**3GPP TSG-RAN WG2 Meeting #121bis electronic *R2-230wxyz***

**Online, April 17-26, 2023**

Agenda Item: 7.9.3

Source: NEC (Email Discussion Rapporteur)

Title: Summary of [AT121bis-e][432]Candidate solutions for lossless delivery

Document for: Discussion, Decision

# Introduction

This document is to provide a summary of the email discussion [AT121bis-e][432]Candidate solutions for lossless delivery:

* [AT121bis-e][432][Relay] Candidate solutions for lossless delivery (NEC)

 Scope: Evaluate candidate solutions for lossless delivery (DL/UL) in U2N service continuity. Intention is to capture solutions for down-selection next meeting.

 Intended outcome: Report to CB session

 Deadline: Monday 2023-04-24 2359 UTC

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# Uplink lossless data delivery for path switch

## Background

In case of indirect-to-direct or indirect-to-indirect inter-gNB path switch for UE-to-Network relay, it is assumed that the gNB holding the PDCP entity for the radio bearers of the Remote UE changes after path switch. Then this scenario is like the inter-gNB handover for normal UEs as in legacy handover procedure, where PDCP is re-established.

In legacy handover, for RLC AM based radio bearer, if the target gNB receives the receiving status of UL PDCP in SN Status Transfer, the target gNB may use it in a PDCP Status Report sent to the UE. This will help the UE to determine if a PDCP packets should be retransmitted to the target gNB after handover.

As specified by PDCP specification (i.e.,TS38.323), the current UL PDCP retransmission determines the boundary with reference to *the first PDCP SDU for which the successful delivery of the corresponding PDCP Data PDU has not been confirmed by lower layers.*

During direct-to-indirect or indirect-to-indirect inter-gNB path switch, from Remote UE point of view, at PDCP layer, it may skip the packet that has already been successfully transmitted (i.e. acknowledged at PC5 RLC by Relay UE at the first hop) during its decision on the packet boundary for retransmission. In addition, the PDCP entity of Remote UE may discard the packet that has already been successfully transmitted (i.e. acknowledged at PC5 RLC by Relay UE at the first hop) when the discard timer expires. This means that during this type of path switch, even though the target gNB receives the receiving status of UL PDCP in SN Status Transfer message and use it to send the accurate PDCP status report to the Remote UE, the Remote UE may not be able to do retransmission for the missing UL packets (i.e. acknowledged at PC5 RLC by Relay UE at the first hop, but did not reach the gNB at the second hop).

## Candidate solutions description for UL

### Solution- U1: Relay UE delays its RLC feedback to Remote UE

Relay UE can maintain the transmission status between the received PC5 RLC packets and the outgoing Uu RLC packets. When providing RLC status report to Remote UE, the Relay UE only provides the positive feedback to Remote UE on the PC5 RLC packets, of which the corresponding Uu RLC packets have been successfully transmitted to source gNB via Uu RLC (which means acknowledgements have been received for these packets over Uu from source gNB).



*Figure 1: Relay UE delays its ACK to Remote UE*

As in legacy handling, the Remote UE will not indicate its successful transmission of such packets (ACKed at PC5 RLC, not ACKed at Uu RLC) to PDCP layer, since the positive acknowledgement for these packets is postponed by Relay UE.

As shown in Figure 1, the RLC packet K+3 and K+4 will not be acknowledged by Relay UE to Remote UE since they are not acknowledged by source gNB to the Relay UE.

**Evaluation**

This solution is transparent to the Remote UE and the gNB but will require changes at the Relay UE. However, the Remote UE may retransmit the unacknowledged packets, which were actually received by Relay UE.

### Solution- U2: Remote UE’s PDCP retransmission based on remaining packets in the buffer

Upon PDCP re-establishment during inter-gNB path switch, the Remote UE transmits/retransmits all PDUs that are in the transmit buffer, even though some packets have already been ACKed by lower layers.

**Evaluation**

Since the Remote UE can retransmit all of the remaining packets within its buffer, it may result in some redundant retransmissions (as the PDCP packets may have already been received at the target gNB.

### Solution- U3: Remote UE’s PDCP retransmission based on DL PDCP Status Report from target gNB

Alternatively, the Remote UE can determine the PDCP SDUs for retransmission to the target gNB following the PDCP Status Report sent from target gNB to the Remote UE after path switch. Remote UE can use this PDCP Status Report to determine the boundary for PDCP SDU retransmission.



*Figure 2: Enhancing Remote UE’s PDCP retransmission*

For example, as shown in Figure-2, if we apply the legacy PDCP retransmission handling (i.e., based on the lower layer confirmation) during PDCP re-establishment for inter-gNB path switch, at Remote UE, the first non-confirmed PDCP SDU is N+6, which means N, N+1, N+2, N+3, N+4 and N+5 were confirmed by lower layer due to its successful transmission at PC5 (i.e., at the first hop). And then legacy handling will retransmit packet N+6 and the packets that follow it. However, in this solution, assuming that target gNB sends a PDCP SR to Remote UE indicating that N+1, N+3, N+4 and N+6 are missing, this solution will allow the Remote UE to retransmit N+1, N+3, N+4, N+6 and the packets that follow N+6.

This option can reduce the data loss during path switch since more PDCP SDUs can be retransmitted from Remote UE to the target gNB at PDCP layer. This will ensure that there will be no UL packet loss upon path switch from indirect to indirect/direct, as long as the packet has not been discarded already due to the expiry of the discard timer.

**Evaluation**

This solution can prevent unnecessary retransmission and present minimum specification change.

### Solution-U4: Enhancing RLC status report to Remote UE

As a option, additional indication can be added by Relay UE within the RLC status report when providing that report to Remote UE for the RLC packets. The additional information can be the status of the acknowledgement at the second hop (i.e., Uu). When receiving the RLC status report including this additional information, Remote UE’s RLC entity calculates the corresponding PDCP SDU packet based on the RLC status report and feedback to PDCP entity to indicate the transmission status of the PDCP packets.

