INVITED PAPER

5G Evolution and Beyond

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SUMMARY The paper provides an overview of the current status of the 5G evolution as well as a research outlook on the future wireless-access evolution towards 6G

key words: 5G evolution, NR evolution, 6G, future wireless access, future wireless networks

1. Introduction

3GPP has recently finalized Release 16 of the 5G “New Radio” (NR) radio-access specifications, something which can also be seen as the first step of the 5G evolution. In parallel, 3GPP has initiated the work on Release 17, further extending the performance and capabilities of 5G. Beyond that, initial discussions have already begun regarding 6G or sixth-generation wireless communication, at this stage focusing on fundamental drivers, basic capabilities, and potential key technology components. In this paper we provide an overview of this wireless-access evolution, covering the 5G evolution in Release 16/17 and the longer-term evolution towards 6G.

2. Current 5G status – Release 16

Release 16 includes several features that enhance the NR performance and/or extends NR with new/enhanced capabilities enabling it to expand towards new use cases. Here we will highlight some of these features. For a more detailed overview of NR Release 16, including details of the techniques described below, the reader is referred to [1] and [2].

NR-U – NR for unlicensed spectrum

Release 16 extends NR to also support operation in unlicensed spectrum, with focus on the 5 GHz (5.15 GHz to 5.925 GHz) and 6 GHz (5.925 GHz to 7.125 GHz) unlicensed frequency bands [3]. Although inherently less reliable compared to operation in licensed spectrum, the possibility to operate also in unlicensed spectrum, as a complement to operation in licensed spectrum, provides an opportunity to boost traffic capacity and achievable data rates in many scenarios.

In contrast to LTE for unlicensed spectrum [4], which only supports licensed-assisted access (LAA) where a carrier in unlicensed spectrum is always operated jointly with a carrier in licensed spectrum, NR supports both LAA and stand-alone operation in unlicensed spectrum, see Figure 1. Furthermore, in case of LAA, an NR carrier in unlicensed spectrum can operate together with either an NR carrier or a 4G LTE carrier in licensed spectrum.

Fig. 1 NR operation in unlicensed spectrum. License-assisted access (left/middle) and stand-alone operation (right)

The extension towards support for operation also in unlicensed spectrum was, to a large extent, taken into account already in the initial (Release-15) NR specifications, with the support of features such as ultra-lean transmission reducing the network “always-on” transmissions, a flexible frame structure allowing for transmissions over only a fraction of a slot, and dynamic TDD, that is, the possibility to dynamically assign time-domain resources to the downlink and uplink transmission directions respectively in case of TDD (Time Division Duplex) operation.

Nevertheless, certain features had to be introduced in NR Release 16 to fully enable efficient operation in unlicensed spectrum, most importantly new means for channel access. Two approaches for channel access in unlicensed spectrum have been defined as part of NR Release 16:

- Dynamic channel access relies on listen-before-talk (LBT), where the transmitter listens to potential

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transmission activity on the channel, applies a random back-off before transmission, and in general follows the same underlying principles as Wi-Fi channel access.

- **Semi-static channel access** does not use a random back-off but instead allows transmissions to start at specific points in time, subject to the channel being available. It specifically targets spectrum sharing with other NR-based transmissions in unlicensed spectrum and can be used if absence of any other technology can be guaranteed on a long-term basis, for example, through regulation or operation in a limited controlled area such as within a specific building.

**IAB – Integrated Access Backhaul**

Integrated Access Backhaul (IAB) [5] enables the use of NR also for the wireless backhaul link between network nodes, in addition to the conventional access link between the network and a device, see also Figure 2. IAB enables, for example, lower-cost and more rapid deployment of small cells by avoiding the need for fiber-based backhaul to all network sites.

IAB is based on the already in Release 15 introduced **CU/DU architecture** according to which a gNB\(^1\) is logically split into two parts

- A **Centralized Unit (CU)** including the PDCP and RRC protocols of the gNB\(^2\)
- One or several **Distributed Units (DUs)** including the RLC, MAC and physical-layer protocols\(^3\)

The CU and DU are connected by means of a 3GPP-specified interface, referred to as the **F1 interface**. The specification of F1 only defines the higher-layer protocols, for example, the signaling messages between the CU and DU, but is agnostic to the lower-layer protocols. In other words, it is possible to use different lower-layer mechanisms to convey the F1 messages.

