5G Evolution and Beyond

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***Abstract*— This paper provides an overview of the evolution of the 5G NR radio-access technology, starting with 3GPP release 16 but also including potential further evolution steps. It also provides a discussion about the use of AI and machine learning as important components of the future evolution of wireless communication**

Keywords—5G evolution, NR evolution, beyond 5G, AI and machine learning in wireless access

I. INTRODUCTION

The first release of the 3GPP 5G/NR radio-access technology [1] was finalized during 2018. Compared to 4G/LTE, the most distinctive feature of NR is an extension of the range of spectrum in which the radio-access technology can operate. While LTE can operate in spectrum up to around 3.5 GHz, already the first release of NR supports operation in spectrum up 52.6 GHz, i.e. well into the mmw-band.[1] Operation in higher frequency bands opens up for new spectrum, enabling higher traffic volumes. It also provides an opportunity for wider transmission bandwidths, with a corresponding potential for higher end-user data rates.

Key to the efficient utilization of higher frequency bands is the use of advanced antenna systems utilizing a large number of antenna elements. Although multi-antenna transmission and/or reception is an important tool for enhanced performance already within LTE, for NR it is a vital feature to counter increased propagation losses and enable reasonable network coverage at higher frequencies, such as above 10 GHz. At the same time, due to a smaller per-antenna-element size, operation in higher-frequency spectrum allows for a larger number of antennas without an unreasonable size of the overall antenna system.

Consequently, NR includes powerful tools for multi-antenna transmission and reception at both the network and device side. For the higher frequencies, where data rates are more often limited by the available received power, rather than by the available bandwidth, the main focus is on transmitter- and receiver-side beam-forming. For lower frequencies, spatial multiplexing enabling higher data rates within a limited bandwidth is more important.

Other key features of NR include significantly lower latency and enhanced network energy performance enabling significantly lower network energy consumption. The latter is enabled by an ultra-lean radio-interface design that significantly reduces always-on transmissions such a transmission of reference signals, broadcast of system information, and the like.

II. 5G EVOLUTION

A. *NR release 16*

As the first release of NR has been finalized, 3GPP has now turned its focus on the evolution of the NR radio-access technology. The first step of the evolution of NR will be part of 3GPP release 16, the work on which is currently ongoing and with planned finalization early 2020. There are several different technology areas being part of release 16. Below we discuss some of these areas.

NR for unlicensed spectrum (NR-U)

Historically, 3GPP radio-access technologies have been limited to operation in licensed spectrum for which, within a geographical area, a given frequency band is assigned to a single mobile-network operator. Operation in licensed spectrum ensures a controlled-interference radio environment enabling a network operator to provide high-quality service in a cost-efficient way. At the same time, the possibility of operating 3GPP technologies also in unlicensed spectrum provides an opportunity for additional network capacity and enables higher end-user data rates when the interference conditions so allow.

In light of this, 4G/LTE was extended to support operation also in unlicensed spectrum based on so-called *Licensed-Assisted Access* (LAA), see e.g. [2]. With LAA, an LTE carrier in unlicensed spectrum is always operating together with a corresponding carrier in licensed spectrum, i.e. the unlicensed carrier is *assisted* by a *licensed* carrier. The fact that a connection always includes a carrier in licensed spectrum implies that the reliability of licensed operation is retained. At the same time, the complementary unlicensed carrier can off-load part of the network traffic, enabling higher overall traffic capacity.

[1] The exact value 52.6 GHz is due to specific regional spectrum situations. As of today, the highest-frequency spectrum which NR is announced to be deployed is around 39 GHz.

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Combining the link capacity of parallel licensed and unlicensed carriers also enables higher end-user data rates.

The first release of NR is limited to operation in licensed spectrum, with support for operation in unlicensed spectrum, sometimes referred to as NR-U, to be introduced as part of release 16 [3, 4]. Similar to LTE unlicensed operation, NR-U will include support for LAA, i.e. operation where the unlicensed NR carrier operates together with a carrier in licensed spectrum. In case of NR-U, the licensed carrier can be an NR carrier in carrier aggregation with the unlicensed carrier. However, the licensed carrier can also be an LTE carrier operating in dual-connectivity with the unlicensed NR carrier.

Alternatively, and in contrast to LTE, an NR unlicensed carrier can also operate *stand-alone*, i.e. without a complementary carrier in licensed spectrum. This enables NR to be used, for example, by operators not having access to licensed spectrum in a certain area.

