**3GPP TSG-RAN WG2 Meeting #128 R2-24xxxxx**

**Orlando, Florida, 18th – 22nd November 2024**

**Agenda Item: 8.13.3**

**Source: InterDigital**

**Title: Report of [POST127][402][Relay] Multi-hop relay control plane**

**Document for: Discussion and Decision**

# 1 Introduction

This contribution gives the discussion summary of following post email discussion.

* [Post127][402][Relay] Multi-hop relay control plane (InterDigital)

 Scope:

 - Describe different solutions (from company contributions) for multihop U2N relay UE by at least describing:

* + Connection establishment procedures
	+ Assumptions on RRC state(s) of intermediate UEs and last relay UE
	+ Assumptions on controlling gNB/cell of each relay UE
	+ How the remote and intermediate relay UEs obtain their configurations in each solution
	+ How to meet QoS requirement e2e

 - Evaluate the feasibility and pros/cons of the different solutions towards downscoping to a single solution

 Intended outcome: Report to RAN2#128

 Deadline: Very long (for RAN2#128)

## Phasing of the Email Discussion

The email discussion has been divided into two phases, where phase 1 will correspond to describing the different solutions in each of the areas identified (connection establishment procedure, RRC state assumptions, assumptions on the controlling gNB/cell, configuration procedure, and E2E QoS). This will ensure that companies have a common understanding of each of the solutions.

In the second phase, the solutions will be evaluated in terms of their feasibility and pros and cons.

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# 2 Phase 1 Discussion

Based on company contributions, there seem to be two main approaches for implementing multipath U2N relays. A first approach is a fully U2N based approach. The network directly controls each of the intermediate relay UEs using dedicated Uu RRC signalling. The second approach is still U2N-based but with some elements of U2U. Only the last relay UE needs to be controlled using dedicated RRC signalling.

For the email discussion, approach 1 and approach 2 will be used as follows:

* Approach 1: The network needs to directly control each of the intermediate relay UEs via Uu RRC.
* Approach 2: Only the last relay UE requires control by the network via Uu RRC.

In each subsection, the procedures and assumptions for each approach will be discussed to get a common understanding of both approach 1 and approach 2 in the context of the following aspects:

* Connection establishment procedures
* Assumptions on RRC state(s) of intermediate relay UEs and last relay UE
* Assumptions on controlling gNB/cell of each relay UE
* How the remote and intermediate relay UEs obtain their configurations in each solution
* How to meet QoS requirement e2e for remote UE

## 2.1 Connection Establishment Procedure

In each subsection, the purpose is to agree on a baseline procedure for connection establishment and RRC state assumptions for both approaches (to serve as the basis for further feasibility and pro/con evaluation.

2.1.1 Approach 1

Using connection establishment procedure for single-hop relays as a baseline, the figure below illustrates rapporteur’s assumptions of the establishment procedure for multiple-hop relays in approach 1.



1. The U2N Remote UE, First Relay UE, Intermediate Relay UE, and Last Relay UE perform discovery procedure, and establish a PC5-RRC connection between each adjacent UE (U2N Remote UE<->First Relay UE, First Relay UE <-> Intermediate Relay UE, Intermediate Relay UE <-> Last Relay UE) using the NR sidelink PC5 unicast link establishment procedure.
2. The L2 U2N Remote UE sends the first RRC message (i.e., *RRCSetupRequest*) for its connection establishment with gNB via the First Relay UE, using a specified PC5 Relay RLC channel configuration. The first Relay UE sends the *SidelinkUEInformationNR* message to request for the dedicated configurations required to support the multi-hop relay operation for the U2N Remote UE. If the First Relay UE is not in RRC\_CONNECTED, it needs to do its own Uu RRC connection establishment via the Intermediate Relay UE (using similar actions as a U2N Remote UE) upon reception of a message from U2N Remote UE on the specified PC5 Relay RLC channel. The Intermediate Relay UE sends the *SidelinkUEInformationNR* message to request for the dedicated configurations required to support the multi-hop relay operation for the U2N Remote UE. If the Intermediate Relay UE is not in RRC\_CONNECTED, it needs to do its own Uu RRC connection establishment via the Last Relay UE (using similar actions as a U2N Remote UE) upon reception of a message from the First Relay UE on the specified PC5 Relay RLC channel. The Last Relay UE sends the *SidelinkUEInformationNR* message to request for the dedicated configurations required to support the multi-hop relay operation for the U2N Remote UE. If the Last Relay UE is not in RRC\_CONNECTED, it needs to do its own Uu RRC connection establishment upon reception of a message from the Intermediate Relay UE on the specified PC5 Relay RLC channel. The Last Relay UE receives SRB0 relaying Uu Relay RLC channel configuration for the Intermediate Relay UE from gNB. The Intermediate Relay UE receives SRB0 relaying Uu Relay RLC channel configuration for the First Relay UE from gNB. The gNB configures SRB0 (for U2N Remote UE) relaying Uu Relay RLC channel to the first Relay UE. The gNB responds with an *RRCSetup* message to U2N Remote UE. The *RRCSetup* message is sent to the U2N Remote UE using SRB0 relaying Last Relay RLC channel over Uu and the specified PC5 Relay RLC channels over each of the PC5 links.
3. The gNB, Last Relay UE, Intermediate Relay UE and First Relay UE perform relaying channel setup procedure over Uu. According to the configuration from the gNB, the First Relay/U2N Remote UE establishes a PC5 Relay RLC channel for relaying of SRB1 towards the U2N Remote UE/First Relay UE over PC5, the Intermediate Relay/First Relay UE establishes a PC5 Relay RLC channel for relaying of SRB1 towards the First Relay UE/Intermediate Relay UE over PC5 and the Last Relay UE/ Intermediate Relay UE establishes a PC5 Relay RLC channel for relaying of SRB1 towards the Intermediate Relay UE/Last Relay UE over PC5.
4. The *RRCSetupComplete* message is sent by the U2N Remote UE to the gNB via the First Relay UE, Intermediate Relay UE and the Last Relay UE using SRB1 relaying channels over PC5 and SRB1 relaying channel configured to the Last Relay UE over Uu. Then the U2N Remote UE is RRC\_CONNECTED with the gNB.
5. The L2 U2N Remote UE and gNB establish security following the Uu security mode procedure and the security messages are forwarded through the First Relay UE, Intermediate Relay UE, and Last Relay UE.
6. The gNB sends an *RRCReconfiguration* message to the U2N Remote UE via the Last Relay UE, Intermediate Relay UE, and First Relay UE to setup the end-to-end SRB2/DRBs of the U2N Remote UE. The U2N Remote UE sends an *RRCReconfigurationComplete* message to the gNB via the First Relay UE, Intermediate Relay UE, and Last Relay UE as a response. In addition, the gNB may configure additional Uu Relay RLC channels between the gNB and Last Relay UE, and PC5 Relay RLC channels between each of the Intermediate Relay UE, First Relay UE, and U2N Remote UE for the relaying traffic.

