3GPP TSG RAN WG1 Meeting #103-e R1-2009384

**e-Meeting, Oct. 26th – Nov. 13th, 2020**

**Source: Moderator (ZTE)**

Title: FL summary #1 on SRS enhancements

Agenda Item: 8.1.3

Document for: Discussion and Decision

# Introduction

In RAN#86, the Rel-17 WID of further enhancements on MIMO for NR is approved [1]. In the approved WID, a particular point is about SRS enhancements in terms of flexibility, coverage and capacity, targeting both FR1 and FR2. The detailed scope of the SRS enhancement is given as follows.

*3. Enhancement on SRS, targeting both FR1 and FR2:*

* 1. *Identify and specify enhancements on aperiodic SRS triggering to facilitate more flexible triggering and/or DCI overhead/usage reduction*
  2. *Specify SRS switching for up to 8 antennas (e.g., xTyR, x = {1, 2, 4} and y = {6, 8})*
  3. *Evaluate and, if needed, specify the following mechanism(s) to enhance SRS capacity and/or coverage: SRS time bundling, increased SRS repetition, partial sounding across frequency*

The relevant agreements made in previous RAN1 meetings are given in Appendix.

In this contribution, we summarize companies’ views on the above SRS enhancements submitted to RAN1#103e [2]-[27].

# Flexibility enhancements

## SRS triggering offset

The following table summarizes companies’ views on three alternatives for SRS triggering offset enhancement.

Table 2-1 Summary of companies’ views on SRS triggering offset enhancement

|  |  |  |
| --- | --- | --- |
|  | Number | Companies |
| Alt 1: Delay the SRS transmission to an available slot later than the triggering offset defined in current specification, including possible re-definition of the triggering offset | 14 | Lenovo, MotM, NEC, Intel, Xiaomi, Ericsson, Qualcomm (legacy triggering offset only), Futurewei, Huawei, HiSilicon, ZTE, vivo, CATT, Samsung |
| Alt 2: Indicate triggering offset in DCI explicitly or implicitly | 14 | Nokia, NSB, NEC, MediaTek, Xiaomi, Spreadtrum, NTT DOCOMO, Qualcomm, Futurewei, InterDigital, vivo, CATT, Samsung, OPPO |
| Alt 3: Update triggering offset in MAC CE | 8 | Nokia, NSB, MediaTek, Xiaomi, Sharp, NTT DOCOMO, Qualcomm, LG, Lenovo/MotM |

FL’s observation is clear majority view falls on Alt 1 and Alt 2. Further, most of the companies support Alt 3 are also supportive of Alt 2. Hence FL suggests to focus on Alt 1 and Alt 2 for seeking compromised solution. Further, most of the companies supporting Alt 1 see the need of having gNB signaling to indicate the location of the available slot to transmit SRS, while the essence of Alt 2 is to use DCI to indicate the location of SRS transmission slot. Hence Alt 1 and Alt 2 are not mutually excluded. Several companies like Futurewei, Samsung, etc., propose to merge Alt 1 and Alt 2. To progress, the following merged solution between Alt 1 and Alt 2 is FL’s suggestion.

***FL proposal 1:*** *A given aperiodic SRS resource set is transmitted in the k-th available slot counting from a reference slot, where k is determined from DCI, or RRC (if only one value of k is configured in RRC). Adopt at least one of the following options for the reference slot.*

* *Opt. 1: Reference slot is the slot with the triggering DCI.*
* *Opt. 2: Reference slot is the slot indicated by the legacy triggering offset.*
* *FFS the detailed definition of “available slot”*
* *FFS explicit or implicit indication of k*
* *FFS whether updating candidate triggering offsets in MAC CE may be beneficial*

Companies’ further views are collected as follows.

