CHAPTER

DEVICE-TO-DEVICE CONNECTIVITY

21

21.1 OVERVIEW

Support for direct *device-to-device* (D2D) connectivity was first introduced in release 12 of the 3GPP LTE specifications. As the name suggests, direct D2D connectivity implies a *direct* radio link between devices.

For obvious reasons, D2D connectivity is only possible between devices in relatively close proximity of each other. Services based on D2D connectivity are therefore sometimes also referred to as *proximity services*, or "*ProSe*."

One reason for introducing support for D2D connectivity in the LTE specifications was an explicitly expressed interest to use the LTE radio-access technology for public-safety-related communication services. For the public-safety use case it is seen as important and in some cases even a requirement to support at least a limited degree of local connectivity between devices even when there is no infrastructure available. Thus, support for direct D2D connectivity was seen as a critical component to ensure LTE fulfillment of all the requirements of the public-safety use case. However, support for D2D connectivity may also enable new types of commercial services, thus expanding the usability of the LTE radio-access technology in general.

LTE distinguishes between two types of D2D connectivity:

- *D2D communication*, implying exchange of user data directly between devices. At this stage, including also LTE release 13, D2D communication is only targeting the public-safety use case. Details of D2D communication are provided in Section 21.2.
- *D2D discovery*, implying the possibility for a device to transmit signals that enable its presence to be directly detected by other devices in its neighborhood.[1] In contrast to D2D communication, D2D discovery has already from the beginning targeted a wider range of use cases, including commercial services. Details of D2D discovery are provided in Section 21.3.

For a direct D2D radio link, the notion of downlink and uplink transmission directions is obviously not applicable. Instead, 3GPP has introduced the term *sidelink* to characterize the

[1]As described in Section 21.3, LTE discovery is not really about discovering devices as such but rather about the discovering *services* announced by devices.

4G, LTE-Advanced Pro and The Road to 5G. http://dx.doi.org/10.1016/B978-0-12-804575-6.00021-2

direct D2D link. In order to align with 3GPP terminology we will from now on use the term sidelink rather than D2D.

21.1.1 SIDELINK TRANSMISSION

LTE sidelink connectivity should be possible in normal cellular (LTE) spectrum, including both paired (FDD) and unpaired (TDD) spectrum. Consequently, good co-existence between sidelink transmissions and normal cellular (downlink/uplink) transmissions in the same spectrum has been a key requirement in the design of LTE sidelink connectivity.

However, sidelink connectivity may also take place in spectrum not used by commercial cellular networks. An example of this is the public-safety use case for which specific spectrum has been assigned in several countries/regions.

In case of paired spectrum, sidelink connectivity takes place in the uplink part of the spectrum. Consequently, devices supporting sidelink connectivity for a certain FDD band need to be able to receive also in the uplink band.

There are several reasons why sidelink connectivity takes place in the uplink band in case of FDD spectrum:

- Regulatory rules are typically concerned with what and how devices transmit but do not restrict what and how devices receive. From a regulatory point of view, sidelink connectivity in uplink spectrum is therefore more straightforward compared to sidelink connectivity in downlink spectrum, as the later would imply device transmission in spectrum assumed to be used for network transmission.
- From a device-implementation point of view, it is less complex to include additional receiver functionality (support for reception in an uplink band) compared to the additional transmitter functionality needed in case sidelink connectivity would take place in downlink bands.

In a similar way, in case of TDD spectrum sidelink connectivity is assumed to take place in uplink subframes. It should be noted though that, while the 3GPP specifications define if a specific (FDD) frequency band is for downlink or uplink, the TDD downlink/uplink configuration is defined by the network, in principle on cell level. As a consequence, at least in principle different cells may have different downlink/uplink configurations, something which needs to be taken into account, for example, in case of sidelink connectivity between devices in different cells.

It should also be understood that sidelink connectivity is fundamentally unidirectional in the sense that all current LTE sidelink transmissions are, essentially, broadcast transmissions with, for example, no associated control signaling in the opposite direction. There may of course be sidelink transmissions from a device A received by a device B and, simultaneously, sidelink transmissions from device B received by device A. But these are then, radio-wise, completely independent transmissions.

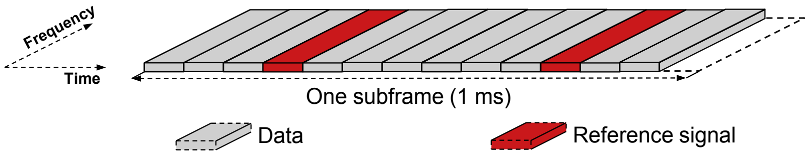

FIGURE 21.1

Subframe structure for sidelink transmission.

In addition to using uplink spectrum, sidelink connectivity also reuses the basic uplink transmission structure, more specifically the basic structure of PUSCH transmission. Thus, all sidelink transmissions, with the exception of sidelink synchronization signals (SLSS), see Section 21.4, are based on DFT-spread OFDM with a subframe structure as illustrated in Figure 21.1. Note that, in case of sidelink transmission, the last OFDM symbol of the subframe is not transmitted. This is done in order to create the guard time needed when switching between sidelink transmission and sidelink reception, as well as between sidelink transmission/reception and regular uplink transmission.

21.1.2 IN-COVERAGE VS. OUT-OF-COVERAGE SIDELINK CONNECTIVITY

As illustrated in Figure 21.2, devices involved in sidelink connectivity may be under network *coverage* ("in-coverage" scenario). However, sidelink connectivity is also possible for devices outside of network coverage ("out-of-coverage" scenario). There could also be situations when some devices involved in sidelink connectivity are under network coverage and some devices are outside network coverage. For the in-coverage scenario, the device receiving a sidelink transmission may be within the same cell as the transmitting device (intra-cell) or in different cells (inter-cell).

For release 12, only sidelink communication was supported out of coverage while sidelink discovery was only possible under network coverage. However, support for out-of-coverage sidelink discovery for the public-safety use case has recently been introduced as part of 3GPP release 13.

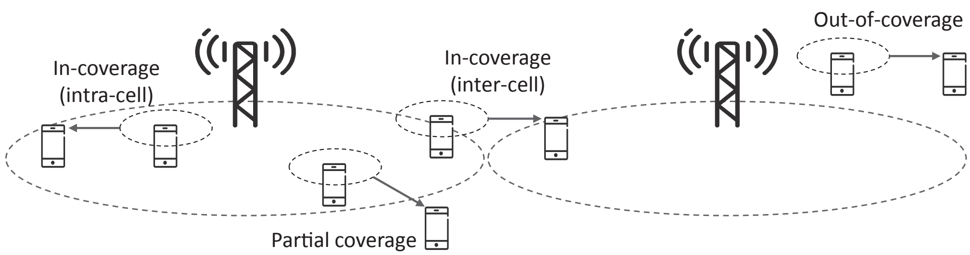

FIGURE 21.2

Different coverage scenarios for sidelink connectivity.

If a device is in coverage or out of coverage will, for example, impact how it acquire its transmission timing and the configuration parameters needed for proper sidelink connectivity as will be discussed in more details in the following.

For devices under network coverage, sidelink connectivity can take place in RRC_CONNECTED state, that is, when the device has an RRC connection to the network. However, sidelink connectivity can also take place in RRC_IDLE state, in which case the device does not have a dedicated connection to the network. It should be noted that being in RRC_IDLE state is not the same thing as being out of coverage. A device in RRC_IDLE state may still be under network coverage and will then have access to, for example, the network system information even if there is no RRC connection established.

21.1.3 SIDELINK SYNCHRONIZATION

Before devices can establish sidelink connectivity, they should be reasonably well synchronized to each other and to the overlaid network if present.

One reason for this is to ensure that sidelink transmissions will take place within intended time–frequency resources, thereby reducing the risk for uncontrolled interference to other sidelink and non-sidelink (cellular) transmissions in the same band.

