Taking 5G-Advanced to the next level and bridging into the 6G era

White paper

5G-Advanced started with 3GPP Release 18 and now shifts up to the next gear with Release 19. It will fine-tune the important themes from Release 18 - such as improved energy efficiency, better coverage-capacity and improved mobility performance – as well as putting in place the foundations of a bridge for a smooth evolution to 6G, including channel modeling, duplex evolution, and the development of a more extensive AI/ML framework. Essentially, Release 19 will offer unprecedented performance to commercial mobile network operators as well as private enterprises, resulting in improved end-user experience and superior operational excellence. At Nokia, we expect standardization of Release 19 to complete by the end of 2025, with commercial availability of the first Release 19 features in the field approximately one year after the standard's completion.

Contents

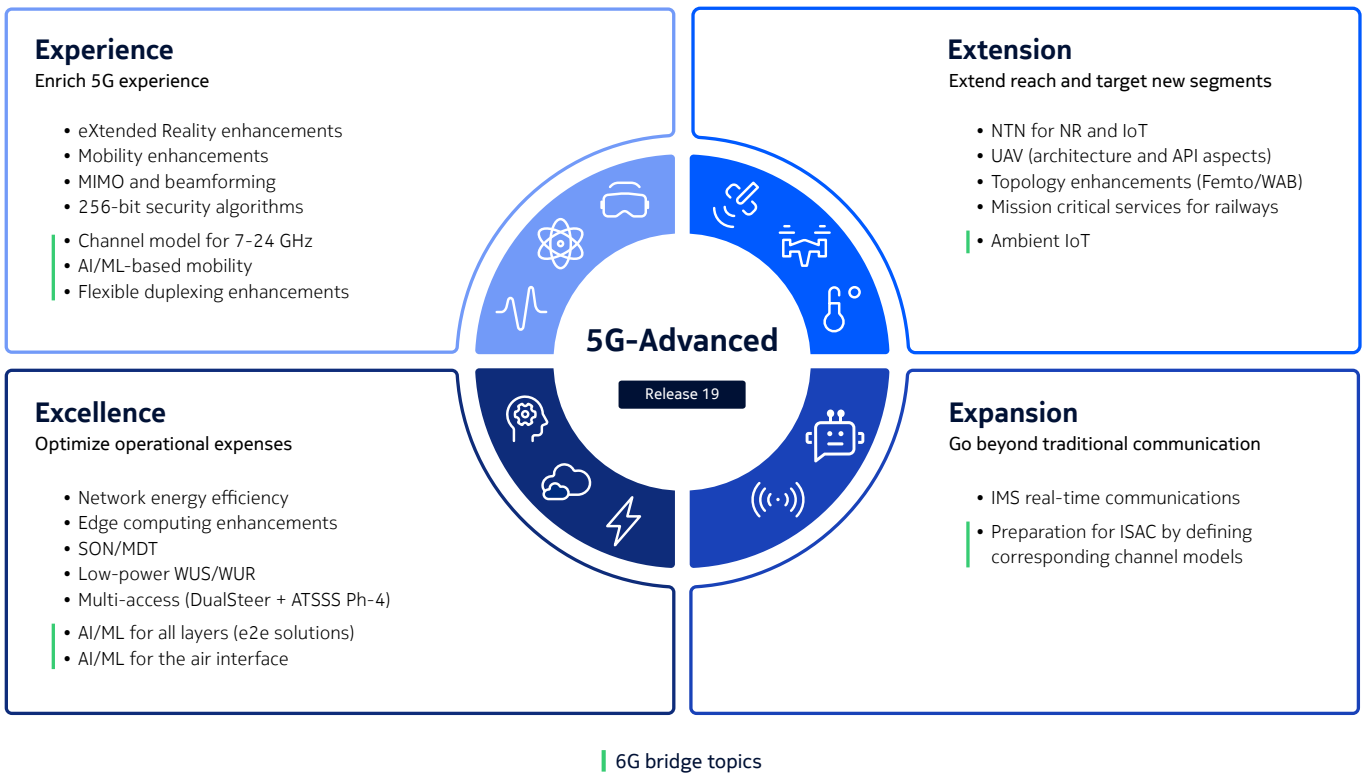
Introduction

5G-Advanced started in 3GPP Release 18 to take 5G to its fullest capabilities. At Nokia, we formulated the so-called "four E" description of 5G-Advanced: improved Experience for people and machines, Extensions for new use cases, and Expansions to offer new services beyond pure communication — all powered by innovations that provide operational Excellence. Our first 5G-Advanced white paper focused on Release 18 [1].

As reported in our "5G-Advanced shifts to the next gear with Release 19" blog post [2] and shown in our "From 5G-Advanced to 6G: Bridge to the future" video [3], 5G-Advanced now moves to a new level and expands into new use cases. Preparation for Release 19 was kicked off in June 2023 with large workshops for radio access network (RAN) and service and system aspects (SA) with close to 200 different stakeholders from across the wireless industry. The features emerging for 5G-Advanced Release 19 build on the foundations of Release 18. Among others, these features will offer refinements for services such as extended reality (XR), while at the same time improving on the radio and system performance. The important themes from Release 18 – such as improved energy efficiency, better coverage, and improved mobility performance – will be carried over into the Release 19 specifications.

In December 2023, 3GPP formally approved the first package of 5G-Advanced Rel-19 RAN and SA items, with more to come in March 2024 when Release 19 items led by the RAN working group responsible for radio performance and requirements will be approved. Release 19 will also include new themes that can be regarded as preparatory steps towards 6G, which we refer to as 6G-bridge topics. The "four E" narrative remains valid for Release 19, with Figure 1 showing how the main Release 19 features map to those Es.

Figure 1. Overview of the main Release 19 items



While Release 19 specifications are not expected to be finalized until 2025, we have a good idea of what the future holds based on 3GPP's approval of Release 19 items in December 2023.

It is also worth noting that several other features that already reached a high level of maturity in Release 18 are not further extended in Release 19. Examples of such features are Industrial IoT (IIoT), Small Data Transmission (SDT), Multi-SIM, High Speed Train (HST), Dynamic Spectrum Sharing (DSS), In-Device Coexistence (IDC), and Dual-Connectivity / Carrier Aggregation (DCCA).

