**3GPP TSG-RAN WG4 Meeting # 104-e R4-2214248**

**Electronic Meeting, 15– 26 August 2022**

**Agenda item:** 11.14.4

**Source:** Moderator (Intel Corporation)

**Title:** Email discussion summary for [104-e][137] FS\_NR\_pos\_UERF

**Document for:** Information

# Introduction

*This document covers RAN4 discussions on general aspects and accuracy improvement studies of the expanded and improved NR positioning study item.*

It is appreciated that the delegates for this topic put their contact information in the table below.

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1. Please add your contact information in above table once you make comments on this email thread.
2. If multiple delegates from the same company make comments on single email thread, please add you name as suffix after company name when make comments i.e. Company A (XX, XX)

# Topic #1: General and work plan

## Companies’ contributions summary

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| **T-doc number** | **Company** | **Proposals / Observations** |
| **[R4-2212149](https://www.3gpp.org/ftp/TSG_RAN/WG4_Radio/TSGR4_104-e/Docs/R4-2212149.zip)**  Work Plan for Study Item on Expanded and Improved NR Positioning | Intel Corporation | *Paper provides a tentative work plan for RAN4 for information purposes* |

## Open issues summary

### Sub-topic 1-1: Work plan

*A tentative work plan for RAN4 tasks is provided below (R4-2212149)*

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| **RAN4 Meetings** | **Tentative Work Plan** |
| RAN4#104-e August 2022, (RF 0.25 TUs) | * Review initial version of the 3GPP TR 38.859 and input to RAN1 on content, if there is any * Study solutions for accuracy improvement based on NR carrier phase measurements   + Focus on RAN4 RF aspects and potential inputs to RAN1, if any * Initial study on potential solutions for PRS/SRS bandwidth aggregation for intra-band carriers considering potential timing errors, phase coherency, frequency errors, power imbalance, etc |
| RAN4#104bis-e October 2022, (RF 0.25 TUs RD 0.5 TUs) | * Evaluation work on potential solutions for PRS/SRS bandwidth aggregation for intra-band carriers considering potential timing errors, phase coherency, frequency errors, power imbalance, etc. * Continue study solutions for accuracy improvement based on NR carrier phase measurements   + Focus on RAN4 RF aspects and potential inputs to RAN1, if any * Preparation of text proposals for 3GPP TR 38.859, if there are any |
| RAN4#105 November 2022,  (RF 0.25 TUs RD 0.5 TUs) | * Finalization of the study on PRS/SRS bandwidth aggregation for intra-band carriers and carrier phase measurements * Preparation of text proposals and study item conclusions on bandwidth aggregation and carrier phase measurements * LS to RAN1 with a request to incorporate RAN4 updates to the 3GPP TR 38.859 |

**Issue 1-1: Work plan for RAN4**

* Recommended WF
  + Companies are encouraged to review the content of the tentative work plan. In case there are any comments, please share them in the **Open issues** section below.

## Companies views’ collection for 1st round

### Open issues

Issue 1-1: RAN4 work plan

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| **Company** | **Comments** |
| ZTE | In general, we are fine with the work plan, however for RD part, we just wonder what’s kind of work would fall into the RD discussion. Is that accuracy performance evaluation with RF impairment to be discussed in RD session, if so, I guess the work efficiency might be impacted at the end. |
| Intel | ZTE raises a good question regarding how the discussion might be split between the RF TUs and the RD TUs. The discussion is mainly related to RF impairments and their impact to potential accuracy. It may not be the most efficient approach to split discussion between 2 sessions for the next meeting and we think it would be useful for the chairman to give this careful consideration in preparations for the next meeting. |

## Summary for 1st round

### Open issues

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|  | **Status summary** |
| **Sub-topic #1-1: Work plan** | **Issue 1-1: Work plan for RAN4**  *The scope and time distribution for RD discussions was brought up as potentially impacting work efficiency. It was further suggested to not split discussions between the two sessions in the upcoming meeting.*  *Recommendations for 2nd round:*  *Consider suggested change to discussion split for upcoming RAN4 #104Bis-e meeting* |

## Discussion on 2nd round

**Issue 1-1: Work plan for RAN4**

*Companies are invited to share their views on the discussion split for upcoming RAN4 #104Bis-e meeting*

## Companies views’ collection for 2nd round

### Open issues

Issue 1-1: RAN4 work plan

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| **Company** | **Comments** |
| Ericsson | We are fine with the suggested change to discussion split for the upcoming meeting. |

## Summary for 2nd round

### Open issues

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|  | **Status summary** |
| **Sub-topic #1-1: Work plan** | *TBA* |

