**3GPP TSG RAN WG1 #102-e R1-20XXXXX**

**e-Meeting, August 17th - 28th, 2020**

**Agenda item:** 8.6.3

**Source:** Moderator (Qualcomm Inc.)

**Title:** FL summary on Coverage Recovery and Capacity Impact for NR RedCap

**Document for:** Discussion/decision

# Introduction

This paper summarizes the contributions submitted to A.I 8.6.3 (Study on Support of Reduced Capability NR Devices: coverage recovery and capacity impact).

The paper is organized as following. In section 2, the evaluation methodology for coverage recovery and capacity impact is summarized, including the target for coverage recovery, link and system level evaluation assumption. Section 3 summarizes potential techniques for coverage recovery, which are expected to be discussed in the following meeting but some of them can also be discussed in this meeting upon the evaluation methodology issues are concluded.

In this section, a set of questions are proposed for discussion. These questions are highlighted with different colors representing different priorities. According to the online discussion, we have different schedules for different priorities.

* [H]: high priority aiming at the discussion/approval on 8/20
	+ May be controversial or have impact on other discussion
* [M]: Medium priority aiming at the discussion/approval on 8/26
	+ Important for simulation but have isolated impact to other topics.
* [L]: For last check on 8/28
	+ Less controversial.

# Evaluation methodology

## Coverage recovery target

Many contributions discuss the coverage recovery target for reduced capability NR devices [3, 4, 6, 7, 8, 11, 12, 16, 17, 19, 20, 24, 29, 30]. Some contributions propose to discuss and decide the target of coverage recovery before studying various candidate techniques for coverage recovery [12, 20]. Some contributions also propose to align the coverage target with the Rel-17 coverage enhancement SI considering that a NW will support both RedCap and eMBB UEs with a same deployment [19].

In general, there are two approaches that could be considered for the coverage recovery due to the device complexity reduction. The first alternative is to consider compensating the coverage loss in each channel of the RedCap UE caused by UE complexity capability reduction. Another alternative is to enhance only the bottleneck channel(s) of the RedCap UE to reach a same target performance as the reference NR UE.

The objective in the SI is to only compensate for potential coverage loss due to UE complexity reduction. However, some companies think it is unnecessary to enhance the coverage of all the channels affected by UE complexity reduction. If the second alternative is adopted, it is required to understand the impact of complexity reduction on the coverage and identify the bottleneck channels for RedCap UEs based on link budget evaluation.

Based on the above summary, a possible way forward is to agree the target of coverage recovery to recover the coverage of bottleneck channel(s) and further discuss the target performance for coverage recovery.

**Question 1: Should the target of coverage recovery be aimed to compensate the coverage loss for the bottleneck channels(s) of the RedCap UE to achieve the same target performance as the reference NR UE?**

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| --- | --- |
| **Company** | **Comments** |
| vivo | Yes, we should identify the bottleneck channel(s) and try to improve the coverage performance targeting same/similar performance as reference NR UE. This target is applicable to most of the PHY channels. But for data channels, PDSCH/PUSCH, the cell-edge target data rate is likely to be lower than normal UEs, which should be discussed separately.  |
| Xiaomi | NO, if we go with compensating the bottleneck channels which can’t satisfy certain coverage requirement, that may go beyond the scope of the Redcap SI. For example, some bottleneck channels may not be resulted by the complexity reduction. In Rel-18, we could further consider compensate the bottleneck channel by using solutions identified by the coverage enhancement project |
| Futurewei | Yes and No. Yes, we should look at bottleneck channels and not all channels, as compensating for every degradation goes beyond the Redcap SI. No because we may not need to exactly match a reference NR UE, as “typical” network deployments may have MCL targets different than the stress point of the bottleneck channel. So, reference deployment rather than UE in Question 1.  |