Based on the above procedure, for gNB to control each relay UE by RRC, each relay UE needs to be in RRC connected. As a result, for connection establishment of the remote UE, each relay UE should trigger its own connection establishment. For the last relay UE, Uu connection establishment is performed. However, for the other relay UEs, upon reception of a message on SL-SLB0, they perform connection establishment as though they are acting as a remote UE.

Question 1: Do you agree that for approach 1

* + the remote UE connection establishment always triggers connection establishment in each of the relay UEs (if they are in IDLE/INACTIVE)
	+ for all relay UE’s except the last relay UE, upon reception of a message on SL-SRB0, it triggers a remote UE connection establishment?
	+ For all relay UE’s except the last relay UE, they need to be configured with a remote UE Uu DRB configuration and SRAP configuration to act as a remote UE (without having any Uu traffic per se).

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| **Companies** | **Yes or No** | **Comments** |
| OPPO | See comments | We agree that all the relay UEs need to be in RRC connected state to serve a RRC connected remote UE, i.e., generally Yes for the first bullet.While for the second and third bullet, we are confused on the intention:* For the second bullet, what is the delta part compared to the first bullet?
* For the third bullet, how to understand “configured with a remote UE Uu DRB configuration”? We understand the relay UE without having any Uu traffic doesn’t need to have DRB configuration (e.g., SDAP, PDCP configuration).
 |
| LG | Yes | We believe that reusing the legacy Rel-17 U2N scheme can be a straightforward way to implement a Rel-19 multi-hop U2N relay. The approach 1 can implement without big spec impact by reusing the legacy Rel-17 U2N procedure as much as possible. Therefore, we generally agree with the approach 1. But we have to clarify the details later. For example, the difference between 2nd and 3rd bullets.  |
| Sharp | See comments | For the first bullet, if the “connection establishment” means Uu RRC connection establishment, bracket should be removed since relay UEs don’t need to trigger connection establishment procedure if these are in RRC\_CONNECTED.For the second bullet, it is unclear what “a remote UE connection establishment” means. If it means that each relay UEs except the Last Relay UE should have PC5 RRC connection with the remote UE, we disagree with this analysis. And for the “SL-SRB0”, it might be “SL-RLC0”.For the third bullet, we understand that all Relay UEs except the Last Relay UE can act as Remote UEs. If the intension is that “all relay UEs are configured with SRAP/RLC configuration for the Remote UE’s Uu E2E DRB/SRB”, wording can be modified. |
| Huawei, HiSilicon | See comments  | We agree that the Relay UEs shall be in RRC\_CONNECTED state to perform relaying of unicast data to the remote UE. Hence agree with the first bullet.However, we are unclear of the intention of the 2nd and 3rd bullet as Oppo has mentioned. In step 2 it is mentioned “If the Last Relay UE is not in RRC\_CONNECTED, it needs to do its own Uu RRC connection establishment upon reception of a message from the Intermediate Relay UE on the specified PC5 Relay RLC channel.” Then we are not sure why bullet 2 mentions “ for all relay UE’s except the last relay UE, upon reception of a message on SL-SRB0, it triggers a remote UE connection establishment”Similarly bullet 3 seems unclear why we need all relay UE’s except the last relay UE, configured with a remote UE Uu DRB configuration and SRAP configuration to act as a remote UE |
| Apple | Yes | We agree with the rapporteur’s analysis. Bullet 1 is self-evident as this is the basic assumption of approach 1.For Bulliet 2, our understanding is that this can be triggered either by SL-SRB0 or SL\_RLC0 (as defined in R17), so this needs to be further discussed. A more important point is that the intermediate relay UE’s RRC establishment is based on the triggering of a so-called “remote UE”, which the relay UE need to report to the NW. Whether this remote UE is the end remote UE or the adjacent “relay UE” also needs to be further discussed. For Bullet 3, based on legacy design of U2N relay, when a relay UE reports its PC5-connection remote UE to the NW, NW will configure both the relay UE and the remote UE with SRAP mappings and Relay RLC channel configurations. So, when an intermediate relay UE or last relay UE reports another PC5-Connected “remote UE”, the NW will assume it need to provide all necessary configurations to support Uu SRB/DRBs reaching this “remote UE” via the reporting relay UE. So, if this PC5-connected remote UE is actually another intermediate relay UE (not the real remote UE), NW will configure Uu DRB SRAP configurations towards this intermediate relay UE instead, which may not be very useful. So, the Bullet 3 is a valid point. However, if approach 1 assume this PC5-conencted “remote UE” reported by the relay UE is actually the end remote UE, then we have to assume End Remote UE is somehow multi-hop U2U connected with an intermediate relay UE first before relay UE reports it. That seems against the principle of Approach 1. So, all this needs to be further discussed.  |
| ZTE | Yes with comments (no for the second bullet) | We generally agree with the first bullet and think that a main point in approach 1 is that all the intermediate relays are connected to the same cell/gNB as the Last relay UE’s serving cell/gNB. For the second bullet, we think it is a complement to the first bullet that, all the intermediate relays enter into RRC\_CONNECTED via indirect path just as Rel-17 U2N remote UE, right?For the third bullet, as above comments how to understand “configured with a remote UE Uu DRB configuration”? Does it mean that the relaying traffic are regarding as the intermediate relay’s(act as a remote UE) own traffic to transmit to the network, which seems like a L3 U2N relay? In our view, intermediate relays only need to be configured with SRAP configuration and PC5 RLC channel configuration to forward relaying traffic. |
| CATT | Yes | Same view as LG and the currnet skeleton build a good start point for further discussion. |
| TCL | Yes  |  |
| Xiaomi | Yes |  |
| Kyocera | Yes | We agree the general idea of the steps are reasonable, although further discussion is needed regarding the contents of the configuration for the relay UEs. For example, in Step 2, it should also be clarified when the first relay UE should forward the remote UE’s RRC Setup Request to the intermediate relay UE in addition to sending its own Uu RRC Connection Establishment request to the intermediate relay UE. |
| Spreadtrum | See comments | We agree the approach 1 and first bullet, but second and third bullet are not clear and we do not support. |
| Ericsson | comments | We see additional design complexity for this approach (in addition to the two aspects in the above)1. during relay discovery, relay (re)selection phase, first relay UE, intermediate relay are required to select the same last relay UE as the remote UE for their own relay connection, this would add additional design complexity/restrictions for RAN2 and SA2.2. in above step 2, it would trigger/include subsequential connection establishment (for last relay UE, intermediate relay UEs), the procedure is not clear. A lot of details need to be studied, e.g., which UE is responsible for send SUI for remote UE.In addition, this approach has below restrictions.1.all relay UEs need to be served in the same cell. 2.significant signaling overhead and latency for remote UE’s E2E connection establishment. |
| Lenovo | Yes with comments | Both bullet#1 and #2 have the similar target. But last relay UE is excluded in bullet#2. Our understanding is that all relay UE including intermediate relay UE and last relay UE should transit into connected from idle/inactive after receiving SL-SRB0 message.Regarding bullet#3, network will configure SRAP configuration and PC5 RLC channel to the relay UE if there is no its own traffic. |
| Samsung | Yes for first two items | For the third item, the DRB configuration is only needed at the remote UE side. While all relay UEs (incl. the last relay UE) only needs the SRAP configurations. Then, we would prefer to Sharp’s rewording, i.e., “all relay UEs are configured with SRAP/RLC configuration for the Remote UE’s Uu E2E DRB/SRB”. Meanwhile, for the last relay UE, both the PC5 RLC channel and Uu RLC channel configurations are needed, while for other relay UEs (except the last relay UE), PC5 RLC channel configuration is enough. |
| vivo | Yes |  |

