Report (e.g., inter-RAT), NPN (Non-Public Networks), RACH report, fast MCG recovery, and NR-U (MRO and UL MLB).

3.20 Enhancements for XR

Majority of the emerging 5G use cases are time critical in nature with demanding requirements on reliable low latency. Such demanding new use cases can be broken down into four categories key categories: real-time media, remote control, industrial control, and mobility automation. The real-time media category includes innovative extended reality (XR) that are of growing interest amongst all segments of subscribers: consumers, enterprise, public institutions etc.

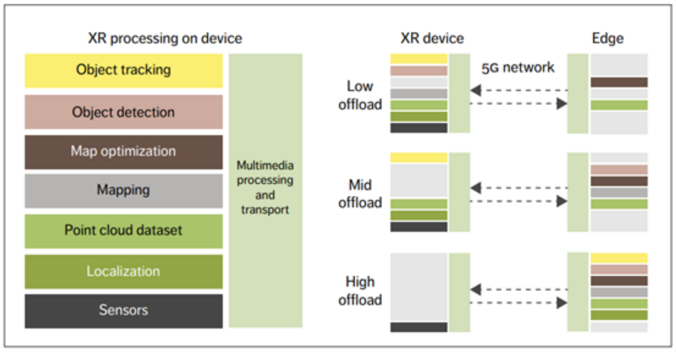
XR is an umbrella term that refers to any of immersive technologies such as Virtual Reality (VR), Mixed Reality (MR) and Augmented Reality (AR). XR is expected to improve productivity and convenience for consumers, enterprises and public institutions in a wide variety of application areas such as entertainment, training, education, remote support, remote control, communications and virtual meetings. It can be used in virtually all industry segments, including health care, real estate, shopping, transportation and manufacturing.

Although VR holds lot of promise for innovation, MR and AR provide true transformational potential. With AR, the users are present in reality and are free to be mobile even when using their Head Mounted Device (HMD). By freeing up user's arm, AR technologies transform the user interaction drastically. As an example, user would be able to perform complex task in factory or lab environment using hands while at the same time getting guidance on HMD through AR. This is supposed to increase users' efficiency dramatically.

Building small, fashionable, low power consuming XR device is critical for HMD based XR use cases. The best way to realize this requirement is to off-load parts of XR processing to the mobile network edge. Figure 16 below shows eight main types of XR functionalities that are split between XR device and the network edge. The devices are categorized into 3 categories depending on the extent of off-load to the network edge.

Many of the XR use cases are characterized by quasi-periodic traffic with high data rate in DL such as video stream, combined with the frequent UL (i.e., pose/control update) and/or UL video stream. Both DL and UL traffic are also characterized by a relatively strict packet delay budget (PDB). Hence, there is a need to study and potentially specify possible solutions to better support such challenging services.

Figure 16: Split architecture options with 5G connectivity [45]



Since most of the XR devices are expected to have a small form factor, it is very important for the devices to be very efficient from a power consumption perspective. Therefore, additional power consumption enhancements may be needed to reduce the overall UE power consumption when running XR services and thus extend the effective UE battery lifetime. It is understood that the current DRX configurations may not fit well for the unique XR traffic characteristics. Hence enhancements would be beneficial in this area.

It is estimated that XR application awareness by devices and infrastructure would improve the user experience, improve NR system capacity in supporting XR services, and reduce UE power consumption.

Study of XR as part of 3GPP RAN release 17 focused on key characteristics that are essential for XR applications such as data rate and latency. Since XR services typically comprise multiple data flows (e.g., video, audio and control). Flows are mainly periodic, but each has a different periodicity and packet sizes. It is significant for having a satisfactory XR service experience to provide high data rate communication while maintaining low and bounded latency. If besides low latency also low loss is of importance, then L4S (Low Loss Low Latency for scalable throughput) can be used, allowing to prioritize latency over data rates in congested situations. [46]

The scope of 3GPP RAN Rel-18 study aims to build upon the release 17 specification. Below is the list of focus areas of study:[47]

- Study and identify the XR traffic (both UL and DL) characteristics, QoS metrics, and application layer attributes beneficial for the gNB to be aware of.
- Study how the above information aids XR-specific traffic handling.
- Study XR specific power saving techniques to accommodate XR service characteristics (periodicity, multiple flows, jitter, latency, reliability, etc…). Focus is on the following techniques:
  - » C-DRX enhancement.
  - » PDCCH monitoring enhancement.
- Study mechanisms that provide more efficient resource allocation and scheduling for XR service characteristics (periodicity, multiple flows, jitter, latency, reliability, etc.).

3.21 New spectrum

New spectrum can enable new applications and enhance existing applications for 5G-Advanced. As shown in Figure 17, the available spectrum for 5G-Advanced cell deployments may be in upper mid bands, such as 7.125 GHz to 24.25 GHz. For the purposes of this white paper, we refer to this frequency range as "FR3" spectrum to differentiate from the already defined FR1 and FR2 spectrum. Ultimately, 3GPP may define frequency range designation(s) for any newly defined 5G-Advanced spectrum. The main advantages of "FR3" spectrum band(s) include the large bandwidth and the suitability for wide-area deployments, though more challenging than FR1 deployments. In other words, "FR3" has the potential to offer the best of FR1 (coverage) and the best of FR2 (wide bandwidth) bands. Wide area coverage with wide bandwidth availability also makes this band a very promising opportunity for enhanced positioning and sensing capabilities as well. "FR3" could become the new frequency range to design and evaluate key 5G-advanced candidate technologies.

On top of Rel-17 coverage enhancement, Rel-18 will further study, and if justified, support the uplink coverage in the following areas.

- PRACH coverage enhancement with either multiple PRACH transmissions with same beams for 4-step RACH procedure or PRACH transmissions with different beams for 4-step RACH procedure.
- Increasing UE power high limit for CA and DC based on Rel-17 RAN4 work on "Increasing UE power high limit for CA and DC".
- Dynamic switching between DFT-S-OFDM waveform and CP-OFDM waveform.

