**3GPP TSG RAN WG1 #110bis-e R1-22xxxxx**

**e-Meeting, October 10th – 19th, 2022**

**Agenda Item: 9.14.1**

**Source: Moderator (China Telecom)**

**Title: [110bis-e-R18-Coverage-01] Email discussion on PRACH coverage enhancement**

**Document for: Discussion**

1. Introduction

In RAN #94 e-meeting, a new Rel-18 work item on further NR coverage enhancements was approved [1] and updated in RAN #96 [2]. The objective of the work item is to specify further uplink coverage enhancements for PRACH, power domain and DFT-S-OFDM. Detailed objectives are listed as follows:

|  |
| --- |
| * Specify following PRACH coverage enhancements (RAN1, RAN2) * Multiple PRACH transmissions with same beams for 4-step RACH procedure * Study, and if justified, specify PRACH transmissions with different beams for 4-step RACH procedure * Note 1: The enhancements of PRACH are targeting for FR2, and can also apply to FR1 when applicable. * Note 2: The enhancements of PRACH are targeting short PRACH formats, and can also apply to other formats when applicable. * Study and if necessary specify following power domain enhancements * Enhancements to realize increasing UE power high limit for CA and DC based on Rel-17 RAN4 work on “Increasing UE power high limit for CA and DC”, in compliance with relevant regulations (RAN4, RAN1) * Enhancements to reduce MPR/PAR, including frequency domain spectrum shaping with and without spectrum extension for DFT-S-OFDM and tone reservation (RAN4, RAN1) * Specify enhancements to support dynamic switching between DFT-S-OFDM and CP-OFDM (RAN1) |

This contribution is a summary of the following email discussion:

[110bis-e-R18-Coverage-01] Email discussion on PRACH coverage enhancement by October 19 – Nanxi (China Telcom)

* Check points: October 14, October 19

1. Summary of contributions

## 2.1 Multiple PRACH transmissions with same beams

Based on companies’ contributions, sometimes the term “PRACH repetition” is utilized to indicate “multiple PRACH transmissions with same beams”. Thus, it needs to be clarified that the term “PRACH repetition” only indicates “multiple PRACH transmissions with same beams”, it doesn’t put any additional restrictions on multiple PRACH transmissions.

### 2.1.1 Resource configuration for multiple PRACH transmissions

#### Issue #1: Resource configuration

Based on the contributions, majority companies [China Telecom, Huawei, ZTE, vivo, Spreadtrum, OPPO, CATT, Intel, Sony, Panasonic, NEC, Lenovo, Mavenir, Xiaomi, CMCC, ETRI, MediaTek, Apple, Sharp, LG, NTT DOCOMO] discuss the resource configuration/allocation for multiple PRACH transmissions. In summary, there are four main options proposed:

* Option 1: Shared preambles and ROs as legacy, i.e., without additionally defined ROs.
  + FFS: Partitioning the existing legacy RACH Occasions for Single and Multi PRACH transmissions.
* Option 2: Separate PRACH preambles with shared ROs.
  + FFS: Whether it is possible to utilize the separate PRACH resources for requesting Msg3 repetition.
* Option 3: Additional separate ROs with shared PRACH configuration.
  + e.g., introduce a frequency and/or time domain offset to define additional ROs.
  + FFS: Whether the legacy ROs can be used for multiple PRACH transmissions.
  + FFS: Separate preambles for different number of PRACH transmissions.
  + FFS: SSB-to-RO mapping.
* Option 4: Separate PRACH configuration.
  + e.g., similar to NB-IoT mechanism for PRACH repetition, including the configuration of time and frequency domain resource, repetition number etc., for different coverage levels.

Based on companies’ contributions, some Pros and Cons of the above options are summarized in the following table.

|  |  |  |
| --- | --- | --- |
| **Options** | **Pros** | **Cons** |
| Option 1 | * Additional PRACH resources are not needed, the spec. impact is minor. | * High collision possibility for PRACH transmission. * Difficult to distinguish with multiple Msg1 transmissions and single Msg1 transmission. |
| Option 2 | * Simple and limited spec. impact. | * There are many existing UE features distinguished through different preamble index, incl., CBRA/CFRA, 2-step/4-step, msg.3 repetition, SI request, etc. The capacity of PRACH repetition would be limited. * Transmission delay of PRACH repetitions will be increased following the existing SSB-to-RO mapping. |
| Option 3 | * May help to implicitly identify the number of PRACH repetition. * No need to further partition the preambles | * May result in hard RO reservation. |
| Option 4 | * No need to consider the coexistence of legacy UE without multiple PRACH. * Flexible design of association between SSB and RO. * Easy to trace the start point and end point of multiple Msg1 transmissions. | * Time-frequency resources may overlap in multiple groups of ROs. gNB needs to perform blind detection to distinguish PRACHs with single or multiple transmission, or ensures that there is no time-frequency resource overlap between ROs in different PRACH configurations. * When switching between the modes of single and multiple PRACH is applied, it is not convenient for gNB and UE. |

Besides, companies have the following additional views on resource configuration:

* [Huawei] The enhanced PRACH and the legacy PRACH resource allocation should be independent, repetition ROs should be shared among different repetition levels by using different preamble sets.
* [ZTE, Intel] Multiple PRACH transmissions with same beam on the ROs associated with the same SSB.
* [Apple] There is no need to introduce new PRACH configuration with more time domain ROs for repetition.
* [Nokia] Investigate mechanisms for transmission of the PRACH repetitions targeting reduction of the probability of collision. Mechanisms based on suitable RO configurations, and different from RO reservation, should be prioritized over mechanisms based on preamble configurations. RAN1 to focus its study and investigations only on flexible RO reservation/configuration. Legacy hard RO reservation is not preferred.
* [Nokia] RAN1 to investigate mechanisms for optimization of the PRACH frequency allocation size to maximize the deliverable EPRE throughout PRACH repetitions.
* [Samsung] The RO determination for multiple PRACH transmission should be based on existing NR RACH framework. The concept of RO bundle can be considered, a RO bundle is formulated with a number of RO inside one RO bundle.



#### Issue #2: ROs pattern for multiple PRACH transmission

Companies [ZTE, China Telecom, vivo, CATT, TCL, NEC, Lenovo, MediaTek, NTT DOCOMO] propose that ROs utilized for multiple PRACH transmissions shall not be overlapped in time domain, i.e., multiple PRACH transmissions shall not be performed in the FDMed ROs. Otherwise, there will be little or even no performance improvement on PRACH detection due to transmit power division in the FDMed ROs. In addition, [LG] proposes that RAN1 to discuss how to determine which RO among the FDMed ROs with same beam index is used for PRACH repeated transmission.

While [Ericsson] thinks that in addition to multiple PRACH transmissions multiplexed in the time domain, the simultaneous PRACH transmissions is a possible option, especially for a UE with multiple Tx chains. Thus, [Ericsson] proposes to study simultaneous PRACH transmissions in Rel-18, including the association of different preambles in a RO and different FDMed ROs to one RACH attempt from a UE.

Moreover, two companies [Ericsson, Huawei] proposes that the repetition ROs should be assigned continuously in time domain.

[Mavenir] proposes a RO locations determination method for multiple PRACH transmission as follows: RACH occasion index [m, n] = first RACH occasion index+ n\*period+ m\* RO interval, where n is from 0,1,2… to (⌈total number of RO in RO period/ period ⌉ -1), m is from 0,1,2…to (total number of PRACH repetition and sweeping-1), where total number of PRACH repetition and sweeping is the number of PRACH repetition multiply by the number of PRACH sweeping.

#### Issue #3: Same or different preamble(s) during multiple PRACH transmission

Companies [CATT, Intel, Apple] think that the same PRACH preamble should be utilized for multiple PRACH transmission, which allow gNB to perform combining on multiple detection statistics for better performance. While two companies [ZTE, Samsung] are open to discuss whether same or different preambles apply to the multiple PRACH transmissions. Two cases are given by [Samsung] to show the use case of same and different preambles:

* Case 1: If the gNB can identify that the multiple PRACHs are from the same UE, then using the same preamble for all transmitted ROs is preferred.
* Case 2: If PRACH transmission is regarded independently to each other, then different preambles in different PRACH transmissions can be considered as well.

### 2.1.2 RAR window and RA-RNTI calculation

#### Issue #4: RAR window

According to TS 38.213, in response to a PRACH transmission, the UE attempts to detect a DCI format 1\_0 with CRC scrambled by a corresponding RA-RNTI during a window that starts at least one symbol after the last symbol of PRACH occasion corresponding to the PRACH transmission. When multiple PRACH transmissions is applied, the design of RAR window may need to be modified correspondingly. Based on the contributions [ZTE, China Telecom, Spreadtrum, vivo, CATT, Intel, Sony, Panasonic, Lenovo, CMCC, ETRI, MediaTek, InterDigital, Samsung, Sharp, LG, NTT DOCOMO, Qualcomm], there are two main options proposed for RAR window design for multiple PRACH transmissions as follows.