As indicated in Figure 21.3, a device under network coverage should use the ordinary cell synchronization signals (PSS/SSS, see Chapter 11) of the serving cell (RRC_CONNECTED state) or the cell the device is camping on (RRC_IDLE state) as timing reference for its sidelink transmissions.

However, to allow for network control of transmission timing to extend beyond the area of direct network coverage LTE sidelink connectivity also includes the possibility for devices to transmit special *sidelink synchronization signals* (SLSSs). A device under network coverage may transmit SLSS in line with the transmission timing acquired from the network. This signal can then be received and used as timing reference for sidelink transmissions by near-by out-of-coverage devices. These devices can then, in turn, transmit their own SLSS that can be

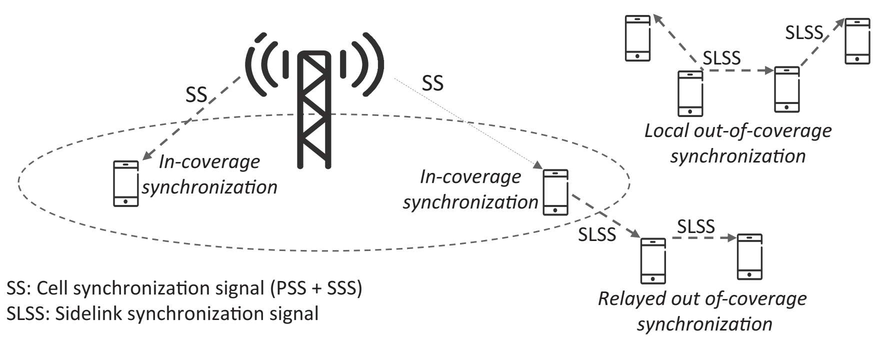

FIGURE 21.3

Transmission-timing acquisition for sidelink transmissions.

detected and used as timing references by other out-of-coverage devices. In this way, the area over which devices are synchronized to and derive their transmission timing from the overlaid network can be further expanded beyond the area of direct network coverage.

A device not within network coverage and not detecting any sufficiently strong SLSS will autonomously transmit SLSS which can then be detected and forwarded by other out-of-coverage devices. In this way, local synchronization between out-of-coverage devices can be achieved even without the presence of an overlaid network.

In addition to its function as a timing reference for sidelink transmissions for out-of-coverage devices, a SLSS can also serve as a timing reference for sidelink *reception*.

To ease the reception of sidelink transmissions, a receiving device should preferably have good knowledge of the timing of the signal to be received. For sidelink connectivity between devices using the same transmission-timing reference, for example, in case of in-coverage devices having the same serving cell, a receiving device can use its own transmission timing also for reception.

To enable sidelink connectivity between devices that do not rely on the same reference for transmission timing, for example, sidelink connectivity including devices in different non-time-aligned cells, a device may transmit SLSS in parallel to its other sidelink transmissions. These synchronization signals can then be used as reference for *reception* timing by receiving devices.

An example of this is illustrated in Figure 21.4. In this case, device A uses the synchronization signal of its serving cell (SS_A) as timing reference for its sidelink transmissions. Similarly, device B uses SS_B as timing reference for its sidelink transmissions. However, as timing reference for the reception of sidelink transmissions from device A, device B will use the synchronization signal $SLSS_A$ transmitted by device A and derived from SS_A. Likewise, device A will use $SLSS_B$ as timing reference for the reception of sidelink transmissions from device B.

Further details of sidelink synchronization, including details of the structure of SLSS, are provided in Section 21.4.

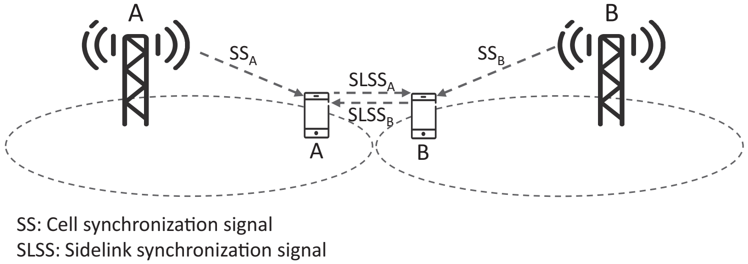

FIGURE 21.4

Use of sidelink synchronization signals (SLSS) as timing references for sidelink reception.

21.1.4 CONFIGURATION FOR SIDELINK CONNECTIVITY

Before a device can take part in sidelink connectivity, it has to be properly configured. Such configuration includes, for example, parameters defining the set of resources (subframes and resource blocks) that are available for different types of sidelink transmission.

Sidelink-related configuration parameters are partly provided as part of the cell system information, see Chapter 11. More specifically, two new SIBs have been introduced for sidelink-related configuration parameters:

- SIB18 for configuration parameters related to sidelink communication.
- SIB19 for configuration parameters related to sidelink discovery.

In addition to this *common configuration* provided via the cell system information, devices in RRC_CONNECTED state that are to engage in sidelink connectivity will also be individually configured by means of dedicated RRC signaling.

Configuration by means of system information or dedicated RRC signaling is obviously not possible for devices that are not under network coverage. Such devices instead have to rely on *pre-configured* sidelink-related configuration parameters. This pre-configuration essentially serves the same purpose as the common configuration provided as part of the sidelink-related system information.

An out-of-coverage device may, for example, have been provided with the pre-configured parameters at an earlier stage when it was under network coverage. Other possibilities include providing the pre-configuration on the SIM card or hard-coded into the device. Note that out-of-coverage operation is currently only targeting the public-safety use case. Out-of-coverage operation is thus typically associated with special devices/subscriptions.

21.1.5 ARCHITECTURE FOR SIDELINK

Figure 21.5 illustrates the network architecture related to sidelink connectivity. To support sidelink connectivity a new *ProSe Function* has been introduced in the core network together with a number of new network interfaces. Among these interfaces, PC5 corresponds to the

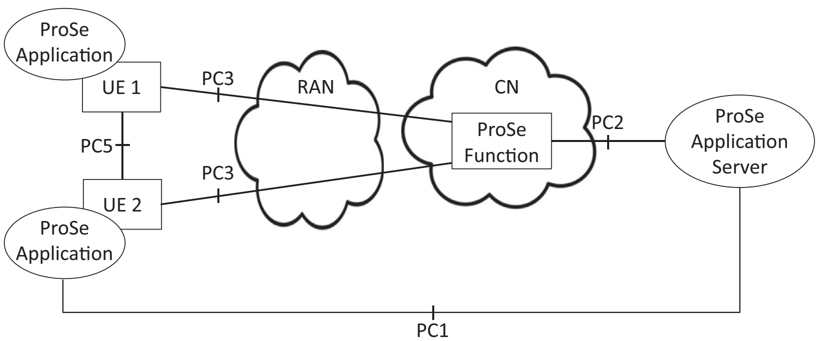

FIGURE 21.5

Architecture for sidelink (ProSe) connectivity.

direct link between devices while PC3 is the interface between sidelink-capable devices and the ProSe Function.

The ProSe Function is responsible for all sidelink functionality within the core network. It, for example, provides devices with the parameters needed to establish sidelink connectivity (discovery or communication). The ProSe Function also provides the mapping between discovery message codes and the actual discovery message, see Section 21.3.

21.1.6 SIDELINK CHANNEL STRUCTURE

Figure 21.6 illustrates the channel structure related to sidelink connectivity, including logical channels, transport channels and physical channels/signals.

The *sidelink traffic channel* (STCH) is the logical channel carrying user data for sidelink communication. It is mapped to the *sidelink shared channel* (SL-SCH) transport channel which, in turn, is mapped to the *physical sidelink shared channel* (PSSCH). In parallel to the PSSCH, there is the *physical sidelink control channel* (PSCCH) carrying *sidelink control information* (SCI) which enables a receiving device to properly detect and decode the PSSCH.