To harvest the potential gains of new spectrum such as FR3, there are several challenges that need to be overcome, which are listed below:

- FR3 has larger propagation loss than FR1. To guarantee similar coverage between FR1 and FR3, techniques to improve both DL and UL coverage in FR3 are essential for the success of FR3 deployment. One of such techniques is Gigantic MIMO, which scales up

FR1 massive MIMO to gigantic MIMO antenna panels (>1K elements) to offer larger beamforming gain to overcome the larger propagation loss in FR3.

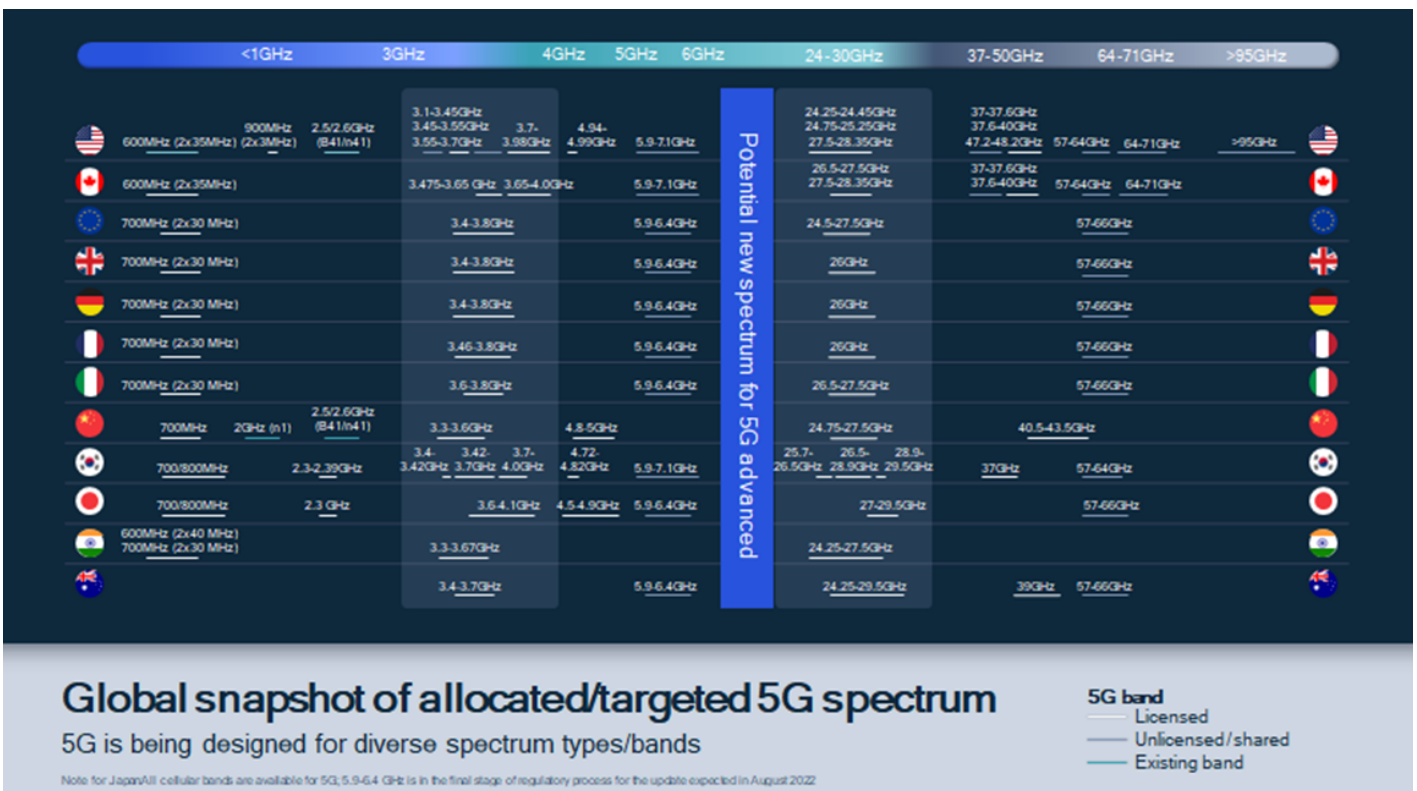
- Cellular communications in new spectrum, such as in FR3, might have to coexist with existing communication systems already deployed in those spectrums. For example, earth/satellite communications have been deployed in many spectrums in FR3. Advanced interference management and suppression techniques are critical to guarantee cellular communications and other communications systems can nicely coexist in new spectrum without interfering with each other.
- New transceivers might be required for cellular communications in new spectrum. The new transceivers could include new RF filter, high performance power amplifier, new antenna designs at both UE and gNB.

The Rel-18 and subsequent studies and specification efforts are expected to solve the above challenging problems and enable 5G-advanced deployed in the new spectrum.

3.22 Coverage Enhancement

Cell coverage is critical to the success of 5G deployment. Guaranteeing good cell coverage at everywhere without coverage holes can deliver good experience of NR services to end users. In Rel-17, 3GPP studied 5G uplink and downlink coverage respectively and identified that uplink coverage is the bottleneck of the system. Therefore, Rel-17 introduced techniques to improve the coverage of uplink channels, including PUSCH, PUCCH, message 3 in RACH. On PUSCH coverage enhancement, the techniques include repetition type A for PUSCH, TB processing over multiple slots for PUSCH, joint channel estimation for PUSCH. On PUCCH coverage enhancement, PUCCH repetition enhancement and joint channel estimation for PUCCH are supported. On message 3 coverage enhancement, type A repetition for message 3 is enhanced.

