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5G Releases 16 and 17 in 3GPP

White paper

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The 5G system based on 3GPP Release 15, comprising 5G core and 5G radio (or New Radio [NR]) with 5G User Equipment (UE), is currently being commercially deployed throughout the world at both sub-6 GHz and mmWave frequency bands. Concurrently, the second (Release 16) and third (Release 17) phases of 5G are being developed in 3GPP. With Rel-16 nearing completion, and Rel-17 commencing development, this paper traces the main themes of these releases of 5G and provides an executive overview of the most important features being introduced.

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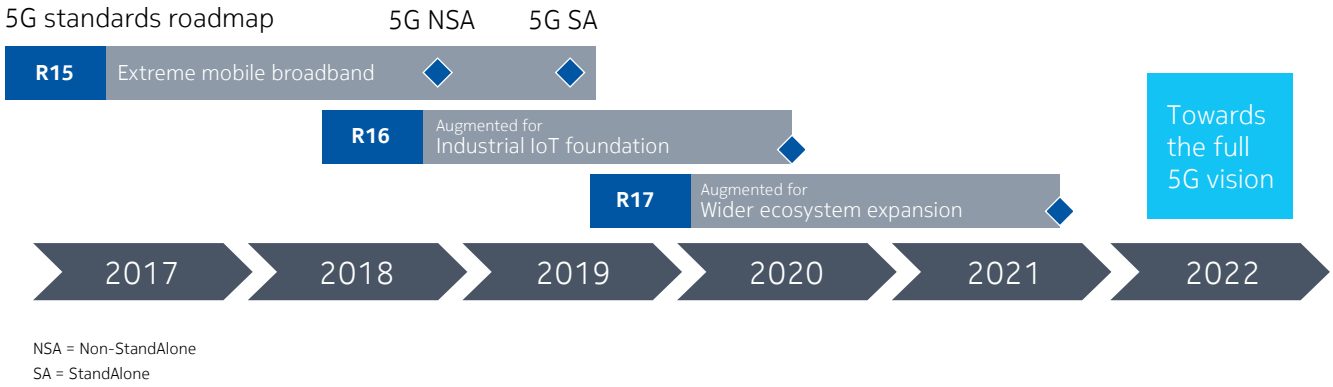
Introduction and timeline

The 5G system is being developed and enhanced to provide unparalleled connectivity and functionality for everyone and everything, everywhere.

The second phase of 5G is being finalized in 3GPP, with the Rel-16 version of the specifications being frozen around the middle of 2020. The 3GPP Plenary meetings in December 2019 decided the work program for the set of features to be included in Rel-17, which is scheduled for completion 15 months after Rel-16, as shown in Figure 1.

