**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

**Contact information**

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| **Company** | **Name (Email)** |
| OPPO | Bingxue (lengbingxue@oppo.com) |
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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. |
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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 |
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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. |
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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. |
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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.. |
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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 |
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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. |
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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 |
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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 |  |
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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**. |
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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.** |
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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: Legacy 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 forward the DL packets that have not been acknowledged by Remote UE to it.

The data forwarding mechanism should be enhanced for the inter-gNB path switch, to allow source gNB forward all the PDCP SDUs in the buffer to the target gNB, 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 a legacy solution (following the legacy handling for inter-gNB handover.) with some assumed gNB implementation.

The feasibility of this solution depends 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.

### 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 the data to the target gNB without receiving the request from target gNB, on top of the current mechanism. This means a new supplementary inter-gNB data forwarding is supported from source gNB target gNB. In practice, this may occur after the normal data forwarding or before it.

**Evaluation**

This solution will have Xn interface impact managed by RAN3.

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. |
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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. |
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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. |
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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. |
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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. |
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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 |  |
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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. |
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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 |
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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. |
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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 |  |
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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. |
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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