* Option 1: One RAR window per each PRACH transmission
  + Note: the RAR window can follow the legacy design.
* Option 2: One RAR window per *K* PRACH transmissions.
  + Note: *K* is less than the number of multiple PRACH transmissions.
* Option 3: One RAR window for all of the multiple PRACH transmission.
  + FFS: the start position of the RAR window.



Illustration of Option 1



Illustration of Option 2 (*K* = 2)





Illustration of Option 3

For Option 1, it is workable for gNB to detect the PRACH transmission and transmit RAR regardless of whether it has the knowledge about the number of PRACH transmissions. Each PRACH detection will be handled individually as legacy way, the corresponding RAR window starts also in a legacy manner.

For Option 2 and Option 3, gNB needs to know the number of PRACH transmissions as well as the corresponding ROs utilized for PRACH transmissions. The start position of the RAR window needs further discussion.

Besides, companies [Sony, ZTE, China Telecom, Spreadtrum, Panasonic] propose to considered/supported early termination of multiple PRACH transmissions if possible, i.e., terminate the follow up PRACH transmission in advance once UE successfully receives RAR.

#### Issue #5: RA-RNTI calculation

According to current spec. TS 38.321, RA-RNTI is calculated as follows:

|  |
| --- |
| RA-RNTI = 1 + s\_id + 14 × t\_id + 14 × 80 × f\_id + 14 × 80 × 8 × ul\_carrier\_id  where s\_id is the index of the first OFDM symbol of the PRACH occasion (0 ≤ s\_id < 14), t\_id is the index of the first slot of the PRACH occasion in a system frame (0 ≤ t\_id < 80), where the subcarrier spacing to determine t\_id is based on the value of μ specified in clause 5.3.2 in TS 38.211 for μ = {0, 1, 2, 3}, and for μ = {5, 6}, t\_id is the index of the 120 kHz slot in a system frame that contains the PRACH occasion (0 ≤ t\_id < 80), f\_id is the index of the PRACH occasion in the frequency domain (0 ≤ f\_id < 8), and ul\_carrier\_id is the UL carrier used for Random Access Preamble transmission (0 for NUL carrier, and 1 for SUL carrier). |

For multiple PRACH transmissions, the RA-RNTI calculation is related to RAR window design. Based on the companies’ contributions [ZTE, China Telecom, Spreadtrum, CATT, Mavenir, CMCC, InterDigital, LG, Qualcomm], there are two options proposed for RA-RNTI calculation as follows:

* **Option 1**: Multiple RA-RNTI candidates within one RAR window, i.e., UE attempts to detect a DCI format 1\_0 with CRC scrambled by one of the multiple RA-RNTI candidates during a RAA window.
* **Option 2**: Single RA-RNTI within one RAR window, i.e., UE attempts to detect a DCI format 1\_0 with CRC scrambled by a corresponding RA-RNTI during a RAA window.
  + **Option 2-1:** The corresponding RA-RNTI is calculated based on RO for the last PRACH repetition.
  + **Option 2-2:** The corresponding RA-RNTI is calculated based on RO for the first PRACH repetitions.
  + **Option 2-3:** The corresponding RA-RNTI is calculated based on RO for a predefined PRACH repetitions except the last and first one.

For Option 1, it indicates that UE should assume multiple RA-RNTIs candidates within one RAR window. This may happen for the case that multiple RAR windows are utilized and there is overlapping between RAR windows.

For Option 2, it indicates that UE only expects one RA-RNTI candidate within one RAR window, UE doesn’t need to assume multiple candidates of RA-RNTI and UE will not increase the complexity on the reception of RAR. Option 2 is workable for single RAR window design.

### 2.1.3 Determine the number of multiple PRACH transmissions

#### Issue #6: Candidate value

As companies point out, the performance gap for FR2 PRACH channel has been derived based on MIL criterion referring to the coverage range of PUCCH format 1 in TR 38.830 based on the link budget evaluation in Rel-17 as follows:

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Scenarios | Target metrics | Channels | MIL | |
| Number of samples | Relative difference vs. PUCCH Format 1 |
| Urban 28GHz TDD NLOS O2I | Scenario dependent target ISD=200m | PRACH Format B4 | 6 | **-1.92** |
| Urban 28GHz TDD NLOS O2O | Scenario dependent target ISD=200m | PRACH Format B4 | 5 | **-7.57** |

Besides, companies have the following observations which may facilitate the determination of number of multiple PRACH transmission:

* [Huawei] Different beams covering different areas have different coupling loss due to the outdoor to indoor penetration and the tree penetration, which implies that different beams require different coverage enhancements.
* [ZTE] If the joint detection of the received PRACH repetitions can be performed at gNB side, the simulation results showed about **1.7~3.7 dB** and **3.7~5.2 dB** gain can be obtained by employing **2 repetitions** and **4 repetitions** respectively in case of PRACH repetition with same beam (@28GHz). It seems the 4 repetitions can hardly compensate the -7.57dB gap. So at least, **up to 8 repetitions** should be supported.
* [vivo] In Urban O2O scenario @28GHz, the performance gain of PRACH repetition is about **4.3dB** for **2 PRACH repetition** and **7.9dB** for **4 PRACH repetition**. In Urban O2I scenario @28GHz, the performance gain is about **3.1dB** for **2 PRACH repetition**, **6.3dB** for **4 PRACH repetition** and **9.3dB** for **8 PRACH repetition**. The additional gain of PRACH repetition with RO hopping is about 0.67dB compared to that of PRACH repetition without RO hopping.
* [Xiaomi] For FR2 in Urban@28GHz O2O scenario, about **2.9dB** and **5.1dB** performance gain can be obtained with **2** and **4 PRACH repetitions**, respectively.
* [Intel] About **2.1dB performance gain** can be achieved for PRACH transmission when **repetition level is doubled**. (@700MHz, PRACH format 0)

Regarding the candidate values, {2, 4, 8} PRACH transmissions are proposed by companies, detailed views are summarized as follows:

* [ZTE] The number of PRACH repetitions with **2, 4** and **8** is proposed for multiple PRACH transmissions.
* [LG] Support the repetition numbers of PRACH as similar level of repetition numbers for Msg. 3 PUSCH (e.g., 2, 4, and 8).
* [vivo] **Up to 4 PRACH repetitions** with same beam should be considered to compensate the maximum performance gap identified in Rel-17 when frequency hopping is not assumed.
* [Xiaomi] The maximum number of repetitions for PRACH enhancement is **8**.
* [MediaTek] At least, 4 or more transmissions should be allowed as the maximum transmission number in a single PRACH repetition set.
* [OPPO] Number of PRACH transmission among different PRACH repetition attempt can be same or different.
* [TCL] Collision factor between UEs should be considered when to determine the maximum number repetition of PRACH transmission.

#### Issue #7: Determination of the number of multiple PRACH transmission

As majority companies [ZTE, Huawei, Spreadtrum, vivo, China Telecom, OPPO, CATT, Intel, NEC, Lenovo, Xiaomi, CMCC, FGI, MediaTek, Apple, InterDigital, Samsung, LG, Qualcomm, Nokia] propose that the determination of the number of PRACH repetitions can be based on the SSB RSRP measurement. **One or more new SSB-RSRP thresholds** can be configured (e.g., in SIB 1) for different PRACH coverage levels, i.e., different number of PRACH repetitions.

Besides, some companies [ZTE, vivo, Panasonic, Qualcomm] think that multiple PRACH transmissions can also be enabled during the PRACH re-attempts in case of transmitting power or number of PRACH retransmissions reaching a threshold. In addition, [Panasonic] propose to support to use multiple PRACH transmissions **only after UE reaches maximum transmission power**.

Other companies’ views are summarized as follows:

* [vivo] Some of the configured parameters for Msg3 repetition could be considered to determine whether PRACH should be repeated. For example, RSRP threshold used for triggering Msg3 repetition can be no less than the RSRP threshold for triggering PRACH repetition.
* [Ericsson] Methods of determination and indication of repetition level of Rel-13 LTE eMTC/NB-IOT are used as starting points for Rel-18 multiple PRACH transmissions.
* [TCL, Lenovo] The number of multiple PRACH transmissions can be indicated explicitly via PRACH configuration table, e.g., add the number of repetitions in each line of the PRACH configuration table.
* [Nokia] UE selects a number of Msg1 repetitions based on expected UL link budget as a function of e.g., SS-RSRP measurements and corresponding number of Msg1 repetitions.

#### Issue #8: Multiple PRACH transmissions mapping to valid ROs

According to current spec., validation rules for ROs have been specified, and a UE only transmits PRACH in valid PRACH slots. Regarding multiple PRACH transmission, the validation rule also needs to be considered. [Ericsson] proposes that validation rules are **applied after** ROs for multiple PRACH occasions are determined for a specific number of PRACH transmissions, while [Qualcomm] propose that the counting of PRACH repetitions is **based on the valid ROs**. Moreover, [Qualcomm] propose that PRACH repetitions are only transmitted in the valid ROs associated with the same SSB at different time with the following order:

* First, in increasing order of time resource indexes for time multiplexed PRACH occasions within a PRACH slot.
* Second, in increasing order of indexes for PRACH slots.
* Third, in increasing order of indexes for PRACH association period.