Figure 1. 3GPP timeline for Release 16 finalization and Release 17



NSA = Non-StandAlone
SA = StandAlone

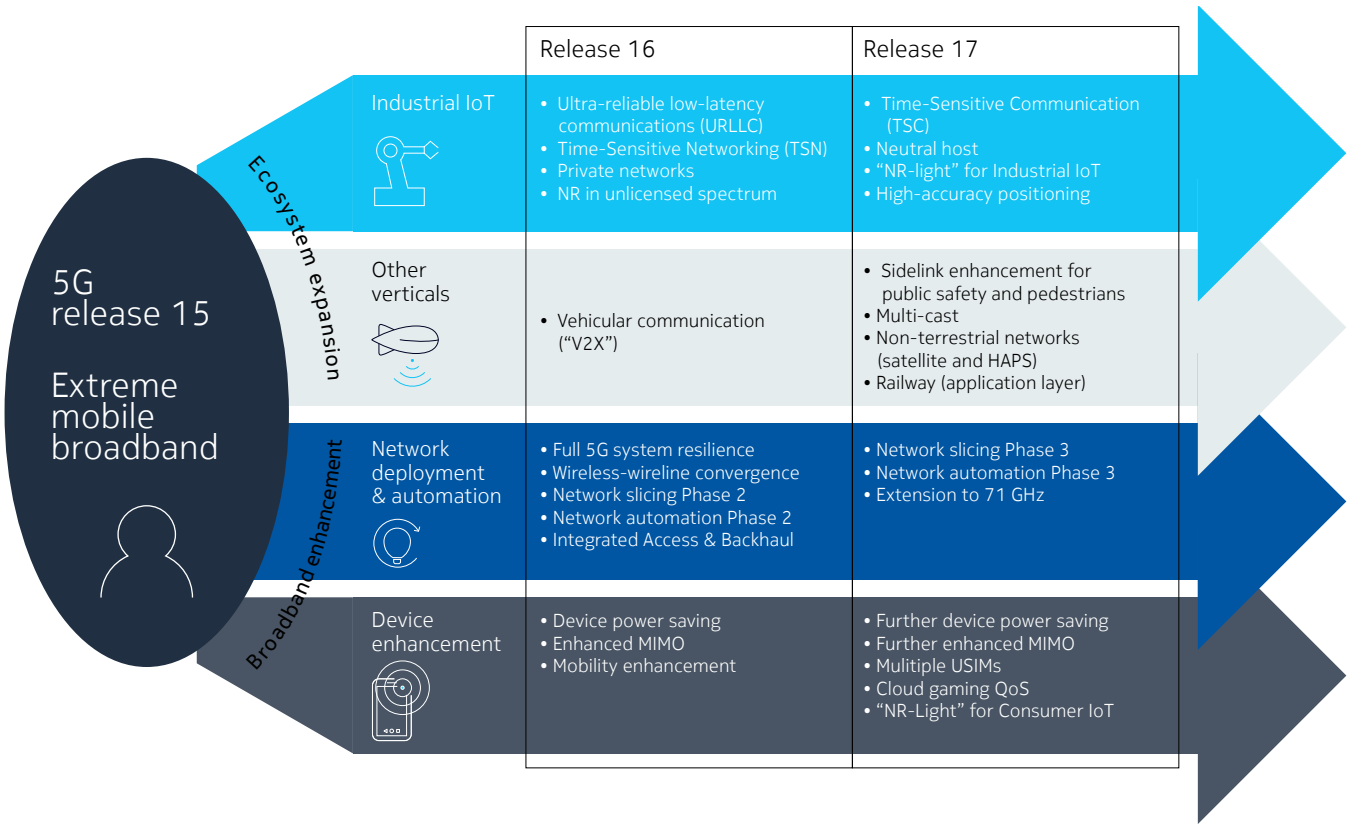
Key themes

Releases 16 and 17 together contain tens of features. For brevity and clarity, we focus here only on the key features we have identified, which we have categorized into four main themes:

1. Industrial IoT
2. Other verticals
3. Network deployment and automation
4. Device enhancement

It is important to recognize that Rel-16 and 17 are not just about incremental improvements to the performance of Rel-15. Rel-15 already provides outstanding performance in KPIs like data rate, spectral efficiency and latency. Rather, Rel-16 and 17 are primarily about expanding the ecosystem that can take advantage of 5G, by adding features to provide the full range of functionality required by new industry segments, as well as making 5G networks easier to deploy and optimize.

Figure 2 illustrates these key themes of Rel-16 and 17, together with the most important new functionalities by which they are realized.



An extended list of features in Rel-16 and 17 is given in the Annex for reference. It should not be forgotten that aspects such as security and network/service management are also integral to the whole 5G system design, even though they are not explicitly highlighted in this paper.

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Industrial IoT

The goal of creating full support for factory automation and other critical industrial IoT (IIoT) applications (some examples of which are given in Table 1) requires effort spanning multiple 3GPP releases. In some markets, the term "Industrial 5G" is used to summarize the Rel-16 and 17 features that form the support of IIoT. These are:

- **Ultra-Reliable Low-Latency Communications (URLLC):** Rel-16 completes the URLLC functionality that is critical for IIoT scenarios, such as factory automation. The foundation of URLLC was already laid in Rel-15 with support for ultra-low latency by means of the "mini-slot," and Rel-16 adds the ability to achieve unprecedented levels of reliability, down to packet error rates of 10-6, otherwise known as "six nines" reliability, as required by smart factory assembly and control operations.
- **Time-Sensitive Communication (TSC):** TSC is a communication service that supports deterministic and/or isochronous communication with high reliability and availability. It provides packet transport with QoS characteristics such as bounded latency and reliability, where end systems and relay/transmit nodes can be strictly synchronized. Rel-16 introduces TSC support based on integration with IEEE Time-Sensitive Networking (TSN), which is the main protocol for factories today. Rel-17 takes this to the next level by enabling TSC without reliance on IEEE TSN, thus offering enhanced enablers for the 5G system to support TSC natively for any application and deployment (e.g., music festivals). This will allow deployment of private wide area networks (WANs). Use cases for this type of network include logistics, shipping harbors and program-making and special events (PMSEs).
- **Private networks:** Rel-16 includes enhancements for private network deployments that are fully isolated to allow only authorized subscribers to camp in the network (referred to as non-public networks (NPNs) in 3GPP parlance). Rel-16 allows support of both an NPN-specific authentication mechanism for UEs without a universal subscriber identity module (USIM) and an Authentication and Key Agreement (AKA) mechanism for UEs with a USIM. In Rel-17, private-network support is being further extended by introducing support for neutral host models, where the network owner and service provider need not be the same entity. This includes enablers for accessing stand-alone private networks using credentials from third-party service providers, including public network operators. Furthermore, support for onboarding and provisioning of UEs to access private networks is being introduced.

Table 1. IIoT deployment examples enabled by 5G Rel-16 & 17

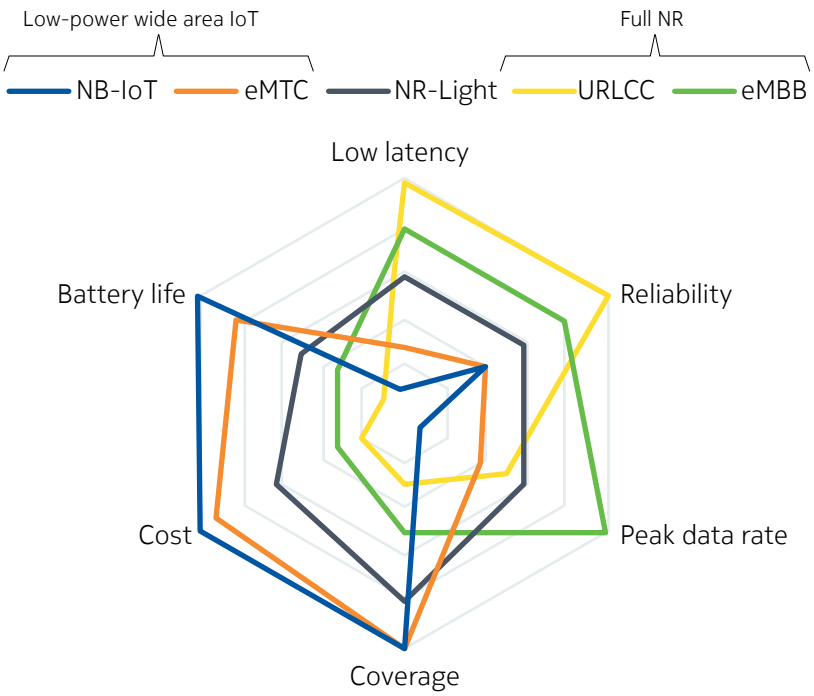
Release 16	Release 17
• Factory automation	• Enhanced factory automation including mobile robots, human–machine interfaces and plant asset management
	• Professional audio/video production, e.g., for live sports and music festivals
	• Advanced logistics and AR/VR-based control, e.g., smart ports/freight

