Device to Device Communication in LTE

Whitepaper

In this whitepaper we describe the device to device communication in LTE from a UE point of view. Network elements are described as far as they concern the UE. In addition to the message transmission and reception, a special emphasis is put on the synchronization between UEs and on the security for the message exchange.

Note:

Visit our homepage for the most recent version of this application note (www.rohde-schwarz.com/appnote/1MA264).

D2D Communication ─ 1MA264_0e

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Whitepaper

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Contents

1 Introduction

Safety critical communication systems, abbreviated in the following as *public safety*, use different standards at present. Which one depends on the geographical region, and may even vary within one country. Consequently, the set of used communication systems is fragmented and accordingly, interworking between different public safety groups may be difficult.

With the worldwide success of LTE, governmental authorities have started to consider LTE as a candidate for safety critical communications. As a result of a following 3GPP study, two main fields were identified as the starting point to use LTE for public safety: *Group communication* and *proximity based services*.

Group communication is an essential part for public safety systems. Under the umbrella work item *Group Communication System Enablers for LTE*, a set of requirements was first specified in [1]. 3GPP Working Group SA2 then specified the associated architecture in [2], from which the concerned working groups created the corresponding stage-3 descriptions.

Proximity based services can be provided when UEs are close to each other. These services comprise:

- ProSe Direct Discovery. This feature identifies that two UEs are in proximity of each other. For two UEs in cellular coverage it may also be used for commercial purposes.
- ProSe Direct Communication between two UEs. LTE resources from cellular traffic are reserved and used for this type of communication.
- Network-level Discovery and Network Support for WLAN Direct Discovery and Communication.

This whitepaper describes the second aspect of the proximity based services, the direct communication between two LTE devices, also called *Device-to-Device (D2D) communication*. In chapter 2 we introduce the overall system and then describe in chapter 3 the message exchange from a RAN protocol stack point of view. Chapter 4 outlines the critical points of receiver synchronization, especially for UEs not in coverage of an eNB. Security aspects in order to prevent message exchange from e.g. eavesdropping is described in chapter 5. Finally, we give an outlook in chapter 6 about further developments for device to device communication in 3GPP Release 13.

2 System Aspects

2.1 Scenarios

In 3GPP Release 12, device to device communication, or ProSe communication, is limited to the public safety usage. According to the associated requirements, ProSe communication has to work in regions, where network coverage cannot be guaranteed. Therefore, ProSe communication is specified for the following scenarios:
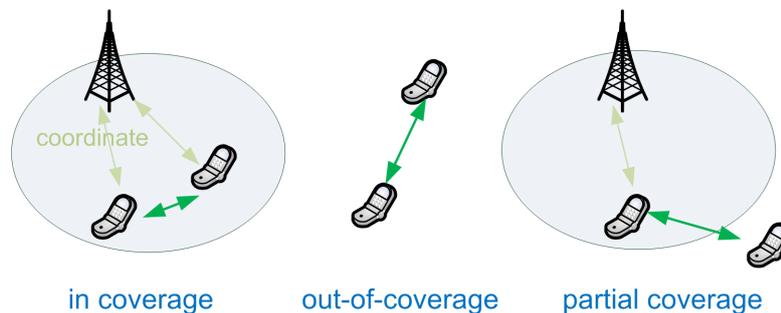

in coverage   out-of-coverage   partial coverage

Fig. 2-1: Coverage scenarios for ProSe communication

In the *in coverage* scenario, the network controls the resources used for ProSe communication. It may assign specific resources to a transmitting UE, or may assign a pool of resources the UE selects from. This way, interferences with the cellular traffic is avoided and in addition the ProSe communication may be optimized.

For the *out-of-coverage* case such a control is not possible. The UE uses resources which are preconfigured, either in the mobile device or in the USIM of the UICC card. However, the term *out-of-coverge* has to be interpreted carefully. It does not mean that there is no coverage at all. It rather means that there is no coverage on the frequency used for ProSe direct communication, although the UE might be in coverage on a different carrier for cellular traffic.

A special case is given in the *partial coverage* case. The UE out-of-coverage uses the preconfigured values, whereas the UE in coverage gets its resources from the eNB. A careful coordination between the network and the preconfigured values is necessary in order to enable communication and to limit the interferences to UEs at the cell boundary near an out-of-coverage UE.

2.2 Network Architecture

In order to describe the principles of ProSe communication, in figure 2-2 we show the network architecture for the non-roaming case [3]:
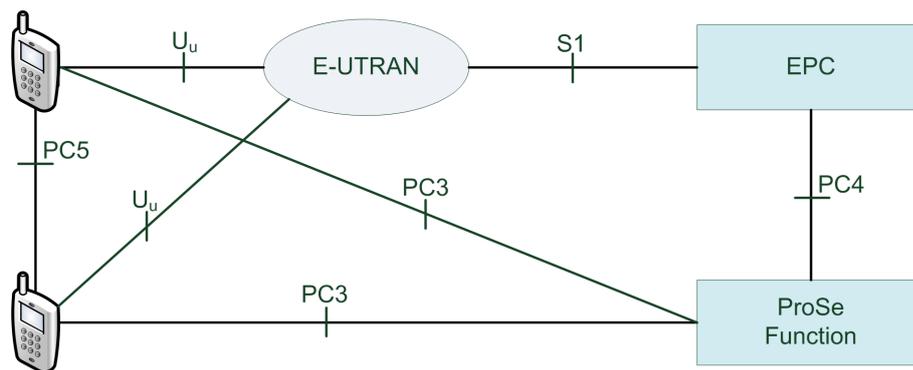
Fig. 2-2: Simplified architecture for ProSe (non-roaming)

Several new interfaces have been introduced. From a UE point of view, the most important ones are the PC5 interface between two UEs and the PC3 interface to a new defined node, the *ProSe Function*.

For Release 12, the PC5 is a *one-to-many* communication interface, i.e. it is specified for group communication. From a higher layer point of view, this is reflected in the assignment of destination IDs, which are always group IDs.

Using the PC3 interface, the UE contacts the ProSe Function. In Release 12, there is only one ProSe Function specified in each PLMN. The IP address of the the ProSe Function might be preconfigured (hard-coded) in the device. The alternative is, that the device identifies the IP address of the ProSe Function via DNS look-up. To contact the ProSe Function the device has to establish an RRC connection with the network (RRC_CONNECTED state). For the information exchange between the UE and the ProSe Function IP messages are used, i.e. HTTP Request and Response message, with its related syntax.

From the ProSe Function the UE receives information for network related actions. This includes service authorization and provisioning of PLMN specific information.

The authorization is always done on a per PLMN basis. However, the UE is not required to be registered in the PLMN in which it wants to do ProSe communication. The UE contacts the ProSe Function in its HPLMN, which in turn requests authorisation information from the ProSe Function in the local PLMN. The authorization also comprises the information, whether and where the UE is allowed to perform ProSe communication when it is out-of-coverage.

In the PLMN specific information provisioning, the ProSe Function sends the following parameters to the UE:

- Security parameters
- Group IDs
- Group IP multicast addresses, including the indication whether the UE shall use IPv4 or IPv6 for the group
- Radio resource parameters for usage in out-of-coverage scenarios

Note that for public safety UEs these parameters may also be preconfigured in the UE or UICC. If they are defined in both, the parameters from the UICC have precedence.

2.3 Protocol Stack

On the air interface, ProSe communication is connectionless, i.e. there is no equivalent to the RRC connection. Messages are created on the application level of the UE and transmitted on the next opportunity. If a connection is required, it has to be done within the application.

For transmission and reception of the associated data packets, the following protocol stack is used, see figure 2-3:
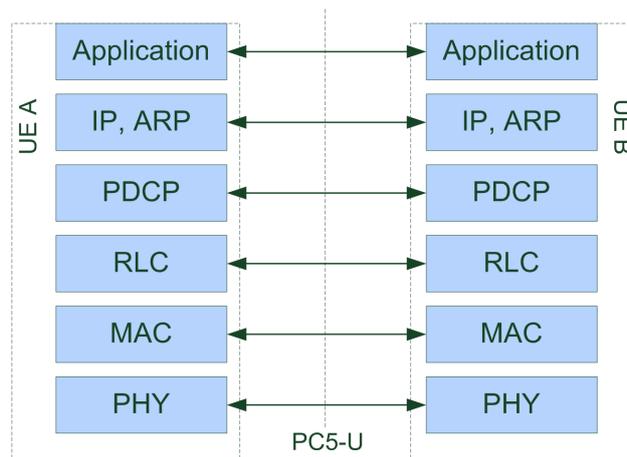
Fig. 2-3: Radio protocol stack for data transmission [3]

For each transmitting UE and each established logical channel, the receiving UE has to keep one PDCP / RLC pair. The UE does not configure them in advance, this is done on reception of the first RLC PDU [4]. As ProSe communication is connectionless, there is no procedure to delete it. Consequently, the duration to keep an RLC / PDCP pair after reception of a message is up to UE implementation.

The PDCP [5] uses *Unidirectional Mode* for header compression. The RLC [6] is operated in the UM. MAC [7] supports HARQ processes, restricted to blind retransmissions without HARQ feedback.

In order to identify the transmitting UE and the group for which the data packet is intended, two identities are provided in each message:

- ProSe UE ID
- ProSe Layer-2 Group ID

These IDs are either provided by the network or may be preconfigured in the UE, see chapter 5, "Security", on page 28 for details. The *ProSe UE ID* has a length of 24 bits and is used in each MAC PDU as *Source* field. The *ProSe Layer-2 Group ID* is used to identify the group, and has also a length of 24 bit. Its 8 LSBs are used in the control channel to filter data packets at the physical layer, and its 16 MSBs in a MAC PDU to identify the destination group, see figure 3-10. Together with the logical channel ID, the ProSe UE ID and the 16 MSBs of the ProSe Layer-2 Group ID identify the PDCP / RLC pair to be used in the receiving UE.