**Question 2: Should the target performance for coverage recovery be based on the link budget of the bottleneck channel for the reference NR UE?**

|  |  |
| --- | --- |
| **Company** | **Comments** |
| vivo | It should be based on the bottleneck channel(s) identified for RedCap UEs.  |
| Xiaomi | NO. We think this way just postpone solving the problem to the future release. The final target is to achieve the same coverage with the normal NR UE. In rel-17, coverage enhancement project aims to compensate the bottleneck channel (e.g., PUCCH, PUSCH) of reference NR UE. In future release, Redcap could reuse the solutions identified in coverage enhancement project to improve the same bottleneck channel of Redcap (e.g., PUCCH, PUSCH). But it is highly possible that other additional solutions to improve the coverage of other channels such as PDSCH, PDCCH is still needed in.  |
| Futurewei | The target should be to introduce RedCap UEs in typical NR networks. As such a reasonable deployment may be defined and within the deployment a target performance for Redcap UEs may be identified such as target MCLs and target data rates (may start with the CE rates) |

## Link level coverage evaluation

The simulation assumptions and performance metrics for coverage evaluations have been discussed in last RAN1 meeting with the following agreements.

|  |
| --- |
| Agreements:If/when coverage evaluations outside the CE SI are needed,* The basic evaluation methodology is based on link-level simulation for FR1.

­       Step 1: Obtain the required SINR for the physical channels under target scenarios and service/reliability requirements.­       Step 2: Obtain the baseline performance based on required SINR and link budget template.­       Note: aspects related to identifying target performance and coverage bottlenecks based on target performance metric is to be handled separately* The evaluation methodology for FR2 is the same as FR1.
 |

Agreements:

 If/when link-level coverage evaluations outside the CE SI are needed,

* The CE SI link-level simulation assumptions can be used as a starting point
* For calibration purposes, the following settings can be used:

|  |  |  |
| --- | --- | --- |
| **Parameters** | **FR1 values** | **FR2 values** |
| Scenario and frequency | Urban:2.6 GHz (TDD) (primary choice)4 GHz (TDD) (secondary choice)Rural:700 MHz (FDD) | Indoor: 28 GHz (TDD) |
| Frame structure for TDD | For 2.6 GHz: DDDDDDDSUU (S: 6D:4G:4U)For 4 GHz:DDDSUDDSUU (S: 10D:2G:2U) | DDDSU (S: 10D:2G:2U) |
| Channel model | TDL-C | TDL-A |
| UE velocity | 3 km/h | 3 km/h |

***Scenario and frequency for coverage evaluation***

Based on contributions, many companies have submitted the coverage evaluation results for three different scenarios:

* FR1, Rural with the carrier frequency of 0.7 GHz
* FR1, Urban with the carrier frequency of 2.6 GHz
* FR2, Indoor with the carrier frequency of 28 GHz

Some companies also submitted the evaluation results for 4GHz Uban scenario [4, 6], which was agreed to be a second choice according to the RAN1-101e agreements for the RedCap study. One company proposed to consider also some FDD bands, e.g. 2GHz and 700MHz for Urban scenario [4], although they are not included in the Rel-17 coverage enhancement SI. Considering majority view is to align the evaluation assumption with the Rel-17 CE SI to reduce the simulation effort, the FL proposal is not to consider any additional scenario and frequency for link level coverage evaluation for the RedCap study.

**Question 3: Should the link level coverage evaluation for the RedCap study consider only the scenario and frequency agreed in the RAN1-101e?**

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| --- | --- |
| **Company** | **Comments** |
| vivo | The scenarios and frequency agreed in RAN1-101e should be considered as baseline. Besides, although 4GHz frequency has lower priority than 2.6GHz to reduce simulation effort, if some additional coverage issues are identified in 4GHz in addition to 2.6GHz (e.g. more channels become the bottleneck), they should also be discussed.  |
| Xiaomi | Yes. Considering the limited left time, it is better to focus on the scenario and frequency agreed in the last meeting.  |
| Futurewei  | Yes that should be sufficient |

***Physical channels, signals and messages***

The concerned channels, signals and messages for link level coverage evaluation will determine the limiting channels for coverage recovery. Based on preliminary results submitted by the companies, there are quite different views. Some contributions indicate that PUSCH is coverage limited for most scenarios [4, 5, 6, 7, 19]. Some contributions also observed that broadcast PDSCH, i.e. PDSCH of Msg2 and Msg4 can be the limiting channels for some scenarios [3, 6, 7, 30]. Some contributions mentioned that RedCap techniques will affect DL coverage rather than UL coverage and propose to de-prioritize or not consider coverage compensation for NR UL channels [9, 11]. Several contributions propose to further discuss the need of evaluation for initial access related channels since the mechanism “*keep trying*” can be used to compensate the coverage loss [4, 10].

