CHAPTER

PHYSICAL TRANSMISSION RESOURCES

5

In Chapter 4, the overall LTE architecture was discussed, including an overview of the different protocol layers. Prior to discussing the detailed LTE downlink and uplink transmission schemes, a description of the basic time—frequency transmission resource of LTE is provided in this chapter. An overview of the concept of *antenna ports* is also provided.

5.1 OVERALL TIME—FREQUENCY STRUCTURE

OFDM is the basic transmission scheme for both the downlink and uplink transmission directions in LTE although, for the uplink, specific means are employed to reduce the cubic metric[1] of the transmitted signal, thereby allowing for improved efficiency for the device transmitter power amplifier. Thus, for uplink user data and higher-layer control signaling corresponding to transmission of the PUSCH physical channel, DFT precoding is applied before OFDM modulation, leading to *DFT-spread OFDM* or *DFTS-OFDM*, see further Chapter 7. As will be described in Chapter 7, for other uplink transmissions, such as the transmission of *L1/L2 control signaling* and different types of *reference-signal transmissions*, other measures are taken to limit the cubic metric of the transmitted signal.

The LTE OFDM subcarrier spacing equals 15 kHz for both downlink and uplink. The selection of the subcarrier spacing in an OFDM-based system needs to carefully balance overhead from the cyclic prefix against sensitivity to Doppler spread/shift and other types of frequency errors and inaccuracies. The choice of 15 kHz for the LTE subcarrier spacing was found to offer a good balance between these different constraints.

Assuming an FFT-based transmitter/receiver implementation, 15 kHz subcarrier spacing corresponds to a sampling rate $f_s = 15000\,N_{\mathrm{FFT}}$, where N_{FFT} is the FFT size. It is important to understand though that the LTE specifications do not in any way mandate the use of FFT-based transmitter/receiver implementations and even less so a particular FFT size or sampling rate. Nevertheless, FFT-based implementations of OFDM are common practice and an

[1]The cubic metric is a better measure than the peak-to-average ratio of the amount of additional back-off needed for a certain signal waveform, relative to the back-off needed for some reference waveform [10].

4G, LTE-Advanced Pro and The Road to 5G. http://dx.doi.org/10.1016/B978-0-12-804575-6.00005-4

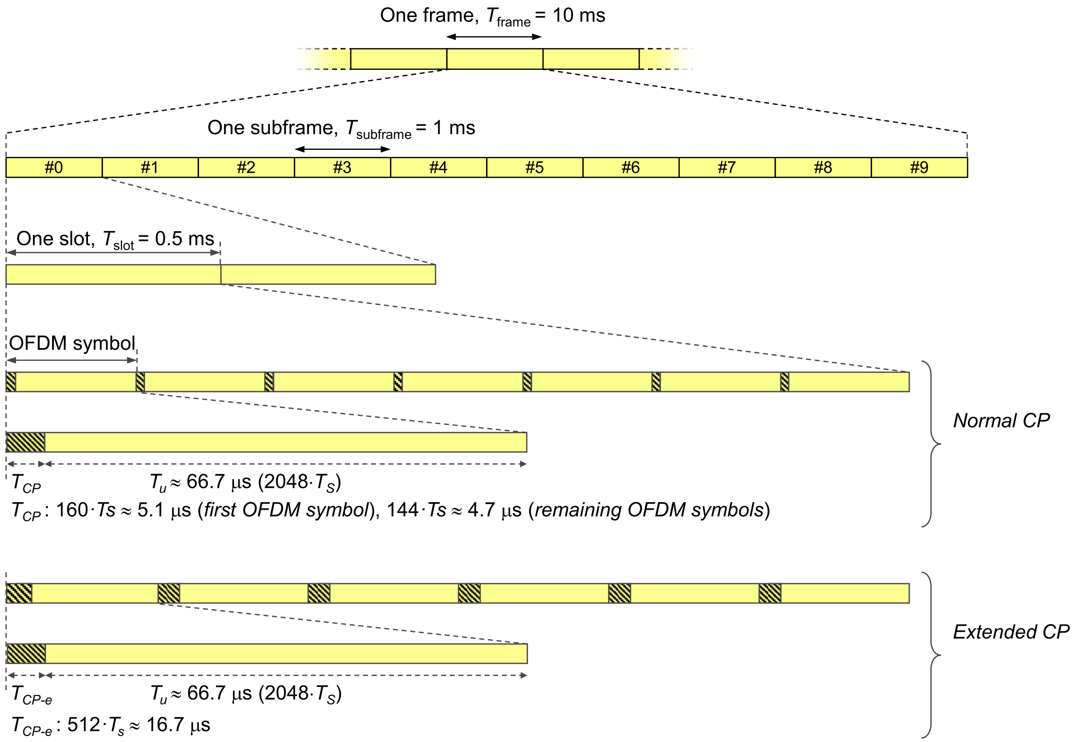

FIGURE 5.1

LTE time-domain structure.

FFT size of 2048, with a corresponding sampling rate of 30.72 MHz, is suitable for the wider LTE carrier bandwidths, such as bandwidths of the order of 15 MHz and above. However, for smaller carrier bandwidths, a smaller FFT size and a correspondingly lower sampling rate can very well be used.

In addition to the 15 kHz subcarrier spacing, a *reduced subcarrier spacing* of 7.5 kHz, with a corresponding OFDM symbol time that is twice as long, is also defined for LTE. The introduction of the reduced subcarrier spacing specifically targeted MBSFN-based multicast/broadcast transmissions (see Chapter 19). However, currently the 7.5 kHz subcarrier numerology is only partly implemented in the LTE specifications. The remaining discussions within this and the following chapters will assume the 15 kHz subcarrier spacing unless explicitly stated otherwise.

In the time domain, LTE transmissions are organized into *frames* of length 10 ms, each of which is divided into ten equally sized *subframes* of length 1 ms, as illustrated in Figure 5.1.