3 Sidelink Transmission

In conventional cellular traffic over U_u, the eNB communicates with the UE via the UL and DL, for both, signaling and data. This concept is extended in ProSe communication with the introduction of the sidelink (SL), see figure 3-1:
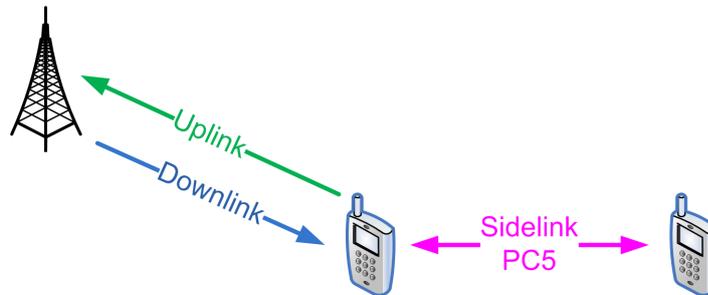

Fig. 3-1: Visualization of the Sidelink

The SL corresponds to the PC5 interface described in the previous chapter. Resources assigned to the SL are taken from the UL, i.e. from the subframes on the UL frequency in FDD or from the subframes assigned to UL in TDD. There are two reasons for this selection: First, the UL subframes are usually less occupied than those on the DL. Second, most DL subframes are never really empty: Unless they are empty MBSFN subframes, there are always at least the cell specific reference signals (CRS) transmitted.

Note the difference between **ProSe** and **sidelink**: ProSe describes the end-to-end application, which is here the device to device communication, whereas sidelink describes the channel structure, i.e. logical channels, transport channels, and physical channels which are used in the air-interface to realize the ProSe application. There are further sidelink channels for the other ProSe application, the ProSe direct discovery, which is not treated in this whitepaper.

3.1 Sidelink Channels

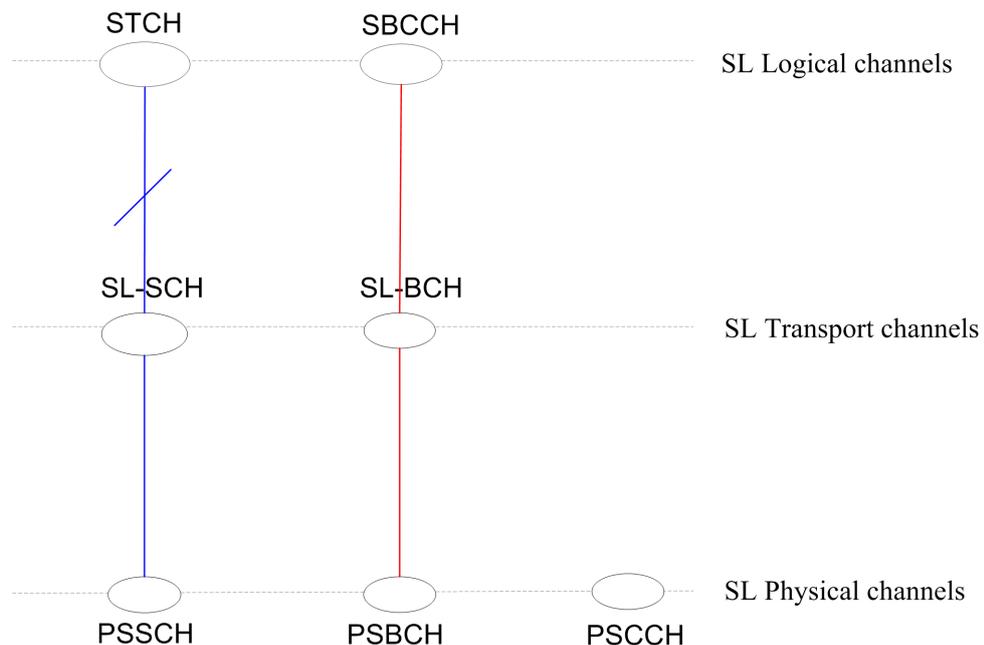Following channels are defined for SL communication [4, 8]:

Fig. 3-2: Sidelink channels for the air interface. In blue is the data path, whereas the path for control signaling is indicated in red.

There are two SL logical channels defined for communication, the SL Traffic Channel (STCH) and the SL Broadcast Control Channel (SBCCH).

The STCH is used for the data transmission carrying the user information from the ProSe application. It is a point-to-multipoint channel, reflecting the group call property of the ProSe communication. It is connected with the SL Shared Channel (SL-SCH), a transport channel which may bear a collision risk, depending on the resource assignment from the eNB. It interfaces to the Physical SL Shared Channel (PSSCH), which transports the data over the air.

The SBCCH carries signaling information used for synchronization in the out-of-coverage or partial coverage scenario, or for synchronization between UEs located in different cells. It is connected with the SL Broadcast Channel (SL-BCH), a transport channel with a predefined transport format, which is possible because the blocks from the SBCCH are all of the same size. The SL- BCH interfaces with the Physical SL Broadcast Channel, the PSBCH.

The Physical SL Control Channel (PSCCH) is the equivalent to the PDCCH in cellular traffic over U_u. It contains the *Sidelink Control Information (SCI)*, which carries the information the receiving UE requires in order to be able to receive and demodulate the PSSCH. So, the SCI is always sent in advance to an STCH data block.

3.2 Resource Pools

Central to sidelink transmission and reception is the concept of *Resouce Pools* (RP). A resource pool is a set of resources assigned to the sidelink operation. It consists of the subframes and the resource blocks within.
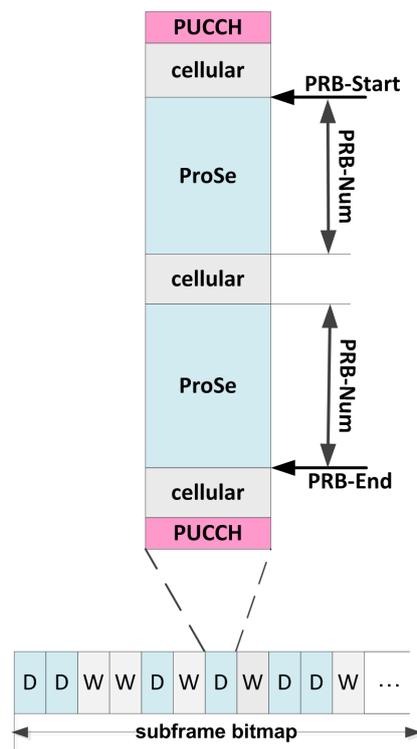
Fig. 3-3: Resource Pool for SL Communication. Subframes to be used for the RP are indicated in blue.

In figure 3-3 the resources for SL communication are indicated. Whether or not a subframe may be used for the sidelink is indicated in a subframe bitmap. After a configurable period, the SL control period (SC Period), the whole pattern repeats.

Within such a subframe, the resources used for SL are in two bands, identified by the occupied *Physical Resource Blocks* (PRBs). One band is starting at PRB-Start, one is ending and PRB-End, each one having a width of PRB-Num resource blocks. This construction allows nesting several resource pools within one subframe, and using the remaining resource blocks for other UEs for cellular traffic. Note that one UE uses a subframe in a given carrier for either cellular traffic or for sidelink, but not for both.

3.2.1 Assignment of Resource Pools

There are two types of RPs: Reception Resource Pools (Rx RPs) and Transmission Resource Pools (Tx RPs). These are either signaled by the eNB for the in coverage case, or preconfigured for the out-of-coverage case.

Of course, for every Tx RP there must be an associated Rx RP in order to enable communication. However, within a cell there may be more Rx RPs than Tx RPs. This way, also reception from UEs in neighboring cells or from UEs out-of-coverage is possible.

There are two modes of resource assignment: In *Mode 1*, the eNB indicates the resources to be used for transmission, including the resources within an RP. In *Mode 2*, the UE selects an RP and the resources therein from a set of assigned pools. Of

course, for Mode 1 the UE needs to be in the RRC_CONNECTED state, whereas Mode 2 also works for UEs either in RRC_IDLE state or even out-of-coverage.

3.2.2 Subframes within a Resource Pool

According to the PSCCH / PSSCH structure of SL communication, the set of sub-frames, i.e. the subframe bitmap, is split into two regions, the control region and the data region. For Mode 1, the subframe assignment is depicted in figure 3-4 [9]:
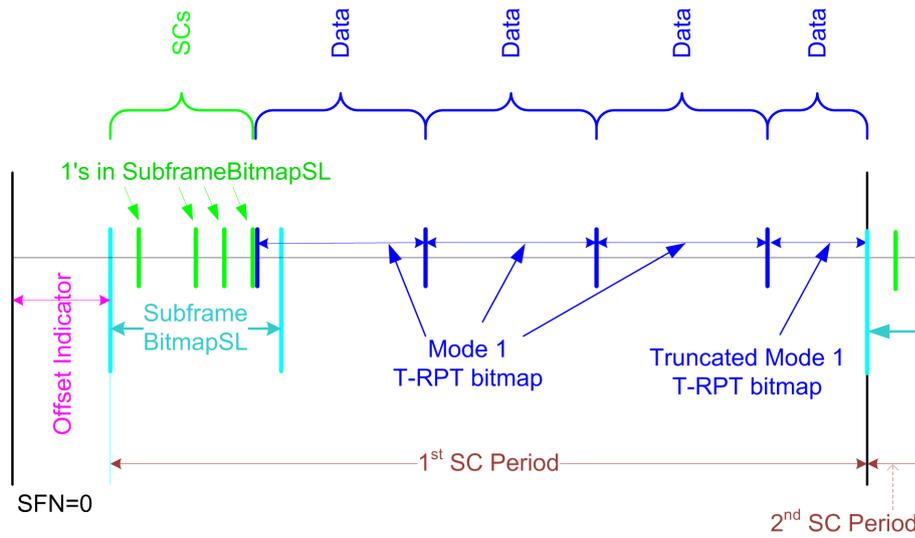

Fig. 3-4: Example of a subframe allocation for Mode 1

The first *SC Period* starts at an offset from SFN=0 and is periodically repeated with a configurable length between 40ms and 320 ms. It starts with the control region which contains the *SCI0* control element carried by the PSCCH, see section chapter 3.4.1, "Sidelink Control Information", on page 17 for details. *SubframeBitmapSL* indicates the subframes used for the PSCCH. Directly after the last bit of the SubframeBitmapSL which is set to *1*, the data region starts. It consists of another bitmap, the *T-RPT bit-map*, which is a bitmap indicating the subframes which are used for the data transmission. This bitmap is repeated until the end of the SC Period, where the last occurence may be truncated.