|  |  |
| --- | --- |
| Companies | Views |
| FL | Add companies’ offline input: NEC, Futurewei. |
| NEC | Support the FL proposal. And we think Opt. 2 can achieve better balance between flexibility and overhead.  In addition, we think the definition of available slot should be clarified, as slot format may be dynamically changed, for example, there may be two points:  1. The timing/slot to determine following slots available or not, as on different timing/slots, the definition of a target slot may be different.  2. Whether a slot with flexible symbols dynamically scheduled by downlink or other uplink signals/channels is regarded as available or not. |
| Nokia/NSB | Support FL’s proposal with changing ‘available slot’ to ‘slot’. We prefer to avoid additional discussion and decision how to define ‘available’ slot and how gNB & UE shares the information about available slot. |
| Huawei, HiSilicon | 1. The DCI is not always there, so, it is better to add “or RRC”.  ***FL proposal:*** *A given aperiodic SRS resource set is transmitted in the k-th available slot after a reference slot, where k is determined from DCI or RRC.*  2. Then, another question is that: Does k-th slot mean the counting is from 1st slot? Then, where is self-contained slot SRS, i.e., SRS transmitted in the same slot with DCI. It should be clarified.  3. For Nokia’s comment, in our understanding, FL’s intention is to merge Alt.1 and Alt.2. If remove available, then the flexible of triggering offset in Alt.1 is removed. So, it should be kept there. Actually, we prefer to support Alt.1, which is similar as LTE’s solution used already. But for Alt.2, till now not clear which DCI based solutions is supported, if increasing DCI bits, then the impact of PDCCH coverage should be considered, if reuse some bits implicitly, then the use case should be discussed. |
| Qualcomm | Although the term ‘available slot’ seems simple on the surface, however it requires a lot of discussion to specify how to determine a slot as an available slot. And even with such definition, there could some scenarios with misalignment between UE behavior and gNB expectation.  We share similar views with Nokia that the SRS delay should be counted in terms of ALL slots starting from the reference slots. Our first preference is dynamic indication by means of DCI (Alt 2) and MAC-CE (Alt 3). However, since there is majority support both Alt 1 and 2, we are okay with FL proposal with replacing the ‘available slot’ with ‘slot’. We support Opt. 2 where the reference slot is indicated by the high-layer parameters slotOffset. We believe that the enhancement of the ‘triggering offset’ should be based on the current framework of A-SRS triggering without redefining the defining of slot offset.  ***FL proposal:*** *A given aperiodic SRS resource set is transmitted in the k-th ~~available~~ slot after a reference slot, where k is determined from DCI.*  Also, there are schemes based on Alt 2 that enables flexible A-SRS without increasing DCI overhead by means of implicit indication (reuse some DCI bit fields). We suggest to further discuss these schemes. |
| ZTE | We support the FL summary.  On Nokia/QC’s comment, we think it is necessary to have “available” in the main bullet.   * Otherwise, gNB still needs to send the DCI in certain locations if non-available slots (e.g., DL slots) are still counted in. Hence the flexibility issue is not solved. * Further, in typical TDD scenarios, it is quite difficult to have a number of consecutive UL slots. Hence if DL slots are included, most of the candidate values in the supported triggering offset list are not useful at all. Hence if we only count available slots, it will make the utilization of gNB signaling including DCI more efficient. * In addition, to remove “available” does not help to reduce workload, as we still need to discuss things like how to handle the situation that a DL/S slot is indicated by DCI, collision, etc..   On Huawei’s comment of adding “or RRC”, we think in the end gNB will configure a list of k values. If gNB only configures one value, it means to use RRC for the indication. Hence it seems natural even we don’t explicitly mention this. So perhaps the following can clarify it.  *A given aperiodic SRS resource set is transmitted in the k-th available slot after a reference slot, where k is determined from DCI, or RRC (in case of only one value of k is configured in RRC).* |
| OPPO | We prefer Alt.2 (DCI indication of dynamic trigger offset). Considering that Alt.1 and Alt.2 are supported by the same number of companies, FL’s proposal by merging Alt1. And Alt.2 seems the only way to move forward. |
| Samsung | Support FL proposal since we think Alt1 and Alt2 itself is not a complete solution. Support either way but slightly prefer to opt.2. |
| Xiaomi | Support FL proposal with opt.2, while the legacy triggering offset does not need to be redefined. |
| Intel | We also think the definition of ‘available slot’ should be clarified.  In addition, if k is determined from DCI, it could be explicit or implicit.  Therefore, we have the following suggestion on FL proposal.  *A given aperiodic SRS resource set is transmitted in the k-th available slot after a reference slot, where k is determined from DCI. Adopt at least one of the following options for the reference slot.*   * *FFS on ‘available slot’* * *Definition of k is FFS* * *Opt. 1: Reference slot is the slot with the triggering DCI.* * *Opt. 2: Reference slot is the slot indicated by the legacy triggering offset.* * *FFS whether updating candidate triggering offsets in MAC CE may be beneficial* |
| LGE | We still prefer Alt 3 based solution, but if majority view is not, we are fine with either Alt 1 or Alt 2, not both. Also, as NEC, Nokia, Qualcomm, and Intel mentioned, “available” slot is still ambiguous considering a slot composed of flexible symbols. |
| Apple | We do not prefer the combined solution of RRC and DCI which is suggested by the proposal. If we decide to get DCI involved, DCI can be used to indicate dynamically any slot offset, the only argument is about the overhead which would not be much anyway. But if there is absolute majority, we would not strongly object.  We also think the available slots is not clear especially for optional 1. For example, currently if gNB triggers AP-SRS with slot offset 4, why do we need to care the 4 slots between DCI and AP-SRS is available or not, i.e. whether it has DL symbols or not. Even option 2, with DCI involved, why UE needs to care about available slot or not unless it is to save some DCI overhead |
| InterDigital | Support FL proposal with Opt.2. As it offers higher flexibility, and also it does not require re-definition of the legacy triggering offset. |
| Ericsson | Support the FL proposal, especially with respect to ‘available’. It is highly restrictive for TDD to require the SRS to be triggered by a PDCCH in that is a fixed delay from the SRS transmission. In our understanding, transmitting in the next available subframe is already supported in LTE, so we don’t see the concern.  We have one suggestion (perhaps a clarification): the triggering offset can be optionally configured in order to save overhead, right? |
| MediaTek | Agree with Intel’s view. It needs to clarify what is ‘available slot’ and how *k* is determined from DCI (or RRC).  For definition of *k*, other than ZTE’s method mentioned above, *k* can also be determined by additional offset (added to legacy offset) indicated in DCI. So if the value carried by DCI is 0, the *k* is the legacy triggering offset.  Also, as other companies (Huawei, QC, etc), we think whether to increase DCI bits or use existing bits need to further discussed. |
| Futurewei | Support the FL’s proposal, and we slightly prefer Option 1.  There may be an issue with Option 2. If the configured legacy RRC slotoffset is, say, 4, and the next slot is an UL slot, then to indicate this UL slot, a negative DCI offset has to be used. |
| Lenovo/MotM | Support FL proposal and we prefer Option 2. |

