Ericsson White Paper
BNEW-22:024836 Uen
June 2022

ERICSSON

5G Advanced: Evolution towards 6G

Executive summary

The 5G evolution starting with Release 18 is called 5G Advanced. This paper provides an overview of 5G Advanced to show the advantages of its technology components with regard to network performance and capabilities. Guidance is provided on which features to expect in 5G Advanced and how those features enhance and enrich the already deployed 5G networks.

5G New radio (NR) and 5G core (5GC) evolution is continuing in 3GPP toward 5G Advanced, to ensure the success of 5G systems globally and to expand the usage of the 3GPP technology by supporting different use cases and verticals. AI/ML will play an important role in 5G Advanced systems in addition to other technology components providing support for extended reality (XR), reduced capability (RedCap) devices, and network energy efficiency. While Ericsson 5G networks already support AI/ML and XR use cases and requirements in an energy efficient manner, it is essential to enhance the 5G standards to improve multi-vendor support and provide better device and network cooperation. The 5G Advanced standardization is an important step in the evolution of cellular wireless access toward 6G.

Content

Introduction

3GPP Release 18 marks the start of 5G Advanced. 5G Advanced builds on the 5G baseline defined by 3GPP in Releases 15, 16, and 17.

5G networks have been deployed in large parts of the world. Thus, initial learnings have been derived from these commercial networks. In addition, the need for the continuous evolution of 5G networks by supporting new verticals and use cases has prompted 3GPP to begin standardization related to 5G Advanced systems. 5G Advanced also provides stepping stones in areas that will influence the future 6G system and thus bridge 5G with 6G.

This white paper provides an overview of 5G Advanced with a special focus on its most vital parts. The main technology components and their use cases are discussed with the goal of providing an overview of 5G Advanced and 3GPP's future direction toward 6G. 6G standardization may officially start from Release 21. Figure 1 provides Ericsson's view of the 5G Advanced and 6G timeline of 3GPP indicating completion of the first 5G Advanced drop in 2024 and completion of the first 6G drop in 2028, followed by 6G evolution.

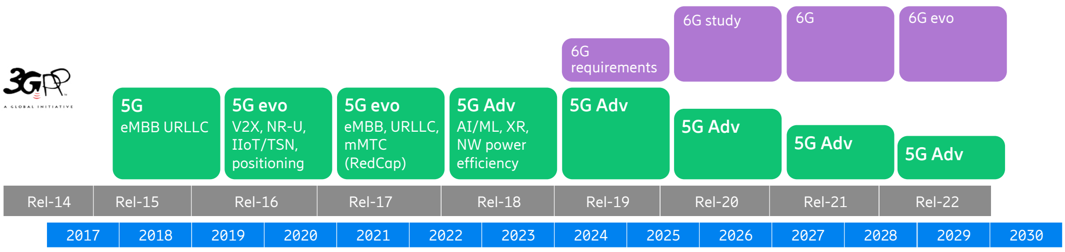

Figure 1: Ericsson's view of the 5G Advanced and 6G timeline of 3GPP (dates beyond 2023 are indicative)

3GPP technology evolution

Since its introduction in Release 15, 5G has targeted several main use case families, such as enhanced Mobile Broadband (eMBB), critical Internet of Things (IoT), and massive IoT. The 5G system (5GS) provides superior network performance in terms of capacity and coverage; enables many new use cases and support for new verticals compared to previous generations of 3GPP systems. In recent years, there are highly prioritized industry trends that calls for reduced carbon footprints, and that demands support for new use cases and vertical requirements such as immersive communication and private networks that all need to be addressed.