Question 2: Do you agree that the above figure and steps can serve as the baseline connection establishment procedure of approach 1 that can serve for further discussion of pros/cons?

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| **Companies** | **Yes or No** | **Comments** |
| OPPO | See comments | We generally agree with the figure, and the detail wording in the steps can be further checked/discussed, e.g.: In step-2, “*The Last Relay UE receives SRB0 relaying Uu Relay RLC channel configuration for the Intermediate Relay UE from gNB. The Intermediate Relay UE receives SRB0 relaying Uu Relay RLC channel configuration for the First Relay UE from gNB. The gNB configures SRB0 (for U2N Remote UE) relaying Uu Relay RLC channel to the first Relay UE.*” We understand gNB provides SRB0 configuration to each UE via RRC message, there is no need to say xx Relay UE relaying Uu relay RLC channel configuration for xx Relay.  |
| LG | Yes | We agree the procedure as the basic procedure for the further pros/cons discussion. |
| Sharp | See comments | Generally, we agree with this figure and analysis. However, we wonder if the Intermediate Relay UEs and the Last Relay UE have to “send” *SidelinkUEInformationNR* since the NW can determine whether the reconfiguration is needed for each relay UEs upon receiving *SidelinkUEInformationNR* from the First Relay UE. (If the Intermediate UE is allowed to be in IDLE/INACTIVE state while the first relay UE is in CONNECTED state, it can be reconsidered.) And other wording can be further discussed.Furthermore, some points should be discussed e.g.;* Whether the First Relay UE and the Intermediate Relay UEs are in RRC\_CONNECTED state while the Remote UE is in RRC\_CONNECTED state.

Whether the dedicated SRB0 configuration for the remote UE should be configured for each the relay UEs. In other words, whether the dedicated SRB0 configuration for multi-hop relaying can be commonly used for the path. |
| Huawei, HiSilicon | Yes | We can agree to take this procedure as the basic procedure for the phase 2 discussions. |
| Apple | Yes with comment | In general, we agree with the above analysis, with a few additional comments.First, I think for approach 1, the step 2/3 is actually more complex than what has been drawn in the figure. As we can see, the description of step 2 is quite complex, and some necessary messages such as SidelinkUEinformation is not even shown in the figure above.Moreover, we think an intermediate relay UE cannot enter CONNECTED state until its adjacent next relay UE enters CONNECTED state first. As a result, the latency for steps above are quite significant if the detailed steps are illustrated as “cascading” sequence below (instead of using a single end-to-end arrow):So, we think RAN2 need to discuss this constraint of Approach 1 and related consequences/issues. |
| ZTE | Yes with comments | We are generally fine with the figure, but the details need further discussion/checking, e.g. about bearer mapping(SRAP) configuration at each Relay UE. For example, the Intermediate relay has no direct Uu with the gNB actually, we wonder why the Intermediate relay needs to be configured with SRB0 relaying Uu Relay RLC channel configuration for the First Relay UE. Suggest to remove “The Intermediate Relay UE receives SRB0 relaying Uu Relay RLC channel configuration ...”(until to the last sentence in step 2), instead, a FFS can be captured for further discussion. |
| CATT | Yes with comments | We agree with the procedure shown in the figure. But the description in Step 2 may needs to be clarified to reach common understanding.  |
| TCL  | Yes |  |
| Xiaomi | Yes |  |
| Kyocera | Yes |  |
| Spreadtrum | Yes |  |
| Ericsson |  | Agree with what Apple commented |
| Lenovo | Yes |  Details can be further discussed. |
| Samsung | Yes with comments | In general, we are fine to take the above flow chart as the starting point. However, we have some initial concerns (which may be addressed when developing the stage-2 flow chart):* Step 1: discovery and PC5 connection for intermediate/last relay UE needn’t to be always at the beginning, e.g., whenever an intermediate/last relay UE receives the first RRC message (i.e., RRCSetupRequest) via a specified PC5 Relay RLC channel, it can trigger the discovery and PC5 connection procedures. So, Step 1 can be applied between remote UE and the first relay UE only. For other nodes, it can be addressed in Step 2.
* Step 2
	+ A better way may be to cite the legacy procedure (i.e., Section 16.12.5.1 in TS38.300) rather than list the procedures of each node.
* Step 3
	+ Except last relay UE, other relay UEs may not be in coverage of gNB so that it cannot perform the relaying channel setup procedure over Uu.
	+ The PC5 and Uu Relay RLC channel for SRB1 may be performed during step 2 since the intermediate node may be configured during its own connection establishment procedure.
	+ The PC5 relay RLC channel establishment between intermediate Relay UEs is missing.
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| vivo | Yes | This figure can be seen as a guideline, but we also have questions about whether we can simplify it to start with only one additional hop, e.g., only contain first relay UE (which is also an intermediate relay UE) and last relay UE, to understand how the whole procedure works. |

2.1.2 Approach 2

Using connection establishment procedure for single-hop relays as a baseline, the figure below illustrates rapporteur’s assumptions of the establishment procedure for multiple-hop relays in approach 2.



