**3GPP TSG-RAN WG2 Meeting #111 electronic *R2-20nnnnn***

**Online, August 17th - 28th, 2020**

Agenda Item: 8.7.3

Source: MediaTek Inc. (Rapporteur)

**Title: [AT111-e][605][Relay] L2 Relay Mechanism (MediaTek)**

Document for: Discussion and decision

# Introduction

This document is to kick off the following email discussion:

* [AT111-e][605][Relay] L2 relay mechanism (MediaTek)

      Scope: Discuss and document the proposed L2 relay design(s), focussing on general mechanisms of L2 architecture based sidelink relaying including protocol stacks and high level description of required UP/CP functionalities.

      Intended outcome: Summary with potential agreeable TP

      Deadline:  Monday 2020-08-24 1200 UTC

**Scope highlight:**

This email discussion covers the L2 relay design(s) based on the relevant submitted tdocs to RAN2#111e on NR Sidelink Relay, focussing on general mechanisms of L2 architecture based sidelink relaying including:

* Protocol stack
* High level description of required UP/CP functionalities

This document will not cover the following aspects of L2 architecture based sidelink relaying:

* Detailed aspects of Relay Selection/Reselection
* Detailed procedure Relay Discovery
* Detailed procedure of connection establishment
* Detailed procedure of service continuity and path switch

# Background

The L2 based FeD2D architecture was studied at Rel-14 for LTE. The overall protocol stack and its high level functionalities can act as the reference to L2 based NR sidelink relay architecture.

The example protocol stacks for the user plane and control plane of NR L2 UE-to-Network Relay architecture are described in Figure 1 and Figure 2, which assume an adaptation layer over PC5 for relaying.

In case of L2 based SL Relay, relaying is performed above RLC sublayer via Relay UE for both CP and UP between Remote UE and network. Uu SDAP/PDCP and RRC are terminated between Remote UE and gNB, while RLC, MAC and PHY are terminated in each link (i.e. the link between Remote UE and UE-to-Network Relay UE and the link between UE-to-Network Relay UE and the gNB). Remote UE connected to 5GC via layer 2 UE-to-network relay, establishes its own PDU sessions/DRBs to support the user plane data transmission[1][2][3][4].



Figure 1: User plane stack for L2 UE-to-Network Relay



Figure 2: Control plane stack for L2 UE-to-Network Relay

An adaptation layer over RLC layer exists over Uu interface between Relay UE and gNB for UE-to-Network Relay. The adaptation layer over RLC layer can exists over PC5 between Relay UE and Remote UE and the details is up to the discussion at the next section.

For L2 UE-to-UE Relay architecture, the protocol stacks are similar like L2 UE-to-Network Relay other than the fact that the termination points are two Remote UEs. The example protocol stacks for the user plane and control plane of L2 UE-to-UE Relay architecture are described in Figure 3 and Figure 4 [2][6], which assume an adaptation layer over both PC5 links for relaying. The similar principle of L2 based UE-to-Network Sidelink Relay applies to L2 UE-to-UE sidelink Relay.



Figure 3: User plane stack for L2 UE-to-UE Relay



Figure 4: Control plane stack for L2 UE-to-UE Relay

# Issue list

## Protocol stack for L2 UE-to-Network Relay

**Discussion on Adaptation layer on Uu (between Relay UE and gNB)**

There are multiple documents submitted to RAN2#111e discussing the basic protocol stack for L2 UE-to-Network Relay and L2 UE-to-UE Relay. The majority view is that the adaptation layer should be put over RLC sublayer for both CP and UP between Remote UE and network. It is necessary for RAN2 to confirm this aspect in order to capture the protocol stack figures into the TR for L2 UE-to-NW relay.

**Question 1a: Do you agree that the adaptation layer is put over RLC sublayer for both CP and UP between Remote UE and network for L2 UE-to-NW relay? If not, please give your alternative solution and the reason.**

|  |  |  |
| --- | --- | --- |
| Company | Yes/No | Comments |
| MediaTek | Yes |  |
| Qualcomm | Yes/No  (Yes for over RLC, No for remote UE) | We agree that adaptation layer is over RLC for both CP and UP. However, the question seems to emphasize adaptation layer is needed for both remote UE and NW. Then, we don’t agree that adaptation layer is needed *for remote UE* which is illustrated in Figure 1-4. In our understanding, adaptation layer is just needed between relay UE and gNB because it is intended for remote UE identification and bearer mapping. And it is enough to have adaptation layer over Uu RLC to support mapping between sidelink bearer and Uu bearer.  Please note that SA2 had specified the below UP and CP protocol stack with adaptation layer only over Uu RLC in Annex A of TR 23.752. We think it is sufficient for L2 relay and can be simply adopted by RAN2: |
| OPPO | Yes | For the hop between relay and network, we assume it is common view.  For the hop between remote and relay (Not sure if rapp would like to use Q1d to address that, or it is also reflected in this Q since it is asked for “**the adaptation layer … between Remote UE and network**”), the existence of adaptation layer would be helpful considering the requirement from the SID that “NOTE 3: Forward compatibility for multi-hop relay support in a future release needs to be taken into account”. |
| Xiaomi | Yes with coments | I understand in this question the adaptation layer is only located in relay and gNB. the necessity of adaptation layer in remote UE is discussed in following questions. |
| Ericsson (Tony) | Yes |  |
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**The placement of protocol layer on Uu and PC5 for relaying**

According to the documents submitted to RAN2#111e discussing the placement of the protocol layers for L2 Relaying, the majority view is that in case of L2 based SL Relay, Uu SDAP/PDCP and RRC are terminated between Remote UE and gNB, while RLC, MAC and PHY are terminated in each link (i.e. the link between Remote UE and UE-to-Network Relay UE and the link between UE-to-Network Relay UE and the gNB). It is proposed for RAN2 to confirm this aspect in order to capture the protocol stack figures into the TR for L2 UE-to-NW relay.