In addition, the already available commercial 5G deployments provide excellent learning on network performance. Many of the above-mentioned new trends and learnings from commercial 5G deployments demand further optimization of 5G systems, thus there is a need to define 5G Advanced systems in the coming releases. Release 18 will include both 5GS architecture enhancements and additional capabilities for new market segments.

eMBB refers mainly to smartphone devices and corresponding applications like web, app, email and video which rely on internet access. Some of these use cases require large amounts of data and are demanding on capacity. 5G NR addresses this by supporting different duplex schemes, frequency ranges, and multi-carrier operations. Ubiquitous coverage and seamless mobility have been essential components as have been the support for multi-antenna systems. These functionalities were already introduced in Release 15 and enhanced in subsequent releases. More functionalities were added in Releases 16 and 17 by standardizing solutions, for example, Integrated Access Backhaul (IAB), NR-U, broadcast and multicast, and non-terrestrial networks (NTN).

With 5G Advanced, eMBB features will also be further enhanced. UL data rate, capacity and coverage are for example expected to be improved. A novel duplexing scheme will be studied that allows simultaneously transmitting and receiving on the same TDD carrier. NR multi-hop solutions will be enhanced by mobile IAB nodes and network controlled repeaters. Dynamic spectrum sharing (DSS) enhancements that come with Release 18 will increase the NR performance, especially when fewer LTE devices share the DSS carrier in the future. Finally, mobility will be enhanced in Release 18 with a special focus on enabling faster handovers by leveraging lower layer functionality.

The 5GS architecture enhancements include, for example, enhancements for location services, edge computing, UE policy, and network slicing. In addition, extending the service-based architecture to the IMS multimedia telephony services will be studied in Release 18.

For new market segments, further enhancements for non-public networks, aerial systems and vehicles, and multicast-broadcast services will be addressed. Deterministic communication transmission delays are required for the industrial internet and will also be addressed by 5G Advanced.

Critical IoT (cIoT) refers to use cases with stringent requirements on latency and reliability. Some of the most prominent applications relate to factory automation and automotive use cases. 5G addressed these use cases from the very beginning by introducing support for fast scheduling, robust transmission schemes, and low latency feedback/retransmission protocols. They have been further enhanced in Releases 16/17, for example, through standardized support for Time Sensitive Networking (TSN), with further enhancements in Release 18 to support Deterministic Networking (DetNet). In Release 16, the NR sidelink was specified, which allowed 3GPP to embrace vehicle-to-vehicle and public safety use cases.

In Release 18, better support for drones and railways will be provided. Drones will benefit from enhanced measurements/reporting as well as from standardized aerial device identification. Railways and some utility use cases will benefit from an NR system that is able to operate in dedicated bands with less than 5-MHz bandwidth. Release 18 will also introduce enhanced support for XR applications. 5G support for massive IoT (mIoT) use cases was inherited from 4G in the form of LTE-MTC and NB-IoT, which already fulfilled all 5G mIoT requirements. These tracks were created in Release 13 and have evolved ever since. The latest addition was the support of mIoT for NTN in Release 17. The first NR-based optimizations for mIoT were introduced in Release 17 by standardizing NR RedCap, which is also considered one of 5G Advanced's most important features.

Some NR functionality is beneficial across different domains and not connected to a specific use only. For instance, NR got a lean design to make efficient use of energy, both on the network and the device side. While the UE energy savings were already considered in Release 17, in Release 18 further network energy saving is in focus.

NR has inbuilt management features, for example, to virtually partition the system into different slices or to collect various types of measurements for self optimization that will evolve in 5G Advanced. NR positioning, which is also beneficial in multiple use cases, was added in Release 16 and is being enhanced in Releases 17 and 18. Another Release 18 noteworthy functionality is the AI/ML features which will be further discussed in the next section.

5G Advanced features in detail

5G Advanced will enhance network performance and add support for new applications and use cases. This report is focusing on the following five important feature areas, where 5G Advanced is expected to bring significant enhancements:

- Intelligent network automation
- Extended reality (XR)
- Reduced capability (RedCap) NR devices
- Network energy savings
- Deterministic networking for IoT

Intelligent network automation

With increasing complexity in network design, for example, many different deployment and usage options, conventional approaches will not be able to provide swift solutions in many cases. It is well understood that manually reconfiguring cellular communications systems could be inefficient and costly.