Each subframe consists of two equally sized *slots* of length $T_{slot} = 0.5$ ms, with each slot consisting of a number of OFDM symbols including cyclic prefix.[2] To provide consistent and exact timing definitions, different time intervals within the LTE specifications are defined as multiples of a basic time unit $T_s = 1/(15000 \cdot 2048)$ s. The basic time unit T_s can thus be seen as the sampling time of an FFT-based transmitter/receiver implementation with an FFT size equal to 2048. The time intervals outlined in Figure 5.1 can thus also be expressed as $T_{frame} = 307200\ T_s$, $T_{subframe} = 30720\ T_s$, and $T_{slot} = 15360\ T_s$ for the frame, subframe, and slot durations, respectively.

On a higher level, each frame is identified by a *System Frame Number* (SFN). The SFN is used to define different transmission cycles that have a period longer than one frame, for example, paging cycles, see Chapter 11. The SFN period equals 1024, thus the SFN repeats itself after 1024 frames or 10.24 s.

The 15 kHz LTE subcarrier spacing corresponds to a useful symbol time $T_u = 2048\ T_s$ or approximately 66.7 µs. The overall OFDM symbol time is then the sum of the useful symbol time and the cyclic prefix length T_{CP}. As illustrated in Figure 5.1, LTE defines two cyclic prefix lengths, the *normal* cyclic prefix and an *extended* cyclic prefix, corresponding to seven and six OFDM symbols per slot, respectively. The exact cyclic prefix lengths, expressed in the basic time unit T_s, are given in Figure 5.1. It can be noted that, in the case of the normal cyclic prefix, the cyclic prefix length for the first OFDM symbol of a slot is somewhat larger compared to the remaining OFDM symbols. The reason for this is simply to fill the entire 0.5 ms slot, as the number of basic time units T_s per slot (15360) is not divisible by seven.

The reasons for defining two cyclic prefix lengths for LTE are twofold:

- A longer cyclic prefix, although less efficient from a cyclic prefix-overhead point of view, may be beneficial in specific environments with extensive delay spread, for example, in very large cells. It is important to have in mind, though, that a longer cyclic prefix is not necessarily beneficial in the case of large cells, even if the delay spread is very extensive in such cases. If, in large cells, link performance is limited by noise rather than by signal corruption due to residual time dispersion not covered by the cyclic prefix, the additional robustness to radio-channel time dispersion, due to the use of a longer cyclic prefix, may not justify the corresponding additional energy overhead of a longer cyclic prefix.
- As is discussed in Chapter 19, the cyclic prefix in the case of MBSFN-based multicast/broadcast transmission should not only cover the main part of the actual channel time dispersion, but also the timing difference between the transmissions received from the cells involved in the MBSFN transmission. In the case of MBSFN operation, the extended cyclic prefix is therefore used.

It should be noted that different cyclic prefix lengths may be used for different subframes within a frame in case of MBSFN subframes. As discussed further in Chapter 19, MBSFN-

[2]This is valid for the "normal" downlink subframes. As described in Section 5.4, the *special subframe* present in case of TDD operation is not divided into two slots but rather into three fields.

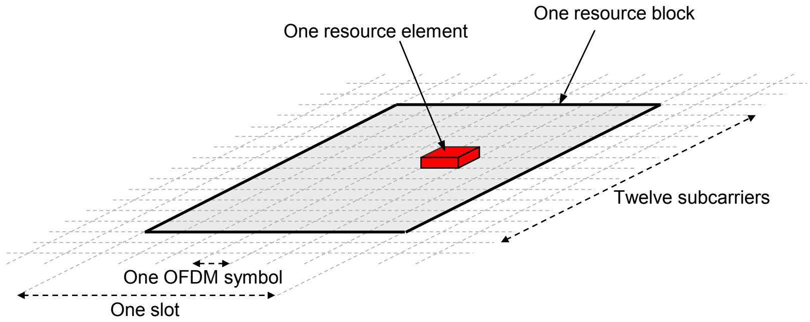

FIGURE 5.2

The LTE physical time—frequency resource.

based multicast/broadcast transmission is always confined to a limited set of subframes, in which case the use of the extended cyclic prefix, with its associated additional cyclic prefix overhead, may only be applied to these subframes.[3]

A *resource element*, consisting of one subcarrier during one OFDM symbol, is the smallest physical resource in LTE. Furthermore, as illustrated in Figure 5.2, resource elements are grouped into *resource blocks*, where each resource block consists of 12 consecutive subcarriers in the frequency domain and one 0.5 ms slot in the time domain. Each resource block thus consists of $7 \cdot 12 = 84$ resource elements in the case of a normal cyclic prefix and $6 \cdot 12 = 72$ resource elements in the case of an extended cyclic prefix.

Although resource blocks are defined over one slot, the basic time-domain unit for dynamic scheduling in LTE is one subframe, consisting of two consecutive slots. The reason for defining the resource blocks over one slot is that *distributed downlink transmission* (described in Chapter 10) and *uplink frequency hopping* (described in Chapter 7) are defined on a slot basis. The minimum scheduling unit, consisting of two time-consecutive resource blocks within one subframe (one resource block per slot), can be referred to as a *resource-block pair.*

The LTE physical-layer specifications allow for a carrier to consist of any number of resource blocks in the frequency domain, ranging from a minimum of six resource blocks up to a maximum of 110 resource blocks. This corresponds to an overall transmission bandwidth ranging from roughly 1 MHz up to in the order of 20 MHz with very fine granularity and thus allows for a very high degree of LTE bandwidth flexibility, at least from a physical-layer-specification point of view. However, as mentioned in Chapter 3, LTE radio-frequency requirements are, at least initially, only specified for a limited set of transmission bandwidths, corresponding to a limited set of possible values for the number

[3]The extended cyclic prefix is then actually applied only to the so-called *MBSFN part* of the MBSFN subframes; see Section 5.2.