In this case, PDCP entity is fully aware of the transmission status of the PDCP SDUs at both first hop and second hop. Remote UE can decide the retransmission boundary for the PDCP SDUs based on both transmission status as received from its RLC layer and the PDCP Status Report he may receive from the target gNB. With this option, Remote UE’s PDCP entity will potentially retransmit missing PDCP packets at the second hop, if the PDCP packet was not discarded due to expiration of PDCP discard timer.

**Evaluation**

This solution requires the RLC specification change to enhance the RLC status report.

### Solution-U5: Source Relay UE continues to transmit UL data to source gNB and gNB forwards to the target gNB

The data loss could happen in the case that the Remote UE’s Uu configuration is released before the UL data are totally transmitted from the Relay UE to the source gNB. One possible way to address this issue is to keep source Relay UE’s Uu configuration for the Remote UE and allow the source Relay UE to continue to transmit the Remote UE’s UL packets. And the source gNB should forward received UL packets to the target gNB. It can leave source gNB implementation (e.g. setting a longer release timer or does not release Remote UE Uu context in the Relay UE, etc) or target gNB implementation (the target gNB will know the UL packets are totally received and request to release the Remote UE context on source part and UL forwarding tunnel.

**Evaluation**

This solution attempts to reuse the existing Uu procedure but requires that the source gNB still keeps the Remote UE/Relay UE context even after the Remote UE’s handover. Meanwhile, it is unclear how long the target gNB should wait for such data forwarding.

## Dicussion

### **Question 1: Do companies agree that the decription and evaluation of solution-U1 is accurate for Uplink lossless data delivery for path switch?**

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| **Company** | **Answer (Yes/No)** | **Comments** |
| OPPO | No | There is a missing point in the evaluation: We think the relay-based enhancement (solution-U1/U4) for this lossless data forwarding is not feasible since there is a backwards compatable issue:* Relay UE is transparent of whether the HO is intra/inter-case;
* R17 relay doesn’t support the enhanced data forwarding.

So if the remote UE is out of coverage, i.e., direct link is unavailable, and if the relay is R17, Solution-U1 is not funcationaly feasible even if the remote UE is R18. |
| Apple | See comment | 1. We think relay-based solution can be considered as we do not think the R18 work shall be utterly constrained by legacy R17 relay UE behavior.
2. But we think U1 is not a solution based on “PDCP status report” as agreed as baseline in the last meeting. So, we think to be fair, this needs to be mentioned in the evaluation.
 |
| InterDigital | Yes | We agree with Apple that backward compatibility should not be a constraint for the solution. In the rare case of R18 remote UE and R17 relay (which we have not agreed whether will be supported in the first case) we can assume a full solution is not needed. |
| CATT | Yes, and | If the Relay UE’s RLC feedback to Remote UE is extended by waiting the Uu feedback, the whole HO delay will be extended. |
| Xiaomi | comments | This solution would result in remote UE always buffer more data than legacy, since HO can occur at any time. |
| CMCC | Yes | We agree Apple’s comments. |
| LG | No | Basically, we agree with Apple and OPPO.Also, if 1:N bearer mapping is configured, i.e., multiple remote UE PC5 RLC channel is multiplexed to one Uu RLC channel, the solution U-1 may not good. In the case that relay UE didn’t get ACK from one Uu RLC channel, multiple remote UEs have to be buffering its PDCP data. We think it’s not fair. |
| ZTE | comments | If relay delays the PC5 RLC feedback to remote UE, it makes the Tx window of remote UE sliding slowly, which may lead to data congestion on the remote UE.In addition, PC5 RLC SN and Uu RLC SN are maintained separately, relay UE needs to identify and keep the mapping between them. |
| Samsung | See comment | Same view as Apple on that this solution is not based on PDCP status report as agreed as a baseline for service continuity solution. |
| Qualcomm | No | Agree with OPPO and ZTE comments. Rel-17 relay UE can not work in this solution, and Relay UE has to maintain the mapping of the two SNs on both hops. Remote UE transmitting window size will be impacted due to the delayed ACK/NACK. From performance perspective, the additional tansmission latency will be introduced due to the delayed ACK/NACK from the Relay UE. |
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### **Question 2: Do companies agree that solution-U1 is a valid solution for Uplink lossless data delivery for path switch?**

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| **Company** | **Answer (Yes/No)** | **Comments** |
| OPPO | No  | Please see the reply for Q1 |
| Apple | See comment | The solution is feasible but we prefer stick to PDCP status report based solution as baseline. This can be considered unless PDCP status report based solution(s) are all deemed infeasible by RAN2 and RAN3 |
| InterDigital | Yes, but | This solution solves the data loss problem. However, it does not follow RAN2 agreement to use PDCP status report as a baseline. |
| CATT | See comment | It is a valid solution, but it is based on enhancement in the source node. Since the souce is two hops, we consider any enhancements in source will introduce time delay for the whole HO. And since RAN2 has already agreed to use PDCP status report as a baseline, it is not a recommend solution by us. |
| Xiaomi | Yes |  |
| CMCC | Yes  | It solves the UL data loss problem.  |
| LG | No | Please see the reply for Q1 |
| ZTE | comments | If relay delays the PC5 RLC feedback to remote UE, it makes the Tx window of remote UE sliding slowly, which may lead to data congestion on the remote UE. |
| Samsung | No | We prefer PDCP status report based solution. |
| Qualcomm | No | Large impact on Relay UE, and impact on transmission latency performance. |
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### **Question 3: Do companies agree that the decription and evaluation of solution-U2 is accurate for Uplink lossless data delivery for path switch?**