# Topic #2: Accuracy improvement studies

## Companies’ contributions summary

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| **T-doc number** | **Company** | **Proposals / Observations** |
| **[R4-2212210](https://www.3gpp.org/ftp/TSG_RAN/WG4_Radio/TSGR4_104-e/Docs/R4-2212210.zip)**  On the feasibility of PRS/SRS bandwidth aggregation for enhanced positioning accuracy | Qualcomm Incorporated | *Timing errors*  **Observation 1:** Timing error between PRS/SRS layers/carriers must be on the order of ~1⁄BW or smaller, where BW is the carrier bandwidth, to obtain coherent combining gain, assuming zero phase error between layers/carriers. Non-coherent gain may still be possible for larger time offsets.  **Observation 2:** Timing errors between carriers can be avoided if all the carriers are generated/transmitted with a single transmitter chain and processed/received with a single receiver chain.  *Phase errors*  **Observation 3:** Phase error between PRS/SRS layers/carriers is a critical factor for determining the feasibility of PRS/SRS bandwidth aggregation. The combining loss due to phase error between carriers can be arbitrarily large.  **Observation 4:** Phase errors between carriers may be avoided if all the carriers are generated/transmitted with a single transmitter chain and processed/received with a single receiver chain.  *Frequency errors*  **Observation 5:** Frequency error between carriers is not a critical factor to determine the feasibility of PRS/SRS bandwidth aggregation.  *Power imbalance*  **Observation 6:** Power imbalance between carriers is not a critical factor to determine the feasibility of PRS/SRS bandwidth aggregation.  *Group delay errors*  **Observation 7:** For SRS/PRS bandwidth aggregation, RAN4 would need to address the question of how to derive corresponding group delay margins, dependent on the transmitter/receiver architecture.  *Single Tx chain*  **Observation 8:** For a single Tx chain architecture,   * PRS/SRS aggregation is feasible * Single Tx chain is not limited to implementations with a single IFFT * Improved group delay calibration accuracy may be achieved vs other architectures that feature separate Tx chains for each layer/carrier.   *Split baseband Tx with dual LOs*  **Observation 9:** For a Tx architecture with split baseband chains and dual LOs,   * PRS/SRS aggregation may be feasible subject to constraints on the maximum timing alignment error and phase error. * The time span of RS allocations across layers/carriers should be coordinated to avoid excessive impact from frequency error. * No improvement in group delay calibration may be achieved vs single layer/carrier.   *Separate Tx chains*  **Observation 10:** For a Tx architecture with separate chains,   * PRS/SRS aggregation may be feasible subject to constraints on the maximum timing alignment error and phase error. * The time span of RS allocations across layers/carriers should be coordinated to avoid excessive impact from frequency error. * No improvement in group delay calibration may be expected vs single layer/carrier.   *Single Rx chain*  **Observation 11:** For a single Rx chain architecture,   * PRS/SRS aggregation is feasible * Single Rx chain is not limited to implementations with a single FFT * Improved group delay calibration accuracy may be achieved vs other architectures that feature separate Rx chains for each layer/carrier.   *Separate Rx chains*  **Observation 12:** For a Rx architecture with separate chains,   * PRS/SRS aggregation may be feasible subject to constraints on the maximum timing alignment error and phase error. * The time span of RS allocations across layers/carriers should be coordinated to avoid excessive impact from frequency error. * No improvement in group delay calibration may be achieved vs single layer/carrier.   *Quasi co-location*  **Observation 13a:** For aggregation of PRS resources from the same TRP across PFLs, if the PRS resources are associated with different ARPs, physical proximity between the ARPs should be considered as a pre-condition for aggregation.  **Observation 13b:** For aggregation of SRS resources across carriers, physical proximity between the UE Tx antennas used to transmit all the SRS resources should be considered as a pre-condition for aggregation.  **Observation 14:** For bandwidth aggregation of PRS/SRS resources, proximity assumptions/conditions on the Tx beams/ports should be considered as a pre-condition for aggregation.  *Time-frequency structure*  **Observation 15:** Assuming a common time-frequency signal structure across layers/carriers, including at least SCS and CP, would facilitate bandwidth aggregation of PRS/SRS resources.  *Proposals*  **Proposal 1:** PRS/SRS bandwidth aggregation over intra-band layers/carriers is feasible for single chain Tx/Rx architectures (not limited to single IFFT/FFT).   * At least contiguous carriers can be supported with single Tx chain * FFS: Support of non-contiguous carriers with single Tx chain * Additional requirements on the frequency response across the full aggregated bandwidth (e.g., phase response characterization accuracy) may be discussed during the WI phase.   **Proposal 2:** For Tx/Rx architectures that cannot avoid timing errors, further study and discuss the maximum timing error that can be tolerated between aggregated PRS/SRS layers/carriers.  **Proposal 3:** For Tx/Rx architectures that cannot avoid phase errors, further study and discuss the maximum phase error that can be tolerated between aggregated PRS/SRS layers/carriers. |
| **[R4-2213277](https://www.3gpp.org/ftp/TSG_RAN/WG4_Radio/TSGR4_104-e/Docs/R4-2213277.zip)**  On accuracy improvement based on PRS/SRS bandwidth aggregation | Ericsson | *Observations*  **Observation 1:** Cramér-Rao lower bound on the ToA error variance scales to the inverse square of the PRS bandwidth under the fixed Tx power assumption.  **Observation 2:** The ToA error variance is inversely proportional to the number of consecutive PRS resources (which is seen if we interpret the PFLs l=1,2,…,m as different PRS resources with the same bandwidth n\_l=n).  **Observation 3:** If the number of PRS resources is doubled (for example, from a 1-slot staggered comb-k PRS to a 2-slot staggered comb-k PRS at the same bandwidth), the ToA error variance is halved.  **Observation 4:** ToA error variance decreases faster with increase in bandwidth than increasing PRS resources in the time dimension.  **Observation 5:** Increased PRS bandwidth by aggregating PRS resources from multiple PFLs helps improve RSTD and UE Rx-Tx measurement accuracy.  **Observation 6:** The total PRS bandwidth after aggregation does not enhance achievable ToA accuracy if the aggregated PRS resources in different PFL that are combined are non-coherent in phase.  **Observation 7:** Maintaining phase consistency between the PRS resources in different PFLs is easier when PFLs are within the same band and are contiguous.  **Observation 8:** Timing alignment between PRS resources transmitted in different PFLs impact achievable ToA accuracy.  **Observation 9:** For intra-band contiguous carrier aggregation, TAE shall not exceed 260ns and 130ns for BS type 1-C/BS type 1-H and BS type 2-O, respectively.  **Observation 10:** For intra-band non-contiguous carrier aggregation, TAE shall not exceed 3μs for base station types 1-C and 1-H and TAE shall not exceed 260ns for BS type 2-O.  **Observation 11:** For inter-band carrier aggregation, TAE shall not exceed 3μs for BS type 1-C and BS type 1-H and TAE shall not exceed 3μs for BS type 2-O.  *Proposals*  **Proposal 1:** RAN4 to study solutions for accuracy improvement based on PRS bandwidth aggregation only for intra-band contiguous carriers.  **Proposal 2:** RAN4 to study solutions for accuracy improvement based on SRS bandwidth aggregation only for intra-band contiguous carriers. |
