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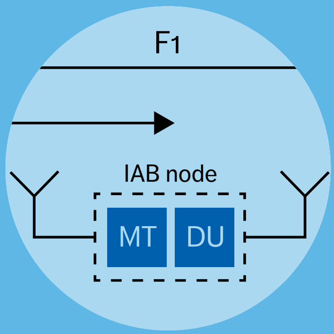
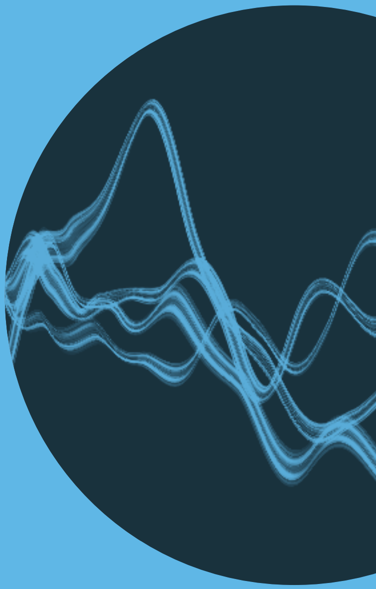
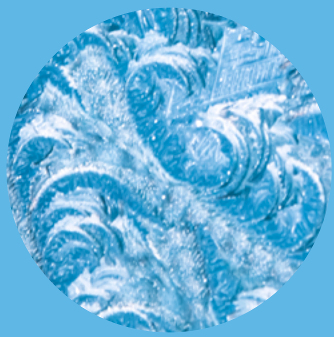
ERICSSON TECHNOLOGY Review





5G NEW RADIO EVOLUTION



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5G evolution:

3GPP RELEASES 16 & 17 OVERVIEW

The enhancements in the 3GPP releases 16 and 17 of 5G New Radio include both extensions to existing features as well as features that address new verticals and deployment scenarios. Operation in unlicensed spectrum, intelligent transportation systems, Industrial Internet of Things, and non-terrestrial networks are just a few of the highlights.

JANNE PEISA,
PATRIK PERSSON,
STEFAN PARKVALL,
ERIK DAHLMAN,
ASBJØRN GRØVLEN,
CHRISTIAN HOYMANN,
DIRK GERSTENBERGER

According to the latest Ericsson Mobility Report, global traffic levels hit 38 exabytes per month at the end of 2019, with a projected fourfold increase to 160 exabytes per month expected by 2025 [1]. Fortunately, the 5G system is designed to handle this massive increase in data traffic in a way that ensures superior performance with minimal impact on the net costs for consumers.

The evolution of 5G New Radio (NR) has progressed swiftly since the 3GPP standardized the first NR release (release 15) in mid-2018. Not only is release 16 nearly finalized but the scope of release 17 has also recently been approved. Making wise decisions in the months and years ahead will require that mobile network operators and other industry stakeholders have a solid understanding of both releases.

NR development started in release 15 [2] [3] with the ambition to fulfill the 5G requirements set by the ITU (International Telecommunication Union) in IMT-2020 (International Mobile Telecommunications-2020). The overall design consists of several key components. The extension to much higher carrier frequencies is an important one due to the continuing demand for more traffic and higher consumer data rates and the associated need for more spectrum and wider transmission bandwidths. The ultra-lean design of NR enhances network energy performance and reduces interference, while interworking and LTE coexistence will make it possible to utilize existing cellular networks. The forward compatibility of NR design will ensure that it is prepared for future evolution. Low latency is also critical to improve performance and enable new use cases. Extensive usage of beamforming and a massive number of antenna elements for data transmission and for control-plane procedures are also notable components of NR design.

Figure 1 shows the time plan for the evolution of NR over the next few years. Release 16, the first step in the NR evolution, contains several significant extensions and enhancements. Some of these are extensions/improvements to existing features, while others are entirely new features that address new deployment scenarios and/or new verticals.