In this white paper we provide a high-level summary of what key features to expect in 5G-Advanced Release 19. We start by outlining the features that fine-tune 5G-Advanced and then progress to the more future-oriented aspects that we see as important steps towards the 6G era. A glossary of all abbreviations used appears at the end of the paper.

Fine-tuning the key 5G-Advanced features

In the following subsections we outline the Release 19 features that build on key 5G-Advanced features from Release 18 (or earlier releases).

eXtended Reality enhancements

Further reading on the exciting future enabled by XR can be found in the recent Nokia white paper [4]. One compelling XR value proposition is Nokia's real-time extended reality multimedia (RXRM) for industries [5], which provides truly immersive, real-time experiences that can redefine the ways in which people work together and enable new revenue sources for operators. It leverages ground-breaking 360° video and spatial 3D audio to improve industrial productivity, enhance employee safety and wellbeing, and initiate a more sustainable working world.

Improved user experience will continue to be boosted in Release 19 for the highly demanding XR services that require medium to high data rates under bounded latency conditions. Nokia was the 3GPP rapporteur for XR enhancements in the RAN in Release 18, which included specification of several enhancements such as XR capacity improvements and user equipment (UE) power saving features tailored for XR traffic characteristics.

The XR improvements started in Release 18 will continue in Release 19, where Nokia acts as rapporteur for both the RAN and SA aspects, ensuring an end-to-end system view. In Release 19, scheduling restrictions arising from UEs performing radio resource management (RRM) measurements will be reduced. There will also be studies related to intra-UE multi-modality to facilitate efficient support for XR applications with multiple quality of service (QoS) flows. Related uplink scheduling enhancements are also in the Release 19 scope, as well as enhancements for acknowledged mode to make it feasible for the XR case with limited packet delay budget.

The framework for XR application awareness – as a capacity booster – that was started in Release 18 with the introduction of packet data unit (PDU) set QoS attributes, will be further refined in Release 19, by making the RAN aware of the XR application attributes. This includes consideration of new 5G QoS identifiers (5Qis) to improve PDU-set based QoS handling as well as related signaling and procedures between the core network (CN) and RAN.

MIMO enhancements

Evolution of multiple-input, multiple-output (MIMO) and mobility will continue in Release 19 to foster even higher capacity, coverage, and rock-solid mobility. One of the ambitions is to enable support for up to 128 transmit ports by introducing enhancements to the channel state information (CSI) framework. Depending on the exact scenario, extending the CSI framework to 64 transmit ports is estimated to offer approximately 20-40% higher spectral efficiency, with even more achievable with 128 ports.

Enhancements related to multi-TRP (transmission reception point) cases are also planned, as well as optimizations for beam management to reduce overhead and latency by letting the UE trigger reports on different beams when certain events occur.

Enhancements will also be introduced for UEs with three uplink transmit antennas, including corresponding non-coherent codebooks. For background on MIMO solutions in current 5G releases, see the Nokia white paper [6].

Mobility enhancements

Mobility based on the physical layer (PHY or L1) and medium access control (MAC) in layer 2 (L2) was introduced in Release 18, also known as lower layer triggered mobility (LTM), complementing the radio resource control (RRC)-based mobility procedures. It includes fast serving cell change via L1/L2 signaling, while keeping the configurations of the upper layers. LTM helps to reduce the interruption time during handovers to only 10-20ms, as well as reducing the signaling overhead. The concept of LTM will evolve in Release 19 for inter-gNB (5G new radio node B) handover cases, including physical layer measurement enhancements for LTM (e.g., event triggered methods and channel state information reference signal (CSI-RS)-based LTM solutions). Aspects of conditional mobility enhancements with short interruption time and LTM for dual connectivity are also candidates for further enhancements. A deeper dive into the 5G and 5G-Advanced mobility solutions can be found in our recent white paper, "Rock solid mobility innovations from 5G to 5G-Advanced" [7], which explains how rock-solid mobility performance is achieved.

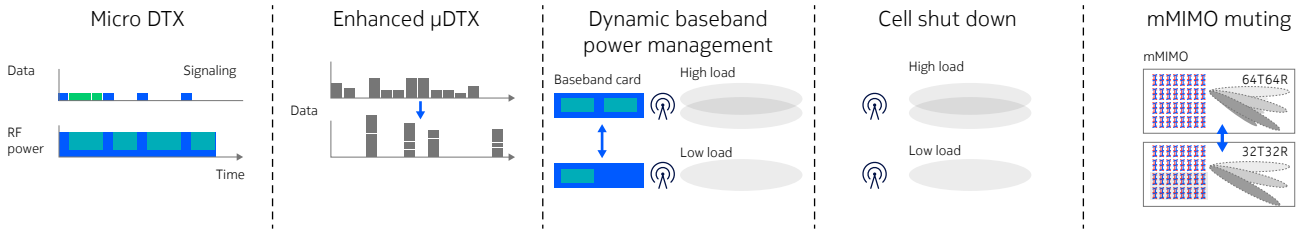
Network energy efficiency

Energy efficiency (EE) continues to be a key goal in Nokia's sustainability mission. Nokia's energy efficient products and circular practices help customers decouple business growth from their environmental footprint. Today, Nokia offers a strong portfolio of energy-saving RAN software features including gNB micro-discontinuous transmission (DTX), cell switch on/off, dynamic baseband power management, and massive MIMO muting (see more details in this Nokia white paper [8]) to help operators to reduce network OPEX. According to the latest GSMA report [9], 87% of the energy used by the operators surveyed is consumed by the RAN, underlining the importance of RAN EE enablers.

Nokia played a very active role in Release 18 EE studies and specification efforts. This included the definition of a solid gNB energy consumption model that allows further development of EE features and realistic assessment of their benefits. Release 18 EE enhancements included more dynamic signaling and feedback from UEs to enable smarter cell sleep opportunities and more energy-efficient transmissions.

