**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, 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.

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

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| **Companies** | **Preferred Options** |
| Intel | We prefer Option 2 + Option 3. |
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#### 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. |
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#### 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.~~ |
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### 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? |
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To facilitate the discussion, companies are also encouraged to provide your preference on the above options.

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| **Companies** | **Preferred Options** |
| Intel | Option 3. |
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### 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. |
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#### 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. |
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#### 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. |
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### 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. |
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## 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. |
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### 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** |
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1. Reference
2. 3GPP RP-213579, “New WI: Further NR coverage enhancements”, China Telecom, RAN#94e, December 6-17, 2021.
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