- **NR-Unlicensed (NR-U):** In order to facilitate deployment of 5G networks for IIoT and other similar enterprise scenarios, Rel-16 introduces the features that are necessary for NR to be operated in unlicensed spectrum. Access to unlicensed spectrum provides an important tool to increase capacity for both service providers and private networks. For service providers, NR-U enables access to additional spectrum to improve the cellular network operation by offloading traffic in hotspots, while for private networks NR-U also enables the operation of stand-alone networks in unlicensed spectrum without any access to licensed spectrum.

The initial focus of NR-U in Rel-16 is on enhanced mobile broadband (eMBB) services in the 5 GHz and 6 GHz frequency bands. Rel-16 NR-U uses the same flexible frame and slot structure and fundamental physical layer design and protocol stack as NR Rel-15, hence limiting the magnitude of changes to the UEs relative to licensed band operation. NR-U adds channel access procedures to enable fair coexistence with other systems such as IEEE 802.11 variants or LTE Licensed-Assisted Access (LAA). In Rel-17, enhancements for IIoT will include enabling URLLC features to be used in unlicensed spectrum to better facilitate industrial use cases.

- **NR-Light:** Rel-17 brings a further step in the support of IoT by NR, in the form of "NR-Light" (aka "reduced-capability NR devices" in 3GPP parlance). Such devices will enable use cases like surveillance cameras and industrial sensors to use 5G, in addition to some wearables and consumer IoT devices. Compared with full 5G UEs, NR-Light devices are likely to be limited to narrower bandwidths, lower peak data rates and fewer antennas in order to reduce cost and complexity, while still enabling advanced connectivity. The characteristics required for these categories of devices, compared with full-blown 5G NR devices and low-power wide-area (LPWA) IoT devices, are illustrated schematically in Figure 3.

Figure 3. Expected capabilities of NR-Light devices



- **High-accuracy positioning:** Precise and up-to-date device location is an essential requirement for emergency calls, as well as new services like IIoT. Rel-15 provided basic positioning protocol support. This is extended in Rel-16 to include the capability to locate devices using the 5G radio signals themselves, leading to an expected accuracy in the order of a few meters for the vast majority of users (subject to the deployment scenario), thanks to 5G's wide transmission bandwidth and directional beamforming. In Rel-17, further enhancements are being considered, aiming for accuracy levels down to a few tens of centimeters, as required for industrial process applications.

Other verticals

While IIoT is the most significant expansion of the 3GPP technology ecosystem addressed by Rel 16 and 17, these releases also introduce features that enable 5G to serve a variety of other dedicated markets where the role of the network operator may be broader than that of typical communication service providers (CSPs). These are loosely referred to as "vertical" markets for 3GPP technology, and the key examples considered in Rel-16 and 17 are highlighted below.

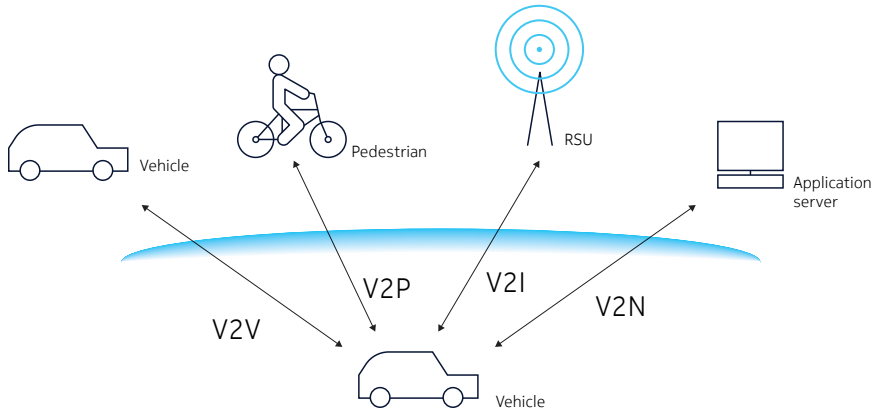
- **Device-to-device use cases, including V2X[1] and critical communications/public safety:** Rel-16 introduces a sidelink feature to enable direct communication between terminals. Unlike LTE, the NR sidelink is specifically designed first for the requirements of cellular V2X (C-V2X), including vehicle-to-vehicle, vehicle-to-pedestrian and vehicle-to-roadside unit (RSU) communication, as illustrated in Figure 4.

  While C-V2X in LTE is primarily designed for broadcasting basic safety messages, NR additionally supports more advanced use cases with lower latency, larger payloads and higher data rates, as well as both groupcast and unicast modes. These capabilities provide the foundations for operations such as platooning and remote driving.

  It should be noted that wherever network coverage is available, V2X can be supported via the base stations using the URLLC functionality of NR together with edge computing to deliver low latencies. If the sidelink is being used, the physical layer resources can either be scheduled by the gNB[2] or autonomously selected by the UE in a contention-based manner.