In Release 19, the work on EE enablers will continue, with on-demand synchronization system block/system information block 1 (SSB/SIB1), SSB/SIB1-less operation, and more agile cell discontinuous reception and transmission (DRX/DTX). Artificial intelligence and machine learning (AI/ML) will play an important role for EE, utilizing the Release 18 framework for RAN data collection to enable smarter on/off switching of cells and massive MIMO muting when traffic conditions allow this without harming the user experience. Release 19 will also investigate EE enhancements in the core network and management layers. A potential framework for network energy consumption exposure will be studied, as will subscription and policy control schemes to supervise services in an energy-aware manner.

Figure 2. Overview of key features for gNB energy efficiency control



Low power wake-up signal/receiver mechanisms

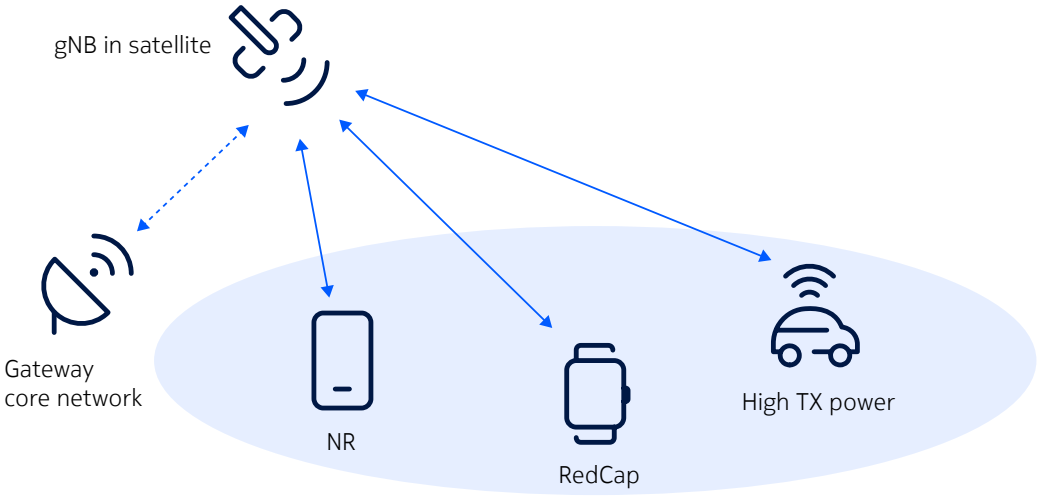
Earlier releases of 5G New Radio (NR) have introduced a number of UE power saving techniques, as outlined in another Nokia white paper [10]. Release 18 conducted a study of low-power (LP) wake-up signals (WUS) and wake-up receivers (WUR) for power-sensitive small-form-factor devices such as industrial sensors and consumer wearables; the objective is to offer additional UE power savings by providing a WUS that can be detected by a much lower power receiver than is needed to monitor current paging and downlink control signaling channels. The outcome of this study is captured in a 3GPP report [11]. In short, it was found that significant UE power saving gain can be achieved from LP-WUS/WUR so the work will continue in Release 19 with the specification of corresponding solutions. The solutions in Release 19 will be designed for at least radio resource control (RRC) Idle and Inactive modes, and, in addition to the LP-WUS itself, will include a new lower power synchronization signal (LP-SS) to allow the LP-WUR to maintain timing synchronization with the gNB and to perform serving cell RRM measurements without waking the main radio. The new LP-WUS signals are not expected to require hardware changes in the gNB, and the radio resource overhead is expected to be marginal.

Satellite connectivity

Recognizing that satellite connectivity can complement terrestrial networks in delivering truly global coverage, 3GPP introduced non-terrestrial network (NTN) solutions in Release 17. Integrated NTN support in cellular networks will help to bridge the digital divide by connecting underserved areas as well as enabling global tracking and monitoring services.

Evolution of NTN Release 19 will include regenerative architectures that place base station functionality on the satellites. This will improve link performance and reduce latency in 5G-Advanced NTNs and enable store-and-forward satellite operation for delay-tolerant IoT NTN applications. This work will include identifying the minimum necessary set of CN functions to be on the satellite for both NR NTN and IoT-NTN (the latter being based on NB-IoT and the evolved packet system (EPS)). Other NTN enhancements in Release 19 will address downlink and uplink coverage and uplink capacity as well as ensure that reduced capability (RedCap) devices can incorporate NTN support. Figure 3 pictures some of those expected NTN use cases and schemes that are anticipated to be addressed in Release 19. For a deeper dive into global coverage of 3GPP NTN solutions, see this Nokia white paper [12].

Figure 3. Simple illustration of some of the expected NTN use cases and schemes



UAV and UAM enablers

3GPP has already standardized several enablers for cellular networks to serve uncrewed aerial vehicles (UAV) as outlined in this Nokia white paper [13]. Interest is also growing in urban aerial mobility (UAM) schemes, which aim to provide sustainable air transportation for passengers and cargo in urban environments, either remotely piloted or with a pilot on board.

In order to meet requirements from aviation fora, 3GPP will study, in Release 19, how network exposure function (NEF) services may be enhanced to support service exposure and interactions between MNOs and UAV traffic management (UTM) functions, e.g., for pre-mission flight planning and in-mission flight monitoring. Network-assisted/ground-based mechanisms for detect and avoid (DAA) will be studied.

Potential enhancements to the application layer architecture will also be studied in Release 19. This will cover aspects of real-time UAV connection status monitoring and reporting, as well as communications between UAVs within the same area. Studies of redundancy, reliability, and application layer service continuity of command and control (C2) traffic for UAVs are also in the scope of Release 19.

All of these enhancements will help make 5G-Advanced fully mature for UAV/UAM use cases and better integrated with UTM.

Architecture and operational efficiency

Release 19 keeps evolving and introduce features to help operators to achieve new efficiencies and optimizations. The suite of self-organizing/-optimizing network (SON) features and the minimization of drive test (MDT) mechanism will continue to evolve in Release 19 to enable support for new functionalities introduced in Release 18. As a few examples, Release 19 will cover mobility robustness optimizations (MRO) for the new Release 18 mobility features such as lower layer triggered mobility (LTM) and conditional handover with candidate secondary cell groups (SCGs). Specifications may include new inter-node information exchange and UE reporting enhancements to facilitate tuning of mobility parameters, as well as intra-NTN mobility and network slicing. These SON/MDT enhancements add to the suite of features that help boost the operational excellence of 5G-Advanced and ease deployment of new features in the network.