1. The U2N Remote UE, First Relay UE, Intermediate Relay UE, and Last Relay UE perform discovery procedure, and establish a PC5-RRC connection between each adjacent UE (U2N Remote UE<->First Relay UE, First Relay UE <-> Intermediate Relay UE, Intermediate Relay UE <-> Last Relay UE) using the NR sidelink PC5 unicast link establishment procedure.
2. The L2 U2N Remote UE sends the first RRC message (i.e., *RRCSetupRequest*) for its connection establishment with gNB via the First Relay UE, using a specified PC5 Relay RLC channel configuration. If the First Relay UE is in RRC\_CONNECTED, it sends the *SidelinkUEInformationNR* message to request for the dedicated configurations required to support the multi-hop relay operation for the U2N Remote UE. Otherwise, it obtains the configuration from SIB or preconfiguration. If the Intermediate Relay UE is in RRC\_CONNECTED, it sends the *SidelinkUEInformationNR* message to request for the dedicated configurations required to support the multi-hop relay operation for the U2N Remote UE. Otherwise, it obtains the configuration from SIB or preconfiguration. The Last Relay UE sends the *SidelinkUEInformationNR* message to request for the dedicated configurations required to support the relay operation for the U2N Remote UE. If the Last Relay UE is not in RRC\_CONNECTED, it needs to do its own Uu RRC connection establishment upon reception of a message on the specified PC5 Relay RLC channel. After the Last Relay UE's RRC connection establishment procedure and sending the *SidelinkUEInformationNR* message, gNB configures SRB0 relaying Uu Relay RLC channel to the Last Relay UE. The gNB responds with an *RRCSetup* message to U2N Remote UE. The *RRCSetup* message is sent to the U2N Remote UE using SRB0 relaying Last Relay RLC channel over Uu and the specified/preconfigured PC5 Relay RLC channels over each of the PC5 links.
3. According to (pre)configuration, the First Relay/U2N Remote UE establishes a PC5 Relay RLC channel for relaying of SRB1 towards the U2N Remote UE/First Relay UE over PC5, the Intermediate Relay/First Relay UE establishes a PC5 Relay RLC channel for relaying of SRB1 towards the First Relay UE/Intermediate Relay UE over PC5 and the Last Relay UE/ Intermediate Relay UE establishes a PC5 Relay RLC channel for relaying of SRB1 towards the Intermediate Relay UE/Last Relay UE over PC5.
4. The *RRCSetupComplete* message is sent by the U2N Remote UE to the gNB via the First Relay UE, Intermediate Relay UE and the Last Relay UE using SRB1 relaying channels over PC5 and SRB1 relaying channel configured to the Last Relay UE over Uu. Then the U2N Remote UE is RRC\_CONNECTED with the gNB.
5. The L2 U2N Remote UE and gNB establish security following the Uu security mode procedure and the security messages are forwarded through the First Relay UE, Intermediate Relay UE, and Last Relay UE.
6. The gNB sends an *RRCReconfiguration* message to the U2N Remote UE via the Last Relay UE, Intermediate Relay UE, and First Relay UE to setup the end-to-end SRB2/DRBs of the U2N Remote UE. The U2N Remote UE sends an *RRCReconfigurationComplete* message to the gNB via the First Relay UE, Intermediate Relay UE, and Last Relay UE as a response. In addition, the gNB may configure additional Uu Relay RLC channels between the gNB and Last Relay UE, and PC5 Relay RLC channels between each of the Intermediate Relay UE, First Relay UE, and U2N Remote UE for the relaying traffic.

The main difference in the procedure with approach 1 is that a relay UE (other than the Last Relay) in RRC\_IDLE/RRC\_INACTIVE is not required to trigger an RRC connection as a result of the remote UE’s RRC connection. Also, rapporteur has assumed (as was done for SL in Rel16, as well as for U2U relays in Rel18) that for a relay UE that is already in RRC\_CONNECTED, the relay UE obtains its configuration using dedicated RRC signaling. For the case of the relay UE in RRC\_IDLE/RRC\_INACTIVE, how the relay UE obtains its configuration is further discussed in section 2.2.

Question 3: Do you agree that for approach 2

* + a relay UE in RRC\_IDLE/RRC\_INACTIVE (other than the Last Relay UE) is not required to trigger its own RRC Connection upon RRC connection establishment of the U2N Remote UE.
	+ similar to legacy (Rel16 SL, and Rel18 U2U), if a relay UE is in RRC\_CONNECTED, it obtains its relaying RLC channel configuration in dedicated signaling.

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| **Companies** | **Yes or No** | **Comments** |
| OPPO | Yes |  |
| LG | Yes | Approach 2 introduces new concepts compared to the legacy Rel-17 U2N; however, the benefits are not understood when the intermediate Relay UE is in RRC\_IDLE/INACTIVE. The intermediate Relay UE has to serve relay functionality while communication is ongoing between the remote UE and gNB regardless of its RRC state. We believe that management by the gNB can be performed efficiently when the intermediate Relay UE is in RRC\_CONNECTED.In step 4, it’s not clear how to deliver the *RRCSetup* message to the remote UE without local ID assignment. The intermediate Relay UE which doesn’t have the local ID of the Remote UE may not deliver the message to the correct Remote UE among multiple other Remote UEs.The local ID assignment scheme may be different from the scheme used in the Rel-18 U2U. In the case of Rel-18 U2U, the relay UE easily assigns the local ID to the source Remote UE and target Remote UE because there are only two hops. When discussing multi-hop extension in Rel-19, a new local ID assignment mechanism should be considered for when the intermediate Relay UE assigns the local ID of the Remote UE. In terms of local ID assignment or QoS split, we may not be able to inherit the legacy Rel-18 U2U relay. |
| Sharp | Yes |  |
| Huawei, HiSilicon | Yes | Legacy U2U mechanisms can be reused. Bullet 1 and 2 seems to follow these principles |
| Apple | Yes |  |
| ZTE | See comments | For the second bullet, if an intermediate relay is in RRC CONNECTED, it is not clear if the intermediate relay needs to connect to the same gNB as the Last relay UE or can be connected to a gNB different from the Last relay UE. For the latter case, we wonder the intention/benefits of the scenario, i.e. the intermediate relay has a direct Uu connection but act as a multi-hop intermediate relay.In addition, we echo LG’s comments about the concerns on approach 2. |
| CATT | Yes |  |
| TCL | YES |  |
| Xiaomi | Yes |  |
| Kyocera | Yes | We share similar view as LG. |
| Spreadtrum | Yes |  |
| Ericsson | Yes | Compared to approach 1, approach 2 has bebefits1. less design complexity for RAN2
2. lower signaling overhead and lower latency for E2E Remote UE connection establishment