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| **Company** | **Answer (Yes/No)** | **Comments** |
| OPPO | See comments | There is a missing point in the evaluation: For the evalution part, whether lossless can be achieved depends on whether the data has been discard by remote UE or not, but it is questionable to us how for remote UE to ensure the concerned data would not be discarded in all cases.  |
| Apple | See comment | To be fair, this solution does add some redundancy as remote UE has no idea which PDCP PDUs have already reached NW side successfuly and which are not. |
| InterDigital | Yes | We do not see an issue based on the comments from OPPO. The assumption with the solution is that the discard timer is configured long enough that it can handle the latency associated with a path switch. |
| CATT | Yes |  |
| Xiaomi | comment | Remote UE may have discard the data confirmed by relay UE reception. Such data is still buffered at relay UE at HO. Remote UE still can’t retransmit such data to target cell. Lossless can’t be ensured. |
| CMCC | Yes  | We share same view as interDigital. |
| LG | Yes | This solution has redundancy because the remote UE doesn’t know which PCDP PDU is successfully transmitted to the gNB or not. |
| ZTE | Yes | The discard timer is common for all the evaluated solutions. If an unacked packet is no longer in the PDCP buffer, it will be lost in any cases. The only way is to configure long discard timer.  |
| Samsung | Yes |  |
| Qualcomm | comments | This solution is not implementable solution since it requires the Remote UE buffering all the PDCP packets forever or for a very long time because Remote UE does not know which packets are received successfully by gNB and when path switch will happen. Due to too many already transmitted packets bufferd, there will be less new packets to be buffered, and then the new packets may not be transmitted or will be delayed. This will largely impact QoS requirements, and will definitely happen for all AM bearers |
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### **Question 4: Do companies agree that solution-U2 is a valid solution for Uplink lossless data delivery for path switch?**

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| **Company** | **Answer (Yes/No)** | **Comments** |
| OPPO | No | See the reply in Q3. |
| Apple | See comment | The solution is feasible but we prefer stick to PDCP status report based solution as baseline. This can be considered unless PDCP status report based solution(s) are all deemed infeasible by RAN2 and RAN3 |
| InterDigital | Yes | Strictly speaking, the solution solves the issues, and can be considered a PDCP-based solution since it only touches the PDCP layer. In addition, it is possibly the solution with the minimum specification impact, although there is some overhead of potentially unnecessary retransmissions. |
| CATT | No | The solution is valid, but it introduce much redundant retransmission in target PC5/Uu which can not be accepted by us. |
| Xiaomi | No | As commented in Q3, this solution may not resolve the issue alone. |
| CMCC | Yes  | We have some concern about whether Solution-U2 is a PDCP status report based solution, strictly. Moreover, it may bring some unnecessary retransmission. Some impacts on XnAP also should be considered. |
| LG | No | The solution is valid, but too much redundant data transmission could happened. |
| ZTE | Yes | In both U2 and U3, the PDCP retransmission should be enhanced. However, U2 cause more redundant re-transmissions.  |
| Samsung | No | We prefer PDCP status report based solution.  |
| Qualcomm | No | The solution is not implementable from UE side and have system level performance impact. The already transmitted PDCP packets will occupy the buffer space, less new incoming data will be buffered, then new data may be lost or the transmission will be delayed. QoS requirement will not be satisfied. |
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### **Question 5: Do companies agree that the decription and evaluation of solution-U3 is accurate for Uplink lossless data delivery for path switch?**

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| **Company** | **Answer (Yes/No)** | **Comments** |
| OPPO | See comments | There is a missing point in the evaluation: Similar to U2, whether the data lossless can be achieved depends on whether the data has been discard or not, while here the assumption is remote UE would always maintain the data before a SR is received. But imagine a scenario where the UE is static, i.e., there is no HO, does it mean the remote UE has to maintain all data in its whole lifetime? It is obviously not feasible.. |
| Apple | Yes | For OPPO’s concern, the discard timer is configured by NW. We think for L2 relay case, the NW can configure a reasonably larger timer given that each UL PDCP PDU need cross two hops to reach the NW. |
| InterDigital | Yes | Similar comment to Apple and to our response in Q4. The network should be able to configure an appropriate discard time, as it does in legacy. |
| CATT | Yes | Agree with Apple that the discard timer is configured, and we do not think it has any difference from the legacy discard timer mechanism. |
| Xiaomi | No | Remote UE may have discard the data confirmed by relay UE reception. Such data is still buffered at relay UE at HO. Remote UE still can’t retransmit such data to target cell. Lossless can’t be ensured. |
| CMCC | Yes  |  |
| LG | Yes | We have a similar view as Apple. But, there could be some losses depending on the size of the remote UE’s buffer if the discard timer is too long as over the remote UE’s buffer size. |
| ZTE | Yes | For OPPO’s concern, the discard timer is common for all the evaluated solutions. If an unacked packet is no longer in the PDCP buffer, it will be lost in any cases. For the U2N relay case, network may configure a longer discard timer for the remote UE if lossless delivery need to be considered.  |
| Samsung | See comment | This solution may not guarantee in-order delivery since lower SN packet can be delivered later than higher SN packet based on the timing of PDCP SR. |
| Qualcomm | No | The Remote UE has to always buffer all the PDCP packets forever or for a very long time (longer discard timer) even though path switching will never happen. Due to too many already transmitted packets bufferd, there will be less new packets to be buffered, and then the new packets may not be transmitted or will be delayed. This will largely impact QoS requirements, and will definitely happen for all AM bearers |
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### **Question 6: Do companies agree that solution-U3 is a valid solution for Uplink lossless data delivery for path switch?**

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| **Company** | **Answer (Yes/No)** | **Comments** |
| OPPO | No | See the reply in Q5 |
| Apple | Yes |  |
| InterDigital | Yes |  |
| CATT | Yes |  |
| Xiaomi | No |  |
| CMCC | Yes | Proper discard timer at PDCP entity should be configured with network implementation.  |
| LG | Yes |  |
| ZTE | Yes |  |
| Samsung | Yes |  |
| Qualcomm | No | The solution is not implementable from UE side and have system level performance impact. The already transmitted PDCP packets will occupy the buffer space, new incoming packets may be lost or transmission will be delayed. QoS requirement will not be satisfied. |
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### **Question 7: Do companies agree that the decription and evaluation of solution-U4 is accurate for Uplink lossless data delivery for path switch?**

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| **Company** | **Answer (Yes/No)** | **Comments** |
| OPPO | No | There is a missing point in the evaluation: We think the relay-based enhancement (solution-U1/U4) for this lossless data forwarding is not feasible since there is a backwards compatable issue:* Relay UE is transparent of whether the HO is intra/inter-case;
* R17 relay doesn’t support the enhanced data forwarding.