Release 18 studied the system architecture for real-time communication services based on IMS enhancements (mainly support of IMS data channel). In Release 19, further improvements to support IMS data channel will be considered. These will include:

- Study support for interworking between devices supporting IMS data channel and devices that do not support IMS data channel
- Enhancements to operational aspects, e.g., IMS data channel without audio/video media
- Exposure of IMS services in the context of IMS data channel to third parties
- Enable IMS based avatar calls and transcoding between avatar and video media.

These types of enhancements are anticipated to offer new business opportunities to operators as they allow network capabilities to be exposed to application service providers, easier introduction of data channel applications, new applications (e.g. gaming) to be offered to end consumers without the need to establish an audio/video session first, and enriching traditional video calls by using any kind of avatars selected by the end user.

Release 19 will further enhance edge computing, building on foundations from previous 5G and 5G-Advanced releases. Release 19 will reduce the impacts to 5GC control plane functions for edge hosting environment (EHE) information management and bring further optimizations for edge application server (EAS) discovery.

Release 19 will also include edge enabler layer (EEL) enhancements, with the aim of specifying solutions for federation, roaming and edge node sharing scenarios, as requested by operator groups in GSMA.

Furthermore, it is beneficial for a device to apply traffic steering and/or switching between two 3GPP access networks connected to the same or different public land mobile networks (PLMNs). Release 19 will therefore study potential architecture and function enhancements to support such DualSteer devices, including use cases such as a single UE with non-simultaneous data transmission over the two networks, or two UEs with simultaneous data transmission over the two networks.

256-bit security algorithms

Quantum computing poses a long-term threat to information security not only for current data but, also, for historic data that may have been collected for future decoding. While symmetric key algorithms are not as susceptible as public key algorithms to the processing power of quantum computing, 256-bit algorithms should be developed now in preparation for possible adoption. Corresponding algorithms have been developed and evaluated by the ETSI SAGE (Security Algorithms Group of Experts) at 3GPP's request.

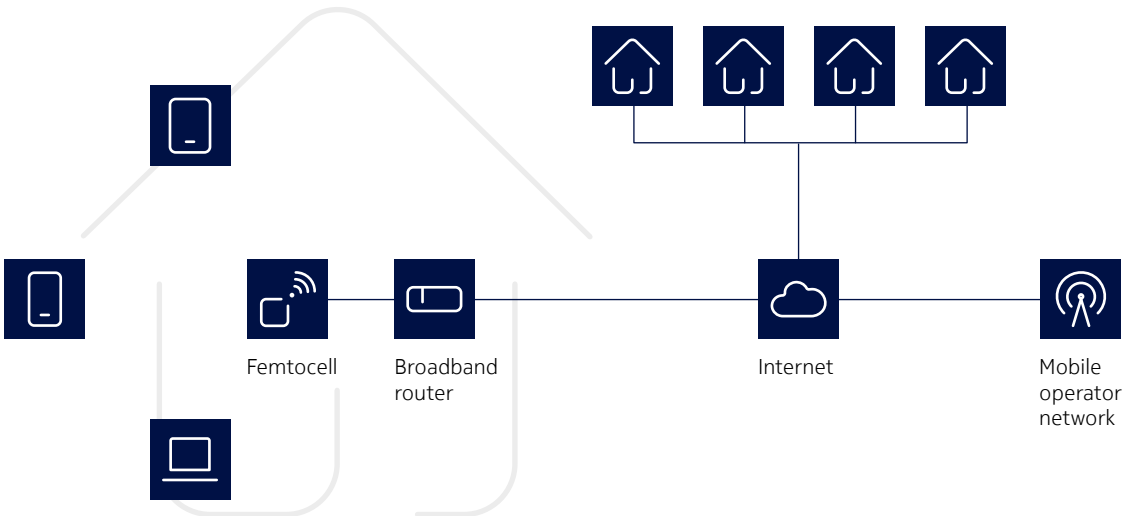
Release 19 will aim to have 256-bit confidentiality and integrity algorithms for the air interface published, with Nokia as rapporteur. In addition to the algorithms for confidentiality and integrity protection, an authenticated encryption with additional data (AEAD) mode will be introduced.

Topological enhancements

Two new network topologies will be introduced in Release 19: 5G femtocells and wireless access backhaul (WAB).

A 5G NR femtocell can be used to improve 5G indoor coverage, offloading traffic from the macro network, as pictured in Figure 4. The work on femtocells will include access control mechanisms, and how to enable access to local services from the femtocell via a co-located local UPF. The Release 19 5G NR set-up of a 5G femtocell should be plug-and-play, with the owner of the femtocell being in control of who can use it.

Figure 4. Simple illustration of a deployment with an indoor Femtocell



WAB is intended, as an example, for vehicle mounted relay scenarios and aims to address gNB mobility within a stationary RAN in proximity to other mobile gNBs. This will involve managing issues of dynamic inter-gNB neighbor relations via inter-gNB and gNB-to-CN signaling.

Mission-critical services for railways

The work on railway specific enhancements for mission-critical cases will continue in Release 19 with Nokia as rapporteur in handling application enablement and critical communication applications. This work is continued from Release 18 to ensure that mission-critical (MC) interconnection, migration, land mobile radio (LMR) system interworking, ad hoc group communication, and gateway UE functionality fully address the needs of railway communications. This includes interworking with GSM-R to specify the architecture and procedures to support interworking with GSM-R for mission-critical push-to-talk (MCPTT) private calls, and ad hoc voice groups and the exchange of small data messages.

For emergency situations, additional ad hoc group communication functionalities are required, e.g., multi-talker support and subsequent voice group calls. Further enhancements to the existing architecture and procedures to support MC gateway UEs, e.g., migration, interconnection, support of multiple gateway UEs per service, will also be considered.

In the RAN, Release 18 specified the ability for 5G NR to operate in dedicated spectrum as narrow as 2.7 MHz to enable migration from GSM-R. Aggregation of such narrow carriers with other bands is expected to be completed in Release 19, providing the full RAN functionality necessary for critical rail communications and signaling.