Artificial intelligence (AI) and machine learning (ML) have the capability to solve complex and unstructured network problems by using a large amount of data collected from wireless networks. Thus, there has been a lot of attention lately on utilizing AI/ML-based solutions to improve network performance and hence providing avenues for inserting intelligence in network operations.

AI model design, optimization, and life-cycle management rely heavily on data. A wireless network can collect a large amount of data as part of its normal operations. This provides a good base for designing intelligent network solutions. 5G Advanced addresses how to optimize the standardized interfaces for data collection while leaving the automation functionality, for example, training and inference up to the proprietary implementation to support full flexibility in the automation of the network.

AI/ML for RAN enhancements

Three use cases have been identified in the Release 17 study item related to RAN performance enhancement by using AI/ML techniques. Selected use cases from the Release 17 technical report will be taken into the normative phase in the next releases. The selected use cases are: 1) network energy saving; 2) load balancing; and 3) mobility optimization.

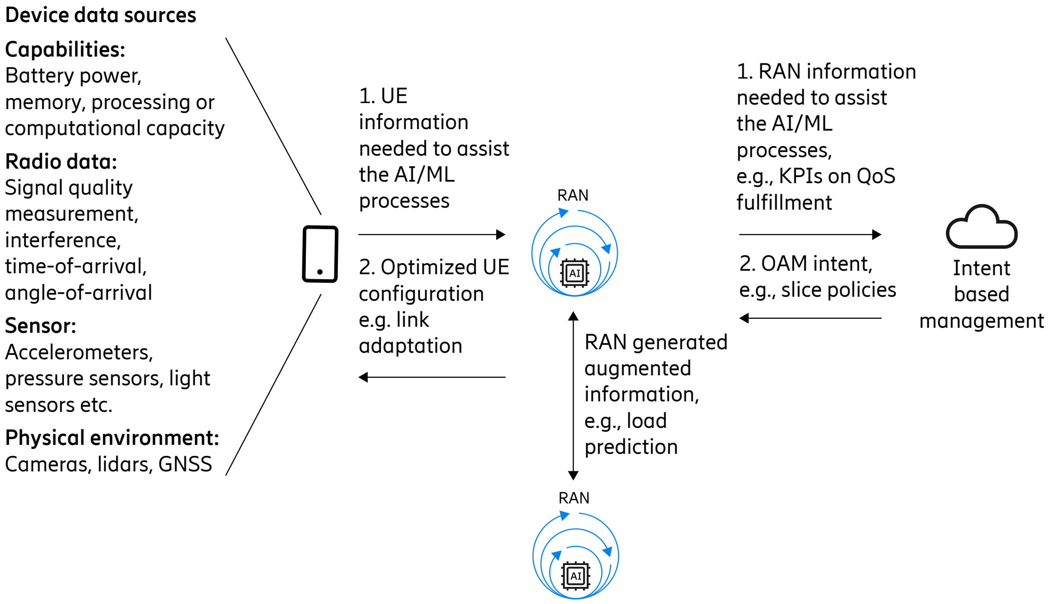

Figure 2 shows a general example overview of AI/ML use-cases in wireless RAN.

The selected use cases can be supported by enhancements to current NR interfaces, targeting performance improvements using AI/ML functionality in the RAN while maintaining the 5G NR architecture. One of the goals is to ensure vendor incentives in terms of innovation and competitiveness by keeping the AI model implementation specific. As shown in Fig.2 an intent-based management approach can be adopted for use cases involving RAN-OAM interactions. The intent will be received by the RAN. The RAN will need to understand the intent and trigger certain functionalities as a result.

AI/ML for physical layer enhancements

It is generally expected that AI/ML functionality can be used to improve the radio performance and/or reduced the complexity/overhead of the radio interface. 3GPP TSG RAN has selected three use cases to study the potential air interface performance improvements through AI/ML techniques, such as beam management, channel state information feedback enhancement, and positioning accuracy enhancements for different scenarios. The AI/ML-based methods may provide benefits compared to traditional methods in the radio interface. The challenge will be to define a unified AI/ML framework for the air interface by adequate AI/ML model characterization using various levels of collaboration between gNB and UE.