Most of the current NR functionality is retained when operating in unlicensed spectrum, with the main modifications/additions being related to mechanisms needed to ensure good co-existence between different independent NR-U carriers as well as between NR-U carriers and legacy unlicensed technologies such as IEEE 802.11 (WIFi) as well as unlicensed LTE.

Integrated Access/Backhaul

Using wireless technology is a well-established approach for providing backhaul for mobile-communication networks. Historically, such *wireless backhaul* has typically been based on proprietary technologies operating in mmw (>10 GHz) spectrum and with line-of-sight propagation conditions.

As described in the introduction, NR extends the spectrum range for the access (network-to-device) link into the mmw spectrum, i.e. into the range of frequencies currently used for wireless backhaul. At the same time, an increasing number of lower-power base stations located at street-level has created a demand for wireless-backhaul solutions that can operate also under non-line-of-sight conditions.

In other words, the characteristics and requirements for the access and wireless-backhaul links are in many respects converging. This speaks in favor of a radio-access technology supporting both access and wireless backhaul and with a common spectrum pool that can be assigned to either access or backhaul on a per-need basis.

Integrated Access/Backhaul (IAB) [5, 6] aims specifically at this, i.e. to extend the NR radio-access technology so that it can be used also for wireless backhaul. In other words, with IAB, NR will provide an *integrated* radio-access technology supporting both conventional device *access* and wireless *backhaul*.

In principle, IAB is targeting any spectrum currently supported by NR. However, the main focus for IAB is, at least initially, on the higher-frequency (mmw) spectrum.

- The large amount of higher-frequency spectrum, compared to the more sparse lower-frequency spectrum, makes it more justified to utilize part of the overall spectrum resource for backhaul
- The extended beam-forming enabled by higher-frequency operation is especially useful for the IAB backhaul link for which both end points are stationary. Furthermore, due to relaxed complexity limitations, more extensive antenna configurations can be applied at an IAB node compared to a portable device.

NR IAB will support *out-of-band* wireless backhaul where the backhaul link operates on a different carrier compared to the access (UE) link. However, NR IAB will also support *in-band* backhaul where the backhaul and access links share the same carrier.

NR IAB is based on the so-called CU/DU split of the gNB as already specified as part of [2] According to this, there is a specified split of the gNB into two parts

- A *Centralized Unit* (CU) containing the PDCP and RRC protocol layers
- A *Distributed Unit* (DU) containing the RLC, MAC, and physical layers

As illustrated in Figure 1, the IAB node only implements the DU part of a gNB with the CU part residing in the donor node. At the other side of the IAB node, an MT, with functionality similar to a UE, communicates with the DU of the a higher-level IAB node or the donor node. Thus, the F1 interface between the donor node CU and the IAB node DU is tunneled over the NR radio interface that is operating between the parent node DU and the MT part of the IAB node.

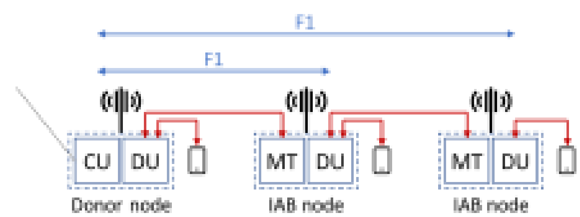

Figure 1 IAB architecture

As also illustrated in Figure 1, NR IAB supports multi-hop backhauling, i.e. operation with multiple IAB nodes in cascade.

On the actual radio-interface, the IAB (backhaul) link inherits most of the release-15 NR functionality. The main modifications/additions relate to the support of in-band relaying under half-duplex constraints within an IAB node. Due to such constraints, the IAB MT part cannot receive while the DU part is transmitting and vice versa. Rather, the DU and MT must share the carrier in the time domain (TDM).

[2] gNB is the 3GPP term for a “base station” node for NR. The corresponding term for LTE is eNB

Enhanced support for Cellular-V2X services

Another important part of the NR evolution in release 16 relates to support for advanced V2X ("Vehicular-to-everything") services [7].

In general, V2X is about communication to, from, and between vehicles and can be divided into several sub-categories:

- Vehicle-to-Network (V2N), i.e. communication between vehicles and the cellular network
- Vehicle-to-Infrastructure (V2I), i.e. communication between vehicles and fixed road-side infrastructure (e.g. traffic lights and speed-limit indicators)
- Vehicle-to-Vehicle (V2V) and Vehicle-to-Pedestrian (V2P), i.e. communication directly between vehicles or between vehicles and pedestrians/smartphones

3GPP already provides support for V2X services by means of LTE. NR-based V2X is intended as a complement for more advanced services, including, for example, autonomous driving.