Based on the CU/DU split, IAB specifies two types of network nodes, see also Figure 3.

- The **IAB donor node** consists of CU functionality and DU functionality and connects to the remaining network via conventional (non-IAB) backhaul, for example, based on fiber technology. A donor-node DU may, and typically will, serve devices like a conventional gNB, but will also serve wirelessly connected IAB nodes.
- The **IAB node** is the node relying on IAB for backhaul. It consists of DU functionality serving devices as well as, potentially, additional IAB nodes in case of multi-hop wireless backhaul. At its other side, an IAB node includes **Mobile Terminal (MT)** functionality providing device-like connectivity with the DU of the parent node of the IAB node. Note that the parent node can either be an IAB donor node or, in case of multi-hop backhauling, another IAB node.

From the above, it is clear that IAB can, in many ways, be seen as implementing the higher-layer F1 interface between a donor node CU and an IAB node DU over one or multiple NR radio links between a parent-node DU and a child-node MT. In other words, in case of IAB the NR radio-access protocols (RLC, MAC, PHY) serves as the lower-layer protocols that convey the F1 messages.

In most respects, the IAB link, that is, the link between a parent-node DU and a corresponding child-node MT, operates as a conventional network-to-device link. Consequently, the IAB-related extensions to the NR physical, MAC, and RLC layers are relatively limited and

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\(^1\) A gNB is, essentially, the 3GPP term for a base station

\(^2\) RRC (Radio Resource Control), PDCP (Packed Data Conversion Protocol), RLC (Radio Link Control), and MAC (Medium Access Control) refers to different layers in the 3GPP protocol stacks, see e.g. [1]
primarily deal with the need to coordinate the IAB-node MT and DUs for the case when simultaneous DU and MT operation is not possible due to self-interference within the IAB node.

Sidelink communication – Cellular V2X

The possibility for direct device-to-device (D2D) communication, also referred to as sidelink communication, was first introduced for LTE as part of 3GPP Release 12. It was subsequently extended in later LTE releases with specific focus on the vehicle-to-vehicle (V2V) use case, that is, direct communication between vehicles.

The first release of the NR specifications (Release 15) did not include support for sidelink communication. However, support for NR sidelink communication was introduced in Release 16 as part of a work item on V2X (Vehicle-to-Anything) [6]. The aim of this work item was to ensure that NR could provide the connectivity required for advanced V2X services, such as Vehicle Platooning, Extended Sensors, Advanced Driving and Remote Driving [7]. Although the work item was not limited to vehicle-to-vehicle communication, but also covered, for example, the vehicle-to-infrastructure communication relevant for the above use cases, the main part of the activities focused on the introduction of NR sidelink communication for the V2V use case.

It is important to understand though that 3GPP develops technology for communication but does not restrict the use of a certain technology feature to a specific use case. Thus, although the Release-16 NR sidelink was developed with focus on the vehicle-to-vehicle use case, this does not prevent the use of it for other applications for which sidelink transmission may be relevant.

NR sidelink supports three basic transmission scenarios

- **Unicast**, in which case the sidelink transmission targets a specific receiving device
- **Groupcast**, in which case the sidelink transmission targets a specific group of receiving devices
- **Broadcast**, in which case the sidelink transmission targets any device that is within the range of the transmission

There are two deployment scenarios for NR sidelink communication in terms of the relation between the sidelink communication and an overlaid cellular network, see also Figure 4.

- **In-coverage** operation, in which case the devices involved in the sidelink communication are under the coverage of an overlaid cellular network. The network can then, to smaller or larger extent, control the sidelink transmissions
- **Out-of-coverage** operation, in which case the devices involved in the sidelink communication are not within the coverage of an overlaid cellular network

One can also envision a partial-coverage scenario where only a subset of the devices involved in the sidelink communication is under network coverage.

![Fig. 4 Different sidelink deployment scenarios](image)

In case of in-coverage operation, the sidelink communication may share carrier frequency with the overlaid cellular network. Alternatively, sidelink communication may take place on a sidelink-specific carrier frequency different from the carrier frequency of the cellular network.

Furthermore, in case of sidelink communication under the control of a network, the network carrier may either be an NR carrier or a 4G/LTE carrier.