The *sidelink discovery channel* (SL-DCH) is the transport channel used for discovery announcements. On the physical layer, it is mapped to the *physical sidelink discovery channel* (PSDCH). Note that there is no logical channel related to sidelink discovery, that is, the discovery message is inserted directly into the SL-DCH transport block on the MAC layer. There are thus no RLC and PDCP layers for sidelink discovery.

Finally, sidelink synchronization is based on two signals/channels:

- The already mentioned SLSS which is associated with a specific *sidelink identity* (SLI).
- The *sidelink broadcast control channel* (S-BCCH) with corresponding transport channel (the *sidelink broadcast channel*, SL-BCH) and physical channel (the *physical sidelink broadcast channel*, PSBCH). This channel is used to convey some very basic sidelink-related "system information," referred to as the sidelink master information block (SL-MIB), between devices, see further Section 21.4.2.

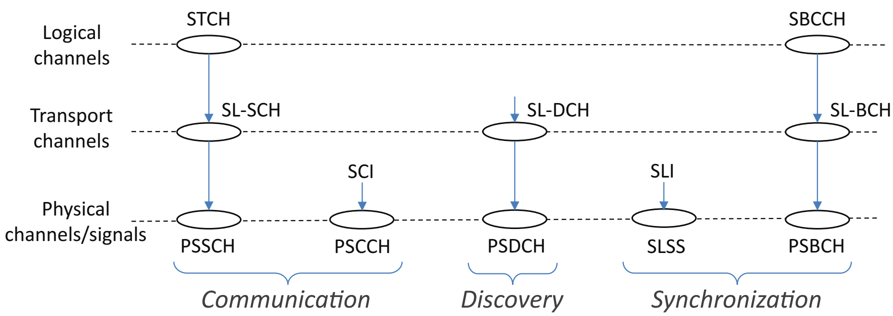

FIGURE 21.6

Sidelink channel structure.

21.2 SIDELINK COMMUNICATION

As already mentioned, sidelink communication implies the exchange of user data directly between close-by devices. In release 12, sidelink communication is limited to *group communication*. In practice this implies that

- the sidelink transmission is broadcast by the device with no assumptions regarding the link properties related to a certain receiving device,
- the sidelink transmission may be received and decoded by any sidelink-communication-capable device in the proximity of the transmitting device, and
- a *group identity* included in the control part of the sidelink transmission allows for a receiving device to determine if it is among the intended receivers of the data.

It should be noted that nothing prevents the group of devices involved in the sidelink communication to consist of only two devices, implying that there is, in practice, only a single intended receiver.

As previously mentioned, sidelink communication is based on two physical channels:

- The *physical sidelink shared channel* (PSSCH) carries the actual transport-channel (SL-SCH) data.
- The *physical sidelink control channel* (PSCCH) carries control information that enables receiving devices to properly detect and decode the PSSCH.

The PSCCH thus serves a similar purpose as the PDCCH/EPDCCH (Chapter 6) which, among other things, carries control information that enables receiving devices to properly detect and decode a corresponding PDSCH carrying downlink transport-channel data.

21.2.1 RESOURCE POOLS AND ASSIGNMENT/SELECTION OF TRANSMISSION RESOURCES

For sidelink communication (as well as for sidelink discovery, see Section 21.3), the concept of *resource pools* has been introduced. Simply speaking, a resource pool is a set of physical resources, in practice subframes and resource blocks, *available* to a device for sidelink transmissions. The exact set of resources to use for a specific sidelink transmission is then assigned/selected from the resource pool.

There are different ways by which a device can be configured with a resource pool:

- Resource pools can be individually configured via dedicated RRC signaling for devices in RRC_CONNECTED mode.
- Common resource pools can be provided by means of the sidelink-specific system information (SIB18 in case of sidelink communication).
- There may be pre-configured resource pools to be used by out-of-coverage devices.

For sidelink communication each resource pool consists of:

- a *PSCCH subframe pool* defining a set of subframes available for PSCCH transmission;
- a *PSCCH resource-block pool* defining a set of resource blocks available for PSCCH transmission within the PSCCH subframe pool;
- a *PSSCH subframe pool* defining a set of subframes available for PSSCH transmission;
- a *PSSCH resource-block pool* defining a set of resource blocks available for PSSCH transmission within the PSSCH subframe pool.

There are two types or *modes* of sidelink communication. The two modes differ in terms of how a device is assigned or selects the exact set of resources to use for the sidelink transmission from a configured resource pool. This includes resources for PSCCH transmission as well as for the actual data (transport-channel) transmission using PSSCH:

- In case of sidelink communication mode 1, a device is explicitly assigned, by means of a *scheduling grant* received from the network, a specific set of PSCCH/PSSCH resources.
- In case of sidelink communication mode 2, a device by itself selects the set of PSCCH/PSSCH resources.

As it relies on explicit scheduling grants provided by the network, mode 1 sidelink communication is only possible for in-coverage devices in RRC_CONNECTED state. In contrast, mode 2 sidelink communication is possible in coverage as well as out of coverage and in both RRC_IDLE and RRC_CONNECTED state.

21.2.2 PHYSICAL SIDELINK CONTROL CHANNEL PERIODS

In the time domain, sidelink communication is based on so-called *PSCCH periods*. Each SFN period, see Chapter 11, consisting of 1024 frames or 10240 subframes, is divided into equal-lengths PSCCH periods.

If the set of resources to be used for transmission is explicitly assigned by the network, that is, in case of sidelink communication mode 1, the assignment is carried out on a PSCCH-period basis. Similarly, if a device, by itself, selects the transmission resources (sidelink communication mode 2), the selection is done on a PSCCH-period basis.

In case of FDD, the length of the PSCCH period can be configured to 40, 80, 160, or 320 subframes. In case of TDD, the set of possible lengths for the PSCCH period depends on the downlink/uplink configuration.

21.2.3 SIDELINK CONTROL INFORMATION/PHYSICAL SIDELINK CONTROL CHANNEL TRANSMISSION

PSCCH is transmitted once every PSCCH period. As already mentioned, the PSCCH carries control information, referred to as *sidelink control information* (SCI), which enables a receiving device to properly detect and decode the data transmission on PSSCH. The SCI

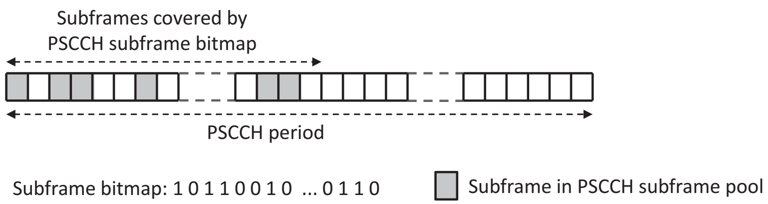

FIGURE 21.7

PSCCH subframe pool within a PSCCH period.[2]

includes, for example, information about the time−frequency resources (subframes and resource blocks) used for the PSSCH transmission. The content of the SCI are described in more detail in Section 21.2.5 after a discussion on the structure of PSSCH transmission.

Channel coding and modulation for SCI is done in essentially the same way as for DCI (Chapter 6) and consists of the following steps:

- 16-bit CRC calculation;
- rate 1/3 tail-biting convolutional coding;
- rate matching to match to the number of coded bits to the size of the PSCCH resource;
- bit-level scrambling with a predefined seed;
- QPSK modulation.

The modulated symbols are then DFT precoded before being mapped to the physical resources (subframes and resource blocks) assigned/selected for the PSCCH transmission.

The *PSCCH subframe pool*, that is, the set of subframes *available* for PSCCH transmission within each PSSCH period is given by a subframe bitmap provided as part of the sidelink configuration, see Figure 21.7.[2] In case of sidelink connectivity in FDD spectrum, the bitmap is of length 40. For TDD, the length of the bitmap depends on the downlink/uplink configuration.

