CHAPTER

Beyond the First Release of 5G

20

The first release of NR, release 15, has focused on basic support for eMBB and, to some extent, URLLC.[1] Release 15 as described in the previous chapters is the foundation upon which the future evolution of NR will be built for the coming releases. The NR evolution will bring additional capabilities and further enhance the performance. Not only will the additional capabilities provide better performance in existing applications, they may also open for, or even be motivated by, new application areas.

In the following, some areas in which NR is likely to evolve are discussed. Studies in some of the areas are already ongoing in 3GPP, while other areas are more relevant for later releases.

20.1 INTEGRATED ACCESS-BACKHAUL

The use of wireless technology for backhaul has been used extensively for many years. In some regions of the world, wireless backhaul constitutes more than 50% of total backhaul. Current wireless-backhaul solutions are typically based on proprietary (non-standardized) technology operating as point-to-point line-of-sight links using special frequency bands above 10 GHz. The wireless backhaul is thus using different technology and operating in different spectra, compared to the access (base-station/device) links. Relaying, introduced in release 10 of LTE, is basically a wireless backhaul link, although with some restrictions. However, it has so far not been used in practice to any significant extent. One reason is that wirelessly connected small-cell deployments, for which relaying was designed, have not yet been extensively used in practice. Another reason is that operators prefer to use their precious low-frequency spectra for the access link. As already mentioned, current wireless backhauling relies on non-LTE technologies capable

[1]The first NR version primarily addressed the low-latency part of URLLC. Means to increase the reliability are worked upon in the latter parts of release 15, targeting the final NR release 15 in June 2018.

5G NR: The Next Generation Wireless Access Technology. DOI: https://doi.org/10.1016/B978-0-12-814323-0.00020-X

of exploiting significantly higher-frequency bands than LTE, thereby avoiding wasting valuable access spectra for backhaul purposes.

However, for NR, a convergence of backhaul and access can be expected for several reasons:

- The access link can exploit mm-wave frequencies—that is, the same frequency range that is currently used for wireless backhaul.
- The expected densification of the mobile networks, with many base stations located indoor and outdoor on street level, will require wireless backhaul capable of operating under non-line-of-sight conditions and, more generally, very similar propagation conditions as the access link.

The requirements and characteristics of the wireless backhaul link and the access link are thus converging. In essence, with reference to Fig. 20.1, there is, radio-wise, no major difference between the wireless backhaul link and the normal wireless link. Consequently, there are strong reasons to consider a convergence also in terms of technology and spectrum with a single radio-access technology that can be used for both access and wireless backhaul. There should preferably also be a common spectrum pool for both the access link and the wireless backhaul. It should also be noted that a common spectrum pool for access and wireless backhaul does not necessarily mean that the access link and the wireless backhaul link should operate on the same carrier frequency ("inband relaying"). In some cases, this will be possible. However, in other cases, having a frequency separation between the backhaul link and the access link is preferred. The key thing is that the separation of spectrum between backhaul and access should, as much as possible, not be a regulatory issue. Rather, an operator should have access to a single spectrum pool. It is then an operator decision how to use this spectrum in the best possible way and how to split it between access and backhaul.

To address backhaul scenarios, a study item on *integrated access-backhaul* [1] is part of release 15 to assess the possibilities and techniques for using NR for backhaul purposes. The NR radio access is well prepared to support the backhaul link and most of the necessary work is on higher-layer protocols.

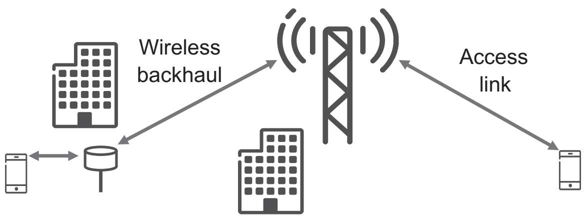

FIGURE 20.1

Wireless backhaul vs the access link.

20.2 OPERATION IN UNLICENSED SPECTRA

Spectrum is fundamental for wireless communication and there is a never-ending quest for more spectra to meet the ever-increasing demands of increased capacity and higher data rates. This is one of the reasons for supporting higher carrier frequencies in NR. The first release of NR was primarily designed for licensed spectra. Such spectra offer many benefits since the operator can plan the network and control the interference. Licensed spectrum is thus instrumental to providing quality-of-service guarantees and wide-area coverage. However, the amount of licensed spectra an operator has access to may not be sufficient and there is typically a cost associated with obtaining a spectrum license.

Unlicensed spectra, on the other hand, are open for anyone to use at no cost, subject to a set of rules, for example on maximum transmission power. Since anyone can use the spectra, the interference situation is typically much more unpredictable than for licensed spectra. Consequently, quality-of-service and availability cannot be guaranteed. Furthermore, the maximum transmission power is modest, making it unsuitable for wide-area coverage. Wi-Fi and Bluetooth are two examples of communication systems exploiting unlicensed spectra in the lower-frequency range: 2.4 GHz or 5 GHz. In addition, some of the higher-frequency bands which NR is likely to address are unlicensed.

