Device to Device Communication in LTE

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***Abstract*— Device to Device communications (D2D) promises to be new key feature of the next generation mobile networks in the path towards providing the proximity based services. D2D-based services represent a new market opportunity that would manage to smoothly integrate new technologies as a complement to cellular technologies. This paper discusses about the Direct Discovery procedure in LTE for Proximity based services. This paper provides in detail how LTE enabled UEs use the side link transmission for Proximity based Direct Discovery.**

Keywords—Sidelink; D2D; ProSe;

1. INTRODUCTION

D2D communication is gaining much interest by mobile stakeholders for connecting client devices. The major driving force for D2D connectivity is the inherent flexibility for operators to offload traffic from the core network and represents a real step for operators to reduce the energy and cost particularly for supporting proximity-based services (ProSe). Proximity based Services (ProSe) can be provided when two UEs are close to each other.

Applications range from Public safety (Fire, explosion etc.), Traffic control/safety and commercial services like proximity based social networking, gaming, and advertisements for by-passers.

The potential gains of D2D communication are

- Capacity gain – due to the possibility of sharing spectrum resources between cellular and D2D users.
- Peak rate gain – due to the close proximity and potentially favorable propagation conditions high peak rates may be achieved.
- Latency gain – when devices communicate over a direct link the end-to-end latency may be reduced.
- Coverage extension – the eNB's coverage can be extended with the assistance of D2D UE located in the cell edge.

2. TERMS AND DEFINITIONS

Term	Description
D2D	Device To Device
eNB	eNodeB
HTTP	Hyper Test Transfer Protocol
LTE	Long Term Evolution
MAC	Medium Access control
PDU	Protocol Data Unit
PDUID	ProSe Discovery UE ID
PHY	Physical Layer
PLMN	Public Land Mobile Network
PRACH	LTE Physical Random Access Channel
PRB	Physical Resource Block
ProSe	Proximity Services
RB	Resource Block
RPAUID	Restricted Prose Application User ID
RRC	Radio Resource Control
RSRP	Reference Signal Received

	Power
SFN	System Frame Number
SIB	System Information Block
SLSS	Side Link Synchronization Signal

ProSe Application ID: The ProSe Application ID is an identity used for open ProSe Direct Discovery, identifying application related information for the ProSe-enabled UE

ProSe Application Code: The ProSe Application Code is associated with the ProSe Application ID and used in the open ProSe Direct Discovery procedures.

ProSe Restricted Code: ProSe Restricted Code is allocated by the ProSe Function in the HPLMN for Restricted Direct Discovery and is associated with one or more Restricted ProSe App User IDs. The ProSe Restricted Code is sent by the announcing UE over the air.

Discovery Entry ID: An identifier allocated by the ProSe Function to reference a discovery entry in the UE's context as a result of a discovery request.

Discovery Filter: A container of a ProSe Application code / ProSe Restricted code, zero or more ProSe Application Mask(s) and Time To Live value. These are used by the monitoring UE to match ProSe Application Codes / ProSe Restricted codes that are received on the PC5 interface for Direct Discovery.

3. PROSE ARCHITECTURE MODEL

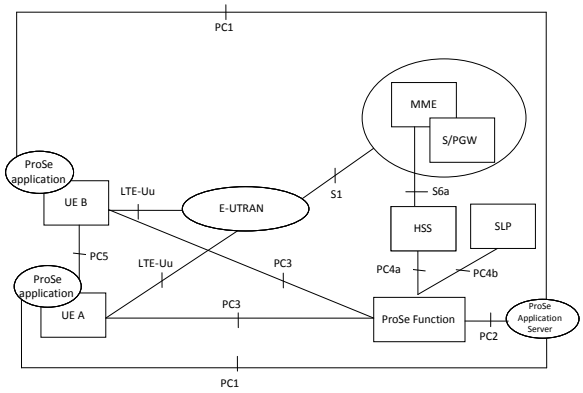

Figure 1: High level Prose architectural reference model

ProSe Function – is the logical function that is used for network related actions, to provision the UE with PLMN specific parameters that allow UE to use ProSe in the specific PLMN. It also generates and maintains the ProSe Discovery UE ID (PDUID) for restricted discovery, allocate and process the mapping of ProSe Application IDs and ProSe Application codes used in Direct Discovery.

The ProSe Application Server saves information of ProSe User, Function IDs, and UE ID, metadata, Mapping of Application Layer User IDs and EPC ProSe User IDs; RPAUID and PDUID.

The proximity based services comprise

- ProSe Direct Discovery: a process that a UE detects and identifies another UE in proximity.
- Prose Direct Communication: LTE resources from cellular are reserved and used for this communication
- EPC-level ProSe Discovery and EPC support for WLAN direct discovery and communication

The ProSe Function provides the necessary charging and security functionality for usage of ProSe. Only Prose Direct Discovery is covered in this paper

4. D2D – SIDELINK TRANSMISSION

Sidelink is used for ProSe Direct Discovery and Prose Direct communication between UEs.

The sidelink corresponds to the communication between two ProSe enabled UEs.

Sidelink communication describes the channel structure consisting of Logical, Transport and physical channels over air interface to realize a ProSe application.