AI/ML in 5G core

5G Advanced will provide further enhancements of the architecture for analytics and on ML model life-cycle management, for example, to improve correctness of the models. The advancements in the architecture for analytics and data collection serve as a good foundation for AI/ML-based use cases within the different network functions (NFs). Additional use cases will be studied where NFs make use of analytics with the target to support in their decision making, for example, network data analytics functions (NWDAF)-assisted generation of UE policy for network slicing.

Extended reality

The 5G bounded-latency communication capabilities will enable a wide range of new applications including extended reality (XR) which refers to anything from virtual reality (VR) and augmented reality (AR) to mixed reality (MR). In AR, digital elements are added to a live view, usually with a camera on a smartphone or AR glasses. On the other hand, with VR one leaves the physical world and experiences complete virtual immersion. The new MR technology considers the interaction of both real-world and digital objects. In XR and Cloud Gaming (CG), with the assistance of handheld and wearable devices, either human-to-machine or human-to-human communications are performed.

There are many emerging new applications of XR in media, remote control and industrial automation, which will benefit from the time-critical capabilities of 5G networks. Mobile service providers can introduce XR to consumers, enterprises, and public institutions to define and improve new practices in areas such as entertainment, training, education, social interactions, and communications [ref: XR and 5G: Extended reality at scale with 5G networks, Ericsson Technology Review, August 2021].

The XR and CG use cases mainly require high data rates, for example, in downlink and uplink video streams. Also, the devices are usually expected to be mobile and with a small form factor, which puts a limitation on their power resources. Moreover, low and bounded end-to-end latency is another challenge in providing communication coverage for these applications. In 3GPP RAN Release 17, the performance of XR services when operating through 5G is extensively studied by looking through the vital parameters such as data rate and latency in these services. XR services typically comprise multiple data flows, for example, video, audio, and control. Flows are mainly periodic, but each has a different periodicity and packet size. It is of significant importance for having a satisfactory XR service experience to provide high data rate communication while maintaining low and bounded latency. If in addition to low latency, the low loss is also of importance, then Low Latency Low Loss for scalable throughput (L4S) can be used, allowing to prioritize latency over data rates in congested situations. The energy saving consideration of the device is also a challenge, which needs to be covered by the solution. In Release 18, the XR awareness in RAN and XR-specific traffic handling, power savings, and capacity improvements are all going to be studied. This is considered an important area, as there is a lot of interest in the industry with the advent of new AR/VR devices.

Reduced capability NR devices

The work on reduced capability (RedCap) UEs started in Release 17 and will continue in Release 18 to take the 5G Advanced IoT support to the next level. RedCap addresses Broadband IoT use cases [ref. Cellular IoT in the 5G era] and provides affordable connectivity, for example, to applications in the entertainment and transportation segments. Compared to earlier 4G based IoT technologies, RedCap brings the advantages of 5G NR and a high deployment flexibility thanks to the support for an unprecedented frequency range.

The Release 17 RedCap specifications provide a significant reduction in device modem cost. The lower cost is achieved by reduced modem complexity: a RedCap UE in frequency range 1 (FR1) can be equipped with single receiver and transmitter branches and support half-duplex operations in combination with 20-MHz operational bandwidth at most. This can be compared with an ordinary FR1 NR UE which may support up to four receiver branches, full-duplex operation, and 100-MHz bandwidth. For devices supporting frequency range 2, similar design relaxations are supported. Release 17 also specifies support for extended discontinuous reception (eDRX) in RRC Idle and RRC Inactive states. eDRX prolongs the configured paging periodicity and thus allows a RedCap device to power down for long periods and save power.

5G Advanced is expected to introduce support for further reductions in modem complexity and even leaner procedures for optimizing the device power consumption. By reducing the supported peak data rates the requirements on the protocol stack buffer sizes will be relaxed. Transport block size scaling is a straightforward and attractive approach for achieving this which is expected to be explored in Release 18.