| **[R4-2213589](https://www.3gpp.org/ftp/TSG_RAN/WG4_Radio/TSGR4_104-e/Docs/R4-2213589.zip)**  Discussion on NR positioning measurement accuracy improvement based on bandwidth aggregation | Nokia, Nokia Shanghai Bell | **Observation 1:** signal characteristic and property in aggregated bandwidth should be investigated in gNB/UE TX and RX respectively. RF impairments appear differently across multiple CCs and impact high accuracy positioning measurements measured in aggregated bandwidth depending on CA configurations.   1. Intra-band contiguous CA with simultaneous PRS/SRS transmission 2. Intra-band contiguous CA with separate PRS/SRS transmission 3. Intra-band non-contiguous CA with simultaneous PRS/SRS transmission 4. Intra-band non-contiguous CA with separate PRS/SRS transmission   **Proposal 1:** The most feasible case of the study will be ‘intra-band contiguous CA with simultaneous PRS/SRS transmission.’ RAN4 prioritizes the case over non-contiguous aggregation manner or scheduling PRS/SRS in different time slots.  **Proposal 2:** RAN4 assumes that the legacy FFT processing strategy of legacy RXs, that is one FFT processing per CC with standard FFT size, must be baseline. Processing with extended FFT-size specifically for high accuracy positioning measurement is not assumed as baseline.  **Proposal 3:** RAN4 investigates if RF impairment (i.e. timing errors, phase coherency, frequency errors, power imbalance) appears consistently in aggregated bandwidth. Especially, phase coherency in aggregated bandwidth is important to achieve high accuracy of ToA estimation.  **Proposal 4:** For FR2 gNB/UE, phase noise is one of RF impairment sources impacting phase coherency, its impact needs to be investigated. |
| **[R4-2213688](https://www.3gpp.org/ftp/TSG_RAN/WG4_Radio/TSGR4_104-e/Docs/R4-2213688.zip)**  Discussion on CA based positioning enhancement | ZTE Corporation | *RF architecture for intra-band contiguous CA*  **Observation 1:** From BS hardware supporting the intra-band contiguous CA case, timing difference/phase coherency among the aggregated contiguous carriers would be mainly impacted by group delay response of PA and analog filtering in different frequency ranges. For other error source which might impact positioning accuracy e.g., frequency error or power imbalance, these contributing factor in intra-band contiguous CA case is negligible.  **Observation 2:** From UE hardware perspective, just similar as BS side, timing difference/phase coherency among the aggregated contiguous carriers would be mainly impacted by group delay response of PA and analog filtering in different frequency ranges. For other error source which might impact positioning accuracy e.g., frequency error or power imbalance, these contributing factor in intra-band contiguous CA case is negligible.  *Performance evaluation for intra-band contiguous CA*  **Proposal 1:** RAN4 need to study the minimum requirements to achieve the positioning accuracy improvement for intra-band contiguous CA compared with single component carrier case and its feasibility to fulfil the minimum requirements  *FR1 intra-band contiguous CA*  **Observation 3:** for FR1 intra-band contiguous CA scenario, extremely small timing difference (e.g., less than 2ns) in UL between contiguous CCs is feasible.  *FR2 intra-band contiguous CA*  **Observation 4:** for FR2 intra-band contiguous CA scenario, extremely small timing difference between contiguous CCs due to RF filtering is around 0.2ns |
| **[R4-2213730](https://www.3gpp.org/ftp/TSG_RAN/WG4_Radio/TSGR4_104-e/Docs/R4-2213730.zip)**  RF impacts on positioning bandwidth aggregation for intra-band carriers | Huawei, HiSilicon | *Intra-band CA scenarios*  **Proposal 1:** Focus on intra-band contiguous CA for positioning bandwidth aggregation.  **Proposal 2:** RAN4 will not discuss the issue of power imbalance for intra-band continuous CA, but should notify RAN1 that UE transmission power may be subject to prioritization of PCell over SCell, when the transmission power exceeds the maximum value.  *RF impact*  **Observation 1:** For transmitter and receiver with the RF architecture to support intra-band contiguous CA, no frequency error can be assumed present between CCs, and the phase coherency can be assumed between CCs.  **Proposal 3:** RAN4 should further study the timing error between intra-band contiguous CCs introduced by different group delays within the bandwidth of the wideband RF filters and amplifiers. |
| **[R4-2212211](https://www.3gpp.org/ftp/TSG_RAN/WG4_Radio/TSGR4_104-e/Docs/R4-2212211.zip)**  On improved positioning via NR carrier phase measurements | Qualcomm Incorporated | **Proposal 1:** RAN4 should study how to model impacts of antenna/beam phase response, residual carrier-frequency offset, and frequency drift on carrier phase positioning |
| **[R4-2213278](https://www.3gpp.org/ftp/TSG_RAN/WG4_Radio/TSGR4_104-e/Docs/R4-2213278.zip)**  On accuracy improvement based on NR carrier phase measurements | Ericsson | **Proposal 1:** RAN4 to wait for further progress in RAN1 to evaluate and assess the scope of solutions based on NR carrier phase measurements to be studied by RAN4. |
| **[R4-2213689](https://www.3gpp.org/ftp/TSG_RAN/WG4_Radio/TSGR4_104-e/Docs/R4-2213689.zip)**  Discussion on carrier phase based positioning | ZTE Corporation | **Observation 1:** for the initial random phase error is limited to 0 ~ 0.001\*2π, the performance is still degraded significantly (esp., for a large scope of integer for searching).  **Proposal 1:** RAN4 need to study the timing error and phase errors among different TRPs and provide the corresponding information to RAN1. |
| **[R4-2213731](https://www.3gpp.org/ftp/TSG_RAN/WG4_Radio/TSGR4_104-e/Docs/R4-2213731.zip)**  RF aspects of carrier phase measurements | Huawei, HiSilicon | *Carrier phase modeling*  **Observation 1:** The receive baseband phase can represent RF carrier phase measurement.  *Practical RF impairments*  **Observation 2:** Tx RF and Rx RF may add additional group delay, which will further add the phase offset, resulting in the observed baseband Rx phase being the lump sum of the following phase components   * Phase corresponding to the fractional part of a wavelength in the propagation distance. * Initial phase difference in the oscillators between Tx and Rx * Additional RF delay caused by filters and amplifiers at both Tx and Rx   **Proposal 1:** The practical RF impairments can be mitigated by double difference methods with the phase measurement in the baseband, and thus will not define the RF requirement for carrier phase measurements.   * The carrier phase measurement requirement should be covered by RRM.   *Phase continuity over time*  **Proposal 2:** No need to define the requirement of phase continuity across slots for carrier phase positioning for both TDD and FDD spectrum. |