The T-RPT bitmap is dynamic and may therefore be different for each UE and for each SC Period. To be more precise, the set of all subframes which are allocated for the resource pool is restricted by using a periodic pattern with a periodicity of 8 for FDD, and a shorter one for some TDD configurations. Necessary parameters to determine this bitmap in order to receive the data part is signaled via the PSCCH, see chapter 3.4.1, "Sidelink Control Information", on page 17.

For Mode 2 this structure is quite similar. The main difference is that start of the data part does not depend on the content of the SubframeBitmapSL, but has a fixed offset from the start of the SC Period. In addition, the algorithm to determine the bitmap pattern is somewhat different and may explicitly exclude some configurations.

3.3 Signaling

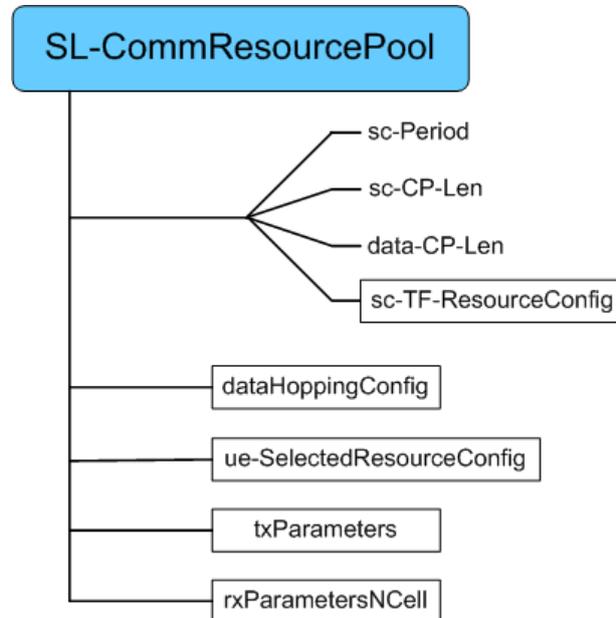The resource pool signaling structure for communication is shown in figure 3-5 [10]:

Fig. 3-5: Resource pool structure in RRC signaling

Elements in a box indicate that there is a further substructure, elements without a box indicate that this is a numerical value.

The field *sc-Period* indicates the SC Period shown in figure 3-4. For both, the PSCCH and the PSSCH, the cyclic prefix (CP) can be set up independently. However, the UE is not expected to receive two different CPs within one subframe, which is essential when two resource pools are defined within one subframe. In the *sc-TF-ResourceConfig* IE the resource block occupation figure 3-3, the subframe offset indicator and the subframe bitmap of the control part are indicated, see figure 3-4.

In the *dataHoppingConfig*, the parameters to determine the resource blocks within a subframe are included for the case that frequency hopping is applied.

The *ue-SelectedResourceConfig* information element (IE) is present for resource pools used for Mode 2. It determines for the data part the used subframes and the offset from the start of an SC-Period.

Information about the allowed transmission power is indicated in the *txParameter* IE. Thus, there are two instances of this IE, one for the control part and one for the data part.

Finally, the *rxParametersNCell* IE is included for the receiving UE. From its content, the UE can derive whether the transmitting UE was in the same cell or not, and can therefore determine whether it has first to synchronize to the transmitting UE. If this is the case the receiving UE also determines whether the sender applies TDD and in which configuration.

3.3.1   Broadcast Information for SL Communication

An eNB indicates support of sidelink communication with the presence of SIB18. Herein, all IEs are optional, however its mere existence indicates to the UE that sidelink operation is allowed in this cell. In figure 3-6 the structure of the SIB18 is shown.

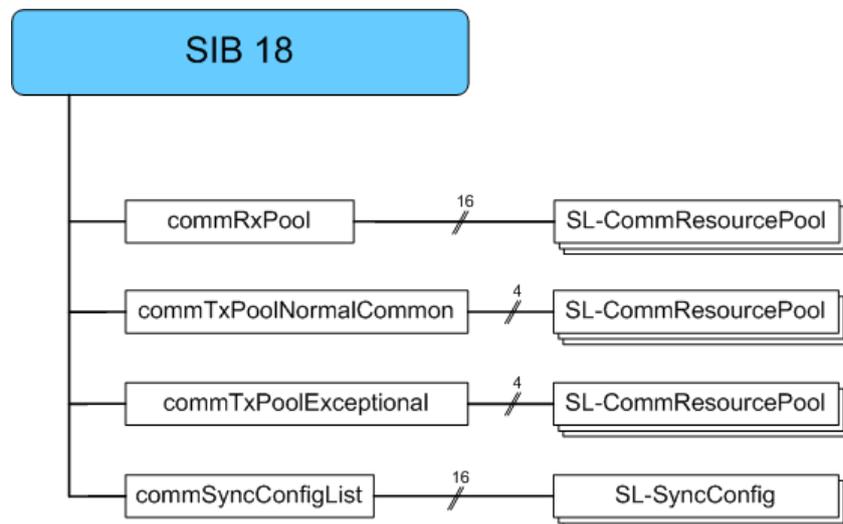*Fig. 3-6: Information elements in SIB18*

The *commRxPool* is a list of up to 16 resource pools (figure 3-5), indicating the resources in which the UE is allowed to receive sidelink transmission. Apart from the transmission pools defined in the same SIB, this list also may include resource pools from dedicated resource assignment, neighboring cells, and from UEs which are out-of-coverage. Reception pools are completely agnostic to the RRC state, so they are only defined in this SIB. Dedicated assignment of resources is only done for transmission pools.

In the *commTxPoolNormalCommon* IE, a list of up to 4 resource pools is given which are used for transmission when the UE is in the RRC_IDLE state. When this list is included, the UE has to use these resource pools while it is in the RRC_IDLE state. It may only request an RRC connection for the purpose to receive dedicated SL transmission resources, if there is no element in this list.

Resources from the *commTxPoolExceptional* may be used, when the UEs RRC state is in transition between RRC_IDLE and RRC_CONNECTED. E.g. the UE detects a radio link failure which then causes an RRC connection re-establishment. In this case, the UE has some time to select a suitable cell to request an RRC connection re-establishment. This exceptional pool is for usage during this time in order to improve service continuity. Note that this situation is quite common for public safety UEs, for example a firefighter entering a building might frequently encounter this situation. Especially in this case, service continuity is extremely important.

Finally, the *commSyncConfigList* contains the necessary information for synchronization between UEs which are not in-coverage in the same cell, see chapter 4, "Receiver Synchronization", on page 21.

3.3.2 Providing the UE with Dedicated Configuration

When the UE is in the RRC_CONNECTED state, it does not use the tx pool resources given in the broadcast message. Instead, it requests the eNB to provide dedicated transmission resources. This process is depicted in figure 3-7:

Fig. 3-7: UE indication to the eNB to request dedicated SL resources

By receiving SIB18, the UE knows that the eNB supports sidelink transmission and may so request dedicated resources. This is done via the *SidelinkUEInformation* message. It contains the frequency the UE is interested to transmit and / or receive sidelink data. Further, a list of up to 16 destination IDs are provided, where each ID identifies one group to which the UE wants to transmit.

The UE sends this message whenever it has sidelink data to transmit and did not send it since entering the RRC_CONNECTED. In addition, it sends this message when it was connected in the meantime to an eNB not supporting sidelink transmission, i.e. which did not broadcast SIB18. This may be necessary e.g. because it is not clear, whether this eNB has the sidelink functionality already implemented at all. In this case, forwarding of the associated configuration data is not guaranteed. Of course, the UE also retransmits this message when the frequency set up by the higher layers has changed. This also includes the case that the UE is not interested anymore to transmit or receive sidelink data

The obvious question is, why the eNB wants to know that the UE is interested to *receive* on the sidelink. The point here is that the UE does not receive sidelink and cellular transmission in the same subframe of the same carrier. So, knowing the UEs interest in receiving sidelink transmission, eNB can avoid to schedule cellular traffic to the UE at the subframes allocated for sidelink.

Upon this request, the eNB can provide dedicated resources to the UE for SL transmission. There are two options for the eNB: It can either provide a list of up to 4 transmission resource pools, from which the UE can autonomously select the pertinent resources. Or, the eNB can provide *scheduled* resources, which indicate exactly the resources for the PSCCH as well as for the PSSCH. In figure 3-8 the associated structure is shown:
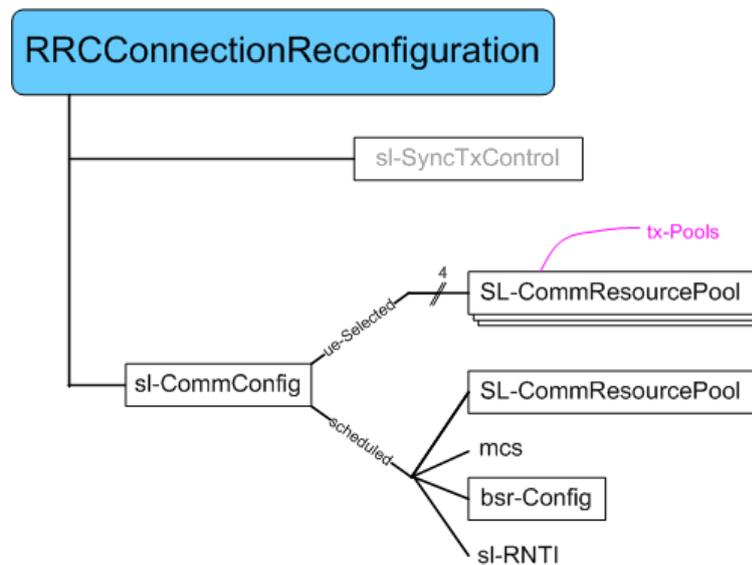
Fig. 3-8: Extensions of the RRCConnectionReconfiguration message for SL-Communication

As shown in this figure, a resource pool is included also for scheduled resource assignment. From this pool, the UE extracts general information like SC-Period length, cyclic prefix length, or maximal transmission power. This information is optionally extended with the modulation and coding scheme (mcs) to be used in PSSCH. If this element is missing, it is up to the UE to select the pertinent one.