So if the remote UE is out of coverage, i.e., direct link is unavailable, and if the relay is R17, Solution-U4 is not funcationaly feasible even if the remote UE is R18. |
| Apple | See comment | For fair evaluatin, we need to mention that this scheme may not be feasible if PC5 RLF occurred after HO or PC5 link quality deterioriates during the HO, remote UE will not be able to receive the most recent RLC status report from the relay UE |
| InterDigital | See comment | We have the same view as Apple. Furthermore, a likely reason for the path switch is the network realizing that the PC5-link may fail shortly. |
| CATT | See comment | Agree with Apple. |
| Xiaomi | Comments | This solution would result in remote UE always store additional data which is not transmitted on second hop. Additional impact to 331 is foreseen, due to the new capability. |
| CMCC | With comments | We agree the comments from Apple.  |
| LG | See comment | As we mentioned in question 1, In the case of 1:N bearer mapping, we think it can not be fair. Due to the RLC SN report on the Uu link, the other SL RLC data PDU multiplexed the same Uu link may have to be buffered. |
| ZTE | comments | Agree with Apple and InterDigital. In addition, the more spec impacts are expected for U4. |
| Samsung | See comment | Agree with Apple’s comment. |
| Qualcomm | Comments | Agree with Apple and Xiaomi. And this may require periodical status report transmission from Relay UE, which increase signalling overhead. |
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### **Question 8: Do companies agree that solution-U4 is a valid solution for Uplink lossless data delivery for path switch?**

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| **Company** | **Answer (Yes/No)** | **Comments** |
| OPPO | No | See the reply in Q7 |
| Apple | See comment | We think this is a complementary solution to U3. If using this solution alone w/o PDCP status report from target gNB (U3), the remote UE may still fail to retransmit UL traffic if the lastest RLC status report is not successfully delivered to remote UE.  |
| InterDigital | No | Similar to solution U1, we think it may be best to stick to previous agreement and at least leave the specification impact to the PDCP layer only. Also, this solution has some issues related to potential PC5 RLF at the HO. |
| CATT | No | Similar to solution U1, we think it is based on enhancement in the source node. Since the souce is two hops, we consider any enhancements in source will introduce time delay for the whole HO. And since RAN2 has already agreed to use PDCP status report as a baseline, it is not a recommend solution by us. |
| Xiaomi | No |  |
| CMCC | With comments | Same understanding as Apple. U4 is a solution that solve the lossless issue from remote UE side.  |
| LG | No |  |
| ZTE | No | Prefer to limit the spec impact to PDCP layer. |
| Samsung | No | We do not see a need of RLC enhancement. |
| Qualcomm | No | It is very possible the RLC status report will not be transmitted to the Remote UE. |
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### **Question 9: Do companies agree that the decription and evaluation of solution-U5 is accurate for Uplink lossless data delivery for path switch?**

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| **Company** | **Answer (Yes/No)** | **Comments** |
| OPPO | Yes |  |
| Apple | See comment | For this scheme to work, the Uu link between Relay UE and source gNB must be still in good quality. It will not be feasible if Uu RLF occurred after HO or Uu link quality deterioriates during the HO. In this case, the UL PDCP PDUs stuck in the relay UE will not be able to reach the source gNB |
| InterDigital | See comment | We have the same concern as Apple as a likely reason for the path switch in the first place would be deterioration of the Uu link. |
| CATT | Yes |  |
| Xiaomi | Yes | Regarding the concern from Apple and InterDigital We understand it’s corner case that relay UE suffer RLF during remote UE’s HO. |
| CMCC | With comments  | As mentioned by moderator, source gNB should keep the Remote UE/Relay UE context even after the Remote UE’s handover, which may bring some implementation complexity to network.  |
| LG | Yes |  |
| ZTE | comments | Share the same view with Apple and InterDigital. |
| Samsung | Yes  |  |
| Qualcomm | Yes with comments | For Apple comment, same view as Xiaomi that it should be corner case, and we even did not address this case for intra-gNB, so no need to consider it for inter-gNB.About the issue that “*it is unclear how long the target gNB should wait for such data forwarding*”, in case that the target gNB receives all missed packet from the source gNB or the Remote UE based on the PDCP SN number, the target gNB may request release, or target gNB or source gNB can release the old context based on a longer timer which is widely used in current HO or path switch procedure |
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### **Question 10: Do companies agree that solution-U5 is a valid solution for Uplink lossless data delivery for path switch?**