## Open issues summary

### Sub-topic 2-1: Study based on PRS/SRS bandwidth aggregation

*This sub-topic addresses the following objective from the study item description (RP-221814):*

* *Study solutions for accuracy improvement based on PRS/SRS bandwidth aggregation for intra-band carriers considering e.g., timing errors, phase coherency, frequency errors, power imbalance, etc. [RAN4]*

**Issue 2-1a: Intra-band CA scenario**

* Proposals
  + Proposal 1: RAN4 to study solutions for accuracy improvement based on PRS bandwidth aggregation only for intra-band contiguous carriers. (Ericsson, R4-2213277)
  + Proposal 2: RAN4 to study solutions for accuracy improvement based on SRS bandwidth aggregation only for intra-band contiguous carriers. (Ericsson, R4-2213277)
  + Proposal 3: The most feasible case of the study will be ‘intra-band contiguous CA with simultaneous PRS/SRS transmission.’ RAN4 prioritizes the case over non-contiguous aggregation manner or scheduling PRS/SRS in different time slots. (Nokia, R4-2213589)
  + Proposal 4: Focus on intra-band contiguous CA for positioning bandwidth aggregation. (Huawei, R4-2213730)
* Recommended WF
  + Above proposals align in focusing the study on intra-band contiguous CA scenario. Companies are invited to share their views on whether to limit scope of study to intra-band contiguous carriers only.

**Issue 2-1b: Scope of study based on PRS/SRS bandwidth aggregation**

* Options
  + Proposal 1: For Tx/Rx architectures that cannot avoid timing errors, further study and discuss the maximum timing error that can be tolerated between aggregated PRS/SRS layers/carriers. (Qualcomm, R4-2212210)
  + Proposal 2: For Tx/Rx architectures that cannot avoid phase errors, further study and discuss the maximum phase error that can be tolerated between aggregated PRS/SRS layers/carriers. (Qualcomm, R4-2212210)
  + Proposal 3: RAN4 investigates if RF impairment (i.e., timing errors, phase coherency, frequency errors, power imbalance) appears consistently in aggregated bandwidth. Especially, phase coherency in aggregated bandwidth is important to achieve high accuracy of ToA estimation. (Nokia, R4-2213589)
  + Proposal 4: For FR2 gNB/UE, phase noise is one of RF impairment sources impacting phase coherency, its impact needs to be investigated. (Nokia, R4-2213589)
  + Proposal 5: RAN4 need to study the minimum requirements to achieve the positioning accuracy improvement for intra-band contiguous CA compared with single component carrier case and its feasibility to fulfil the minimum requirements (ZTE, R4-2213688)
  + Proposal 6: RAN4 will not discuss the issue of power imbalance for intra-band continuous CA, but should notify RAN1 that UE transmission power may be subject to prioritization of PCell over SCell, when the transmission power exceeds the maximum value. (Huawei, R4-2213730)
  + Proposal 7: RAN4 should further study the timing error between intra-band contiguous CCs introduced by different group delays within the bandwidth of the wideband RF filters and amplifiers. (Huawei, R4-2213730)
* Recommended WF
  + Companies are encouraged to provide feedback on the above proposals
    - Consider which impairments, and under which conditions, should be prioritized as part of the PRS/SRS study. May also include issues to avoid.
    - If needed, additional aspects can be added. The goal is to align on and prioritize the impairments to be analysed.

**Issue 2-1c: Baseline assumptions**

* Proposal (Nokia, R4-2213589)
  + Proposal 1: RAN4 assumes that the legacy FFT processing strategy of legacy RXs, that is one FFT processing per CC with standard FFT size, must be baseline. Processing with extended FFT-size specifically for high accuracy positioning measurement is not assumed as baseline.
* Recommended WF
  + Companies should share their views on whether the baseline assumption in the proposal is agreeable.

**Issue 2-1d: Initial conclusion**

* Proposal (Qualcomm, R4-2212210)
  + Proposal 1: PRS/SRS bandwidth aggregation over intra-band layers/carriers is feasible for single chain Tx/Rx architectures (not limited to single IFFT/FFT).
    - At least contiguous carriers can be supported with single Tx chain
    - FFS: Support of non-contiguous carriers with single Tx chain
    - Additional requirements on the frequency response across the full aggregated bandwidth (e.g., phase response characterization accuracy) may be discussed during the WI phase.
* Recommended WF
  + Qualcomm proposes a conclusion for the case of a single chain Tx/Rx architecture. ZTE (R4-2213688) also provides some results relevant to this proposal. Companies are encouraged to share their views on whether RAN4 can conclude that PRS/SRS bandwidth aggregation for intra-band contiguous carrier is feasible for single chain Tx/Rx architectures.

### Sub-topic 2-2: Study based on carrier phase measurements

*This sub-topic focuses on the following objective (RP-221814):*

* *Study solutions for accuracy improvement based on NR carrier phase measurements [RAN1, RAN4]*
  + *Reference signals, physical layer measurements, physical layer procedures to enable positioning based on NR carrier phase measurements for both UE-based and UE-assisted positioning [RAN1]*
  + *Focus on reuse of existing PRS and SRS, with new reference signals only considered if found necessary*

**Issue 2-2a: Scope of RAN4 study based on carrier phase measurements**

* Proposals
  + Proposal 1: RAN4 should study how to model impacts of antenna/beam phase response, residual carrier-frequency offset, and frequency drift on carrier phase positioning (Qualcomm, R4-2212211)
  + Proposal 2: RAN4 to wait for further progress in RAN1 to evaluate and assess the scope of solutions based on NR carrier phase measurements to be studied by RAN4. (Ericsson, R4-2213278)
  + Proposal 3: RAN4 need to study the timing error and phase errors among different TRPs and provide the corresponding information to RAN1. (ZTE, R4-2213689)
* Recommended WF
  + Companies are invited to provide their views on the proposals and what aspects of carrier phase measurements RAN4 should study. Also consider whether RAN1 input is needed for the scope.