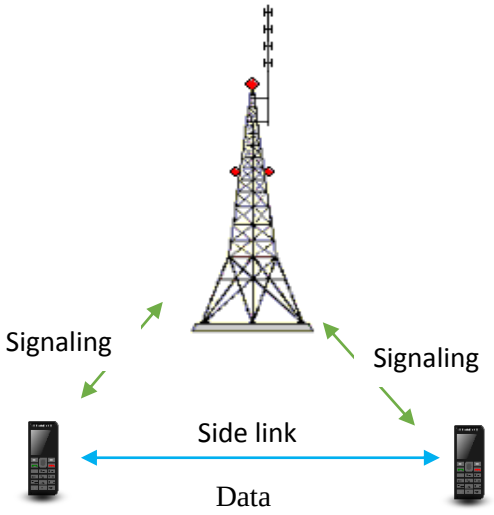

Figure 2: Sidelink Control and Data Communication links

PROTOCOL STACK

Figure 3 shows the control plane signaling between UE and ProSe Function

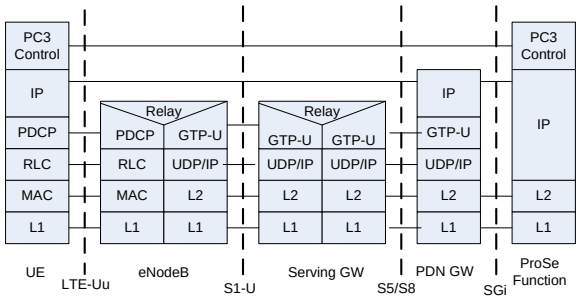

Figure 3: UE-ProSe Function Control plane for PC3 interface

The control plane stack consists of protocols for control and support of the user plane functions:

- Controlling the configuration of ProSe enabled UEs
- Controlling ProSe Direct Discovery
- Controlling the connection between Remote UE and the ProSe UE-to-Network Relay
- Controlling the attributes of an established network access connection e.g. activation of an IP address

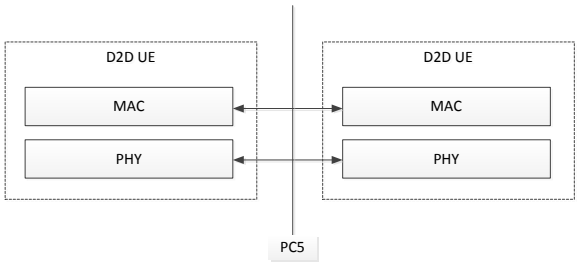

Figure 4: Protocol stack for D2D Direct Discovery

ProSe UE and ProSe Application identities are assigned/re-assigned/allocated in upper layers and Access Stratum transmits them transparently.

Discovery Transmission consists of a MAC PDU of size 224 bits, allocated in 2 contiguous RBs in frequency.

Types of Discovery

Type 1: Resources for discovery signal transmission are allocated on a non-UE specific basis.

Type 2: Resources are allocated per UE specific basis,

2A: Resources are allocated for each specific transmission instance of discovery signals.

2B: Resources are semi-persistently allocated for discovery signal transmission.

The information exchange by the layers in the UE used for a Discovery procedure is,

- The Access Stratum performs the following functions:
  - Interface with Upper Layer: The MAC layer receives the discovery information from the upper layers (Application layer or NAS). The IP is layer is not used for transmitting the discovery information and is transparent to Access Stratum.
  - Scheduling: The MAC layer determines the radio resources to be used for transmitting the discovery information.
  - Discovery PDU generation: The MAC layer builds the MAC PDU containing the discovery information and send the MAC PDU to the PHY layer for transmission.
- In the UE, RRC informs the resource pools to MAC
- No need for MAC header
- MAC receiver forwards all received discovery messages to upper layers
- Only correctly received messages are forwarded and is assumed L1 indicates whether a discovery message has been correctly received.

Transmission modes:

- Mode 1 – eNB allocates exact resources to the UE
- Mode 2 – UE selects from the resource pools configured by the higher layers.

5. PROSE DIRECT DISCOVERY

Two types of Prose Direct Discovery are possible, open and restricted.

In open no explicit permission is needed from the UE being discovered, whereas restricted discovery only takes place with explicit permission from the UE being discovered.

The ProSe Direct discovery can be a standalone service enabler that could use information from the discovered UE for a certain applications in the UE that are permitted to use this information e.g. finding restaurant/multiplex etc. In such cases the UE does not participate in Prose Direct Discovery procedures when coverage is lost, but continues if enabled for Public Safety

6. PROSE DIRECT DISCOVERY MODELS AND PROCEDURES

The following models exist for Direct Discovery.

Model A: defines two roles for Prose enabled UEs participating

- Announcing UE: The UE announces certain information that could be used by UEs in proximity that has permission to discover.
- Monitoring UE: The UE that monitors certain information of interest in proximity of announcing UEs.

In this model the announcing UE broadcasts discovery messages at certain pre-defined discovery intervals and the monitoring UEs read and process them. This model is equivalent to "I am here" as the announcing UE broadcasts information about itself.

Model A supports both open and restricted types of discovery. A UE serves as an "announcing UE" only in the carrier frequency signaled by the Serving PLMN, but can act as "monitoring UE" both in serving and Local PLMNs.

Model B: Used mainly for restricted type which again defines two roles for ProSe enabled UEs participating in direct discovery

- Discoverer UE: The UE transmits a request containing information about what it is interested to discover.
- Discoveree UE: The UE that receives the request can respond with information related to discoverer's request.

This model is equivalent to 'Who is there/are you there?' since the discoverer UE sends request for ProSe Application identity information for other UEs in the group to respond.

When using Model B discovery, the discoverer UE and discoveree UE can announce in the carrier frequency signaled by the serving PLMN.

The various PC3 Control Protocol procedures supported by ProSe Direct Discovery are:

- Announce request
- Monitor request
- Match report and
- Network initiated direct discovery update

These procedures are between UE and Prose Function, and use HTTP as the transport protocol.

This requires UE to perform ProSe Function discovery which is to establish a PDN connection with the Prose Function over the PC3 interface. Only IP connectivity is required to allow the UE to access the ProSe Function.

SERVICE AUTHORIZATION

The first step to use ProSe services require authorization and UE gets the service authorization for ProSe Direct Discovery with a given valid time from the ProSe Function. In case of restricted discovery ProSe Discovery UE ID is also assigned and sent to the UE.