### 2.1.4 Power control

Companies [Huawei, ZTE, CMCC, OPPO] discuss the power control and power ramping for multiple PRACH transmission. Regarding the power control part, [Huawei] observes that the power control formula of multiple transmission specified in eMTC PRACH coverage enhancement can be reused. Regarding the power ramping part, the following views are summarized:

* Within one PRACH attempt consists of multiple PRACH transmission,
  + **Option 1:** Transmission power for each PRACH transmission is the same. The same measurement of the same reference signal to calculate the pathloss should be applied for each PRACH transmissions.
  + **Option 2:** Transmission power is ramped one by one during multiple PRACH transmissions.  
    FFS: The initial power and power ramping step.
* For inter-PRACH attempts, the power of PRACH is ramped with the increase of PRACH repetition attempt.  
  FFS: Whether similar power ramping principle as Rel-15 is reused, i.e., the power ramping counter increases during the RACH re-attempt if the selected UL Tx beam and the selected SSB doesn’t change, otherwise, the power ramping counter should be kept unchanged.

### 2.1.5 Others

* **SSB-to-RO mapping**

[Xiaomi] consider the following potential solutions for the mapping between SSBs and PRACH resources: The UE selects multiple TDMed valid ROs associated with the same SSB for mulitple PRACH transmssions. Multiple TDMed PRACH resources for PRACH repetitions are taken as one RO, and are associated with the same SSB.

[Nokia] RAN1 to analyze and specify optimizations to the framework for mapping of ROs-to-SSB indices targeting consecutive PRACH repetitions while limiting the number of SSB indices per time occasion.

* Multiple PRACH transmissions on multi panels

Considering UE who supports transmission on multiple panels, [ZTE] proposes three options for multiple PRACH transmissions on multiple panels.

* Option 1: Multiple PRACH transmissions always transmit in one panel. This is traditional way, through which channel reciprocity under TDD can be ensured.
* Option 2: Multiple PRACH transmissions simultaneously transmit in multiple panels. This needs higher UE capability. The benefit is aggregated transmitting power and panel diversity gain.
* Option 3: Multiple PRACH transmissions are hopping among the multiple panels. The benefit may be the panel diversity gain. But the latency of panel switch may not satisfy the multiple PRACH transmissions if the ROs for multiple PRACH are successive.
* Phase continuity for multiple PRACH transmissions

[NEC] observes that If multiple PRACH is transmitted on time continuous ROs with the same frequency and beam resources, and if PRACH is format A1/A2/A3, then there is no gap between each transmission but the phase is not continuous. Discontinuous phase will cause larger PAPR. Thus, it is suggested to study PRACH signal generation across time continuous PRACH occasion to maintain a continuty transmission phase.

## 2.2 Multiple PRACH transmissions with different beams

### 2.2.1 Potential use cases

#### Issue #9: Association between SSB and multiple PRACH transmissions with different beams

Notice that the objective doesn’t have a limitation on whether multiple PRACH transmissions with different beams is associated with same or different SSBs, companies [China Telecom, CATT] think there is a need to clarify this issue. Additional companies’ views are summarized as follows:

* [China Telecom] For multiple PRACH transmissions with different beams while associated with the same SSB, separate PRACH detection and RA-RNTI calculation mechanism may be helpful for UE Tx beam indication. For multiple PRACH transmissions with different beams while associated with different SSBs, some modification is needed for cell search procedure. Moreover, further discussion on how to perform multiple PRACH transmissions is needed for the following cases: the UE selected SSBs are associated with the same RO; the ROs associated with the selected SSBs are FDMed.
* [ETRI] Discuss whether a UE can generate multiple beams for PRACH from one SSB. If a UE can derive multiple beams from one SSB, then the UE may have multiple antenna panels or large antenna array in an antenna panel. Each antenna panel can be associated to a beam for PRACH, or an antenna array can generate multiple sharper beams than a SSB’s and all of those beams correspond to the same SSB. The latter case implies that the UE should monitor multiple SSBs for the Msg1 transmission. In addition, study the need for a switching gap between consecutive PRACH transmissions with different beams.

Moreover, based on the contributions, companies [ZTE, CATT, China Telecom, Intel, Spreadtrum, ETRI, Nokia, Ericsson, Samsung, Lenovo, TCL] identify three useful cases for multiple PRACH transmissions with different beams as follows:

* Case 1: UE Tx/Rx beam correspondence cannot be guaranteed, more than one PRACH are transmitted on ROs associated with the same SSB.
* Case 2: According to SSB-based measurement, the UE can determine a UL beam. Based on this beam, the UE can use multiple finer beams to send PRACH to obtain additional beamforming gain.
* Case 3: If multiple SSB measurements satisfy the threshold, UE transmits all/part of PRACHs in the ROs associated with corresponding SSBs, i.e., PRACH repetitions with different beams on the ROs associated with the different SSBs.



For Case 1 and Case 2, multiple PRACH is transmitted on ROs associated with the same SSB. While for Case 3, multiple PRACH is transmitted on ROs associated with different SSBs, which indicates that UE needs to select more than one SSB during the cell search phase, and this breaks the principle of initiating the RACH process oriented to an SSB.

In summary, Companies [TCL, Intel, Lenovo, Samsung, NTT DOCOMO, Nokia, Ericsson] propose to support multiple PRACH transmissions with different beams, while companies [vivo, Sharp, MediaTek, CMCC, InterDigital, LG] think multiple PRACH transmissions with different beams should be deprioritized/not supported. Based on companies’ contributions, some Pros and Cons of multiple PRACH transmissions with different beams are summarized in the following table.

|  |  |
| --- | --- |
| Props | Cons |
| * Latency reduces in multiple transmission with different beams as ROs of different beams are used for repetition. * Multiple PRACH transmission with different beams increases robustness even for UE with beam correspondence. * PRACH transmission with different beams could increase the possibility of being detected by any of the TRPs which may locate in different directions. * Msg3 transmission may be transmitted with the best narrow beam observed during PRACH. | * BS has to indicate the association groups of beams, UEs select association group for repetition correspondingly, and extra operation is required to determine the RAR beam, which results in an increased complexity and signaling cost. * The benefits and target scenarios are not clear. * UE complexity will increase obviously. * Larger spec. impact. |

### 2.2.2 Performance gain

Based on the contributions, companies [vivo, Ericsson, Nokia] provide some link-level simulation results as follows:

* [vivo] The performance gain of single beam repetition is **2.1dB better than that of multiple beam repetition** for the case of 8 PRACH repetitions. (@28GHz, PRACH format B4, CDL-A (DS 100ns) for different beams, TDL-A (DS 100ns) for single beam, soft combination within one PRACH signal for same beam)
* [Ericsson] For the same number of PRACH transmissions, **the transmission with different beams** (beam sweeping) has a **loss of about 5dB** compared with transmissions **with the same best beam**. **A single PRACH transmission with the best beam performs better than UE sweeping four beams**. (@28GHz, PRACH format B4, CDL-A (DS 100ns))
* [Ericsson] PRACH transmissions with **different beams (beam sweeping) outperforms** the transmissions with the **same wide beam** by **about 1dB** for the same number of transmissions. (@28GHz, PRACH format B4, CDL-A (DS 100ns))
* [Ericsson] About **2dB gain is observed when the number of PRACH transmissions doubles**, and the gain slightly decreases when the number of PRACH transmissions increases. It is observed for PRACH transmissions with the same best beam, the same wide beam, or with different beams. (@28GHz, PRACH format B4, CDL-A (DS 100ns))
* [Nokia] 4 PRACH repetitions with **a same wide beam** provide around **5dB gain** compared to single PRACH transmission with a wide beam. (@28GHz, PRACH format B4, CDL-A with 100ns delay spread, non-coherent combining at the receiver)
* [Nokia] 4 PRACH repetitions with **different beams provide a gain** of around **7dB** compared to the case of one single PRACH transmission with narrow beam pointing to the direction of maximum energy for the channel model under consideration. (@28GHz, PRACH format B4, CDL-A with 100ns delay spread, the single PRACH transmission pointing to the direction of maximum energy for the channel model, receiver does not perform repetition combining)
* [Nokia] Multiple PRACH transmissions with **different narrow beams perform** **better** than multiple PRACH transmission with a same wide beam. (Comparison of SNR values at 99% detection probability, 4 PRACH transmissions with same wide transmission beam is -13dB, 4 PRACH transmissions with different narrow beams is -17dB)

Regarding the simulation, companies [MediaTek, Ericsson] proposed to consider the following two cases:

* Case 1: UE without *beamCorrespondence* feature support.
* Case 2: UE with *beamCorrespondence* feature support.

Regarding the simulation assumptions, companies’ views are summarized as follows:

* [Ericsson] Simulate UEs with up to eight antenna elements (with 4 dual polarized antenna pairs). CDL-A in 38.901 is used for simulation.
* [Nokia] RAN1 to use LLS for investigating the performance of multiple PRACH transmissions with different beams. Analyze only an urban scenario at 28GHz with a more realistic number of UE antenna elements equal to 4.

### 2.2.3 Others

* Resource configuration

[Huawei] PRACH resource assignment in multiple transmissions with different beams is similar to that in multiple transmissions with the same beam, but at a granularity of beam groups rather than beams.