**Issue 2-2b: RF requirements**

* Proposals (Huawei, R4-2213731)
  + Proposal 1: The practical RF impairments can be mitigated by double difference methods with the phase measurement in the baseband, and thus will not define the RF requirement for carrier phase measurements.
    - The carrier phase measurement requirement should be covered by RRM.
  + Proposal 2: No need to define the requirement of phase continuity across slots for carrier phase positioning for both TDD and FDD spectrum
* Recommended WF
  + Companies should provide feedback on the two proposals and which RF requirements are most relevant to the study

## Companies views’ collection for 1st round

### Open issues

Sub topic 2-1: Study based on PRS/SRS bandwidth aggregation

Issue 2-1a: Intra-band CA scenario

Issue 2-1b: Scope of study based on PRS/SRS bandwidth aggregations

Issue 2-1c: Baseline assumptions

Issue 2-1d: Initial conclusion

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| **Company** | **Comments** |
| ZTE | Issue 2-1a: Intra-band CA scenario  We could prioritize the intra-band contiguous CA case and further discuss the intra-band non-contiguous CA in the next meeting if possible.  Issue 2-1b: Scope of study based on PRS/SRS bandwidth aggregations  From our understanding, RAN4 mainly need to discuss the following issues  1st objective: RF impairments .e.g. timing error (group delay), phase error , frequency error, phase coherency, power imbalance for DL and UL,  Note: frequency error, phase coherency or power imbalance is not applicable for certain RF architecture and this could be down-prioritized if possible.  2nd objective: the maximum tolerated RF impairments or minimum requirements to ensure its positioning accuracy improvement.  Issue 2-1c: Baseline assumptions  From our understanding, it’s not necessary to mandate the FFT assumption since multiple FFT could also be well timing aligned within basedband, therefore there is no additional timing error needed to be considered for multiple CCs.  Issue 2-1d: Initial conclusion  Fine with the following proposals which is also aligned with intra-band contiguous CA assumption:   * + - At least contiguous carriers can be supported with single Tx chain     - FFS: Support of non-contiguous carriers with single Tx chain |
| Huawei, HiSilicon | Issue 2-1a: We support to limit the scope to intra-band contiguous CA scenarios to reduce the work load.  Issue 2-1b: We think that we should first confirm the RF architecture to support intra-band contiguous CA scenarios, and then focus on the type of impairments. In general, we think that for the most typical architecture, the only impairment that needs to consider is the RF group delay.  In addition, we think that power allocation of positioning SRS across multiple cells may be subject to prioritization when exceeding the UE maximum transmit power, which can be informed to RAN1.  Issue 2-1c: In general, we think the legacy FFT size should be reused, but this is more of RAN1 discussion, and should not have any RAN4 specification impact.  Issue 2-1d: We support such a conclusion. |
| Apple | Issue 2-1a: agree to prioritize intra-band contiguous case. Intra-band non-contiguous CA is associated with higher TAE and potentially large propagation delay differences due to non-collocated scenarios. It is not straightforward and pre-mature to consider intra-band non-contiguous CA in this WI.  Issue 2-1b: RF impairment model including timing/frequency/phase can be studied first to understand the performance/accuracy gain with realistic RF impairment. However, no new RF requirements are expected out of this study.  Issue 2-1c: the baseline assumption in the proposal seems reasonable.  Issue 2-1d: for intra-band contiguous CA, it is reasonable to assume single Tx/Rx RF chain. However, as part of another R18 WI for intra-band non-collocated CA, there is a chance to extend the non-collocated scenario to intra-band contiguous CA. Such scenario should be precluded from this WI. |
| LGE | Issue 2-1a: We support focusing on intra-band contiguous CA scenarios.  Issue 2-1c: In our view, we don’t need to consider the FFT assumption as long as there is no RF impact.  Issue 2-1d: We support the conclusion. |
| Ericsson | Issue 2-1a: Limit scope of the study to intra-band contiguous carriers only.  Issue 2-1b:   * P1: study achievable gain in accuracy when TAE is within the specified requirement for intra-band contiguous carriers only. * P2: Prefer P3 on phase consistency part. * P3: Fine. Limit study do intra-band contiguous carriers only. * P4: Seems this proposal is similar to P3. * P5: Requirements are not clearly mentioned in the proposal. Is this about the target accuracy and the trade-of between the costs and gains compared to the single-carrier case? * P6:. First part is fine. Second part needs more discussion. * P7: Fine   Issue 2-1c: Proposal 1 is fine.  Issue 2-1d: Based on the proposals in issue 2-1a FFS part can be removed. |
| Qualcomm | Issue 2-1a: Intra-band CA scenario  We agree that the intra-band contiguous scenario is the most favorable scenario and it should be given higher priority. Intra-band non-contiguous cases would require further study and may be treated with lower priority.  Issue 2-1b: Scope of study based on PRS/SRS bandwidth aggregations  On Proposal 6, we agree that discussion of power imbalance can be deprioritized. Regarding the limitation on UE transmit power, it would be good to bring up this point to RAN1’s attention. It may be discussed further during the specification phase whether different prioritization rules should be applied in the case of positioning SRS aggregation across carriers.  Issue 2-1c: Baseline assumptions  In our view, it is not necessary to assume single FFT/IFFT for the purposes of this study. It does not have impact on the question of feasibility or the impairments which are the main focus of the study objectives.  Issue 2-1d: Initial conclusion  We support the conclusion in Proposal 1. |
| Nokia | Issue 2-1a: ‘intra-band contiguous CA scenario with simultaneous PRS/SRS transmission in a same slot  Issue 2-1b: Overall any RF impairments can be studied within the scope, especially impacts due to timing errors and phase error/noise can be focused.  Issue 2-1c: RX schemes should be possible without RF architecture changes or impacts to process high time resolution (i.e. FFT size). |
| Intel | Issue 2-1a: We are OK to limit the study to the intra-band contiguous CA scenario.  Issue 2-1b: We consider that the RF impairments already identified in the SID all need to be considered in the study. We tend to agree with the Huawei comment that if we could agree to focus the study on a single RF architecture (i.e. single Tx/Rx chain) then it would possible to minimize the study effort for a number of these impairments. If we cannot conclude now to focus on the single chain Tx/Rx architecture then all of the impairments will need to be studied.  Regarding the proposal 5, our understanding of the SID is that there are no defined requirements for the accuracy that is to be achieved by the improvements (this applies for both the aggregation and carrier phase improvements).  Issue 2-1c: From RAN4 point of view, it is not clear why we would need to start with this assumption. Any discussion of baseband processing structures may be more appropriate for RAN1.  Issue 2-1d: We agree that RAN4 can take a conclusion that PRS/SRS bandwidth aggregation over intra-band contiguous layers/carriers is feasible for single chain Tx/Rx architectures. Note that even if RAN4 can agree on this conclusion, it is not fully clear to us whether it is intended to prevent ongoing study based on other Tx/Rx architectures. |