less restriction to the intermediate relay UE, which no need to belong to the same cell as last relay UE. |
| Lenovo | Yes | In approach#2, the relay UEs in RRC\_IDLE/RRC\_INACTIVE are not required to transit connected state. That means the intermediate relay will leave but gNB is not aware of it.  |
| Samsung | Yes with comments | Technically, the above approach 2 may be workable. However, we share the concern from LG. Moreover, we are wondering if there is security issue, i.e., how to ensure the packets to/from remote UE can be well protected when conveying via the relay UE (except last relay UE) in idle/inactive state.  |
| vivo | Yes |  |

Question 4: Do you agree that the above figure and steps can serve as the baseline connection establishment procedure of approach 2 that can serve as further discussion of pros/cons?

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| **Companies** | **Yes or No** | **Comments** |
| OPPO | Yes |  |
| LG | Yes |  |
| Sharp | Yes |  |
| Huawei, HiSilicon | Yes  |   |
| Apple | Yes with comment | As explained in the rapporteur, the transmission of SUI message(s) by the intermediate relay UE is optional in Approach 2, because those UEs are not required to enter RRC\_CONNECTED. Also, there is no need for each intermediate relay UE to trigger RRC messages for its own RRC connection setup. So, it would be better to highlight those differences in the signaling diagrams.  |
| CATT | Yes |  |
| TCL | Yes  |  |
| Xiaomi | Yes |  |
| Kyocera | Yes |  |
| Spreadtrum | Yes |  |
| Ericsson | Yes | Agree with Apple |
| Lenovo | Yes |  |
| Samsung  | Yes |  |
| vivo | Yes |  |

## 2.2 Assumptions on the Controlling cell/gNB

The controlling cell/gNB of the remote UE and associated relay UEs may depend on the RRC state of the remote UE and the coverage situation of the relay UE.

For a remote UE in RRC\_IDLE/RRC\_INACTIVE, the U2N remote UE acquires SIB of a cell that may eventually provide network connectivity. As with the single-hop case, it’s assumed this is the SIB read by Last Relay UE that would eventually be the cell controlling the U2N Remote UE.

Question 5: Do you agree (for both approach 1 and approach 2) that the U2N Remote UE in RRC\_IDLE/RRC\_INACTIVE gets its SI from the Last Relay UE?

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| **Companies** | **Yes or No** | **Comments** |
| OPPO | See comments | We agree that the U2N Remote UE should use the SI of the cell that the Last Relay camps, while it is a little confusing to say “gets its SI from the Last Relay UE” since it relates to SI forwarding mechanism. |
| LG | See comments | If the intermediate Relay UE is connected, the serving cell of the intermediate Relay UE is the same as the last Relay UE’s cell. We believe that the U2N Remote UE in RRC\_IDLE/INACTIVE can receive its SI from the directly connected intermediate Relay UE.  |
| Sharp | See comments | Same view with OPPO. If it means that Last Relay UE delivers SIB(s) to the remote UE, it implies supporting of multi-hop U2U relay. |
| Huawei, HiSilicon | Yes | Similar views as Oppo |
| Apple | Yes | As intermediate relay UE(s), with high probability, are OOC, then intermediate relay UE will not be able to get SI by itself. Remote UE, and those intermediate relay UE need to get SI from the last relay UE. Regarding OPPO’s comment, I assume Approach 1 intends to exclude L2 U2U relay mechamism is used for SI forwarding, then something equivalent to L3 U2U relay mechanism would be introduced for SI and Paging forwarding. One way or the other, some sort of U2U relay is inevitable, in regardless of whether Approach 1 or Approach 2 is chosen. |
| ZTE | See comments | Same view with OPPO, we think the U2N Remote UE should use the SIBs of the cell that the Last Relay camps. It is better to reword the sentence/Question5.In our view, R17 L2 U2N remote UE SI request/forwarding over PC5 hop can be reused for MH remote UE and each intermediate relay UE to get the SIBs over each PC5 hop, this is not some sort of U2U relay.  |
| CATT | Yes with comments | Similar view as OPPO. |
| TCL | Yes | Similar views as Oppo |
| Xiaomi | Comments | This is related to whether there is E2E connection between remote UE and intermediate relay UE. But we can confirm remote UE and last relay UE applies the same SI. |
| Kyocera | Yes | We share similar view as OPPO. |
| Spreadtrum | Yes | Same view as OPPO |
| Ericsson | Yes | Agree with Apple |
| Lenovo | See comments | We agree that the remote UE should use the system information same as the serving of last relay UE. If the first relay UE can get the system information, e.g first relay UE is connected or in-coverage, the first relay UE can monitor SI for the remote UE.  |
| Samsung | Comments | Precisely speaking, **the SI information obtained by the remote UE should be the same as the one obtained by the last rely UE**. Thus, the last relay UE should forward the SI information via the intermediate relay UEs. How to perform such forwarding may need further discussion.  |
| vivo | See comments | Generally speaking, the UEs should be able to directly obtain the SIB from its ‘parent’ node, which means that e.g. the U2N remote UE can acquire the SIB1 from First relay UE.However as there are multiple relay UEs on the path, it is possible that the relay UEs (first relay UE and intermediate relay UE) may acquire the SIBs either in the similar way as a legacy U2N Remote UE or acquire the requested SIBs in its Uu interface. Those details should be discussed further. |

In single-hop relaying, the U2N Relay is in coverage and connected via Uu. The remote UE is assumed to be out of coverage, and therefore, the control is assumed to come from the same cell as the cell to which the U2N Relay is connected. In approach 1, a relay UE (other than the Last Relay UE) acts as a remote UE. As a result, if a relay UE (other than the Last Relay UE) is out of coverage, its control should come from the same cell to which a parent relay UE is connected to. This is illustrated below and should also apply for approach 2.