  In Rel-17, enhancements to the sidelink and proximity services are being introduced to support critical communications and public safety applications, for example where emergency workers can benefit from direct device-to-device communication. In particular, sidelink power-saving features are being introduced for handheld devices, which will also benefit pedestrian devices designed to communicate directly with vehicles for pedestrian safety.

Figure 4. V2X communication modes



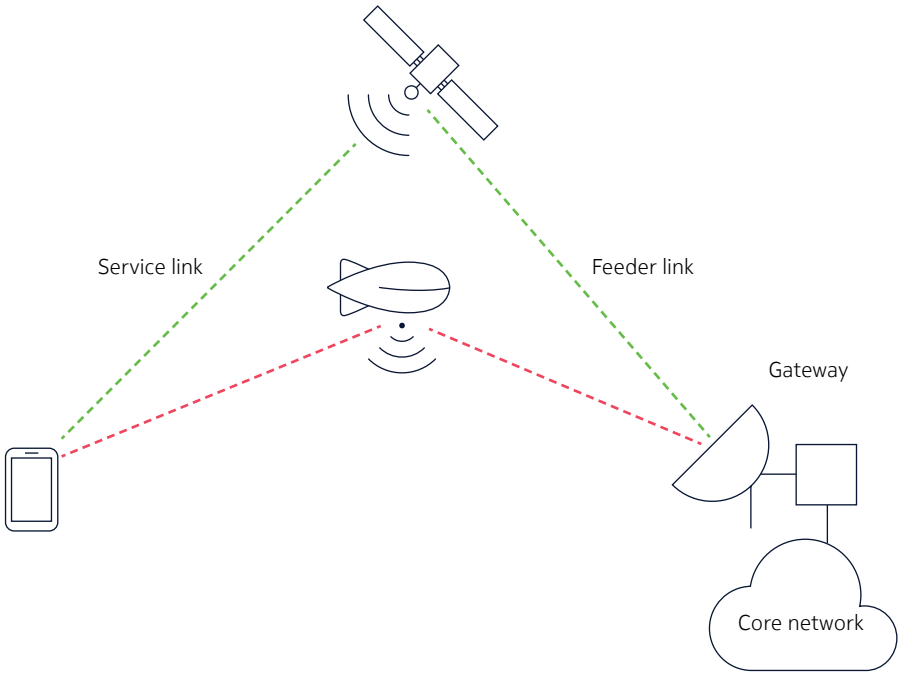
- **Multicast communication:** Rel-17 is, for the first time in 5G, introducing support for multicast communication, mainly aimed at the use cases of critical communications / public safety, V2X and railways. These cases require efficient communication to multiple terminals within an area of up to a

1 Vehicle-to-everything communication
2 5G NR base station

few cells. The basis for this mode of communication will be Single-Cell Point-to-Multipoint (SC-PTM) transmission, where multiple UEs receive a single physical channel within one cell. This will be combined with a content distribution mechanism and architecture, enabling the same content to be multicast in multiple cells independently. Non-transparent single-frequency network (SFN) operation will not be included, in order to avoid the complex impacts on the UE implementation that have prevented market uptake of multicast/broadcast features in previous generations.

- **Non-terrestrial networks (NTNs):** NTNs, in which base stations are deployed on satellites or as High-Altitude Platform Stations (HAPSs), are valuable for supplementing the coverage of terrestrial networks and extending service provision to remote areas. Rel-17 is introducing the minimum set of changes needed to 5G NR to support the challenges of the longer propagation range and delay of non-terrestrial systems. It will be based on a transparent architecture for the non-terrestrial infrastructure, with the possibility of extension to regenerative architectures in a later release. The feeder link (aka backhaul link) terminates in a ground-based gateway that is connected to the 5G core network, as shown in Figure 5.

Figure 5. Non-terrestrial networking



- **Railway communications:** Global System for Mobile Communications – Rail (GSM-R) is the current technology for railways. It is a modified off-the-shelf technology system based around manufacturers' commercial GSM offerings. Due to the expected sunsetting of GSM, Nokia has initiated the development of the Future Railway Mobile Communications System (FRMCS). Rel-17 is expected to cover all the essential needs of the International Union of Railways (representing the railway industry on behalf of individual actors), enabling deployment of application-layer railway solutions over LTE- or NR-based networks. (Note that a standalone 5G NR railway network requires sufficient spectrum availability, or alternatively it could be deployed using a CSP's network by means of network slicing.)

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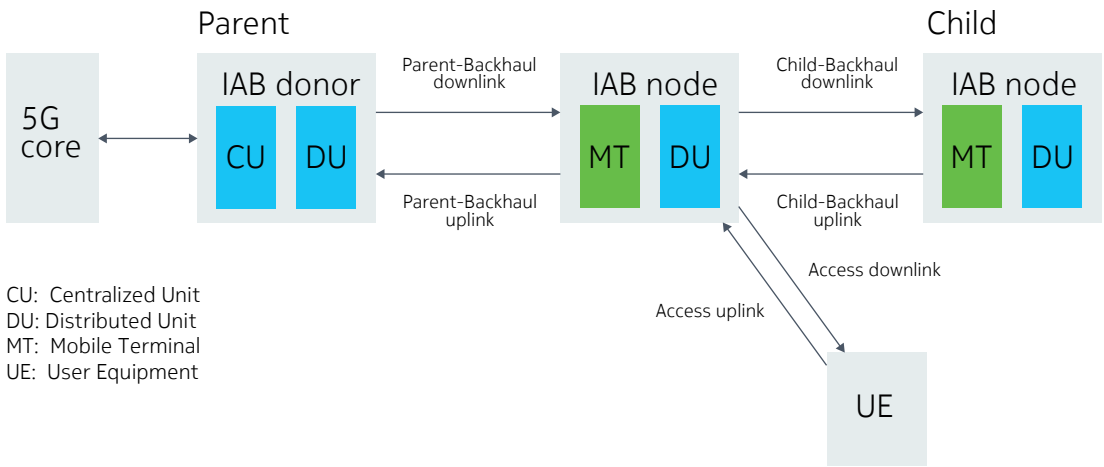
Network deployment and automation

This theme mainly comprises features that enable new deployment capabilities for CSPs, or which provide the means to reduce the operating expenses of running the 5G system.