**Question 1b: Do you agree that in case of L2 based UE-to-NW Relay, Uu SDAP/PDCP and RRC are terminated between Remote UE and gNB, while RLC, MAC and PHY are terminated in each link? If not, please give your alternative solution and the reason.**

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| --- | --- | --- |
| Company | Yes/No | Comments |
| MediaTek | Yes |  |
| Qualcomm | Yes | As we comment in Q1a, we think the UP/CP protocol stacks specified by SA2 in TR 23.752 is sufficient for L2 relay and can be simply adopted by RAN2. |
| OPPO | Yes |  |
| Xiaomi | Yes | The adaptation layer is also terminated in each link. |
| Ericsson (Tony) | Yes |  |
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**Establishment of Remote UE PDU sessions/DRBs**

According to the documents submitted to RAN2#111e discussing the basic protocol stack for L2 Relaying, there is a discussion on the PDU session/DRB establishment for Remote UE, the general view is to let the Remote UE to establish its own PDU sessions/DRBs with the network before user plane data transmission.This should be a general aspect for L2 relaying operation and then RAN2 needs to confirm it for L2 UE-to-NW relay.

**Question 1c: Do you agree that in case of L2 based SL Relay, Remote UE needs to establish its own PDU sessions/DRBs with the network before user plane data transmission? If not, please give your alternative solution and the reason.**

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| --- | --- | --- |
| Company | Yes/No | Comments |
| MediaTek | Yes |  |
| Qualcomm | Yes |  |
| OPPO | Yes | There seems no alternative to allow the remote UE to send UP data before CP established.. |
| Xiaomi | Yes |  |
| Ericsson (Tony) | Yes but | We think the question is not crystal clear. We agree in principle that the remote UE needs to establish its own PDU session/DRBs (i.e., that is PC5+Uu), but the establishment of the PC5-RRC and the Uu SRB can be decoupled (i.e., remote UE establish the PC5-RRC and exchange some configuration with the relay UE and then the relay UE establish an SRB with the network, is needed to transit to CONNECTED).  Maybe good to address also this aspect related to the link establishment. |
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**Discussion on Adaptation layer on PC5 (between Relay UE and Remote UE)**

Regarding the support of adaptation layer over PC5, there are diverse views in the documents submitted to RAN2#111e. Some companies see the benefits. Some companies see that it is not essential. The benefits described in the documents mainly include the following [2][3][8][23][42]:

* many-to-one mapping between end-to-end Remote UE Radio bearer and PC5 RLC channel
* The forward compatibility support

In [5] and [10], it is suggested to refer to IAB BAP specified at Rel-16 to design the adaptation layer. In [5], it is suggested to introduce both one-to-one mapping and many-to-one mapping for bearer mapping with reference to IAB BAP specified at Rel-16 and it is proposed to enable both one-to-one mapping and many-to-one mapping for Remote UE RBs to PC5 RLC channel mapping, as supported in the backhaul link between Relay UE and gNB. In [16], it is proposed that multiple Uu relaying backhaul bearers may be used to carry traffic of different QoS classes, for one or multiple remote UEs when relay UE forwards remote UE’s traffic. In [16], it is also proposed that the mapping of the remote UE’s Uu DRB to PC5 RLC channel could be one-to-one or many-to-one mapping.

It should be noted that, if many-to-one mapping is considered between Remote UE RBs and PC5 RLC channel, the placement of adaptation layer over PC5 interface is the precondition, since a protocol layer is needed at PC5 to indicate the exact end-to-end Uu DRB of the data packets that come from a particular Remote UE or going to a particular Remote UE.

With regard to the need of adaptation layer over PC5 for L2 UE-to-Network Relay, RAN2 needs to confirm this in order to describe the protocol stack for L2 UE-to-Network relaying in the TR.

**Question 1d: Which option do you prefer with regard to the need of adaptation layer over PC5 for L2 UE-to-Network Relay? Please give your explanation for your choice:**

**Option1: The adaptation layer is needed over PC5**

**Option2: The adaptation layer is optional needed over PC5**

**Option3: The adaptation layer is not needed over PC5**

**Option4: The adaptation layer is needed over Uu RLC of relay and gNB (as specified in Annex A of TR 23.752)**

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| --- | --- | --- |
| Company | Preferred Option | Comments |
| MediaTek | Yes | We support the option to put adaptation layer over PC5 for L2 UE-to-Network Relay with the following consideration (1) It offers the flexibility for mapping over PC5 (i.e. many-to-one mapping) between Remote UE and Relay UE. If not the relay implementation will be complicated with the supported remote UE going up (2)Alignment with UE-to-UE protocol stack |
| Qualcomm | Option 4 | We don’t understand why many-to-1 mapping is needed for PC5. Is it because the number of PC5 RLC channel may not be enough or multi-hop only?   * If it is for not enough number of PC5 RLC channel, we don’t think it is an easy conclusion we can make it now. The similar issue was discussed in IAB for a long time. Thus, we do not agree with this argument. The companies raising issue, please provide a qquantitative analysis why current PC5 RLC channel number is not enough based on SA1 requirement of sidelink relay, and we do think it needs first online discussion. * If it is for multi-hop, note that remote UE is assumed to be connected to only one Relay UE via single-hop in Rel-17, and, does not need to support any multiplexing on the PC5 LCHs.   As we commented in Q1a, we think the UP/CP protocol stacks specified by SA2 in TR 23.752 is sufficient for L2 relay and can be simply adopted by RAN2. |
| OPPO | 1 | For the necessity of adaptation layer over PC5:   1. If there is only Uu-traffic (network as termination point) from remote UE, the motivation to allow many-to-one mapping is not that strong, since the number of Uu-DRB per UE is limited to 16 (if without PDCP duplication), while the number of PC5 LCH is also limited to 16, so there is no much need for the many-to-one mapping. However, in order to carry both Uu-traffic (network as termination point) and PC5-traffic (relay as termination point) from remote UE, if one does not allow adaptation layer @ PC5 hop, the LCID space for PC5 has to be extended.   Furthermore, if considering the support of multi-hop relay in the future, as indicated in the SID, it would be more future proof, i.e., considering the remote-UE in 1-hop relay could be the relay-UE in 2-hop rely, and at that time, the adaptation layer would be still needed for the remote-UE of the 1-hop relay, and furthermore, the LCID space extension is also needed, considering the Uu-traffic for the remote-UE of 2-hop relay. |
| Xiaomi | Option 3 | There is only one destination, i.e. gNB, in the U2N relay. We don’t think many to one mapping on PC5 is needed for U2N relay. |
| Ericsson (Tony) | Option1 | We are okay to have the adaptation layer on the relay UE and remote UE. But maybe the question is not crystal clear about this aspect.  From our understanding, the main benefit will be to achieve a unified protocol option for U2U and U2N. The mapping relations comprise two kinds of mapping  Mapping 1: Remote UE RB and PC5 RLC/ RB. This mapping is sufficient to be 1 to 1.  Mapping 2: PC5 RLC/RB and Uu RLC/RB. This mapping can be M to one or one to one.  The adaptation layer at the remote UE is responsible for Mapping 1. However, the adaptation layer is not mandatory in case there is only one to one mapping.  The adaptation layer at the relay UE is responsible for Mapping 2. |
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## Protocol stack for L2 UE-to-UE Relay

In [23], specific to L2 UE-to-UE relay, it is described that the traffic of one or multiple Remote UEs may be mapped to a single DRB of PC5 interface of the UE-to-UE Relay UE. Multiple SL DRBs may be used to carry traffic of different QoS levels (QoS flows) for one or multiple Remote UEs.