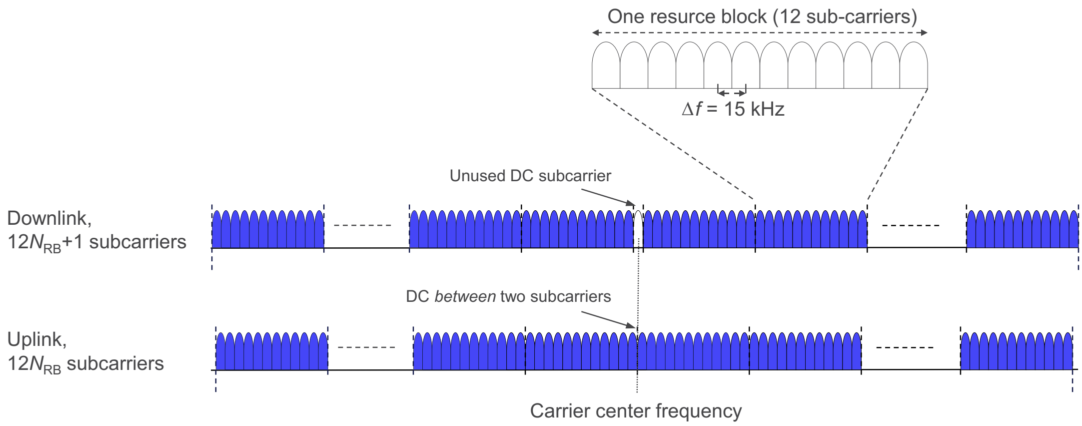

FIGURE 5.3

Frequency-domain structure for LTE.

of resource blocks within a carrier. Also note that, in LTE release 10 and later, the total bandwidth of the transmitted signal can be significantly larger than 20 MHz, up to 100 MHz in release 10 and 640 MHz in release 13, by aggregating multiple carriers, see Section 5.5.

The resource-block definition above applies to both the downlink and uplink transmission directions. However, there is a minor difference between the downlink and uplink in terms of where the carrier center frequency is located in relation to the subcarriers.

In the downlink (upper part of Figure 5.3), there is an unused *DC subcarrier* that coincides with the carrier center frequency. The reason why the DC subcarrier is not used for downlink transmission is that it may be subject to disproportionately high interference due to, for example, local-oscillator leakage.

On the other hand, in the uplink (lower part of Figure 5.3), no unused DC subcarrier is defined and the center frequency of an uplink carrier is located *between* two uplink subcarriers. The presence of an unused DC-carrier in the center of the spectrum would have prevented the assignment of the entire cell bandwidth to a single device and while still retaining the assumption of mapping to consecutive inputs of the OFDM modulator, something that is needed to retain the low-cubic-metric property of the DFTS-OFDM modulation used for uplink data transmission.

5.2 NORMAL SUBFRAMES AND MBSFN SUBFRAMES

In LTE, each downlink subframe (and the DwPTS in the case of TDD; see Section 5.4.2 for a discussion of the TDD frame structure) is normally divided into a *control region*, consisting of the first few OFDM symbols, and a *data region*, consisting of the remaining part of the subframe. The usage of the resource elements in the two regions is discussed in detail in

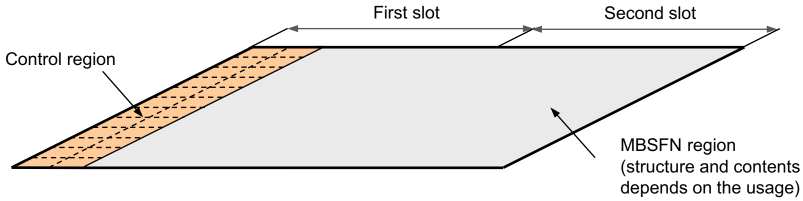

FIGURE 5.4

Resource-block structure for MBSFN subframes, assuming normal cyclic prefix for the control region and extended cyclic prefix for the MBSFN region.

Chapter 6; at this stage all we need to know is that the control region carries L1/L2 signaling necessary to control uplink and downlink data transmissions.

Additionally, already from the first release of LTE, so-called *MBSFN subframes* have been defined. The original intention with MBSFN subframes was, as indicated by the name, to support MBSFN transmission, as described in Chapter 19. However, MBSFN subframes have also been found to be useful in other contexts, for example, as part of relaying functionality as discussed in Chapter 18. Hence, MBSFN subframes are therefore better seen as a generic tool and not related to MBSFN transmission only.

An MBSFN subframe, illustrated in Figure 5.4, consists of a control region of length one or two OFDM symbols, which is in essence identical to its counterpart in a normal subframe, followed by an *MBSFN region* whose contents depend on the usage of the MBSFN subframe. The reason for keeping the control region also in MBSFN subframes is, for example, to be able to transmit control signaling necessary for uplink transmissions. All devices, from LTE release 8 and onward, are capable of receiving the control region of an MBSFN subframe. This is the reason why MBSFN subframes have been found useful as a generic tool to introduce, in a backward-compatible way, new types of signaling and transmission not part of an earlier release of the LTE radio-access specification. Such transmissions can be carried within the MBSFN region of the subframe and earlier-release devices, not recognizing these transmissions, will simply ignore them.

Information about the set of subframes that are configured as MBSFN subframes in a cell is provided as part of the system information (Chapter 11). In principle, an arbitrary pattern of MBSFN subframes can be configured with the pattern repeating after 40 ms.[4] However, as information necessary to operate the system (to be more specific, synchronization signals, system information, and paging, all of which are discussed in detail in later chapters) needs to be transmitted in order for devices to find and connect to a cell, subframes where such information is provided cannot be configured as MBSFN subframes. Therefore, subframes 0, 4, 5, and 9 for FDD and subframes 0, 1, 5, and 6 for TDD cannot be configured as MBSFN

[4]The reason for repetition time of 40 ms is that both the 10 ms frame length and the 8 ms hybrid-ARQ roundtrip time are factors in 40 ms which is important for many applications, for example, relaying; see further Chapter 18.

subframes, leaving the remaining six subframes of a frame as candidates for MBSFN subframes.