*Enhanced support for URLLC services*

URLLC or Ultra-Reliable Low-Latency Communication is one of the 5G service classes defined by ITU, the other two being enhanced Mobile Broadband (eMBB) and massive Machine-Type Communication (mMTC). As the name suggests, URRLC services are characterized by requirements on very low latency and very high reliability.

Low latency and high reliability have been supported already from the initial NR release (Release 15), for example, by means of

- Shorter slots and the possibility for transmission over only a part of a slot, the latter sometimes referred to as “mini-slot” transmission
Possibility for downlink inter-device pre-emption, that is, the possibility to interrupt an ongoing downlink transmission in favor of a more urgent transmission to the same or a different device.

Data duplication and multi-site connectivity as tools to increase reliability of the connectivity.

Release 16 introduced additional enhancements in terms of latency and reliability, especially targeting use cases such as factory automation, power distribution, and transport industry [8]. These enhancements included:

- Uplink inter-device pre-emption based on either explicit cancellation of an already scheduled lower-priority transmission or power boosting, that is, the use of relatively higher transmit power for a higher-priority transmission.

- Enhancements to downlink semi-persistent scheduling and uplink configured grants including lower minimum periodicity of semi-persistent scheduling and the possibility for multiple configurations for both semi-persistent scheduling and configured grants where certain logical channels can be restricted to only a subset of the configurations.

- Enhancements to uplink “mini-slot” transmission, in practice allowing for such transmissions to also cross slot borders (realized by repetition of shorter mini-slot transmissions).

In addition, Release 16 introduced support for time-sensitive networking (TSN), for which tight time synchronization between devices and very limited latency variations are important. More specifically, by receiving specific network messages indicating absolute transmission timing, together with knowledge of the propagation delay, the device can determine an absolute timing reference down to sub-\(\mu\)s levels, for example, within industrial sites.

**NR-based positioning**

NR Release 15 did not include any native support for positioning but relied on either independent techniques such as GPS or on the positioning capabilities of LTE.

To also enable downlink-based NR-native positioning, Release 16 introduced a new downlink Positioning Reference Signal (PRS) as well as new downlink measurements and corresponding device reporting of different parameters including:

- \(PRS-RSRP\) (Reference Signal Received Power), that is, the received power of a PRS,
- \(PRS\ RSTD\) (Reference Signal Received Power), that is, the relative time difference between the received PRS of two different cells,
- \(RX-TX\) (Reception-Transmission) time difference, that is, the time offset between downlink reception and uplink transmission at the device.

Likewise, in order to enable uplink-based positioning, Release 16 introduced new base-station measurements on the existing sounding reference signals (SRS), more specifically:

- \(SRS\ RSRP\)
- Relative time of arrival,
- Angle of arrival, assuming beam-forming at the base station receiver,
- Rx-Tx time difference at the base station.

The different measurements, for either downlink- or uplink-based positioning, are assumed to be reported to a Location Server that may implement different positioning algorithms including, for example, TDOA (Time-Difference-Of-Arrival) and AOA (Angle-Of-Arrival).

**3. Next step of the 5G evolution - Release 17**

Currently, the main radio-access-related activity within 3GPP is on NR Release 17. The content on Release 17 was decided on in December 2019 but, due to the Covid-19 pandemic and its impact on 3GPP, work on Release 17 has just recently (as of fall of 2020) started with an expected finalization date of spring of 2022. Below, some of the main Release 17 features are summarized.

**Spectrum beyond 52.6 GHz**

The first releases of NR (Release 15/16) support operation in spectrum up to 52.6 GHz. As part of Release 17 this will be extended to operation up to 71 GHz, a spectrum range including, for example, the unlicensed 60 GHz band (57–66 GHz) and the recently identified 66–71 GHz band. The extension to higher frequency bands will include the introduction of one or several new NR numerologies with higher subcarrier spacing, and related timing aspects. The work item will also consider other
physical-layer procedures and protocol aspects that may be required to enable operation in unlicensed bands above 52.6 GHz.

Extensions to IAB

As outlined above, IAB was first introduced in NR Release 16. Release 17 will include extensions to IAB targeting enhancements in terms of robustness, spectral efficiency, latency, and end-to-end performance.