Then a relevant question as abovementioned (i.e. Question 1a) needs also be answered for L2 UE-to-UE relay case. However, before that, it would be helpful to confirm the need of adaptation layer over PC5 in order to describe the protocol stack for L2 UE-to-UE relaying. It should be noted that there are two PC5 links for L2 UE-to-UE Relay case, i.e. PC5 link between transmitting Remote UE and Relay UE, and PC5 link between Relay UE and receiving Remote UE. The discussion here is about the adaptation layer support over PC5 link between Relay UE and receiving Remote UE (i.e. the ingress link for Relay UE).

**Question 2a: Which option do you prefer with regard to the need of adaptation layer over PC5 for L2 UE-to-UE Relay? Please give your explanation for your choice:**

**Option1: The adaptation layer is needed over PC5 link (between Relay UE and receiving Remote UE)**

**Option2: The adaptation layer is optional needed over PC5 link (between Relay UE and receiving Remote UE)**

**Option3: The adaptation layer is not needed over PC5 link (between Relay UE and receiving Remote UE)**

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| --- | --- | --- |
| Company | Preferred Option | Comments |
| MediaTek | Option1 | The traffic of one or multiple Remote UEs may be mapped to a single DRB of PC5 interface between the UE-to-UE Relay UE and receiving Remote UE. |
| Qualcomm | Option 1 with comments | Agree with MediaTek that it is needed for many to 1 bear mapping between relay and remote receiving UE.  Meanwhile, we don’t think it is needed between remote transmitting UE and relay, which is similar to our preference on protocol stacks of L2 UE-to-NW relay |
| OPPO | 1 | Adaptation layer is needed if the relay UE is serving multiple transmitting UEs for a same receiving UE, and if the traffic is to be carried on a same link (i.e., a pair of source / destination UE pair), an adaptation layer is necessary to differentiate the transmitting UE and bearers. |
| Xiaomi | Option1 | Similar as relay to network link. |
| Ericsson (Tony) | Option1 | This question is not crystal clear either. Is the question related to ingress link or egress link? Anyway, for egress link, the adaptation layer is needed at the relay UE to identity the packet is from where and to where.  For ingress link, the adaptation layer is needed at the remote UE for forward competitivity (for example, multiple hop U2U will be supported). |
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Based on the discussion of question 2a, we can discuss the placement of adaptation layer over PC5 link between Relay UE and receiving Remote UE as below if the answer of question 2a is Option1 or Option2.

**Question 2b: Do you agree that the adaptation layer is put over RLC sublayer for both CP and UP for L2 UE-to-UE relaying between Relay UE and receiving Remote UE? If not, please give your alternative solution and the reason.**

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| --- | --- | --- |
| Company | Yes/No | Comments |
| MediaTek | Yes |  |
| Qualcomm | No | As we comment in Q2a, we think it is sufficient to have adaptation layer over PC5 RLC between relay and receiving remote UE. And it should be aligned with L2 UE-to-NW relay protocol stacks  Below is an example of UP protocol: |
| OPPO | Yes | Although the question is misleading: “**the adaptation layer … between two Remote UEs**” i.e., different from the question 2a, about “**between Relay UE and receiving Remote UE**”… |
| Xiaomi | Yes | Different from U2N, one transmitting remote UE may connect to multiple receiving remote UEs via U2U relay. In this cse, we see the benefit of many to one mapping on both links. |
| Ericsson (Tony) | Yes |  |
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With regard to the placement of the protocol layers for L2 Relaying. A relevant question as abovementioned (i.e. Question 1c) needs also be answered for L2 UE-to-UE relay case.

**Question 2c: Do you agree that in case of L2 based UE-to-UE Relay, SL SDAP/PDCP and RRC are terminated between two Remote UEs, while RLC, MAC and PHY are terminated in each PC5 link? If not, please give your alternative solution and the reason.**

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| --- | --- | --- |
| Company | Yes/No | Comments |
| MediaTek | Yes |  |
| Qualcomm | Yes | It is illustrated in our example figure in Q2b |
| OPPO | Yes |  |
| Xiaomi | Yes |  |
| Ericsson (Tony) | Yes |  |
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The discussion on the need of adaptation layer over PC5 should be also applicable to L2 UE-to-UE Relay, RAN2 needs to confirm this in order to describe the protocol stack for L2 UE-to-UE relaying. It should be noted that there are two PC5 links for L2 UE-to-UE Relay case, i.e. PC5 link between transmitting Remote UE and Relay UE, and PC5 link between Relay UE and receiving Remote UE. The discussion here is about the adaptation layer support over PC5 link between transmitting Remote UE and Relay UE (i.e. the egress link for Relay UE).

**Question 2d: Which option do you prefer with regard to the need of adaptation layer over PC5 for L2 UE-to-UE Relay? Please give your explanation for your choice:**

**Option1: The adaptation layer is needed over PC5 link (between transmitting Remote UE and Relay UE)**

**Option2: The adaptation layer is optional needed over PC5 link (between transmitting Remote UE and Relay UE)**

**Option3: The adaptation layer is not needed over PC5 link (between transmitting Remote UE and Relay UE)**

**Option4: Other way (please specify)**

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| --- | --- | --- |
| Company | Preferred Option | Comments |
| MediaTek | Option1 | The role of transmitting Remote UE can be also receiving Remote UE for the data stream at opposite direction. Then if the answer of Question 2a is Option1, the answer to this question should be also Option1. |
| Qualcomm | Option 3 | As we comment in Q2a, we think it is sufficient to have adaptation layer over PC5 RLC between relay and receiving remote UE. And it should be aligned with L2 UE-to-NW relay protocol stacks |
| OPPO | 1 | Basically, the same argument used for 1d above is applicable here, i.e., adaptation layer is needed considering the need to carry not only the 1-hop relayed traffic, but also the traffic between transmitting UE and relay UE directly, and the multi-hop traffic. |
| Xiaomi | Option 1 | Different from U2N, one transmitting remote UE may connect to multiple receiving remote UEs via U2U relay. In this cse, we see the benefit of many to one mapping on both links. |
| Ericsson (Tony) | Option1 | We are okay to have the adaptation layer on the relay UE and remote UE.  See more comments for Q2a. |
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## Functionality of Adaptation layer