With such enhancements anticipated for Release 19, the standard is ready for initial deployments as it covers all must-have functions requested by International Union of Railways for the future railway mobile communication system (FRMCS).

Enablers towards 6G

5G-Advanced will be also an important step towards 6G in several technical areas as will be described in more detail in the next sections.

Accelerated support for AI/ML

An extensive study of air interface AI/ML enablers for the lower radio layers (PHY and MAC) of 5G-Advanced was undertaken in Release 18. That study focused on the use cases of CSI compression/prediction, positioning, and beam management. Using AI/ML for beam management and positioning is now being taken forward to be standardized in Release 19, including a generic framework in support of AI/ML for one-sided models – i.e., models that are trained either by the UE or by the base station but not both. This framework will enable the overall management of ML inference, performance monitoring, data collection for inference and monitoring, functionality selection, activation and deactivation, switching, and fallback to conventional operation. This includes generic lifecycle management (LCM) signaling as reported in this Nokia blog [14].

Proper specification of related RAN performance requirements and test cases will be of paramount importance for air interface AI/ML features to become a reality. A new framework of performance requirements will, therefore, be included to ensure that AI/ML always brings improvements, and, if performance cannot be guaranteed (e.g., due to insufficient training for certain scenarios), it will fall back to conventional operation.

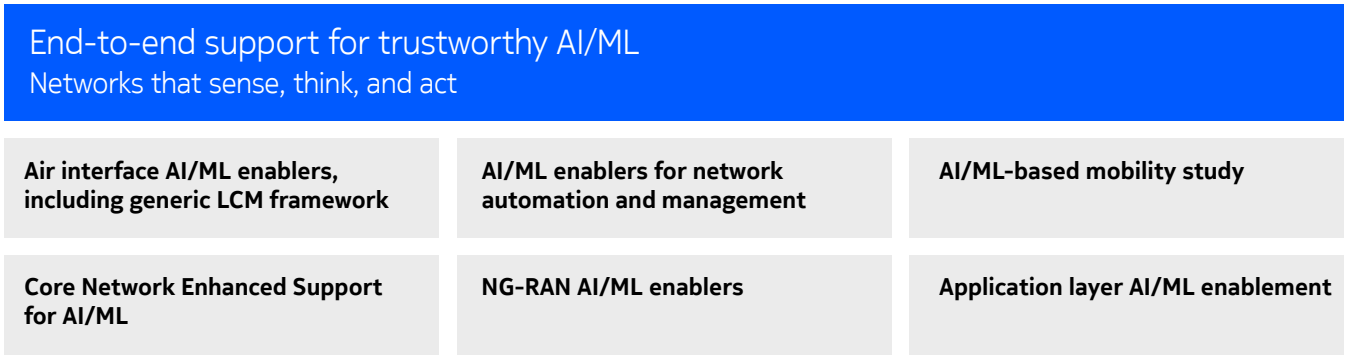
Release 19 will also include a new study of AI/ML based mobility, focusing on L3-based handover optimization. This may include aspects of cell-level measurement predictions, handover and radio link failure predictions, interruption time predictions, and target cell predictions, all with the purpose of improving the overall mobility performance and enabling better end-user experience. The study will also include potential forecasting of the RRM measurements for inter-frequency/inter-RAT cells.

At the NG-RAN architecture level, Release 19 is set to study further AI/ML enhancements for the existing NG-RAN interfaces and architecture (including both non-split and split architectures). This includes AI/ML for network energy saving enhancements, among others. At the system architecture level, work will be pursued to expand the scope of network AI/ML services to enable to enable 5GC support for air interface intelligence.

The 3GPP SA6 working group responsible for application enablement and critical communication application will focus on supporting additional application layer AI/ML enablement. First, this includes support for application-specific use cases, including vertical application layer (VAL), transfer, and distribution of training. Second, enhancing and potentially extending existing analytics enablement services will be considered. This includes studies of enhanced or new enablement capabilities for supporting ML model training and inference and federated learning in coordinated deployments of application and data analytics enablement services (ADAES). It also includes a possible study of whether and how digital twin modelling data at the network side can be utilized as part of the AI/ML model lifecycle.

Together, these enablers constitute AI/ML support at all layers, including RAN, CN and management layers. Nokia's ambition is to enable full end-to-end AI/ML support for networks that sense, think and act: sensing through collection of data and measurements, thinking as they learn, and acting through smarter beam management, mobility, and network parameter optimization. See the summary in Figure 5. It will result in better end-user experienced performance, more efficient overall network performance optimization and operation, as well as ease of deployment.

Figure 5. AI/ML enablers to aid full E2E AI/ML support



The 5G-Advanced Release 19 AI/ML specifications, and related studies, are expected to form a solid basis for the AI/ML in 6G, where AI/ML is envisioned to be an integral part from day one. Similarly, the simulation methodology for 5G-Advanced in Releases 18 and 19 is also expected to serve as a reference for the upcoming 6G studies.

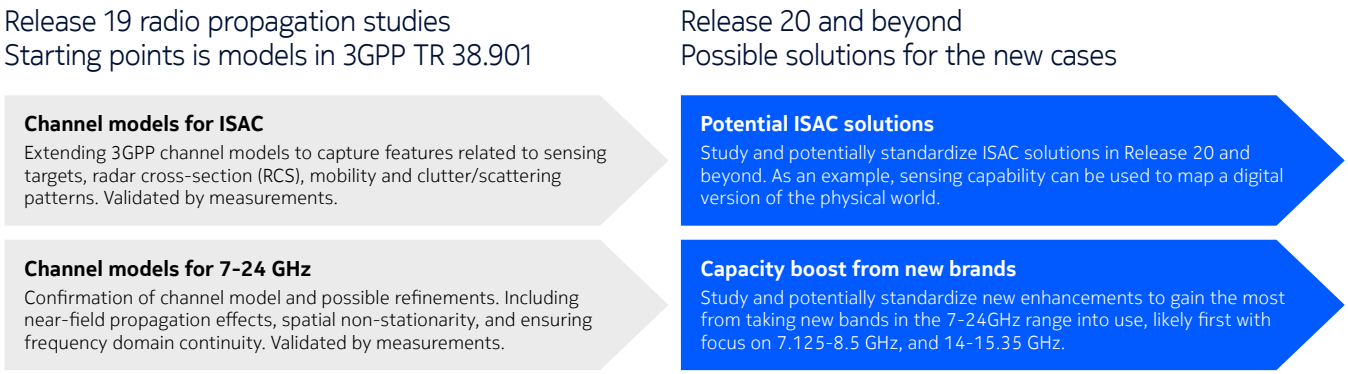
Channel modeling for new bands and use cases