* Power control

[Huawei] The power control of multiple transmission with different beams should be studied.

[ZTE] The power should remain unchanged in case of multiple PRACH transmissions with different beams.

* Transmission scheme

[NEC] For multiple PRACH transmissions with different beams, opportunity type is applied, where opportunity type means to detect preamble on each of PRACH occasion among multiple occasions.

[Samsung] UE will be allowed to select multiple DL beams (e.g., SSBs) to enable the multiple PRACH transmission. For example, each SSB with only one RACH transmission is kept as in current NR RACH framework. As an example shown in following figure, each SSB associated with two ROs. Then the UE could select two SSBs and transmit one PRACH with each of the selected SSB, overall two PRACH transmissions from the same UE are allowed. By using this method, the potential benefit is that mostly the RACH resource and determination procedure could follow current RACH framework, connection latency can be additionally improved, and different TRPs can be accessed by the UE, but how to handle the multiple RACH procedure or follow-up feedback from gNB needs further study.



Fig.2 – Illustration of RO bundle with associated SSBs.

* Indication of the best UL Tx beam

[Mavenir] Under the PRACH sweeping scenario, it is beneficial to indicate to UE the best Tx beam of preamble transmission detected by the network, which could be used by UE for Msg3 transmission. 3 potential options are provided and could be considered and discussed as below:

* Option1: by MAC RAR.
* Option2: by PDSCH (Msg2) DMRS.
* Option3: by PDSCH (Msg2) CRC mask.
* Beam association

[Huawei] Beam association group where each beam in this group is used to transmit the same preamble repeatedly is the main characteristic in multiple transmission with different beams. The number of beam association groups and the number of associated beams in one group should be small values.

## 2.3 Interaction between multiple PRACH transmissions and other transmission with repetition

When multiple PRACH transmissions is enabled, it may have some interaction with other transmissions, e.g., Msg3 repetitions. Companies [ZTE, Spreadtrum, OPPO, vivo, CATT, Intel, FGI, Qualcomm, Ericsson] think the coupling/interaction between PRACH repetitions, Msg.3 repetitions (and PUCCH repetitions for HARQ-ACK of Msg4) should be investigated. Moreover, companies [OPPO, CMCC] propose to study joint design of PRACH and Msg.3 repetition.

Besides, [Ericsson] has the following observations based on link-level simulation and propose to study how Msg3 performance can be improved by PRACH transmissions with different beams:

* In FR2, the required SNR for Msg3 with 8 repetitions and inter-slot frequency hopping at 10% BLER is 1.7 dB higher than that of a single PRACH transmission with a wide beam and 8 dB higher than a single PRACH transmission with the best beam for 1% missed detection. The gap could be 4.5 dB more for 10% mis-detection rate.
* With Rel-18 PRACH enhancement, the performance gap between Msg1 and Msg3 would grow. Msg3 needs further enhancement to be on par with Rel-18 PRACH.

## 2.4 CBRA and CFRA

Based on the contributions, companies [ZTE, Spreadtrum, vivo, Panasonic, NTT DOCOMO, Ericsson, Sony, Qualcomm, Ericsson] propose to support multiple PRACH transmission for both **CBRA** and **CFRA**. Applying multiple PRACH transmissions to CFRA can improve PRACH detection rate in SNR limited scenarios, which is essential to the cases of handover and beam failure recovery. Moreover, for CFRA, it is more flexible for network to configure the PRACH resources for PRACH repetition as dedicated signalling can be applied.

## 2.5 Others

* Frequency hopping

[Intel, Apple] propose to support PRACH frequency hopping. In addition, [Intel] observes that for 2 and 4 PRACH repetitions with frequency hopping, ~2.5dB performance gain can be achieved compared to PRACH repetitions without frequency hopping.

* Coverage enhancement for FWA scenario

[ZTE] proposes to study potential coverage enhancements for PRACH in FWA scenario to address the demands from practical network deployment.

* Impact of maximum permissible exposure (MPE)

[Samsung] proposes to further study multiple PRACH transmission enhancements when UE experiences MPE issues, e.g., impact of MPE on: number of multiple PRACH transmission, power settings, the trigger for multiple PRACH transmission.

* Switching Tx filter within RO boundaries

[Nokia] Investigate mechanisms for switching Tx filter within RO boundaries for short PRACH formats.

1. Email discussion (1st round)

## 3.1 Multiple PRACH transmissions with same beams

### 3.1.1 Resource configuration for multiple PRACH transmissions

#### Proposal 1

**For multiple PRACH transmissions with same beams, down-select from the following options.**

* Option 1: Multiple PRACH are transmitted with shared preambles on shared ROs, i.e., no separate ROs or preambles are defined for multiple PRACH transmissions.
  + FFS: detailed scheme, e.g., partitioning the existing legacy ROs for single and multi PRACH transmissions.
* Option 2: Multiple PRACH are transmitted with separate preamble on shared ROs.
  + FFS: detailed scheme, e.g., whether to utilize the separate PRACH resources for requesting Msg3 repetition.
* Option 3: Multiple PRACH are transmitted on separate ROs, where the ROs are determined based on legacy PRACH configuration.
  + FFS: detailed scheme, e.g., introduce a frequency and/or time domain offset to define additional ROs, whether utilizing separate preambles for different number of PRACH transmissions, SSB-to-RO mapping.
* Option 4: Multiple PRACH are transmitted based on separate PRACH configuration.
  + FFS: detailed scheme, e.g., consider a NB-IoT-like mechanism for PRACH repetition, the separate PRACH configuration including time and frequency domain resource, repetition number etc., for different coverage levels.
* Other options are not precluded.

Companies are encouraged to provide views on the above proposal.