In a way equivalent to the UL transmissions, the UE is configured to provide a buffer status report using the *bsr-Config* information element. When the UE has data to send over the sidelink and the associated buffer status report is triggered, the UE waits for a grant which is indicated in the PDCCH via a newly defined DCI, the DCI5. The *sl-RNTI* is used to identify the UE for which this grant is intended.

This DCI5 contains the following information:

- *Resource for PSCCH.* Together with the data from the associated resource pool, this field identifies the subframes and resource blocks to be used for the SCI0 transmission.

- Transmission power control command for the PSCCH and PSSCH.

- *Frequency hopping flag*, indicates whether frequency hopping is applied. Both, type 1 and type 2 frequency hopping are supported.

- *Resource block assignment and hopping resource allocation* indicates information about frequency hopping if the frequency hopping flag is set, and the information about the physical resource blocks used in the data transmission.

- *Time resource pattern* provides the information about the subframes to be used in the data part, the T-RPT bitmap

For the case of mode 2 transmission, the UE autonomously selects the pertinent resources.

3.4 Data Transmission

All relevant details for the transmission of control information on the PSCCH can be found in [10]. In Rel-12 there is only one Sidelink Control Information (SCI) format defined, which is SCI format 0. As there is no HARQ process and to increase probability of correct demodulation of the SCI format 0 content two identical copies are send. These two identical transmissions occupy one pair of RB but in different subframes. In other words PSCCH is transmitted twice, using always QPSK modulation. For the entire content of SCI0 format, please refer to chapter 3.4.1, "Sidelink Control Information", on page 17.

As stated above SCI transmission on PSCCH takes place on different time-frequency resources impacted by several parameters. First of all, the configured transmission resource pool(s). As discussed in chapter 3.2, "Resource Pools", on page 8 three parameters (PRB_Start, PRB_End, PRB_Num) determine which resource blocks are actually reserved for transmission in a subframe dedicated to D2D. The total number of available RBs (parameter called MPSCCH_RB) is a first parameter impacting which subframes and which RB in that subframe carries the PSCCH transmission. The actual number of subframes (LPSCCH) used for D2D are determined by the bits that are set to '1' in *SubframeBitmap-SL*, provided by SIB18. Last but not least, the time-frequency resources that a device uses to transmit PSCCH and therefore SCI format 0 are impacted by the parameter that is called n_{PSCCH}, which is set by the eNB (on mode 1). The base station sends this parameter as part of its scheduling information to the device. MPSCCH, LPSCCH define a certain range that n_{PSCCH} can be in. The eNB selects one value out of this parameter range and sends it (*Resource for PSSCH*) among other information via DCI5 to the UE.

Lets take an example. For simplicity we focus in the following only on transmission mode 1 (resource scheduled by the eNB via DCI5) and a signal bandwidth of 10 MHz (50 RB) for the uplink. FDD mode is used. Two RB cluster are available per subframe (defined by PRB_Start, PRB_End), where PRB_Num is set to 10. Therefore MPSCCH is 20 RB. n_{PSCCH} has to be in the range between 0 to 99 and in our example we assume it to be 55. With these parameters the first PSCCH transmission would occur using 5th RB in subframe #5 of the SC-Period. Second transmission would use 15th RB in subframe #1. The occupied resources are marked yellow in figure 3-9. Per UE the eNB would assign a different value for n_{PSCCH} so that the UEs are using different resources and thus avoiding collisions.
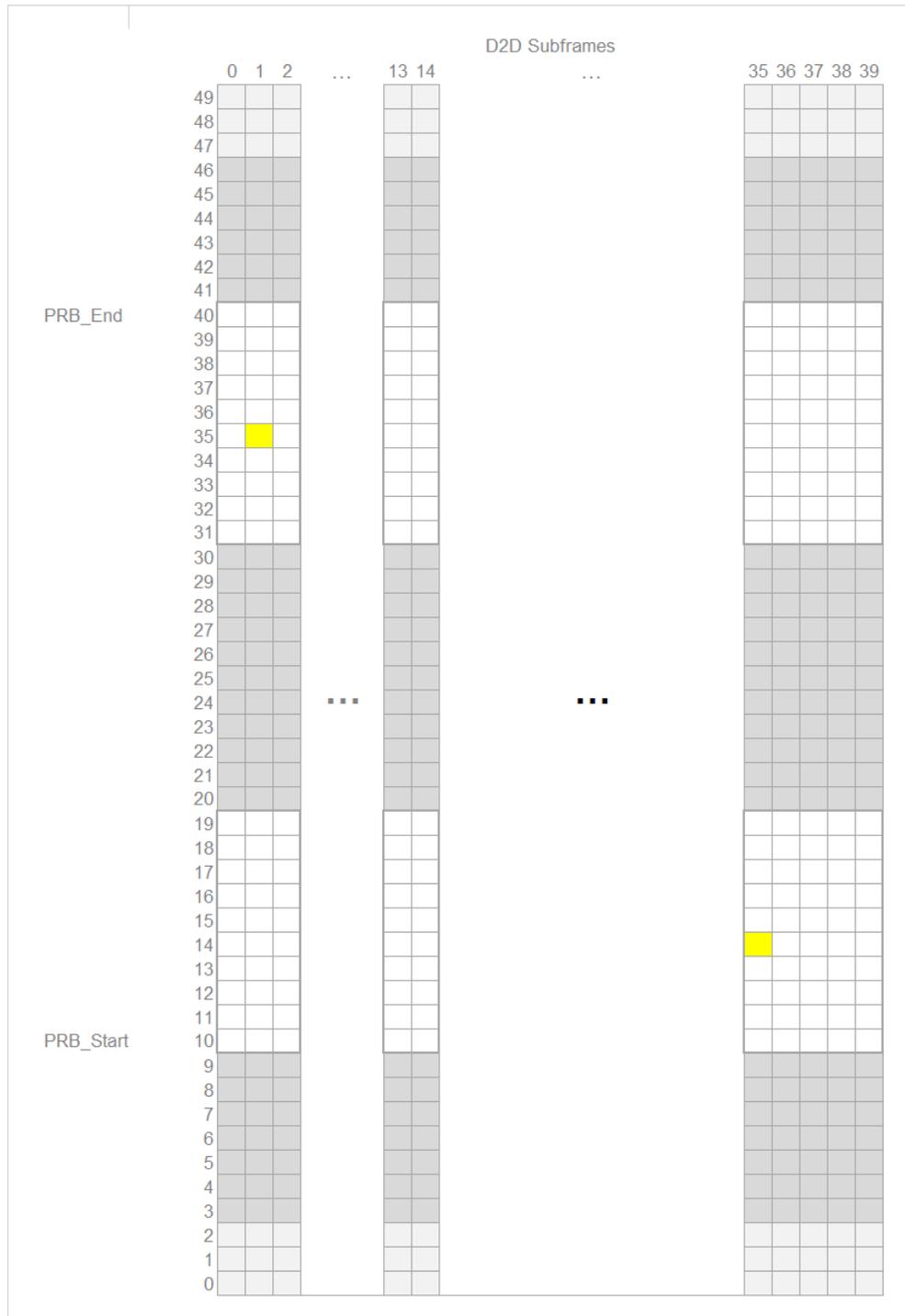
Fig. 3-9: Example of SCI0 transmissions in the control region of the SC Period. Only the subframes indicated with 1 in the SubframeBitmapSL are shown.

Using mode 1, the UE knows the time and frequency resources to transmit the SCI0 and the data. On mode 2, it selects these resources from the configured resource pool in a random way. For the case that several resource pools are configured, the UE

always selects the first resource pool, at least for Release 12. This way, an optimized selection algorithm to be defined in later releases remains possible.

3.4.1 Sidelink Control Information

With the SCI0, the receiving UE can identify on the physical layer, whether the data packet is intended for it, and deduce the information necessary to demodulate.

The SCI0 provides the following information:

- Frequency hopping flag: Indicates, whether frequency hopping is applied for the data part.
- Resource block assignment and hopping resource allocation: Provides information about the number of allocated resource blocks and their location. If frequency hopping is applied, it provides further information about the hopping configuration.
- Time resource pattern: Indicates the subframes used for the data part, see chapter 3.2.2, "Subframes within a Resource Pool", on page 10.
- Modulation and coding scheme
- Timing advance indication: This element is only used in mode 1. It indicates the timing adjustment value for the receiver.
- Group destination ID: Used for a receiver selection on the physical layer. This field corresponds to the 8 LSBs of the *ProSe Layer-2 Group ID* described in chapter 2.3, "Protocol Stack", on page 6.

Note that the *Group destination ID* does not uniquely identify the receiving group. Also the 16 MSBs of the *ProSe Layer-2 Group ID* are required, as described in the next section.

3.4.2 Data Packets

The basic data segment to be transmitted is the MAC PDU. It is essentially the same as the one for the UL-SCH. The differences are, that there are no MAC CEs contained and that a SL-SCH subheader is prepended to the remaining fields of the MAC header:
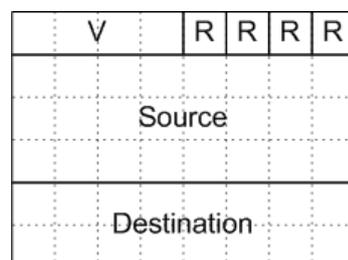

Fig. 3-10: SL-SCH subheader, prepended to the legacy fields in the MAC header [7]

This SL-SCH subheader is not referring to any MAC SDU or padding region. Instead, it indicates the tranmitting UE (Source), its intended receiver (Destination), and a version number (V). The latter is included so that a possible extension in a later release may

be standardized. The bits marked with *R* are reserved and may be used for such an extension.