Sub topic 2-2: Study based on carrier phase measurements

Issue 2-2a: Scope of study based on carrier phase measurements

Issue 2-2b: RF requirements

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| **Company** | **Comments** |
| ZTE | Issue 2-2a: Scope of study based on carrier phase measurements  To study the following RF impairments: antenna/beam phase response, residual carrier-frequency offset, and frequency drift and timing error and phase error among different TRPs.  Issue 2-2b: RF requirements  From our understanding, we don’t need to discuss the RF requirement in SI phase, this is part of WI discussions. |
| Huawei, HiSilicon | We think that given that RAN1 is already studying double difference methods, which can cancel most of the RF impairments for carrier phase positioning, there is no urgency for RAN4 to define any RF requirements. |
| Apple | We agree that RAN4 can hold this work until we have clear picture of RAN1’s progress and conclusion. |
| LGE | We support P1 in Issue2-2b about RF requirement. Theoretically the double difference methods can mitigate the RF impairment. And we think further evaluation would be needed to verify mitigation of RF impairment using double difference method. |
| Ericsson | Issue 2-2a: prefer Proposal 2  Issue 2-2b:  P1: Agree with the observation in the first part of proposal 1. Agree with second part of the proposal  P2: Agree with P2. |
| Qualcomm | Issue 2-2a: Scope of study based on carrier phase measurements  We can support Proposal 1 and Proposal 3.  Issue 2-2b: RF requirements  Regarding proposal 1, our understanding is that RAN4 still needs to study the impact of transceiver contributions to phase error. There are scenarios where double difference methods may not be able to cancel all sources of error. Some examples are mentioned in our discussion paper.  Similar comment for proposal 2, for example if carrier phase measurements are compared differentially across time slots within a PRS instance. Wouldn’t this be a valid case? Perhaps the proponent can clarify their view. |
| Intel | Issue 2-2a: While identifying RAN4 as the secondary responsible group for the study of carrier phase positioning, the SID objectives do not identify specific aspects for RAN4 to study. Based on this we think that it would be reasonable to wait until RAN1 provides RAN4 with an update on their progress or asks specific questions to RAN4.  Issue 2-2b: See comment to 2-2a. It may be too early to conclude whether or not specific RF requirements may need to be specified. |