According to the agreements in RAN1-101e for the CE SI, the link level evaluation will include PRACH, PUCCH, PUSCH, Msg3 in the uplink and PDCCH, PDSCH, SSB, PDCCH of Msg2 and PDSCH of Msg4 in the downlink. Therefore, it is desirable to align with the CE SI to consider all the physical channels, signals and messages for the RedCap study.

**Question 4: For link level coverage evaluation, should the RedCap study include PUCCH, PUSCH, PDCCH and PDSCH? If not, what modifications are needed?**

|  |  |
| --- | --- |
| **Company** | **Comments** |
| vivo | Yes |
| Xiaomi  | It highly depends on the target. Different target results in different impacted channels. But we think considering the impact of Rx reduction, the evaluation should include PDCCH and PDSCH at least.  |
| Futurewei | Depends on the particular scenario considered and also depends on what the Study group decides on Question 1 and 2. Our initial thinking is that the uplink channels are least impacted by the complexity reduction techniques and therefore the focus should be on the downlink channels.  |

**Question 5: For link level coverage evaluation, should the RedCap study include also the initial access related channels, i.e. PRACH, Msg3, SSB, SIB1, Msg2 and Msg4? If not, what modifications are needed?**

|  |  |
| --- | --- |
| **Company** | **Comments** |
| vivo | Yes |
| Xiaomi  | It highly depends on the target. Different target results in different impacted channels. But we think considering the impact of Rx reduction, the evaluation on Msg.2, Msg4, SIB1 and SSB can be included.  |
| Futurewei | May focus on Msg2, Msg4 and Msg3.  |

***Target data rate for coverage evaluation***

The evaluation methodology for PDSCH and PUSCH is based on obtaining the required SINR for which a target data rate is achieved. For control channels the methodology is based on obtaining the required SINR for which a target BLER is achieved.

For target data rates of PDSCH and PUSCH, one company [4] propose to consider the reference bitrate (e.g. 5Mbps for PDSCH and 2Mbps for PUSCH) given in the revised SID [2] in addition to the target data rates discussed in the Rel-17 CE SI. Some contributions [3, 7, 30] indicate the data rate for a physical channel of the RedCap should be adjusted lower to reflect the bandwidth constraint. It was proposed in [16] to define a limited number of target data rates considering the prioritized use cases for RedCap that need to be satisfied at the edge of coverage, e.g. 1Mbps for both DL and UL in Urban scenario.

Since the RedCap SI includes study of techniques such as reduced UE bandwidth, it seems reasonable to adjust the target data rates used in the CE SI to reflect the BW constraint.

**Question 6: For target data rates, can the RedCap study reuse the same assumption in the CE study? If not, what modifications are needed?**

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| --- | --- |
| **Company** | **Comments** |
| vivo | The reference data rate for RedCap UE is significantly lower than normal UEs, correspondingly, a lower target data rate should be assumed for RedCap UEs. We suggest to consider 1Mbps in DL and 0.5Mbps in UL.  |
| Xiaomi | Some modification is needed considering the BW reduction and the different traffic characteristics for Redcap. At least the target data rate should be set lower than that in the CE SI  |
| Futurewei | OK with the CE defined target data rates. A modification for Redcap UE may be OK if it is a *single* target for all of FR1 and FR2. We are not OK with multiple different targets to be evaluated. |

***Other LLS parameters***

According to the agreements in RAN1-101e, the CE SI link-level simulation assumptions can be used as a starting point for the RedCap study. In the RAN1 NR e-mail reflector, a set of link-level simulation assumptions and parameters were proposed for calibration purpose, for which most of the parameters are same as the CE SI link-level assumption. Based on the companies’ contributions, it can be seen that the majority prefer to reuse the CE SI LLS assumptions and performance metrics as much as possible in order to avoid duplicate works. It is also discussed in some contributions [3, 4, 7, 16, 30] that some LLS assumptions agreed in the CE SI may not be suitable for RedCap, such as number of antennas, UE BW, and should be adjusted accordingly considering the reduced UE capability.