|  |  |
| --- | --- |
| **Companies** | **Comments** |
| Intel | We would like to understand better on the intention of the proposal. Is this mainly for differentiation between single PRACH transmission and multiple PRACH transmissions with same Tx beams or between different PRACH repetition levels for multiple PRACH transmission with same Tx beam?  For Option 1, we do not know how the PRACH performance improvement can be achieved if the gNB does not know whether this is for single PRACH transmission or multiple PRACH transmission.  For Option 2 and Option 3, we suggest to remove the detailed schemes after e.g., We have different understanding on the examples. For instance, for Option 3, “introduce a frequency and/or time domain offset to define additional ROs”, as this is based on legacy PRACH configuration, it is not clear to us why we need to introduce time/freq. offset.  For Option 4, we do not quite follow separate PRACH configuration. Does that mean we will introduce a new PRACH configurable row in the PRACH configuration table? We do not think this is desirable considering the large spec impact.  Based on the discussions above, we suggest to remove Option 1 and Option 4. We also think a combination of Option 2 and Option 3 can be supported, similar to Msg3 PUSCH repetition.  **For multiple PRACH transmissions with same beams, ~~down-select from~~ consider the following options.**   * ~~Option 1: Multiple PRACH are transmitted with shared preambles on shared ROs, i.e., no separate ROs or preambles are defined for multiple PRACH transmissions.~~   + ~~FFS: detailed scheme, e.g., partitioning the existing legacy ROs for single and multi PRACH transmissions.~~ * Option 2: Multiple PRACH are transmitted with separate preamble on shared ROs.   + FFS: detailed scheme, ~~e.g., whether to utilize the separate PRACH resources for requesting Msg3 repetition.~~ * Option 3: Multiple PRACH are transmitted on separate ROs, where the ROs are determined based on legacy PRACH configuration.   + FFS: detailed scheme, ~~e.g., introduce a frequency and/or time domain offset to define additional ROs, whether utilizing separate preambles for different number of PRACH transmissions, SSB-to-RO mapping.~~ * ~~Option 4: Multiple PRACH are transmitted based on separate PRACH configuration.~~   + ~~FFS: detailed scheme, e.g., consider a NB-IoT-like mechanism for PRACH repetition, the separate PRACH configuration including time and frequency domain resource, repetition number etc., for different coverage levels.~~ * Other options are not precluded. |
| CATT | Our understanding of the proposal is to discuss whether the RO/preambles are shared or separated for single PRACH transmissions and multiple PRACH transmissions with same beam. But the proposal seems not clear.  For Option 1, we share the same view as Intel and also suggest removing Option 1.  The difference between Option 3 and Option 4 is not clear. Our understanding is that both options support separate PRACH configurations (i.e. ROs) for PRACH repetitions and single PRACH transmissions. The difference is that Option 3 does not introduce new entries in the existing PRACH configuration tables defined in 38.211 while Option 4 does. We think it is second-level details and can be included in the FFS and there is no need to differentiate Option 3 and Option 4 at this point. |
| DOCOMO | We support the proposal to further discuss the four options.  For option 1, we think possible performance gain can come from the multiple PRACH transmissions even though gNB does not know whether this is for single PRACH transmission or multiple PRACH transmission. For example, if the successful detection probability for one PRACH transmission is p, then the successful detection probability for N independent PRACH transmissions can be 1- (1-p)^N.  We agree with the pros/cons analysis in section 2.1.1. From our perspective, we are open to two kinds of solutions:   * Simple spec impact, without joint detection for multiple PRACH transmissions, i.e. gNB does not know multiple PRACH transmissions are subject to repetitions for single PRACH transmission or independent multiple PRACH transmissionS.   More spec impact, with joint detection for multiple PRACH transmissions, i.e. gNB can know multiple PRACH transmissions are subject to repetitions for single PRACH transmission or independent multiple PRACH transmissions. |
| Panasonic | We would like to clarify the meaning of main bullet. Does “multiple PRACH transmissions with same beams” mean that   * Alt. 1: There are multiple PRACH transmissions and multiple beams   + A subset of multiple PRACH transmissions is sent based on each of multiple beams * Alt. 2: There are multiple PRACH transmissions and a same beam, i.e., there is a typo in “same beams”   Can FL clarify the intention of the main bullet (Alt. 1 or Alt. 2 or other)? |
| FL | Thanks for the comments. The initial intention of the proposal is to identify how to configure/allocate the resources for multiple PRACH transmission. Based on the contributions, from FL perspective, companies’ related proposals can be summarized into the above options. Regarding how to separate single PRACH transmission and multiple PRACH transmissions, it may be related to the resource configuration, which can be further discussed.  @ Panasonic, from FL point of view, it indicates Alt.2, if companies prefer to delete the “s” as “multiple PRACH transmissions with same beam~~s~~”, I’m ok to revise this. |
| Qualcomm | We prefer option 2. We are fine with the proposal, though similar to Intel and CATT, we think option 1 can be removed. |
| LG | Regarding the Option 1, it does not distinguish the RO and the preamble index between single transmission and multiple transmissions, so if we support Option 1, the gNB may not know which preamble is for repeated transmission. Therefore, the gNB should accumulate all preambles respectively, and at the same time, the gNB should send the RAR for all successful preambles, even if the preambles were actually used for repeated transmissions. It means the UE should monitor the RARs after every single preamble transmission, then the UE complexity will be increased.  Regarding the Option 3, it is an appropriate option when RACH resources are not significantly needed, such as IAB. In other words, it may be not preferred for PRACH repetition because it is difficult to allocate a large number of ROs using offsets from legacy PRACH configurations.  Therefore, we prefer to remove the Option 1 and Option 3 in this proposal. |
| vivo | To avoid long latency and reduce the impact to legacy PRACH transmission，we propose to have first repetition to be shared with legacy RO and configure a set of ROs after (via a slot level offset) a set of legacy ROs (e.g. legacy ROs in one PRACH slot) for remaining PRACH repetitions. This would be a combination of option 2 and option 3 if we understand the definition of option 2 and 3 correctly.  For option 1: Is it correct understanding that this is for the case of multiple independent PRACH transmission wherein gNB doesn’t have to know whether the PRACH transmissions are from single UE or from multiple UEs? If the answer is yes, then these multiple PRACH transmissions could be mapped to different SSBs since it’s up to UE to determine the SSB for PRACH resource selection for different PRACH transmissions.  For option 4, this is completely independent separate RO configuration for PRACH repetition, right? But this seems covered by option 3.  Regarding whether different repetition levels should be supported, we’re open to discuss and it depends on how we determine the maximum number of repetitions being discussed in other section.  Another comment is for “**same beams**” the main body text, it should be “**same beam~~s~~**” given only single is assumed for all repetitions. |
| Samsung | If the intention of the proposal is to discuss whether to allow shared RO/preamble and/or separate RO/preamble for multiple PRACH transmission, we think this proposal could be simplified as following:  **For multiple PRACH transmissions with same beams, considering to use shared RACH resource and/or separate RACH resource (including RO and/or preamble) with legacy single PRACH transmission.**  **FFS details.** |
| CMCC | Our first preference is to make gNB knows that how many times a UE transmit PRACH based on mechanism like a separate RO and/ or separate preamble. We do not want gNB to blind detect all the possible candidate of repetition factors, which may cause too much complicity. |
| Spreadtrum | We have a confusion about the definition of the “shared RO” and “separate RO”.  For the example sentence "**partitioning the existing legacy ROs for single and multi PRACH transmissions.**" in Option1, if the existing legacy ROs will be partitioned for single and multi PRACH transmissions, from our point of view, it should be called separate RO and shared preamble are not exists. So we proposed the example sentence should be moved to Option 3. |
| ZTE | Explanation for option 4, the separate PRACH configuration means the whole structure of the RRC configuration for PRACH is new compared to the legacy RRC configuration. An example is the NB-IoT RACH resource configuration.  We also think option 1 is not helpful for gNB to identify whether the multiple PRACH transmission is used and the reception combination gain cannot be achieved which deviates from the motivation of this WI.  For Option 3, the mechanism is similar as IAB RACH. The proportion of UEs at the cell edge need the coverage enhancement is not so much, and the resource allocation is feasible for the PRACH repetition.  I share the view from CATT, that we could merge the Option 3 and Option 4 to a higher level Option as “**Multiple PRACH are transmitted on separate ROs**”  We observed some companies propose the multiple PRACH transmissions can be based on the separate RO and share RO together if any, then we suggest adding the following Option 5,   * Option 5: Multiple PRACH are transmitted on separate ROs and shared ROs if any,   + FFS: detailed scheme.   It is possible that the different options can be used for different cases respectively. And it is also possible the combination of some options is feasible. |
| Lenovo | We don’t think option 1 is needed. Same with CATT and other, option 3 and option 4 can be combined, since they both are regarding configuring separate ROs for PRACH repetition. |

To facilitate the discussion, companies are also encouraged to provide your preference on the above options.

|  |  |
| --- | --- |
| **Companies** | **Preferred Options** |
| Intel | We prefer Option 2 + Option 3. |
| CATT | Option 2+ Option 3 (Option 4 is combined with Option 3) |
| FGI | Option 3 or option 4 |
| DOCOMO | We prefer “option 2 + option 3” or option 4. |
| Qualcomm | We prefer option 2. |
| LG | We prefer to support Option 2 and Option 4. |
| vivo | We prefer Option 2 + Option 3 if our understanding of the definition of options is correct. |
| Samsung | All option 2,3,4 could be considered further. |
| CMCC | We prefer to further study all the options except option 1 |
| Spreadtrum | Option 3 or option4 |
| ZTE | We prefer Option 3 and other pptions are not precluded as we can accept the different options can be used for different cases respectively or the combination of some options. |
| Lenovo | We prefer Option 2 and Option 3/Option 4 (FFS which option to configure separate ROs) |

#### Proposal 2

**For multiple PRACH transmissions with same beams, only TDMed ROs can be utilized for the transmissions.**

Companies are encouraged to provide views on the above proposal.

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| --- | --- |
| **Companies** | **Comments** |
| Intel | A clarification question: does this imply that multiple PRACH transmissions in different ROs cannot be multiplexed in a FDM manner in different time instances? Our understanding is that we also need to consider the freq. hopping for multiple PRACH transmissions to improve the link budget, similar to what was defined for eMTC. |
| CATT | We agree with the proposal. |
| FGI | We agree with this limitation for this release. |
| DOCOMO | Support the proposal. |
| Panasonic | Assuming multiple PRACH transmissions with same beam (not beams), we support that only TDMed ROs can be utilized for the transmissions. |
| Qualcomm | Support |
| LG | Support in principle. To be clearer, we can modify the proposal 2 as follows.  **Proposal 2a**  **For multiple PRACH transmissions with same beams, only ROs located at different times (e.g., starting OFDM symbol or RACH slot) ~~TDMed ROs~~ can be utilized for the transmissions.** |
| vivo | Fine with the proposal in principle.  We assume this does not preclude the RO hopping for multiple PRACH transmissions, to make it clear, it might be good to add an FFS on whether RO hopping can be supported. On top of that, considering only single beam should be assumed for multiple PRACH transmissions, we propose to have following updates. Proposal 2 **For multiple PRACH transmissions with same beam~~s~~, only TDMed ROs can be utilized for the transmissions.**   * FFS whether RO hopping is supported for multiple PRACH transmissions. |
| Samsung | We share the intention of the proposal, some wording change:  **At least TDMed ROs can be utilized for the multiple PRACH transmissions with same beams in one attempt.**  **FFS other options.** |
| CMCC | Support. |
| Spreadtrum | We agree with the proposal. |
| ZTE | Fine with the proposal.  @Intel, frequency hopping is not a FDM manner and won’t be precluded by this proposal. |
| Lenovo | Support the proposal in general. To avoid any misunderstanding, suggest revising the proposal to “**For multiple PRACH transmissions with same beams, FDMed ROs in a same time instance is not supported. ~~only TDMed ROs can be utilized for the transmissions.~~”** |

#### Proposal 3

**For multiple PRACH transmissions with same beams, same PRACH preamble is utilized during the transmissions.**

* + FFS: whether a different preamble can be utilized for re-transmission.

Companies are encouraged to provide views on the above proposal.