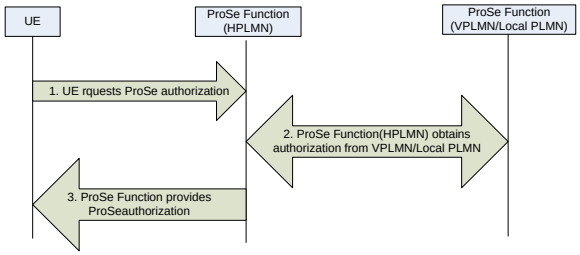

Figure 5: Service Authorization for ProSe Direct Discovery

Service authorization is initiated by UE when,

- No valid authorization information or has to send a Discovery message.
- Changes its PLMN while already engaged in ProSe Direct Discovery procedure.
- Service authorization expires.

The ProSe provides the service authorization info to the UE. The authorization info applies to the serving PLMN and PLMNs determined by the HPLMN as local PLMNs to be available to the UE. UE stores this authorization information. The authorization can be revoked or changed by the ProSe function. Service

authorization update is initiated by Network (Prose Function or HSS) when there is a change in ProSe related Subscription data.

DIRECT DISCOVERY CONTROL PROCEDURES

Discovery Request

The Discovery Request is sent by 'announcing UE' or 'monitoring UE' in order to be authorized to access the discovery resources to perform ProSe Direct Discovery.

Figure 6 shows the procedure followed by UE for announcing both in open and restricted discovery.

Announce request procedure is initiated by UE to obtain one or more Application codes to be announced over the PC5 interface, to inform the ProSe Function that the UE wants to stop announcing a ProSe Application code, to upload metadata associated with a ProSe Application ID.

The UE includes one of the ProSe Application Code(s) obtained as a result of a successful announce request procedure per PC5_DISCOVERY message and passes the PC5_DISCOVERY messages to the lower layers for transmission over the PC5 interface.