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| **Company** | **Answer (Yes/No)** | **Comments** |
| OPPO | Yes | U5 based on our understanding is the most feasible/easy solution since the **relay UE has all the required data, and this solution even doesn’t need spec effort**. |
| Apple | See comment | We think this is still a relay-based solution, which may not work with R17 relay. For R17 relay, once PC5-RRC is released by remote UE, the Relay will remove remote UE context and discard all SRAP PDUs not delvivered yet. So, this will also not backward-compatiable soluton as same as U1/U4.We think this is a complementary solution to U3. If using this solution alone w/o PDCP status report from target gNB (U3), the remote UE may still fail to retransmit some UL traffic stuck in the relay UE when relay UE unable to continue to deliver them to source gNB.  |
| InterDigital | No | We have similar concern as for solution U4. |
| CATT | No | For inter-gNB path switching, we do not think it is feasible, since for in-order delivery case, the source node may need to send the received packet to the target node. And if it is unclear how long the target gNB should wait for such data forwarding, or even the packets can not be received in the source Uu from the relay UE due to e.g. Uu RLF, the whole delivery of the packets from gNB will be largerly delayed. |
| Xiaomi | Yes |  |
| CMCC | No |  |
| LG | Yes | When source gNB configures HO to the remote UE, the source gNB can buffer the received data. How long the data is buffered in the source gNB is gNB implementation. We think gNB can handle its implementation. This method has the advantage of not changing the current spec and solving the lossless delivery. |
| ZTE | No | We could not assume Uu hop is always in good quality and the PC5 link is not released by remote UE until relay UE transmits all buffered remote UE’s packets to gNB.  |
| Samsung | Yes with comment | We think that this solution and PDCP status report can be used together. |
| Qualcomm | Yes | This is the easiest way to address UL lossless issue, has no much specification change, no data loss, and no system permence impact.For Apple comments, Remote UE context should be released by source gNB, and the same handling is assumed to be used for intra-gNB case; otherwise, lossless can not be ensured even for intra-gNB case. So there is no different Relay behaivor between intra-gNB and inter-gNB case, and Rel-17 Relay UE can work.For CATT’s comment, in case that the target gNB receives all missed packet from the source gNB or the Remote UE based on the PDCP SN number, the target gNB will request release, or target gNB or source gNB can release the old context based on a longer timer. All of these can be left to gNB implementation. |
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### **Question 11: Do companies see any additional solution(s) for Uplink lossless data delivery for path switch?**

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| **Company** | **Answer (Yes/No)** | **Comments** |
| OPPO | Yes | The added U5 by QC is feasible and should not be excuded before discussion. |
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### **Question 12: Do companies agree to take solution-U1/U2/U3/U4/U5 as the candidate solutions for Uplink lossless data delivery for path switch for downselection next meeting?**

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| --- | --- | --- |
| **Company** | **Answer (Yes/No)** | **Comments** |
| OPPO | See comments | As explained above, * U1/U4 are not feasible due to the BC issue;
* Whether U2/U3 works depends on whether the data at remote UE has been discard (for which we do not see they are feasible way-out).

And U5 based on our understanding is the most feasible/easy solution since **the relay UE has the required data, and this solution even doesn’t need spec effort.** |
| Apple | See comments | We think only U3 can be considered as baseline,<U3 +U4> or , <U3+U5> combination can be considered based on company contribution in the next meeting |
| InterDigital | See comments | We prefer to downselect between U2 and U3, or consider U3 as the baseline since U3 does not suffer from the inefficiencies mentioned about U2. |
| CATT | See comments | We think only U3 can be considered as baseline. |
| Xiaomi | Comment | U1 or U5 |
| CMCC | Comments  | We prefer to consider U3+U4 combination. |
| LG | Comment | U3 and U5 |
| ZTE | comments | We may take U3 as baseline. |
| Samsung | See comment | We think that U3, U5 with PDCP status report can be candidate solutions. |
| Qualcom | comments | U5, there is almostly no impact on current specification, and no impact on UE side.Other solutions has large impact on specification change, UE implementation and system performance. |
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TBD: Rapporteur summary:

**TBD: Proposal-X:**

# Downlink lossless data delivery for path switch

## Background

In legacy handover, for RLC AM based radio bearer, from source gNB perspective, the unacknowledged PDCP SDUs are forwarded to target gNB during handover. In addition, the PDCP Status Report (by UE report) helps target gNB to skip the PDCP SDUs that are received by the UE but source gNB has not received the acknowledgement from the UE.

If we assume the symmetric operation of PDCP entity be adopted by gNB in practical implementation, logically the similar issue, as discussed for UL data loss, should be applicable to DL also. The only thing different is that the sender of the data for retransmission is changed from source gNB to target gNB. In addition, target gNB determines the retransmission boundary for PDCP packets PDCP Status Report reported by the UE and the packets forwarded from source gNB.

For the packets that was acknowledged at Uu RLC by Relay UE at the first hop, but did not reach the Remote UE at the second hop (i.e. PC5), the source gNB may discard them when the discard timers expire, then source gNB has no chance to forward these packets to target gNB for retransmission, which will lead to data loss at downlink data transmission.

Following the legacy spec, for i2d/i2i case, the DL data has not been acknowledged by the Relay RLC may be forwarded, but the data acknowledged by Relay UE but lost in the source PC5 link will not be forwarded to the target gNB, therefore it cannot be re-transmitted from the target gNB to the UE, no matter the PDCP status report is configured to be sent by the UE or not.

In intra-gNB path switch (Rel-17 scenario), the network may be able to configure a long enough PDCP discard timer to hold the concerned PDCP packets, or use other private mechanism to keep the packets at the gNB. Then the gNB can perform DL packet retransmission when it is not acknowledged by PDCP status report from the UE later on.

For the inter-gNB scenario (Rel-18 scenario), following the same example as described above, it may require the target gNB to fetch the missing PDCP packets from source gNB based on the UE PDCP status report after path switch, which requires the source gNB to keep the PDCP packets after the completion of path switch. This is an unusual handling and may be extremely difficult within the multi-vendor deployment scenarios.

This is why network implementation (i.e., Rel-17 mechanism) cannot handle Rel-18 scenario.

##  Candidate solutions description for DL

### Solution-D1: Relay UE delays its RLC feedback to source gNB

Relay UE can maintain the transmission status between the received Uu RLC packets and the outgoing PC5 RLC packets. When providing RLC status report to source gNB, the Relay UE only provides the positive feedback to source gNB on the Uu RLC packets, of which the corresponding PC5 RLC packets have been successfully transmitted to Remote UE via PC5 RLC, which means acknowledgements have been received for these packets over PC5 from Remote UE. Base station’s PDCP/RLC entity operation is not specified by 3GPP, but we assume the symmetric operation of PDCP/RLC entity corresponding to UE side is adopted by Base Station. As in legacy symmetric RLC operation, the source gNB’ RLC does not indicate its successful transmission of such packets (ACKed at Uu RLC, not ACKed at PC5 RLC) to its PDCP layer, since the positive acknowledgement for these packets is postponed by Relay UE.