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| --- | --- |
| **Companies** | **Comments** |
| Intel | Our understanding is that for each re-transmission, UE can randomly select one preamble for PRACH. It is not clear to us whether the FFS is needed.  To make the proposal clear, we suggest the following update:  **For multiple PRACH transmissions with same beams, same PRACH preamble is utilized during the multiple PRACH transmissions.**   * + ~~FFS: whether a different preamble can be utilized for re-transmission.~~ |
| CATT | We have the same understanding as Intel and agree with the update from Intel. |
| FGI | We propose to modify the proposal a little bit for further clarifying E.g., the same PRACH preamble is utilized during each attempt of a RA procedure |
| DOCOMO | We think it may be related with whether joint detection is required, and also related with Proposal 1. For example, if option 1 in Proposal 1 is supported, joint detection is not possible. It seems not necessary to keep the same preamble on different repetitions. |
| Panasonic | Assuming multiple PRACH transmissions with same beam (not beams), we support that same PRACH preamble is utilized during the transmissions. |
| Qualcomm | We are fine with proposal. In general, we think either the same preamble should be used for all the repetitions or the preambles for different copies should be determined uniquely based on the preamble of the first copy. |
| LG | Agree with Intel. |
| Vivo | We share similar view as Intel that for PRACH retransmission (reattempt after RAR window and back off time), PRACH sequence is selected by UE implementation, it could be random. “multiple PRACH” seems not necessarily repeated in the main bullet.  Furthermore, only single beam should be assumed for PRACH transmissions.  According to above, we propose to have following updates: Proposal 3 **For multiple PRACH transmissions with same beam~~s~~, same PRACH preamble is utilized during the transmissions.**   * ~~FFS: whether a different preamble can be utilized for re-transmission.~~ |
| Samsung | Suggested change:  **For multiple PRACH transmissions with same beams, at least support same PRACH preamble is utilized for all transmissions in the multiple PRACH transmissions ~~during the transmissions.~~**   * + FFS: whether a different preamble can be utilized **in different ~~all~~ transmissions in the multiple PRACH transmissions** ~~for re-transmission~~. |
| CMCC | Fine. |
| Spreadtrum | We suggest making some minor changes to this proposal like “**For multiple PRACH transmissions with same beams, same PRACH preamble is utilized during the transmissions in one RACH attempt.**” |
| ZTE | We think this proposal is fine for CBRA. For CFRA, as the preamble for different repetitions can be configured directly by gNB, it is feasible to further optimize the preamble for multiple PRACH transmissions to achieve the performance gain due to the reduction of collision probability by randomized preamble indexes. So we suggest updating the proposal for further study. Updated Proposal 3 **For multiple PRACH transmissions with same beams under CBRA, same PRACH preamble is utilized during the transmissions.**   * + FFS: whether a different preamble can be utilized for re-transmission.   + FFS: whether a different preamble can be utilized during multiple PRACH transmissions under CFRA. |
| Lenovo | Support the proposal in general. Prefer to remove the FFS. |

### 3.1.2 RAR window and RA-RNTI calculation

#### Proposal 4

**For multiple PRACH transmissions with same beams, down-select one option from the following options.**

* Option 1: One RAR window per each PRACH transmission, the RAR window follows the legacy design.
* Option 2: One RAR window per *K* PRACH transmissions, a RAR window starts after *K* PRACH transmissions.
  + Note: *K* is less than the number of multiple PRACH transmissions.
* Option 3: One RAR window for all of the multiple PRACH transmission.
  + FFS: the start position of the RAR window.

Companies are encouraged to provide views on the above proposal.

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| --- | --- |
| **Companies** | **Comments** |
| Intel | We are generally fine with the proposal. For Option 2, we may need to add a sub-bullet for the determination of K values.   * Option 2: One RAR window per *K* PRACH transmissions, a RAR window starts after *K* PRACH transmissions.   + FFS: details on K   + Note: *K* is less than the number of multiple PRACH transmissions.   One thing for clarification: for Option 1 and 2, if multiple RAR windows overlap in time, do we consider it as single RAR window or still multiple RAR windows? |
| CATT | In our understanding, Option 2 includes Option 1 when *K*=1 so Option 1 can be removed.  One minor editorial comment for Option 3:   * Option 3: One RAR window for all of the multiple PRACH transmissions. |
| FGI | It seems current proposal 2 is a kind of implementation of proposal 3 i.e., K=FFS of option 3. |
| DOCOMO | Generally fine with the proposal.  It should be noted that RAR solution is highly dependent on whether gNB can identify multiple PRACH repetitions, i.e. the PRACH resource configuration design will impact feasibility of these options. |
| Panasonic | We support the proposal 4. |
| Qualcomm | We are fine with the proposal. We prefer option 3. |
| LG | Regarding Option 1, it has the advantage of not having to change the specification, but the UE complexity will be increased since the UE should monitor multiple RARs during multiple PRACH transmissions. Regarding Option 2, it is not beneficial since the specification should be changed and the UE complexity will be increased as well.  Therefore, we prefer to support Option 3. |
| vivo | Some minor updates from our side on top of the updates from Intel: Proposal 4 **For multiple PRACH transmissions with same beam~~s~~, down-select one option from the following options.**   * Option 1: One RAR window per each PRACH transmission, the RAR window follows the legacy design. * Option 2: One RAR window per *K* PRACH transmissions, a RAR window starts after *K* PRACH transmissions.   + FFS: details on K   + Note: *K* is less than the number of multiple PRACH transmissions. * Option 3: One RAR window for all of the multiple PRACH transmission.   + FFS: the start position of the RAR window.   Option 3 is preferred to avoid RAR window optimization. |
| Samsung | We did not see the use case or motivation of option2 so far, but we can live with it in current listed options |
| CMCC | Generally fine with this proposal. |
| Spreadtrum | We are fine with proposal 4. We prefer option 3.  For options 1 and 2, there may be some overlap between two or more RAR windows. UE may need to detect DCI scrambled with two RA-RNTIs in the overlapping area, which may increase the UE complexity. |
| ZTE | Fine with the proposal. |
| Lenovo | Support the proposal. And actually option 2 can include option 1 when K=1. |

To facilitate the discussion, companies are also encouraged to provide your preference on the above options.

|  |  |
| --- | --- |
| **Companies** | **Preferred Options** |
| Intel | Option 3. |
| CATT | Option 3 |
| FGI | Option 3 |
| DOCOMO | If gNB can identify multiple PRACH repetitions, option 3 is preferred. Otherwise, option 1 is the only feasible solution. |
| Panasonic | We prefer Option 1 such that early termination of multiple PRACH transmissions is possible to terminate the subsequent PRACH transmission(s) in advance when UE successfully receives RAR. |
| Qualcomm | Option 3 |
| LG | Option 3. |
| vivo | Option 3 |
| Samsung | Slightly option 3, but can open to discuss option 1 as well. |
| CMCC | We prefer to study Option 1 and 3, depending on whether gNB can detect the tansmissions from same UE. |
| Spreadtrum | Option 3 |
| ZTE | We prefer Option 3 as one RAR window has less impact on UE implementation.  We can also accept Option 1, as Option 1 has less spec impact but need minor enhancement of UE capability on the detection of multiple RARs scrambled with different RA-RNTIs in the overlapping area of RAR windows. |
| Lenovo | We are open to study all the options |

### 3.1.3 Determine the number of multiple PRACH transmissions

#### Proposal 5

**Support at least {2 ,4, 8} for the number of multiple PRACH transmissions with same beams.**

Companies are encouraged to provide views on the above proposal.

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| --- | --- |
| **Companies** | **Comments** |
| Intel | We are fine with the proposal. |
| CATT | We are fine with the proposal. |
| FGI | We agree to have these options |
| DOCOMO | We are fine with the proposal. |
| Panasonic | Assuming multiple PRACH transmissions with same beam (not beams), we support the proposal 5. |
| Qualcomm | Support |
| LG | Support. |
| vivo | According to companies’ evaluation results, at least {2, 4} repetitions are needed if we look at 1% Pmiss (note that 10% Pmiss was assumed for PRACH repetition in eMTC) and do not consider RO hopping.  We do not see the need to consider 8 repetitions which would cause more RO overhead or RA collision to the existing system. If more than 4 repetitions are pursued though not needed, retransmissions can be utilized already when RAR window expires.  Therefore, we propose following updates: Proposal 5 **Support at least {2 ,4~~, 8~~} for the number of multiple PRACH transmissions with same beam~~s~~.** |
| Samsung | Support. |
| CMCC | Support. |
| Spreadtrum | Support the proposal. |
| ZTE | We are fine with the proposal. |
| Lenovo | We are fine with the proposal. |

#### Proposal 6

**For multiple PRACH transmissions with same beams, new SSB-RSRP threshold(s) can be introduced for indicating the number of PRACH transmissions.**

* + FFS detailed scheme, e.g., the number of SSB-RSRP thresholds.
  + FFS: whether multiple PRACH transmissions is enabled only when the transmission power or number of PRACH retransmissions reaching a threshold.
  + FFS: whether multiple PRACH transmissions is enabled only UE reaches maximum transmission power for PRACH transmission.

Companies are encouraged to provide views on the above proposal.