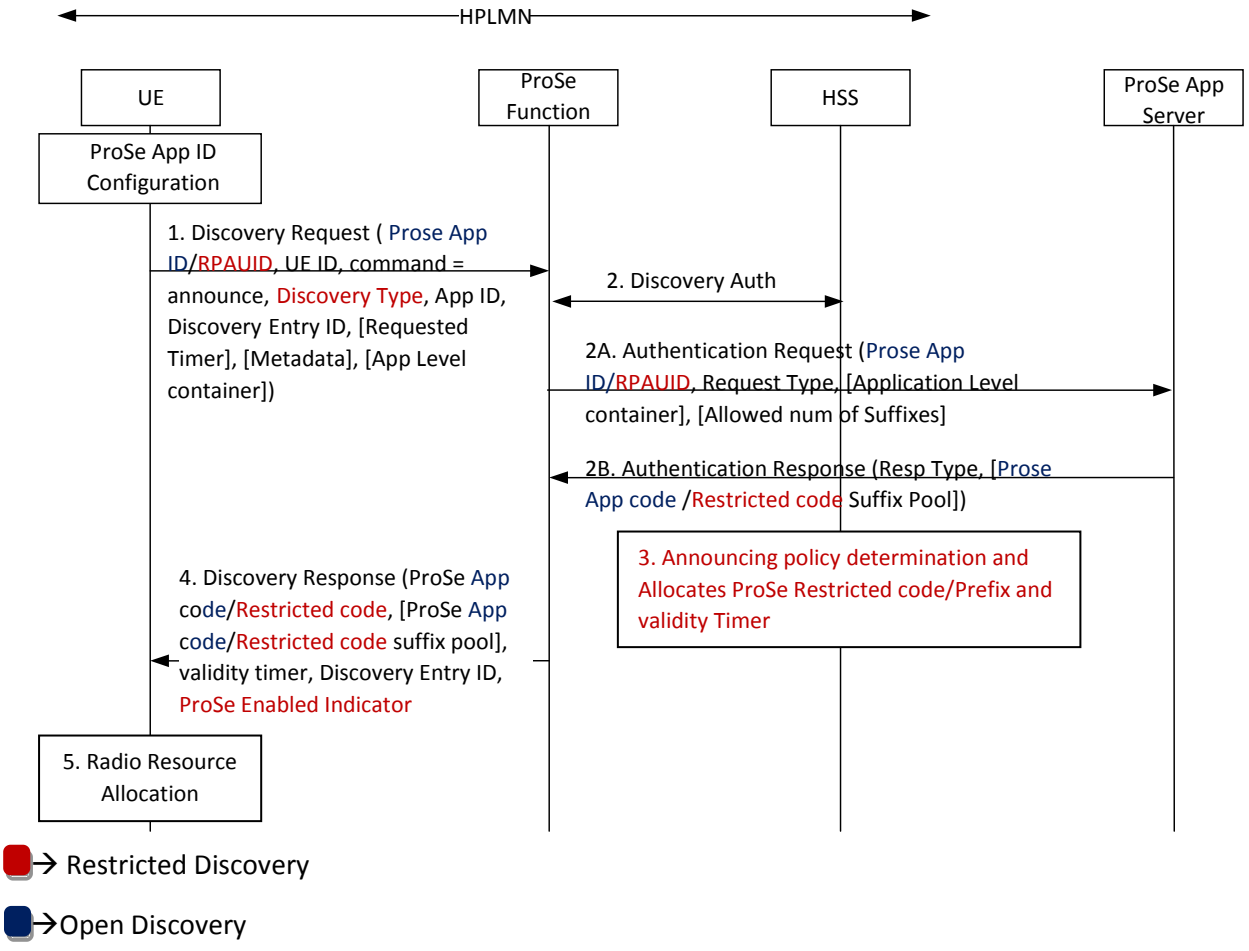

Figure 6: Announce Request Procedure

Monitor Request

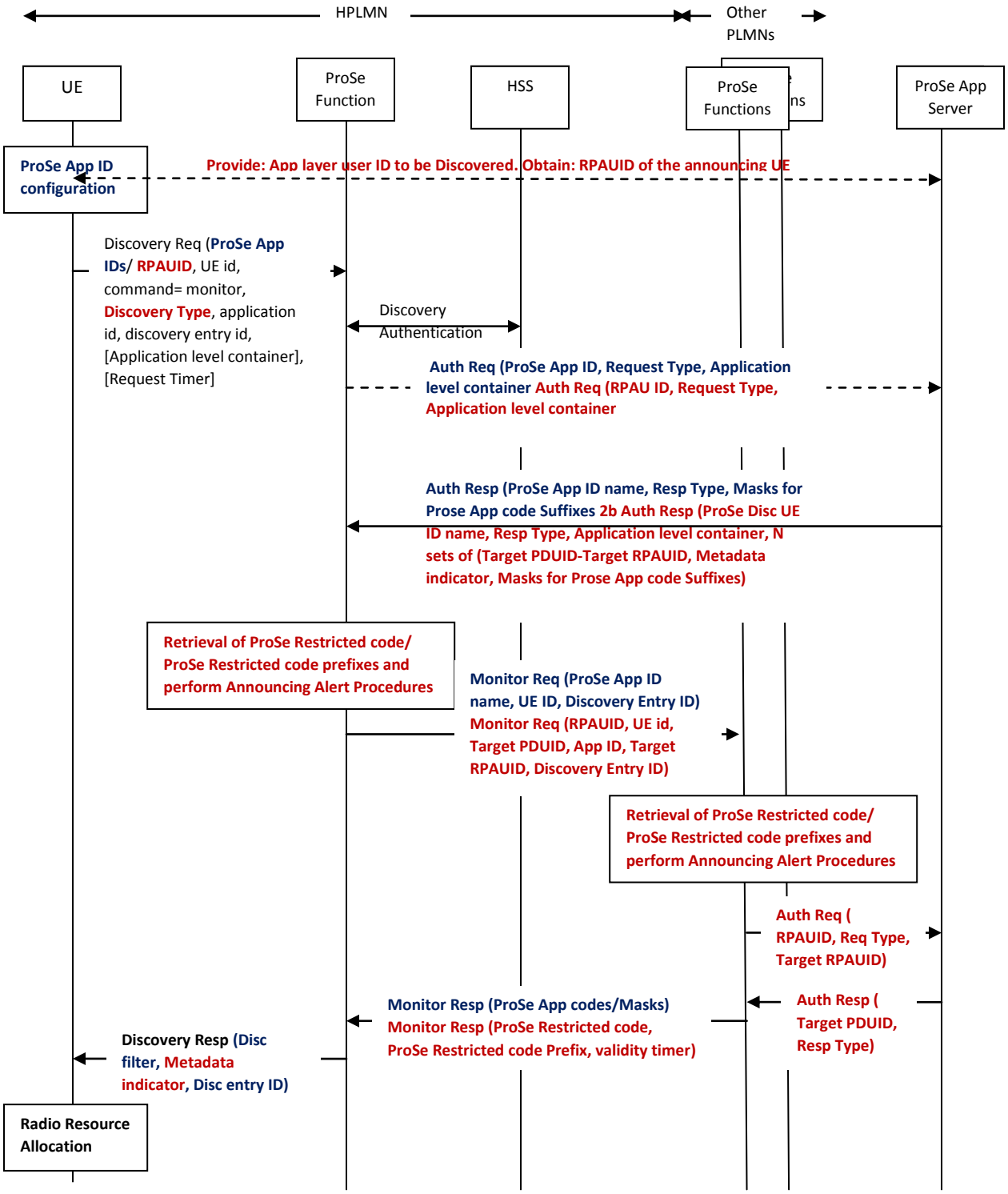

Figure 7: Monitor Request Procedure for Open and Restricted Discovery

Match Report

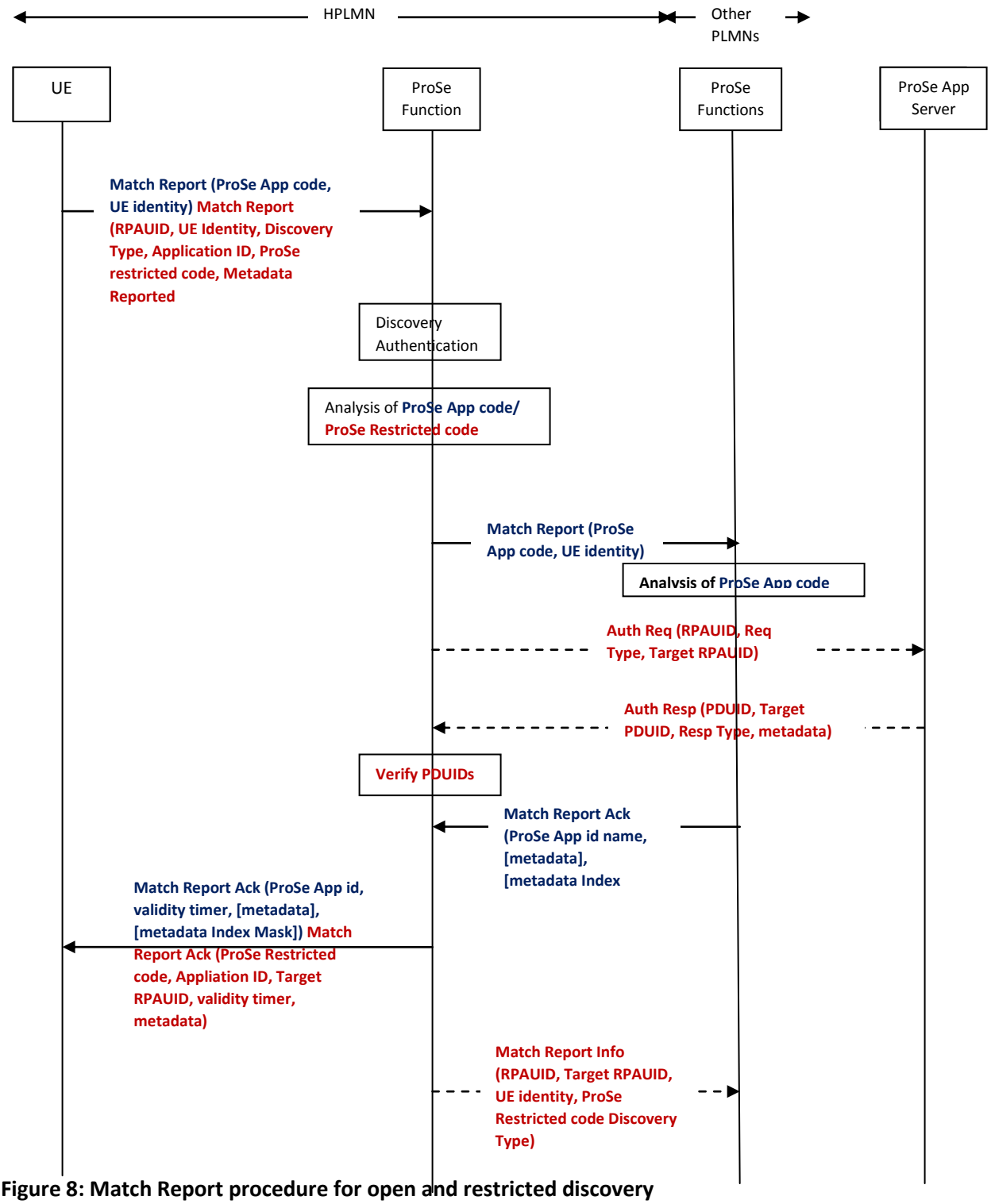

Figure 8: Match Report procedure for open and restricted discovery

Figure 7 shows the Monitor request procedure. The purpose of this request is to receive and process the PC5_DISCOVERY messages upon a request, to update the ProSe Function that the UE wants to stop using Discovery Filters.

As a result of the monitor request procedure completing successfully, the UE obtains one or more Discovery Filters, along with a TTL (Time-To-Live) timer T4002 for each Discovery Filter indicating the time during which the filter is valid.

Figure 8 shows the Match Report procedure. The purpose of the Match report procedure for open ProSe direct discovery is to allow a UE to send a ProSe Application Code that was matched during the monitoring operation and receive the corresponding ProSe Application ID or the updated metadata, if there is no such a mapping stored locally or the Metadata Index in the ProSe Application Code indicates the metadata is updated.

The UE shall only initiate the match report procedure if it has been authorized for open ProSe direct discovery monitoring in the monitored PLMN based on the service authorization procedure.

The UE obtains a ProSe Application ID once the match report procedure is completed successfully, which the UE may store locally and pass to the upper layers.

7. RADIO ASPECTS OF SIDELINK DIRECT DISCOVERY