## Flexible DCI

A number of companies see the need to enhance at least one DCI format for triggering aperiodic SRS, so that the use case that gNB triggers SRS solely without data and without CSI can be enabled. Their views on different alternatives are summarized in the following table.

Table 2-2 Summary of companies’ views on SRS triggering DCI enhancement

|  |  |  |
| --- | --- | --- |
|  | Number | Companies |
| Alt 1: Use UE-specific DCI, e.g., extending DCI 0\_1 without uplink data and without CSI | 13 | Nokia, NSB, Xiaomi, NTT DOCOMO, Ericsson, Qualcomm, Futurewei, ZTE, Huawei, HiSilicon, vivo, CATT, Samsung |
| Alt 2: Use group-common DCI, e.g., extending DCI 2\_3 for cases other than carrier switching | 5 | Xiaomi, Sharp, Qualcomm, Futurewei, Samsung |

FL’s observation is that Alt 1 stands for the clear majority view. Besides, most of the companies supporting Alt 2 are also supportive of Alt 1. Hence the following is FL’s suggestion to progress.

***FL proposal 2:*** *Support at least DCI 0\_1 to trigger aperiodic SRS without data and without CSI.*

* *FFS how to re-purpose the unused fields, e.g., the triggering offset(s) and the frequency resources for triggering A-SRS on one or more component carriers, SFI-index, etc.*
* *FFS UL/DL DCI with data for aperiodic SRS*
* *FFS group common DCI for cases other than carrier switching in addition*

Companies’ further views are collected as follows.

|  |  |
| --- | --- |
| Companies | Views |
| FL | Add offline input from Futurewei. |
| NEC | Support the FL proposal. |
| Nokia/NSB | Support FL’s proposal |
| Huawei, HiSilicon | OK |
| Qualcomm | Support FL proposal and suggest the following edit..   * *FFS how to re-purpose the unused fields, e.g., the triggering offset(s) and the frequency resources for triggering A-SRS on one or more component carriers, etc.* |
| ZTE | Support FL’s proposal. |
| Samsung | We think both UE-specific and group-common DCI for triggering AP SRS are beneficial. We suggest to have the following proposal:  Proposal: Support both DCI 0\_1 without uplink data and without CSI and DCI 2\_3 to trigger aperiodic SRS for cases other than carrier switching for SRS triggering DCI enhancement |
| Xiaomi | Support the proposal, and we think group DCI is also a good approach to enhance SRS and would be beneficial in MU-MIMO. |
| Intel | Support FL’s proposal |
| Apple | We are fine |
| InterDigital | Support FL proposal with addition of following sub-bullet   * *FFS how to re-purpose the unused fields, e.g., for triggering offset(s), on which carrier(s), on which subbands/PRBs, SFI-index, etc.* |
| Ericsson | Agree that UE specific DCI is a more logical starting point. For us, the key problem to solve for triggering is the trigger offset, so if there is some question on priority between the proposals in sections 2.1 and 2.2, we prefer that at least proposal in section 2.1 is agreed. Regarding group common DCI, while we think it can reduce overhead in some scenarios, we think the overhead gains should be carefully considered. Group common DCI requires larger aggregation levels, and a given RNTI will address a fixed group of UEs, which can restrict triggering flexibility. Furthermore, UE specific DCI can be designed according to overhead-flexibility tradeoffs.  The wording of the proposal (now the FFS bullet) is also a bit ambiguous; it could be read to say it is FFS if we enhance both carrier switching and an additional group common DCI, rather than if we add new functionality for group common DCI.  Therefore, we suggest the following:  ***FL proposal 2:*** *Support at least DCI 0\_1 to trigger aperiodic SRS without data and without CSI.*   * *FFS how to re-purpose the unused fields, e.g., the triggering offset(s) and the frequency resources for triggering A-SRS on one or more component carriers, SFI-index, etc.* * *FFS UL/DL DCI with data for aperiodic SRS* * *FFS group common DCI ~~for cases other than carrier switching in addition~~* |
| MediaTek | Support FL’s proposal |
| Futurewei | Support the FL’s proposal. |