From the discussion above, it can be seen that these two spectrum types have different benefits and drawbacks. An attractive option is to combine the two such that licensed spectra are used to provide wide-area coverage and quality-of-service guarantees, with unlicensed spectra used as a local-area complement to increase user data rates and overall capacity without compromising on overall coverage, availability, and reliability. This has been done as part of the LTE evolution, see *License-Assisted Access (LAA)* in Chapter 4 and Fig. 20.2. For NR, a study on *NR-based Access to Unlicensed Spectrum* [9] is part of release 15 with specification work targeting release 16.

Although NR release 15 does not support unlicensed spectra, it was considered in the development of the basic NR framework. One example hereof is the possibility to transmit over a fraction of a slot (see Chapter 7). Extending NR into an LAA-like operation is therefore relatively simple, using the existing flexibility and following the approach developed for LTE.

One important characteristic of operation in unlicensed spectra, which was accounted for in the LTE/LAA work, is fair sharing of unlicensed spectra with other operators and other systems, in particular Wi-Fi. There are several mechanisms that can be used to enable this. *Dynamic frequency selection* (DFS), where the network node searches and finds a part of the unlicensed spectra with low load, can be used to avoid other systems if possible. *Listen-before-talk* (LBT) mechanism, where the transmitter ensures there are no ongoing transmissions on the carrier frequency prior to transmitting, is another mechanism well proven at lower-frequency bands that could be added to NR. For higher-frequency bands,

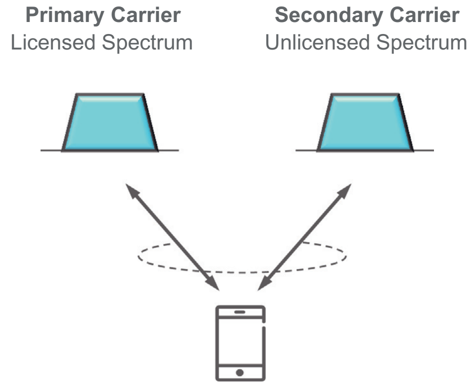

FIGURE 20.2

License-assisted access.

where extensive beam-forming is typically used, the LBT mechanism may need some modifications.

Beyond license-assisted access to unlicensed spectra, a complete solution for standalone operation in unlicensed spectra can also be envisioned. This obviously requires mechanisms for system-information delivery and mobility capable of handling unlicensed spectra.

20.3 NON-ORTHOGONAL MULTIPLE ACCESS

NR primarily uses orthogonal multiple-access where different devices are separated in time and/or frequency. However, non-orthogonal access has the potential to increase capacity in some scenarios. During the early stages of NR development, *non-orthogonal multiple access* (NOMA) was briefly studied but down-prioritized. Nevertheless, studies on NOMA are ongoing in release 15 and may become relevant for NR in later releases.

20.4 MACHINE-TYPE COMMUNICATION

Machine-type communication is a very wide term, covering many different use cases and scenarios. It is common to divide machine-type communication into massive machine-type communication and ultra-reliable low-latency communication (URLLC), as already discussed at the beginning of this book.

Massive machine-type communication refers to scenarios where a device typically sends a very small amount of data, has relaxed latency requirements, but low power consumption and low cost are at premium. The number of devices is often very large. Such scenarios will be addressed by LTE and NB-IoT for the near- to mid-term perspective, in particular for the low-end massive MTC regime. Specific mechanisms such as the reserved resources discussed in Chapter 17 have been introduced to simplify the coexistence between NR and these access technologies. In the longer time perspective, NR is expected to evolve with improved native support of massive machine-type communication, primarily focusing on the mid-to-high-end massive MTC. Reduced bandwidth support, extended sleep-mode solutions, wake-up signaling, and non-orthogonal waveforms are examples of what could be relevant to study as part of such an evolution.

Factory automation is an example of an application area related to machine-type communication. In many cases, such applications are demanding in terms of reliability and latency and the URLLC aspects of NR are therefore highly relevant. Examples of possible enhancements to NR relevant for factory automation are higher-layer enhancements to support commonly used industrial protocols (other than TCP/IP) and local breakout from the core network.

20.5 DEVICE-TO-DEVICE COMMUNICATION

Support for direct device-to-device (D2D) connectivity (Fig. 20.3), also referred to as sidelink connectivity, using LTE was introduced in 3GPP release 12 with two main use cases in mind:

- Device-to-device communication, focusing on the public-safety use case;
- Device-to-device discovery, targeting public safety but also commercial use cases.

The D2D framework has also served as the basis for the V2V/V2X work in the LTE evolution in later releases as discussed in Chapter 4.