- **Full 5G system resilience:** The 5G system architecture builds on a cloud-native foundation by means of the service-based architecture (SBA) and compute-data split in the 5G core. In Rel 16, initial limitations on overall system resilience are lifted, and 1:N redundancy, efficient transaction processing and operational efficiency can be applied to all 5G core network functions. Furthermore, security features for service-based interfaces, transport layer security (TLS), and token-based authorization using the OAuth framework are introduced.
- **Wireless-wireline convergence (WWC):** Multi-access capabilities are improved in Rel-16, as it will natively support fixed access as well as provide simultaneous multi-access capabilities to maximize data rates, increase reliability and improve user experience. Rel-17 will further extend traffic steering capabilities between mobile and fixed accesses.
- **Network slicing (NS):** Rel-16 (NS Phase 2) allows operators to outsource network slice subscription management to third parties who are using the operators' networks to provide services to their own customers. Rel-16 also introduces Network Slice-Specific Authentication and Authorization (NSSAA); this allows a third party to manage a user's subscription to a particular slice without requiring the operator to be involved in managing transitions (adding/removing end users to/from a slice). For example, a car manufacturer who is offering V2X services can itself manage its end users who get access to its slice. Rel-17 (NS Phase 3) will further improve the overall operability and automation of network slice deployments.
- **Network automation (NA):** 3GPP is step-by-step moving toward analytics-powered networks. Rel-16 (NA Phase 2) continues to enhance the Network Data Analytics Function (NWDAF) in the 5G system. The NWDAF collects event information about different network domains and uses them to provide analytics-based statistics and predictive insights to 5G core network functions and operations and maintenance. Advanced machine learning algorithms can utilize the information collected by the NWDAF for tasks such as UE mobility prediction and optimization, anomaly detection, predictive QoS, network performance and data correlation. Rel-17 (NA Phase 3) will bring core-network-specific enhancements such as reporting of user plane KPIs toward the NWDAF, data collection improvements, and cooperation between multiple NWDAFs. Rel-17 will also include RAN-driven improvements such as Self-Optimizing Networks (SON), Minimization of Drive Tests (MDT) and RAN-level massive data collection.
- **Integrated Access and Backhaul (IAB)** has been introduced in Rel-16 as a key enabler for fast and cost-efficient deployments, mainly targeting dense mmWave deployments outdoors. IAB nodes use the same spectrum and air interface for access and backhaul, creating a hierarchical wireless multi-hop network between sites. The hops eventually terminate at a donor node that is connected by means of a conventional fixed backhaul to the core network. IAB nodes may be deployed for four fundamental purposes: (i) to remedy isolated coverage gaps, (ii) to provide backhaul where fiber deployment is sparse, (iii) to enhance system capacity and (iv) to bridge coverage from outdoor to indoor. Figure 6 shows the architecture of IAB, with a central IAB node connected to the core network via parent links to a donor node, child links to a node downstream from the central IAB node, and access links to devices served directly by the central IAB node. The IAB architecture leverages the 5G NR gNB logical split architecture, with a Centralized Unit (CU) at the IAB donor node and Distributed Units (DUs) at IAB nodes. An IAB node contains a Mobile Terminal (MT) part that behaves like a UE toward the parent node. On the child links, the DU part of an IAB node behaves like a gNB toward the next-hop IAB node. On the access links, the IAB nodes behave exactly like normal gNBs, providing the NR radio interface for UEs in their coverage areas.

Enhancements to IAB in Rel-17 will improve the options for resource multiplexing between the parent and child links of an IAB node, as well as provide increased flexibility and robustness in the topology and traffic routing.

Figure 6. IAB architecture

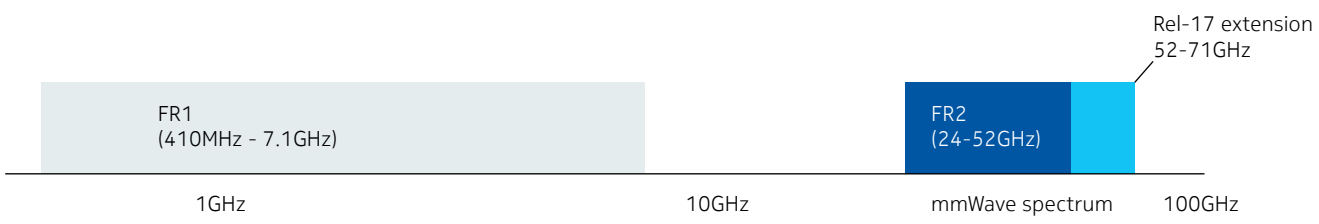


- **Extension to 71 GHz:** In Rel-15 and 16, 5G NR was designed to operate in both conventional cellular spectrum, known as Frequency Range 1 (FR1), and mmWave spectrum up to 52.6 GHz (FR2), as shown in Figure 7. As new spectrum becomes relevant, 3GPP continues to define new bands and band combinations in which 5G can be deployed, aiming to meet the demands of operators worldwide.