## Usage/overhead reduction

A number of companies discuss the issue of supporting specification solution to reuse same SRS resource(s) for multiple usages explicitly. Table 2-3 summarize their views.

Table 2-3 Summary of companies’ views on SRS resource reuse enhancement

|  |  |  |
| --- | --- | --- |
|  | Number | Companies |
| Support specification solution to reuse same SRS resource(s) for multiple usages | 11 | MediaTek (for only T=R), Intel (for only T=R, and Full power mode 2 is not enabled), Spreadtrum (Using MAC CE or DCI to indicate multiple usages), NTT DOCOMO, Ericsson, vivo, CATT (for the case that ‘codebook’ and ‘antenna switching’ has same number of Tx ports), CMCC, Apple, Nokia, NSB |
| Do not support or need further study | 8 | Futurewei, Huawei, HiSilicon, Qualcomm, OPPO, ZTE, Xiaomi, LG, Lenovo/MotM |

It seems more input and discussion are needed to draw conclusion for this issue. FL encourages more companies to share input.

***FL Proposal 3****: Further discuss in RAN1#103e on whether to support specification solution to reuse same SRS resource(s) for multiple usages.*

Companies’ further views are collected as follows.

|  |  |
| --- | --- |
| Companies | Views |
| Nokia/NSB | We support reuse of same SRS resource sets for multiple purpose. We expect the usecase captured above would require no specification impact, or only small modification at the specification. |
| Huawei, HiSilicon | The SRS resources can be shared for multiple usages from Rel-15, where implementation solutions are shown in R1-2007591, we do not see the necessity to discuss it again. |
| Qualcomm | We also believe that current implementation approach based on legacy SRS configuration is sufficient for 4Rx UE. Further discussion may be needed after the introduction of the antenna switching for 6Rx and 8Rx antennas. |
| OPPO | We share the same view as Huawei and QC. The sharing of SRS resources has been used in the practical deployment. We don’t see clear benefits for further enhancement. |
| Xiaomi | We cannot see enough benefit besides overhead reduction. So more clarification on the scenarios are needed… |
| Intel | Support to discuss this issue.  Some correction on the captured views from Intel.  Intel (for only T=R, and Full power mode ~~1 and~~ 2 ~~are~~ is not enabled) |
| LGE | Prefer implementation based solution for sharing SRS resource for multiple SRS resource set. |
| Apple | We support to reuse the same SRS resource set for different purposes. For 1T4R, 2T4R and 1T2R, UE can finish both the codebook based SRS sounding and the antenna switching in the same SRS resource set.  We should define a clean and clear 3GPP solution. (1) 1T4R has no corresponding codebook based SRS sounding (2) without allowing multiple usage of the same SRS resource set, there is no incentive or specification justification for UE to even support 2 resources per resource set or codebook based SRS |
| Ericsson | In our understanding, the spec does not allow us to reuse ‘codebook’ SRS for SRS switching SRS. Even if a UE indicates support for, say 2T2R antenna switching, there is no guarantee that the 2 receive paths are the same as the 2 TX paths if codebook based precoding is used. This also means that if a same 2 port SRS resource is configured in both a SRS resource set with ‘codebook’ resources and an SRS resource set with ‘switching’ resources, this could be a gNB misconfiguration. Therefore, common understanding on what the spec supports should be a first step. If there is no common understanding, then the specs should be clarified.  So, can we have a more detailed proposal for next meeting to hopefully progress a bit more?  ***FL Proposal 3****: Further discuss in RAN1#103e to conclude on what is presently supported and on whether to support specification solution to reuse same SRS resource(s) for multiple usages.* |
| Futurewei | Support the FL’s propsal |
| Lenovo/MotM | This function can be implemented according to the current spec. We cannot see the necessary to discuss it. |

## Flexible antenna switching

3 companies discuss the issue of indicating a subset of antennas to support more flexible antenna switching. Their views are summarized in the following table.