An adaptation layer is supported in Uu between Relay UE and the network to perform bearer mapping for L2 UE to network relaying. The adaptation layer between the Relay UE and gNB is able to map multiple end-to-end Radio Bearers (SRBs, DRBs) of a particular Remote UE and/or different UEs into one Radio Bearer over the direct Uu path. If the adaptation layer over PC5 is supported for L2 UE-to-Network and L2 UE-to-UE relaying, the adaptation layer mainly functions as bearer mapping between end-to-end Radio Bearers and PC5 RLC channels when considering only one-hop case. In summary, the basic functionality of adaptation layer should be bearer mapping.

There is also an understanding to support packet routing function at adaptation layer. The packet routing function includes the following cases:

* In case of L2 UE-to-Network relay, for downstream transmission from gNB to Remote UE, the Relay UE needs to route the packets to the correct Remote UE
* In case of L2 UE-to-UE relay, for data transmission from one Remote UE to another, the Relay UE needs to route the packets to the correct Remote UE
* In case of multiple hop relaying (both L2 UE-to-Network relay and L2 UE-to-UE relay), the Relay UE needs to perform packet routing function as supported by IAB node.

In addition, in [7], it is proposed to adopt the local ID based packet routing in order to support forward compatibility of L2 based relaying operation.

It should be noted that packet routing function is needed when considering multi-hop case for L2 relaying. However, the multi-hop case may be not the priority case for Rel-17 SL relay study. It is a need to clarify the basic functionalities of adaptation layer for L2 relaying.

**Question 3: Which option do you prefer with regard to the actual functionality set of adaptation layer for L2 Relaying? Please give your explanation for your choice:**

**Option1: Bearer mapping only**

**Option2: Bearer mapping and packet routing**

**Option3: More functions need to be considered (with reference to BAP for IAB)**

**Option4: No need to clarify it at study stage**

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| --- | --- | --- |
| Company | Preferred Option | Comments |
| MediaTek | Option1 | In case of one-hop, we assume that in order to support bearer mapping, Relay UE needs to maintain a mapping table between ingress channel/RB and egress channel/RB, where the identity of Remote UE may be included. We also assume that the identity of Remote UE should be populated along the relaying communication path and then this identity can be also used to find the right destination of the data packets. So then it seems that if bearer mapping is supported, the mentioned packet routing is supported for free.  If the multiple hop relaying case is not considered at Rel-17, the explicit packet routing may be not very much essential. |
| Qualcomm | Option 1 | Please note that multi-hop is not in scoping of Rel-17 SI. We may have some consideration on how to leave some room for future extension to multi-hop, but we need to only support one-hop in this release. |
| OPPO |  | It is not clear definition for the bearer mapping and routing. Our understanding of the adaptation layer is (taking U2N relay as an example)  For UL: mapping from PC5 RLC channel to Uu RLC channel at relay, identifying source node (i.e., remote UE) and/or bearer ID at RAN;  For DL: mapping from Uu RLC channel to firstly specific remote UE, and secondly the PC5 RLC channel at relay (somehow one can understand 1st part as routing and 2nd part as mapping), identifying source node (i.e., RAN/relay UE) and/or bearer ID at remote UE. |
| Xiaomi | Option2 | If we support multiple SLRBs from different remote UEs to one DRB mapping, packet routing is necessary to support. Otherwise, relay/gNB is not able to route RLC SDUs to correct remote UE’s RLC/PDCP.  I also agree with MTK the routing can be achieved together with bear mapping. |
| Ericsson (Tony) | Option2 | We agree with MediaTek, but we also think that for future proofing it would be better to have packet routing already now.  This is also in line with what stated in the SID:  NOTE 3: Forward compatibility for multi-hop relay support in a future release needs to be taken into account.  Even for single hop case, packet routing is needed to distinguish flows/packets terminated at the relay UE and flows/packets terminated at the receiving remote UE. |
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## Bearer mapping

The support of bearer mapping at adaptation layer requires the specific design of the header of adaptation layer. With regard to the header design of adaptation layer i.e. which fields should be put into the header of the adaptation layer, there are proposals that suggest to indicate the ID of remote UE and the end-to-end Radio Bearers (SRB and DRB) of remote UE in [7] and [8] at the header of the adaptation layer, in order to allow the receiver node to perform needed Bearer mapping. In [1], it is also proposed to put the bearer information of end-to-end RB within the adaptation layer in order to enable Bearer mapping. In [6], it is proposed that the functions of the new adaptation layer include identifying transmitting node and destination node, identifying UE bearer and bearer mapping in the case of UE-to-Network relay. In [36], it is discussed that the Remote UE may be identified in the adaptation layer header on Uu by a local identifier which is known at least to the gNB and Relay UE.

It would be helpful to clarify the information that needs to be put into the header of adaptation layer (over Uu between Relay UE and gNB) from the perspective of Bearer mapping, etc. The discussion needs to cover both down-stream (from gNB to Relay UE) and up-stream (from Relay UE to gNB). RAN2 can attempts to clarify the needed information within adaptation layer for both L2 UE-to-Network relay and L2 UE-to-UE relay.

