CHAPTER

LTE/NR Interworking and Coexistence

17

The initial deployment of a new generation of mobile-communication technology typically takes place in areas with high traffic density and with high demands for new service capabilities. This is then followed by a gradual further build-out that can be more or less rapid depending on the operator strategy. During this subsequent gradual deployment, ubiquitous coverage to the operator network will be provided by a mix of new and legacy technology, with devices continuously moving in and out of areas covered by the new technology. Seamless handover between new and legacy technology has therefore been a key requirement at least since the introduction of the first 3G networks.

Furthermore, even in areas where a new technology has been deployed, earlier generations must typically be retained and operated in parallel for a relatively long time in order to ensure continued service for legacy devices not supporting the new technology. The majority of users will migrate to new devices supporting the latest technology within a few years. However, a limited amount of legacy devices may remain for a long time. This becomes even more the case with an increasing number of mobile devices not being directly used by persons but rather being an integrated part of other equipment, such as parking meters, card readers, surveillance cameras, etc. Such equipment may have a life time of more than 10 years and will be expected to remain connectable during this life time. This is actually one important reason why many second-generation GSM networks are still in operation even though both 3G and 4G networks have subsequently been deployed.

However, the interworking between NR and LTE goes further than just enabling smooth handover between the two technologies and allowing for their parallel deployment.

- NR allows for *dual-connectivity* with LTE, implying that devices may have simultaneous connectivity to both LTE and NR. As already mentioned in Chapter 5, the first release of NR actually relies on such dual-connectivity, with LTE providing the control plane and NR only providing additional user-plane capacity;
- NR can be deployed in the same spectrum as LTE in such a way that the overall spectrum capacity can be dynamically shared between the two

5G NR: The Next Generation Wireless Access Technology. DOI: https://doi.org/10.1016/B978-0-12-814323-0.00017-X

technologies. Such *spectrum coexistence* allows for a more smooth introduction of NR in spectra already occupied by LTE.

17.1 LTE/NR DUAL-CONNECTIVITY

The basic principle of LTE/NR dual-connectivity is the same as LTE dual-connectivity [28], see also Fig. 17.1):

- A device has simultaneous connectivity to multiple nodes within the radio-access network (eNB in the case of LTE, gNB in the case of NR);
- There is one *master node* (in the general case either an eNB or a gNB) responsible for the radio-access control plane. In other words, on the network side the signaling radio bearer terminates at the master node which then also handles all RRC-based configuration of the device;
- There is one, or in the general case multiple, *secondary node(s)* (eNB or gNB) that provides additional user-plane links for the device.

17.1.1 DEPLOYMENT SCENARIOS

In the case of LTE dual-connectivity, the multiple nodes to which a device has simultaneous connectivity are typically geographically separated. The device may, for example, have simultaneous connectivity to a small-cell layer and an overlaid macro layer.

The same scenario, that is, simultaneous connectivity to a small-cell layer and an overlaid macrolayer, is a highly relevant scenario also for LTE/NR dual-connectivity. Especially, NR in higher-frequency bands may be deployed as a small-cell layer under an existing macro-layer based on LTE (see Fig. 17.2). The LTE macro layer would then provide the master nodes, ensuring that the control plane is retained even if the connectivity to the high-frequency small-cell layer is temporarily lost. In this case, the NR layer provides very high capacity and very high data rates, while dual-connectivity to the lower-frequency LTE-based macro

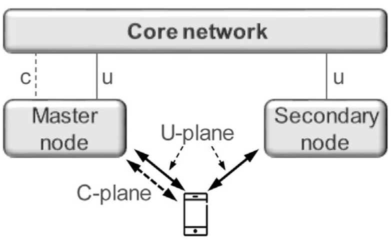

FIGURE 17.1

Basic principle of dual-connectivity.