Table 2-4 Summary of companies’ views on antenna switching flexibility enhancement

|  |  |  |
| --- | --- | --- |
|  | Number | Companies |
| Support indicating a subset of Tx/Rx antennas for SRS antenna switching via MAC CE or DCI | 6 | Qualcomm, ZTE, Intel, Samsung, Lenovo, Motorola Mobility |
| Not supportive | 5 | Nokia, NSB, Huawei, HiSilicon, LG |

It seems more discussion and input are needed.

***FL Proposal 4****: TBD*

Companies’ further views are collected as follows.

|  |  |
| --- | --- |
| Companies | Views |
| Nokia/NSB | Not support. We don’t see a necessity, and we prefer to finish antenna switching configuration first. |
| Huawei, HiSilicon | Not necessary. RRC configuration is sufficient. |
| Qualcomm | Support the FL proposal to enable flexible reconfiguration of the antenna switching. RRC re-configuration is slow process and the dynamic indication will make the adaption much faster and enable lower overhead than RRC re-configuration. |
| ZTE | We think if only RRC is used, the NW will suffer performance loss if it configures only a part of UE’s maximum capability. This will defeat the purpose of introducing combined capability for UEs to achieve power saving. Hence it is beneficial to track the channel time variation by indicating the best part of antenna subset in MAC CE or DCI. |
| Samsung | Support the FL proposal in principle. Besides, a related issue, dynamic DL MIMO layer adaptation, is being treated in UE power saving agenda. We prefer to discuss all those issues together. |
| Intel | Support to discuss this issue. With the current framework, there should be SRS resource reconfiguration for the UE to perform downgraded antenna switching, which is not flexible. |
| LGE | We share the view with Nokia and Huawei. |
| Apple | No strong view here |
| Ericsson | We are open to considering this further. It seems to be a further optimization on SRS overhead to us on top of the savings we already have with aperiodic or semi-persistent triggering, so our impression is that the approach in previous sections should be considered with higher priority. |
| Futurewei | We do not see the necessity, but we can be open to discuss based on the majority view. |
| Lenovo/MotM | We agree with ZTE and Intel. This feature should be discussed for flexible channel sounding when up to 8RX antennas are equipped by the UE. |

## Others

The following are proposed by one or two companies.

|  |  |
| --- | --- |
| Enhance cross-carrier SRS triggering | Qualcomm, Intel, Lenovo/MotM |
| Support TRP-specific SRS triggering in multi-TRP | Intel |
| Joint triggering of SRS and CSI-RS for beam management | Intel |
| Support one usage of SRS with multiple time-domain types | CMCC |
| Enhance fast beam selection in SRS for non-codebook based UL | CEWiT |
| Reuse TDRA design for SRS slot/symbol indication | Futurewei |
| Enhance UL/DL DCI with data to allow SRS to reuse data transmission parameters | Futurewei |
| Dynamic SRS sounding bandwidth indication (e.g., SRS bandwidth can be inherited from PUSCH FDRA field) | LGE |

Companies’ further views are collected as follows.

|  |  |
| --- | --- |
| Companies | Views |
| FL | Add offline input from Futurewei. |
| LGE | Our proposal is added. |
| Futurewei | Suggest to consider our proposal of reusing TDRA design for the triggering offset indication, at least as a potential starting point. The TDRA design uses only a few bits to flexibly indicating the slot position and symbol position/length, so it can be a good baseline moving forward.  We also support LGE’s proposal on dynamic SRS sounding bandwidth indication. The proposed approach of inheriting from PUSCH FDRA field is similar to our proposal of allow SRS to reuse data transmission parameters, including both PUSCH and PDSCH transmission parameters. |

# Antenna switching up to 8Rx

## Supported configurations

A number of companies reveal their views on supported configurations for antenna switching up to 8Rx, which are summarized in the following table.

Table 3-1 Summary of companies’ views on antenna switching up to 8Rx

|  |  |  |
| --- | --- | --- |
|  | Number | Companies |
| Alt 1: Support all, i.e., {1T6R, 1T8R, 2T6R, 2T8R, 4T6R, 4T8R} | 12 | Lenovo, MotM, NEC, MediaTek, Intel, Xiaomi, Spreadtrum, NTT DOCOMO, Qualcomm, CATT, Sony, ZTE |
| Alt 2: Support >=2 Tx antennas | 4 | Ericsson, Huawei, HiSilicon (2T4R, 2T6R, 4T8R), LG |
| Alt 3: Support <= 2 Tx antennas | 1 | Samsung |
| Alt 4: Support all other than 4T6R | 1 | OPPO |

Relevant simulation observations submitted to RAN1#103e are summarized in Table 3-2.