5.3 ANTENNA PORTS

Downlink multi-antenna transmission is a key technology of LTE. Signals transmitted from different antennas or signals subject to different, and for the receiver, unknown *multi-antenna precoders*, see Section 6.3, will experience different "radio channels" even if the set of antennas are located at the same site.[5]

In general, it is important for a device to understand what it can assume in terms of the relation between the radio channels experienced by different downlink transmissions. This is, for example, important in order for the device to be able to understand what reference signal(s) should be used for channel estimation for a certain downlink transmission. It is also important in order for the device to be able to determine relevant channel-state information, for example, for scheduling and link-adaptation purposes.

For this reason, the concept of *antenna port* has been introduced in the LTE specifications, defined such that *the channel over which a symbol on the antenna port is conveyed can be inferred from the channel over which another symbol on the same antenna port is conveyed*. Expressed differently, each individual downlink transmission is carried out from a specific antenna port, the identity of which is known to the device. Furthermore, the device can assume that two transmitted signals have experienced the same radio channel *if and only if* they are transmitted from the same antenna port.[6]

In practice, each antenna port can, at least for the downlink, be seen as corresponding to a specific reference signal. A device receiver can then assume that this reference signal can be used to estimate the channel corresponding to the specific antenna port. The reference signal can also be used by the device to derive detailed channel-state information related to the antenna port.

It should be understood that an antenna port is an abstract concept that does not necessarily correspond to a specific physical antenna:

- Two different signals may be transmitted in the same way from multiple physical antennas. A device receiver will then see the two signals as propagating over a single channel corresponding to the "sum" of the channels of the different antennas and the overall transmission would be seen as a transmission from a single antenna port being the same for the two signals.
- Two signals may be transmitted from the same set of antennas but with different, for the receiver unknown, antenna transmitter-side precoders. A receiver will have to see the

[5]An unknown transmitter-side precoder needs to be seen as part of the overall radio channel.

[6]For certain antenna ports, more specifically those that correspond to so-called demodulation reference signals, the assumption of same radio channel is valid only within a given subframe.

unknown antenna precoders as part of the overall channel implying that the two signals will appear as having been transmitted from two different antenna ports. It should be noted that if the antenna precoders of the two transmissions were known to be the same, the transmissions could be seen as originating from the same antenna port. The same would be true if the precoders were known to the receiver as, in that case, the precoders would not need to be seen as part of the radio channel.

5.3.1 QUASI-CO-LOCATED ANTENNA PORTS

Even if two signals have been transmitted from two different antennas, the channels experienced by the two signals may still have many *large-scale* properties in common. As an example, the channels experienced by two signals transmitted from two different antenna ports corresponding to different physical antennas at the same site will, even if being different in the details, typically have the same or at least similar large-scale properties, for example, in terms of Doppler spread/shift, average delay spread, and average gain. It can also be expected that the channels will introduce similar average delay. Knowing that the radio channels corresponding to two different antenna ports have similar large-scale properties can be used by the device receiver, for example, in the setting of parameters for channel estimation.

However, with the introduction of different types of multi-point transmission in LTE release 11, different downlink transmit antennas serving the same device may be much more geographically separated. In that case the channels of different antenna ports relevant for a device may differ even in terms of large-scale properties.

For this reason, the concept of *quasi-co-location* with respect to antenna ports was introduced as part of LTE release 11. A device receiver can assume that the radio channels corresponding to two different antenna ports have the same large-scale properties in terms of specific parameters such as average delay spread, Doppler spread/shift, average delay, and average gain *if and only if* the antenna ports are specified as being quasi-co-located. Whether or not two specific antenna ports can be assumed to be quasi-co-located with respect to a certain channel property is in some cases given by the LTE specification. In other cases, the device may be explicitly informed by the network by means of signaling if two specific antenna ports can be assumed to be quasi-co-located or not.

As the name suggests, in practice, two antenna ports will typically be "quasi-co-located" if they correspond to physical antennas at the same location while two antenna ports corresponding to antennas at different locations would typically not be "quasi-co-located." However, there is nothing explicitly stated in the specification about this and quasi-co-location is simply defined with regard to what can be assumed regarding the relation between the long-term channel properties of different antenna ports.

5.4 DUPLEX SCHEMES

Spectrum flexibility is one of the key features of LTE. In addition to the flexibility in transmission bandwidth, LTE also supports operation in both paired and unpaired spectrums

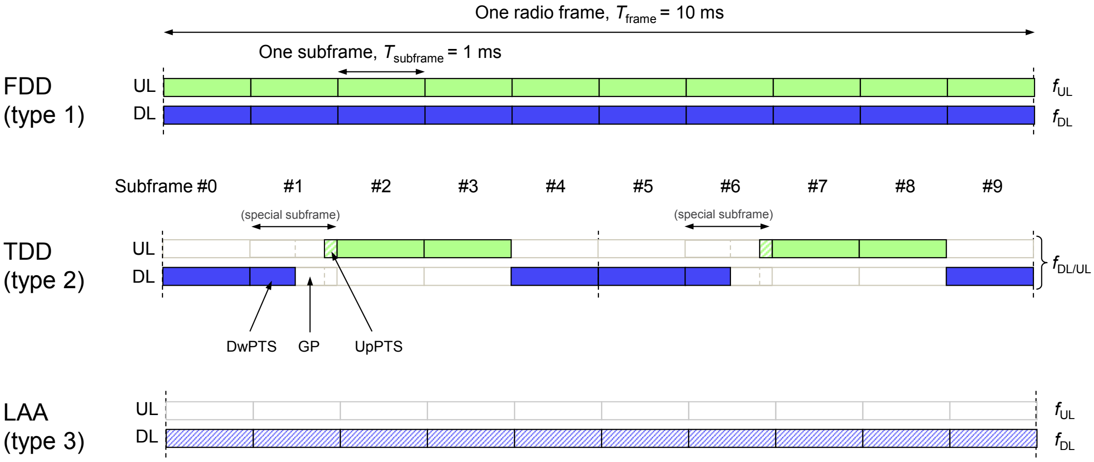

FIGURE 5.5

Uplink/downlink time–frequency structure in case of FDD and TDD.

by supporting both FDD- and TDD-based duplex operation with the time–frequency structures illustrated in Figure 5.5. This is supported through two slightly different frame structures, type 1 for FDD and type 2 for TDD. Operation in unlicensed spectrum was added in release 13, known as *license-assisted access*, and for this reason frame structure type 3 was introduced. Although the time-domain structure is, in most respects, the same for all three frame structures, there are some differences, most notably the presence of a *special subframe* in the case of frame structure type 2. The special subframe is used to provide the necessary guard time for downlink–uplink switching, as discussed in the following.