At the ITU World Radiocommunication Conference 2023 (WRC-23), it was agreed to address allocation of new licensed spectrum for cellular mobile communications in the 6G era in the 7–15 GHz range (specifically 7.125–8.4 GHz and 14.8–15.35 GHz), which has the potential to provide substantial and much-needed additional capacity. In preparation, the current 3GPP radio channel model will be validated for these frequencies using radio channel measurements and, potentially, refined or expanded to fully reflect propagation effects in these bands. In particular, possible effects of near-field propagation and spatial non-stationarity are expected to be examined.

A further area where channel modeling studies will be undertaken is to support integrated sensing and communication (ISAC). This may in the future enable new “sensing as a service” applications, by using the radio signals to detect and/or track objects such as UAVs, intruders, and hazardous objects on roads and railways. ISAC falls under Expansions to offer new services beyond pure communication, hence, new business cases. A prerequisite for this is to have reliable and spatially consistent radio channel models that enable the radio characteristics of wanted and unwanted objects to be modeled and distinguished. Release 19 will therefore include a study of channel modeling for sensing, extending the existing 3GPP models to cover features such as radar cross-section (RCS), mobility of objects and clutter/scattering patterns.

The 5G-Advanced study of radio channel models for ISAC will lay the foundation for study of ISAC solutions in the 6G era. Figure 6 shows an overview of how the Release 19 channel modeling studies are projected to be used in future 3GPP releases for both 5G-Advanced and 6G studies.

Figure 6. Release 19 channel modeling studies and their projection to be used in future 3GPP releases for 5G-Advanced and 6G.



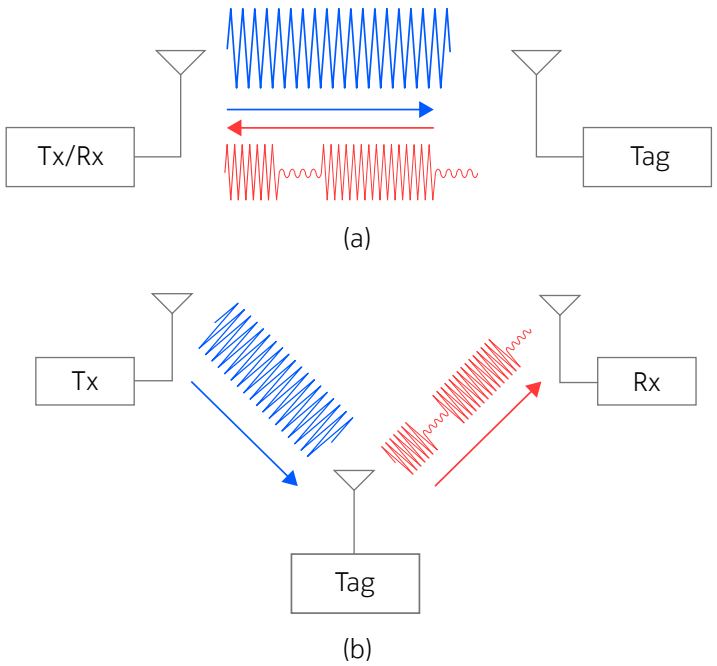
Ambient IoT

During Release 18 a study of ambient IoT was conducted, with further background information on ambient IoT appearing in this Nokia blog [15]. Unlike earlier IoT systems, ambient IoT devices have very limited energy storage capability and do not need a battery to be replaced or recharged manually. Proposed use cases for ambient IoT include object tracking for logistics purposes. The Release 18 Ambient IoT study came to the preliminary conclusion that ambient IoT is feasible and beneficial, so further working group level studies are recommended before proceeding to the normative standardization phase. Thus, Release 19 includes a second phase of more detailed ambient IoT studies to further assess the possible detailed solutions of 5G-Advanced ambient IoT. The Release 19 Ambient IoT study also includes work in other RAN and SA working groups, including system study by the system architecture working group. As per the Release 18 Ambient IoT recommendations, the study will focus on solutions for FR1 (frequency range one, up to 7.125 GHz) licensed FDD spectrum. The Release 19 Ambient IoT work will cover a larger variety of aspects such as device architecture and characteristics, physical layer design aspects, user- and control-plane protocols, security aspects, interaction between the RAN and CN, etc.
The focus will be on two types of devices:

- Device with ~1 µW peak power consumption and energy storage and without downlink or uplink amplification in the device. The device's uplink transmission is backscattered on a carrier wave provided externally.
- Device with not more than a few hundred µW peak power consumption and energy storage. Both downlink and/or uplink amplification may be possible in the device. The device's uplink transmission may be generated internally by the device or backscattered on a carrier wave generated externally.

Detailed performance studies will naturally be an important part of this, including link budget studies, coexistence studies, radio resource management performance, and more. Figure 7 shows the basic principles of (a) monostatic ambient IoT communication, where the same node acts as both illuminator and reader of an ambient IoT tag, and (b) bistatic ambient IoT communication, where the illuminator and reader nodes are different. Ambient IoT solutions studied in Release 19 are likely to be so-called G-agnostic so they may be equally relevant for both 5G-Advanced and 6G.

Figure 7. Ambient IoT options: monostatic (a) and bistatic/multistatic (b)



Flexible duplexing evolution

In Release 18, 3GPP started an extensive study of more flexible duplexing methods for unpaired bands. The study included performance assessment of potential enablers for dynamic time-division duplex (TDD) as well as sub-band full duplex (SBFD). The motivation for such techniques is to have better uplink coverage, capacity, and latency by allowing more flexible uplink resource configurations. This comes, however, with a cost and coexistence challenges.