**Evaluation**

This solution is transparent to the Remote UE and the gNB but will require changes at the Relay UE. However, the source gNB may retransmit the unacknowledged packets, which were actually received by Relay UE.

### Solution-D2: Relay UE indicates the packet transmission status to source gNB

As described by R2-2302859, Relay UE indicates the packet transmission status to source gNB, in order for source gNB to better determine which packet(s) should be forwarded to the target gNB for retransmission during path switch.

There are following two options for such indication:

Option 1: a simple indication that there is received data in the Relay UE from the source gNB, but not yet delivered to the Remote UE successfully. Based on this indication, the source gNB can forward all the buffered PDCP PDUs (acknowledged or non-acknowledged from the lower layers) to the target gNB.

Option 2: the indication includes further information, e.g., the number of TBs that is received from the gNB, but not delivered to the Remote UE successfully yet, or the list of RLC SNs or the earliest RLC SN that the Relay UE received from the gNB, but not delivered to the Remote UE successfully yet. Based on the indication, the source gNB can identify which data has been acknowledged from the lower layers but still not delivered to the Remote UE successfully so that those data should be forwarded to the target gNB.

**Evaluation**

This solution requires changes on RLC or MAC specification.

### Solution-D3: A new PDCP status report sent from Remote UE to the source gNB

As described by R2-2302859, the source gNB triggers the Remote UE to send a PDCP status report to the source gNB before the source gNB performs SN status transfer to the target gNB. The source gNB can then forward the buffered data to the target gNB, and the target gNB can retransmit PDCP Data PDUs to the Remote UE as required.

The PDCP status report can be triggered by the source gNB at one of the following timelines:

* Upon receiving the path switch command
* An explicit trigger before path switching command
* Measurement reporting event triggers status report

This solution requires to specify a new trigger for PDCP status report before handover for PDCP specification (TS38.323).

**Evaluation**

This solution can only work if the source gNB can receive an accurate PDCP status report before the SN status transfer, and assumes the the source gNB can send the required data to the target gNB during path switch.

### Solution-D4: Enhanced Data forwarding from source gNB to target gNB per target gNB request (legacy PDCP status report based)

As proposed by some companies in the contributions, target gNB relies on the legacy PDCP status report sent from the Remote UE after path switch. The target gNB requests the source gNB to additionally forward the missing DL packets that were not forwarded earlier after receiving the PDCP status report.

The data forwarding mechanism should be enhanced for the inter-gNB path switch, to allow source gNB forward missing DL packets to the target gNB after it receives a request, and then, the target gNB re-transmits all the PDCP SDUs for which the successful delivery of the corresponding PDCP Data PDU has not been confirmed by PDCP status report in the target gNB after path switch.

**Evaluation**

This solution basically is an addon to the legacy solution (following the legacy handling for inter-gNB handover where the data is forwarded as usual during HO) with additional late/supplementary forwarding based on the target gNB request.

This solution will have Xn interface impact for supplementary forwarding but can ensure lossless DL data delivery as the target gNB can request any missing DL packets.

### Solution-D5: Proactive Data forwarding from source gNB to target gNB

Following the same principle of the solution-D4, this solution allow the source gNB to forward all the buffered data to the target gNB without receiving the request from target gNB, and is based on source gNB implementation to do so.

**Evaluation**

This solution is fully dependent on source gNB’s implementation.

The feasibility of this solution depends on if source gNB (PDCP sublayer) can buffer (i.e., will not discard) the DL data even though the delivery of the data may be acknowledged by its lower layer (i.e., RLC). In practice, this may require the source gNB to buffer a lot of data and lots of data needs to be forwarded to target gNB, which leads to unnecessary data forwarding, since this data forwarding is not based on the target gNB request.

## Discussion

### **Question 13: Do companies agree that the decription and evaluation of solution-D1 is accurate for DL lossless data delivery for path switch?**

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| --- | --- | --- |
| **Company** | **Answer (Yes/No)** | **Comments** |
| OPPO | No | There is a missing point in the evaluation: We think the relay-based enhancement (solution-D1D) for this lossless data forwarding is not feasible since there is a backwards compatable issue:* Relay UE is transparent of whether the HO is intra/inter-case;
* R17 relay doesn’t support the enhanced data forwarding.

So if the remote UE is out of coverage, i.e., direct link is unavailable, and if the relay is R17, Solution-D1 is not funcationaly feasible even if the remote UE is R18. |
| Apple | See comment | We think D1 is not a solution based on “PDCP status report” as agreed as baseline in the last meeting. So, we think to be fair, this needs to be mentioned in the evaluation. |
| InterDigital | Yes |  |
| CATT | Yes |  |
| Xiaomi | Yes |  |
| CMCC | Yes |  |
| LG | No | If 1:N bearer mapping is configured, i.e., multiple remote UE PC5 RLC channel is multiplexed to one Uu RLC channel, the solution D-1 may not good. In the case that relay UE didn’t get ACK from one SL RLC channel, the ACK from multiple remote UEs, which have to be delivered to the gNB, have to be waiting in relay UE. We think it’s not fair. |
| ZTE | comment | Same comments as Q1. For this solution, PC5 RLC SN and Uu RLC SN are maintained separately, relay UE needs to identify and keep the mapping between them. |
| Samsung | See comment | same comment as Q1 |
| Qualcomm | No | Similarly with UL, large impact on Relay RLC layer, and will introduce additionally latency due to the delayed ACK/NACK from the Relay UE. That means the normal system performance will be impact definitely due to one case which may not happen. |
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### **Question 14: Do companies agree that solution- D1 is a valid solution for DL lossless data delivery for path switch?**