SIDELINK CONFIGURATION FROM eNB

System Information Broadcast:

Broadcast of System Information Block 19 indicates the support of Sidelink direct discovery by eNodeB. Figure 9, depicts the parameters of SIB19

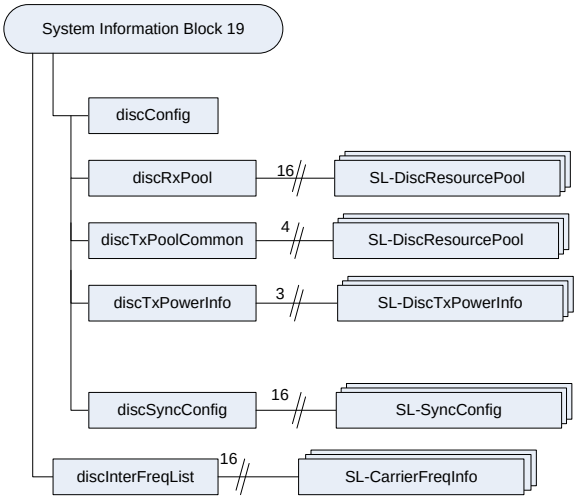

Figure 9: SIB 19 Message for sidelink

SIB 19 carries **discRxPool**, which indicates the resources which a UE shall use to monitor the Direct Discovery announcements in RRC_IDLE and RRC_CONNECTED state. *discRxPool* contains a list of maximum 16 resource pools.

Optionally, SIB 19 shall carry

- **discTxPoolCommon**, which indicates the resources which a UE shall use to transmit the Direct Discovery announcements in RRC_IDLE state. *discTxPoolCommon* contains a list of maximum 4 resource pools.. UE in RRC_IDLE state can use the resources for announcement from next discovery period
- *discTxPowerInfo* contains a list of 4 *SL-DiscTxPowerInfo* elements which indicates the power control parameters per power class. UE uses the this parameter for sidelink discovery transmission
- *discSyncConfig* indicates the configuration by which UE is allowed to receive and transmit the synchronization information.

discSyncConfig contains a list of maximum 16 sync configurations.

- *discInterFreqList* indicates the neighboring frequencies on which sidelink direct discovery announcement is supported. *discInterFreqList* **co**ntains a list of maximum 16 frequencies

SIDELINK UE MESSAGE

The purpose of the procedure is to inform the eNodeB is interested/no longer interested in Sidelink Direct Discovery and also to request/ release the resources for Direct Discovery.