5.4.1 FREQUENCY-DIVISION DUPLEX

In the case of FDD operation (frame structure type 1) uplink and downlink are carried on different carrier frequencies, denoted f_{UL} and f_{DL} in the upper part of Figure 5.5. During each frame, there are thus ten uplink subframes and ten downlink subframes, and uplink and downlink transmission can occur simultaneously within a cell. Isolation between downlink and uplink transmissions is achieved by transmission/reception filters, known as duplex filters, and a sufficiently large *duplex separation* in the frequency domain.

Even if uplink and downlink transmission can occur simultaneously within a cell in the case of FDD operation, a device may be capable of *full-duplex* operation or only *half-duplex* operation for a certain frequency band, depending on whether or not it is capable of simultaneous transmission/reception. In the case of full-duplex capability, transmission and reception may also occur simultaneously at a device, whereas a device capable of only half-duplex operation cannot transmit and receive simultaneously. As mentioned in Chapter 3, half-duplex operation allows for simplified device implementation due to relaxed or no duplex filters. Simplified device implementation can be relevant in several cases, for example, devices for massive machine-type communication (see Chapter 20) where a low device cost is of uttermost importance. Another example is operation in certain frequency bands with a very narrow duplex gap with correspondingly challenging design of the duplex filters. In this case, full-duplex support can be *frequency-band dependent* such that a device may support only half-duplex operation in certain frequency bands while being capable of full-duplex operation in the remaining supported bands. It should be noted that full/half-duplex capability is a property of the *device*; the base station is operating in full duplex irrespective of the device capabilities.

From a network perspective, half-duplex operation has an impact on the sustained data rates that can be provided to/from a single mobile device as it cannot transmit in all uplink subframes. The cell capacity is hardly affected as typically it is possible to schedule different devices in uplink and downlink in a given subframe. No provisioning for guard periods is required as the network is still operating in full duplex and therefore is capable of simultaneous transmission and reception. The relevant transmission structures and timing relations are identical between full-duplex and half-duplex FDD and a single cell may therefore simultaneously support a mixture of full-duplex and half-duplex FDD devices. Since a half-duplex device is not capable of simultaneous transmission and reception, the scheduling decisions must take this into account and half-duplex operation can be seen as a scheduling restriction, is discussed in more detail in Chapter 9.

From a device perspective, half-duplex operation requires the provisioning of a guard period where the device can switch between transmission and reception, the length of which depends on implementation. LTE therefore supports two ways of providing the necessary guard period:

- *Half-duplex type A*, where a guard time is created by allowing the device to skip receiving the last OFDM symbol(s) in a downlink subframe immediately preceding an uplink subframe, as illustrated in Figure 5.6. Guard time for the uplink-to-downlink switch is handled by setting the appropriate amount of timing advance in the devices, implying that a base station supporting half-duplex devices need to apply a larger timing advance value for all devices compared to a full-duplex-only scenario. The type A mechanism is part of LTE since its creation.
- *Half-duplex type B*, where a whole subframe is used as guard between reception and transmission to allow for low-cost implementations with only a single oscillator that is retuned between uplink and downlink frequencies. Half-duplex type B was introduced in LTE release 12 to enable even lower cost devices for MTC applications; see Chapter 20 for more details.

5.4.2 TIME-DIVISION DUPLEX

In the case of TDD operation (frame structure type 2, middle part of Figure 5.5), there is a single carrier frequency and uplink and downlink transmissions are separated in the time domain on a cell basis. As seen in the figure, in each frame some subframes are allocated for

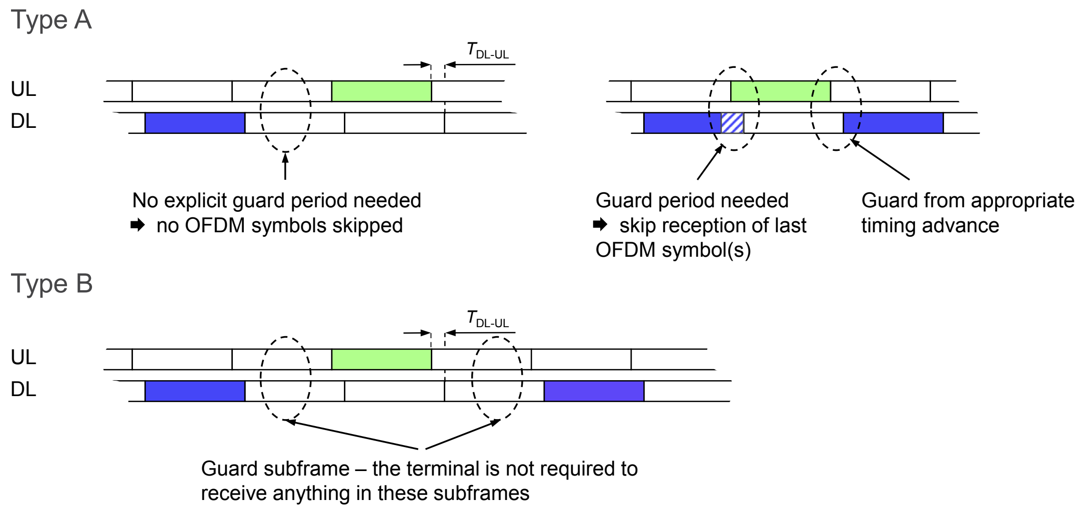

FIGURE 5.6

Guard time at the device for half-duplex FDD for type A (top) and type B (bottom).

uplink transmissions and some subframes are allocated for downlink transmission, with the switch between downlink and uplink occurring in a *special subframe* (subframe 1 and, for some uplink–downlink configurations, also subframe 6). Different asymmetries in terms of the amount of resources—that is, subframes—allocated for uplink and downlink transmission, respectively, are provided through the seven different uplink–downlink configurations illustrated in Figure 5.7. As seen in the figure, subframes 0 and 5 are always allocated for downlink transmission while subframe 2 is always allocated for uplink transmissions. The remaining subframes (except the special subframe; see the following paragraphs) can then be flexibly allocated for downlink or uplink transmission depending on the uplink–downlink configuration.