While V2N links can be straightforwardly provided by NR of today, V2V, V2P, and V2I require the possibility for direct communication links between devices, in 3GPP terminology referred to as *sidelink* communication. For LTE, sidelink was initially introduced as a more general, albeit relatively limited, feature [2] that was subsequently extended/adapted for the V2X use case. In contrast, NR is initially introducing sidelink communication specifically targeting V2X, reflecting the importance that 3GPP sees in the support for V2X services.

More general enhancements

In addition to the above discussed new features, release 16 will also include more general enhancements to the release 15 features. This includes for example

- MIMO (multi-antenna) enhancements, introducing, for example, enhanced multi-user MIMO support based on enhanced CSI feedback, enhanced multi-panel transmission, and enhanced multi-beam operation
- Enhancements for so-called URLLC (Ultra-reliable Low-latency communication) services, introducing, for example, enhanced and more robust layer-1 control signaling and improved HARQ and CSI time lines

B. Next step

Within 3GPP, discussions on the further NR evolution, in a first step targeting 3GPP release 17, has, as of today (February 2019), not yet started. However, some potential directions of this evolution can already now be anticipated.

Further extrended spectrum range.

As mentioned in the introduction, the first release of NR supports operation up to 52.6 GHz. However, there are already discussion on further extending this up to at least 100 GHz.[3]

A key question related to a possible extension of NR to even higher frequencies is if the current OFDM-based NR waveform would still be the best choice. Compared to a "single-carrier" type of waveforms, OFDM clearly has a disadvantage in terms of power-amplifier efficiency. This has historically mainly been an issue the for the device side, i.e. for the uplink transmission direction. However, it is more and more becoming relevant also for the network side, i.e. for the downlink transmission direction

A main advantage of OFDM is the possibility to multiplex transmission to/from different devices in the frequency domain. However, in case of analog beam forming, a beam can only be point in one direction at a time, anyway preventing frequency-domain multiplexing and potentially making the OFDM benefit in this respect less important.

It should be noted that spectrum above 52.6 GHz would include the relatively large amount of unlicensed spectrum currently available around 60 GHz. The extension of NR above 52.6 GHz could thus also include the extension of NR-U into the 60 GHz band.

More general sidelink

As discussed above, sidelink communication will be introduced in NR release 16 targeting the V2X use case. However, there are many other potential use cases that could benefit from a possibility of direct communication between devices and it is likely that, similar to LTE, the support for this will be introduced in later NR releases.

Mobile IAB nodes

IAB for release 16 is targeting stationary IAB nodes. In essence, IAB provides a more flexible and, in many cases, more cost-efficient alternative to wireline backhaul for otherwise rather conventionally deployed network nodes.

Another scenario that would require wireless backhaul is the use of inherently mobile base stations, for example, base stations located on trains and/or buses. To support such scenarios, one could extend NR IAB to also cover non-stationary IAB nodes. The basic IAB (backhaul) radio-interface is very much a straightforward extension of the release-15 NR radio interface and is thus well-adapted to mobile conditions. However, the IAB architecture based on the CU/DU split as described above would require more effort to extend to the non-stationary case.

An alternative or complementary way to support non-stationary network nodes would be to extend the NR sidelink concept. In such a case, the mobile network nodes would, formally, be special devices by means of which other devices are communicating using the NR sidelink.

C. Further 5G evolution and beyond 5G

Looking even further into the future the evolution of mobile communication will undoubtedly continue. It is to early to start to talk about detailed technologies for new beyond-5G radio access. However, research is carried out on new technology components that could, in the future be applied either to the continued evolution of 5G /NR or as part of an even more future

[3] 114 GHz has been mentioned as a possible upper limit

beyond-5G radio-access technology. Below we discuss some such technology components.

Even further extended spectrum ranges

There are already today discussions, mainly in academia, about extending the spectrum range of wireless communication even further, perhaps all the way into the THz range. Clearly this would lead to even more challenging propagation conditions and new implementation issues. Before proceeding further on such a path, more studies are therefore needed. This should also include gathering real-life information and insights from the large number of mmw NR networks currently being deployed.

New network topologies

Despite the tremendous advancements in mobile wireless communication for that last 30+ years, the networks are still to a large extent based on the same paradigm of a device communicating with a single cell site, that was introduced with the first analog cellular systems in the early the 1980th .