SBFD allows concurrent uplink and downlink transmissions at one time instant at different frequency domain resources, as compared to TDD that allows exclusive uplink or downlink only at each time instant. Nokia, and other companies, showed possible performance improvements for dynamic TDD by introducing light inter-gNB coordination methods and interference mitigation mechanisms to combat the potentially strong gNB-to-gNB cross-link interference (CLI). Otherwise, the Release 18 feasibility study focused on SBFD, including aspects of multi-operator coexistence aspects. As an example, the left part of Figure 8 shows the SBFD/TDD frame structure and how adjacent carriers need to be aligned, while the right part of the figure pictures SBFD CLI links. The main observation from the Release 18 SBFD is that such solutions are feasible, offering some uplink gains under low to medium load conditions. However, building radios for SBFD for high power wide area gNBs comes with additional cost and complexity as it requires tunable RF filters at the receiver (Rx) panel to attenuate the gNB's own and other gNB's interference due to high transmitter (Tx) power.

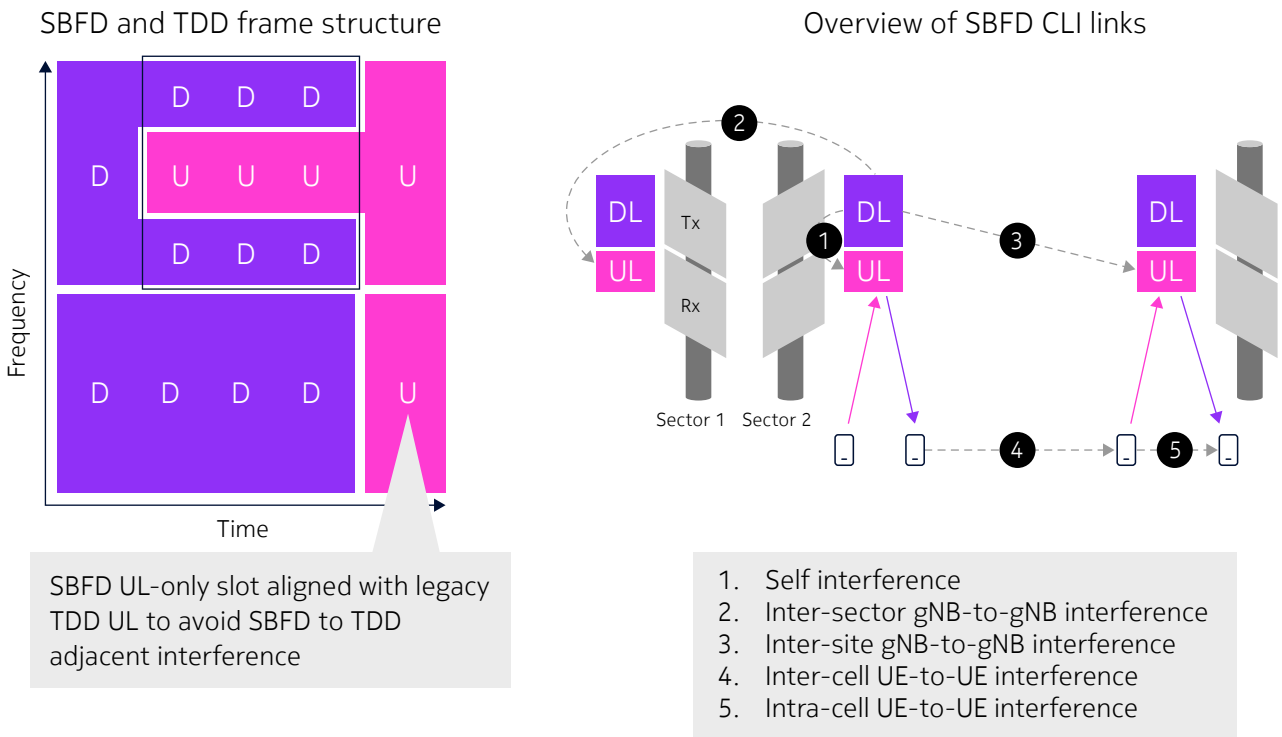
SBFD will be specified in Release 19. This will include indication to the UEs of time- and frequency-domain locations of SBFD sub-bands, UE transmission and reception behavior in SBFD symbols and/or non-SBFD symbols, enhancements to the frequency allocation for existing CSI-RS and physical downlink shared channel (PDSCH) signals to cope with the presence of concurrent UL and DL resource blocks, and RF and self-interference requirements for SBFD operation at gNB. It will also specify gNB-to-gNB CLI mitigation schemes as relevant for both SBFD and dynamic TDD use cases. The adjacent channel coexistence

between different operators should be considered for SBFD cases. It is likely that SBFD will not become mainstream before 6G, given the challenges for SBFD in 5G-Advanced, namely:

- gNB self-interference mitigation
- Adjacent channel coexistence
- Coexistence with legacy gNBs
- UEs not supporting SBFD.

Even with the arrival of 6G, gNB self-interference mitigation will continue to be a challenge in terms of hardware cost and potentially higher energy consumption.