## Summary for 1st round

### Open issues

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|  | **Status summary** |
| **Sub-topic #2-1: Study based on PRS/SRS bandwidth aggregation** | **Issue 2-1a: Intra-band CA scenario**  *Companies are aligned on prioritizing intra-band contiguous CA*  *Tentative agreement:*  *Prioritize intra-band contiguous CA scenario in study*  *Recommendations for 2nd round:*  *Confirm tentative agreement*  **Issue 2-1b: Scope of study based on PRS/SRS bandwidth aggregation**  *Candidate options:*   * + Proposal 1: For Tx/Rx architectures that cannot avoid timing errors, further study and discuss the maximum timing error that can be tolerated between aggregated PRS/SRS layers/carriers.   + Proposal 2: For Tx/Rx architectures that cannot avoid phase errors, further study and discuss the maximum phase error that can be tolerated between aggregated PRS/SRS layers/carriers.   + Proposal 3: RAN4 investigates if RF impairment (i.e., timing errors, phase coherency, frequency errors, power imbalance) appears consistently in aggregated bandwidth. Especially, phase coherency in aggregated bandwidth is important to achieve high accuracy of ToA estimation.   + Proposal 4: For FR2 gNB/UE, phase noise is one of RF impairment sources impacting phase coherency, its impact needs to be investigated.   + Proposal 5: RAN4 need to study the minimum requirements to achieve the positioning accuracy improvement for intra-band contiguous CA compared with single component carrier case and its feasibility to fulfil the minimum requirements   + Proposal 6: RAN4 will not discuss the issue of power imbalance for intra-band continuous CA, but should notify RAN1 that UE transmission power may be subject to prioritization of PCell over SCell, when the transmission power exceeds the maximum value.   + Proposal 7: RAN4 should further study the timing error between intra-band contiguous CCs introduced by different group delays within the bandwidth of the wideband RF filters and amplifiers.   *Several aspects were suggested to help focus the scope of the study. These include:*   * *Aligning on the RF architecture before diving into the impairments* * *Studying RF impairment model (timing/frequency/phase) first to assess performance and accuracy gain with realistic impairments* * *Studying achievable accuracy gain when TAE is within specified requirement for intra-band contiguous CA* * *Deprioritizing power imbalance discussion*   *Recommendations for 2nd round:*  *Companies are encouraged to share their views on the following:*   * *RF architecture – can we agree to focus on a single RF architecture (i.e., single Tx/Rx chain)* * *Studying RF impairment model (timing/group delay/frequency/phase) first to assess performance and accuracy gain with realistic impairments* * *Studying achievable accuracy gain when TAE is within specified requirement for intra-band contiguous CA* * *Deprioritizing power imbalance discussion* * *Notifying RAN1 of the UE transmit power limitation due to potential prioritization*   *As the RF architecture assumption may have an impact on the other items, companies are asked to explain how their views may differ depending on the conclusion of the first bullet*  **Issue 2-1c: Baseline assumptions**  *Candidate option:*   * + Proposal 1: RAN4 assumes that the legacy FFT processing strategy of legacy RXs, that is one FFT processing per CC with standard FFT size, must be baseline. Processing with extended FFT-size specifically for high accuracy positioning measurement is not assumed as baseline.   *Companies have diverse views on taking Proposal 1 as baseline assumption. Some agree, while others do not think it is needed or relevant to our study. Also, there were comments on this being a RAN1 discussion.*  *Recommendations for 2nd round:*  *Continue discussions and consider whether this assumption is truly needed in our study, and if it is better suited for RAN1 discussion.*  **Issue 2-1d: Initial conclusion**  *Candidate option:*   * + Proposal 1: PRS/SRS bandwidth aggregation over intra-band layers/carriers is feasible for single chain Tx/Rx architectures (not limited to single IFFT/FFT).     - At least contiguous carriers can be supported with single Tx chain     - FFS: Support of non-contiguous carriers with single Tx chain     - Additional requirements on the frequency response across the full aggregated bandwidth (e.g., phase response characterization accuracy) may be discussed during the WI phase.   *Companies agree RAN4 can conclude that PRS/SRS bandwidth aggregation for intra-band contiguous carrier is feasible for single chain Tx/Rx architectures.*  *Tentative agreement:*  *PRS/SRS bandwidth aggregation for intra-band contiguous carrier is feasible for single chain Tx/Rx architectures*  *Recommendations for 2nd round:*  *Confirm tentative agreement* |
| **Sub-topic #2-2: Study based on carrier phase measurements** | **Issue 2-2a: Scope of RAN4 study based on carrier phase measurements**  *Candidate options:*   * + Proposal 1: RAN4 should study how to model impacts of antenna/beam phase response, residual carrier-frequency offset, and frequency drift on carrier phase positioning   + Proposal 2: RAN4 to wait for further progress in RAN1 to evaluate and assess the scope of solutions based on NR carrier phase measurements to be studied by RAN4.   + Proposal 3: RAN4 need to study the timing error and phase errors among different TRPs and provide the corresponding information to RAN1.   *Views diverge on whether to consider specific scope for this study or wait on RAN1 progress and feedback to for our work.*  *Recommendations for 2nd round:*  *Discuss if agreeing on detailed scope for study is needed now or if RAN4 should wait on RAN1 progress and input*  **Issue 2-2b: RF requirements**  *Candidate options:*   * + Proposal 1: The practical RF impairments can be mitigated by double difference methods with the phase measurement in the baseband, and thus will not define the RF requirement for carrier phase measurements.     - The carrier phase measurement requirement should be covered by RRM.   + Proposal 2: No need to define the requirement of phase continuity across slots for carrier phase positioning for both TDD and FDD spectrum   *Majority view is that there is either no need or urgency to discuss RF requirements at this time and that it may be too early to know whether RF requirements are needed.*  *Recommendations for 2nd round:*  *Discuss if we should postpone RF requirement discussion for this study* |

## Discussion on 2nd round

**Issue 2-1a: Intra-band CA scenario**

*Companies are invited to confirm whether the tentative agreement captured below is agreeable:*

* *Prioritize intra-band contiguous CA scenario in study*

**Issue 2-1b: Scope of study based on PRS/SRS bandwidth aggregation**

*Companies are encouraged to share their views on the following:*

* *RF architecture – can we agree to focus on a single RF architecture (i.e., single Tx/Rx chain)*
* *Studying RF impairment model (timing/group delay/frequency/phase) first to assess performance and accuracy gain with realistic impairments*
* *Studying achievable accuracy gain when TAE is within specified requirement for intra-band contiguous CA*
* *Deprioritizing power imbalance discussion*
* *Notifying RAN1 of the UE transmit power limitation due to potential prioritization*

*As the RF architecture assumption may have an impact on the other items, companies are asked to explain how their views may differ depending on the conclusion of the first bullet.*

**Issue 2-1c: Baseline assumptions**

*Continue discussions and consider whether the assumption in the proposal below is truly needed in our study, and if it is better suited for RAN1 discussion.*

* *Proposal 1: RAN4 assumes that the legacy FFT processing strategy of legacy RXs, that is one FFT processing per CC with standard FFT size, must be baseline. Processing with extended FFT-size specifically for high accuracy positioning measurement is not assumed as baseline.*

**Issue 2-1d: Initial conclusion**

*Companies are invited to discuss whether the tentative agreement below is agreeable:*

* *PRS/SRS bandwidth aggregation for intra-band contiguous carrier is feasible for single chain Tx/Rx architectures*

**Issue 2-2a: Scope of RAN4 study based on carrier phase measurements**

*Discuss if agreeing on detailed scope for study is needed now or if RAN4 should wait on RAN1 progress and input*

**Issue 2-2b: RF requirements**

*Discuss if we should postpone RF requirement discussion for this study*

## Companies views’ collection for 2nd round

### Open issues

Sub-topic 2-1: Study based on PRS/SRS bandwidth aggregation

Issue 2-1a: Intra-band CA scenario

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| **Company** | **Comments** |
| Ericsson | We agree with tentative agreement. |
| Qualcomm | Follow GTW (8/22) agreement |
| LGE | We are fine with GTW(8/22) agreement. |
| ZTE | We are fine to follow the GTW agreement and encourage companies to provide the evidence for the feasibility concerns for intra-band non-contiguous CA. |