  A major step in this domain in Rel-17 is the introduction of support for NR in the 52–71 GHz frequency range, where up to 14 GHz of spectrum is available, including both unlicensed spectrum for NR-U and the possibility of licensed spectrum in the 66–71 GHz range following the identification of this band as IMT spectrum at WRC-19.

  Developing NR to work above its current upper limit of 52 GHz requires careful analysis of the transmitter and receiver impairments at these frequencies, as well as the power amplifier characteristics. Additionally, the narrower beams and higher attenuation at these frequencies will provide higher spatial isolation than is seen in lower-frequency bands, and this will need to be taken into account in defining coexistence requirements for unlicensed operation in this frequency range.

Figure 7. Spectrum for 5G



- **Learnings from first 5G stand-alone deployments:** In 2020 we expect the first deployments of the 5G standalone architecture to occur. Learnings from the field will be fast-tracked in 3GPP and are likely to lead to additional Rel-17 specification enhancements.

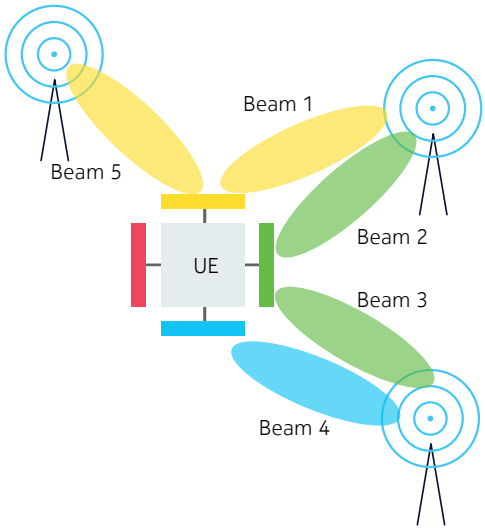
Device enhancement

As 5G deployments become more widespread and mature, Rel-16 and 17 introduce enhancements to the fundamental mobile broadband experience provided by 5G. These include:

- **Device power saving:** Device battery life is a key element of user experience. While many aspects of battery life depend on implementation design and tend to improve organically as the technology matures, there are some aspects of the 5G standards that directly impact the energy efficiency of devices. Rel-16 introduces signaling from the network to the devices, specifically to help them reduce their "connected mode" power consumption when conditions allow, enabling the device power consumption to be well optimized during periods of active transmission and reception. Rel-17 enhancements will focus on power-saving enhancements for devices that are in "inactive" or "idle" modes, thus helping to improve standby battery life.
- **Enhanced MIMO:** 5G has from the beginning provided extensive support for large-scale antenna arrays often referred to as "massive MIMO." The whole design of NR is "beam-based," which means that all the transmissions can be beamformed to enhance coverage and capacity. To support massive MIMO beam management, it is necessary for each transmitter to have accurate information about the characteristics of the radio channel. Signaling of this information incurs overhead, and Rel-16 introduces new compression techniques to reduce this overhead when beams are serving multiple users with high data rates simultaneously, thus improving the overall efficiency of massive MIMO operation.

  Rel-16 and 17 further introduce the possibility of transmission and reception at multiple Transmission & Reception Points (TRPs) on the network side, leading to a kind of Coordinated Multi-Point (CoMP) operation that is especially relevant for ensuring reliability for URLLC services. Rel-17 will also enhance support for devices with multiple antenna panels (as shown in Figure 8), which are particularly effective for increasing data rates when operating at mmWave frequencies.

Figure 8. UE with multiple antenna panels, communicating with multiple TRPs



- **Mobility enhancements:** Seamless mobility without loss of connectivity is vital for good user experience. Rel-16 therefore includes mobility enhancements aimed at improving the reliability of handover from one cell to another, further reducing the already low interruption time on handover, and facilitating rapid recovery in the event of handover failure.
- **Devices with multiple USIMs:** Many commercially deployed devices support more than one USIM card (typically two). In the past, these multi-USIM devices have been particularly popular in emerging economies, but are now spreading in other regions too. Multi-USIM devices are currently handled in an implementation-specific manner without any support from the 3GPP specifications, resulting in an unpredictable variety of implementations and UE behaviors. Rel-17 will formally define devices with multiple USIMs in the 3GPP specifications, giving special focus to mobile termination services and UE paging to avoid any unnecessary interruptions of the service in the current system and to save system resources.
- **Cloud gaming QoS:** Cloud gaming services have become increasingly popular in recent years. For cloud gaming, rendering can be performed on the network side, which means that sensor/pose data are transmitted to the network in the uplink direction and rendered data are transmitted to the UE in the downlink direction. In the uplink, the sensor/pose data require treatment with low latency and high reliability (e.g., four nines), while in the downlink the rendered data (i.e., audio and video) require low latency and potentially high bandwidth (e.g., 100 Mbps), but the reliability can be less stringent (e.g., three nines). The current 5G QoS mechanism does not offer suitable QoS parameters for asymmetric traffic. Rel-17 will therefore define new 5G QoS attributes to optimize resource usage on the network side and improve the UE's battery life when rendering is offloaded to the network.
- **"NR-Light" for consumer IoT:** As introduced above in relation to IIoT, NR-Light devices will enable much of the advanced connectivity of 5G to be achieved by devices with reduced cost and complexity. The advent of such devices will benefit consumers as well as industry, as devices such as 5G smart watches can also be developed based on the NR-Light foundation.