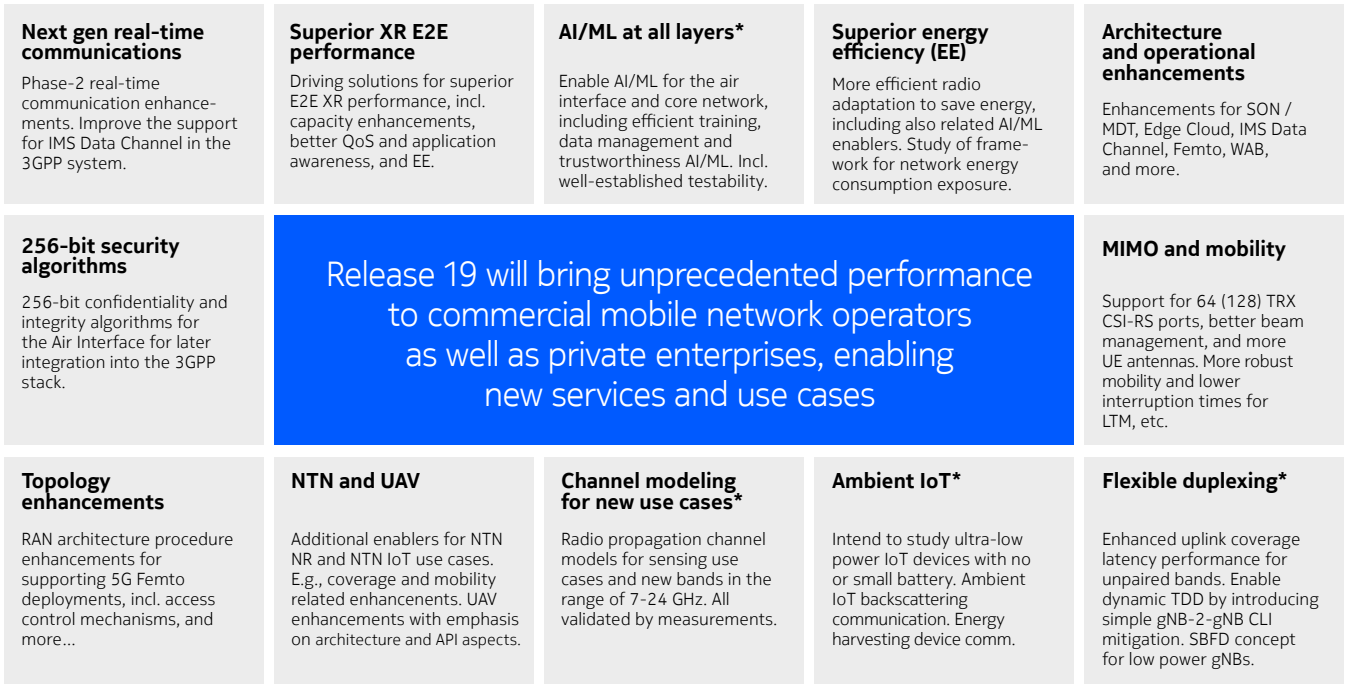
Figure 8. Overview of SBFD and TDD frame structures (left) and SBFD CLI links (right)



Summary

In this white paper we have outlined the scope of 5G-Advanced Release 19, the second release of 5G-Advanced. Release 19 will build on the foundation of 5G-Advanced Release 18 features and studies, as well as those from earlier 5G releases. Release 19 is also an important step towards 6G, as the work in this release will set the baseline and starting points for several of the studies expected to be part of 6G, i.e., paving the way for future 6G studies. Figure 9 summarizes the main features and studies for 5G-Advanced Release 19. It is evident that Release 19 will introduce new capabilities; it will bring unprecedented performance for mobile network operators and enterprises, ease deployment of networks, and generally offer more efficient network operation.

Figure 9. Summary of selected features and studies for 5G-Advanced Release 19



* Items that are bridging into the 6G-era.

At Nokia, we continue to actively contribute to the completion of 3GPP Release 18 by June 2024 and Release 19 by end of 2025. Nokia will take a prominent role in Release 19 with more than ten leader rapporteur roles, driving key differentiators such as XR, network energy efficiency, AI/ML at all layers, security, and enabling new special use cases, just to name a few. Nokia will also ensure that corresponding test cases and performance requirements are specified.

Abbreviations

3GPP	3rd generation partnership program
5GS	5G system
5QI	5G quality indicator
ADAES	Application and data analytics enablement service
AEAD	Authenticated encryption with additional data
AI	Artificial intelligence
C2	Command and control
CAG	Closed access group
CLI	Cross-link interference
CN	Core network
CSI	Channel state information
CQI	Channel quality indicator
DAA	Detect and avoid
DCCA	Dual-connectivity carrier aggregation
DL	Downlink
DRX	Discontinuous reception
DSS	Dynamic spectrum sharing
DTX	Discontinuous transmission
EAS	Edge application server
EE	Energy efficiency
EEL	Edge enabler layer
EHE	Edge hosting environment
EPS	Evolved packet system
ETSI	European Telecommunications Standards Institute
FDD	Frequency division duplex
FR1/2	Frequency range 1 (sub-7.125 GHz) / Frequency range 2 (24.25–52.6 GHz)
FRMCS	Future railway mobile communication system
gNB	5G new radio node B
GSMA	Global System for Mobile Communications Association
GSM-R	Global System for Mobile Communications – Railway
HST	High-speed train

IDC	In-device coexistence
IoT	Internet of things
IioT	Industrial IoT
IMS	IP multimedia sub-system
ISAC	Integrated sensing and communication
L1/2/3	Layer 1/Layer 2/Layer 3
LCM	Lifecycle management
LMR	Land mobile radio
LOS	Line-of-sight
LP	Low-power
LTE	Long term evolution
LTM	Lower layer triggered mobility
MAC	Medium access control
MC	Mission-critical
MCPTT	Mission-critical push-to-talk
MDT	Minimization of drive test
MIMO	Multiple-input, multiple-output
ML	Machine learning
MNO	Mobile network operator
MRO	Mobility robustness optimization
NB-IoT	Narrowband IoT
NEF	Network exposure function
NR	New radio
NTN	Non-terrestrial network
PDSCH	Physical downlink shared channel
PDU	Packet data unit
PLMN	Public land mobile network
PUSCH	Physical uplink shared channel
QoS	Quality of service
RAN	Radio access network
RAT	Radio access technology
RCS	Radar cross-section
RedCap	Reduced capability UE

RF	Radio frequency
RRC	Radio resource control
RRM	Radio resource management
RXRM	Real-time extended reality multimedia
RS	Reference signal
Rx	Receiver
SAGE	Security Algorithms Group of Experts
SBFD	Sub-band full duplex
SCG	Secondary cell group
SDT	Small data transmission
SDU	Service data unit
SON	Self-organizing/-optimizing network
SS	Synchronization signal
TDD	Time division duplex
TR	Technical report
TRP	Transmission reception point
Tx	Transmitter
UAM	Urban air mobility
UAV	Uncrewed aerial vehicle
UL	Uplink
UTM	UAV traffic management
VAL	Vertical application layer
WAB	Wireless access backhaul
WRC	World radio conference
WUR	Wake-up receiver
WUS	Wake-up signal

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