The *Source* field is identical to the *ProSe UE ID* and has a length of 24 bits. The 16 bit *Destination* field is identical to the 16 MSBs of the *ProSe Layer-2 Group ID* and indicates the receiver group. Using the Destination field, the UE can drop data packets at the MAC layer.

3.4.3 Transmission and Retransmission

The so constructed MAC PDU is sent as one transport block within one subframe. On the receiver side there is HARQ combining, however no HARQ feedback is transmitted. So, in order to improve reliability, the MAC PDU is retransmitted three times in consecutive subframes for sidelink. Each transmission has a different redundancy version, using a fixed pattern. Only the first transmission is indicated with SCI0, the receiving UE can derive itself all required data to demodulate the retransmissions.

When there is more data to send after this transmission, the UE creates another MAC PDU to be sent on the next 4 subframes defined for sidelink. However, within one SC Period there is only the possibility to transmit on logical channels with the same Source and Destination Layer-2 ID pairs. Nevertheless it is possible to receive from several sources and even for several destinations, if the UE belongs to more than one group. Correspondingly, there are several HARQ processes in the MAC layer of the receiving UE, as one HARQ process is always related to the transmission or reception of one MAC PDU.

PSSCH data transmission is done using Uplink resource allocation type 0, with or without frequency hopping. If applied, type 1 and type 2 hopping is supported.

3.4.4 Power Control

In order to control the SL transmission power, there are several parameters available. First there is the maximum allowed power $P_{CMAX,PSCCH}$ for the control channel, and $P_{CMAX,PSSCH}$ for the maximum allowed power of the data channel. These upper limits are either cell specific and transmitted as RRC messages, or they are preconfigured. However, these values never exceed the UE power class.

The eNB can further control the transmission power for each resource pool separately. The associated parameters are provided in the *txParameters* contained therein:
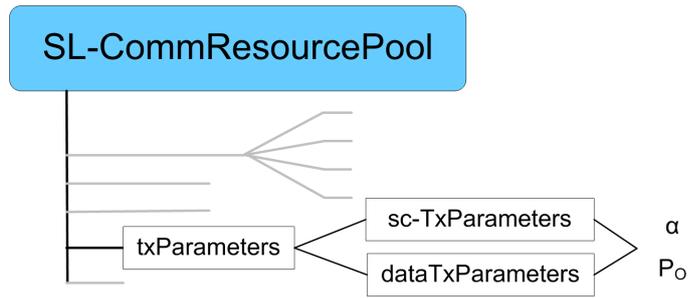
Fig. 3-11: Tx parameter in the resource pool for power control

Two parameters, α and P_O are defined, each for the control and the data part, respectively.

For sidelink transmission Mode 1, there is the TPC command in DCI5. If this bit is set to 0, then the maximum transmission power of the control part, P_{PSCCH}, and of the data part, P_{PSSCH}, is given by:

$$P_{PSCCH} = P_{CMAX, PSCCH}$$

$$P_{PSSCH} = P_{CMAX, PSSCH}$$

If the TPC command in DCI5 is set to 1, or if the resource pool is used for Mode 2 transmission, the maximum transmission power is given by

$$P_{PSCCH} = \min\{ P_{CMAX, PSCCH}, P_{O, sc} + \alpha_{sc} \cdot PL \}$$

$$P_{PSSCH} = \min\{ P_{CMAX, PSSCH}, 10 \cdot \log_{10}(M_{PSSCH}) + P_{O, data} + \alpha_{data} \cdot PL \}$$

where M_{PSSCH} is the bandwidth of the PSSCH resource assignement given in the number of resource blocks, *PL* is the expected path loss which the UE calculates using the *referenceSignalPower* of the cell and the filtered RSRP measurements.

3.5 Multicarrier Support

The sidelink resource configuration via SIB18 is always valid for the frequency on which the UE receives it. For the case that the UE has one or more SCells configured, the dedicated configuration is always applied for the PCell. On the other hand, the frequency on which the UE transmits or receives sidelink communication is set up by higher layers. Thus the UE has to know how to do SL communication in a cell different to its PCell. This includes UL carrier aggregation, but also sidelink communication on carriers which are not actually assigned to the UEs PCell.

For the sidelink reception, the UE has to take essentially the same procedure as for the PCell. If it has coverage on the SL cell, the UE first reads its SIB18 and retrieves information about the rx pools. If it is out-of-coverage on the SL cell, it uses the preconfigured resources.

For the sidelink transmission, the process depends on the RRC state. UEs in the RRC_IDLE state not camping on a ProSe cell may consider the ProSe cell to be the highest priority cell, i.e. it may camp on that cell. It then transmits sidelink according to the procedure defined in RRC_IDLE, i.e. using tx resource pools from SIB18 or requesting an RRC connection to that cell.

A UE in the RRC_CONNECTED state may send the *SidelinkUEInformation* message indicating the frequency on which it wants to communicate on sidelink. The eNB may then setup an RRM measurement, and, if the measurement indicates sufficient coverage, initiate a handover to that cell. If this handover is successful, sidelink transmission is done on this new cell in the way described in the previous sections. If not, the UE may still send sidelink data on the desired frequency, however in the same way as if it would be in the RRC_IDLE state, i.e. using the tx pools from SIB18 of that cell for the case that it has coverage, or else from the preconfigured resource pools.

4 Receiver Synchronization

In order to demodulate the transmitted data, the receiver has to synchronize to the sender. This is no problem as long as both UEs are in coverage of the same cell or of two synchronized cells. In this case, the receiver has only to balance the propagation delay.

The situation changes when the UEs are in different non-synchronized cells, or if at least one of the UEs is out-of-coverage. Then the timing of both UEs are not related and the receiving UE needs additional information.

So, in the first section we introduce these additional synchronization signals and their usage in the network. Then we describe which UEs transmit them and where they get the associated data in different situations. Finally, we describe how the receiving UE knows that a synchronization to the sender is necessary before it attempts to demodulate the data packet and how it applies the appropriate synchronization steps.

4.1 Synchronization Signals

There are two types of signals for synchronization:

- Sidelink Synchronization Signals (SLSS) for synchronization in time and frequency.
- Master Information Block SL (MIB-SL), providing additional information.

For the SLSS there are primary and secondary sidelink synchronization signals, the PSSS and SSSS. Each of those occupy 62 resource elements in the frequency range around the center, and two adjacent SC-FDMA symbols in time. If normal cyclic prefix is applied, the PSSS is transmitted in symbols 1 and 2 of the first slot, the SSSS in symbols 4 and 5 of the second slot in the same subframe , see figure 4-2. For extended cyclic prefix, the synchronization signals are shifted by one symbol.

The SLSS ID is in the range from 0 to 335 and is divided into two sets:

- SLSS ID $\in$ {0,..,167}: Either the transmitting UE is in coverage or gets the synchronization directly from a UE in coverage
- SLSS ID $\in$ {168,..,335}: The UE is out-of-coverage and has no direct connection to a UE in coverage

Consequently, the receiving UE knows from the detected SLSS ID whether the sender is at least in close connection to an LTE cell.

The MIB-SL is transmitted over the SBCCH (see figure 3-2) and carries the following information:
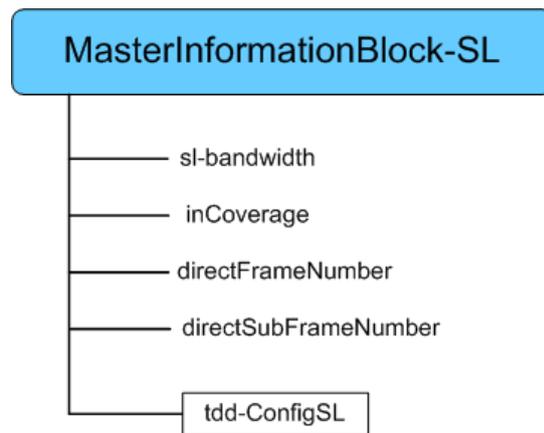
Fig. 4-1: MIB-SL transmitted from a UE

The *inCoverage* flag indicates, whether the sender is in coverage of a cell. *directFrameNumber* and *directSubFrameNumber* correspond to the SFN and subframe in case of a connection to coverage and is a UE internal counter for the case that no connection to a cell exists.

The MIB-SL is transmitted in the same subframe as the SLSS, indicated in the following picture:
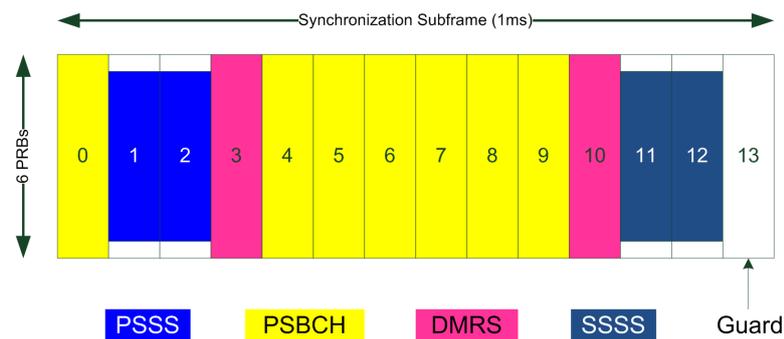

Fig. 4-2: Subframes used for the synchronization signals PSSS, SSSS, DMRS, and MIB-SL contained in the PSBCH

4.2 Transmission of the Synchronization Signals

The last section raises the question, which of the UEs act as a source for synchronization, i.e. transmit the Sync Signals. For this decision, there are three cases to distinguish: The network may instruct the UE to transmit them, the UE decides itself while it is in coverage, or while it is out-of-coverage.