Longer eDRX cycles for the RRC Inactive state and the so-called wake-up signal (WUS) are expected to be supported in 5G Advanced to optimize the time a device can spend in its most energy-efficient state. WUS is a compact signal tailored to indicate an incoming paging message and will reduce the amount of power a device spends on monitoring paging occasions.

5G Advanced will also introduce RedCap support for new use cases such as positioning. To keep the complexity low, RedCap positioning is expected to build on the already specified 5G positioning methods.

Network energy savings

From the start 5G was designed to meet increasing traffic demands while limiting the power consumption of mobile networks. With 5G Advanced the focus on network energy savings is further pronounced. The increasing energy consumption curve of mobile networks is neither sustainable from a cost or an environmental perspective. Breaking the energy curve is not only an option but an industry responsibility [ref: Breaking the energy curve, Ericsson, 2020].

Energy efficiency has always been an important part of 3GPP considerations by allowing smart sleep modes for mobile devices and exploiting lower bands to extend the coverage while increasing capacity and speed with carrier aggregation. However, now in Release 18, a dedicated study on network energy savings will be carried out. Key performance indicators, consumption models, and evaluation methodologies will be defined, and focus areas, potential techniques, and features for enabling network energy savings will be studied. Previously, similar work was performed in the area of user equipment (UE) power savings in Release 16 and 17. In the case of system level network energy savings, traffic load balancing and sleep mode for gNB are among the important factors to be studied in urban micro and macro scenarios with massive MIMO.

Deterministic networking for IoT

Industrial and Critical IoT has been an important 5G topic from the start. One example of an Industrial IoT use case is the media production and delivery which requires bounded low-latency IP communication. A framework of functionalities has been specified for 5G time-sensitive communication (TSC) supporting both Ethernet and IP, covering amongst others UE to UE communication through UPF, time synchronization, and 5G TSN integration. The latter enables 5GS to act as a managed Ethernet switch or managed Ethernet switches.

However, there is a demand to support deterministic networking (DetNet) for application areas requiring not only bounded low latency for IP but also low delay variation and extremely low loss. 5G Advanced will add support for DetNet IP flows in Release 18 based on the TSC Framework defined in Release 17 (see also Figure 3, where the top part shows the DetNet principle and the bottom part indicates the mapping to 5GS as a logical DetNet node).

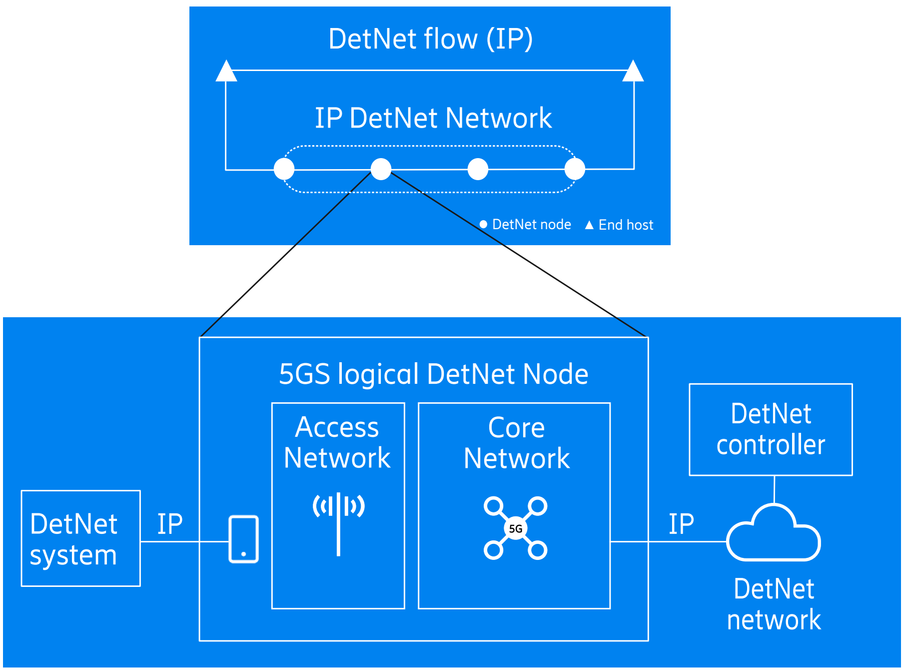

Figure 3: Deterministic Networking using IP for IoT (principles and mapping to 5GS)