Figure 17: Global snapshot of allocated/targeted 5G spectrum



4. System Architecture, Core Networks, and Services

4.1 Enhancements for Edge Computing

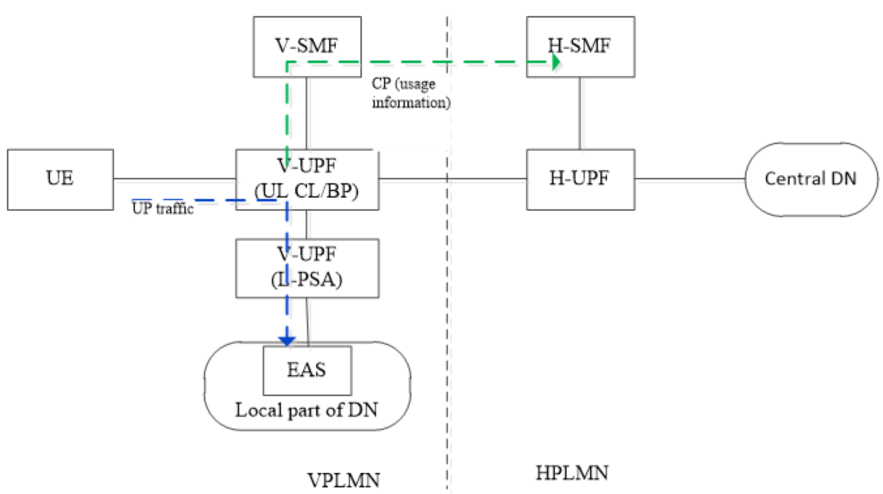
3GPP has developed Edge Computing capabilities to bring application computing services closer to end users to help solve the key challenges of bandwidth and latency. Edge computing can provide a hybrid applications model where centralized connectivity can be used for all the usual communication services while edge computing is used when the requirements of workloads require processing in near real time such as Augmented/Virtual Reality based services.

By release 17, 3GPP core network standards for Edge Computing have a full set of features. This encompasses abilities such as allowing the applications and UEs to obtain Edge configuration information and discovery the Edge Data Networks and Edge Application Servers. Network exposure and event notifications features allow the network to supply a long list of information such as UE location and mobility, e.g., movements of UEs in/out of geographic boundaries, the current network conditions, e.g., congestion or changes in user data paths, UL/DL packet delay measurements periodically when it exceeds a threshold, the constant monitoring of UE reachability status and loss of connectivity, and finally charging support.

Further features available in release 17 involve dynamic traffic routing through edge data networks and other resources by influencing the selection of User Plane Functions (UPFs). This influence can be done for the services of a single UE or group of UEs. There is also support for edge relocation when the UE moves too far away from its current edge services. In some cases, service continuity support further provides the means for application relocation with user context transfer and/or application instance relocation.

Looking ahead to evolved 5G systems in release 18, there are additional enhancements to Edge Compute (EC) being studied. A key capability is to address roaming when using applications in Edge Hosting Environments (EHEs) in VPLMNs. When the UE is roaming, there are two scenarios: (1) UE accessing V-EHE via a Local Breakout (LBO) PDU Session and (2) UE accessing V-EHE via a Home Routed (HR) PDU Session (i.e., with PSA in HPLMN as shown below). For (1), two different PDU Sessions are required to access an EHE in VPLMN and Home DN in HPLMN simultaneously. The UE must dedicate an LBO PDU Session for the local traffic routing, and another home routed (HR) PDU Session for other services. One or more dedicated DNN(s) have to be assigned to these applications in URSP rules determined by the HLPMN.

Figure 18: Visited EHE via a HR PDU Session



For (2) as shown in Figure 18, a single PDU Session and (DNN+S-NSSAI) can support both EC and non-EC applications in either roaming or non-roaming cases. However, it needs to be studied how the UE can access the V-EHE via an HR PDU Session. And in this scenario, one has to consider whether the HPLMN has the knowledge of EAS deployment information in VPLMN for specific services. If the HPLMN does, it can provide information to the UE to trigger EAS discovery and local traffic routing in VPLMN. If the HPLMN does not, some other solution must be developed.

Some solutions in the Rel 18 study are also looking at the need for edge relocation due to roaming. Relocation involves the moving of a running application from one edge application server to another server in a different edge hosting environment. The requirement to expand edge relocation between home and visited networks was mentioned by the GSMA Operator Platform Group.

Another feature in Release 18 is the fast and efficient network exposure of UE traffic related information to Edge Application Server via the Local UPF or Network Exposure Function (NEF). Edge applications need to react quickly to changing network conditions that impact the latency and BW of user data with the UE. The network exposes UE traffic related information, such as network congestion status, to the common Edge Application Server. This is critical for some applications such as XR/media or AI/ML services running in the Edge Hosting Environment.

Release 18 will also support more granular sets of UEs or allow dynamic collection of UEs to be created. In particular, there is a need to support offload policies to match more granular sets of UEs without exposing operator-internal configurations to 3rd party AFs. Furthermore, there is a need to influence the packet services anchor UPF and EAS (re)location for collections of UEs in scenarios when UEs need not use the same EAS and are not members of a pre-defined group.

And finally, Release 18 must support various configurations of EHEs as required by the GSMA Operator Platform Group. The first GSMA scenario is when the EHE is hosted by a 3rd party apart from the MNO. In another scenario, EHEs might be shared amongst multiple operators: visited and home as well as through partnerships. It should be noted that interconnectivity between EHEs of different operators cannot be assumed to be available for all deployments.

4.2 Personal IoT and Residential Networks

The Personal IoT Network or PIN is about connecting devices that can be placed around the body such as headsets, watches, earphones, and health monitoring sensors, or placed around the home such as smart lights, cameras, thermostats, door sensors, voice assistants, speakers, and household appliances. PIN also includes connecting commercial devices placed around the office or the factory floor such as printers, meters, and industrial sensors.