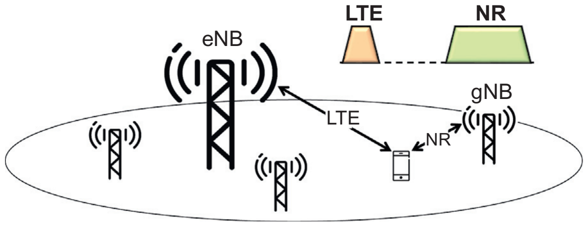

FIGURE 17.2

LTE/NR dual-connectivity in a multi-layer scenario.

layer provides additional robustness to the inherently less robust high-frequency small-cell layer. Note that this is essentially the same scenario as the LTE dual-connectivity scenario described above, except for the use of NR instead of LTE in the small-cell layer.

However, LTE/NR dual-connectivity is also relevant in the case of co-sited LTE and NR network nodes (Fig. 17.3).[1] As an example, for initial NR deployment an operator may want to reuse an already deployed LTE site grid also for NR to avoid the cost of deploying additional sites. In this scenario, dual-connectivity enables higher end-user data rates by allowing for aggregation of the throughput of the NR and LTE carriers. In the case of a single radio-access technology, such aggregation between carriers transmitted from the same node would be more efficiently realized by means of *carrier aggregation* (see Section 7.6). However, NR does not support carrier aggregation with LTE and thus dual-connectivity is needed to support aggregation of the LTE and NR throughput.

Co-sited deployments are especially relevant when NR is operating in lower-frequency spectrum, that is, in the same or similar spectrum as LTE. However, co-sited deployments can also be used when the two technologies are operating in very different spectra, including the case when NR is operating in mm-wave bands (Fig. 17.4). In this case, NR may not be able to provide coverage over the entire cell area. However, the NR part of the network could still capture a large part of the overall traffic, thereby allowing for the LTE part to focus on providing service to devices in poor-coverage locations.

In the scenario in Fig. 17.4, the NR carrier would typically have much wider bandwidth compared to LTE. As long as there is coverage, the NR carrier would therefore, in most cases, provide significantly higher data rates compared to LTE, making throughput aggregation less important. Rather, the main benefit of dual-connectivity in this scenario would, once again, be enhanced robustness for the higher-frequency deployment.

[1]Note that three would in this case still be two different logical nodes (an eNB and a gNB) although these could very well be implemented in the same physical hardware.

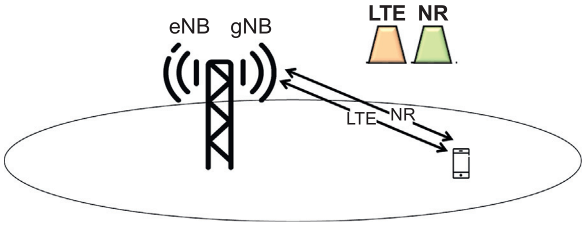

FIGURE 17.3

LTE/NR dual-connectivity, co-sited deployment.

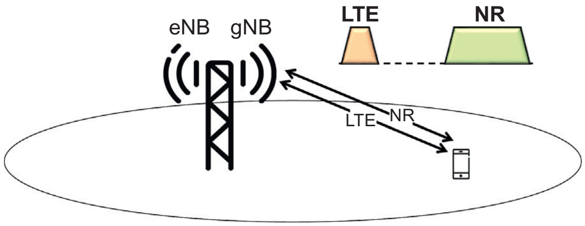

FIGURE 17.4

LTE/NR dual-connectivity, co-sited deployment in different spectrum.

17.1.2 ARCHITECTURE OPTIONS

Due to the presence of two different radio-access technologies (LTE and NR) as well as the future availability of a new 5G core network as an alternative to the legacy 4G core network (EPC), there are several different alternatives, or *options*, for the architecture of LTE/NR dual-connectivity (see Fig. 17.5). The labeling of the different options in Fig. 17.5 originates from early 3GPP discussions on possible NR architecture options where a number of different alternatives were on the table, a subset of which was eventually agreed to be supported (see Chapter 6 for some additional, non-dual-connectivity, options).

It can be noted that LTE/NR dual-connectivity using EPC with NR providing the master node is not included among the options outlined in Fig. 17.5. At the time of the writing of this book, the possible support for this alternative is still under discussion.