5G NR release 16 – enhancements to existing features

The most notable enhancements to existing features in release 16 are in the areas of multiple-input, multiple-output (MIMO) and beamforming enhancements, dynamic spectrum sharing (DSS), dual connectivity (DC) and carrier aggregation (CA), and user equipment (UE) power saving.

Multiple-input, multiple-output and beamforming enhancements

Release 16 introduces enhanced beam handling and channel-state information (CSI) feedback, as well as support for transmission to a single UE from multiple transmission points (multi-TRP) and full-power transmission from multiple UE antennas in the uplink (UL). These enhancements increase throughput, reduce overhead, and/or provide additional robustness [4]. Additional mobility enhancements enable reduced handover delays, in particular when applied to beam-management mechanisms used for deployments in millimeter (mm) wave bands [5].

Dynamic spectrum sharing

DSS provides a cost-effective and efficient solution for enabling a smooth transition from 4G to 5G by allowing LTE and NR to share the same carrier. In release 16, the number of rate-matching patterns available in NR has been increased to allow spectrum sharing when CA is used for LTE.

Dual connectivity and carrier aggregation

Release 16 reduces latency for setup and activation of CA/DC, thereby leading to improved system capacity and the ability to achieve higher data rates. Unlike release 15, where measurement configuration and reporting does not take place until the UE enters the fully connected state, in release 16 the connection can be resumed after periods of inactivity without the need for extensive signaling for configuration and reporting [6]. Additionally, release 16 introduces aperiodic triggering of CSI reference signal transmissions in case of the aggregation of carriers with different numerology.

User equipment power saving

To reduce UE power consumption, release 16 includes a wake-up signal along with enhancements to control signaling and scheduling mechanisms [7].

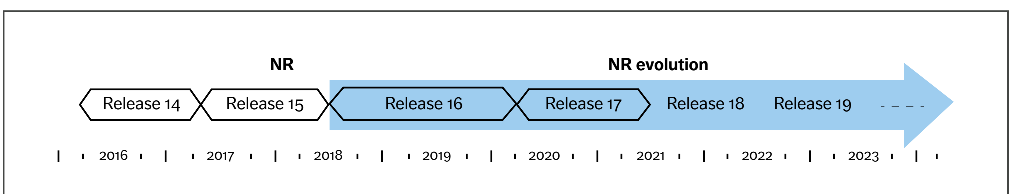

Figure 1 NR evolution time plan

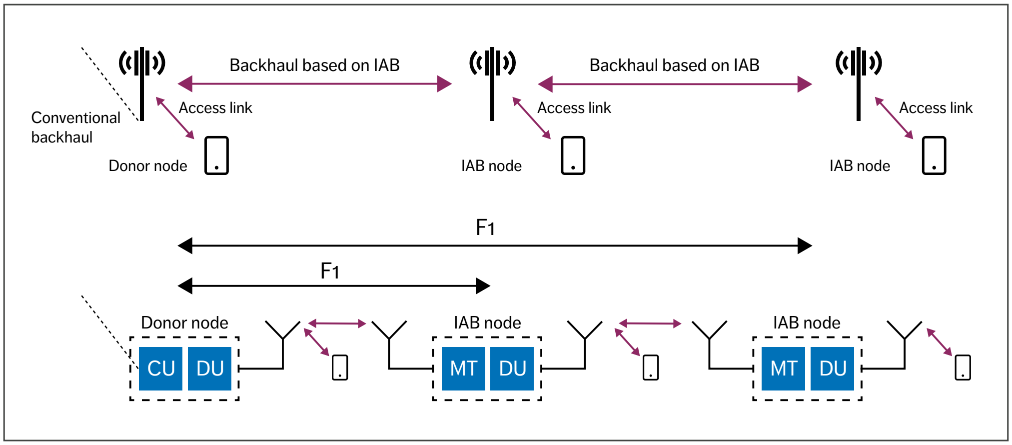

Figure 2 High-level architecture of IAB

5G NR release 16 – new verticals and deployment scenarios

The most notable new verticals and deployment scenarios addressed in release 16 are in the areas of:

- Integrated access and backhaul (IAB)
- NR in unlicensed spectrum
- Features related to Industrial Internet of Things (IIoT) and ultra-reliable low latency communication (URLLC)
- Intelligent transportation systems (ITS) and vehicle-to-anything (V2X) communications
- Positioning.