4.2.1 Network Instructed Transmission of Synchronization Signals

UEs in RRC_CONNECTED obtain their transmission resources from the *RRCConnectionReconfigutaion* message, as shown in figure 3-8. As an optional element, the *sl-*

SyncTxControl information may be appended. It contains the field *networkControlled-SyncTx*, which has a boolean value (on/off):
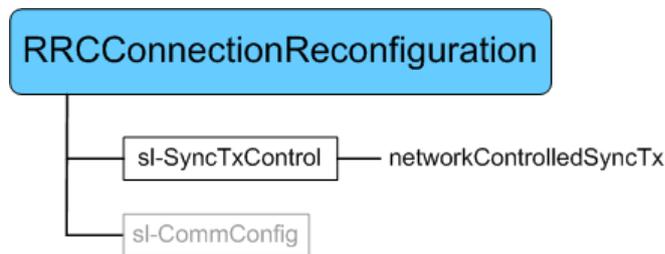

Fig. 4-3: Network controlled transmission of Synchronization Signals

If this element is included and set to *on*, the UE transmits the SLSS and MIB-SL every 40ms, no matter whether is has data to send or not. If it is included and set to *off*, the UE does not send the synchronization signals, no matter how the conditions on the air-interface are or whether it has data to send.

When the UE is instructed to transmit SLSS and MIB-SL, it has to select the parameters and to determine the corresponding subframes. In order to create the content of the MIB-SL message, it takes the *sl-bandwidth* from SIB2, and the tdd-configSL from SIB1. Note that this field contains the FDD modus as a special case. It selects the frame and subframe numbers to the ones in which it transmits this message.

SIB18 provides the information on the selection of the SLSS ID and the subframes for transmission, see figure 3-6. Here, a list of up to 16 instances of the *SL-SyncConfig* information elements is included. Each one of them has the following content:
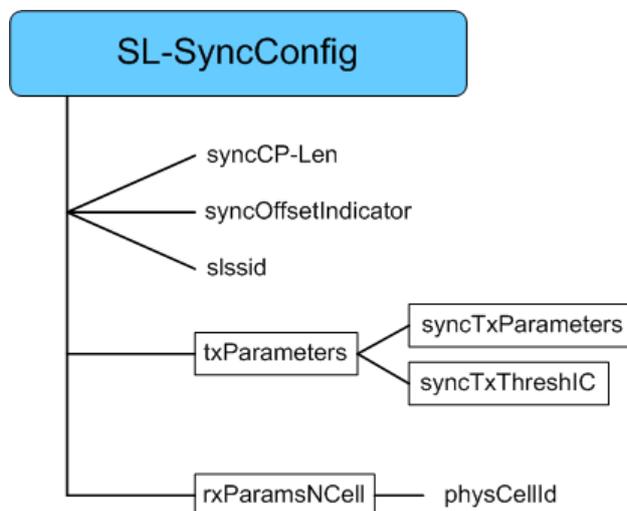

Fig. 4-4: SL-SyncConfig information element with the content for sidelink operation

The *txParameters* are contained in exactly one *SL-SyncConfig* list element. The UE selects this one, reads the *slssid* and the *syncOffsetIndicator*, and obtains the subframes for transmission from the latter. Finally, the *syncTxParameters* are used for power control.

4.2.2 UE Selected Transmission when In Coverage

When the UE is either in the RRC_IDLE state, or in the RRC_CONNECTED state with the *networkControlledSyncTx* not included in the resource asignement, the UE has to decide on its own whether to transmit the synchronization signals or not. For this decision, it takes the *syncTxThreshIC* threshold (figure 4-4) and compares the RSRP measurement of its cell to this value. If this RSRP measurement is below the syncTxThreshIC, it transmits SLSS and MIB-SL, getting the necessary parameters in the same way from the SL-SyncConfig as for the eNB instructed transmission. However, these transmissions only occur during the SC-Period in which the UE sends data.

Let us clarify here, why the received power from the serving eNB is compared to a threshold, allthough it is the link to another UE which is at the center of interest. In order to see this, have a look at figure 4-5:
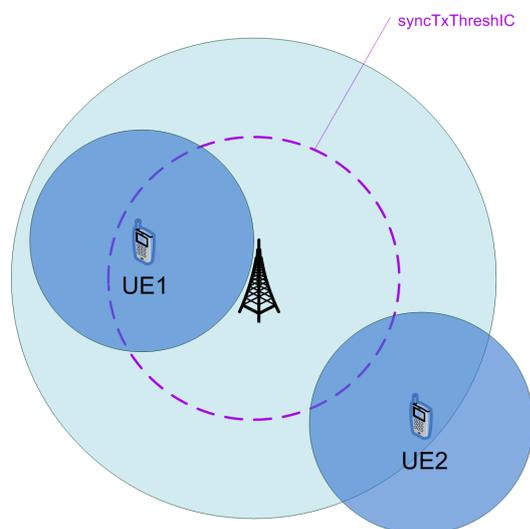

Fig. 4-5: Range extension provided by UE2

In light-blue we show the range of the cell. A violet dashed line indicates the *syncTxThreshIC*. Outside this line, the measured RSRP values is below this threshold. When we now consider UE1, there is no benefit in transmitting further synchronization signals. The cell itself already covers this range completely. However, for UE2 the situation is different: Parts of the transmitted signals are outside the cell range and provide a way for cell range extension.

4.2.3 UEs Out-of-Coverage

When a UE is out-of-coverage, it first looks for another UE providing synchronization reference. For this search it uses the SLSS IDs as measurement parameters. Such a UE, if found, is called *SyncRef UE*. The UE obtains from this SyncRef UE the time and frequency synchronization as well as the information provided by the MIB-SL.

In order to find a SyncRef UE, first all SLSS IDs are searched. For each of these IDs, the UE measures the *Sidelink Reference Signal Received Power* (S-RSRP) applying L3 filtering with preconfigured filter coefficients. S-RSRP is measured on Demodulation

Reference Signals (DMRS) which are embedded in the synchronization subframe see figure 4-2. All UEs for which the so obtained S-RSRP exceeds a prefconfigured threshold (see ch. 9.3.2 of [10]) and for which the MIB-SL was received are partitioned into three priority groups:

- Highest priority have those UEs, which are in coverage, indicated by the associated flag in the MIB-SL
- Next priority have those UEs, which have an SLSS ID in the set for in coverage
- Lowest priority have the remaining UEs.

Within these groups, the UEs are sorted with respect to the received S-RSRP. The so obtained UE which has the strongest S-RSRP in the highest priority group is finally selected as the SyncRef UE. In the same way, the UE performs a reselection of the SyncRef UE when the situation changes.

When the UE has selected a SyncRef UE this way, it has to decide whether it should transmit itself the synchronization signals. For that decision, it compares the S-RSRP value received from the SyncRef UE with a preconfigured threshold. When these measurements are below that threshold (see [10], *syncThresOoC*), it transmits the synchronization signals. This way, it is prevented that too many UEs act as a synchronization source.

The UE extracts the *sl-bandwidth* and the *tdd-ConfigSL* value from the received MIB-SL, and sets the frame- and subframe number to the subframe in which it transmits the SLSS and MIB-SL. However, in this case these subframes are determined from preconfigured values. Two of them are provided, and the UE selects those subframes which are not used by the SyncRef UE. So, two neighboring UEs which transmit the synchronization signals use different sets of subframes, which minimizes the interference.

The SLSS ID which the UE uses for its own transmission is the same as the one received from the SyncRef UE. An exception occurs, if the SyncRef UE is out-of-coverage but has an SLSS ID from the range for in coverage. In this case, the value of the SLSS ID is 168 higher than the received one.

If the UE has not found any SyncRef UE at all, it transmits the synchronization signals when it has data to transmit. It determines the MIB-SL values from preconfigured values. The SLSS ID is randomly selected from the set of IDs for out-of-coverage, and the subframes from the preconfigured set.

4.2.4 Example Configuration of a Network

In the following figure, we show an example how this procedure shows up in a network:
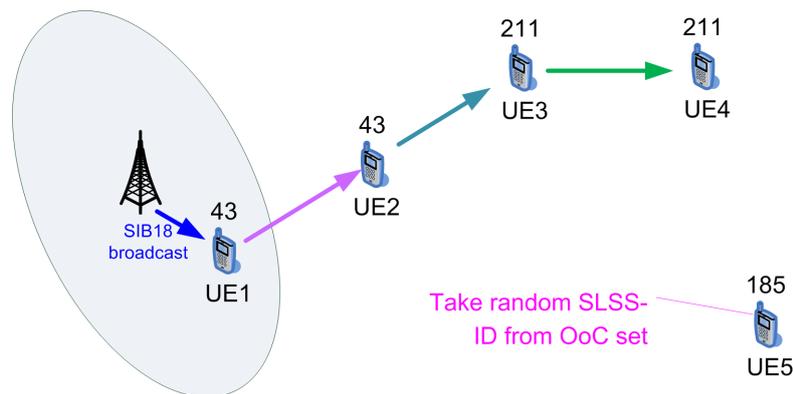
Fig. 4-6: Example network configuration. The numbers indicate the SLSS ID which the UE uses when it transmits the SLSS itself.

The arrows indicate the delivery of the synchronization signals. UE1 is in coverage and uses the SLSS ID 43, which it obtains from SIB18. UE2 Also uses ID 43, because it receives its synchronization from a UE in coverage, as it can verify by considering the MIB-SL. However, UE3 gets the synchronization information from a UE out-of-coverage with an SLSS ID from the in coverage range. Thus it adds 168 to that value, resulting in the ID 211. Finally, UE4 sees that the SLSS ID is from the out-of-coverage range, and thus retransmits the same value.

For UE5 there is neither a SyncRef UE nor a cell coverage, so it selects the SLSS ID randomly from the set of out-of-coverage values. This random selection is done using a uniform distribution.

4.3   Synchronize to the Sender

How does the UE know, whether it has to synchronize to the sender? The answer to that question is provided by the rx resource pools. As indicated in figure 3-6 there are up to 16 resource pools defined for data reception, each one of them with the fields as shown in figure 3-5.

The decisive point is the element *rxParametersNCell*. This is an optional field which is omitted when this rx pool corresponds to a tx pool for the same cell (or a synchronized neighboring cell). In this case, the UE uses the cell timing also for the reception of SL data. However, if this field is included, the UE knows that the associated tx resource pool is not synchronized to the sender, either it is on a neighboring cell or from a UE out-of-coverage. Then the UE has first to synchronize to the sender before it can decode the message.