One objective of IAB Release 17 is to introduce extended possibilities for multiplexing transmissions between the backhaul and access links, that is, simultaneous DU and MT operation, within an IAB node. Especially, Release 17 is expected to introduce enhanced support for simultaneous transmission (Tx) and/or simultaneous reception (Rx) between the MT and DU, see Figure 5. 3GPP is also considering simultaneous MT-Rx/DU-Tx and simultaneous DU-Rx/MT-Tx, often referred to as IAB-node full duplex.

These multiplexing options, which can improve IAB efficiency and reduce the overall latency, are at least partly already possible with Release 16 IAB. However, some additional features—like new timing relations between the DU and MT part of an IAB node, for example, to align the DU and MT transmission timing—will further extend the applicability and ease implementation of these multiplexing combinations.

The Release-17 IAB extensions also include extended means for topology adaptation, that is, adaptation of parent/child-node relations, to enable enhanced backhaul robustness, as well as more general topology, routing, and transport enhancements for improved IAB efficiency.

More general sidelink

As described above, Release 16 introduced the possibility for sidelink (device-to-device) communication in NR with focus on the V2X use case. Further extensions to NR sidelink communication are pursued as part of Release 17. The scope of these extensions includes, for example, reduced device energy consumption during sidelink operation and enhanced reliability and reduced latency for sidelink communication for URLLC type of applications.

In parallel to these general sidelink enhancements, 3GPP will also carry out studies on sidelink-based relaying, that is, the use of device-to-device communication as a way to extend the network coverage outside the area directly covered by the network infrastructure.

Reduced-capability devices

The basic massive-MTC use cases, characterized by requirements on very low device cost and very low device energy consumption in combination with wide-area coverage, can be very well provided by means of LTE-based eMTC and NB-IoT (Narrow-Band-IoT) [9] also in the 5G era. However, there are other use cases that require lower device complexity and reduced device energy consumption and, at the same time, have higher requirements in terms of, for example, data rates and latency compared to what can be provided with the LTE-based massive-MTC technologies.

To address such use cases, work on reduced-capability devices is part of Release 17. The intention is not to replace eMTC/NB-IoT, but rather to provide a complement filling a possible hole in terms of IoT support between the LTE-based technologies for massive MTC and the URLLC support currently provided by NR, see also Figure 6.
decodings for control-channel detection and by extending the DRX (Discontinuous Reception) functionality.

4. Further evolution towards 6G

Looking even further into the future, the evolution of mobile communication will undoubtedly continue and will eventually enter a 6G or sixth-generation era. It is yet unclear if 6G will imply a completely new radio-access technology or be based on a more long-term evolution of the currently available technologies. As of today, the best definition of 6G wireless access is probably that it corresponds to the overall wireless-access solution available from around the 2030, following the trend of a new generation of wireless-access technology roughly every ten years.

Also, the technical details of such a 6G wireless-access solution is still very open, as is the scope and structure of a future 6G system. Currently, the activities on 6G wireless access are focusing on

- Creating an understanding of the main drives for the future 6G wireless-access network and the corresponding capabilities that such a network should possess
- Identifying key technology components that can be used to realize the envisioned 6G capabilities.

Below we provide an overview of our current view on this wireless-access evolution towards 6G. For more information, see [10].

4.1 Key drivers for the future

We have identified four key drivers for the future evolution of wireless-access networks towards 6G:

**Trustworthiness**

With wireless-access networks more and more becoming an integrated part of society, trust in the data delivered via the network, as well as in the network itself, will also become more and more important. Society must be able to completely rely on the networks delivering critical services while, at the same time, being able to fully trust the integrity of the information provided by the network.

**Sustainability**

The quest for a more sustainable society is on top of all agendas and wireless connectivity will be an important component to enable this. This includes a higher degree of sustainability in the network itself, for example, by further optimizing the network energy performance thus enabling network operation with an overall lower energy consumption despite the expected massive increase in network traffic.

However, even more important is the role that the wireless-access network will play in terms of enabling a more sustainable society as a whole, for example, by enabling increased efficiency in the use of different resources and supporting more sustainable ways of living.

**Extreme performance**

Already today there is a strong increase in highly demanding applications, such as virtual, augmented, and mixed reality as well as remote control of sensitive operations, requiring, for example, very low latency and very high end-user data rate. Going towards 2030, we expect this evolution to continue with even higher demands on the performance that networks should deliver.