Integrated access and backhauling

IAB provides an alternative to fiber backhaul by extending NR to support wireless backhaul [8]. As a result, it is possible to use NR for a wireless link from central locations to distributed cell sites and between cell sites. This can simplify the deployment of small cells, for example, and be useful for temporary deployments for special events or emergency situations. IAB can be used in any frequency band in which NR can operate. However, it is anticipated that mm-wave spectrum will be the most relevant spectrum for the backhaul link. Furthermore, the access link may either operate in the same frequency band as the backhaul link (known as inband operation) or by using a separate frequency band (out-of-band operation).

Architecture-wise, IAB is based on the CU/DU split introduced in release 15. The CU/DU split implies that the base station is split into two parts – a centralized unit (CU) and one or more distributed units (DUs) – where the CU and DU(s) may be physically separated depending on the deployment. The CU includes the RRC (radio resource control) and PDC (packet data convergence) protocols, while the DU includes the RLC (radio link control) and MAC (multiple access control) protocols along with the physical layer. The CU and DU are connected through the standardized F1 interface.

Figure 2 illustrates the basic structure of a network utilizing IAB. The IAB node creates cells of its own and appears as a normal base station to UEs connecting to it. Connecting the IAB node to the network uses the same initial-access mechanism as a terminal. Once connected, the IAB node receives the necessary configuration from the donor node. Additional IAB nodes can connect to the network

through the cells created by an IAB node, thereby enabling multi-hop wireless backhauling.
The lower part of the figure highlights that an IAB node includes a conventional DU part that creates cells to which UEs and other IAB nodes can connect. The IAB node also includes a mobile-termination (MT) part providing connectivity for the IAB node to (the DU of) the donor node.

New Radio in unlicensed spectrum

Spectrum availability is essential to wireless communication, and the large amount of spectrum available in unlicensed bands is attractive for increasing data rates and capacity for 3GPP systems. To exploit this spectrum resource, release 16 enables NR operation in unlicensed spectrum, targeting the 5GHz and 6GHz unlicensed bands. It supports both standalone operation, where no licensed spectrum is necessary, and licensed-assisted operation, where a carrier in licensed spectrum aids the connection setup. This greatly adds to deployment flexibility compared with LTE, where only licensed-assisted operation is supported.

Operation in unlicensed spectrum is dependent on several key principles including ultra-lean transmission and use of the flexible NR frame structure. Both of these were included in release 15. Channel access mechanisms based on listen-before-talk (LBT) are probably the most obvious area of enhancement in release 16. NR largely reuses the same LBT mechanism as defined for Wi-Fi and LTE in unlicensed spectrum. Interestingly, it was demonstrated during standardization that replacing one Wi-Fi network with an NR network can lead to improved performance for the remaining Wi-Fi networks [9] as well as for the NR network itself.

Industrial IoT and ultra-reliable low-latency communication

The IIOT is a major vertical focus area for NR release 16. To widen the set of potential IIoT use cases and support increased demand for new use cases such as factory automation, electrical power distribution and the transport industry, release 16 includes latency and reliability enhancements that build on the already very low air-interface latency and high reliability [10] provided by release 15. Support for time-sensitive networking (TSN), where very accurate time synchronization is essential, is also introduced. *Figure 3* illustrates TSN integration in 5G NR.