Issue 2-1b: Scope of study based on PRS/SRS bandwidth aggregations

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| **Company** | **Comments** |
| Ericsson | Agree with first 4 bullets. Last bullet can be FFS until next meeting. |
| Qualcomm | This point was agreed in GTW (8/22):   * Deprioritizing power imbalance discussion   Regarding other RF impairments to be studied by RAN4, we commented earlier that it depends on which RF architectures are considered in the study.   * For single Tx/Rx chain we understand that (non-linear) phase response calibration should be studied. Other impairments can be deprioritized for this RF architecture. * For other RF architectures, if any, RAN4 would need to study timing errors, group delay errors, frequency errors, phase errors.   RAN4 should not assume that timing error between carriers can be up to existing TAE requirement for intra-band contiguous CA. It depends on the Tx architecture. For single Tx chain the main source of Tx timing error would be group delay error across the aggregate bandwidth.  No strong view on this last point:   * Notifying RAN1 of the UE transmit power limitation due to potential prioritization |
| Apple | Can we confirm what “deprioritize power imbalance discussion” means zero power imbalance is assumed in the WF? |
| ZTE | The current TAE requirement will make the intra-band CA based positioning enhancement not workable  In addition, more clarification on phase response calibration should be studied for single Tx chain, can Qualcom clarify further on it. |

Issue 2-1c: Baseline assumptions

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| **Company** | **Comments** |
| Ericsson | We are fine with proposal 1. |
| Qualcomm | Single IFFT/FFT assumption is not necessary. There has not been a convincing justification for this assumption. Does the proponent imply that the study should be limited to a certain number of aggregate RS RBs? |
| Apple | As long as intra-band contiguous CA is focused, we also don’t think FFT related assumption is not necessary, and it should be UE implementation issue. Regardless single or separated FFT, we don’t expect different requirements. |
| ZTE | We also think that this is implementation issue and should not be as baseline assumption |

Issue 2-1d: Initial conclusion

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| **Company** | **Comments** |
| Ericsson | We are fine with the tentative agreement. |
| Qualcomm | Follow agreement in GTW (8/22) |
| LGE | We are fine with GTW(8/22) agreement. |
| ZTE | We are fine with GTW(8/22) agreement. |

Sub-topic 2-2: Study based on carrier phase measurements

Issue 2-2a: Scope of RAN4 study based on carrier phase measurements

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| **Company** | **Comments** |
| Ericsson | RAN4 is not the primary group on carrier phase-based positioning study. We propose RAN4 to wait for RAN1 progress and input. |
| Qualcomm | In our view RAN4 can start studying sources of error that would impact phase carrier measurements under typical assumptions. We supported Proposals 1 and 3 in the first round. Double differencing methods cannot completely cancel these errors and, therefore, they will impact positioning accuracy. |
| Apple | We agree that RAN4 can hold the related work until RAN1 requests inputs from RAN4. |

Issue 2-2b: RF requirements

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| **Company** | **Comments** |
| Ericsson | RAN4 shall postpone RF requirement discussion for this study. |
| Qualcomm | We do not think it is necessary to discuss definition of requirements during the study phase of the WI. The objective now is to study error sources and their impact on carrier phase positioning. |
| LGE | We have similar view with Qualcomm. |
| ZTE | Similar understanding as Qualcomm and LGE. |

# Recommendations for Tdocs

## 1st round

**New tdocs**

|  |  |  |  |
| --- | --- | --- | --- |
| **New Tdoc number** | **Title** | **Source** | **Comments** |
| R4-2214462 | WF on expanded and improved NR positioning study | Intel Corporation |  |

**Existing tdocs**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Tdoc number** | **Revised to** | **Title** | **Source** | **Recommendation** | **Comments** |
| R4-2212149 |  | Work Plan for Study Item on Expanded and Improved NR Positioning | Intel Corporation | Noted |  |
| R4-2212210 |  | On the feasibility of PRS/SRS bandwidth aggregation for enhanced positioning accuracy | Qualcomm Incorporated | Noted |  |
| R4-2213277 |  | On accuracy improvement based on PRS/SRS bandwidth aggregation | Ericsson | Noted |  |
| R4-2213589 |  | Discussion on NR positioning measurement accuracy improvement based on bandwidth aggregation | Nokia, Nokia Shanghai Bell | Noted |  |
| R4-2213688 |  | Discussion on CA based positioning enhancement | ZTE Corporation | Noted |  |
| R4-2213730 |  | RF impacts on positioning bandwidth aggregation for intra-band carriers | Huawei, HiSilicon | Noted |  |
| R4-2212211 |  | On improved positioning via NR carrier phase measurements | Qualcomm Incorporated | Noted |  |
| R4-2213278 |  | On accuracy improvement based on NR carrier phase measurements | Ericsson | Noted |  |
| R4-2213689 |  | Discussion on carrier phase based positioning | ZTE Corporation | Noted |  |
| R4-2213731 |  | RF aspects of carrier phase measurements | Huawei, HiSilicon | Noted |  |

Notes:

1. Please include the summary of recommendations for all tdocs across all sub-topics incl. existing and new tdocs.
2. For the Recommendation column please include one of the following:
   1. CRs/TPs: Agreeable, Revised, Merged, Postponed, Not Pursued
   2. Other documents: Agreeable, Revised, Noted
3. For new LS documents, please include information on To/Cc WGs in the comments column
4. Do not include hyper-links in the documents

## 2nd round

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| **Tdoc number** | **Revised to** | **Title** | **Source** | **Recommendation** | **Comments** |
| R4-22xxxxx |  | CR on … | XXX | Agreeable, Revised, Merged, Postponed, Not Pursued |  |
| R4-22xxxxx |  | WF on … | YYY | Agreeable, Revised, Noted |  |
| R4-22xxxxx |  | LS on … | ZZZ | Agreeable, Revised, Noted |  |
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Notes:

1. Please include the summary of recommendations for all tdocs across all sub-topics.
2. For the Recommendation column please include one of the following:
   1. CRs/TPs: Agreeable, Revised, Merged, Postponed, Not Pursued
   2. Other documents: Agreeable, Revised, Noted
3. Do not include hyper-links in the documents