**Question 7: For the common LLS parameters, can the RedCap study adopt the CE agreement on the number of gNB TX and RX chains, channel model, delay spread and antenna correlation? If not, what modifications are needed?**

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| --- | --- |
| **Company** | **Comments** |
| Vivo | Yes |
| Futurewei | yes |

**Question 8: For the channel specific LLS parameters other than target data rates, can the RedCap study reuse the link-level simulation assumptions adopted by the Rel-17 CE SI? If not, what modifications are needed?**

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| --- | --- |
| **Company** | **Comments** |
| Vivo | Yes |
| Futurewei | Yes |

***Link Budget Template***

A reference link budget is needed to determine potential coverage loss resulting from complexity reduction. One company [3] proposed to use an adapted version of the IMT-2020 link budget template, and one company [30] proposed to consider the simplified template in TR 36.824 for the RedCap study. According to the offline discussion in last RAN1 meeting, it seems the majority want to align with the output of the CE SI on the link budget template, for which a down-selection is required in RAN1-102e according to the following agreement.

Agreement:

Down selection on the following options for the link budget template for FR1 in next meeting.

* Option 1: Adopt single link budget template based on IMT-2020 self-evaluation with necessary revisions, including adding/removing/revising some parameters.
* FFS: The template provided by FL in Tdoc [R1-2005005](file:///C%3A%5CUsers%5Cgokuls%5CAppData%5CLocal%5CDocs%5CR1-2005005.zip).
* Option 2: Adopt both templates, i.e. link budget template in IMT-2020 self-evaluation and link budget template in TR 36.824.
* Option 3: Adopt single link budget template in TR 36.824 with necessary revisions, including adding/revising some parameters.

**Question 9: For link budget template, should the RedCap study reuse/align the link budget template with the CE SI? If not, what modifications are needed?**

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| --- | --- |
| **Company** | **Comments** |
| vivo | Yes, we should align the link budget template. We prefer option 1.  |
| Xiaomi | We prefer Option 1 |
| Futurewei | Prefer to see the arguments for and against before deciding on options |

***Modelling of reduced antenna efficiency***

In the revised SID [2], the potential reduced antenna efficiency of wearables is identified as one issue for study. The extent of additional recovery loss due to reduced antenna efficiency is to be limited to 3dB. In the [6, 18], it was proposed that the reduced antenna efficiency for wearables can be modelled as part of the UE antenna gain for all uplink and downlink channels, and in the [9] it is indicated that the impact of reduced antenna efficiency can be compensated by increasing the PA power and keeping the radiated transmit power unchanged thus no impact on UL coverage.

**Question 10: For the impact of small form factor antenna on coverage, should the RedCap study consider the loss of antenna gain for all the uplink and downlink channels or only for the downlink channels?**

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| --- | --- |
| **Company** | **Comments** |
| Yes | This applies to all DL and UL channels.  |
| Futurewei | Downlink only, FFS uplink |

## System level capacity evaluation

The revised SID in [2] requires also to study the impact to network capacity and spectral efficiency resulting from UE complexity reduction. In [3], the assumption for baseline system level evaluation was discussed based on an adapted version of assumptions from TR 38.802, Table A.2.1-1. In the [4], the preliminary results were provided with an observation of a loss of downlink SE from 30%-50% for RedCap. In the [18, 32], it was proposed to discuss and decide the percentage of RedCap UE for system level evaluation. In the [09], it was proposed to prioritize the impact of RedCap techniques on DL network capacity for wearable devices by considering both the impact of a single RedCap technique and a collection of multiple RedCap techniques.

**Question 11: For evaluating the impact of network capacity and spectrum efficiency, can the RedCap study use the assumption in TR 38.802, Table A.2.1-1 as the starting point?**

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| --- | --- |
| **Company** | **Comments** |
| vivo | The assumptions in TR 38.802, Table A.2.1-1 can be considered as the starting point, it is beneficial to down-select the scenarios such that the results from different companies can be comparable, for example urban macro can be selected. In addition to the above basic assumptions, we think the following are important and should be discussed and concluded before carrying on the evaluation (details in our paper R1-2005383 section 2.6)* System parameters

|  |  |  |
| --- | --- | --- |
| **Parameters** | **FR1 values** | **FR2 values** |
| Scenario and frequency | Urban:2.6 GHz (TDD) (primary choice)4 GHz (TDD) (secondary choice) | Indoor: 28 GHz (TDD) |
| Frame structure for TDD | For 2.6 GHz: DDDDDDDSUU (S: 6D:4G:4U)For 4 GHz:DDDSUDDSUU (S: 10D:2G:2U) | DDDSU (S: 10D:2G:2U) |