As a baseline, the same uplink–downlink configuration, provided as part of the system information and hence seldom changed, is used in each frame. Furthermore, to avoid severe interference between downlink and uplink transmissions in different cells, neighboring cells typically have the same uplink–downlink configuration. However, release 12 introduced the possibility to dynamically change the uplink–downlink configurations per frame, a feature that is further described in Chapter 15. This feature is primarily useful in small and relatively isolated cells where the traffic variations can be large and inter-cell interference is less of an issue.

As the same carrier frequency is used for uplink and downlink transmission, both the base station and the device need to switch from transmission to reception and vice versa. The switch between downlink and uplink occurs in the special subframe, which is split into three parts: a downlink part (DwPTS), a guard period (GP), and an uplink part (UpPTS).

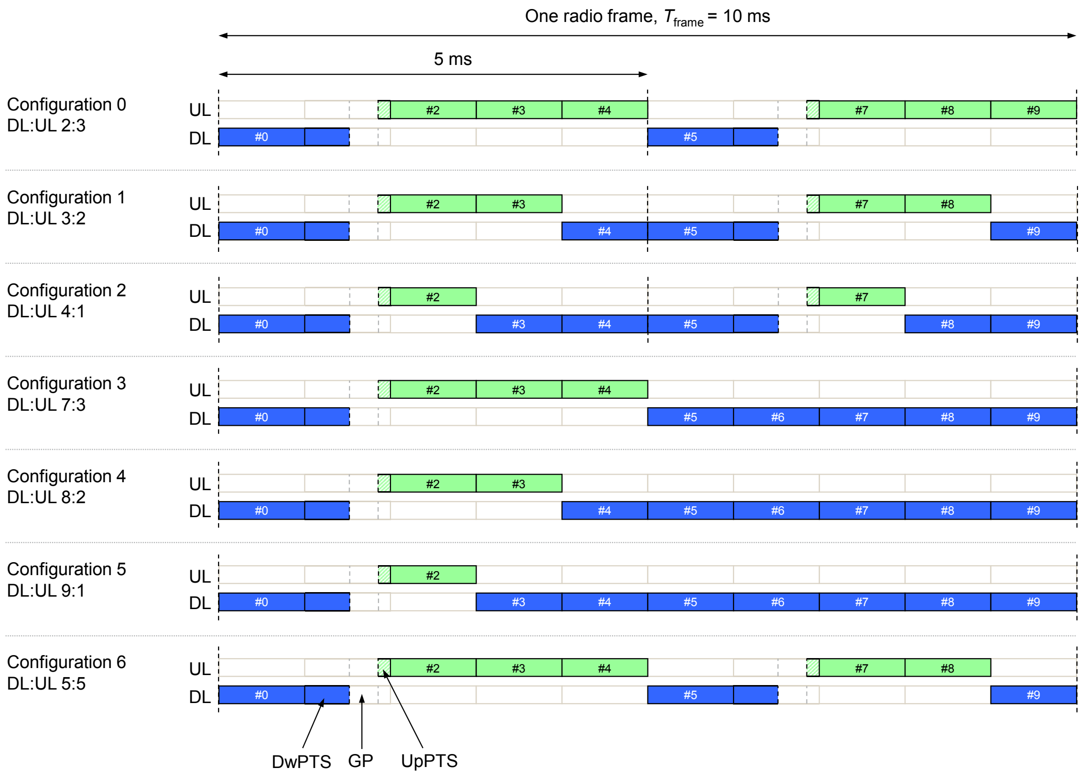

FIGURE 5.7

Different uplink–downlink configurations in case of TDD.

The DwPTS is in essence treated as a normal downlink subframe,[7] although the amount of data that can be transmitted is smaller due to the reduced length of the DwPTS compared to a normal subframe. The UpPTS, however, is not used for data transmission due to the very short duration. Instead, it can be used for channel sounding or random access. It can also be left empty, in which case it serves as an extra guard period.

An essential aspect of any TDD system is the possibility to provide a sufficiently large *guard period* (or guard time), where neither downlink nor uplink transmissions occur. This guard period is necessary for switching from downlink to uplink transmission and vice versa and, as already mentioned, is obtained from the special subframe. The required length of the guard period depends on several factors. First, it should be sufficiently large to provide the necessary time for the circuitry in base stations and the devices to switch from downlink to

[7]For the shortest DwPTS duration of three OFDM symbols, DwPTS cannot be used for PDSCH transmission.

uplink. Switching is typically relatively fast, of the order of 20 ms, and in most deployments does not significantly contribute to the required guard time.

Secondly, the guard time should also ensure that uplink and downlink transmissions do not interfere at the base station. This is handled by advancing the uplink timing at the devices such that, at the base station, the last uplink subframe before the uplink-to-downlink switch ends before the start of the first downlink subframe. The uplink timing of each device can be controlled by the base station by using the timing advance mechanism, as elaborated in Chapter 7. Obviously, the guard period must be large enough to allow the device to receive the downlink transmission and switch from reception to transmission before it starts the (timing-advanced) uplink transmission. In essence, some of the guard period of the special subframe is "moved" from the downlink-to-uplink switch to the uplink-to-downlink switch by the timing-advance mechanism. This is illustrated in Figure 5.8. As the timing advance is proportional to the distance to the base station, a larger guard period is required when operating in large cells compared to small cells.