**Question 4a: Which identities in the following are needed within the header of adaptation layer (over Uu) to enable Bearer mapping for L2 UE-to-Network relay? Please give your explanation for your choice:**

(1) Identity of the Remote UE known by gNB and Relay UE (Remote UE ID or a local ID)

(2) Identity of End-to-End Remote UE RB

(3) Other Identity (Please specify, e.g. Transmitter Node ID; Destination node ID)

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| --- | --- | --- |
| Company | ID List preferred | Comments |
| MediaTek | 1,2 | The Identity of the Remote UE and the Identity of Remote UE RB can uniquely address the RB for purpose of bearer mapping |
| Qualcomm | 1,3 (PC5 local RLC channel ID) | We think it may be a bit rushed to discuss contents of adaptation layer header before we confirm the requirement of adaptation layer (e.g. whether to support 1-to-1 mapping, whether to support many-to-1 mapping)  Our understanding on functionalities of adaptation layer in this release are the below 2 aspects:  • Multiplexing of Remote UE(s) traffic on Relay UE’s Uu LCHs  • Mapping traffic from Remote UE Uu SRBs/DRBs to corresponding PC5 LCHs and Uu LCHs and vice versa  Based on them, we think 1 (remote UE ID) makes sense to identify remote UE for support of many-to-1 mapping; 2 (remote UE RB ID) can work to support bear mapping from sidelink beaer to Uu bearer. But we think that it needs gNB to indicate an addition mapping for remote UE RB ID to relay, which cause extra overhead. Instead, we can just use PC5 local RLC channel ID.  We can further discuss what is the “identifier” after the functionality of adaptation layer is concluded. |
| OPPO | 1,2, 3 (RAN node ID) | At this stage, RAN node ID maybe not necessary, but in future it may be needed if considering: 1) to align the relay protocol stack with U2U L2 relay as much as possible; 2) DC architecture maybe supported in future for U2N L2 relay; |
| Xiaomi | 1, 2 | Identity of remote UE and RB is enough to do the bearer mapping and packet routing. |
| Ericsson (Tony) | 1,2 |  |
|  |  |  |

**Question 4b: Which identities in the following are needed within the header of adaptation layer over PC5 to enable Bearer mapping for L2 UE-to-UE relay? Please give your explanation for your choice:**

(1) Identity of Remote UE known by peer Remote UE and Relay UE (Remote UE ID or a local ID)

(2) Identity of End-to-End Remote UE SLRB

(3) Other identity (Please specify, e.g. Transmitter Node ID; Destination node ID)

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| --- | --- | --- |
| Company | ID List preferred | Comments |
| MediaTek | 1,2 | The Identity of the Remote UE and the Identity of Remote UE SLRB can uniquely address the SLRB for purpose of bearer mapping |
| Qualcomm | 1,3 (PC5 local RLC channel ID) | Same justification for L2 UE-to-NW relay. And we should follow the guideline of SID:  ““NOTE 2: It is assumed that UE-to-network relay and UE-to-UE relay use the same relaying solution” |
| OPPO | 1,2 | For 1, we assume that both source and destination UE ID should be included. |
| Xiaomi | 1, 2 | Same as Q4a. |
| Ericsson (Tony) | 1,2 |  |
|  |  |  |

## Basic aspects for connection setup for UE-to-NW relay

It is necessary to reuse the PC5 unicast link establishment procedure to support the unicast communication between the L2 remote UE and relay UE. Only after successful PC5 unicast link setup, L2 remote UE and relay UE can exchange the remote UE control plane and user plane traffic. It means Rel-16 NR V2X PC5 unicast link establishment procedures can be reused to setup a secure unicast link between Remote UE and Relay UE for L2 relay option [1]. The remote UE can then establish a Uu RRC CONNECTION via a UE-to-NW relay once the PC5-RRC connection for relaying is established with the relay UE [17]. RAN2 needs to confirm that this understanding.

**Question 5a: Do you agree that Rel-16 NR V2X PC5 unicast link establishment procedures can be reused to setup a secure unicast link between Remote UE and Relay UE for L2 relaying (before Remote UE establishes a Uu RRC CONNECTION with the network via Relay UE)? If not, please give your alternative solution and the reason.**

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| --- | --- | --- |
| Company | Yes/No | Comments |
| MediaTek | Yes |  |
| Qualcomm | Yes | It makes sense to reuse Rel-16 NR V2X procedure, at least to reduce spec work. We don’t think it is necessary to introduce new procedure for unicast PC5 link establishment for L2 relay.  Furthermore, we think it is better to have a unified PC5 link establishment procedure for L2 and L3 relay. Please note that SA2 has specified that a unicast PC5 link establishment procedure is needed for L3 UE-to-NW relay in section 6.6 of TS 23.752, as per the architecture recommendations in 5G ProSe SA2 TR. |
| OPPO | Yes with comment | When talking about “**Rel-16 NR V2X PC5 unicast link establishment procedures**”, apparently the PC5-S procedure part is out of RAN2 scope.. what RAN2 can decide is the reusing of AS-layer configuration and capability transfer as PC5-RRC procedure. |
| Xiaomi | Yes |  |
| Ericsson (Tony) | Yes with comment | We do not see the need to change something that is already working.  However, we may need to study if additional information may be provided during link establishment to help the remote UE and relay UE to establish the PC5-RRC for the relay path (e.g., if remote UE forward traffic information the relay UE may inform right away that he is not able to handle the traffic of the remote UE, if a PC5-RRC is established). |
|  |  |  |

**Discussion on SRB0 configuration for Remote UEs in cellular coverage**

[7] suggests that for SRB0 of the Remote UE, Uu RLC bearer configuration for the Relay UE can be predefined by specification and differentiated from the ones for the Relay UE’s SRBs. In rapporteur understanding, the SRB0 configuration for Remote UEs in cellular coverage can be configured by pre-configurations, broadcast based mechanism (i.e. SIB based distribution) and/or dedicated RRC signaling based approach.

**Question 5b-1: Which option(s) do you prefer for the configuration of Uu SRB0 of the Remote UE (in coverage)?**

Option1: pre-configurations

Option2: Broadcast based mechanism (i.e. SIB based distribution)

Option3: Dedicated RRC signaling

|  |  |  |
| --- | --- | --- |
| Company | Yes/No | Comments |
| MediaTek | Option1/2 |  |
| Qualcomm | See comments | The question is not clear. First, remote UE can’t use Uu SRB0 when it is in OOC, right? Secondly, we are not sure what “predefined by specification” means, e.g. is it pre-configuration or default configuration. Some clarifications are needed. |
| OPPO |  | We understand it is not possible to always rely on dedicated RRC to configure the related PC5 parameter considering this procedure happens before connection establishment.  While we are open to fixing it in spec, we wonder why pre-configuration does not work if the remote UE is OOC, and why SIB configuration does not work if the remote UE is in-coverage? |
| Xiaomi | No | According to previous question, remote UE shall establish sidelink unicast connection before establishing Uu connection. If so, the SRB0 configuration could be configured by relay via sidelink unicast. |
| Ericsson (Tony) | No with comment | We think that this question is only valid in certain use cases/scenarios on when the remote UE is out of coverage.  However, we need to address also the case when the remote UE is out-of-coverage and, in this case, there is no SRB0 for the remote UE.  In such a case, we may rely on relay UE using the SRB0 for establishing the relay path (i.e., if the relay in IDLE or INACTIVE).  On top if this, we believe that also the cases when the remote UE is out-of-coverage should be addressed. |
|  |  |  |