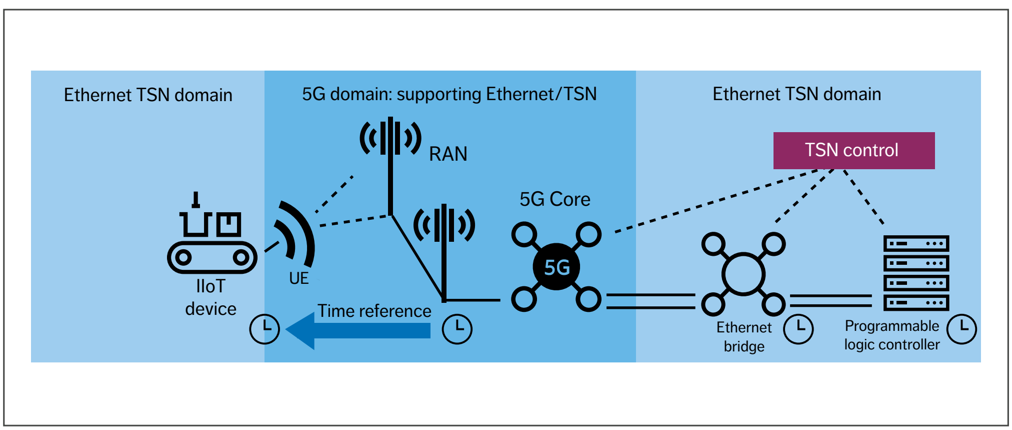

Figure 3 Overview of the TSN integration

Although many of the URLLC-related improvements are small in themselves, taken together they significantly enhance NR in the area of URLLC [11].

The inter-UE downlink (DL) preemption that is already supported in release 15 is extended in release 16 to include the UL, such that a UE's previously scheduled lower-priority UL transmission can be preempted (that is, cancelled) by another UE's higher-priority UL transmission. Release 16 also supports standardized handling of intra-EU UL resource conflicts.

To reduce latency, release 16 supports more frequent control-channel monitoring. Furthermore, for both UL configured grant and DL semi-persistent scheduling, multiple configurations can be active simultaneously to support multiple services. These enhancements are especially useful in combination with TSN traffic, where the traffic pattern is known to the base station.

> CURRENTLY, 25 USE CASES FOR ADVANCED V2X COMMUNICATIONS HAVE BEEN DEFINED

Intelligent transportation systems and vehicle-to-anything communications

ITS, which provide a range of transport and traffic-management services, are another major vertical focus area in release 16. Among other benefits, ITS solutions improve traffic safety as well as reducing traffic congestion, fuel consumption and environmental impacts. To facilitate ITS, communication is required not only between vehicles and the fixed infrastructure but also between vehicles. Currently, 25 use cases for advanced V2X communications have been defined, including vehicle platooning and cooperative communication using extended sensors [12].

In release 15, communication with fixed infrastructure is provided by the access-link interface between the base station and the UE. Release 16 adds the option of the NR sidelink (PC5), which can operate in in-coverage, out-of-coverage and partial-coverage scenarios, utilizing all NR frequency bands. It supports unicast, groupcast and broadcast communication, and hybrid automatic repeat request (hybrid-ARQ) retransmissions can be used for scenarios that require more robust communication. Groups can be either configured or formed, and the group members communicate using groupcast transmissions. A truck platoon, for example, could be configured using dedicated hybrid-ARQ signaling between the receivers and transmitter, or formed in a dynamic manner based on the distance between the transmitter and receiver(s).

Positioning

For many years, UE positioning has been accomplished with Global Navigation Satellite Systems assisted by cellular networks. This approach provides accurate positioning but is typically limited to outdoor areas with satellite visibility. There is currently a range of applications that requires accurate positioning not only outdoors but also indoors. Architecture-wise, NR positioning is based on the use of a location server, similar to LTE. The location server collects and distributes information related to positioning (UE capabilities, assistance data, measurements, position estimates and so on) to the other entities involved in the positioning procedures. A range of positioning methods, both DL-based and UL-based, are used separately or in combination to meet the accuracy requirements for different scenarios.