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Summary

Releases 16 and 17 take 5G to the next phase of ecosystem expansion. Whereas the first 5G release (Rel-15) addressed predominantly the immediate needs of extreme mobile broadband for CSPs, Rel 16 and 17 take 5G toward the full 5G vision, balancing the needs of CSPs with expansion into new markets including vertical players.

The key features of Rel-16 and 17 are described in this paper, showing how they address the 5G evolution themes of IIoT, other verticals, network deployment and automation, and device enhancement. They cover both continued enhancements of existing features and the introduction of new features to bring the benefits of ultra-high data rate, low latency, time-bounded and highly reliable communications to an ever wider ecosystem.

In the longer term, the highly performing and flexible 5G system is well capable of receiving further adaptations in Rel-18 and beyond, meeting the needs of new market opportunities and delivering value for much of the present decade.

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Annex

This annex provides additional information on the content of Releases 16 and 17 (not fully exhaustive, but intended to give a guide to the larger features).

Release 16 features

- **Cellular IoT support and evolution for the 5G system:** Introduces a set of features to the 5GC similar to those introduced for EPC support of Cellular IoT in LTE (NB-IoT, LTE-M).
- **Enhancement of URLLC support in 5GC:** Adds various methods to support redundant transmission in the network for improved reliability and resiliency E2E. Covered under "Industrial IoT" in this paper.
- **Enhanced support of vertical and LAN services:** This is 3GPP's official feature name, which introduces IIoT Phase 1 as described in this paper.
- **Enhancement to the 5GC location services:** In Rel-15, location services were primarily for emergency call handling. Rel-16 adds support for commercial and IoT use and also support for non-3GPP access, as well as the possibility for positioning techniques using the cellular network transmissions on a standalone NR carrier. See under "Industrial IoT" in this paper.
- **Architecture enhancements for 3GPP support of advanced V2X services:** Provides support for the following use cases: vehicle platooning, advanced driving, extended sensors and remote driving.
- **Enhancements to the 5G system service-based architecture:** Improved support for service-based architecture with flexible service framework catering for the needs of various deployment models. Enablers to support a fully resilient 5GC, allowing both stateful and stateless implementations. Service framework and resiliency solutions are backward-compatible with Rel-15 network functions.
- **Enhancement of network slicing:** The UE NSSAA allows the service provider to outsource subscription management in wholesale scenarios. The UE is assigned to a slice-specific Session Management Function (SMF) after mobility from the EPS in "idle" or "connected" mode.
- **Enhancing topology of SMF and User Plane Function (UPF) in 5G networks:** Allows deployment of SMF/UPF/5G Access Network such that they are grouped into autonomous regions while ensuring session continuity when the UE moves between these regions.
- **User data interworking, coexistence and migration:** Enables independent scaling of Unified Data Management (UDM) and Home Subscriber Service (HSS) by using an open interface between them.
- **Optimization on UE radio capability signaling:** Optimizes the size of the information sent by the UE to the network to signal its capabilities in the EPS and the 5G System. Optimizes the size of the information stored in the network to identify UE capabilities. Optimizes the size of UE radio capability information in the UE context transferred in the network-function-to-network-function signaling messages.
- **Enhanced IP Multimedia Subsystem (IMS) to 5GC integration:** Aligns the IMS protocols to the 5G system service-based architecture approach by allowing use of HTTP instead of DIAMETER.
- **Enablers for network automation for 5G:** Covered under "Network deployment and automation" in this paper.
- **Wireless and wireline convergence for the 5G system architecture:** Covered under "Network deployment and automation" in this paper.
- **Access traffic steering, switch and splitting support in the 5G system architecture:** Covered under "Network deployment and automation" in this paper.

- **Single radio voice continuity from the 5G system to 3G:** Allows voice call continuity in mobile networks not deploying LTE but only 3G. Allows voice call continuity in holes of LTE coverage for mobile networks with both Voice over New Radio (VoNR) and Voice over LTE (VoLTE) enabled.
- **System enhancements for Provision of Access to Restricted Local Operator Services by Unauthenticated UEs (PARLOS):** Enables restricted local operator services as per FCC regulations for E-UTRAN (same as what was available in CDMA). Allows activation of a SIM card.
- **5GS transfer of policies for background data transfer:** Policy control of background data transfer initiated at UE based on the time and location of the UE so that the 5G system can optimally use the control plane and/or user plane resources.
- **MIMO enhancements:** Covered under "Device enhancement" in this paper.
- **NR-U:** Covered under "Industrial IoT" in this paper.
- **Two-step Random Access Channel (RACH):** Introduces a shortened initial access procedure.
- **Remote Interference Management (RIM) and Cross-Link Interference (CLI) Management:** Introduces techniques for managing interference from distant cells in Time Division Duplex (TDD) networks in the presence of tropospheric scattering, as well as managing inter-operator interference.
- **UE power saving:** Covered under "Device enhancement" in this paper.
- **Multi-RAT dual connectivity and carrier aggregation enhancements:** Introduces NR-NR dual connectivity, as well as various enhancements for LTE-NR dual connectivity and NR-NR carrier aggregation, especially to reduce delays.
- **Mobility enhancements:** Covered under "Device enhancement" in this paper.
- **IAB:** Covered under "Network deployment and automation" in this paper.
- **NR UE capability signaling optimization:** Aims to reduce the overheads of UE capability signaling.
- **NR SON and MDT:** Covered under "Network automation" in this paper.
- **Private network support:** Covered under "Industrial IoT" in this paper.