Table 3-2 Summary of simulation observations on antenna switching up to 8Rx

|  |  |
| --- | --- |
| Companies | Observations |
| Ericsson | * Increasing the number of UE antennas from 4 to 8 yields significant DL throughput gains for the case when genie-aided (i.e., perfect) CSI is available at the gNBs. * Increasing the number of UE antennas from 4 to 8 yields significant throughput gain (see, e.g., Table 4) also in the case of SRS-based CSI acquisition using antenna switching. * Sounding all of 8 receive antennas provides significant throughput gains over sounding 4 of 8 receive antennas, at least in the case of MU-MIMO. |
| Qualcomm | * For low mobility scenarios, it is preferred to have low-dimensionality antenna switching (1T6R and 1T8R) to improve SRS coverage and also for UE power saving purposes. * For higher mobility scenarios, it is preferred to have high-dimensionality antenna switching (4T6R and 4T8R) to get accurate channel states and the overcome the fast aging of the channel. * For 6Rx/8Rx UE with single Tx chain, there is performance gain by sounding all Rx antennas even in the presence of added insertion loss as compared to limiting the sounding to few antennas. * From system level, insertion loss has limited influence on the DL throughput performance for the antenna switching cases. |

FL’s observation is that the majority of companies are fine to support all the possible configuration. Further, there are evaluation results from Qualcomm showing even considering the impact of insertion loss, 1T6R or 1T8R can still provide gain over 1T4R. Hence the following is FL’s suggestion to move forward.

***FL proposal 5:*** *For antenna switching up to 8Rx, support SRS resource configurations for {1T6R, 1T8R, 2T6R, 2T8R, 4T6R, 4T8R}.*

Companies’ further views are collected as follows.

|  |  |
| --- | --- |
| Companies | Views |
| NEC | Support the FL proposal. |
| Nokia/NSB | Support FL’s proposal |
| Huawei, HiSilicon | We can compromise to accept 1Tx cases if that is majority view. But for 4T6R, we are not clear the physical antenna mapping to RF chains and how to switching? |
| Qualcomm | Support the FL proposal. |
| ZTE | Support FL’s proposal. |
| OPPO | We don’t see any UE implementation will support 4T6R. But, we can be open to it if majority companies support it.  In summary, we support FL’s proposal and open to remove or keep 4T6R |
| Samsung | We are fine for considering up to 8RX. However, based on the current implementation and also considering other companies view, we think that it would be better to give higher prioritization for 2TX. |
| Xiaomi | Support the proposal |
| Intel | Support FL’s proposal |
| LGE | We prefer to support 2T and 4T cases than 1T cases because of configuration complexity(e.g., for 1T cases, more SRS resource (set) is needed with more time span). If majority support 1T cases, we are fine to accept 1T cases to move forward.  And, as Huawei and OPPO said, further study is needed for 4T6R. |
| Apple | We do not see any need for any of the above combinations. But no strong view here |
| InterDigital | Support the FL proposal. |
| Ericsson | We are OK to agree to >=2T now, and think it can be prioritized as Samsung suggests. For the 1T cases, we would like to better understand the rationale for coverage gain. Is the presumption that 1T SRS for antenna switching can transmit at full power? This is not clear in the current specification, unfortunately. |
| MediaTek | Support FL’s proposal |
| Futurewei | Support the FL’s proposal.  A question: is there actually any implementation of 4T6R? |
| OPPO2 | Regarding the comments on 1Tx cases, we would like to elaborate a bit more on it  The architecture with 1 Tx antenna and 8 Rx antennas is typical for some types of CPE. Moreover, such kind of CPE has been used in Japan and China market. Thus, any further enhancement of Rel-17 should consider this architecture that has been used for practical products.   * For this type of CPE, the 8 Rx antenna are allocated in different directions to ensure CPE can receive the signal from any angle since the CPE is usually fixed in a place and it doesn’t know where the gNB is. During the DL data transmission, some Rx antennas can receive signals with good quality whereas the other Rx antenna will can only receive very weak signals. Thus, it is useful for gNB to get DL CSI by antenna switching * As for the full power transmission of 1T SRS, the insertion loss may impact the actual transmission power. The exact insertion loss is expected to be determined by RAN4.   It is also possible to reduce 8 Tx antennas to 6 Tx antennas by some advanced design. Thus, we think 1T6R and 1T8R are very important for the CPE ecosystem in additional to 2T cases. |
| Lenovo/MotM | Support FL proposal. |

# Coverage and capacity enhancements

Companies’ views on SRS coverage and capacity enhancements are summarized in the following table.