Question 6: Do you agree (for both approach 1 and approach 2) that the control/configuration of an out of coverage relay UE connected to only one parent, when it is RRC\_CONNECTED and the U2N Remote UE is in RRC\_CONNECTED, comes from the same cell controlling/configuring the remote UE and the Last Relay UE?

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| --- | --- | --- |
| **Companies** | **Yes or No** | **Comments** |
| OPPO | Yes |  |
| LG | Yes |  |
| Sharp | Yes |  |
| Huawei, HiSilicon | Yes for approach 1 | For approach 1, each UE connects to the same cell of its parent relay UE, thus all the UEs are in the same cell.For approach 2, if we follow the legacy U2U relay mechanism, all the U2U relay UEs, namely the intermediate relay UEs and the first relay UE can be in a different cell compared to the last relay UE and the remote UE. |
| Apple | Yes for Approach 1. FFS for Approach 2 | For approach 2, an OOC intermediate relay UE is not required to enter RRC\_CONNECTED, so we are not sure under what circumstances that this relay UE is in RRC\_CONNECTED. 1. If relay UE is connected via the next-hop relay UE (for its own traffic), then we agree it would under NW control of the last relay UE’s cell. But if the relay UE does not have its own traffic, then we are not sure why this relay UE wants to be connected to gNB via a relay UE in Approach 2.
2. If Relay UE is connected to its serving cell directly, but the serving cell does not support relay operation, then it will still act as OOC UE and use pre-configuration, which is not under dedicated NW control.
3. Also, for IDLE/INACTIVE relay UE, the intermediate relay UE may camp on a cell, but acting as an intermediate relay for a remote UE because the remote UE is not allowed to access the cell the relay UE is camped on.

So, we need some further discussion on Approach 2.  |
| ZTE | Yes |  |
| CATT | Yes |  |
| TCL | Yes  |  |
| Xiaomi | Yes for approach 1 |  |
| Kyocera | Yes |  |
| Spreadtrum | Yes |  |
| Ericsson | Yes for approach 1 | Intermediate relay UE in approach 1 will obtain the control information from the same cell configuring the remote UE and the last relay UE. However, in approach 2, the intermediate relay UE can get control information from a different cell than the cell configuring the remote UE and the last relay UE. |
| Lenovo | Yes for approach#1 | If the relay UE is idle/inactive and in-coverage, the relay UE could be served by a cell which is different from the serving cell of last relay UE. Once the relay UE is expected to connected state due to remote UE, the relay UE can access the network via the last relay UE. |
| Samsung | Yes for approach 1 | The question assumes that both relay UE(s) and remote UE are in the RRC connected state, which is only applicable for the approach 1.  |
| vivo | Yes for approach 1 | We understand for approach 2 the case is more complicated because the OOC intermediate relay UE may not need to be seen by network and may just use pre-configuration. We need further discussions about that. |

In the previous case, a relay UE (other than the Last Relay UE) could potentially be RRC connected to a different cell. This would be the case, for example, if the relay UE is in coverage, or if it has two PC5 links with two different parent relays (connected to two different cells). In this case, it could obtain its relaying configuration from a cell which is different than the cell from which the remote UE is obtaining its end-to-end configuration. This is shown in the figure below. The same situation would arise for a relay UE connected to two different parent relays, and also applies to both approach 1 and approach 2.



Question 7: Should we support the case (for both approach 1 and approach 2) the relay UE (other than the last relay UE) is RRC connected to (and obtains its configuration from) a different cell than the remote UE and parent relay UE for that remote UE?

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| **Companies** | **Yes or No** | **Comments** |
| OPPO | No | Firstly, this is out of R19 multi-hop U2N relay scope since for the relay UE it has two legs towards different NWs (i.e., multipath topology).And we are wondering what the use case of this scenario is, i.e., a relay UE has direct connection to the network (can support single hop U2N Relay) but chose to act a multi-hop U2N intermediate relay. |
| LG | No | In this case, the intermediate Relay UE has two paths. One is a direct path and the other is an indirect path. It looks out of the scope in Rel-19. |
| Sharp | No | In this case, the Intermediate Relay UE should act as a Last Relay UE. If the Intermediate Relay UE is configured with multi-path, PCell should be on a direct path. And the PCell should be indicated as a serving cell in RRC container within a discovery message. Therefore, there is no use case of this scenario. |
| Huawei, HiSilicon | No | In approach1, a UE always connects to one parent relay UE. To limit the scope and keep the mult hop relay mechanism simpler, we should not support multi-path relay in multi-hop relay scenario in R19. Otherwise it will be very complicated. For approach 2, the situation is different, since in current U2U relay mechanism, the U2U relay UE can be in a different cell with each remote UE. |
| Apple | No for approach 1,FFS for approach 2 | For approach 1, the relay UE has to use the same NW control as its parent relay UE.But for approach 2, even in RRC\_CONNECTED, the relay UE can still acting as OOC mode and use pre-configuration, as I explained in Q6. |
| ZTE | No | Agree with above comments that the relay UE has direct path and indirect path towards different gNBs is not in the scope of Rel-19. It is not clear how to coordinate the multi-hop related configuration from the two different gNBs.Not understand why “and parent relay UE for that remote UE” is included in the Q7. The parent relay of the remote UE is the first intermediate relay. We think the intention is to discuss whether the relay UE could connect to a different cell than the Last relay UE/remote UE (In Q5 the intention is to discuss that the remote UE is controlled by the same cell as the Last relay.).  |
| CATT | No |  |
| TCL | No  |  |
| Xiaomi | No for approach 1FFS for approach 2 | In approach 2, intermediate relay UE acts similar as U2U relay. In U2U, relay UE and remote UE can be in different cells. |
| Kyocera | No | We agree with LG that this is essentially a multipath configuration which isn’t in the Rel-19 scope. We also agree with OPPO and Sharp that such an Intermediate Relay UE should just serve as a Last Relay UE, similar to the Rel-17 U2N Relay UE. |
| Spreadtrum | No |  |
| Ericsson | Yes | We think this would be good to provide flexibility for intermediate relay UEs. It is too restrict if intermediate relay UEs need to be served in the same cell as the cell configuring remote UE and the last relay UE  |
| Lenovo | No | If the relay UE is located in other cell different from last relay UE, the relay UE should access the serving cell via the last relay UE and detach its direct path. This case may occur when the relay UE is located at the cell edge which can not meet the condition of being a ‘last relay UE’. |
| Samsung | No  | This results in multi-path, which is out of WID scope.  |
| vivo | No | We think this case should not be supported, similar reason as other companies mentioned that this is out of R19 WID scope.We also shared the view with OPPO that the scenario itself is quite confusing when a Relay UE would act as an intermediate relay UE while connecting to NW directly. |