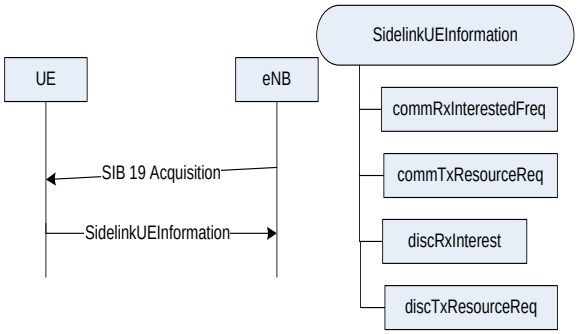

Figure 10: Sidelink UE Information message and contents

On receiving SIB 19,

- A UE configured to receive Direct Discovery Announcements shall send a Sidelink UE message to eNB to indicate its interest in reception (discRxInterest)
- A UE configured to transmit Direct Discovery Announcements shall send a Sidelink UE message to eNB to indicate the resources required by UE for Sidelink Direct Discovery Announcements. discTxResourceRequest parameter is set to the number of separate Discovery messages UE wants to transmit every discovery period

UE shall send a Sidelink UE message to eNB also

- To indicate it is no longer interested to monitor the Sidelink Discovery Announcements
- To indicate the release of the resources assigned for transmission of Sidelink Discovery Announcements

SIDELINK DEDICATED CONFIGURATION

A UE in RRC_CONNECTED shall not use the resources from discTxPoolCommon received in SIB 19. It shall receive the resource information in *sl-DiscConfig* sent in RRCConnectionReconfiguration message.

A UE that wants to transmit Sidelink Direct Discovery Announcement shall initiate an RRC Connection procedure if discTxPoolCommon is not received in SIB19

Figure 11 show the SL-DiscConfig received in RRCReconfiguration message

If discTxResources IE is set to '*Release*', then from next Discovery period UE shall release the resources allocated for Sidelink Direct Discovery Announcements

If discTxResources is IE set to 'Setup', then from next Discovery period UE shall use the resources indicated by discTxResources for Sidelink Direct Discovery Announcements

UE in RRC_CONNECTED shall use the resources indicated in discTxResources for transmission of Direct Discovery Announcements as follows:

If discTxResources is set to '*Scheduled*', UE shall use the resources indicated by Scheduled. This indicates the set of resources specifically assigned to the UE.

If discTxResources is set to '*ue-Selected*', UE shall select a resource from the poolToAddModList. poolToAddModList contains

a list maximum of 4 resource pools.. Each pool is associated with an identity referred as SL-TxPoolIdentity.

poolToReleaseList is used to release one or more individual pool entries used for transmissions of Sidelink Discovery Announcement

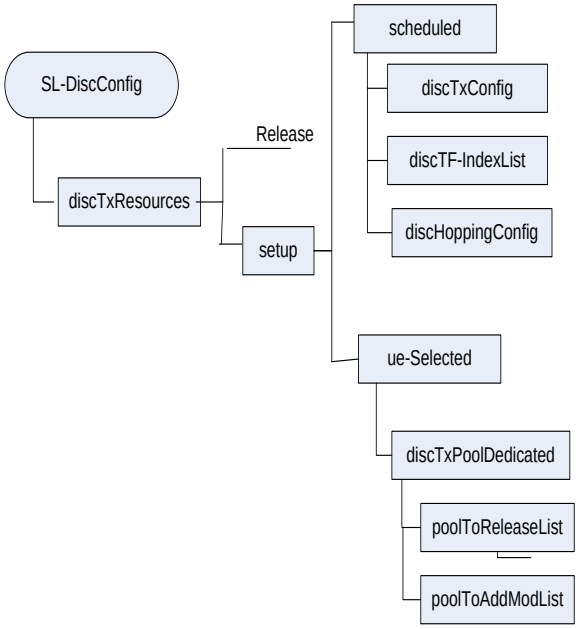

Figure 11: Sidelink SL-DiscConfig message

RESOURCE POOL

Resource pool consists of Subframe pool and Radio Block pool. There are two types of pools

- Reception Pools: Indicates the set of resources UE shall monitor for Sidelink Direct Discovery Announcements
- Transmission Pools: Indicates the set of resources from which a UE shall select for the transmission of Sidelink Direct Discovery Announcements

SL-DiscResourcePool IE contains the resource pool information. Contents of SL-DiscResourcePool is depicted in the figure 12.

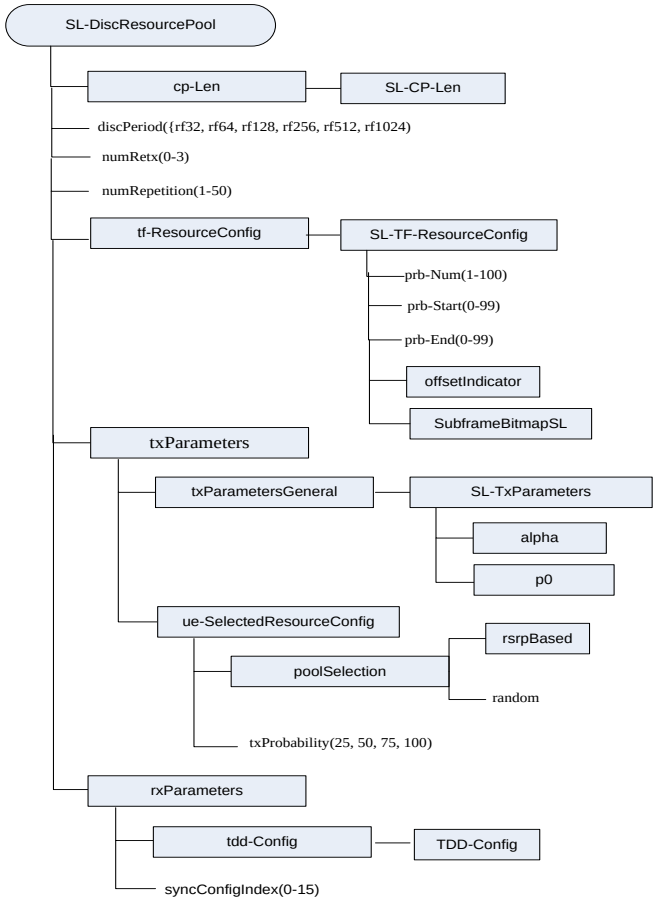

Figure 12: SL-DiscResourcePool message contents

RECEPTION POOLS

A UE shall use the discRxResource pool received in SIB 19 for monitoring the Sidelink Discovery Announcement.