Finally, the selection of the guard period also needs to take interference between base stations into account. In a multi-cell network, inter-cell interference from downlink transmissions in neighboring cells must decay to a sufficiently low level before the base station can start to receive uplink transmissions. Hence, a larger guard period than that motivated by the cell size itself may be required as the last part of the downlink transmissions from distant base stations may otherwise interfere with uplink reception. The amount of guard period depends on the propagation environments, but in some cases the inter-base-station interference is a non-negligible factor when determining the guard period.

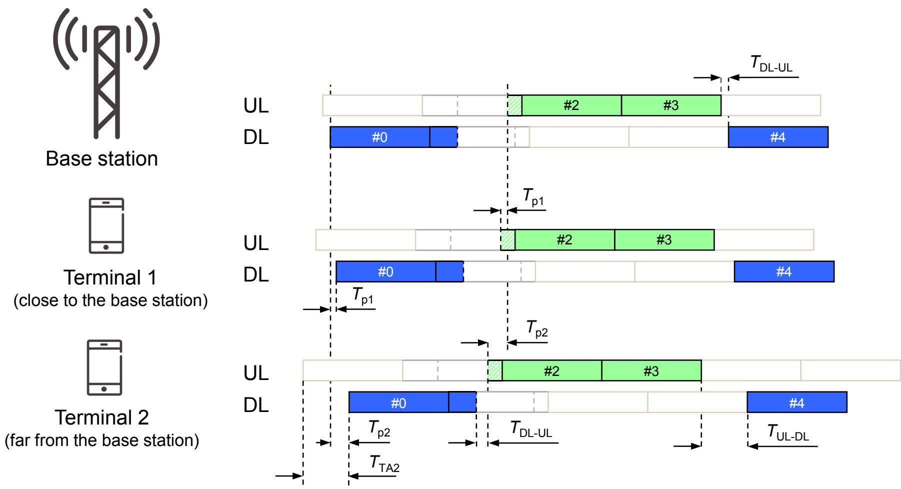

FIGURE 5.8

Timing relation for TDD operation.

Table 5.1 Resulting Guard Period in OFDM Symbols for Different DwPTS and UpPTS Lengths (Normal Cyclic Prefix)

DwPTS	12	11		10		9		6[a]	3	
GP	1	1	2	2	3	3	4	6	9	10
UpPTS	1	2	1	2	1	2	1	2	2	1

[a]*The 6:6:2 configuration was added in release 11 to improve efficiency when coexisting with some common TD-SCDMA configurations (devices prior to release 11 use 3:9:2).*

From the discussion in the preceding paragraphs, it is clear that a sufficient amount of configurability of the guard period is needed to meet different deployment scenarios. Therefore, a set of DwPTS/GP/UpPTS configurations is supported as shown in Table 5.1, where each configuration corresponds to a given length of the three fields in the special subframes. The DwPTS/GP/UpPTS configuration used in the cell is signaled as part of the system information.

5.4.3 LTE AND TD-SCDMA COEXISTENCE

In addition to supporting a wide range of different guard periods, an important aspect in the design of TDD in LTE was to simplify coexistence with, and migration from, systems based on the 3GPP TD-SCDMA standard.[8] Basically, to handle inter-system interference from two different but co-sited TDD systems operating close in frequency, it is necessary to align the switch-points between the two systems. Since LTE supports configurable lengths of the DwPTS field, the switch-points of LTE and TD-SCDMA (or any other TDD system) can be aligned, despite the different subframe lengths used in the two systems. Aligning the switch-points between TD-SCDMA and LTE is the technical reason for splitting the special subframe into the three fields DwPTS/GP/UpPTS instead of locating the switch-point at the subframe boundary. An example of LTE/TD-SCDMA coexistence is given in Figure 5.9.

The set of possible lengths of DwPTS/GP/UpPTS is selected to support common coexistence scenarios, as well as to provide a high degree of guard-period flexibility for the reasons discussed earlier in this chapter. The UpPTS length is one or two OFDM symbols and the DwPTS length can vary from three[9] to twelve OFDM symbols, resulting in guard periods ranging from one to ten OFDM symbols. The resulting guard period for the different DwPTS and UpPTS configurations supported is summarized in Table 5.1 for the case of normal cyclic prefix. As discussed earlier in this chapter, the DwPTS can be used for downlink data transmission, while the UpPTS can be used for sounding or random access only, due to its short duration.

[8]TD-SCDMA is one of three TDD modes defined by 3GPP for UTRA TDD and the only one having been deployed on a larger scale

[9]The smallest DwPTS length is motivated by the location of the primary synchronization signal in the DwPTS (see Chapter 11).

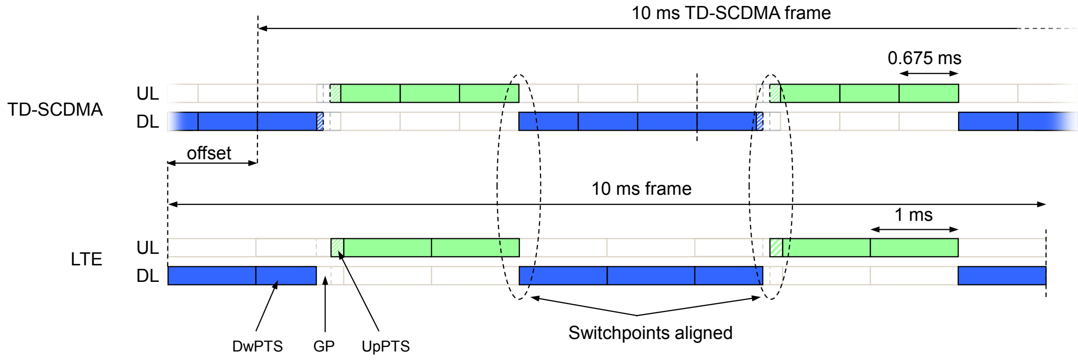

FIGURE 5.9

Coexistence between TD-SCDMA and LTE.