One remaining case for an RRC\_CONNECTED remote UE that is specific to approach 2 is when one or more of the relay UE’s are in RRC\_IDLE/RRC\_INACTIVE/OOC during active relaying for the U2N Remote UE. If we use rules which are consistent with previous releases of SL and relays, the relay UE may obtain its configuration from SIB/preconfiguration. The remaining question would then be to determine which SIB to use in the case where there are multiple cells involved. Alternatively (and deviating from previous release assumptions), it could obtain its configuration from a parent relay UE (e.g., the Last Relay UE) that obtains its configuration via dedicated RRC signaling.

Question 8: In approach 2, when the remote UE is RRC\_CONNECTED and the relay UE (other than the Last Relay UE) is in RRC\_IDLE/RRC\_INACTIVE/OOC, where does this relay UE get its configuration?

1. From its camping cell, when IDLE/INACTIVE, or from preconfiguration, when OOC.
2. From SIB of the cell of a parent relay UE that receives it on Uu
3. From a parent relay UE (e.g., the Last Relay UE) that obtains it via dedicated signaling.

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| **Companies** | **Response** | **Comments** |
| OPPO | Do not see the need to support approach-2 | We understand each option has some further issues to resolve:* How to configure UE ID to avoid collision in the multi-hop link.
* For Option A and Option B, how for the relay UE to derive the bearer configuration from SIB/Pre-configuration based on per-QoS flow or per-bearer Uu QoS information.
* For Option C, how for the Last Relay UE to report sidelink UE information for the whole link

Therefore, the complexity by supporting this approach is not justified by the gain if any. |
| LG | See the comments | It can be different depending on the topology scenario. If the intermediate Relay UE is allowed to have two different parent Relay UEs, the way in which the intermediate Relay UE receives its configuration will be different depending on whether the parent Relay UE belongs to the same cell or not. So, we think it is better to discuss this issue after deciding on the topology scenario.  |
| Sharp | See comments | Similar view with OPPO. If some relay UEs are in RRC\_CONNECTED and other relay UEs are not in RRC\_CONNECTED, since some of them obtain configuration itself from SIB/pre-configuration and some of them obtain configuration by dedicated RRC signaling, the signaling order for each relay UE’s configuration and the information to be informed to the gNB should be complex. Therefore, it is difficult to determine QoS related configuration (e.g. bearer configuration) from UE/gNB perspective. |
| Huawei, HiSilicon | See comment  | A is the legacy mechanism in U2U relay. However, as Oppo mentioned, we also do not see a need to support approach 2 due to the complexity it brings with probably no gains. |
| Apple | Option A  | I think Option A is the most-straight forward choice for Approach 2 |
| ZTE | See comments | It is not clear how to allocate Local ID in approach 2, and how intermediate relay UE identify different remote UEs and how to perform the right bearer mapping/routing.Not sure what’s the difference for Option B and Option C. If the parent relay is in RRC connected, this question may have relation to Question 7. If the case in Q7 is not supported, i.e. the parent relay can only connect to the same gNB as the Last relay, then it means all intermediate relays use the SIBs of the cell of the Last relay. Only if the case in Q7 is supported, we then discuss whether the SIBs of the cell of direct path is used or the SIBs of the cell of the indirect path is used. As commented in Q7, we do not see the benefits to support the case.  |
| CATT | See comments | For approach2, Option A is the basic solution as in U2U relay. But we only support approach 1. |
| TCL | Option A | Option A is the only feasible solution.  |
| Xiaomi | A or B |  |
| Kyocera | Option A | Even with Option A, some coordination may still be needed between the cells, including the resources to be used for its transmission. |
| Spreadtrum | Option A |  |
| Ericsson | A | We think A is most preferred, which gives the best flexibility |
| Lenovo | Option A | But don’t see the need to support approach#2. |
| Samsung  | See comments | Share the view of OPPO and Huawei |
| vivo | Option A | If we are going to support approach 2 then we think option-A should be adopted with least complexity. However we kind of echo some companies’ view that we should further discuss whether to support approach 2 considering the complexity it brings.  |

## 2.3 E2E QoS

End-to-end QoS is guaranteed in relaying by splitting the QoS requirements (i.e., latency) between the different hops. In approach 1, each relay UE is in RRC\_CONNECTED when the U2N Remote UE is RRC\_CONNECTED. It is therefore natural that the gNB performs the QoS splitting for each hop, considering this was done for single hop U2N relays where the L2 U2N relay also needed to be RRC\_CONNECTED.

Question 9: Do you agree that for approach 1, the QoS split is performed by the network?

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| --- | --- | --- |
| **Companies** | **Yes or no** | **Comments** |
| OPPO | Yes |  |
| LG | Yes |  |
| Sharp | Yes |  |
| Huawei, HiSilicon | Yes | The network can guarantee the QoS during multi hop operation |
| Apple | Yes |  |
| ZTE | Yes |  |
| CATT | Yes |  |
| TCL | Yes  |  |
| Xiaomi | Yes |  |
| Kyocera | Yes |  |
| Spreadtrum | Yes |  |
| Ericsson | Yes |  |
| Lenovo | Yes |  |
| Samsung | Yes |  |
| vivo | Yes |  |

In approach 2, only the Last Relay UE needs to be in RRC\_CONNECTED. Since the Uu hop is managed by the network, it should be the network to determine the QoS split (i.e., the portion of the latency) associated with the Uu hop.

Question 10: Do you agree that for approach 2, the QoS split on the Uu hop is determined by the network?