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| **Company** | **Answer (Yes/No)** | **Comments** |
| OPPO | No | See our reply above. |
| Apple | See comment | We think this is a candidate but we would rather focus on PDCP-based solutons as agreed as baseline, before exploring RLC-based approaches. |
| InterDigital | No | Similar to the UL case |
| CATT | No | It is a valid solution, but it is based on enhancement in the source node. Since the souce is two hops, we consider any enhancements in source will introduce time delay for the whole HO. And since RAN2 has already agreed to use PDCP status report as a baseline, it is not a recommend solution by us. |
| Xiaomi | Yes |  |
| CMCC  | No |  |
| LG | No | Please, see the comment in Q1. |
| ZTE | See comment | See comments in Q13. |
| Samsung | No | We prefer PDCP status report based solution. |
| Qualcomm | No | See comments in Q13. |
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### **Question 15: Do companies agree that the decription and evaluation of solution-D2 is accurate for DL lossless data delivery for path switch?**

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| **Company** | **Answer (Yes/No)** | **Comments** |
| OPPO | No | There is a missing point in the evaluation: We think the relay-based enhancement (solution-D1D) for this lossless data forwarding is not feasible since there is a backwards compatable issue:* Relay UE is transparent of whether the HO is intra/inter-case;
* R17 relay doesn’t support the enhanced data forwarding.

So if the remote UE is out of coverage, i.e., direct link is unavailable, and if the relay is R17, Solution-D2 is not funcationaly feasible even if the remote UE is R18. |
| Apple | See comment | Same comment as for D1 |
| InterDigital | Yes |  |
| CATT | Yes |  |
| Xiaomi | Comments | How relay UE can acknowledge gNB supports such indication? Additional configuration indication from gNB is needed in RRC. |
| CMCC | Yes |  |
| LG | Yes | Does the relay UE send indication to the source gNB according to the configuration? Then, when the source gNB When source gNB configure HO to the remote UE,  |
| ZTE | comments | For Option 1, it may cause many redundant data forwarding over Xn.For Option 2, since PC5 RLC SN and Uu RLC SN are maintained separately, relay UE needs to identify and keep the mapping between them.  |
| Samsung | See comment | Same comment as Q1 |
| Qualcomm | No | Similarly, has impact on system performance, additional DL tansmission latency will be introduced due to deplayed acknowledgement from the Relay UE. |
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### **Question 16: Do companies agree that solution-D2 is a valid solution for DL lossless data delivery for path switch?**

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| --- | --- | --- |
| **Company** | **Answer (Yes/No)** | **Comments** |
| OPPO | No | See our reply above. |
| Apple | See comment | Same comment as for D1 |
| InterDigital | No | Similar to UL |
| CATT | No | Similar to D1 and see Q14. |
| Xiaomi | No | Additioan impact is foreseen in RRC. |
| CMCC | No  |  |
| LG  | No | Additional impact in RRC is expected. |
| ZTE | No | See our comments in Q15. |
| Samsung | No | We prefer PDCP status report based solution. |
| Qualcomm | No | Impact on RLC, and impact on DL latency |
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### **Question 17: Do companies agree that the decription and evaluation of solution-D3 is accurate for DL lossless data delivery for path switch?**

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| **Company** | **Answer (Yes/No)** | **Comments** |
| OPPO | No | The description is wrong: Using the PDCP status report before path switch doesn’t need to be a new trigger of PDCP status report, it can be up to source gNB, by the current signaling and procedure, via setting r*eestablishPDCP* or *recoverPDCP* , to trigger the remote UE to deliver PDCP SR, after this, by obtaining the SR, source gNB can do the lossless switching. |
| Apple | Yes with comment | But we think this delays the completion of inter-gNB HO procedure. Also, remote UE may not be able to deliver the PDCP status report successfully to source gNB due to poor radio link quality during the HO procedure.. |
| InterDigital | Yes |  |
| CATT | Yes |  |
| Xiaomi | Yes |  |
| CMCC | Yes  |  |
| LG | Yes |  |
| ZTE | See comment | Source gNB may not receive the PDCP status report before HO. In addition, gNB may receive the PDCP status report may be too early before HO, then there are still many redundant data forwarding over Xn. |
| Samsung | See comment | Similar view with OPPO that the PDCP status report by Source gNB with handover command not a new operation and this could be happen based on gNB implementation.  |
| Qualcomm | See comment | Agree with OPPO, existing status report trigger can be reused. |
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### **Question 18: Do companies agree that solution-D3 is a valid solution for DL lossless data delivery for path switch?**

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| --- | --- | --- |
| **Company** | **Answer (Yes/No)** | **Comments** |
| OPPO | Yes if we revise the D3 as we commented in Q15 |  |
| Apple | Yes |  |
| InterDigital | Yes |  |
| CATT | No | Similar to D1 and see Q14. This solution can not guarantee there has an available link in the source since it is decided to perform path switching. |
| Xiaomi | Yes |  |
| CMCC | Yes  |  |
| LG | Yes |  |
| LG | Yes |  |
| ZTE | Comments | See comments above. |
| Samsung | Yes |  |
| Qualcomm | Yes | Reuse existing PDCP status report trigger. |
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### **Question 19: Do companies agree that the decription and evaluation of solution-D4 is accurate for DL lossless data delivery for path switch?**

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| **Company** | **Answer (Yes/No)** | **Comments** |
| OPPO | No | The evaluation of this scheme is not correct: For the evalution on “this may require the source gNB to buffer a lot of data”, we understand it is just the same as R17, i.e., in R17 intra-gNB case, the gNB needs to do the same thing, rather than a delta part from R18 compared to R17. |
| Apple | Yes |  |
| InterDigital | Yes |  |
| CATT | Yes |  |
| Xiaomi | Yes |  |
| CMCC | Yes |  |
| LG | Yes | We need to check from RAN3. |
| ZTE | Yes | This solution can ensure lossless DL data delivery without redundant data forwarding over Xn. |
| Samsung | Yes |  |
| Qualcomm | Yes with comments | Agree with OPPO’s comments. |
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### **Question 20: Do companies agree that solution-D4 is a valid solution for DL lossless data delivery for path switch?**