The *PSCCH resource-block pool*, that is, the set of resource blocks *available* for PSCCH transmission within the subframe pool, consists of two equal-size sets of frequency-wise consecutive resource blocks, see Figure 21.8. The resource-block pool can thus be fully described by

- the index S_1 of the first resource block in the “lower” set of resource blocks;
- the index S_2 of the last resource block in the “upper” set of resource blocks;
- the number M of resource blocks in each of the two sets.

As illustrated in Figure 21.9, a PSCCH transmission is carried out over two subframes and within one resource block pair[3] in each subframe. Exactly what subframes and resource

[2]Note that the figure assumes sidelink communication in paired/FDD spectrum. In case of unpaired/TDD spectrum, the bitmap only covers the uplink subframes as defined by the current DL/UL configuration.

[3]Remember that one subframe consists of two resource blocks.

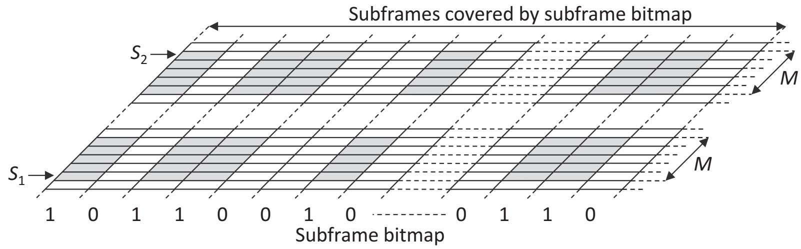

FIGURE 21.8

Structure of PSCCH resource pool.

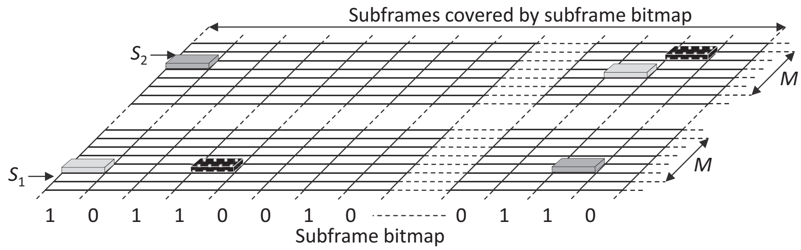

FIGURE 21.9

PSCCH transmission.

blocks, within the configured resource pool, to use for a certain PSCCH transmission is jointly given by a parameter n_{PSCCH}. n_{PSCCH} is either provided in the scheduling grant delivered by the network (for sidelink communication mode 1) or autonomously selected by the transmitting device (sidelink communication mode 2).

The mapping from n_{PSCCH} to actual set of PSCCH resources is such that if the transmission in the first subframe takes place in the lower set of resource blocks, the transmission in the second subframe will take place in the upper set of resource blocks and vise versa. The mapping is also such that if two different values of n_{PSCCH} imply mapping to the same first subframe, the second transmission will take place in different subframes or vise versa. Thus, PSCCH transmissions corresponding to different values of n_{PSCCH} will, time-wise, only collide in one of the two subframes. This has two benefits:

- Due to near-far effects, simultaneous sidelink transmissions from multiple devices in the same subframe may severely interfere with each other even if they are frequency-wise separated, that is, taking place in different resource blocks. The PSCCH mapping ensures that such collisions will only occur in one of the two subframes as long as the devices have been assigned or selected different values for n_{PSCCH}.
- A device cannot transmit and receive PSCCH in the same subframe. The PSCCH mapping ensures that a device could still transmit and receive PSCCH *in the same*

PSCCH period, assuming that different values of n_{PSCCH} are used for the two transmissions.

21.2.4 SIDELINK SHARED CHANNEL/PHYSICAL SIDELINK SHARED CHANNEL TRANSMISSION

Actual transport channel (SL-SCH) data is transmitted in form of transport blocks on the PSSCH physical channel. Each transport block is transmitted over four consecutive subframes within the PSSCH subframe pool. Transmission of *M* transport blocks within a PSCCH period thus requires 4*M* subframes. Note that a single SCI on PSCCH carries control information related to PSSCH transmission for the entire PSCCH period. This is in contrast to DCI which normally only defines the PDSCH transmission within the same subframe.

Channel-coding and modulation for SL-SCH is done in the same way as for uplink (UL-SCH) transmission (Chapter 7) and consists of the following steps:

- CRC insertion;
- code-block segmentation and per-code-block CRC insertion;
- rate 1/3 Turbo coding;
- rate matching (based on physical-layer hybrid-ARQ functionality);
- bit-level scrambling;
- data modulation (QPSK/16QAM).

The rate matching matches the set of coded bits to the size of the physical resource assigned/selected for the transmission of the transport block, taking the modulation scheme into account. There is no Hybrid ARQ for SL-SCH. However, rate matching and mapping of a coded transport block to the four subframes is done in the same way as the selection of redundancy versions for Hybrid-ARQ retransmissions.

The bit-level scrambling depends on the group identity, that is, the identity of the group that the sidelink transmission targets.

PSSCH data modulation is limited to QPSK and 16QAM. The network may impose a specific modulation scheme to use for PSSCH transmission as part of the sidelink configuration. If the network does not impose a specific modulation scheme, the transmitting device autonomously selects the modulation scheme. Information about the assigned/selected modulation scheme is then provided to receiving devices as part of the SCI.

After channel coding and modulation, DFT precoding is applied followed by mapping to the physical resource assigned/selected for the PSSCH transmission.

In case of sidelink communication mode 1, the PSSCH subframe pool, that is, the set of subframe *available* for PSCCH transmission, consists of all uplink subframes after the last subframe of the PSCCH subframe pool, see Figure 21.10.

The exact set of subframes to use for PSSCH transmission in a PSCCH period is given by a *time repetition pattern index* (TRPI) provided as part of the scheduling grant. As illustrated in Figure 21.11, the TRPI points to a specific *time repetition pattern* (TRP) within a *TRP table*

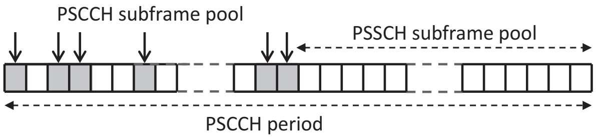

FIGURE 21.10

Subframes available for PSSCH (data) transmission within a PSCCH period (the "PSSCH subframe pool") for sidelink communication mode 1.

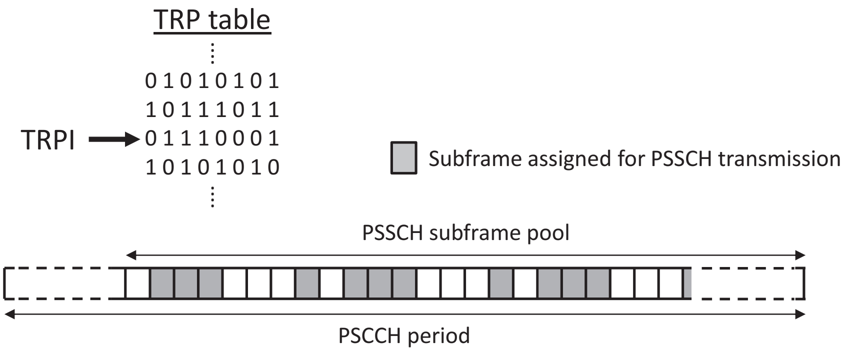

FIGURE 21.11

Assignment of subframes to PSSCH (sidelink communication mode 1).

explicitly defined within the LTE specifications.[4] Periodic extension of the indicated TRP then gives the uplink subframes assigned for the PSSCH transmission.

The TRPI is then included in the SCI in order to inform receiving devices about the set of subframes in which the PSSCH is transmitted.

In case of sidelink communication mode 2 the PSSCH subframe pool, that is, the set of (uplink) subframes available for PSSCH transmission, consists of a subset of the mode 1 subframe pool. More specifically, a periodic extension of a bitmap defined in the sidelink configuration indicates what subframes are included in the PSSCH subframe pool. In this way the network can ensure that certain subframes will not be used for PSSCH transmissions.