**Discussion on SRB0 configuration for Remote UEs out of coverage**

We need also discuss the handling for SRB0 for Remote UEs at out of coverage. There are multiple options to handle the issue. At first the SRB0 configuration can be defined by pre-configuration and then SRB0 can be initiated by Remote UE as legacy procedure but applying the pre-configured parameters. Secondly, Relay UE can inform the SRB0 configuration to the Remote UEs based on the established unicast PC5 link. In this way, Relay UE may get the SRB0 configuration from the network ahead of the PC5 based SRB0 configuration distribution. Thirdly, we may rely on relay UE to establish the relay path between Remote UE and gNB, which means when the two direct links are available, the indirect link is assumed to be available.

**Question 5b-2: Which option(s) do you prefer for the configuration of Uu SRB0 of the Remote UE (out of coverage)?**

Option1: Pre-configurations

Option2: Relay UE can inform the SRB0 configuration to the Remote UEs

Option3: implicit establishment (relying on relay UE to establish the relay path)

Option4: other way (Please specify)

|  |  |  |
| --- | --- | --- |
| Company | Yes/No | Comments |
| MediaTek | Option1 |  |
|  |  |  |
|  |  |  |
|  |  |  |

**Discussion on other RB configuration for Remote UEs**

**Question 5c: Do you agree that the Uu SRB(1/2) and DRB of the Remote UE is subject to legacy configuration procedures? If not, please give your alternative solution and the reason.**

|  |  |  |
| --- | --- | --- |
| Company | Yes/No | Comments |
| MediaTek | Yes |  |
| Qualcomm | Yes for the principle | Agree the principle. However, some details of connection management need further discussion, e.g. what is “legacy configuration procedures” for OOC remote UE. |
| OPPO | Yes |  |
| Xiaomi | Yes |  |
| Ericsson (Tony) | Maybe with comment | We think that this question is only valid in certain use cases/scenarios on when the remote UE is out of coverage.  However, we need to address also the case when the remote UE is out-of-coverage and, in this case, there is no SRB0 for the remote UE.  In such a case, we may rely on relay UE using the SRB0 for establishing the relay path (i.e., if the relay in IDLE or INACTIVE).  On top if this, we believe that also the cases when the remote UE is out-of-coverage should be addressed. |
|  |  |  |

## Security aspects

In case of L2 based UE-to-Network Relay, the PDCP layer terminates at both Remote UE and gNB for a particular relaying radio bearer. The Security (confidentiality and integrity protection) is enforced at the PDCP layer between the endpoints at the Remote UE and the gNB [2] [23]. The PDCP traffic is relayed securely over two links, one between the Remote UE and the UE-to-Network Relay UE and the other between the UE-to-Network Relay UE to the gNB without exposing any of the Remote UE's plaintext data to the UE-to-Network Relay. [5] indicated that SA3 is going to study security and privacy aspects of UE-to-Network relay and security aspects of UE-to-UE relay. The relay architecture e.g. Layer-2 relay may also affect the SA3 work. RAN2 should await the progress in SA2 and SA3 before further discussion on security issues.

As a high level description for the security aspects for L2 relaying, the end-to-end Security (confidentiality and integrity protection) is enforced at the PDCP layer between the endpoints (i.e. between Remote UE and gNB for UE-to-Network Relay and between two Remote UEs for UE-to-UE Relay), and then there is no data exposure. RAN2 can attempt to agree this high level description.

Meanwhile, we recognize that SA3 needs to have input into the security aspects, but PDCP functionality is in RAN2’s expertise and we all know that security is terminated between the PDCP entities. So it seems reasonable to capture the basic information that end-to-end PDCP means end-to-end security, and we can incorporate further information from SA3 on the details when we receive it.

**Question 6: Do you agree to capture “The end-to-end security (confidentiality and integrity protection) is enforced at the PDCP layer between the endpoints and then there is no data exposure for L2 relaying.” Into the TR? If not, please give the reason.**

|  |  |  |
| --- | --- | --- |
| Company | Yes/No | Comments |
| MediaTek | Yes |  |
| Qualcomm | See comments | We agree that the principle of the sentence is correct. However, we don’t think it is crystal clear. We have below 3 questions for clarification:  1. Who are “the endpoints”?  2. For "no data exposure for L2 relaying”, is it “L2 UE-to-NW relay” or “L2 UE-to-UE relay”, or both?  3. For "no data exposure for L2 relaying”, exposure to whom? |
| OPPO | Yes |  |
| Xiaomi | Yes |  |
| Ericsson (Tony) | Yes but | We agree in principle with the content of the question, but we think that SA3 needs to be consulted before to include in the TR something that may ne not correct.  We may need to send an LS to SA3. |
|  |  |  |

## DL reachability and Paging for UE-to-NW relay

[7], [11], [14], [17], [29] and [42] discuss the DL reachability for the remote UE. [7], [17] and [42] suggests to use the conclusion of feD2D study as the baseline of paging monitoring. [14] proposes enhancement based on PO based monitoring. [29] suggests to differ the cases and the mechanism can be discussed case by case.

It is suggested that the Option 2 as studied in TR36.746 for FeD2D paging is selected as the baseline paging relaying solution for L2 based UE-to-Network relaying case. This means Relay UE monitors the Remote UE's PO in addition to its own PO. It also means there is some Relay UE-Remote UE association stored by the network. RAN2 is suggested to confirm this work assumption to avoid unnecessary debate during the study. It should be noted that the discussion on the RRC states within the email discussion on requirements and scenarios may be an input for this issue.