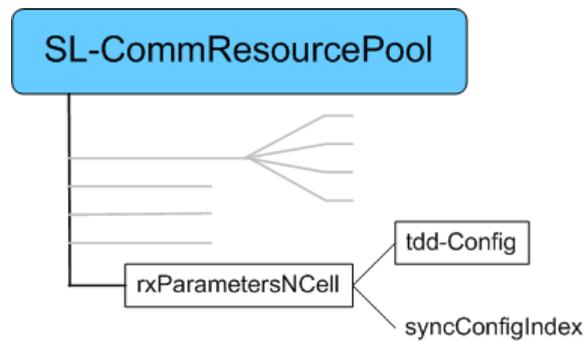The structure of this field is shown in the following figure:

Fig. 4-7: Indication that the UE has to synchronize to the sender

The *tdd-Config* indicates the TDD configuration, including the usage of FDD as a special case. *syncConfigIndex* is a number pointing to the *SL-SyncConfig* list element of SIB18, see figure 3-6. From this SL-SyncConfig element, the physical CellID and the SLSS ID used in this cell can be read off. For the case that the UE receives both, cell synchronization and reception of the SLSS, the cell synchronization has precedence.

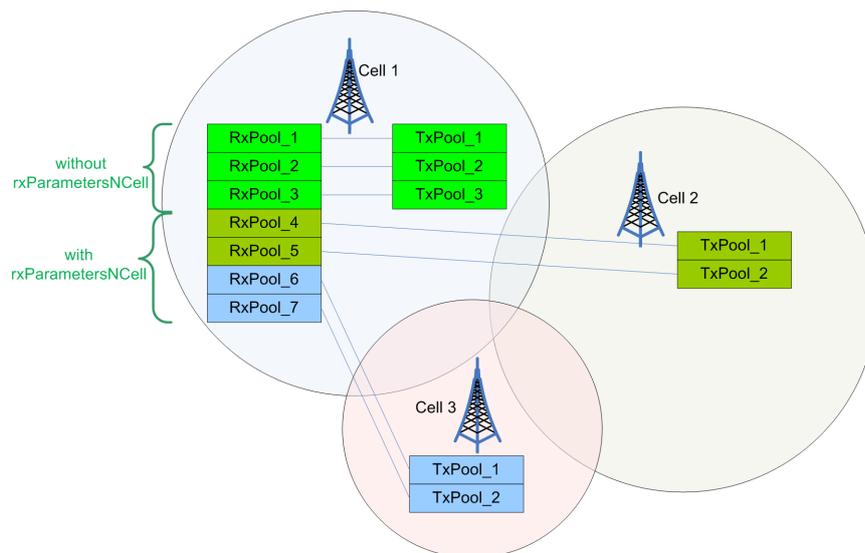An example configuration is shown in figure 4-8

Fig. 4-8: Example of an rx pool configuration

The UE connected or camping on Cell 1 is configured with 7 rx resource pools. The first three resource pools correspond to tx pools within the same cell, so there is no additional synchronization required. If the UE wants to receive SL data from Cell 2, it has first to synchronize to this cell, as indicated with the rxParametersNCell in its rx resource pool. Having this synchronization, the UE can also monitor the rx pool 5, because it refers to the same synchronization information. However, in order to receive sidelink data from the rx pools 6 and 7, the UE needs further synchronization as indicated by syncConfigIndex referring to a different SL-SyncConfig element.

5 Security

In this section we describe the security features for the ProSe operation from the UE point of view. Of course, also the interfaces between network entities are secured, see [12] for a detailed description.

For the PC5 interface, security consists of bearer level security mechanism and media plane security mechanism. As this whitepaper mainly concentrates on the RAN protocol stack, we describe the former security mechanism in detail, for a description of the media plane security mechanism see [12].

5.1 Parameters

Security parameters are provided by a network node called the *ProSe Key Management Function*. This node may physically be part of the ProSe Function (figure 2-2), however it is regarded in this section as a separate logical unit. The UE accesses this node via the PC8 interface. PC8 is defined over IP and is thus acccessed over the cellular user plane.

The parameters which have to be configured for a group are depicted in figure 5-1:

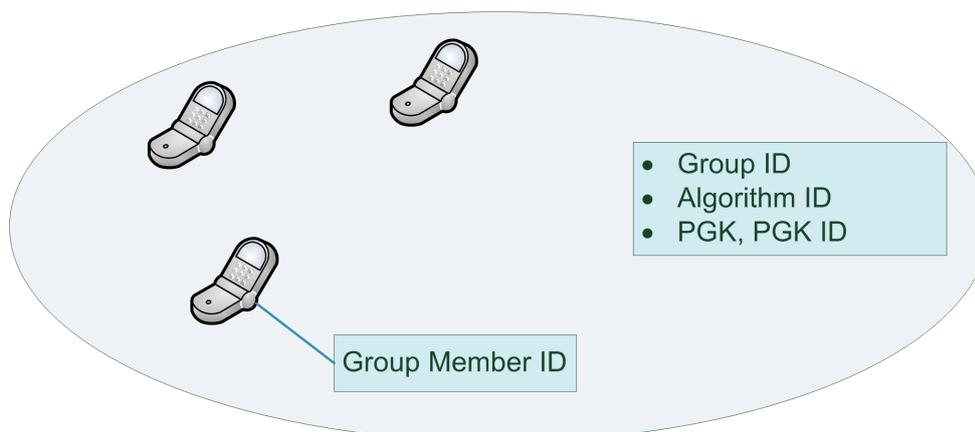- Group ID
- Algorithm ID
- PGK, PGK ID

Group Member ID

Fig. 5-1: Security parameters configured for a group

Each group is identified with a *Group ID*, which has a length of 24 bits and corresponds to the *ProSe Layer-2 Group ID*, see chapter 2.3, "Protocol Stack", on page 6. Each UE within the group is identified with the *Group Member ID*, corresponding to the ProSe UE ID defined in the same section. Note that one UE generally has different Group Member IDs in different groups.

Central to the security is the *ProSe Group Key* (PGK). It is used as a basis to derive input parameters for the security algorithm. Each PGK is provided with an expiry time. By providing the UE with PGKs valid for different times, the UE may operate for a longer time without further parameter provisioning, e.g. out-of-coverage, always taking a PGK valid for the actual time.

Several PGKs may be valid simultaneously. In order to know for the receiving UE which PGK the transmitting UE has used, each PGK is also provided with a PGK ID. The ProSe Key Management function ensures, that for each time instance, the PGK may be uniquely determined by the 5 LSBs of the PGK ID within a group.

Finally, also the algorithm is specified for the whole group. Mandatory ciphering algorithms to be used for ciphering are EEA0 (no ciphering), 128-EEA1, and 128-EEA2. Optionally, the UE may support 128-EEA3. All these algorithms are listed in [13].

5.2 Parameter Signaling

The network provides the required parameters with a message sequence shown in figure 5-2:
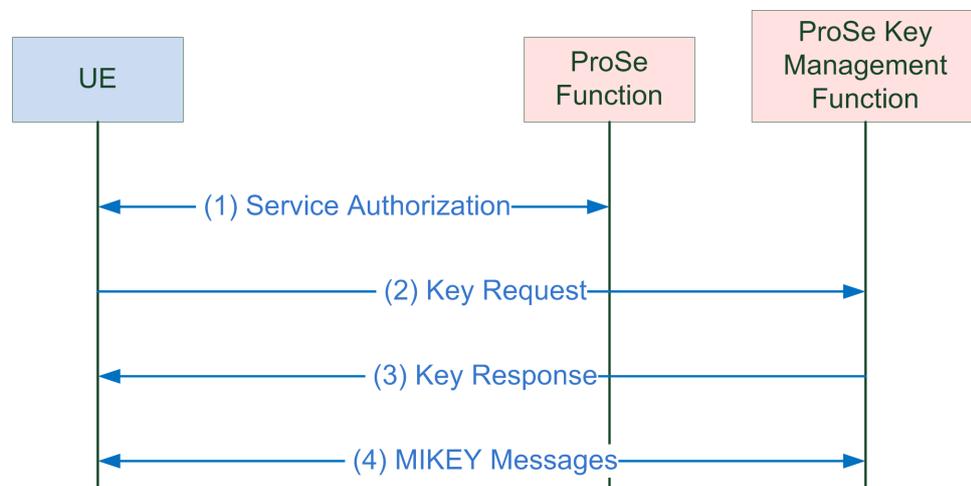

Fig. 5-2: Key exchange procedure to provide the UE with the required parameters

(1): If not already preconfigured in the USIM card, the UE first has to authorize for ProSe communication in the ProSe function. Apart from the authorization and the pertinent communication parameters, the UE receives for each group of interest the *Group ID* and the information whether bearer level security is applied therein. Optionally the UE also obtains the address of the ProSe Key Management Function to be used for the remaining steps.

(2): In order to request the keys for the groups of interest, the UE sends the Group IDs obtained in message (1) and the UEs security capabilities. It also adds the groups for which it has no interest anymore to participate in group communication.

(3): For each group, the ProSe Key Manamgement Function checks whether the UE is authorized to participate and whether its security capabilties are sufficient for ProSe communication. It then returns the *Key Response* message, in which it includes the *Group Member ID* the UE has in each group, and the security algorithm to be used therein. This message may also contain another key, the *ProSe MIKEY Key (PMK)* to be used for step (4), together with an associated *PMK ID*. If the PMK is not transmitted, the previously sent PMK has to be reused.

(4): In this step, the ProSe Key Management Function sends the sets of *PGK*, *PGK ID* and their associated expiry time. Both sides use the *Multimedia Internet Keying* (MIKEY) exchange process described in [12], for which the PMK is the associated pre-shared key.

Using this procedure, the UE acquires all parameters indicated in figure 5-1. Note that the messages between the UE and the ProSe function, as well as the *Key Request* and *Key Response* messages are protected by integrity, confidentiality and from replays. Details of this procedure are described in chapter 5.3 of [12]. The MIKEY message protection is independent thereof.