The device then autonomously decides on the exact set of subframes to use for the PSSCH transmission by randomly selecting a TRP from the TRP table. Similar to sidelink communication mode 1, the receiving device is informed about the selected TRP by including the corresponding TRPI in the SCI.

In addition to limiting the set of subframes that are part of the PSSCH subframe pool, in case of sidelink communication mode 2 there are also limitations in the TRP selection.

[4]For FDD the TRP table consists of 106 entries, with each TRP consisting of eight bits. For TDD the size of the TRP table, as well as the length of the TRP, depends on the downlink/uplink configuration.

In general, the TRP table consists of TRPs with different number of ones, corresponding to different fractions of subframes assigned for the PSSCH transmission. This includes, for example, the all-one TRP corresponding to assigning all subframes of the PSSCH pool for PSSCH transmission from a specific device. However, in case of sidelink communication mode 2 the TRP selection is restricted to TRPs with a limited number of ones, thus limiting the PSSCH transmission duty cycle. For example, in case of FDD, the TRP selection is limited to TRPs with a maximum of four ones, corresponding to a 50% duty cycle for the PSSCH transmission.

In addition to the set of subframes, a device also needs to know the exact set of resource blocks to be used for the PSSCH transmission.

In case of sidelink communication mode 1, where the network assigns the resources to use for the sidelink communication, information about the resource blocks to use for the PSCCH transmission are given in the scheduling grant provide by the network. The structure of that resource, and the way by which it is signaled, is essentially identical to single-cluster allocation for uplink (PUSCH) transmissions, see Section 6.4.7. Thus the resource grant includes a 1-bit frequency-hopping flag and a resource-block assignment, the size of which depends on the system bandwidth. Note that there is no restriction in terms of what resource blocks can be assigned except that it should be a set of consecutive resource blocks. In other words, in case of sidelink communication mode 1, the PSSCH resource-block pool consists of all resource blocks within the carrier bandwidth.

In case of sidelink communication mode 2, there are restrictions in terms of what resource blocks are available for PSSCH transmission. This PSSCH resource block pool has the same structure as the PSCCH resource-block pool, that is, it consists of two sets of frequency-wise consecutive resource blocks defined by three parameters S_1, S_2, and M, compare Figure 21.8. Note that the parameters defining the PSSCH resource-block pool are configured separately from those defining the PSCCH resource-block pool. A device configured to operate in sidelink communication mode 2 will then autonomously select a set of consecutive resource blocks from the PSSCH resource-block pool.

Information about the assigned/selected set of resource blocks is provided to receiving devices as part of the SCI.

21.2.5 SIDELINK CONTROL INFORMATION CONTENT

As discussed in the preceding section, the SCI carries information needed by a receiving device to properly detect and decode the PSSCH and extract the SL-SCH data. This includes information about the exact set of resources (subframes and resource blocks) in which the PSSCH is transmitted:

- The TRPI, indicating the set of subframes used for the PSSCH transmission.
- *A frequency hopping flag* indicating whether or not frequency hopping is used for the PSSCH transmission.

- *A resource-block and hopping-resource allocation* indicating what resource blocks, within the subframes indicated by the TRPI, are used for the PSSCH transmission.

The last parameter is essentially identical to the corresponding parameters in the uplink scheduling grant in DCI format 0.

In addition, the SCI includes

- a five-bits indicator of the modulation and coding scheme (MCS) used for the PSSCH transmission;
- an eight-bit *group destination ID*, indicating the group for which the sidelink communication is intended;
- an eleven-bit timing-advance indicator.

21.2.6 SCHEDULING GRANTS AND DCI FORMAT 5

As described above, devices within network coverage can be configured to only initiate sidelink communication when having been provided with an explicit scheduling grant by the network (sidelink communication mode 1). This is similar to devices being allowed to transmit on the uplink only when having an explicit scheduling grant for uplink transmission, see Chapter 7. As described in Chapter 6, such scheduling grants are provided via PDCCH/ePDCCH using DCI format 0 or DCI format 4. In a similar way, sidelink scheduling grants are provided via the PDCCH/ePDCCH using a new *DCI format 5*.

DCI format 5 includes the following information:

- The parameter n_{PSCCH} indicating the physical resource (subframes and resource blocks) on which PSCCH is to be transmitted.
- The TRPI indicating what subframes within the PSSCH subframe pool to use for the PSSCH transmission.
- *A frequency hopping flag* indicating whether or not frequency hopping should be applied for the PSSCH transmission.
- *A resource-block and hopping-resource allocation* indicating what resource blocks, within the subframes indicated by the TRPI, should be used for the PSSCH transmission.

The last parameter is, essentially, identical to the corresponding parameters of the scheduling grant for conventional uplink (PUSCH) transmission, see Chapter 7.

In addition, DCI format 5 includes a 1-bit transmit power control (TPC) command that applies to both PSCCH and PSSCH.

As outlined in Figure 21.12, the sidelink scheduling grant is valid for the next PSCCH period starting at least four subframes after the arrival of the scheduling grant. Note that this provides the same amount of time from the arrival of the scheduling grant to the actual scheduled transmission, as for normal uplink (PUSCH) transmission.

The transmission of scheduling grants for sidelink communication is supported by buffer-status reports (BSRs) provided to the network by devices involved in sidelink

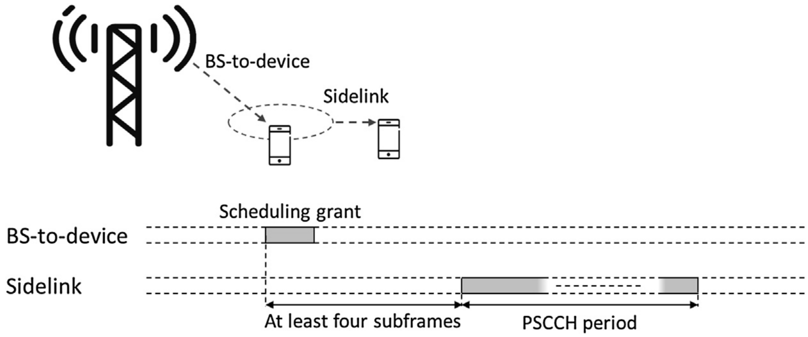

FIGURE 21.12

Timing relation for uplink scheduling.

communication. Similar to uplink buffer status reports, see Chapter 9, the sidelink BSRs are conveyed as MAC control elements and indicate the amount of data available for transmission at the device.

21.2.7 RECEPTION RESOURCE POOLS

In the preceding section the concept of a resource pool, defining the set of resources (subframes and set of resource blocks) that are available for transmissions related to sidelink communication (PSCCH and PSSCH) has been described.

In addition to this *transmission resource pool*, a device that is to take part in sidelink communication is also configured with one or several *reception resource pools* related to sidelink communication.

A reception resource pool describes the set of resources (subframes and resource blocks) in which a device can expect to *receive* sidelink-communication-related transmissions. Especially, the PSCCH part of the reception resource pool describes the set of resources in which the device should search for PSCCH transmissions. Furthermore, the PSSCH part of the resource is needed for the receiver to be able to properly interpret the resource information in the SCI.

The reason why a device may be configured with multiple reception pools is that it may receive sidelink communication from multiple devices and these devices may be configured with different transmission pools. This may be the case regardless of whether the devices are within the same cell or within different cells.[5] In principle, one can say that a device should be configured with a reception pool that is the union of the transmission resource pools of the devices with which it is to communicate. In practice, this is realized by configuring the device

[5]Devices in RRC_IDLE state within the same cell will use the same transmission resource pool provided by SIB 18. However, devices within the same cell in RRC_CONNECTED state may be individually configured with different transmission pools. Devices in RRC_IDLE state in different cells may also be configured with different transmission pools.

with multiple reception pools that jointly covers the transmission pools of the relevant devices.

Reception pools for sidelink communication are provided as part of the sidelink-related system information (SIB18) for in-coverage devices and as part of the pre-configuration for out-of-coverage devices.