**Question 7: Do you agree that the Option 2 as studied in TR36.746 for FeD2D paging is selected as the baseline paging relaying solution for L2 based UE-to-Network relaying case (i.e. Relay UE monitors the Remote UE's PO in addition to its own PO.)? If not, please give your alternative solution and the reason.**

|  |  |  |
| --- | --- | --- |
| Company | Yes/No | Comments |
| MediaTek | Yes |  |
| Qualcomm | Yes | Maybe some clarifications are needed:   * Whether in-coverage remote UE can receive paging via relay forwarding * How is it relayed? e.g. via groupcasting, or a container over PC5, or will it be placed into PC5 messages with new formats to be defined. * Whether RAN or CN paging are supported is needed. We assume that FeD2D solution in TR36.746 is only for CN paging because INACTIVE is not supported in LTE. |
| OPPO | Yes |  |
| Xiaomi |  | This is related to whether remote UE is allowed to be in IDLE or INACTIVE from gNB point of view. If remote UE is only allowed to be in CONNECTED, paging relay is not necessary. Note there are companies suggest remote UE stay in connected after relay connection establishment. |
| Ericsson (Tony) | Yes | We are fine to consider Option 2 in TR 36.746 as baseline, but the details and the changes needed should be further studied in this SI. |
|  |  |  |

## System information reception for remote UE (UE-to-NW relay)

[7], [11], [14], [17], [29] and [42] discuss the System information delivery and forwarding to Remote UE. In rapporteur’s understanding, the system information reception mechanism as studied by TR36.746 for FeD2D can be reused. This means the Relay UE supports relaying of system information for its linked Remote UEs [17]. However, which SIBs are relayed can be discussed at normative phase.RAN2 is suggested to confirm this.

**Question 8a: Do you agree that the system information reception mechanism as studied by TR36.746 for FeD2D can be reused for L2 UE to Network Relaying (i.e. Relay UE supports relaying of system information for its linked Remote UEs)? If not, please give your alternative solution and the reason.**

|  |  |  |
| --- | --- | --- |
| Company | Yes/No | Comments |
| MediaTek | Yes |  |
| Qualcomm | Yes | Maybe some clarifications are needed:   * Whether in-coverage remote UE can receive SIB via relay forwarding * What type of SIB it needs to relay? e.g. common SIB1, or dedicated SIB12 * How is it relayed? e.g. via groupcasting, or a container over PC5, or will it be placed into PC5 messages with new formats to be defined. |
| OPPO |  | It is OK to support it, but due to the unclear wording of the Question, it is hard to judge the intention of the rapporteur, e.g., whether it is to copy the whole section of 5.1.2.3, which is apparently not feasible since it is addressed for LTE..  And for “**(i.e. Relay UE supports relaying of system information for its linked Remote UEs)**”, does it mean that SI-forwarding is only for “linked” remote UE? |
| Xiaomi | Yes |  |
| Ericsson (Tony) | Partially | We believe that relay for all system information message(s) is not efficient for the relay/remote UE and this is because the remote UE may need also some of the information included in the SIB(s).  Since the relay UE needs to decode anyway the SIB(s) broadcasted by the network, a more efficient (from signaling and packet size) solution would be that the relay UE just send to the remote UE the necessary information via dedicated PC5-RRC signaling within new IEs.  Keep in mind that forwarding of the system information by the relay UE implies that we do need to support SIB segmentation also over PC5. |
|  |  |  |

The support of on-demand SI delivery is proposed in some of the papers [7] [14] [29] [42].

From on demand SI perspective, it is not good way to let the remote UE go through the legacy Msg1/Msg3-based procedure, as it cannot be simply forwarded. RAN2 needs to discuss the handling over PC5 to support RRC Idle mode based on demand SI delivery for Remote UE.

In NR Rel-16, the on-demand system information transmission is enhanced to support RRC-Connected mode UE also. There may be scenarios where Relay UE is RRC connected, and Remote UE is also RRC connected. So then there may be a case that On-demand SI transmission needs to be supported between Remote UE and network. The necessary PC5 RRC may need to be enhanced in order to enable the relaying operation at Relay UE for the On-demand SI transmission.

RAN2 is suggested to confirm the need to support the On-demand SI transmission for both RRC Idle and RRC connected Remote UEs.

**Question 8b: Which option do you prefer with regard to the support on-demand SI delivery for Remote UE? Please give the reason for your choice.**

**Option1: Support on-demand SI delivery for Remote UEs in RRC Idle/Inactive**

**Option2: Support on-demand SI delivery for Remote UEs in RRC Connected**

**Option3: Support on-demand SI delivery for Remote UEs in RRC Idle/Inactive and RRC Connected**

**Option4: Do not support on-demand SI delivery for Remote UE**

**Option5: Re-use legacy on-demand SI delivery for the Relay UE (in IDLE/INACTIVE/CONNECTED)**

|  |  |  |
| --- | --- | --- |
| Company | Preferred Option | Comments |
| MediaTek | Option 3 | We need to support all scenarios for on-demand SI delivery based on the discussion for on-demand SI at NR Rel-15/Rel-16. PC5 based SIB forwarding may need be supported to enable on-demand SI from the network to the UE. |
| Qualcomm | See comments | We think we first need to get the use case and scenario clarified. We are open to discuss when on-demand SI delivery is required via relay.  In addition, since we have discussed RRC state of relay, then one clarification may be needed what is valid RRC state combination between remote UE and relay, e.g.:   * Relay in CONNECTED while remote IDLE * Relay in IDLE while remote CONNECTED * Both Relay and remote in CONNECTED * Both Relay and remote in IDLE |
| OPPO | 3 | Yet we fail to understand the connection between the justification text and question here.  For idle UE, the sending of rrcSystemInfoRequest is not different from other SRB0 UL message, andfor connected UE, the sending of dedicatedSIBRequest is not different from other SRB1 UL message, and thus there could be no extra enhancement due to supporting this. |
| Xiaomi | Option 4 | First, we should identify which SIB is needed for remote UE.  We think only SIB1, 6, 7, 8 are needed for remote UE. SIB 1 is always broadcast. SIB 6, 7, 8 should be broadcast if there is CMAS or ETWS notification. Therefore, the need of SI request is not justified. |
| Ericsson (Tony) | Option 3 and Option 5 | Not sure why the INACTIVE state has been left out.  Relay UE, that is in coverage, already support legacy on-demand SI/SIB request and thus we can re-use this for free. There is no benefit to allow the remote UE to request SI/SIBs on demand as this it may be out-of-coverage. |
|  |  |  |

## Other issues

There may be additional issues that need to be discussed to describe the L2 relaying from high level perspective.