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| **Companies** | **Yes or no** | **Comments** |
| OPPO | Yes |  |
| LG | Yes |  |
| Sharp | Yes |  |
| Huawei, HiSilicon | Yes |  |
| Apple | Yes |  |
| CATT | Yes |  |
| TC; | Yes  |  |
| Xiaomi | Yes |  |
| Kyocera | Yes |  |
| Spreadtrum | Yes |  |
| Ericsson | Yes |  |
| Lenovo | Yes |  |
| Samsung  | Yes with comments | There is no QoS split over Uu hop since Uu hop is a single hop. Precisely speaking, it may be “**the network determines the QoS on the Uu hop for multi-hop sidelink relay**.”  |
| vivo | Yes |  |

The remaining question is how to perform the splitting over the path between the Last Relay UE and the U2N Remote UE. If the relays are all in RRC\_CONNECTED, the situation is the same as the assumption for approach 1, and the network can perform the splitting. On the other hand, if the relays are in RRC\_IDLE/RRC\_INACTIVE/OOC, it would be possible to use the U2U mechanism in Rel18 and leave the splitting to the relay UE implementation.

Question 11: For approach 2, which entity should perform the QoS split of each link of the path between the Last Relay UE and the U2N Remote UE?

1. Network.
2. Relay UE serving that link

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| **Companies** | **Response** | **Comments** |
| OPPO | See comments | We understand for Option-B, the further clarification is needed on which relay UE to do the splitting when there are 2 relays serving the same link (i.e., the link between 2 relays). |
| LG | See comment | We need to discuss this issue further. In the case of Rel-18 U2U, it was easy for the relay UE to split the QoS, because there were only two links on both sides of the relay UE. However, as the multi-hop count increases, a single relay UE cannot know the quality of the entire link between hops. Before determining how the intermediate Relay UE knows the overall link quality, we cannot make any decisions. For Approach 2, both option A and option B have the same problem. That is, how the network or Relay UE serving that link can know the overall hop link quality. |
| Sharp | See comments | Same view with OPPO. Option B may not align with the previous agreement “RAN2 intend to minimize the impact of hop count on the multi-hop relay mechanisms.” To achieve this, all relay UEs must always know the remaining number of hops and the remaining QoS. |
| Huawei, HiSilicon | See comments | Following the Rel-18 mechanism Option B seems to be the way to do it but it will be complex for the Relay to perform the split with muti hops |
| Apple | Option B | We do not see much complexity to let relay UE to split QoS as the mechanism in L2 U2U relay design can be reused. On the contrary, we think Approach 1 has its own complexity issue in regards of signalling overhead, delay and scalability concerns, |
| ZTE | See comments | It is better to clarify how the NW or relay UE to perform the QoS split (considering at least two intermediate relays are supported) and the potential spec impacts, so to evaluate the complexity of different solutions for approach 2. |
| CATT | See comments | Agree with OPPO, option B needs to be clarified if selected. |
| TCL | Option A |  |
| Xiaomi | B | Since intermediate relay UE may be in RRC\_IDLE/INACTIVE, NW may not be aware of the intermediate relay UE’s PC5 channel condition and is not able to split the QoS. Relay UE is the only option. |
| Kyocera | Option B | Details on which relay to perform the QoS split can be further discussed, if approach 2 is adopted. |
| Spreadtrum | Option B |  |
| Ericsson | B |  |
| Lenovo | Option B |  |
| Samsung  | Need clarification for both options | Option A: since the intermediate relay UE are not in RRC connected state, the NW control becomes meaningless. Specifically, the NW cannot derive any information on the PC5 link between two relay UEs. Option B: the E2E QoS needs to be satisfied along the whole path. A relay UE cannot determine the QoS split among other links since it cannot know the PC5 link quality of other links.  |
| vivo | Option A with comments | We slightly prefer to make gNB generally responsible for performing QoS split even for approach 2, especially consider that there may be more than one relay UE and the Rel-18 U2U mechanism cannot be inherited directly. However, it may not be possible that every hop can be known well by the gNB in approach 2 especially the intermediate relay UE may not be controlled/seen by network, so e.g. the network may only be able to assign a QoS between U2N remote UE and last relay (including more than one hop).This may also be discussed in SA2 in 23.700 where they mentioned:*End-to-end QoS management for multi-hop U2N Relays is done similarly to the end-to-end QoS management for single hop L3 U2N Relay as defined in TS 23.304 [4], with enhancement to handle QoS split over multiple legs of the PC5 interface.*Anyway, we think further discussion is needed for approach 2 and we can further conclude on that. |

3 Phase 2 Discussion

Following discussion in Phase 1 to agree on the high level details of the different solutions, Phase 2 will discuss feasibility and pros/cons of the different solutions.

TBD

4 Conclusion

This contribution makes the following proposals:

TBD

# 5 References

1. R2-2406366 Control plane procedures of multi-hop U2N relay OPPO
2. R2-2406494 Discussion on control plane procedures for multi-hop relays MediaTek Inc.
3. R2-2406506 Considerations on Control Plane of Multi-hop Relay NEC discussion
4. R2-2406529 Discussions on the L2 Intermediate U2N Relay in multi-hop L2 U2N Relay ASUSTeK
5. R2-2406563 E2E Connection Setup and QoS Split for Multi-hop Relay CATT
6. R2-2406612 Initial considerations on CP and UP aspects for R19 multi-hop relay Samsung
7. R2-2406633 Control plane procedure for multi-hop U2N relay Sony
8. R2-2406684 Control Plane Design for Multi-hop UE-to-NW Relay Apple
9. R2-2406696 Discussion on architecture and control plane procedures for support of multi-hop SL relay ZTE Corporation, Sanechips
10. R2-2406713 Scenarios, QoS Handling, and Control Plane Procedures for Multi-hop InterDigital France R&D, SAS
11. R2-2406755 Discussion on QoS handling for NR sidelink multi-hop relay Spreadtrum Communications
12. R2-2406888 Control plane in Multi-hop relay Lenovo
13. R2-2407008 Discussion on multi-hop U2N Relay Control Plane Procedures vivo
14. R2-2407034 discussion on control plane procedure Ericsson, FirstNet, AT&T
15. R2-2407058 Discussion on Control Plane Procedure LG Electronics France
16. R2-2407102 Control procedure for multi-hop L2 based U2N relay Qualcomm Incorporated
17. R2-2407206 Control Plane under multihop L2 U2N relaying Kyocera
18. R2-2407295 Control plane procedures for multi-hop relay Huawei, HiSilicon
19. R2-2407318 Control plane procedure for multi-hop relay Nokia
20. R2-2407403 discussion on C-plane procedure for multi-hop relay Sharp