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| **Company** | **Answer (Yes/No)** | **Comments** |
| OPPO | Yes | Although the solution may need RAN3 confirmation  |
| Apple | Yes |  |
| InterDigital | No | It is upto RAN3 whether such solution is needed, and RAN3 has not agreed to add it yet. |
| CATT | Yes | It is a valid solution and depend on RAN3 discussion. |
| Xiaomi | Yes |  |
| CMCC | Yes  | Depend on RAN3 discussion. |
| LG | Yes |  |
| ZTE | Yes | This solution can ensure lossless DL data delivery without redundant data forwarding over Xn. |
| Samsung | Yes | Share the view that this solution needs RAN3 discussion/decision. |
| Qualcomm | Yes | Can be confirmed by RAN3. |
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### **Question 21: Do companies agree that the decription and evaluation of solution-D5 is accurate for DL lossless data delivery for path switch?**

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| **Company** | **Answer (Yes/No)** | **Comments** |
| OPPO | No | The evaluation of this scheme is not correct: 1/ For the evalution on “this may require the source gNB to buffer a lot of data”, we understand it is just the same as R17, i.e., in R17 intra-gNB case, the gNB needs to do the same thing, rather than a delta part from R18 compared to R17.2/ For the evaluation on “This solution will have Xn interface impact managed by RAN3.”, we do not think so since there is no new inter-gNB interaction behavior required for this scheme, it is just source gNB, as in R17, to buffer more data, and the data forwarding procedure, from target gNB perspective, has no difference than legacy.  |
| Apple | Yes with comment | But this proactive forwarding solution is not based on PDCP status report. |
| InterDigital | Yes |  |
| CATT | Yes |  |
| Xiaomi | Yes |  |
| CMCC | Yes |  |
| LG | Yes |  |
| ZTE | Yes | But there are many redundant data forwarding over Xn. |
| Samsung | See comment | The buffer or discard timer configuration is totally up to gNB implementation. Exising PDCP discard timer could be long enough to support this lossless delivery. |
| Qualcomm | Yes | Agree with OPPO’s comments. Actually, in current stage 3 Xn specification, there is no any restriction on what type of PDCP SDU should be forwarded, then no stage 3 change is required.Xn user plane overhead is usually not most important issue. For Apple’s comment, existing PDCP status report to target gNB is till used. |
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### **Question 22: Do companies agree that solution-D5 is a valid solution for DL lossless data delivery for path switch?**

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| **Company** | **Answer (Yes/No)** | **Comments** |
| OPPO | Yes |  |
| Apple | No | We think this is a candidate but we would rather focus on PDCP-based solutons as agreed as baseline first.. |
| InterDigital | No | It is upto RAN3 if such solution should be added, and RAN3 has not decided to add it as of yet |
| CATT | Yes | It is a valid solution and depend on RAN3 discussion. |
| Xiaomi | Yes |  |
| CMCC | Yes  | Depend on RAN3 discussion. |
| LG | Yes | But, we need to check from RAN3. |
| ZTE | Yes |  |
| Samsung | Yes with comment | This is up to gNB implementation and RAN3 discussion/decision is needed. |
| Qualcomm | Yes | Can check with RAN3. |
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### **Question 23: Do companies see any additional solution(s) for DL lossless data delivery for path switch?**

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| **Company** | **Answer (Yes/No)** | **Comments** |
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### **Question 24: Do companies agree to take solution-D1/D2/D3/D4/D5 as the candidate solutions for DL lossless data delivery for path switch for downselection next meeting?**

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| **Company** | **Answer (Yes/No)** | **Comments** |
| OPPO | See comment | As replied, D1 and D2 are not feasible since the BC issue.While D3/4/5 are feasible way-out in our view.  |
| Apple | See comment | Only D3, D4 |
| InterDigital |  | Only D3 and D4. |
| CATT | See comment | Only D4 and D5. |
| Xiaomi |  | D1, D3, D4, D5 |
| CMCC |  | D3 is ok;D4 and D5 require further discussion in RAN3. |
| LG |  | D3, D4, D5 |
| ZTE | See comment | D4 and D5 may be prioritized. |
| Samsung | See comment | D3, D4 are preferred. We think that D5 is also considerable but it is up to RAN3. |
| Qualcomm | See comment | D3, D4, D5 |
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TBD Rapporteur summary:

TBD: Proposal

# Conclusion and Proposal

We have the following proposals:

TBD

# Reference

1. R2-2302493 Support of Lossless Path Switching
2. R2-2302602 Considerations on Service Continuity Enhancements for L2 U2N Relay
3. R2-2302859 Discussion on lossless data delivery during inter-gNB path switching
4. R2-2302860 Discussion on service continuity issues for Inter-gNB path switching of L2 U2N relay
5. R2-2302869 Discussion on lossless path switching and measurement events
6. R2-2302903 Discussion on Inter-gNB Service Continuity
7. R2-2302923 Lossless path switching from indirect to indirect/direct
8. R2-2302971 Discussion on Service Continuity Enhancements
9. R2-2302995 Path switching procedure for the service continuity enhancement
10. R2-2303006 Further discussion on service continuity for SL relay
11. R2-2303089 Service continuity enhancements for UE sidelink relay
12. R2-2303110 Discussion on lossless data forwarding for inter-gNB service continuity ,
13. R2-2303117 Discussion on service continuity enhancement
14. R2-2303223 Service continuity for Inter-gNB path switching
15. R2-2303341 Remaining issues on service continuity enhancement for L2 U2N relay
16. R2-2303389 Discussion on Service continuity enhancement of L2 U2N relay
17. R2-2303507 Scenarios and solution on lossless delivery during path switch from indirect path to target path
18. R2-2303546 Discussion on service continuity CMCC
19. R2-2303558 Discussion on Service Continuity
20. R2-2303564 Service continuity enhancements support for L2 U2N relay
21. R2-2303609 CP and UP aspects of inter-gNB path switching
22. R2-2304075 remaining issues for U2N path switching with lossless delivery
23. R2-2304124 Lossless data delivery in the inter-gNB cases