TRANSMISSION POOLS

A UE shall use the following pools for transmission of sidelink direct discovery announcements:

- In RRC_CONNECTED state, UE shall use the resource pool –poolToAddModList received in SL-DiscConfig of RRCConnectionReconfiguration
- In RRC_IDLE state, UE shall use the resource pool – discTxPoolCommon received in SIB19

UE shall select a resource in the Resource pool for transmission as follows:
In the IE ue-SelectedResourceConfig,

- If the poolSelection is set to '*rsrpBased*', the UE shall select an entry for which RSRP measurement is between threshold High and threshold Low.

Note: When performing resource pool selection based on RSRP, the UE uses the latest results of the available measurements used for cell reselection evaluation in RRC_IDLE/ for measurement report triggering evaluation in RRC_CONNECTED

- If the poolSelection is set to '*random*', then UE shall select an entry randomly using uniform distribution.

Note: A random value p1 in the range from 0 to 1, where the random function shall be such that each of the allowed selections can be chosen with equal probability;
If p1 is less than tx-Probability:
Select a random resource from the pool of resources (excluding any resources which are overlapping with PRACH or resources already selected for transmissions on SL-DCH in this discovery period), where the random function shall be such that each of the allowed selections can be chosen with equal probability.

8. RESOURCE ALLOCATION

Resource pool consist of Subframe pool & Resource Block

SUBFRAME POOLS

UE determines the Subframe pools based on the following parameters:

- *discoveryOffsetIndicator:* indicates the offset of the first period of pool of resources within a SFN cycle
- *discoveryPeriod:* Indicates the period over which resources are allocated in a cell for discovery message transmission/reception
- *discoverySubframeBitmap& length:* Indicates the subframe bitmap indicating resources used for sidelink.
- *discoveryNumRepetition:* Indicates the number of times *subframeBitmap*is repeated for mapping to Subframe that occurs within a *discPeriod*.

For every discovery period, UE determines the Subframe that are part of Subframe pools as follows:

If subframeBitmap is 11001100 i.e., length is 8 & If NumRepetition is set to 2, then the total bitmap is repeated the NumRepetition times. Hence for the discPeriod, the bitmap becomes 1100110011001100.
A Subframe is part of the Subframe pool if the corresponding Subframe bit is '1'

Hence in the above example, if the discoveryPeriod is set to 32 frames and OffsetIndicator is '0', then the Subframe included in the Subframe pool are;

In first discPeriod(0-31): #0, #1, #4, #5,#8,#9,#12, #13

In second discPeriod(32-63): #32, #33, #36, #37,#40,#41,#44, #45 and so on

In the same example, if the OffsetIndicator is set to '3', then the first discPeriod starts at subframe #3. Hence the subframe pools consist of;

In first discPeriod(3-34): #3, #4, #7, #8,#11,#12,#15, #16

In second discPeriod (35-66): #35, #36, #39, #40,#43,#44,#47, #48 and so on.

The parameter L_{PDSCH} denotes the number of subframes in the subframe pool per discPeriod. For the above example, $L_{PDSCH} = 8$

RESOURCE BLOCK POOLS

UE determines the Resource blocks in the Resource block pools based on the following parameters

- *discoveryStartPRB*
- *discoveryEndPRB*
- *discoveryNumPRB*

Sidelink discovery transmissions on a sub-frame can occur

- on PRB with index greater than or equal to *startPRB*and less than *StarPRBt+ NumPRB*, and
- on PRB with index greater than *EndPRB-NumPRB*and less than or equal to *EndPRB*.

For example,

discoveryStartPRB = 3,

discoveryEndPRB = 11,

discoveryNumPRB = 4

Resource block pools consists of PRBs which are between (3 -6) & (8-11) i.e., PRBs – 3, 4, 5, 6. 8, 9, 10, 11

There is a parameter defined M_{PDSCH_RP}- denotes the number of Resource Blocks in a Resource block pool.