5.3 Data Encryption

The *PGK* itself is not used for data encryption, instead, further keys are derived. The associated procedure is delineated in figure 5-3.
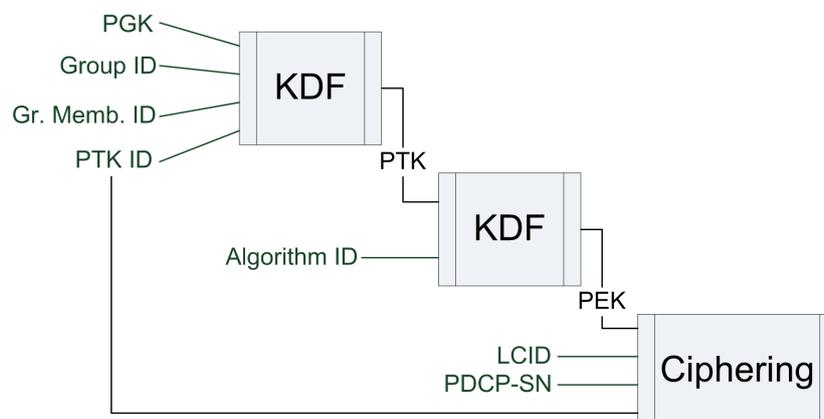

Fig. 5-3: Key derivation for data ciphering. The two KDFs are different, they are described in Annex A3 and A4 of [12], respectively.

From the PGK, the *ProSe Traffic Key* (PTK) is derived when the first PDCP entity for a group is created. The PTK is unique for a given UE and group, which is ensured by including the Group ID and Group Member ID as input to the *Key Derivation Function* (KDF). Also a counter, the *PTK ID* which has a length of 16 bit, is used for input. For a new PGK, the PTK ID is initialized with the value *1*, it is incremented each time a new PTK is derived.

From the PTK, the UE derives a *ProSe Encryption Key* (PEK), using the Algorithm ID as further input. With this PEK, the UE ciphers the PDCP PDU's data segment, with the PTK ID as an additional input. In order to prevent that the same ciphering is applied in two messages, the PDCP instance, identified with the LCID, and a PDCP internal counter, the PDCP-SN, are used as well. The PDCP-SN is incremented for each data packet which the associated PDCP creates.

No PTK ID value may be used twice with the same PGK, and no PDCP-SN value may be reused with the same LCID and PEK. So, if the PDCP-SN wraps, the corresponding PDCP entity increases the PTK ID, and uses a new PGK if the PTK ID wraps as well. In both cases, new values for PTK and PEK are calculated.

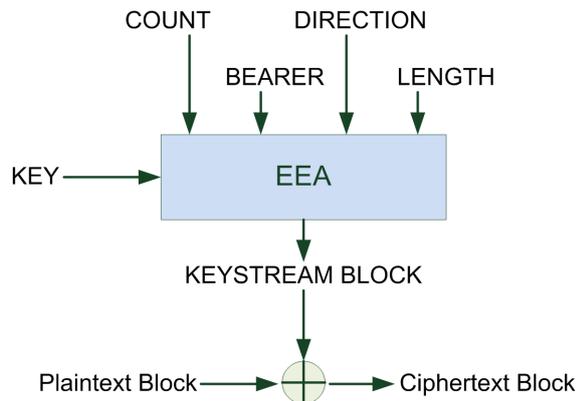The principle of the data encryption is shown in figure 5-4, see [13]:

Fig. 5-4: Data encryption for ciphering. The different ciphering methods are realized by chosing the pertinent EEA procedure (source: [13])

The parameter KEY is the ProSe encryption key PEK. The 16 MSBs of COUNT are the PDCP-SN, the 16 LSBs the PTK ID. BEARER is set to the LCID and the DIRECTION to *0*, i.e. like in UL transmission. The LENGTH corresponds the the length of the data packet to be encrypted and EEA denotes the encryption algorithm.

Encryption for the data packet (*Plaintext Block*) is done using a bitwise XOR with the KEYSTREAM BLOCK.

5.4 Data Decryption

In order to reverse a ciphering created by a bitwise XOR operation, the receiver has to apply the same operation on the Ciphertext Block using the same KEYSTREAM BLOCK. Consequently, the receiving UE has to know the transmitter's ciphering parameters in order to create the KEYSTREAM BLOCK.

These parameters are obtained in the following way: From the assigned group, the UE knows the Group ID and the algorithm ID. The Group Member ID is signaled in the MAC header as the ProSe UE ID, and the LCID is contained therein as well. The remaining fields the receiving UE has to know are included in the PDCP header, figure 5-5:

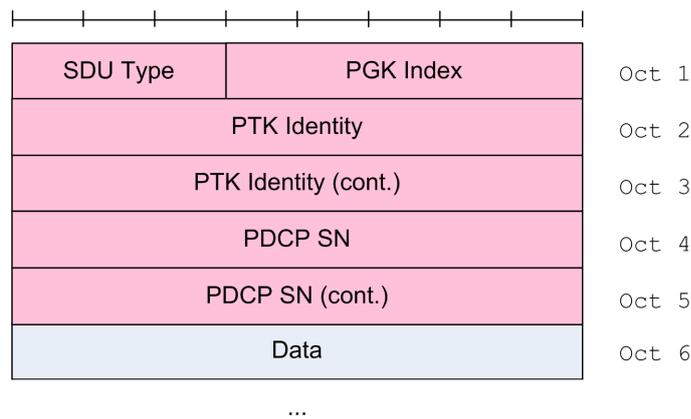|		
SDU Type	PGK Index	Oct 1
PTK Identity		Oct 2
PTK Identity (cont.)		Oct 3
PDCP SN		Oct 4
PDCP SN (cont.)		Oct 5
Data		Oct 6

...

Fig. 5-5: PDCP header for SL communication [5]

The PGK used by the transmitter is identified with the PGK ID, which is the reason why for a given time instance the PGK has to be uniquely identifyable by the 5 LSBs of this ID. Of course, the PGK itself may never be transmitted between two UEs. The PTK ID and the selected PDCP SN are included in the header as well.

If ciphering is not applied, the *PGK Index* is set to *0*. This special value for the PGK ID is always linked to the non-ciphering case and is never used to identify a valid PGK. In this case, the *PTK ID* and *PDCP SN* fields are set to *0* as well.

So, the receiving UE can now determine the KEYSTREAM BLOCK and revert the ciphering by applying the same algorithm as the transmitting UE, as shown in .

6 Summary and Outlook

In Release 12, 3GPP has specified the basic functionalities for device to device communication. This comprises support from the network, message transfer over the air, synchronization also with the out-of-coverage UEs, and security for both, signaling and data transfer.

In Release 13, the features for public safety device to device communication will be extended. Missing features defined in [14], as well as new features will be specified. These comprise

- ProSe communication in presence of multiple carriers and PLMNs. This is important in order to avoid, that a UE which participates in ProSe communication has also to camp on that cell, which may cause unnecessary load imbalance.
- UEs in coverage may act as a UE to network relay, this way enhancing the coverage. This relay function is layer 3 based.
- Support of priority of different groups.
- Identify, whether the new created work item *MCPTT* has impacts on the RAN protocol stack

The last point, MCPTT, refers to the new created work item *Mission Critical Push To Talk* in Release 13. This service can be used for public safety applications and also for commercial applications. The requirements for this service are listed in [15], and the associated architectue is currently in the specification procedure.

7 References

[1] 3GPP TS 22.468 V12.1.0, September 2014; Technical Specification Group Services and System Aspects; Group Communication System Enablers for LTE

[2] 3GPP TS 23.468 V12.5.0, June 2015; Technical Specification Group Services and System Aspects; Group Communication System Enablers for LTE

[3] 3GPP TS 23.303 V12.5.0, June 2015; Technical Specification Group Services and System Aspects; Proximity-based services

[4] 3GPP TS 36.300 V12.6.0, June 2015; Technical Specification Group Radio Access Network; Evolved Universal Terrestrial Radio Access (E-UTRA) and Evolved Universal Terrestrial Radio Access Network (E-UTRAN); Overall description

[5] 3GPP TS 36.323 V12.4.0, June 2015; Technical Specification Group Radio Access Network; Evolved Universal Terrestrial Radio Access (E-UTRA); Packet Data Convergence Protocol (PDCP) specification

[6] 3GPP TS 36.322 V12.2.0, March 2015; Technical Specification Group Radio Access Network; Evolved Universal Terrestrial Radio Access (E-UTRA); Radio Link Control (RLC) protocol specification

[7] 3GPP TS 36.321 V12.6.0, June 2015; Technical Specification Group Radio Access Network; Evolved Universal Terrestrial Radio Access (E-UTRA); Medium Access Control (MAC) protocol specification

[8] 3GPP TS 36.211 V12.6.0, June 2015; Technical Specification Group Radio Access Network; Evolved Universal Terrestrial Radio Access (E-UTRA); Physical channels and modulation

[9] 3GPP TS 36.213 V12.6.0, June 2015; Technical Specification Group Radio Access Network; Evolved Universal Terrestrial Radio Access (E-UTRA); Physical layer procedures

[10] 3GPP TS 36.331 V12.6.0, June 2015; Technical Specification Group Radio Access Network; Evolved Universal Terrestrial Radio Access (E-UTRA); Radio Resource Control (RRC)

[11] 3GPP TS 36.212 V12.5.0, June 2015; Technical Specification Group Radio Access Network; Evolved Universal Terrestrial Radio Access (E-UTRA); Multiplexing and channel coding

[12] 3GPP TS 33.303 V12.4.0, June 2015; Technical Specification Group Services and System Aspects; Proximity-based Services (ProSe); Security aspects

[13] 3GPP TS 33.401 V12.14.0, March 2015; Technical Specification Group Services and System Aspects; 3GPP System Architecture Evolution (SAE); Security architecture

[14] 3GPP TS 22.278 V12.6.0, December 2014; Technical Specification Group Services and System Aspects; Service requirements for the Evolved Packet System (EPS)

[15 3GPP TS 22.179 V13.2.0, June 2015; Technical Specification Group Services and System Aspects; Mission Critical Push To Talk (MCPTT) over LTE

8 Additional Information

Please send your comments and suggestions regarding this white paper to

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9 Rohde & Schwarz

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