NR release 15 does not support direct device-to-device communication, but it is a likely candidate for a future release. Instead of focusing on a specific use case, device-to-device connectivity should be seen as a general tool to enhance

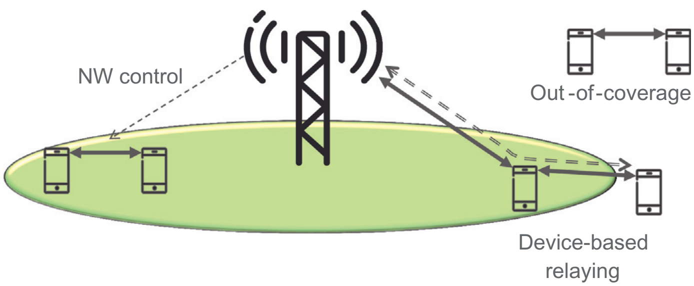

FIGURE 20.3

Device-to-device connectivity.

connectivity within the 5G network. In essence, direct data transfer between devices should be configured if the network concludes that this is more efficient (requires less resources) or provides better quality (higher data rates and/or lower latency) compared to indirect connectivity via the infrastructure. The network should also be able to configure device-based relay links to enhance the connectivity quality, for example for massive machine-type devices with bad or no coverage. The lower latency of NR could also prove valuable for some D2D applications, for example platooning, as mentioned in Chapter 4.

20.6 SPECTRUM AND DUPLEX FLEXIBILITY

Duplex flexibility is a wide area, aiming at improving the usage of the available spectrum. The tools part of NR from the start—for example bandwidth parts, a flexible slot structure, and carrier aggregation also across duplex schemes—provide a lot of flexibility and ensure NR can be deployed in a wide range of scenarios. Nevertheless, further enhancements in this area can be envisioned.

Currently, the FDD spectrum is split into a downlink part and an uplink part. However, what is relevant from a technical perspective is primarily not downlink vs uplink, but low power vs high power. The downlink typically uses high power and relatively high above-rooftop antennas, while the uplink uses significantly lower transmission power and antenna installations. Hence, from an interference perspective, a low-power downlink transmission in the uplink spectrum is not different from a low-power uplink transmission in the same spectrum. Consequently, there are ideas on allowing downlink transmission also in the uplink bands. To some extent, this is the FDD counterpart to dynamic TDD as it allows for a dynamic change to the "transmission direction." From a technical perspective, NR is well prepared to such enhancements because of the flexible slot structure. The potential issues are primarily regulatory.

Another area related to spectra and possible future enhancements is interference measurements and dynamic TDD. The TDD scheme in NR is built upon a dynamic framework and dynamic TDD is therefore part of release 15. However, in practice, such deployments are primarily limited to small cells. In larger cells, with a correspondingly higher downlink transmission power, the intercell interference typically calls for a more static duplex operation. One possibility to improve the number of scenarios where dynamic TDD is feasible could be to include various interference measurement mechanisms. For example, if the scheduler knows the interference situation for the different devices, it can schedule dynamically for some devices while taking a more static approach for other devices. Different intercell interference coordination mechanisms can also be thought of.

There have recently been different proposals for "true" full-duplex operation [53]. In this context, full-duplex operation means that transmission and reception

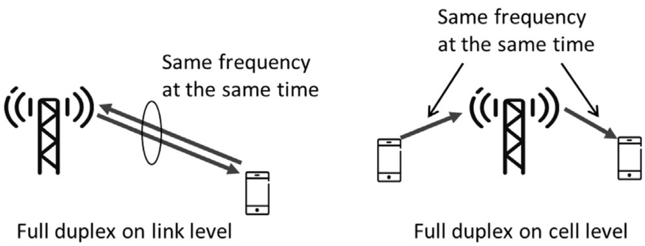

FIGURE 20.4

Full duplex on link level vs cell level.

are carried out *at the same frequency at the same time* (see also Fig. 20.4).[2] Full-duplex operation obviously leads to very strong "self" interference from the transmitter to the receiver, an interference that needs to be suppressed/canceled before the actual target signal can be detected.

In principle, such interference suppression/cancellation is straightforward, as the interfering signal is in principle completely known to the receiver. In practice, the suppression/cancellation is far from straightforward due to the enormous difference between the target signal and the interference in terms of received power. To handle this, current demonstrations of full-duplex operation rely on a combination of spatial separation (separate antennas for transmission and reception), analog suppression, and digital cancellation. The technology is still to a large degree at the research level and not mature enough for large-scale deployments. Implementation on the network-side only (see right part of Fig. 20.4) might be less complex than implementation on the device-side due to a higher degree of spatial separation of receive and transmit antennas on the network side.

Even if full duplex would be feasible in real implementation, its benefits should not be overestimated. Full duplex has the potential to double the link throughput by allowing for continuous transmission in both directions on the same frequency. However, there will then be two simultaneous transmissions, implying increased interference to other transmissions, something which will negatively impact the overall system gain. The largest gain from full duplex can therefore be expected to occur in scenarios with relatively isolated radio links.

20.7 CONCLUDING REMARKS

Above, some examples of technology areas relevant for NR evolution are outlined. Some of these are likely to be part of future NR releases, while other may not happen at all. However, as always, when trying to predict the future, there are

[2]Not to be up mixed with *full-duplex FDD* as used in LTE.

a lot of uncertainties and new, not-yet-known requirements or technologies, which may motivate evolutions into directions not discussed above. The emphasis on future compatibility in the basic NR design ensures that introduction of extension in most cases is relatively straightforward. It is clear though that NR is a very flexible platform, capable of evolving in a wide range of directions and an attractive path to future wireless communication.