DL-based positioning is supported by providing a new reference signal called the positioning reference signal (PRS). Compared with LTE, the PRS has a more regular structure and a much larger bandwidth, which allows for a more precise

> THE ENHANCEMENTS… RELATE TO SPECIFIC NEW REQUIREMENTS THAT ARE EMERGING IN THE MARKET

correlation and time of arrival (ToA) estimation. The UE can then report the ToA difference for PRSs received from multiple distinct base stations, and the location server can use the reports to determine the position of the UE.

UL-based positioning is based on release 15 sounding reference signals (SRSs) with release 16 extensions. Based on the received SRSs, the base stations can measure and report (to the location server) the arrival time, the received power and the angle of arrival from which the position of the UE can be estimated.

The time difference between DL reception and UL transmission can also be reported and used in round-trip time (RTT) based positioning schemes, where the distance between a base station and a UE can be determined based on the estimated RTT. By combining several such RTT measurements, involving different base stations, the position can be determined.

5G NR release 17

The work items approved by the 3GPP in December 2019 will lead to the introduction of new features for the three main use case families: enhanced mobile broadband (eMBB), URLLC and massive machine-type communications (mMTC). The purpose is to support the expected growth in mobile-data traffic, as well as customizing NR for automotive, logistics, public safety, media and manufacturing use cases. The enhancements to existing features introduced in release 17 will be for functionality already deployed in live NR networks or relate to specific new requirements that are emerging in the market. The table presented in *Table 1* summarizes the scope of the enhancements to existing NR features in release 17, while the table in *Table 2* summarizes the scope of the new features.

Terms and abbreviations

CA – Carrier Aggregation | **CSI** – Channel-State Information | **CU** – Centralized Unit | **DC** – Dual Connectivity | **DL** – Downlink | **DSS** – Dynamic Spectrum Sharing | **DU** – Distributed Unit | **eMBB** – Enhanced Mobile Broadband | **FR1, FR2** – Frequency Range 1, 2 | **hyrbrid-ARQ** – Hybrid Automatic Repeat Request | **IAB** – Integrated Access and Backhaul/Backhauling | **IIoT** – Industrial Internet of Things | **IoT** – Internet of Things | **ITS** – Intelligent Transportation Systems | **LBT** – Listen-Before-Talk | **LTE-M** – LTE Machine-Type Communications | **MIMO** – Multiple-Input, Multiple-Output | **mMTC** – Massive Machine-Type Communications | **MT** – Mobile Termination | **MTC** – Machine-Type Communications | **Multi-TRP** – Multiple Transmission Points | **NR** – New Radio | **PC5** – Direct Mode Interface | **PRS** – Positioning Reference Signal | **RTT** – Round-Trip Time | **SON** – Self-Organizing Networks | **SRS** – Sounding Reference Signal | **ToA** – Time of Arrival | **TSN** – Time-Sensitive Networking | **UE** – User Equipment | **UL** – Uplink | **URLLC** – Ultra-Reliable Low-Latency Communication | **V2X** – Vehicle-to-Anything | **XR** – Anything Reality