**Question 9: Please give the explanation of any additional issues to describe the L2 relaying from high level perspective.**

|  |  |  |
| --- | --- | --- |
| Company | Agree/Disagree | Comments |
| Ericsson (Tony) | Remote UE out-of-coverage | It looks like the assumption of the email discussion rapporteur is that the remote UE is “always” in coverage.  However, would should not limit the analysis only to this use case at this stage. For the sake of the study item, we have to study both situations on when the remote UE may be in coverage or out-of-coverage.  We kindly ask, then, to include the out-of-coverage remote UE use cases in the proposed questions. |
| Ericsson (Tony) | Exchanging of capability | In situations when the remote UE is out-of-coverage, the remote UE may not be able to exchange its capability with the gNB/UE.  In this case, the relay UE should do it. |
| Ericsson (Tony) | RRC states of the relay UE and remote UE | Out assumption is that the relay UE and remote UE may have different RRC states, but we should limit the combination of those because some of them may not be practical. In the following table to explain what our idea of the supported RRC state combinations is:   |  |  |  | | --- | --- | --- | | **RL UE state** | **RM UE state** | **Validity** | | CONNECTED | CONNECTED | Valid | | CONNECTED | INACTIVE | Valid | | CONNECTED | IDLE | Valid | | INACTIVE | CONNECTED | Invalid | | INACTIVE | INACTIVE | Valid | | INACTIVE | IDLE | Valid | | IDLE | CONNECTED | Invalid | | IDLE | INACTIVE | Valid | | IDLE | IDLE | Valid | |
| Ericsson (Tony) | Inactivity monitoring | How to handle the inactivity monitoring of the relay/remote UE is not clear yet. Our assumption is that the presence of a relay path should be taken into account when performing inactivity monitoring at the NG-RAN or UE for the relay UE. |
| Ericsson (Tony) | Service continuity | Not sure this need to be addressed here, but is probably among the most important items to be investigated in this study item. |
|  |  |  |

# Rapporteur’s summary

This document promulgated the following proposals with a companion TP:

# References

[1]R2-2006572 Architecture Options for Sidelink Relay MediaTek Inc.

[2]R2-2006555 UE-to-network relay architecture and procedures Qualcomm Incorporated

[3]R2-2007100 Discussion on User Plane mechanisms for Layer 2 Relay Apple

[4]R2-2008019 Relaying mechanism for NR sidelink LG Electronics Inc.

[5]R2-2007181 Overview of Layer-2 and Layer-3 sidelink relay mechanisms Sony

[6]R2-2007460 Protocol stack design for L2 relay Lenovo, Motorola Mobility

[7]R2-2008047 Study aspects of UE-to-Network relay and solutions for L2 relay Huawei, HiSilicon

[8]R2-2006604 Protocol stack and CP procedure for SL relay OPPO

[9]R2-2006867 Mechanisms and Characteristics in NR Sidelink Relaying Fujitsu

[10]R2-2006962 Mechanisms for supporting L2-based Sidelink Relays AT&T

[11]R2-2007041 Protocol stack and service continuity for L2 and L3 relay vivo

[12]R2-2007044 Discusssion on architecture for NR sidelink relay Spreadtrum Communications

[13]R2-2007100 Discussion on User Plane mechanisms for Layer 2 Relay Apple

[14]R2-2007101 Discussion on Control Plane mechanisms for Layer 2 Relay Apple

[15]R2-2006722 Protocol Stack and Connection Setup Procedure of Sidelink Relay Futurewei

[16]R2-2006737 Discussion on NR SL Relay Architecture ZTE Corporation, Sanechips

[17]R2-2006759 Discussion and TP on UE to NW Relay Based on L2 Relay Architecture InterDigital

[18]R2-2006760 Discussion and TP on UE to UE Relay Based on L2 Relay Architecture InterDigital

[19]R2-2006855 Considerations for L3 UE-to-Network Relays Nokia, Nokia Shanghai Bell

[20]R2-2007203 L3 vs L2 relaying Samsung Electronics GmbH

[21]R2-2007292 Considerations on L2 and L3 SL relay protocol design Ericsson

[22]R2-2006611 L2/L3 UE-to-NW Relay Comparison CATT

[23]R2-2006718 Characteristics of L2 and L3 based Sidelink relaying Intel Corporation

[24]R2-2006843 View on L2/L3 SL relay ITL

[25]R2-2006557 Discussion on NR sidelink relay selection and reselection Qualcomm Incorporated

[26]R2-2006770 Discussion on SL relay (re)selection and authorization OPPO

[27]R2-2006861 NR Sidelink Relay (Re-)Selection Criterion and Procedure Fraunhofer IIS, Fraunhofer HH

[28]R2-2006639 L2 vs L3 - Relay (re-)Selection, Quality of Service (QoS) Fraunhofer HHI, Fraunhofer IIS

[29]R2-2006571 RRC States for Relaying MediaTek Inc.

[30]R2-2007462 RRC state and CN registration of the remote UE Lenovo, Motorola Mobility

[31]R2-2008048 Service continuity for L2 UE-to-Network relay Huawei, HiSilicon

[32]R2-2008066 Discussion on service continuity from Uu to relay Xiaomi communications

[33]R2-2006641 L2 vs L3 Relay/Remote UE Authorization, Service Continuity Fraunhofer HHI, Fraunhofer IIS

[34]R2-2006723 Service Continuity with Sidelink Relay Futurewei

[35]R2-2007461 Relayed connection management Lenovo, Motorola Mobility

[36]R2-2007608 Impact on user plane protocol stack/control plane procedure for Sidelink Relay Intel

[37]R2-2007816 Considerations on UE-to-NW Relay ETRI

[38]R2-2008043 Consideration of Relay characteristics LG Electronics Inc.

[39]R2-2007040 Selection/Authorization and Security for L2 and L3 relay vivo

[40]R2-2006724 QoS Control with Sidelink Relay Futurewei

[41]R2-2007099 Discussion on NR Sidelink Relay Scenarios Apple, Convida Wireless

[42]R2-2006610 User and Control Plane Procedures for L2 UE-to-NW Relay CATT

# TP on L2 relay mechanism

TP to be developed:

# Annex for company contacts

Company contacts for this discussion is captured in the table below:

|  |  |  |
| --- | --- | --- |
| Company | Contact | Email of Contact |
| MediaTek | Xuelong Wang | Xuelong.Wang@ MediaTek.com |
| Ericsson | Antonino Orsino | antonino.orsino@ericsson.com |
| Qualcomm | Peng Cheng | Peng Cheng <chengp@QTI.QUALCOMM.COM> |
| OPPO | Qianxi Lu | Qianxi Lu <qianxi.lu@OPPO.COM> |
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