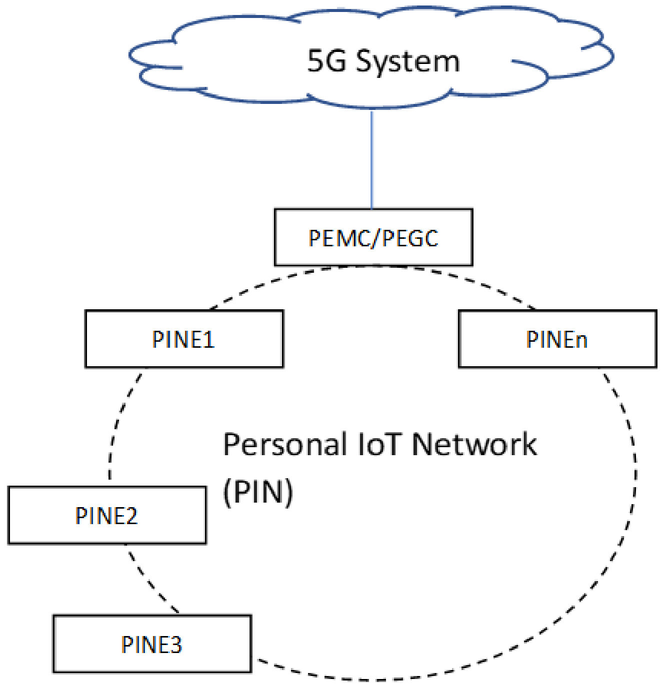
The majority of these IoT devices have various constraints in terms of their size, weight, battery capacity and cost which then lead to constraints on the types of radio interfaces and communications complexity they can support. Today, most of these IoT devices connect to the Internet via relays or gateways that use wireline access or via a UE connected to 5G. In such situations, the current 5G Systems are generally unaware of these IoT devices. To leverage 5G services and allow operators options to add value, evolved 5G Systems need to be aware of these devices.

Due to the personal nature of PINs, the end user needs to be able to easily create and delete PINs which are part of the customer premises network. They also must be able to effortlessly add or remove devices to their PINs. At the start of release 18, 3GPP has defined three kinds of PIN devices, called PIN elements or PINEs. Devices have capabilities for (1) communication, (2) gateway functions, and (3) management of the PIN. The most basic kind of PINE has only communication capability to connect to local devices directly or connect to remote devices via a gateway device. A gateway capable PINE connects other devices but can directly access the 5G system (thus it is a UE), and a PINE with management capabilities can add/remove PINEs and maintain PIN parameters with the help of the 5G system. Of course, a particular device may have multiple capabilities.

Thinking about the whole picture, we can see a set of characteristics for PINs. The evolved 5G system has to support at a minimum:

- The ability to identity PINs and PINEs for 5G system awareness of devices.
- The abilities to create/delete PINs, authorize/de-authorize PINEs as well as PINEs with gateway and management capabilities to manage PINs.
- The ability for network discovery and PINE discovery.
- Communication or connectivity between PINEs locally.

Figure 19: Example PIN Architecture (for illustration only, not formally agreed)



Closely related in functionality to the PIN is the use of devices in the home behind a Residential Gateway (RG) for fixed wireless services. For release 18, the main task for 3GPP is to determine a method of providing differentiated services, in terms of QoS and charging, for a mixture of both UEs and Non-3GPP devices connected behind a 5G RG. A non-3GPP device is defined as a device that uses non-3GPP access technology (typically, this is Wi-Fi) to connect to the RG and does not support the Non-Access Stratum (NAS) signalling messages.

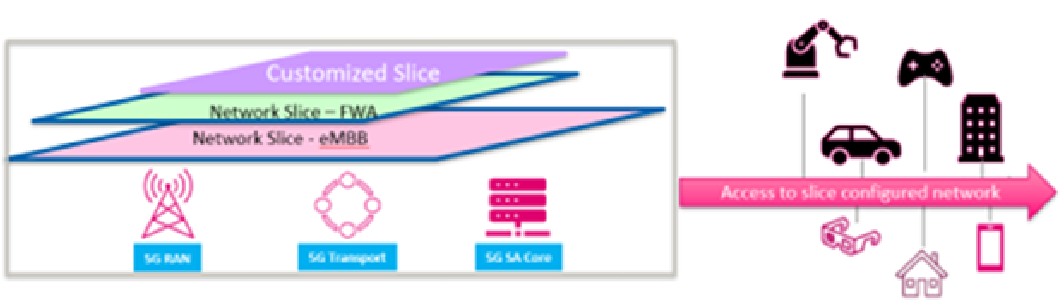
We further have to support two kinds of non-3GPP devices behind an RG depending on whether the 5G system can authenticate them. Either Authenticable Non-3GPP devices which can indeed be authenticated or Non-Authenticable Non-3GPP devices which cannot. An example of a non-authenticable non-3GPP device would be a Wi-Fi device that does not support USIM.

While 3GPP is studying solutions for PINs and devices behind Residential Gateways as separate efforts, solutions and technologies will likely be developed and deployed collectively for these two related areas.