eMBB feature	
IAB	• Addition of (limited) support for network topology changes • Improved duplexing of access and backhaul links (simultaneous operation on child and parent link, for example) • Routing enhancements
MIMO	• Improvements based on experience from commercial networks focusing on multi-beam operation mainly for frequency range 2 (FR2), support for multi-TRP deployment, SRSs, and CSI measurement and reporting
DSS	• Cross-carrier scheduling enhancements • Other scheduling enhancements
Coverage	• Enhanced wide-area coverage for both FR1 and FR2 (to be studied) • Focus on mobile broadband and voice services use cases, with the exception of the low-power wide area use case
Multi-radio dual connectivity	• More efficient activation/deactivation mechanism of secondary cells • Conditional primary-secondary cell change/addition
UE power saving	• Improved mechanisms in the area of discontinuous reception and blind decoding of control channels
Data collection	• Simplified deployment and enhancements to support self-organizing networks (SON) with improved data-collection mechanisms for SON and minimization of drive tests
QoE management and optimizations for diverse services	• Generic framework for triggering and configuring QoE measurement collection and reporting for various 5G use cases
URLLC feature	
IIoT and URLLC support	• Improved support for factory automation and URLLC, including physical layer feedback enhancements and enhancements for support of time synchronization • Identification of enhancements for URLLC/IIoT operation in controlled environments on unlicensed bands
Positioning	• Higher accuracy (horizontal and vertical) and lower latency, especially for IIoT use cases
Sidelink	• Focus on V2X, public safety and commercial use cases • Resource allocation enhancement • Sidelink discontinuous reception
RAN slicing (also relevant for the mMTC use case)	• Mechanisms to enable UE fast access to the cell supporting the intended slice • Mechanisms to support service continuity for intra-radio-access technology handover service interruption
mMTC feature	
Small data transmissions in inactive state	• Reduced overhead from connection establishment • Use cases: keep-alive messages, wearables and various sensors

Table 1 Summary of release 17 enhancements to existing features

eMBB feature	
Supporting NR from 52.6GHz to 71GHz	• Extended NR frequency range to allow exploitation of more spectrum, including the 60GHz unlicensed band • Definition of new OFDM (orthogonal frequency-division multiplexing) numerology and channel access mechanism to comply with the regulatory requirements applicable to unlicensed spectrum
Multicast and broadcast services	• Primarily targeted at V2X, public safety, IP multicast, software delivery and Internet of Things (IoT) applications
Support for multi-SIM devices	• Paging collision avoidance • Network notification when a UE switches networks
Support for non-terrestrial networks	• Support for satellites (especially Low Earth orbit and geostationary satellites) and high-altitude platforms as an additional means to provide coverage in rural areas
Sidelink relaying	• L2 versus L3 relaying (study and compare) • Scenarios include single-hop, UE-to-UE and UE-to-network relaying
URLLC feature	
Anything reality (XR) evaluations	• Evaluate needs in terms of simultaneously providing very high data rates and low latency in a resource-efficient manner • Intended to support various forms of augmented reality and virtual reality, collectively referred to as XR
mMTC feature	
Support of reduced-capability NR devices	• Targeted at mid-tier applications such as machine-type communications for industrial sensors, video surveillance, and wearables with data rates between Narrowband IoT/LTE-M data rates and "full" NR data rates • Addresses issues including complexity reduction, UE power saving and battery lifetime enhancement

Table 2 Summary of new functionality added in release 17

Conclusion

The enhancements in the 3GPP's releases 16 and 17 will play a critical role in expanding both the availability and the applicability of 5G New Radio to a wide range of new applications and use cases in both industry and public services. In order to make the details of these two releases more easily digestible, we have identified what we consider to be the most significant enhancements and grouped them into two categories: enhancements to existing features and features that address new verticals and deployment scenarios.

From Ericsson's point of view, the overall ambition of the NR evolution from a use-case perspective must be to ensure that 5G NR covers all relevant use cases to fulfill the vision of ubiquitous connectivity – that is, the ability to connect anything anywhere at any time. From a features perspective, we believe that the evolution of NR functionality must be driven by the goal of increasing efficiency and effectiveness when and where it is commercially justified.

Looking ahead, it is critical that the industry works together to ensure that NR is easy to deploy and operate, and that it continues to provide superior performance compared with competing technologies. We must also ensure that NR provides a high degree of energy efficiency on both the network and device sides, and that it retains its ability to coexist smoothly with LTE.

At Ericsson, we are convinced that the best way forward is for NR to continue to support all use cases from one platform, with a focus on forward compatibility, sufficient configurability and maximal simplicity. We must also work to avoid unnecessary updates in the network hardware and ensure that functionality is specified in a common way that benefits multiple use cases.