17.1.3 SINGLE-TX OPERATION

In the case of dual-connectivity between LTE and NR there will be multiple uplink carriers (at least one LTE uplink carrier and one NR uplink carrier) transmitted from the same device. Due to non-linearities in the RF circuitry, simultaneous transmission on two carriers will create intermodulation products at the transmitter output. Depending on the specific carrier frequencies of the

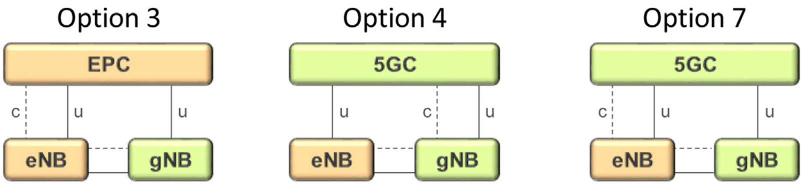

FIGURE 17.5

Different architecture options for LTE/NR dual-connectivity.

transmitted signals, some of these intermodulation products may end up within the device receiver band causing "self-interference," also referred to as *intermodulation distortion* (IMD). The IMD will add to the receiver noise and lead to a degradation of the receiver sensitivity. The impact from IMD can be reduced by imposing tighter linearity requirements on the device. However, this will have a corresponding negative impact on device cost and energy consumption.

To reduce the impact of IMD without imposing very tight RF requirements on all devices, NR allows for *single-TX* dual-connectivity for "difficult band combinations." In this context, difficult band combinations correspond to specifically identified combinations of LTE and NR frequency bands for which lower-order intermodulation products between simultaneously transmitted LTE and NR uplink carriers may fall into a corresponding downlink band. Single-TX operation implies that there will not be simultaneous transmission on the LTE and NR uplink carriers within a device even though the device is operating in LTE/NR dual-connectivity.

It is the task of the LTE and NR schedulers to jointly prevent simultaneous transmission on the LTE and NR uplink carriers in the case of single-TX operation. This requires coordination between the schedulers, that is between an eNB and a gNB. The 3GPP specifications include explicit support for the interchange of standardized inter-node messages for this purpose.

Single TX operation inherently leads to time multiplexing between the LTE and NR uplink transmissions within a device, with none of the uplinks being continuously available. However, it is still desirable to be able to retain full utilization of the corresponding downlink carriers.

For NR, with its high degree of scheduling and hybrid-ARQ flexibility, this can easily be achieved with no additional impact on the NR specifications. For the LTE part of the connection the situation is somewhat different though. LTE FDD is based on synchronous HARQ, where uplink HARQ feedback is to be transmitted a specified number of subframes after the reception of the corresponding downlink transmission. With a single-TX constraint, not all uplink subframes will be available for transmission of HARQ feedback, potentially restricting the subframes in which downlink transmission can take place.

However, the same situation may already occur within LTE itself, more specifically in the case of FDD/TDD carrier aggregation with the TDD carrier being the primary cell [28]. In this case, the TDD carrier, which is inherently not continuously available for uplink transmission, carries uplink HARQ feedback corresponding to downlink transmissions on the FDD carrier. To handle this situation, LTE release 13 introduced so-called *DL/UL reference configurations* [28] allowing for a TDD-like timing relation, for example for uplink feedback, for an FDD carrier. The same functionality can be used to support continuous LTE downlink transmission in the case of LTE/NR dual-connectivity constrained by single-TX operation.

In the LTE FDD/TDD carrier-aggregations scenario, the uplink constraints are due to cell-level downlink/uplink configurations. On the other hand, in the case of single-TX dual-connectivity the constraints are due to the need to avoid simultaneous transmission on the LTE and NR uplink carriers, but without any tight interdependency between different devices. The set of unavailable uplink subframes may thus not need to be the same for different devices. To enable a more even load on the LTE uplink, the DL/UL reference configurations in the case of single-TX operation can therefore be shifted in time on a per-device basis.

17.2 LTE/NR COEXISTENCE

The introduction of earlier generations of mobile communication has always been associated with the introduction of a new spectrum in which the new technology can be deployed. This is the case also for NR, for which the support for operation in mm-wave bands opens up for the use of a spectrum range never before applied to mobile communication.