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Release 17 features

- **NTNs:** Covered under “Other verticals” in this paper.
- **IIoT Phase 2:** Covered under “Industrial IoT” in this paper.
- **Device-to-device (D2D) communication, multicast, V2X and positioning enhancements**: Includes D2D communication for public safety, 5G multicast capability for public safety and V2X, support of pedestrian UEs as part of V2X, high-accuracy and low-latency positioning especially for IIoT. Also includes sidelink relaying.
- **NA and NS enhancements:** Covered under “Network deployment and automation” in this paper.
- **Multi-USIM:** Standards enablers for supporting multi-USIM devices in the network. Solutions to deal with paging collision, parallel user plane/control plane and prioritization of services.
- **NR-Light:** Covered under “Industrial IoT” in this paper.
- **IAB enhancements:** Covered under “Network deployment and automation” in this paper.
- **MIMO enhancements:** Enhanced multi-beam operations especially for above 24 GHz, multi-transmission-point support enhancement, enhanced channel state information (CSI) feedback, and enhancement on sounding reference signals (SRS).
- **Access traffic steering:** Covered under “Network deployment and automation” in this paper.
- **QoS for cloud gaming:** Defining new and optimized QoS parameters to match cloud gaming (relevant also for AR/VR/XR applications) requirements for latency, reliability and data rates.
- **Drones:** Creating capabilities in the 3GPP system to identify and track unmanned aerial vehicles (UAVs).
- **Multi-access edge computing (MEC) enhancements:** Optimizing edge networking support (mobility, discovery and provisioning).
- **Extension to 71 GHz:** Covered under “Network deployment” in this paper.
- **Dynamic spectrum sharing (DSS) enhancement:** Minor scheduling enhancements, not strongly related to DSS.
- **Positioning enhancements:** Methods to improve accuracy and integrity of positioning.
- **Coverage enhancement:** Study to identify any potential standards-based coverage enhancement techniques.
- **XR:** Study of the requirements and implications of AR/VR application traffic.
- **UE power saving:** Mainly addressing Idle and Inactive UEs.
- **SON/MDT and QoE enhancements:** Covered under “Network automation” in this paper.

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Abbreviations

5G	5th generation, the latest generation of cellular mobile communications
3GPP	3rd Generation Partnership Project
AKA	Authentication and Key Agreement
AR	Artificial or Augmented Reality
CDMA	Code-Division Multiple Access
CLI	Cross-Link Interference
CoMP	Coordinated Multi-Point
CSI	Channel State Information
CSP	Communications Service Provider
CU	Centralized Unit
C-V2X	Cellular Vehicle to X, where X can be, for example, Vehicle, Pedestrian, or Roadside Unit
D2D	Device-to-Device
DSS	Dynamic Spectrum Sharing
DU	Distributed Unit
eMBB	Enhanced Mobile Broadband
EPC	Evolved Packet Core
E-UTRAN	Evolved UMTS Terrestrial Radio Access Network
FCC	Federal Communications Commission
FR1	Frequency Range 1
FR2	Frequency Range 2
FRMCS	Future Railway Mobile Communications System
gNB	Next Generation Node B
GSM	Global System for Mobile Communications
GSM-R	Global System for Mobile Communications – Rail
HAPS	High-Altitude Platform Stations
HSS	Home Subscriber Service
IAB	Integrated Access and Backhaul
IEEE	Institute of Electrical and Electronics Engineers
IMS	IP Multimedia Subsystem
IoT	Internet of Things
IIoT	Industrial IoT
KPI	Key Performance Indicator

LAA	Licensed-Assisted Access
LPWA	Low-Power Wide-Area
LTE	Long-Term Evolution
LTE-M	Long Term Evolution (4G), category M1
MDT	Minimization of Drive Tests
MEC	Multi-access Edge Computing
MIMO	Multiple Input, Multiple Output
mmWave	millimetre Wave
MT	Mobile Terminal
NA	Network Automation
NB-IoT	Narrowband Internet of Things
NPN	Non-Public Network
NR	New Radio
NR-U	NR - Unlicensed
NS	Network Slicing
NSA	Non-Stand-Alone
NSSAA	Network Slice-Specific Authentication and Authorization
NTN	Non-Terrestrial Networks
NWDAF	Network Data Analytics Function
PARLOS	Provision of Access to Restricted Local Operator Services by Unauthenticated UEs
PMSE	Program-Making and Special Events
QoS	Quality of Service
RAN	Radio Access Network
RACH	Random Access Channel
RAT	Radio Access Technology
Rel-15	Release 15
Rel-16	Release 16
Rel-17	Release 17
Rel-18	Release 18
RIM	Remote Interference Management
RSU	Roadside Unit
SA	Stand-Alone
SBA	Service-Based Architecture

SC-PTM	Single-Cell Point-to-Multipoint
SFN	Single-Frequency Network
SIM	Subscriber Identity Module
SMF	Session Management Function
SON	Self-Optimizing Network
SRS	Sounding Reference Signal
TDD	Time Division Duplex
TLS	Transport Layer Security
TRP	Transmission and Reception Point
TSC	Time-Sensitive Communication
TSN	Time-Sensitive Networking
UAV	Unmanned Aerial Vehicle
UDM	Unified Data Management
UE	User Equipment
UPF	User Plane Function
URLLC	Ultra-Reliable Low-Latency Communication
USIM	Universal SIM
V2X	Vehicle to X, where X can be, for example, Vehicle, Pedestrian, or Roadside Unit
VoLTE	Voice over LTE
VoNR	Voice over New Radio
VR	Virtual Reality
WRC-19	World Radiocommunication Conference 2019
WWC	Wireless-Wireline Convergence
XR	Extended Reality

About Nokia

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