** Emergence of AI**

The use of artificial intelligence (AI) and machine learning (ML) is expanding rapidly everywhere and we are still just at the beginning of this development. Future wireless communication networks must have the ability to provide the connectivity for a vast number of intelligent machines deployed all over society and industry. Such connected intelligent machines will not have the same limitations as humans, something which will further expand the demands in terms of, for example, supported data rates and latency.

4.2 Required capabilities

To answer up to the above drivers and be able to serve as a platform for a vast range of new and evolving services, the capabilities of future wireless-access networks need to be enhanced and extended in multiple dimensions compared to the networks of today. This includes extensions/enhancements in terms of “classical” capabilities, such as data rates, latency, and system capacity, as well as new capabilities emerging from new drivers and use cases.

In terms of data rates and latency the focus should always be on higher achievable data rates (rather than theoretical peak data rates) and improved latency in all relevant scenarios. This includes the possibility to provide extreme
data rates in the order of several hundred gigabits per second and/or sub-millisecond latency in specific scenarios. Equally important is the possibility to provide high-speed connectivity with predictably low latency.

The future wireless-access network will have to serve an exponentially growing traffic without an increase in the overall costs. Higher spectral efficiency of the radio-access technology is one component for this, with access to additional spectrum naturally being another. Even more important, though, is the possibility for cost-efficient deployment of very dense network infrastructure.

There is a need to continue the expansion of wireless communication and target full global coverage supporting a dramatically higher number of devices that will be embedded throughout society. As a fundamental principle to allow for further digital inclusion, the total cost of ownership (TCO) should be on a sustainable level.

As already indicated, as wireless networks are becoming more and more critical components of the society, resilience and security of the services provided by the network connectivity is becoming more and more crucial. This includes the possibility to continue to provide service even when part of the infrastructure is disabled, for example, due to natural disasters, local disturbances or breakdowns in society. Furthermore, the network must offer further enhanced resistance to, and be robust against, deliberate malicious attacks.

As part of the trustworthiness, the networks must also be able to leverage new confidential computing technologies, improve service availability, and provide enhanced security identities and protocols with end-to-end assurance.

4.3 Some technology components of the future

Although the final decisions on the technical details of the future 6G wireless-access technology still lies several years into the future, there are several technology components that can be expected to be part of such an overall 6G wireless-access solution. Here we summarize some of these identified technology components.

Dynamic network deployments

Mechanisms to ensure dynamic network deployments will be key to supporting future cost-efficient deployments of high-capacity and resilient networks. This will make an operator more agile when it comes to adapting to new business opportunities and new emerging use cases. A key challenge is to seamlessly integrate traditional service-provider-deployed network nodes with complementary ad-hoc, temporary, user-deployed, mobile and/or non-terrestrial network nodes.

The possibility for multi-hop communication — already partly introduced in 5G through IAB — will be one important component when it comes to enabling such dynamic network deployments. We expect this to further evolve, ensuring seamless multi-hop wireless connectivity with low cost and high flexibility. This will also partly erase the distinction between wireless access links to devices and wireless backhaul links between network nodes, creating a unified framework for wireless connectivity.

Cloud-based processing and cross-RAN-CN-transport optimizations

Cloud-based processing is already extensively used in communication networks and this trend is expected to continue. Not only the core network (CN) but also large parts of the radio-access network (RAN) can be implemented on a cloud platform. This removes some of the reasons to duplicate functionalities, having RAN rely on the CN as a “data store” for idle devices. Consequently, it is important to revisit some architecture assumptions behind today’s functional separation between RAN and CN.

A smart choice when it comes to the right set of RAN and CN functions and interfaces is needed to provide the best performance, use cases, and deployment versatility while at the same time keeping development efforts and network operations manageable. A set of multi-vendor interfaces needs to be selected carefully so that it ensures openness in networks and the ecosystem while minimizing system complexity, ensuring the development of agility and a robust and resilient network.

Future applications need to leverage high-performance connectivity, fulfilling required bandwidth, dynamic behaviors, resilience, and further demands. Network capabilities need to be available end-to-end and match the evolution of applications and internet technology. This affects, for instance, application–network collaboration, resilience mechanisms, evolution of the end-to-end transport protocols, and ways to deal with latency.
Spectrum flexibility

Spectrum is — and will continue to be — an essential resource for wireless connectivity. Access to additional wideband spectrum as well as efficient utilization of the existing spectrum is of critical importance, and both licensed and unlicensed spectrum are of interest.