In the example, M_{PDSCH_RP} = 8

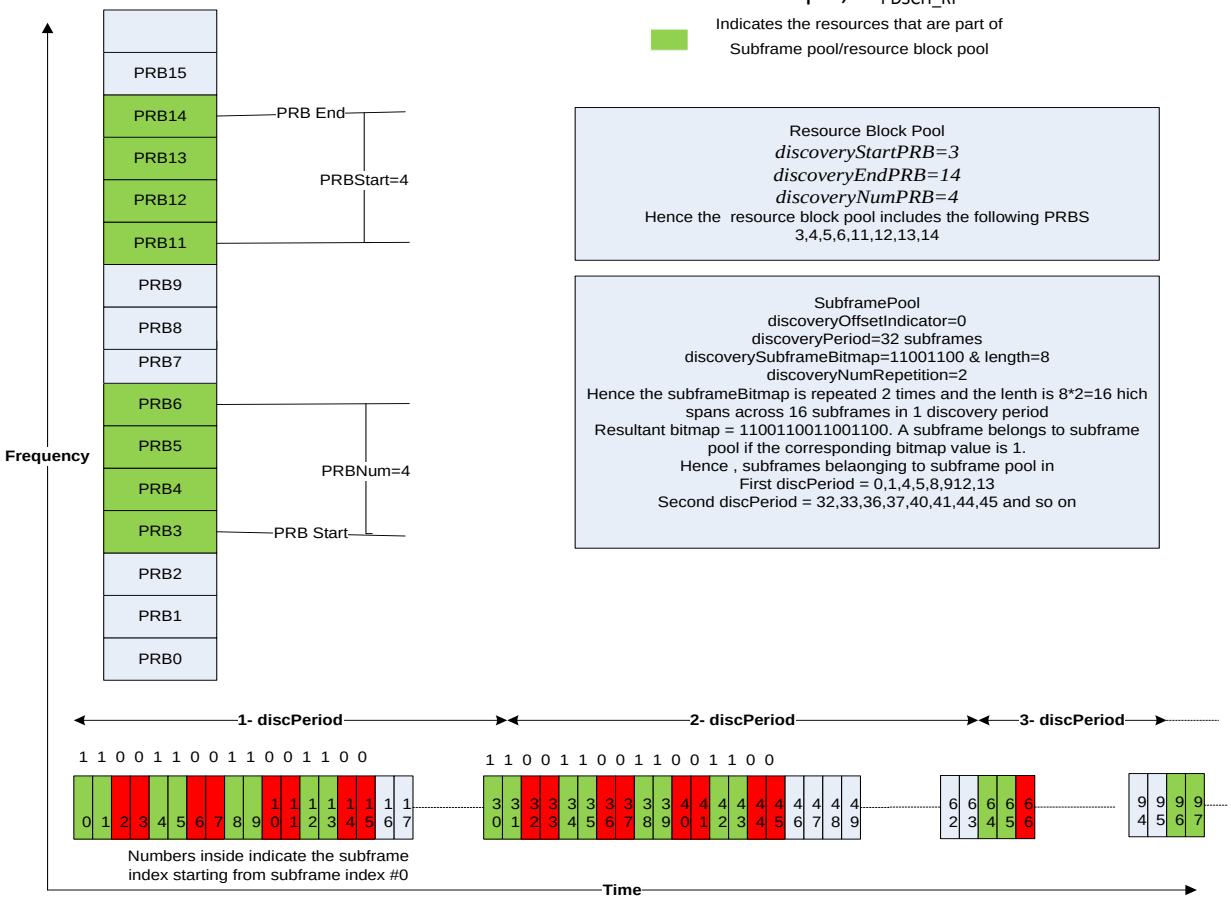

Figure 13: Resource block allocation for sidelink transmission

DIRECT SYNCHRONIZATION INFORMATION TRANSMISSSION

The purpose of this procedure is to provide synchronization information to a UE. The synchronization information concerns a Sidelink Synchronization Signal (SLSS) for sidelink direct discovery

UE shall receive the parameter networkControlledSyncTx as part of RRCConnectionReconfiguration message. This field indicates whether the UE shall transmit synchronization information (i.e. become synchronization source). Value On indicates the UE to transmit synchronization information while value off indicates the UE to not transmit such information.

A UE is capable of transmission of SLSS transmission

- If UE is in RRC_CONNECTED state and networkControlledSyncTx is set to 'ON'.
- If networkControlledSyncTx is not set to 'ON' and the RSRP measurement is below the syncTxThreshIC received in SIB 19

Figure 14 below depicts the discSyncConfig parameters received in SIB 19. SIB 19 can include up to 16 sync configurations

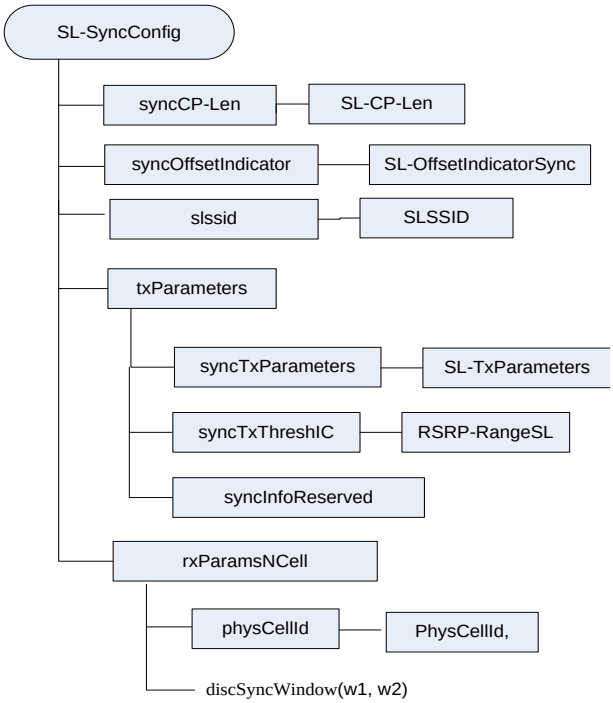

Figure 14: discSyncConfig Parameters received in SIB 19 message

9. CONCLUSION

In this paper we discussed about the D2D communication using the Prose Direct Discovery, various discovery procedures and radio aspects of sidelink direct discovery, that include configuration, and resource allocation and reception pools. Also covered the physical layer mapping and synchronization. The radio aspects presented are mainly based on 3GPP Release 12 specification.

Though out of scope of this paper, further in Release 13, the public safety functionalities are enhanced, considering the applicability to voice and video. Mission Critical Push-to-talk over LTE (MPCTT), capabilities include group calls, person to person calls prioritization of calls and of individuals also uses Proximity Services (ProSe) to allow public safety devices to communicate directly with each other.

10. ACKNOWLEDGEMENT

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11. REFERENCES

[1] 3GPP TS 23.303 v13.3.0 March 2016, Technical Specification Group Services and system Aspects; Proximity Based Services

[2] 3GPP TS 24.334 v13.3.1 March 2016, Technical Specification Group Core Network and Terminals ProSe UE to ProSe functional Protocol aspects

[3] 3GPP TS 36.843 v12.0.1 Mar 2014 Group Radio Access Network; Study on LTE Device to Device Proximity Services; Radio Aspects

[4] Smart Device to Smart Device Communication Edited by Shahid Mumtaz and Jonathan Rodriguez, Springer International Publishing Switzerland 2014

[5] 3GPP TS 36.331 v12.6.0 July 2015 Group Radio Access Network; E-UTRA Radio Resource control Protocol Specification

[6] 3GPP TS 36.213 v12.5.0 April 2015 Group Radio Access Network; E-UTRA Physical Layer Procedures

[7] 3GPP TS 36.213 v12.5.0 April 2015 Group Radio Access Network; E-UTRA Medium Access Control Protocol Specification

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