21.3 SIDELINK DISCOVERY

Sidelink discovery is about devices repeatedly broadcasting short fixed-size messages that can be directly detected ("discovered") by other nearby devices. These messages could, for example, be announcements of "services," such as a restaurant announcing a special menu to by-passers, or requests for information such as asking for near-by people with specific competence.

It is important to understand that the actual message to be conveyed is not explicitly included in the broadcast message. Instead, the broadcast message consists of a user identity and a message code. Mapping from message codes to actual message is then provided by the network ProSe Function, see Section 21.1.5.

As described in Section 21.1.6, discovery messages are transmitted in form of transport blocks on the SL-DCH transport channel which, in turn is mapped to the PSDCH (physical sidelink discovery channel) physical channel. Thus, in contrast to sidelink communication there is no PSCCH/PSSCH structure with associated control information carried on a separate physical channel for discovery transmissions.

Comparing with sidelink communication, the transmission of discovery messages (SL-DCH transport blocks) on PSDCH is in many respects more similar to the transmission of control information (SCI) on the PSCCH, than the SL-SCH transmission on PSSCH:

- Similar to PSCCH, the PSDCH payload (the SL-DSCH transport block) is of fixed size (232 bits).
- Similar to PSCCH, a receiving device "searches" for PSDCH in a reception pool. In contrast, for PSSCH reception the receiver is informed about the exact resource by means of the SCI.

As will be seen in the following section, the resource-pool structure for PSDCH transmission is also, in many ways, similar to the resource-pool structure for PSCCH transmission.

21.3.1 RESOURCE POOLS AND SELECTION/ASSIGNMENT OF TRANSMISSION RESOURCES

In the time domain, discovery is based on equal-sized *discovery periods* similar to the PSCCH periods used for sidelink communication, see Section 21.2.2.

Similar to sidelink communication, for sidelink discovery a device is configured with one or several *resource pools* defining the resources available for the discovery (PSDCH) transmission. In case of discovery, each resource pool consists of

- a *PSDCH subframe pool* defining a set of subframes available for discovery transmission;
- a *PSDCH resource-block pool* defining a set of resource blocks available for discovery transmission within the subframe pool.

The PSDCH subframe pool is given by a subframe bitmap, similar to the PSCCH subframe pool (Section 21.2.3). However, while the bitmap directly gives the PSCCH subframe pool, the discovery subframe pool is given by a *periodic repetition* of the subframe bitmap.

The discovery resource-block pool consists of two sets of frequency-wise consecutive resource blocks defined by three parameters S_1, S_2, and M, that is, the same structure as the PSCCH resource-block pool (Section 21.2.3 and Figure 21.8).

Similar to sidelink communication there are two types or modes of sidelink discovery that differ in terms of how a device is assigned/selects the exact set of resources to use for the discovery (PSDCH) transmission[6]:

- In case of discovery type 1, a device by itself selects the set of physical resources to use for the discovery transmission from a configured resource pool.
- In case of discovery type 2B, a device is explicitly assigned, by means of RRC signaling, the set of resources to use for the discovery transmission from a configured resource pool.[7]

While discovery type 1 can be used by devices in both RRC_IDLE and RRC_CONNECTED state, discovery type 2B is only possible in RRC_CONNECTED state.

It should be noted that, for discovery type-2B, the assignment of discovery resources is done by means of RRC signaling. The assignment is then valid until explicitly changed. This is in contrast to sidelink communication mode 1, for which the transmission resources are *dynamically* assigned by means of scheduling grants (DCI format 5) on PDCCH/EPDCCH and with the assignment only valid for the PSCCH period in which it is provided. [8] This also means that while, for sidelink communication, the device is first configured with a resource pool (by means of RRC signaling) and then dynamically assigned the specific resource to use for the sidelink transmission by means of DCI on PDCCH/EPDCCH, for sidelink discovery the configuration of resource pool and the assignment of the exact resource to use for a discovery transmission, is done jointly as part of the sidelink configuration.

In case of discovery type 1, that is, when the device selects the exact set of resources to use for discovery transmission, each device may be configured with multiple resource pools

[6]The specification somewhat arbitrarily uses the term *mode* for sidelink communication and the term *type* for discovery. To align with the specification we will do the same here.
[7]At an early stage of the 3GPP work on sidelink connectivity, there was discovery type 2, with a special case referred to as type 2B. In the end, only the special case remained.
[8]Note that the numbering of the discovery types is reversed compared to the case of sidelink communication. In case of discovery, "type 1" refers to the type/mode where the device selects the resources while, in case of sidelink communication, the corresponding mode is referred to as mode 2.

where each pool is associated with a certain *RSRP range*, where RSPR (Reference Signal Receiver Power) is essentially a measure of the path loss to a certain cell. The device selects the resource pool from which to select the discovery resources based on the measured RSRP for the current cell. This allows for the separation of devices into non-overlapping resource pools depending on the path loss to the current cell and thus, indirectly, depending on the distance to other cells.

21.3.2 DISCOVERY TRANSMISSION

As already mentioned, a discovery message, that is, the SL-DSCH transport block, is of a fixed size of 232 bits.

Channel-coding and modulation for SL-DCH is done in the same way as for uplink (UL-SCH) transmission (Chapter 7) and consists of the following steps:

- CRC insertion;
- code-block segmentation and per-code-block CRC insertion;
- rate 1/3 Turbo coding;
- rate matching;
- bit-level scrambling with a predefined seed (510);
- data modulation (QPSK only).

DFT precoding is then applied before the mapping to the time–frequency resource selected/assigned for the PSDCH transmission.

Each SL-DCH transport block, is transmitted over $N_{RT} + 1$ consecutive subframes within the discovery subframe pool, where the "*number of retransmissions*" N_{RT} is part of the discovery configuration provided by the network.

Within each subframe, two frequency-wise consecutive resource blocks of the resource-block pool are used for the discovery transmission, with the resource blocks changing for each subframe.

21.3.3 RECEPTION RESOURCE POOLS

Similar to sidelink communication, there is also for discovery a set of common *reception* resource pools provided to devices as part of the sidelink-related system information, that is, SIB19 in case of discovery. Similar to sidelink communication, devices that are to receive sidelink discovery messages search for PSDCH transmissions within the configured set of resource pools.

21.4 SIDELINK SYNCHRONIZATION

As already mentioned in Section 21.1.3, the aim of sidelink synchronization is to provide timing references for sidelink transmission as well as for sidelink reception.

In general, an in-coverage device should use the synchronization signal (PSS + SSS) of the serving cell (for devices in RRC_CONNECTED state) or the cell the device is camping on (for devices in RRC_IDLE state) as timing reference for its sidelink transmissions.

Out-of-coverage devices may acquire transmission timing from special SLSS transmitted by other devices. Those devices could, themselves, be in coverage, implying that their transmission timing, including the timing of their SLSS transmissions, is derived directly from the network. However, they may also be out of coverage, implying that their transmission timing has either been derived from SLSS transmissions from yet other devices or been selected autonomously.

Selecting an SLSS as timing reference for sidelink transmission, is, in the LTE specifications, referred to as selecting a *synchronization reference* UE *or SyncRef UE*.

It should be understood that, despite the term "SyncRef UE," what a device selects as timing reference is not a device as such but *a received SLSS*. This may seem like semantics but is an important distinction. Within a cluster of out-of-coverage devices, several devices may transmit the same SLSS. A device using that SLSS as timing reference will thus not synchronize to an SLSS transmission of a specific device but to the aggregated SLSS corresponding to multiple devices.

SLSS may also be used as timing reference for sidelink reception by both out-of-coverage devices and in-coverage devices. Such a reception timing reference is needed when a device is to receive a sidelink transmission originating from a device with a different transmission-timing reference, for example, an in-coverage device having a different serving cell. Each reception pool is associated with a certain *synchronization configuration*, in practice with a specific SLSS. When receiving sidelink transmissions according to a certain reception pool, a device should use the corresponding SLSS as timing reference for the reception.