Even taking into account the use of antenna configurations with a large number of antenna elements enabling extensive beam forming, operation in such high-frequency spectrum is inherently disadvantageous in terms of coverage. Rather, to provide truly wide-area NR coverage, lower-frequency spectrum must be used.

However, most lower-frequency spectrum is already occupied by current technologies, primarily LTE. Furthermore, an additional low-frequency spectrum is planned to be deployed with LTE in the relatively near future. In many cases NR deployments in lower-frequency spectrum will therefore need to take place in spectrum already used by LTE.

The most straightforward way to deploy NR in a spectrum already used by LTE is static frequency-domain sharing, where part of the LTE spectrum is migrated to NR (see Fig. 17.6).

There are two drawbacks with this approach though.

At least at an initial stage, the main part of the traffic will still be via LTE. At the same time, the static frequency-domain sharing reduces the spectrum available for LTE, making it more difficult to satisfy the traffic demands.

Furthermore, static frequency-domain sharing will lead to less bandwidth being available for each technology, leading to a reduced peak data rate per

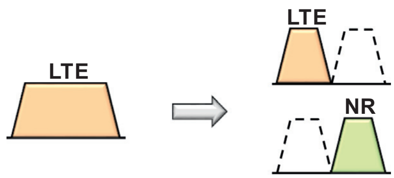

FIGURE 17.6

Migration of LTE spectrum to NR.

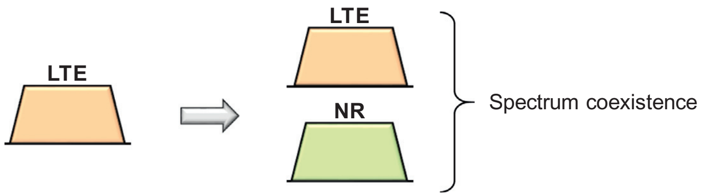

FIGURE 17.7

LTE/NR spectrum coexistence.

carrier. The possible use of LTE/NR dual-connectivity may compensate for this for new devices capable of such operation. However, at least for legacy LTE devices there will be a direct impact on the achievable data rates.

A more attractive solution is to have NR and LTE dynamically share the same spectrum as illustrated in Fig. 17.7. Such spectrum coexistence will retain the full bandwidth and corresponding peak data rates for each technology. Furthermore, the overall spectrum capacity could be dynamically assigned to match the traffic conditions on each technology.

The fundamental tool to enable such LTE/NR spectrum coexistence is the dynamic scheduling of both LTE and NR. However, there are several other NR features that play a role in the overall support for LTE/NR spectrum coexistence:

- The availability of the LTE-compatible 15 kHz NR numerology that allows for LTE and NR to operate on a common time/frequency grid;
- The general NR forward-compatibility design principles listed in Section 5.1.3. This also includes the possibility to define reserved resources based on bitmaps as described in Section 9.10;
- A possibility for NR PDSCH mapping to avoid resource elements corresponding to LTE cell-specific reference signals (see further details below).

As already mentioned in Section 5.1.11 there are two main scenarios for LTE/NR coexistence (see also Fig. 17.8):

- Coexistence in both downlink and uplink;
- Uplink-only coexistence.

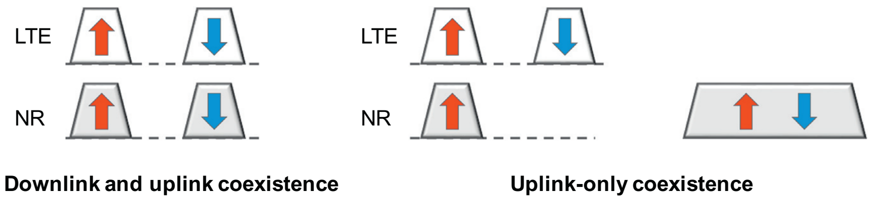

FIGURE 17.8

Downlink/uplink coexistence vs uplink-only coexistence.

A typical use case for uplink-only coexistence is the deployment of a supplementary uplink carrier (see Section 7.7).