* Ratio between Redcap and normal UE is not higher than 1:1
* Different traffic models for Redcap (IM traffic for wearables) and normal UEs (FTP traffic), reuse the parameters from TR38.840

|  |  |  |
| --- | --- | --- |
|  | FTP traffic | Instant messaging |
| Model | FTP model 3 | FTP model 3 |
| Packet size | 0.5 Mbytes | 0.1 Mbytes |
| Mean inter-arrival time | 200 ms | 2 sec |
| DRX setting | Period = 160 msInactivity timer = 100 ms | Period = 320 msInactivity timer = 80 ms |

* Performance metrics:
	+ UPT to measure the performance impact to normal UEs
	+ Cell served throughput to measure the system capacity
 |
|  |  |

**Question 12: Can the system level evaluation focus on the downlink capacity and down-prioritization of the uplink capacity?**

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| --- | --- |
| **Company** | **Comments** |
| vivo | Yes |
| Xiaomi | Yes, downlink capacity should have higher priority. But UL capacity analysis should be encouraged as well.  |
| Futurewei | Yes |

# Potential techniques for coverage recovery

The section summarizes the potential techniques for coverage recovery based on all the contributions. This can be discussed once the coverage evaluation are concluded or in the next meeting. Note some contributions [5] indicate that the existing NR coverage recover techniques can be reused for RedCap, and therefore the solution not requiring specification change is also included here.

***SSB coverage recovery***

Based on companies’ contributions, two coverage recovery mechanisms have been proposed for SSB illustrated in the following table, including “keep-trying” and a shorter SSB period. It is a majority view that UE can compensate for potential coverage loss by combining SSB within a longer time interval when the requirement on system acquisition time is relaxed for the RedCap UE.

|  |  |
| --- | --- |
| **Coverage recovery mechanisms** | **Companies** |
| Keep-trying | Ericsson, Huawei, ZTE, ITL |
| Shorter SSB period, e.g. 5 or 10ms | MTK, Spreadtrum |

***PDCCH coverage recovery***

For PDCCH coverage recovery, there are a lot of proposals summarized in the following table, among which the techniques of the compact DCI and PDCCH repetition have got more supports than the others.

|  |  |
| --- | --- |
| **Coverage recovery mechanisms** | **Companies** |
| Reduce DCI size | Ericsson, Huawei, Sony, NEC, Intel, LGE, ITL, InterDigital, DCM, Sequans, WILUS (DCI size reduction by splitting) |
| Increase largest aggregation level beyond 16 | Ericsson, ZTE, Xiaomi, Sharp, WILUS |
| Repetition | Ericsson, vivo, ZTE, Nokia, MTK, TCL, Lenovo, OPPO, Spreadtrum, LGE, ITL, InterDigital, Sequans, WILUS, QC |
| Frequency hopping | Ericsson, ZTE, Sony, Lenovo, ITL, InterDigital |
| Longer duration CORESET | vivo, MTK, TCL, Lenovo, LGE |
| CORESET bundling | vivo |
| PDCCH link adaptation | Samsung |
| Multiplex RedCap and non-RedCap CORESET | Lenovo |
| DMRS enhancement | InterDigital, QC |

***PDSCH coverage recovery***

For PDSCH coverage recovery, there are more supports for studying repetition, frequency hopping and DMRS enhancement. For the other proposed solutions, there is only one or two supporters.

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| --- | --- |
| **Coverage recovery mechanisms** | **Companies** |
| Frequency hopping across a larger BW | Ericsson, Huawei, ZTE, Sony, Xiaomi, Apple, Convida, DCM, QC |
| Repetition | Ericsson, vivo (support for broadcast PDSCH), ZTE, Nokia (larger number of repetitions), Intel (lager number of repetitions), Xiaomi, OPPO, Spreadtrum, ITL, Apple, Sequans, Futurewei |
| DMRS enhancement | Huawei (overhead reduction), ZTE, Xiaomi, ITL (DMRS bundling), QC (DMRS bundling) |
| Lower MCS table 5.1.3.1-3 | FutureWei, Sequans |
| Time interleaving | Sony |
| TBS scaling for small data | NEC, QC |
| Inter-beam combining | CMCC |
| Beam refinement | QC |