21.4.1 SIDELINK IDENTITY AND STRUCTURE OF THE SIDELINK SYNCHRONIZATION SIGNAL

Similar to cell synchronization signals corresponding to different cell identities, an SLSS is associated with a *sidelink identity* (SLI). There are 336 different SLIs divided into two groups with 168 SLIs in each group:

- The first group, consisting of SLI number 0 to SLI number 167, is used by devices that are either in coverage or out of coverage but have a SyncRef UE corresponding to a device that is in coverage. We refer to this as the *in-coverage group*.
- The second group, consisting of SLI number 168 to SLI number 335, is used by the remaining devices, that is, out-of-coverage devices that have a SyncRef UE corresponding to a device that is also out of coverage or out-of-coverage devices that have no SyncRef UE at all. We will refer to this as the *out-of-coverage group*.

One can also group the 336 SLIs into *SLI pairs*, each consisting of one SLI from the in-coverage group and the corresponding SLI from the out-of-coverage group. Comparing with

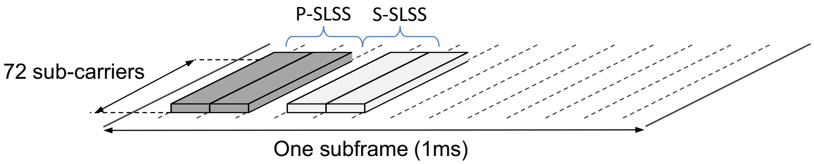

FIGURE 21.13

Structure of sidelink synchronization signal.

the cell synchronization signals, the 168 different SLI pairs consisting of two SLIs each can be seen as corresponding to the 168 different cell-identity groups consisting of three cell identities each (see Chapter 11).

Similar to a cell synchronization signal, an SLSS actually consists of two components—a *primary sidelink synchronization signal* (P-SLSS) and a *secondary sidelink synchronization signal* (S-SLSS).

As outlined in Figure 21.13, the P-SLSS consists of two OFDM symbols transmitted within the second and third[9] symbol of a subframe while the S-SLSS consists of two OFDM symbols transmitted within the fifth and sixth symbol. Similar to the cell synchronization signal, each SLSS covers the 72 center subcarriers of the carrier.[10]

The two P-SLSS symbols are identical and are generated in the same way as the PSS. As described in Chapter 11 there are three different PSS derived from three different Zadoff-Chu (ZC) sequences, where each PSS corresponds to one specific cell identity from each of the 168 cell-identity groups. In the same way, there are two different P-SLSS derived from two different ZC-sequences (different from the ZC-sequences of the PSS). The two different P-SLSS correspond to SLIs in the in-coverage group and out-of-coverage group, respectively.

The two S-SLSS symbols are also identical and generated in the same way as the SSS, see Chapter 11. There are 168 different S-SLSS, where each S-SLSS corresponds to one of the 168 different SLI pairs.

SLSS can only be transmitted in certain *SLSS subframes* corresponding to every 40th subframe. The exact set of SLSS subframes is given by a *subframe offset* that locates the SLSS subframes relative to the first subframe of the frame with SFN = 0. For in-coverage devices the subframe offset is provided as part of the sidelink-related system information (SIB 18 and SIB 19 for devices involved in sidelink communication and sidelink discovery, respectively). For out-of-coverage devices there are to two offsets, corresponding to two different sets of SLSS subframes, provided as part of the pre-configuration. The reason for providing two offsets is to allow for out-of-coverage devices to transmit and receive SLSS in the same 40 ms period, see further Section 21.4.4.

[9]The first and second symbol in case of extended cyclic prefix.

[10]In contrast to the downlink carrier, on the sidelink carrier there is no non-transmitted DC carrier, compare Figure 11.3.

SLSS can only be transmitted in SLSS subframes. However, a device does not necessarily transmit SLSS in every SLSS subframe. Exactly in what SLSS subframes a device is to transmit SLSS depends on what triggers the SLSS transmission and also whether the device is involved in sidelink communication or sidelink discovery, see further Section 21.4.4.

21.4.2 THE SIDELINK BROADCAST CHANNEL AND SIDELINK MASTER INFORMATION BLOCK

A device that serves as a possible synchronization source, that is, a device that transmits SLSS may also transmit the sidelink broadcast channel (SL-BCH) mapped to the PSBCH. The SL-BCH carries some very basic information, contained within the *sidelink master information block* (SL-MIB), needed for out-of-coverage devices to establish sidelink connectivity. More specifically, the SL-MIB carries the following information:

- Information about carrier bandwidth assumed by the device transmitting the SL-MIB.
- Information about the TDD configuration assumed by the device transmitting the SL-MIB.
- Information about the frame number (SFN) and subframe number of the frame/subframe in which the SL-BCH is transmitted. This allows for devices to synchronize to each other also on frame/subframe level.
- An *in-coverage indicator*, indicating whether or not the device transmitting the SL-BCH is within network coverage. As described further in Section 21.4.3, the in-coverage indicator is used by out-of-coverage devices when selecting SyncRef UE.

After convolutional coding and modulation (QPSK), the PSBCH is transmitted in the same subframe and the same resource blocks as used for the SLSS transmission.

An out-of-coverage device, after acquiring an SLSS, decodes the corresponding SL-BCH and acquires the SL-MIB. Based on, among other things, the in-coverage indicator on the SL-MIB, the device decides if the acquired SLSS is to be used as synchronization reference, that is, as SyncRef UE. In that case, the device uses the remaining SL-MIB information (carrier bandwidth, TDD configuration, and SFN/subframe number) as assumptions for subsequent sidelink transmissions.

21.4.3 SYNCREF UE SELECTION

There are well-specified rules for how an out-of-coverage device should select a SyncRef UE, that is, select a timing reference for sidelink transmissions, see also Figure 21.14:

- If no sufficiently strong cell can be found, implying that the device is out of coverage, the device should first search for SLSS corresponding to devices that in themselves are under network coverage. If a sufficiently strong such SLSS can be found the device should use that SLSS as SyncRef UE.

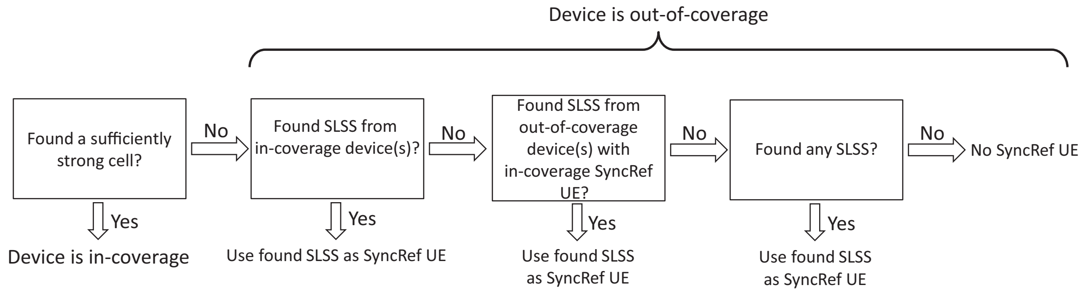

FIGURE 21.14

SyncRef UE selection.

- If no such SLSS can be found the device should instead search for SLSS corresponding to devices that are out of coverage but in themselves have a SyncRef UE corresponding to in-coverage devices. If a sufficiently strong such SLSS can be found the device should use that SLSS as SyncRef UE.
- If no such SLSS can be found the device should search for any SLSS. If a sufficiently strong SLSS can be found the device should use that SLSS as SyncRef UE.
- If no SLSS can be found, the device will autonomously decide its transmission timing, that is, the device will have no SyncRef UE.

Note that the this procedure assumes that a device can determine

- that a found SLSS corresponds to devices that are under network coverage and
- that a found SLSS corresponds to devices that are out of coverage but in themselves have an in-coverage SyncRef UE.