4.3 Enhancement of RAN slicing

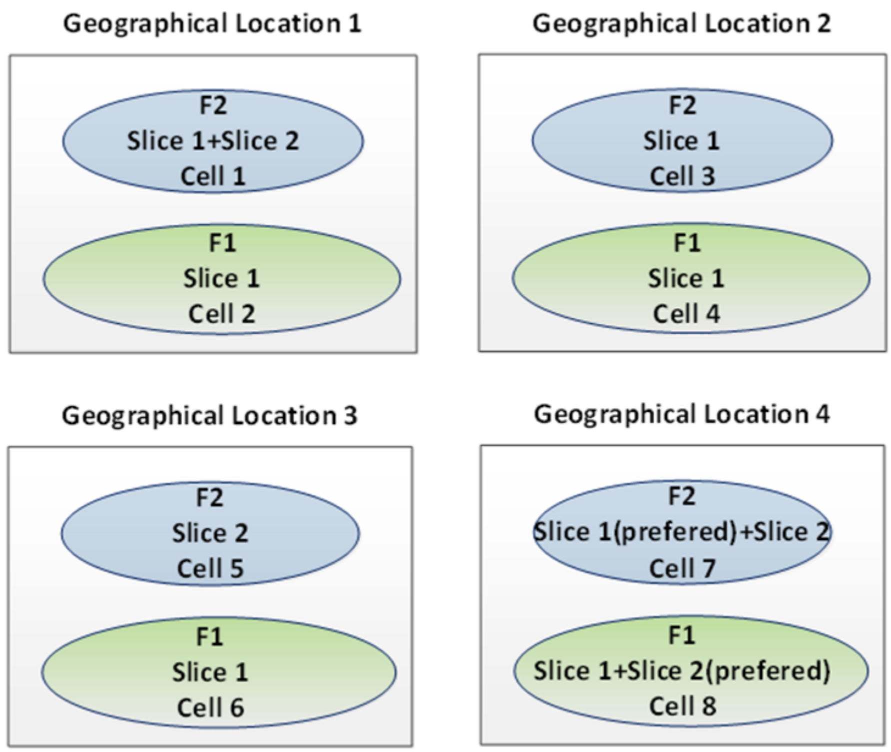
Strong demand in wireless communication has been expected in vertical markets, as connectivity and mobility empower the transformation and innovation in industries such as manufacturing, transportation, energy and civil services, healthcare, and many more use cases in Figure 20. These diverse vertical services bring about a wide range of performance requirements in throughput, capacity, latency, mobility, reliability, position accuracy, etc. Network slicing in Rel-15 moves from advanced network architecture towards more flexibility and higher scalability for a multitude of services of disparate requirements.

Figure 20: Network slice supports more use cases



NR technology promises a common RAN platform to meet the challenges of current and future use cases and services, not only for those that we can envision today but also for those that we cannot yet imagine. Rel17 provides technical tools in RAN for network operators to get application providers involved in customizing RAN's design, deployment and operation for better support of the applications providers' business. The multiple network slicing feature requirements and solutions are based the following network slicing scenarios in Figure 21.

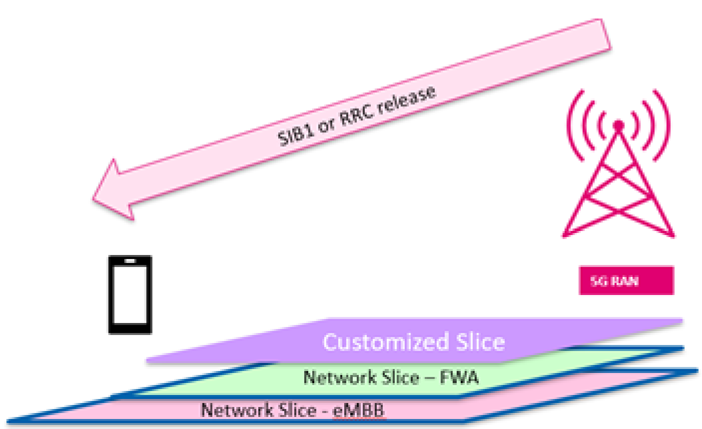
Figure 21: Example of slice deployment scenarios



Note: Geographical location number (1-4) can be one of deployment scenario with different frequency band in the geographical with designed slice for different services (e.g., EMBB or URLLC).

gNB supports slice-based cell reselection mechanisms and signaling with slice feature requirements. First, gNB broadcasts the supported slice information of the current cell and neighbor cells. Cell reselection priority per slice is signaled in system information (SI) or in RRCRelease message. Second, gNB shall support slice-based RACH configuration, specify mechanisms and signaling including configuration of both separated PRACH and RACH parameters priority for slice or slice group in Figure 22.

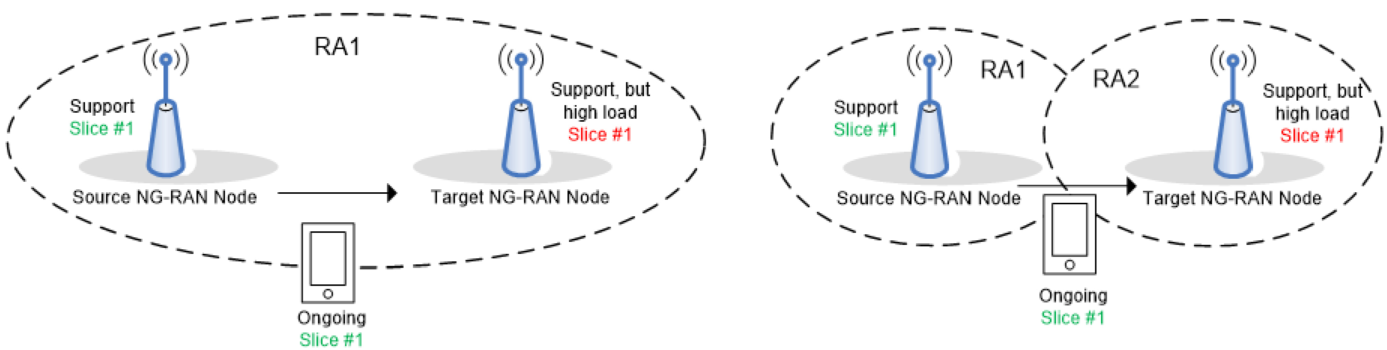
Figure 22: Slice-based cell reselection



Third, gNB shall support service continuity with resource management that includes slices resource re-partitioning /sharing or configuration-based solution. Service Continuity feature supports service interruption due to slice not supported during Inter-gNB mobility if is a specific SLAs, where the original slice is required to be available in a specific geographical are (TA/RA) only. There are multiple scenarios were studied in Rel17. Some scenarios are shared as reference.

Scenario 1 in Figure 23, Slice resource shortage during Intra-RA/Inter-RA mobility. Target gNB fails to accept the UE with at least one of the ongoing S-NSSAIs due to high slice-related load at target gNB. The service is/are interrupted for the UE.

Figure 23: Service interruption due to slice resource shortage



Scenario 2 in Figure 24: Inter-RA Mobility with Non-supported slice, the UE is moving towards an area that does not support at least one of UE's ongoing slices. The target gNB fails to accept the UE with at least one of the ongoing S-NSSAIs. Service(s) for failed ongoing slice(s) is/are interrupted for the UE.