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| --- | --- |
| **Companies** | **Comments** |
| Intel | In Rel-17, we introduced RSRP threshold for the request of Msg3 PUSCH repetition. Our understanding is that we may consider a unified solution for PRACH repetition and Msg3 repetition. In this case, at least when a single PRACH repetition level is configured, we may not need to introduce a new RSRP threshold. Instead, we can consider to reuse the existing one for Msg3 repetition. |
| CATT | We think it is better to replace “new” with “separate”.  We are fine with the proposal with the above replacement. |
| FGI | Agree. We also prefer to have proper linkage between triggering multiple Msg1 transmissions and request for Msg3 repeat. |
| DOCOMO | We are fine with the proposal. |
| Panasonic | Assuming multiple PRACH transmissions with same beam (not beams), we support the proposal 6. |
| Qualcomm | Similar to Intel, we think linkage to the SS-RSRP threshold for Msg3 repetition request should be consider. Therefore, we suggest adding the following bullet:   * + FFS: linkage to the SS-RSRP threshold for Msg3 repetition request. |
| LG | Support in principle. Also we agree with Intel’s comment as well. |
| vivo | Considering PRACH performance is normally better than Msg3 transmission when repetition and retransmission are not applied, therefore a lower threshold may be needed for PRACH repetition compared to the threshold used for request of Msg3 repetition.  Whether this RSRP threshold should be new or it’s just an offset to the RSRP threshold for request of Msg3 repetition can be further studied.  The 2nd and 3rd bullet may be not associated to the RSRP measurement condition, “only” would be better to be removed at this stage.  In current spec. SS-RSRP is used, so it’s better to use same term.  According to above, we have following proposed updates: Proposal 6 **For multiple PRACH transmissions with same beam~~s~~, ~~new~~ SS~~B~~-RSRP threshold(s) can be ~~introduced~~ applied for ~~indicating the number of~~ requesting multiple PRACH transmissions.**   * + FFS detailed scheme, e.g., the number of SS~~B~~-RSRP thresholds, the determination of SS-RSRP thresholds.   + FFS: whether multiple PRACH transmissions is enabled ~~only~~ when the transmission power or number of PRACH retransmissions reaching a threshold.   + FFS: whether multiple PRACH transmissions is enabled ~~only~~ UE reaches maximum transmission power for PRACH transmission. |
| Samsung | We understand the intention is to apply RSRP to determine the use of multiple PRACH transmission. Thus some following change is suggested:  **For multiple PRACH transmissions with same beams, ~~new~~ the SSB-RSRP threshold(s) can be introduced for determining the use of multiple PRACH transmission ~~indicating the number of PRACH transmissions~~.**  **FFS: details.** |
| CMCC | If this threshold also determine whether or not PRACH repetition is activated, then the numbers of multiple PRACH transmissions should include {1}, or it should be **“new SSB-RSRP threshold(s) can be introduced for indicating the number of PRACH transmissions / for enabling multiple PRACH transmissions.”** |
| Spreadtrum | Generally fine with this proposal.  If poor uplink coverage exists, it may have the requirement of both PRACH and Msg3 repetition. So we share the same view with Qualcomm. |
| ZTE | Fine with the proposal.  @Intel, Qualcomm, We are not sure the threshold for Msg3 repetition and PRACH repetition is the same as the two channels has different detection and decoding performance requirement. If we want to reuse the threshold for Msg3 repetition, the coupling relationship between PRACH repetition and Msg.3 repetition should be studied first. Moreover, there is only one threshold for Msg3 repetition which is not sufficient for the demand of multiple thresholds for different repetition factors of PRACH. |
| Lenovo | Fine with the proposal. |

#### Discussion for issue #8

FL comment: As summarized in section 2.1.3 Issue #8, companies discuss the mapping between multiple PRACH transmissions and valid RO. [Ericsson] proposes that validation rules are **applied after** ROs for multiple PRACH occasions are determined for a specific number of PRACH transmissions, while [Qualcomm] propose that the counting of PRACH repetitions is **based on the valid ROs**.

Companies are encouraged to provide views on the above issue.

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| **Companies** | **Comments** |
| Intel | Our understanding is that it should be based on valid ROs. Otherwise, we may complicate the SSB to RO association for multiple PRACH transmissions. |
| CATT | We think this can be discussed later after discussing the SSB-to-RO mapping for PRACH repetitions. |
| FGI | Since the multiple PRACH transmissions may occupy ROs (TDMed is assumed) spreading along with several association periods/configuration periods. It is possible to meet cases that ROs are not valid. We agree to have such restriction and to further discuss definition of the valid ROs. |
| DOCOMO | We think it is more reasonable to be based on valid ROs. |
| Panasonic | We think both approaches can work. Qualcomm’s approach can obtain more actual repetitions than Ericsson’s approach, but it requires more discussion because Ericsson’s approach just uses the existing mechanism. |
| LG | We slightly prefer the first option proposed by Ericsson, but we can discuss further this issue. |
| vivo | Share similar view as Intel that in legacy SSBs are only mapped to valid ROs. If invalid ROs are considered to repetitions, then there would be no SSBs mapped to that repetition.  So valid RO should be considered for multiple PRACH transmission if we reuse legacy ROs for all repetitions.  However, if we configure separate ROs after some legacy ROs, then those ROs could be invalid but may be counted for PRACH repetitions though they may be not actually used for some PRACH repetitions.  Therefore, this depends on how we configure the ROs for PRACH repetitions and we propose to come back to this discussion when PRACH resource configuration is clear. |
| Samsung | This issue could be deferred until more clear resource design of multiple PRACH has come out. |
| CMCC | The understanding about the valid ROs for gNB and UE should be aligned. |
| Spreadtrum | We think PRACH repetitions should be based on the valid ROs since the repetitions number reached the expectation. |
| ZTE | If Multiple PRACH transmissions will use part of shared ROs, the original principle should be followed, i.e., mapping based on valid RO.  If Multiple PRACH transmissions will only use separate RO, we can further study whether the validation rules are applied after ROs determination. The obvious gain should be observed if we want change the rules. Primitively, I think a unified rule, i.e., multiple PRACH transmissions based on valid ROs is better for the compatibility. |
| Lenovo | We think it should be based on valid ROs. |

### 3.1.4 Power control

#### Proposal 7

**For multiple PRACH transmissions with same beams, down-select one option from the following options.**

* Option 1: Transmission power ramping is not applied during the multiple PRACH transmissions.
  + The same measurement of the same reference signal to calculate the pathloss is applied for each PRACH transmissions.
* Option 2: Transmission power ramping is applied per PRACH transmission during the multiple PRACH transmissions.
  + FFS: The initial power and power ramping step.

Companies are encouraged to provide views on the above proposal.

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| --- | --- |
| **Companies** | **Comments** |
| Intel | We would like to understand better on the motivation of Option 2. It is not clear to us why we need to introduce power ramping during multiple PRACH transmissions. This may create severe near far issue for PRACH detection, especially when the number of repetitions is large. |
| CATT | We are also not clear about the motivation of Option 2 and prefer Option 1. |
| FGI | We prefer option 1. |
| DOCOMO | Open to further discuss pros/cons/motivations for the two options. We slightly prefer option 1 now. |
| Panasonic | Assuming multiple PRACH transmissions with same beam (not beams), we support Option 1. |
| Qualcomm | We prefer option 1. |
| LG | We prefer to support Option 1. |
| vivo | Fine to discuss the 2 options.  For option1, we should also discuss whether separate power control parameters are needed when repetition is enabled compared to PRACH transmission without repetition.  For option 2, in our understanding, if UE would do power ramping after finishing all repetitions, then power ramping during the repetitions would be helpful so that UE can reach highest power as early as possible. Note that PRACH repetitions can be combined in different segments or noncoherently if more repetitions are introduced. Currently we do not think that many repetitions are needed, 2 or 4 repetitions are enough as we discussed in earlier section. Proposal 7 **For multiple PRACH transmissions with same beam~~s~~, down-select one option from the following options.**   * Option 1: Transmission power ramping is not applied during the multiple PRACH transmissions.   + The same measurement of the same reference signal to calculate the pathloss is applied for each PRACH transmissions.   + FFS: The initial power and power ramping step * Option 2: Transmission power ramping is applied per PRACH transmission during the multiple PRACH transmissions.   + FFS: The initial power and power ramping step. |
| Samsung | We did not see the reason why in the multiple PRACH transmission of the same attempt, there should be different power applied. Thus, we did not support option2 even listed as one option to be discussed. We can discuss how to do power ramping for RACH re-attempt/retransmission. |
| CMCC | We prefer option 1. |
| Spreadtrum | Option1 can be used as a basic option, but Option 2 should not be excluded in current stage. We agree to further discuss the pros/cons/motivations for option 2. |
| ZTE | Fine with the proposal. We prefer Option 2 as the multiple PRACH transmission can be regarded as the legacy PRACH retransmission compressed in time domain. Then the power ramping principle can also be used for multiple PRACH transmissions in one attempt.  A question to be clarified? Does the sub-bullet under Option 1 can also be applied for Option 2. I think the sub-bullet implies for each PRACH, UE will try to measure the SSB again, and the pathloss may be different among all the measurements.  We can update the Option 2 as below if my understanding is right.  Option 2: **Transmission power ramping is applied per PRACH transmission during the multiple PRACH transmissions.**   * + FFS: The initial power and power ramping step.   + FFS: The same measurement of the same reference signal to calculate the pathloss is applied for each PRACH transmissions. |
| Lenovo | We prefer option 1. We think all the transmission within the repetition should be seen as one PRACH attempt. |

## 3.2 Multiple PRACH transmissions with different beams

### 3.2.1 Potential use cases

#### Discussion for issue #9

FL comment: As summarized in section 2.2.1 Issue #9, the objective doesn’t have a limitation on whether multiple PRACH transmissions with different beams is associated with same or different SSBs, companies [China Telecom, CATT] think there is a need to clarify on this issue.