Future wireless networks may support a much more heterogenous topology of the wireless-access network. A first step of this is already taken with IAB that, in practice introduces a network-based multi-hop-communication structure. Future networks may include support for more mesh-like network structures where there may be multiple wireless paths connecting two end points and where the path or set of paths may be more adaptively updated to dynamically provide optimal performance.

Cooperative devices

Related to the above is an evolution towards more extensive device cooperation as an integrated part of the wireless network. In the future the possibility for direct device-to-device communication may not only be a tool for more efficient end-to-end connectivity between near-by devices but may also serve as a more general tool for enhanced network connectivity.

- Devices may be used for forwarding of data to other devices outside of direct network coverage.
- Joint transmission or reception at multiple close-by devices may be used to enhance the overall network performance by creating a virtual multi-antenna device by the cooperation between multiple single-antenna devices.

A main argument against such device cooperation has always been that device owners will not accept that the battery of their devices may be drained due to the use of the device as, for example, a relaying node by other users. However, the situation may be different for future IoT applications where there may be a large number of devices belonging to the same "user". In such a scenario, the energy consumption of a specific device may not be the key thing but rather the overall performance of a large set of devices working together.

III. AI IN THE CONTEXT OF MOBILE COMMUNICATION

During the last few years there have been dramatic advancements within the area of machine learning and artificial intelligence. These advancements will undoubtedly have a big impact on the design and operation of future wireless-access networks.

Using machine learning in current 5G networks

The most immediate use of artificial intelligence in 5G networks would be to apply machine learning to dynamic radio-resource-management (RRM) algorithms, such as power control, link adaptation, admission control or handover decision.

Current 5G systems have numerous individual algorithms, each designed to optimize a particular metric. For example, a handover-decision algorithm might be optimized to minimize the number of failed handovers and a link-adaptation algorithm might be optimized to maximize the throughput of a UE. Even though most of these algorithms are potential candidates for machine learning, it is not clear that an algorithm based on machine learning is automatically better than an algorithm created by expert engineers. A potentially even more promising area for artificial intelligence is designing algorithms that work well together. Currently a significant part of a 5G system design is spent on integrating different algorithms and features. The use of machine-learning algorithms that can be trained together might lead to a more optimized solution.

Enhanced machine learning and AI support

There are several potential ways to enhance 5G systems to allow for better support for machine learning and AI.

First, the availability of data for machine learning purposes could be enhanced. 3GPP has agreed to a study on data collection and utilization with focus on measurements, collection and utilization of data. One part of this study is storing of local RRM information in the Core Network, which would also allow increased exposure of RRM information for machine learning algorithms.

Modern network-management approaches are also expected to provide access to data and enable actuation. It is expected that data access and actuation can be realized for slow control loops (e.g. access control, load balancing) and offline training, but are not sufficient fast for fast and real-time loops (e.g. link adaptation).

In addition to providing access to existing data, 5G systems might benefit from having additional functionality specified solely for machine learning purposes.

The simplest examples of machine learning specific include adding new configuration options (e.g. new measurement events or triggers) for existing measurements and specifying completely new measurements for machine learning (e.g. UE orientation, altitude, interference per slot, etc.)

Examples of more advanced AI specific functionality include prediction-based triggering of UE actions, labelling of data for machine learning purposes (e.g. indication on which gNB provides better service at a given location) and triggering UE to enter a "training phase", where the UE transmits additional data specifically designed to train the machine learning models.

In all cases when artificial intelligence models are independently trained in each UE, there is a risk that the UE behavior varies significantly between different UEs. One possible approach to unify the UE behavior would be to specify in detail used machine learning models. However, even though such an approach might lead to unified UE behavior, it would greatly limit the potential benefits by forcing all UEs to implement a fixed model, designed for the least capable UE at the time of specification. Less restrictive approaches should definitely be explored.

One particularly attractive way of controlling machine learning models in the UEs would be specify a special machine learning execution environment in the UE. This would allow network operator to maintain full control the deployed methods, but at the same time allow tailoring of different algorithms for different terminals (e.g. based on UE capabilities).

IV. SUMMARY

This paper has discussed the evolution of the 5G NR radio access technology. This evolution is already ongoing with new/enhanced features such as NR for unlicensed spectrum, Integrated access/backhaul and support for cellular V2X services is due to be introduced as part of NR release 16. Further down the road additional features and technology components will be considered, including further extension of the spectrum range, extensive device co-operation, and the possibility for devices zero energy consumption.

In parallel, the dramatic advancements within the area of artificial intelligence and machine learning will have a big impact on future wireless access systems, both in terms of system deployments and in the basic structure of the radio-access solution.

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