As will be seen in the following section, this is possible by means of a combination of the in-coverage indicator on the sidelink broadcast channel (SL-BCH) and the rule by which an out-of-coverage device selects its Sidelink Identity (SLI) depending on the SLI of the selected SyncRef UE.

21.4.4 TRANSMISSION OF SIDELINK SYNCHRONIZATION SIGNALS

21.4.4.1 In-coverage Devices

Transmission of SLSS by in-coverage devices can be triggered in different ways as follows:

- A device in RRC_CONNECTED state can be explicitly configured by the network to transmit SLSS.
- If not explicitly configured to transmit SLSS, transmission of SLSS can be triggered by the measured received signal strength (RSRP) of the current cell being below a certain

threshold provided as part of the sidelink-specific system information (SIB 18 and SIB 19 for sidelink communication and sidelink discovery, respectively).

Exactly how and when the SLSS is transmitted depends on how the SLSS transmission was triggered and also whether the device is configured for sidelink discovery or sidelink communication.

In case of sidelink discovery, regardless of whether SLSS transmission is explicitly configured or triggered by RSPR measurements, a single SLSS is transmitted in the SLSS subframe that comes closest in time and not after the first subframe of the discovery subframe pool in which discovery messages are to be transmitted. Note that, for release 12, sidelink discovery will only take place in coverage. Transmission of SLSS by devices involved in sidelink discovery is therefore only done to provide timing references for sidelink reception.[11]

In case of sidelink communication, if SLSS transmission is explicitly configured the device will transmit SLSS in every SLSS subframe regardless of if actual sidelink communication is carried out in a PSCCH period or not. On the other hand, if SLSS transmission is triggered by RSRP measurements the device will only transmit SLSS in the SLSS subframes contained within the PSCCH period(s) in which actual sidelink communication will be carried out.

Exactly what SLSS to transmit or, more specifically, the SLI, is provided as part of the sidelink-related system information.

21.4.4.2 Out-of-coverage Devices

An out-of-coverage device should transmit SLSS if it has no selected SyncRef UE or if the RSRP of the selected SyncRef UE is below a certain threshold, where the threshold is provided as part of the pre-configured information.

In general, a device that has a selected SyncRef UE should either use the same SLI as the SyncRef UE or the corresponding paired SLI (the SLI from the out-of-coverage group if the SLI of the SyncRef UE is from the in-coverage group or vice versa).

Furthermore, in general the SLSS should be transmitted assuming one of the two different SLSS subframe offset that are provided as part of the pre-configuration. More specifically, the device should select the offset so that the transmitted SLSS does not collide with the reception of the SLSS of the received SyncRef UE.

The rules for selecting the SLI and for setting the in-coverage indicator of the SL-MIB are as follows, see also Table 21.1:

- An out-of-coverage device with a SyncRef UE for which the in-coverage indicator is set to TRUE should, regardless of the SyncRef UE SLI,
  - use the same SLI as the SyncRef UE,
  - set the SL-MIB in-coverage indicator to FALSE.

[11]This is changed in release 13, see Section 21.5.

Table 21.1 Rules for Selection SLI and Setting In-Coverage Indicator

		SyncRef UE In-coverage Indicator	
		TRUE	**FALSE**
SyncRef UE SLI	From in-coverage group	Set in-coverage indicator to FALSE Set SLI to $SLI_{SyncRef\ UE}$	Set in-coverage indicator to FALSE Set SLI to $SLI_{SyncRef\ UE} + 168$
	From out-of-coverage group		Set in-coverage indicator to FALSE Set SLI to $SLI_{SyncRef\ UE}$

- An out-of-coverage device with a SyncRef UE which has an SLI from the in-coverage group and for which the in-coverage indicator is set to FALSE should
  - use the corresponding SLI from the out-of-coverage group,
  - set the SL-MIB in-coverage indicator to FALSE.
- An out-of-coverage device with a selected SyncRef UE which has an SLI from the out-of-coverage group and for which the in-coverage indicator is set to FALSE should
  - use the same SLI as the SyncRef,
  - set the SL-MIB in-coverage indicator to FALSE.

Thus, from the SyncRef UE in-coverage indicator and SLI, a device can conclude on the in-coverage/out-of-coverage status of a candidate SyncRef UE, see also Figure 21.15:

- If the in-coverage indicator is "TRUE," the candidate SyncRef UE is in-coverage regardless of the SLI of the SyncRef UE.
- If the in-coverage indicator is "FALSE" and the SLI is from the in-coverage group, the candidate SyncRef UE is out of coverage but, in itself, has a SyncRef UE that is in coverage.
- If the in-coverage indicator is "FALSE" and the SLI is from the out-of-coverage group, the candidate SyncRef UE is out of coverage and, in itself, also has a SyncRef UE that is out-of-cover-coverage.

As discussed in Section 21.4.3, this information is needed for a device to make a proper selection of SyncRef UE.

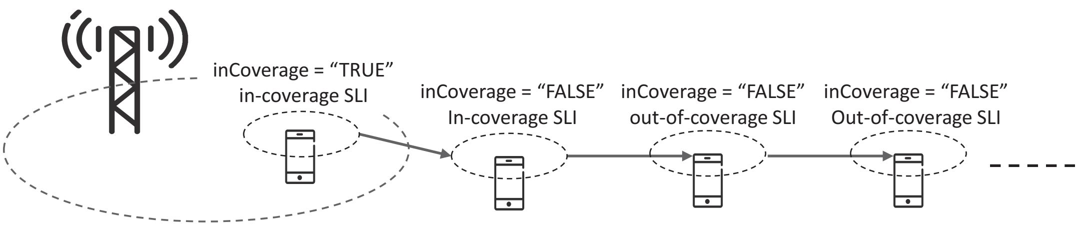

FIGURE 21.15

Sidelink synchronization.

21.5 DEVICE-TO-DEVICE EXTENSIONS IN LTE RELEASE 13

The focus of the previous sections has been on the initial LTE sidelink functionality in release 12. The sidelink functionality is further extended in release 13 with the main features being:

- The possibility for sidelink discovery also for devices that are not within network coverage.
- The extension of network coverage by means of Layer-3-based relaying via an intermediate device.

21.5.1 OUT-OF-COVERAGE DISCOVERY

Release-13 out-of-coverage discovery only targets the public-safety use case. It relies on the same mechanisms as the release-12 in-coverage discovery although limited to discovery type 1, that is, the mode when the device autonomously selects the resources to use for the discovery transmission from, in this case, a *pre-configured* resource pool.

Out-of-coverage discovery also impacts transmission of SLSS, that is, the sidelink synchronization channel, and the sidelink broadcast channel (SL-BCH) carrying the sidelink MIB.

For release 12, the only task of SLSS transmission in the context of discovery is to provide a timing reference for discovery reception, for example, for reception of discovery transmissions by devices in neighbor cells. As a consequence, in the context of sidelink discovery SLSS is only transmitted in direct combination with actual discovery transmissions.

This is in contrast to sidelink communication where SLSS is also used to provide a timing reference for sidelink transmissions for out-of-coverage devices. Thus, devices configured for sidelink communication can be configured to transmit SLSS also when not having any actual data to transmit.

For release 13, the same is possible also for devices configured for sidelink discovery. Furthermore, devices configured for sidelink discovery may, in release 13, also transmit the SL-BCH providing the SL-MIB information to out-of-coverage devices.

21.5.2 LAYER-3 RELAYING

The introduction of Layer-3 relaying has very little impact on the actual radio-access specifications as it very much relies on the functionality of the sidelink communication and sidelink discovery mechanisms introduced already in release 12.

A device capable of serving as a Layer-3 relay announces this by means of the sidelink-discovery mechanism. The D2D link of the relaying then relies on the sidelink-communication mechanisms while the relaying-device-to-network communication relies on the normal LTE cellular mechanisms. The only impact of the Layer-3 relaying functionality to the radio specifications is in terms of RRC functionality, for example, functionality to configure the relaying device.