Figure 24: Service interruption due to slice does not support

For Rel17 remapping traffic into a resource pool used by other slices requires a pre-configured policy by OAM or 5GC. The Slice remapping decision is determined by the AMF and the target gNB and can be made in the target gNB at the Xn based handover or at the NG-based handover. Additional slice resource re-partitioning solution is applicable using with spectrum resource (e.g., slots, beams, carries etc.), transport resources (e.g., backhaul capacity) and hardware resource (e.g., specific processors, processing load etc.). Multi-carrier radio resource sharing solution is applicable to Scenarios.

A network slice based unified access control framework has been development and shall be applicable to UEs in RRC Idle, RRC Inactive

4.4 Others

There are several other areas and enhancements, currently under 3GPP study/work in Rel-18, related to aspects (beyond RAN) specific to system architecture, CN, security, multimedia, and application enablement. This section provides as small sample of those projects, across different areas and working groups, including a short summary of their scope together with references to the corresponding WID/SIDs (for extra background, motivations, and detailed objectives).

4.4.1 Enhancements on Non-Public Networks (NPN)

3GPP introduced NPN support and further enhancements in Rel-16 and Rel-17.

The ongoing Rel-18 study covers the following new functionalities:

- Support for enhanced mobility between SNPNs
- Support for non-3GPP access for SNPN
- Enabling Localized Services via a local hosting NPN, including
  - » configuration for UEs to discover, select and access the local hosting NPN and services
  - » user manual selection

For more details, please refer to SP-211656[48].

4.4.2 Seamless UE context recovery

The Rel-18 work on Seamless UE context recovery targets the problem and optimized handling in 5GS, of certain UE "unavailability periods" due the execution of specific events, for example OS upgrade or modem SW updates (also commonly called as binary updates).

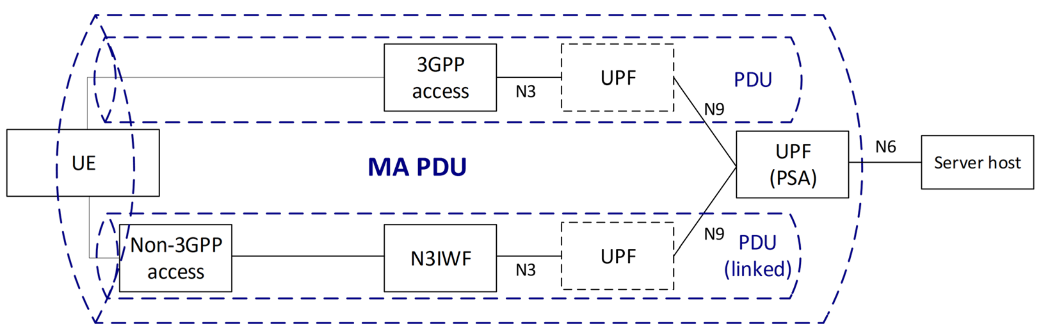
Enabling some co-ordination between UE and operator/application function, and some knowledge in the network, would minimize impacts to critical operations of certain application serves.

For more details, please refer to SP-211654[49].

4.4.3 Evolution of Access traffic steering split & switch (ATSSS)

Basic ATSSS support (see Figure 25) has been introduced in Rel-16, with some additions defined in Rel-17.

Figure 25: High-level ATSSS concept: multi-access PDU across 3GPP and non-3GPP access



3GPP is studying further enhancements in Rel-18, including:

- new functionalities able to steer/switch/split non-TCP traffic flows (e.g., UDP traffic flows and IP traffic flows), including further study (started in R17) on QUIC-based steering
- functionalities based on DCCP protocol & multipath extensions (e.g., per-packet splitting)
- redundant traffic steering, for both GBR and non-GBR traffic
- switching between two non-3GPP access paths in the same PLMN
- support of one 3GPP access path via 5GC and one non-3GPP access path via ePDG/EPC

For more details, please refer to SP-211612[50].

4.4.4 Location services (LCS) enhancements

The Rel-18 SA study on LCS enhancements covers several areas, among which:

- support positioning signaling via user plane
- reduction of location service latency, signaling overhead and location estimate exposure
- support flexible and efficient periodic and triggered location for UE power savings
- location service continuity for UE mobility, i.e., between EPS and 5GS
- other enhancements, in collaboration with RAN, e.g., related to low power high accuracy positioning, use of Positioning Reference Units (PRUs), network verified UE location and controlled positioning for satellite access

For more details, please refer to SP-211637[51].

4.4.5 Next generation Real Time Communication (RTC)

3GPP is studying further enhancements for RTC, including:

- new eMMTEL requirements and IMS functionalities, e.g., related to AR telephony communication and 3rd party / enterprise verification of specific identity information (on the callee side).
- support of Data Channel usage in IMS network, e.g., separate control plane and media plane functions, Data Channel application repository, procedures between Data channel server and IMS AS to support call event notifications.
- IMS media control interfaces for service-based architecture, besides Cx/Dx and Sh/Dh, supporting capabilities for new applications and efficient media processing (considering backward compatibility and based on SIP as core IMS signaling protocol).

For more details, please refer to SP-211644[52].

4.4.6 Enhancement of 5G UE Policy

The study on UE Policy enhancements aims at investigating the following areas:

- URSP rule provisioning and updating procedures for home-routed and LBO roaming scenarios
- Optimization on UE Policy requesting and provisioning related aspects
- Potential enhancements for provisioning UE with consistent URSP across 5GC and EPC
- Support of optimized operator specific URSP traffic categories/descriptors

For more details, please refer to SP-211649[53].

4.4.7 Timing Resiliency & other URLLC enhancements

3GPP is looking at new functionalities related to Timing Resiliency, together with further enhancements to URLLC. Some objectives of the ongoing work are:

- Support of 5G Timing Resiliency requirements, including
  - » Reporting of 5GS network timing synchronization status (such as divergence from UTC and 5GS network timing source degradation) to UEs and 3rd party applications (AFs)
  - » how to enable AFs to request time synchronization service in a specific coverage area
  - » control of 5G time synchronization service based on subscription
- Study how to enable an AF to explicitly provide PER to NEF/PCF.
- Support for low latency mechanisms for interworking with TSN transport networks.