Stepping stone toward 6G

5G systems are currently being deployed at a rapid pace, providing high-speed low-latency connectivity for a wide range of services. There is no doubt that the ongoing transformation will give rise to challenges beyond what 5G and 5G Advanced can meet. The increasing expectations set a clear target for those in the industry and research community—6G should contribute to an efficient, human-friendly, sustainable society through ever-present intelligent communication [ref: 6G – Connecting a cyber-physical world, Ericsson]. Nevertheless, several of the above-discussed 5G advanced technology components can be seen as precursors to some of the 6G building blocks. For example, XR will gradually evolve into immersive communication for human-machine interaction which may pose new requirements on 6G to provide an even better experience. In the area of machine-type communication, RedCap can be complemented by zero-energy devices, a class of devices harvesting energy from the surroundings and providing input to digital twins. AI/ML will also play an important role in the fully data-driven architecture of 6G and the intelligent network platform of the future.

Conclusion

The 5G evolution starting from Release 18 is branded 5G Advanced. As 5G Advanced builds on a baseline defined by Releases 15, 16, and 17, this new marker indicates the aggregated value of the 5G evolution from 2018 and onwards. In Release 18, there are both architecture enhancements and additional capabilities for new market segments.
5G systems are currently being deployed at a rapid pace, providing high-speed, low-latency connectivity for a wide range of services. New services will be introduced, for example, advanced XR services, which will further increase the expectations on network performance. Support for RedCap will widen the range of machine-type communication. Applications requiring real-time networking using IP will benefit from Deterministic Networking providing bounded low latency, low delay variation, and extremely low loss. To meet all these demands efficiently, service providers will increase the use of AI/ML and network automation while continuing the journey toward further reducing energy consumption. It is therefore important for 3GPP to focus on these areas as part of the 5G Advanced work while service providers prepare to leverage the benefits of 5G Advanced systems. These technology components are also important precursors to several 6G building blocks.

Authors

Imadur Rahman joined Ericsson in 2008. Rahman is a master researcher in Research Area Radio at Ericsson Research in Stockholm, Sweden and is currently co-manager of the 5G Advanced standardization research project at Ericsson Research. Rahman holds a Ph.D. in wireless communications from Aalborg University, Denmark.

Olof Liberg joined Ericsson in 2008 and currently leads the company's 3GPP RAN standardization team. Liberg has an M.Sc. in engineering physics from Uppsala University, Sweden

Sara Modarres Razavi joined Ericsson in 2014 and is currently a master researcher and co-manager of the 5G Advanced standardization research project at Ericsson Research. Razavi holds a Ph.D. in infra informatics from Linköping University, Sweden.

Christian Hoymann joined Ericsson Research in 2007 and currently leads a research group at Ericsson Eurolab in Herzogenrath near Aachen, Germany. Hoymann holds a Ph.D. in electrical engineering from RWTH Aachen University.

Stefan Parkvall joined Ericsson Research in 1999 and is currently a senior expert based in Stockholm, Sweden. Parkvall holds a Ph.D. in electrical engineering from the Royal Institute of Technology, Sweden, and is an IEEE Fellow.

Göran Rune joined Ericsson in 1989 and is currently a principal researcher in system and network architectures. Rune holds a Lic. Eng. in solid state physics from the Institute of Technology at Linköping University.

Ralf Keller joined Ericsson in 1996 and is an expert in core network migration. His current focus is on packet core architecture and technology in his role as Chief Architect. Keller holds a Ph.D. in computer science from the University of Mannheim in Germany.

Patrik Persson joined Ericsson in 2007 and is currently a 6G program manager director. Persson holds a Ph.D. in electrical engineering from KTH Royal Institute of Technology, Sweden.