The lower frequency bands (up to around 6GHz) currently used by 4G/5G will remain the backbone for wide-area-coverage connectivity also in the 6G era. Since very little, if any, new lower-frequency spectrum is expected to be made available, it is essential that any new 6G radio-access technology for lower-frequency spectrum can spectrum-wise co-exist with previous generations. Note that this is similar to how 5G NR can dynamically share spectrum with 4G LTE. The mmWave frequency bands in the 24–52GHz range, pioneered by 5G and likely to soon be extended up to 100GHz, will naturally be used by 6G as well.

The 7–24GHz frequency range is currently used for other purposes than mobile communication but can be exploited for 6G by deploying advanced sharing mechanisms. Above 100GHz, often referred to as sub-THz spectrum, there are opportunities for relatively large amounts of spectrum but, given the very challenging propagation conditions, it is mainly of interest for very specific scenarios requiring extreme traffic capacity and/or data rates in very dense network deployments.

Joint communication and sensing

Cellular networks are widely deployed to support wireless connectivity, where the propagation of the radio waves depends on many factors in the environment. Using data analytics on the radio signals received, it is possible to sense and estimate quantities impacting the radio propagation. As an example, the received signal quality in microwave links is affected by the presence of rainfall, information that is valuable for weather forecasting. Active sensing, where radio signals are transmitted solely for the purpose of sensing, is also possible, allowing a base station to act as a radar system in addition to serving the communication needs of an area. This can be used to build and continuously update a map of surrounding areas to, for example, detect changes in road traffic or set off alarms if a person enters a restricted area in a factory hall. Reusing cellular systems for sensing can provide more cost-efficient sensing compared to dedicated systems specifically deployed for sensing only.

Non-terrestrial network component

Extending the conventional terrestrial access to also include a non-terrestrial access component will be necessary to realize truly global coverage for future wireless connectivity. Such a complementary non-terrestrial access component may be provided by different means, including, for example, drones, high-altitude platforms (HAPS), and/or satellites. It will be an integrated part of the overall wireless access solution, providing seamless coverage truly everywhere.

Multi connectivity and distributed MIMO

In order to enhance robustness and performance as well as to ensure more consistent quality in wireless connectivity, multi-point connectivity is expected to become common in the future. Already today, technologies such as multi-radio, dual-connectivity, and multi-point transmissions are available for 5G, but we expect them to expand in the future. This might include, for instance, massive multi-connectivity on the physical layer, where devices have simultaneous physical links to a large number of tightly coordinated network transmission points (sometimes referred to as “distributed MIMO”), or multi-RAT (multi-radio-access-technology) connectivity, where devices have simultaneous connectivity to a network using multiple radio-access technologies that may provide different simultaneous services in a more optimized way and improve the robustness of the overall connectivity.

“Zero-energy” devices

Current massive machine-type communication provides data rates up to a few hundred kilobits per second, serving applications such as remote meter reading. Although their battery life can be up to ten years in some cases, battery replacement or charging limits the applicability of these devices. Energy harvesting, where the device energy is obtained from ambient energy in the form of light, vibrations, temperature differences, or even radio waves, opens up the possibility for devices to not need battery replacement or charging. The amount of energy possible to harvest is typically very small, though, implying that extremely energy-efficient communication protocols need to be developed. Given the minuscule amounts of energy available, the volume of information that could be transmitted will be small — in many cases, only a couple of bytes per hour. For applications such as asset tracking, though, this is sufficient, and radio-based technologies
could be a more appealing choice than the current solutions, such as the optical reading of bar codes or facilitating communication with items out of direct sight.

5. Summary

The third release of NR, Release 17, is already being standardized in 3GPP and will further enhance and expand the application of mobile networks with focus on flexible backhaul and resilient access, higher bands, and simpler devices. With this 5G will continue to evolve into a 6G era of 2030, for which we identify key drivers of trustworthiness, sustainability, AI, and extreme performance. The 6G network will need both enhanced capabilities like higher data rates and new dimensions like extreme numbers of embedded devices. To meet these future demands we should develop technical solutions for dynamic network deployment, cloud-based processing and cross-RAN/CN/transport functionality, spectrum flexibility, joint communication and sensing, non-terrestrial access, multi-connectivity and distributed MIMO, and zero-energy devices.

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