For more details, please refer to SP-211634[54].

4.4.8 Deterministic Networking (DetNet)

One more interesting project, under study in SA2, regards TSC enhancements to enable support of so-called Deterministic Networking (DetNet). DetNet, already standardized in IETF, relies on IP and Multiprotocol Label Switching (MPLS) layer mechanisms, providing time-sensitive features that guarantee almost zero packet loss rates and bounded latency.

The 3GPP study investigates 5GS support for DetNet including e.g., interworking between a central DetNet controller entity (as defined in IETF) and the 5G system, translation of DetNet traffic/flow profiles into 5GS QoS parameters, information to be exposed from the 5G system to the DetNet controller.

For more details, please refer to SP-211633[55].

1.1.1 Enhancements for Wireless Wireline Convergence (WWC)

3GPP is studying further enhancements for WWC, including:

- support of devices connecting behind 5G-RG, for example providing differentiated service (QoS and charging) for UE and Non-3GPP devices connected behind a 5G RG
- Trusted/untrusted non-3GPP access network, e.g., how to select a TNGF/N3IWF that supports the S-NSSAI(s) needed by the UE
- For more details, please refer to SP-211640[56].

4.4.9 Security for split-RAN

On the security side, there are several ongoing projects and enhancements under work, many of which related to other stage-2 architectural features, plus few studies addressing specific security areas.
Among the latter, one study targets to create a new 5G SeCurity Assurance Specification (SCAS) to cover security tests for split gNB architecture (e.g., CU-DU, CU-CP/CU-UP split). For example, the study objectives include:

- identify new threats and critical assets for split gNB entities
- specific security functional requirements and related test cases for split gNB entities
- vulnerability testing requirements and related test cases

For more details, please refer to SP-220200[57].

4.4.10 Multimedia and XR enhancements

3GPP continues to enhance the 5G system for supporting new multi-media applications, devices and protocols. In the area of XR, several specific enhancements are being studied, few of them summarized below.

Split Rendering Media Service Enabler: This is a work item that will develop a Media Service Enabler that packages all required enablers and defines the required formats and protocols to make split rendering accessible (e.g., as SDK) to media service and application providers. The scope of this WID is limited to the interface between the Split-rendering EAS and the UE, covering the following aspects:

- profiles for edge, QoS allocation, and network assistance functionality for the split rendering Media Service Enabler
- control protocols for establishing and managing split rendering sessions between the 5GMS AS/EAS and the UE
- RTP configurations for real-time media transport, media formats and corresponding protocols for split rendering to be exchanged between the Split rendering AS EAS and the UE
- edge requirements, such as the EAS profiles, as well as edge discovery and relocation configurations appropriate for split rendering
- necessary APIs (for the application on the UE) to use the split rendering Media Service Enabler control functions

For more details, please refer to SP-220612[58].

Media Capabilities for Augmented Reality: This work defines service-independent media capabilities for AR devices. For example, the objectives include:

- Potential new AR device categories, and corresponding terminal architecture, media types and formats, integration of relevant 3GPP codecs, encoding/decoding capabilities.
- Define capability exchange mechanisms, e.g., based on device support of EAS KPIs for provisioning of edge/cloud resources
- VR QoE metrics that can be reused or enhanced for AR media (e.g., resolution per eye, Field of view (FOV), round-trip interaction delay, etc.) and relevant KPIs dedicated to AR/MR
- Specify encapsulations into RTP, ISOBMFF and CMAF
- codec-level parameters for session setup and negotiation of the media delivery
- 5G Media Streaming profiles based on AR media capabilities
- Future integration of IVAS

For more details, please refer to SP-220242[59].

Smartly Tethering of AR Glasses: For enhanced end-to-end QoS and/or QoE, AR glasses may need to provide functions beyond the basic tethering connectivity function, and the resulting AR glasses may be referred to as Smartly Tethering AR Glasses (SmarTAR).

A key challenge for wireless Tethered AR UEs is to properly estimate the required QoS allocations for the AR sessions considering the wireless/wired tethering link from the glass to the UE. The objectives of the ongoing 3GPP study are to investigate how to address those challenges, including:

- different tethering architectures for AR Glasses including 5G sidelink and non-5G access
- media handling aspects of different tethering architectures
- end-to-end QoS-handling and supporting mechanisms to compensate for the non-5G link between the UE and the AR glasses

For more details, please refer to SP-220240[60].

Conclusion

5G continues to be technically enhanced to drive an era of innovation in cellular communications. In 2022, 3GPP finalized Release 17 and initiated the work on Release 18.

In Release 17, the existing NR capabilities were enhanced from Release 16, improving the operational efficiency of the radio-access technology. In parallel, Release 17 has introduced new capabilities, extending NR towards new verticals. Some key features of NR Release 17 are:

- Extending the operation of NR to spectrum above 52.6 GHz to 71 GHZ
- Introducing Reduced Capability NR devices, that is, 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
- Enhanced uplink coverage
- Multi-SIM devices
- More advanced sidelink communications
- Small Data Transmission (SDT) capabilities
- Enabling broadcast/multicast services within NR
- Support for non-terrestrial networks (i.e., a satellite component of NR)

In December of 2021, 3GPP defined the scope for Release 18 work items to improve network capacity, latency, coverage, power efficiency and mobility. For Release 18, many new features and further enhancements have been outlined in this paper including:

- Study on Artificial Intelligence (AI)/Machine Learning (ML) for NR Air Interface and NG-RAN
- Study on Evolution of NR Duplex Operation such as sub-band full duplex (SBFD)
- Study on network energy saving
- Study on network controlled smart repeaters
- More advanced XR technologies to enable more/new XR applications.
- Continue to enhance NR MIMO, sidelink and sidelink relay, positioning, dynamic spectrum sharing, multi-carrier communications, Non-Terrestrial Networks (NTN) and IoT NTN, multicast and broadcast, IAB technologies.
- Further reduction of NR Redcap UE complexity

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.