In general, coexistence in the uplink direction is more straightforward compared to the downlink direction and can, to a large extent, be supported by means of scheduling coordination/constraints. NR and LTE uplink scheduling should be coordinated to avoid collision between LTE and NR PUSCH transmissions. Furthermore, the NR scheduler should be constrained to avoid resources used for LTE uplink layer 1 control signaling (PUCCH) and vice versa. Depending on the level of interaction between the eNB and gNB, such coordination and constraints can be more or less dynamic.

Also for the downlink, scheduling coordination should be used to avoid collision between scheduled LTE and NR transmissions. However, the LTE downlink also includes several non-scheduled "always-on" signals that cannot be readily scheduled around. This includes (see [28] for details):

- The LTE PSS and SSS, which are transmitted over two OFDM symbols and six resource blocks in the frequency domain once every fifth subframe;
- The LTE PBCH, which is transmitted over four OFDM symbols and six resource blocks in the frequency domain once every frame (10 subframes);
- The LTE CRS, which is transmitted regularly in the frequency domain and in four or six symbols in every subframe depending on the number of CRS antenna ports.[2]

Rather than being avoided by means of scheduling, the concept or reserved resources (see Section 9.10) can be used to rate match the NR PDSCH around these signals.

Rate matching around the LTE PSS/SSS can be done by defining reserved resources according to bitmaps as described in Section 9.10. More specifically a single reserved resource given by a {bitmap-1, bitmap-2, bitmap-3} triplet could be defined as follows (see also Fig. 17.9):

- A bitmap-1 of a length equal to the number of NR resource blocks in the frequency domain, indicating the six resource blocks within which LTE PSS and SSS are transmitted;

[2]Only one or two symbols in case of so-called MBSFN subframes.

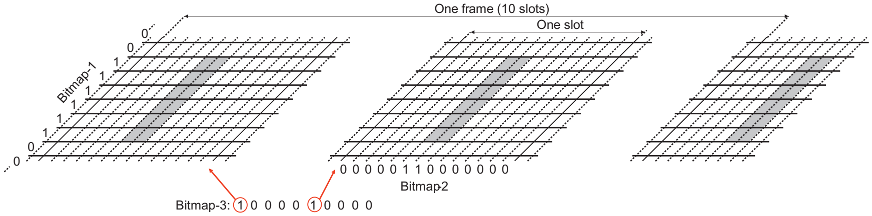

FIGURE 17.9

Configuration of reserved resource to enable PDSCH rate matching around LTE PSS/SS. Note that the figure assumes 15 kHz NR numerology.

- A bitmap-2 of length 14 (one slot), indicating the two OFDM symbols within which the PSS and SSS are transmitted within an LTE subframe;
- A bitmap-3 of length 10 indicating the two subframes within which the PSS and SSS are transmitted within a 10 ms frame.

This assumes a 15 kHz NR numerology. Note though that the use of reserved resources based on bitmaps is not limited to 15 kHz numerology and, in principle, a similar approach to rate match around LTE PSS and SSS could be used also with, for example, a 30 kHz NR numerology.

The same approach can be used to rate match around the LTE PBCH with the only difference that bitmap-2 would, in this case, indicate the four symbols within which PBCH is transmitted, while bitmap-3 would indicate a single subframe.

Regarding the LTE CRS, the NR specification includes explicit support for PDSCH rate matching around resource elements corresponding to CRS of an overlaid LTE carrier. In order to be able to properly receive such a rate-matched PDSCH, the device is configured with the following information:

- The LTE carrier bandwidth and frequency domain location, to allow for LTE/NR coexistence even though the LTE carrier may have a different bandwidth and a different center-carrier location, compared to the NR carrier;
- The LTE MBSFN subframe configuration, as this will influence the set of OFDM symbols in which CRS transmission takes place within a given LTE subframe;
- The number of LTE CRS antenna ports as this will impact the set of OFDM symbols on which CRS transmission takes place as well as the number of CRS resource elements per resource block in the frequency domain;
- The LTE CRS shift, that is, the exact frequency-domain position of the LTE CRS.

Rate matching around LTE CRS is only possible for the 15 kHz NR numerology.