Table 4-1 Summary of companies’ views on SRS coverage and capacity enhancement

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|  | Number | Companies | Sub-schemes | Companies |
| Class 1 (Time bundling) | 7 | MediaTek, Intel, NTT DOCOMO, ZTE, CATT, CMCC, Futurewei | Scheme 1-1: Bundling among consecutive symbols across slots | MediaTek, Intel |
| Scheme 1-2: Bundling between aperiodic and periodic SRS resources | ZTE, CMCC |
| Scheme 1-3: Bundling among multiple resources in the same resource set based on signaling indication | CATT |
| Scheme 1-4: Bundling is supported based on a given pattern in time domain | CATT |
| Class 2 (Increase repetitions) | 21 | Nokia, NSB, Lenovo, MotM, MediaTek, Intel, Xiaomi, Sharp, Spreadtrum, Futurewei, Huawei, HiSilicon, ZTE, vivo, CMCC, OPPO, Sony, LG, Fraunhofer IIS, Fraunhofer HHI, Apple | Scheme 2-0: Increase the number of repetition symbols in one slot | Nokia, NSB, Lenovo, MotM, Xiaomi, Sharp, Spreadtrum, Futurewei, CMCC, OPPO, Sony, LG, Fraunhofer IIS, Fraunhofer HHI |
| Scheme 2-1: Repetition with TD-OCC | MediaTek, Intel, ZTE, Sharp |
| Scheme 2-2: Repetition with CS hopping | Huawei, HiSilicon |
| Scheme 2-3: Support inter-slot repetition | vivo, Futurewei |
| Class 3 (Partial frequency sounding) | 18 | Lenovo, MotM, MediaTek, Xiaomi, Spreadtrum, Qualcomm, Futurewei, Huawei, HiSilicon, vivo, CATT, Samsung, OPPO, Sony, LG, Fraunhofer IIS, Fraunhofer HHI, NEC | Scheme 3-1: Support RB-level partial frequency sounding | Lenovo, MotM, Xiaomi, Spreadtrum, Qualcomm, Futurewei, ZTE, Huawei, HiSilicon, vivo, Fraunhofer IIS, Fraunhofer HHI, NEC |
| Scheme 3-2: Support subcarrier-level partial frequency sounding | MediaTek, Qualcomm, Futurewei, vivo, CATT, OPPO, Sony, NEC |
| Scheme 3-3: Support subband-level partial frequency sounding | vivo, Spreadtrum, Futurewei, Fraunhofer IIS, Fraunhofer HHI |

Relevant simulation observations submitted to RAN1#103e are summarized in Table 4-2.

Table 4-2 Summary of simulation observations on SRS coverage and capacity enhancement