Acronyms

3GPP: 3rd Generation Partnership Project

5GC: 5G Core

5GS: 5G System

ACK: Acknowledgement

AI/ML: Artificial Intelligence/Machine Learning

AR: Augmented Reality

ATG: Air To Ground

ATSSS: Access Traffic Steering Split & Switch

BWP: Bandwidth Part

C-JT: Coherent Joint Transmissions

CA: Carrier Aggregation

CAG: Closed Access Group

CBRS: Citizen Broadband Radio Service

C-DRX: Connected Mode Discontinuous Reception

CSI: Channel State Information

CU: Centralized Unit

DAS: Distributed Antenna System

DCI: Downlink Control Information

DCS: Default Credential Server

DetNet: Deterministic Network

DL: DownLink

DMRS: Demodulation Reference Signal

DNN: Data Network Name

DRX: Discontinuous Reception

DSS: Dynamic Spectrum Sharing

DU: Distributed Unit

eDRX: Extended Discontinuous Reception

eIMTA: Enhanced Interference Mitigation & Traffic Adaptation

EIRP: Effective Isotropically Radiated Power

eMBB: Enhanced Mobile Broad Band

eMMTEL: Enhancements Multimedia Telephony

eMTC: Enhanced Machine Type Comminications

FDD: Frequency Division Duplex

FR1: Frequency Range 1 (410 MHz-24.25 GHz)

FR2: Frequency Range 2 (24.25 GHz-71 GHz)

FR3: Frequency Range 3 (potential new 5G-Advanced FRs)

FWA: Fixed Wireless Access

GEO: Geosynchronous Earth Orbiting

GHz: Giga Hertz – 1 billion cycles per second

HAPS: High Altitude Platform Station

HARQ: Hybrid Automatic Repeat reQuest

HPLMN: Home Public Land Mobile Network

IAB: Integrated Access and Backhaul

IIoT: Industrial Internet of Things

IMS: IP Multimedia Subsystem

IMSI: International Mobile Subscriber Identity

IoT: Internet of Things

IP: Internet Protocol

IRAP: Infosec Registered Assessors Program

IT: Information Technology

ITU: International Telecommunication Union

KHz: Kilohertz – 1 thousand cycles per second

LAA: Licensed Assisted Access

LAN: Local Area Network

LCS: LoCation Services

LEO: Low Earth Orbiting

LPWA: Low Power Wide Area

LTE: Long Term Evolution

MDT: Minimization of Drive Tests

MIMO: Multiple Input Multiple Output

mMTC: Massive Machine Type Communications

mmWave: Millimeter wave

Acronyms

MR: Mixed Reality

MNO: Mobile Network Operator

mTRP: Multiple Transmission and Reception Point

MUSIM: Multi-User Suscription Information Module

NAS: Non-Access Stratum

NB-IoT: NarrowBand Internet of Things

NPN: Non-Public Network

NR: New Radio

NTN: Non-Terrestrial Network

OAM: Operation Administration & Maintenance

OEM: Original Equipment Manufacturer

OTA: Over The Air

PDCCH: Physical Downlink Control Channel

PDSCH: Physical Downlink Shared Channel

PDU: Protocol Data Unit

PEI: Permanent Equipment Identifier

PLMN: Public Land Mobile Network

ProSe: Proximity Services

PUCCH: Physical Uplink Control Channel

PUSCH: Physical Uplink Shared Channel

QoE: Quality of Experience

QoS: Quality of Service

RACH: Random Access Channel

RAN: Radio Access Network

RAT: Radio Access Technology

RedCap: Reduced Capacity

RF: Radio Frequency

RG: Residential Gateway

RLM: Radio Link Monitoring

RRC: Radio Resource Control

RTC: Real Time Communication

RU: Radio Unit

SCAS: SeCurity Assurance Specification

SI: System Information

SIM: Subscriber Identity Module

SLA: Service Level Agreement

SmarTAR: Smartly Tethering AR Glasses

SNPN: Stand-alone Non-Public Network

S-NSSAI: Single - Network Slice Selection Assistance Information

SON: Self-Organizing Networks

SPS: Semi-Persistent Scheduling

SR: Scheduling Request

SRS: Sounding Reference Signal

TDD: Time Division Duplex

TPMI: Transmit Precoding Matrix Index

TRP: Transmission and reception point

UAV: Uncrewed Aerial Vehicle

UDP: User Datagram Protocol

UE: User Equipment

UL: Uplink

UPF: User Plane Function

URLLC: UltraReliable and Low-Latency Communications

USIM: User Subscription Information Module

VMR: Vehicle Mounted Repeater

VPLMN: Visiting Public Land Mobile Network

VPN: Virtual Private Network

VR: Virtual Reality

WAN: Wide Area Network

WWC: Wireless Wireline Convergence

XR: eXtended Reality

Acknowledgments

5G Americas' Mission Statement: 5G Americas facilitates and advocates for the advancement and transformation of LTE, 5G and beyond throughout the Americas.

5G Americas' Board of Governors members include Airspan Networks, Antel, AT&T, Ciena, Cisco, Crown Castle, Ericsson, Intel, Liberty Latin America, Mavenir, Nokia, Qualcomm Incorporated, Samsung, Shaw Communications Inc., T-Mobile USA, Inc., Telefónica, VMware and WOM.

5G Americas would like to recognize the significant project leadership and important contributions of group leaders Yi Huang, Senior Staff Engineer, Qualcomm Incorporated, Tingfang Ji, VP of Engineering, Qualcomm Incorporated, Mark Younge, Distinguished MTS, T-Mobile USA Inc., and Jun Liu, Manager, Systems Architecture, T-Mobile USA Inc. along with many representatives from member companies on 5G Americas' Board of Governors who participated in the development of this white paper.

Endnotes

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