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Further reading

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- **A new standard for Dynamic Spectrum Sharing, available at:** *https://www.ericsson.com/en/blog/2019/6/dynamic-spectrum-sharing-standardization*
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THE AUTHORS

Janne Peisa

◆ has worked at Ericsson in the research and development of 3G, 4G and 5G systems since 1998. He is currently responsible for coordinating Ericsson's research on 5G evolution and beyond 5G activities. Previously, he coordinated Ericsson's RAN standardization activities in the 3GPP and led Ericsson Research's 5G program. In 2001, he received the Ericsson Inventor of the Year award. Peisa has authored several publications and patents and holds a Ph.D. in theoretical physics from the University of Helsinki, Finland.

Patrik Persson

◆ joined Ericsson Research in 2007 and currently serves as a principal researcher. Since 2014 he has been responsible for the Ericsson back-office work in the 3GPP RAN standardization of 4G and 5G. Prior to that, he worked extensively in the areas of antennas and propagation as well as proprietary development of LTE. Persson holds a Ph.D. in electrical engineering from KTH Royal Institute of Technology in Stockholm, Sweden.

Stefan Parkvall

◆ is a senior expert working with future radio access. He joined Ericsson in 1999 and played a key role in the development of HSPA, LTE and NR radio access. Parkvall has also been deeply involved in 3GPP standardization for many years. He is an IEEE (Institute of Electrical and Electronics Engineers) fellow and has coauthored several popular books, including 4G: LTE/LTE-Advanced for Mobile Broadband, and 5G NR: The Next Generation Wireless Access Technology. He has more than 1,500 patents in the area of mobile communication and holds a Ph.D. in electrical engineering from KTH Royal Institute of Technology.

Erik Dahlman

◆ joined Ericsson in 1993 and is currently a senior expert in radio-access technologies within Ericsson Research. He has been involved in the development of wireless-access technologies from early 3G to 4G LTE to 5G NR. He is currently focusing on the evolution of 5G as well as technologies applicable beyond 5G wireless access. He is the coauthor of the books 3G Evolution: HSPA and LTE for Mobile Broadband, 4G: LTE and LTE-Advanced for Mobile Broadband, 4G: LTE-Advanced Pro and the Road to 5G, and, most recently, 5G NR: The Next Generation Wireless Access Technology. Dahlman holds a Ph.D. in telecommunications from KTH Royal Institute of Technology.

THE AUTHORS

Asbjørn Grøvlen

◆ is a principal researcher in physical layer standardization who joined Ericsson in 2014. He currently works as Ericsson's technical coordinator for 3GPP RAN WG1 and has been involved in the standardization of wireless-access technologies from 3G to 4G LTE and 5G NR. His contribution to NR (5G) has been on initial access and mobility. Grøvlen holds an M.Sc. in electrical engineering from the Norwegian University of Science and Technology in Trondheim.

Christian Hoymann

◆ joined Ericsson Research in 2007 and currently leads a research group at Ericsson Eurolab in Aachen, Germany. His team focuses on standardization of 4G and 5G radio networks (Wi-Fi, LTE and NR). In addition, he heads up Ericsson's 3GPP RAN standardization delegation as the company's technical coordinator for 3GPP RAN. Hoymann holds a Ph.D. in electrical engineering from RWTH Aachen University, Germany.

Dirk Gerstenberger

◆ joined Ericsson in 1997 after earning a Dipl-Ing. in electrical engineering from Paderborn University in Germany. He is currently a manager at the Standards & Technology department within Business Area Networks at Ericsson, working with the evolution of radio-access standards and radio-network deployments. Gerstenberger led the radio-access standardization as head of Ericsson's RAN1 delegation and chairman of 3GPP RAN1 during standardization of 3G and 4G, and he was also engaged in industry initiatives leading to the standardization of 5G. He received the Ericsson Inventor of the Year award in 2008 and is named as the inventor in more than 100 patents.

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Ericsson
SE-164 83 Stockholm, Sweden
Phone: +46 10 719 0000