***PRACH coverage recovery***

Similar to SSB, the coverage recovery for PRACH can be implementation specific by using “keep trying” mechanism or a longer PRACH preamble. One company also proposed to consider frequency hopping per one PRACH transmission instance to achieve frequency diversity gain.

|  |  |
| --- | --- |
| **Coverage recovery mechanisms** | **Companies** |
| Repeat random access attempts (keep trying) | Ericsson, ZTE, Lenovo (enhancement on the mapping) |
| Use longer PRACH preambles | Ericsson |
| Frequency hopping | ITL |

***PUCCH coverage recovery***

For PUCCH coverage recovery, the majority view is to enhance the repetition scheme, e.g. using a larger number of repetitions. Several contributions also propose to enhance frequency hopping across a larger BW for PUCCH.

|  |  |
| --- | --- |
| **Coverage recovery mechanisms** | **Companies** |
| Use a longer format | Ericsson, ITL |
| Repetition | Ericsson, ZTE, Intel (lager number of repetitions), ITL, Apple, DCM (sub-slot based) |
| Frequency hopping  | ZTE, ITL, DCM |
| Payload reduction (L1 measurement payload reduction) | Qualcomm |

***PUSCH coverage recovery***

For PUSCH coverage recovery, one company [vivo06] indicate the solutions for UL channels in the CE SI can be reused for RedCap to avoid the duplicate work. Two companies [Sony09] [MTK11] do not support compensating for the PUSCH coverage loss. For the proposed techniques for PUSCH coverage recovery, repetition and frequency hopping are supported by most of the companies.

|  |  |
| --- | --- |
| **Coverage recovery mechanisms** | **Companies** |
| Repetition | Ericsson, ZTE, OPPO, ITL, Apple |
| Frequency hopping across a larger BW | Ericsson, Huawei, ZTE, Nokia (larger number of repetitions), Intel (lager number of repetitions), ITL, Apple, DCM, QC |
| SUL | Huawei |
| DMRS enhancement | Huawei, ZTE, QC |
| Payload reduction (L1 measurement payload reduction) | QC |

Based on the above summary, the FL proposal is to further study the potential techniques for coverage recovery, with more focus on the PDCCH and PDSCH, considering UL coverage enhancement will be mainly considered in the Rel-17 CI SI and the solutions can be tailored or reused for the RedCap.

**Question 13: For studying potential techniques for coverage recovery, can the RedCap study focus on the PDCCH and PDSCH, and down-prioritize the other channels?**

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| **Company** | **Comments** |
| vivo | Yes. Based on our evaluation, depending on the selection of coverage target, in DL there would be some issues for PDCCH and PDSCH, especially the broadcast ones.  |
| Xiaomi | It depends on the target of the coverage recovery. But at current stage, potential solutions on PDCCH and PDSCH should be investigated.  |
| Futurewei | Yes, seems reasonable.The lists of techniques should separate existing techniques and new techniques. All existing techniques should be considered before new ones developed. |

**Question 14: For studying potential techniques for coverage recovery, can the RedCap study focus on the PUCCH and PUSCH, and down-prioritize the other channels?**

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| --- | --- |
| **Company** | **Comments** |
| vivo | We do observe PUSCH is the bottleneck channel for RedCap UEs, which is the same situation for coverage enhancement SI. We think the UL coverage enhancements study should be studied in the coverage enhancement SI considering both normal UE and RedCap UEs and solutions that are applicable for both UE types should be preferred. To avoid duplicated discussion, we think in RedCap SI we should focus on the DL coverage recovery and leave the UL coverage study to the coverage enhancement SI.  |
| Xiaomi | It depends on the target of the coverage recovery. But at current stage, potential solutions on PDCCH and PDSCH should be investigated. |
| Futurwei | Focus mostly on the downlink channels. This also highly depends on how the study group defines the target and compensation mechanism. For example, if the compensation is due to only complexity reduction techniques, uplink channels may not be impacted due to having 1 Tx in UL and therefore may be downprioritized.Note however that all existing techniques for recovering performance losses due to complexity reduction that might impact coverage should be listed in the TR and recommended, even if they are not evaluated. So, the question needs to be rephrased for evaluation, not for including in the study or TR. |

# References

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