* Option 1: Multiple PRACH transmissions with different beams are associated with the same SSB.
* Option 2: Multiple PRACH transmissions with different beams are associated with different SSBs.

Companies are encouraged to provide views on the above options.

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| **Companies** | **Comments** |
| Intel | We think at least Option 1 can be supported for Rel-18 given the benefit of improving reliability and reduced latency, especially for initial access. We are open to consider to study Option 2 if time permits. |
| CATT | We think Option 1 can be prioritized for further study. |
| FGI | We slightly prefer option 1. |
| DOCOMO | We are open to discuss the two cases. |
| Panasonic | We would like to clarify the meaning of “different beams”.   * For Option 1, does “different beams” refer to different finer beams? * For Option 2, does “different beams” refer to different finer beams or different SSB-based beams? |
| Qualcomm | We are open to discuss both cases. However, we think option 2 can be more problematic (may need more time for discussion). |
| LG | Support for multiple PRACH transmissions with different beams requires additional specification changes (e.g., best beam indication) compared to supporting only multiple PRACH transmissions with the same beam. Moreover, the discussion of improving Msg3 PUSCH coverage using Tx beam diversity is not the scope of Rel-18 CE. Therefore, we think that multiple PRACH transmission with same beams are prioritized in Rel-18 CE. After that, if discussion time is available, then this issue can be discussed further. |
| vivo | Option1 to us is up to UE implementation, which is already what UE does in current spec. There’s no requirement for UE to use the SSB beam for PRACH transmission. In our understanding, if the narrower beams are intended for beam refinement of Msg3 or later uplink transmissions, this would require long latency to complete the beam sweeping meaning that UE can already do retransmission in which uplink beam sweeping can also be performed. In addition, this is out of the scope of this work item and we should focus on PRACH enhancement itself.  For Option 2, when PRACH repetitions are mapped to different SSBs and different beams are used, UE would select best beam for multiple PRACH transmissions. There’s no need to introduce such multiple beam PRACH transmission.  According to the discussions in section 3.1, 2 to 4 repetitions with same beam can already compensate the performance gap, there’s no need to discuss multiple beam PRACH repetition transmissions which will also have large spec. impact. |
| Samsung | For discussion purpose, we think eventually both options can have some use cases. Option 2 could be used for the method that allowing multiple SSB selection to facilitate multiple PRACH transmission. Also it could be used for UE with multiple panel, which is decoupled with whether associated same/different SSB. |
| CMCC | We think option1 can be further study firstly. For the option 2, gNB may can not decided how to merge ROs associated with different SSBs |
| Spreadtrum | We prefer option 1.  For option 2, it should be further clarified the way in which multiple PRACH transmissions with different beams are associated with different SSBs, such as 1:1 mapping or N:1 mapping, etc. |
| ZTE | Similar as Intel, at least Option 1 can be supported for Rel-18.  Actually, the specification work for multiple PRACH transmissions with different beams is not much more than that for the multiple PRACH transmissions with the same beam. Most rules can be reused. For some specific enhancement such as best beam indication, if any, the implicit indication can be considered and the specification work is not big issue. |
| Lenovo | We are fine with the proposal. |

### 3.2.2 Performance gain

FL comment: Based on the contributions, companies compared the performance between multiple PRACH transmissions with same beam and different beams, link-level simulation results are provided. FL propose to discuss the following observations.

#### Observation 1

* One source (R1-2208671) shows the performance gain of single beam repetition is **2.1dB better than that of multiple beam repetition** for the case of 8 PRACH repetitions. (@28GHz, PRACH format B4, CDL-A (DS 100ns) for different beams, TDL-A (DS 100ns) for single beam, soft combination within one PRACH signal for same beam)
* One source (R1-2209672) shows that for the same number of PRACH transmissions, **the transmission with different beams** (beam sweeping) has a **loss of about 5dB** compared with transmissions **with the same best beam**. PRACH transmissions with **different beams (beam sweeping) outperforms** the transmissions with the **same wide beam** by **about 1dB** for the same number of transmissions. (@28GHz, PRACH format B4, CDL-A (DS 100ns))
* One source (R1-2210165) shows that 4 PRACH repetitions with **different beams provide a gain** of around **7dB** compared to the case of one single PRACH transmission with narrow beam pointing to the direction of maximum energy for the channel model under consideration. (@28GHz, PRACH format B4, CDL-A with 100ns delay spread, the single PRACH transmission pointing to the direction of maximum energy for the channel model, receiver does not perform repetition combining)
* One source (R1-2210165) shows that multiple PRACH transmissions with **different narrow beams perform** **better** than multiple PRACH transmission with a same wide beam. (Comparison of SNR values at 99% detection probability, 4 PRACH transmissions with same wide transmission beam is -13dB, 4 PRACH transmissions with different narrow beams is -17dB)

Companies are encouraged to provide views on the above observation.

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| **Companies** | **Comments** |
| vivo | Agree that PRACH repetition with multiple narrow beams could help the beam management of latter uplink transmissions after PRACH transmission according to the evaluations though the gain may be different due to different precoders and CDL models considered. However, This is not in scope of this study. And for PRACH itself the repetition with same beam is already enough to compensate the gap with a small number of repetitions. Furthermore, note that PRACH retransmission would also help UE to try different narrow beams so that UE can pick a best uplink narrow beam for latter retransmission or repetitions. All these can be performed up to UE implementation.  Moreover, supporting beaming sweeping in uplink would also be a new UE capability compared to legacy PRACH transmission and the PRACH repetition with same beam. This means another level of PRACH partitioning would be needed which would be too complex for this work item.  According to above, we think PRACH repetition with multiple beams should be deprioritized and we focus on design of PRACH repetition with same beam. |
| Samsung | Among some of the simulation, especially for comparing the multiple PRACH with different beam with same beam, e.g., the one from [R1-2208671], we think the assumption that UE always know the best UL tx beam is not always applicable, it should be explicitly noted when states the observation based on the simulation results. |
| ZTE | Multiple PRACH transmissions with different beams is suitable for the UEs incapable of beam correspondence as UE may not find the best beam in the first attempt. For the simulation, the comparison baseline should be the performance of single PRACH transmission with wide beam or randomized selected finer beam. From some simulations results, it can be observed that the coverage gain from the transmission with different beams is obvious. |

1. Reference
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3. 3GPP RP-221858, “Revised WID on Further NR coverage enhancements”, China Telecom, RAN #96, Budapest, Hungary, June 6-9, 2022.
4. R1-2208411 Discussion on PRACH coverage enhancements Huawei, HiSilicon
5. R1-2208488 Discussion on PRACH coverage enhancements ZTE
6. R1-2208575 Discussion on PRACH coverage enhancements Spreadtrum Communications
7. R1-2208671 Discussions on PRACH coverage enhancements vivo
8. R1-2208784 Discussion on PRACH coverage enhancement China Telecom
9. R1-2208846 PRACH coverage enhancements OPPO
10. R1-2208963 PRACH coverage enhancements CATT
11. R1-2209001 PRACH coverage enhancements TCL Communication Ltd.
12. R1-2209025 Discussion on PRACH Coverage Enhancement Fujitsu
13. R1-2209078 Discussions on PRACH coverage enhancement Intel Corporation
14. R1-2209116 PRACH Coverage Enhancement using Multi PRACH Transmissions Sony
15. R1-2209130 Discussion on PRACH coverage enhancements Panasonic
16. R1-2209159 Discussion on PRACH coverage enhancement NEC
17. R1-2209223 PRACH coverage enhancements Lenovo
18. R1-2209249 Discussion on solutions for NR PRACH coverage enhancement Mavenir
19. R1-2209272 Discussion on PRACH coverage enhancements xiaomi
20. R1-2209363 Discussion on PRACH coverage enhancements CMCC
21. R1-2209412 PRACH coverage enhancements ETRI
22. R1-2209415 Discussion on triggering multiple PRACH transmissions FGI
23. R1-2209521 Enhancements for PRACH coverage MediaTek Inc.
24. R1-2209608 Discussion on PRACH coverage enhancement Apple
25. R1-2209661 Discussion on PRACH repetition InterDigital, Inc.
26. R1-2209672 Discussion on PRACH coverage enhancement Ericsson
27. R1-2209759 PRACH coverage enhancements Samsung
28. R1-2209788 Views on multiple PRACH transmission for coverage enhancement Sharp
29. R1-2209803 Discussion on PRACH repeated transmission for NR coverage enhancement LG Electronics
30. R1-2209925 Discussion on PRACH coverage enhancements NTT DOCOMO, INC.
31. R1-2210013 PRACH Coverage Enhancements Qualcomm Incorporated
32. R1-2210165 PRACH coverage enhancements Nokia, Nokia Shanghai Bell