5.4.4 LICENSE-ASSISTED ACCESS

License-assisted access, that is exploiting unlicensed spectrum as a complement to, and assisted by, licensed spectrum, was introduced in release 13 targeting the 5 GHz band. This band is an unpaired band and hence TDD is the relevant duplex scheme. However, since listen before talk, that is, checking whether the spectrum resource is available prior to transmission, is required in some regions and highly beneficial from a Wi-Fi coexistence point of view, frame structure type 2 with its fixed split into uplink and downlink cannot be used. Furthermore, as unlicensed spectrum can be used for downlink only and not uplink in release 13, there is a need for a third frame structure suitable for starting downlink transmissions in any subframe subject to listen before talk. From most perspectives, frame structure type 3 has the same mapping of signals and channels as frame structure type 1.

License-assisted access is described in detail in Chapter 17.

5.5 CARRIER AGGREGATION

The possibility for *carrier aggregation* was introduced in LTE release 10 with enhancements in the following releases. In the case of carrier aggregation, multiple LTE carriers, each with a bandwidth up to 20 MHz, can be transmitted in parallel to/from the same device, thereby allowing for an overall wider bandwidth and correspondingly higher per-link data rates. In the context of carrier aggregation, each carrier is referred to as a *component carrier*[10] as, from an RF point of view, the entire set of aggregated carriers can be seen as a single (RF) carrier.

Up to five component carriers, possibly of different bandwidths up to 20 MHz, can be aggregated allowing for overall transmission bandwidths up to 100 MHz. In release 13 this

[10]In the specifications, the term "cell" is used instead of "component carrier," but as the term "cell" is something of a misnomer in the uplink case, the term "component carrier" is used.

was extended to 32 carriers allowing for an overall transmission bandwidth of 640 MHz, primarily motivated by the possibility for large bandwidths in unlicensed spectrum. A device capable of carrier aggregation may receive or transmit simultaneously on multiple component carriers. Each component carrier can also be accessed by an LTE device from earlier releases, that is, component carriers are *backward compatible*. Thus, in most respects and unless otherwise mentioned, the physical-layer description in the following chapters applies to each component carrier separately in the case of carrier aggregation.

Carrier aggregation is described in more detail in Chapter 12.

5.6 FREQUENCY-DOMAIN LOCATION OF LTE CARRIERS

In principle, an LTE carrier could be positioned anywhere within the spectrum and, actually, the basic LTE physical-layer specification does not say anything about the exact frequency location of an LTE carrier, including the frequency band. However, in practice, there is a need for restrictions on where an LTE carrier can be positioned in the frequency domain:

- In the end, an LTE device must be implemented and RF-wise such a device can only support certain frequency bands. The frequency bands for which LTE is specified to operate are discussed in Chapter 2.

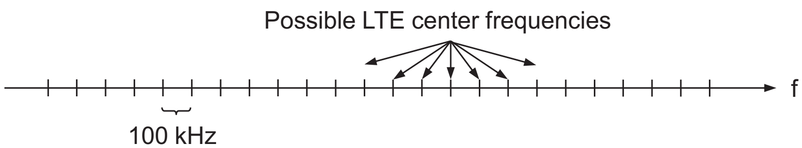

FIGURE 5.10

LTE carrier raster.

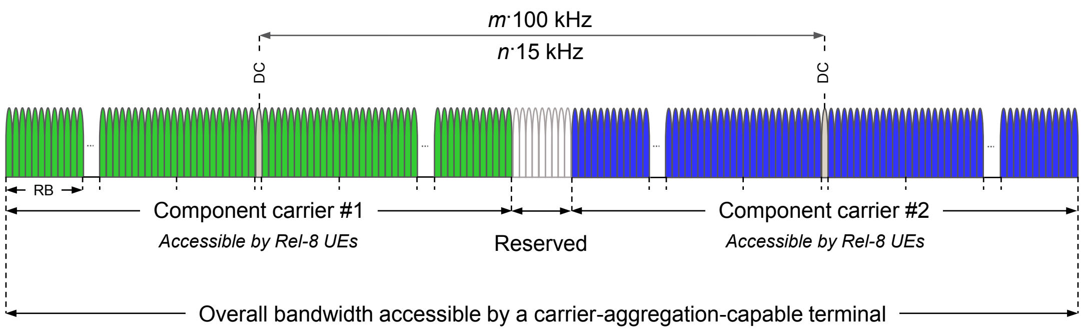

FIGURE 5.11

LTE carrier raster and carrier aggregation.

- After being activated, an LTE device has to search for a network-transmitted carrier within the frequency bands supported by the device. In order for that carrier search to not take an unreasonably long time, there is a need to limit the set of frequencies to be searched.

For this reason, it is assumed that, within each supported frequency band, LTE carriers may exist on a 100 kHz carrier raster or carrier grid, that is, the carrier center frequency can be expressed as $m \cdot 100$ kHz, where m is an integer (see in Figure 5.10).

In the case of carrier aggregation, multiple carriers can be transmitted to/from the same device. In order for the different component carriers to be accessible by earlier-release devices, each component carrier should fall on the 100 kHz carrier grid. However, in the case of carrier aggregation, there is an additional constraint that the carrier spacing between adjacent component carriers should be a multiple of the 15 kHz subcarrier spacing to allow transmission/reception with a single FFT.[11] Thus, in the case of carrier aggregation, the carrier spacing between the different component carriers should be a multiple of 300 kHz, the smallest carrier spacing being a multiple of both 100 kHz (the raster grid) and 15 kHz (the subcarrier spacing). A consequence of this is that there will always be a small gap between two component carriers, even when they are locateds as close as possible to each other, as illustrated in Figure 5.11.

[11]This is obviously only relevant for component carriers that are contiguous in the frequency domain. Furthermore, in case of independent frequency errors between component carriers, separate FFTs may be needed at the receiver.