|  |  |
| --- | --- |
| Companies | Observations |
| Lenovo, MotM | * The performance loss of both subcarrier-level and RB-level partial sounding schemes are not obvious in the given channel condition. * It can be seen that the performance difference of UL throughput is marginal with different comb values in the lower speed scenario and with increased SNR the performance gap becomes smaller between different comb values. In a lower SINR range, the performance of comb 16 has approximately 7% performance loss compared with comb 2. * It can be seen that the performance loss of RB-level partial sounding is negligible in lower speed scenario, because the channel is changed very slowly in this condition. * It can be seen the partial sounding scheme has approximate 0.6dB SNR loss at 10e-2 BLER compare with full band sounding. |
| Intel | From the link level simulation results, it could be observed that SRS with repetition factor of 4 shows obvious gain over repetition factor of 1. SRS with repetition factor of 8 shows some gain over repetition factor of 4 for low MCS, but for high MCS the gain of SRS with repetition factor of 8 is not obvious. Regarding SRS with repetition factor of 12 over repetition factor of 8, it can be seen that the gain is very limited. |
| NTT DOCOMO | As can be observed, better channel estimation performance can be obtained with larger SRS bundle sizes. Another interesting observation from Fig. 4-2 is that, even though higher speeds do not bother much for intra-slot time bundling performance, this can be an issue for inter-slot time bundling. In particular, channel estimation performance degrades compared to slow mobility situations, for larger SRS bundle sizes, i.e., bundle size = 4. This is because, at higher speeds, channel gets outdated much faster as a result of higher Doppler. |
| Ericsson | * The gains seen with increased SRS repetition factor depend largely on the reference case. * Only minor gains are found with increased SRS repetition for wideband reciprocity-based precoding. * The throughput gain with SRS repetition quickly diminishes with increased UE speed. * Gains from SRS time bundling are noticeable, but not large, in the presence of larger amplitude error and at lower SNRs. * Increased SRS repetition shows only marginal gains in system-level simulations for which SRS interference is taken into account. * Increasing the number of frequency hops per slot is an effective way to increase DL throughput with the same amount of SRS overhead. |
| Qualcomm | * The gain in the DL throughput from SRS time bundling vanishes with increasing non-coherency. * SRS repetition more than 4 symbols improves the quality of the channel estimates which reflect to better DL throughput. * Frequency hopping within SRS repetition improves the quality of the channel estimates which reflect to better DL throughput while preserving the same capacity without hopping * Partial frequency sounding shows similar throughput performance compared with full-band sounding scheme while higher capacity is achieved by assigning partial sounding bandwidth to each UE. * The association between SRS and CSI-RS helps improve the link adaptation based on the pre-whitened channel estimation, which reflect to better DL throughput for SU-MIMO and MU-MIMO. * Partial frequency hopping achieves higher multiplexing capacity compared to full-band sounding or full frequency hopping. Comparing with full-sounding, partial frequency hopping slightly improves the DL throughput due to the power boost. * For partial frequency hopping, the association between SRS and CSI-RS also helps improve the link adaptation, which reflect to better DL throughput for SU-MIMO and MU-MIMO. * Larger comb increases the channel capacity while preserving a similar performance to comb 2. * RB level partial frequency sounding increases the channel capacity while preserving a similar performance to full band sounding. |
| Huawei, HiSilicon | * The performance of SRS bounding is impacted significantly by TA misalignment, which should be addressed for SRS bundling. * Increasing SRS repetitions has the similar performance with reducing hopping bandwidth, but SRS multiplexing capacity will decrease by increasing SRS repetitions. * Partial sounding can provide better performance than legacy SRS hopping for the case with 24 RBs SRS hopping bandwidth. * For small hopping bandwidth (such as 4 RBs), performance of partial sounding can be obtained with reducing SRS cyclic shift, but the multiplexing capacity will be reduced. |
| Vivo | * No obvious advantages and disadvantages across pattern-based schemes without SRS hopping in DL BLER performance comparison. * Large comb value without SRS hopping achieves some performance gain in DL BLER compared with others. * Comb 8 with 1111 has the best performance gain and then followed pattern-based configuration of 0110 in SRS hopping mechanism in DL BLER comparison. * Comb 8 with 1111 has the best performance gain and then comb4 with 0110 in SRS hopping mechanism in UL BLER comparison. * The performance of comb 2 with 0110 is slightly worse than that of comb 4 with 0110 * Large comb value with SRS hopping achieves some performance gain in UL BLER compared with others. * Large comb value has the best performance in DL throughput comparison, and the performance of normal comb scheme is better than pattern-based configuration in UL throughput comparison. * No obvious gain is achieved on bundle mechanism. * Repetition of 2 has about 0.5 dB gain over without repetition and repetition of 4 has about 0.2 dB gain over repetition of 2 for intra-slot repetition, while intra-slot repetition of 8 brings approximately 1 dB gain over without repetition. * The performance of both scheme 1 and scheme 2 with inter-slot repetition of 8 is between that of intra-slot repetition of 8 and intra-slot repetition of 4. * Inter-slot repetition doesn’t bring much performance degradation if suitable symbol distance among inter-slot repetition is configured. |
| ZTE | The following is observed from LLS results for coverage enhancement   * All the three Classes can achieve gain on single-link performance compared with baseline. * The gain of time bundling is about 1-2dB over baseline. * The gain of partial frequency sounding is about 0.5-1dB over baseline. * The gain of 8 repetitions is about 1-2dB over 4 repetitions.   The following is observed from SLS results for coverage and capacity enhancement   * Partial frequency sounding can bring significant system-level performance gain compared with baseline schemes. * Performance loss of increasing repetition is significant if there is no way to compensate the loss of SRS capacity. * Compared with the number of Ues multiplexed in one slot, the SRS channel estimation performance has much smaller impact on the final UPT performance. |
| OPPO | * The performance improvement of UL BLER for time bundling is negligible with considering the phase discontinuity. * It is observed that the performance differences between those three methods of partial sounding are negligible. |
| Futurewei | Partial frequency sounding can bring significant system-level DL performance gain compared with baseline schemes in TDD, by associating the frequency resources for sounding to the corresponding data transmission. ([2] and R1-2007547) |

FL’s observation is Class 2 and Class 3 stand for clear majority view. From the submitted simulation observations,

* Whether Class 1 has gain is impacted significantly by phase non-coherency.
* Class 2 can achieve gain on link-level performance, but it may bring loss on system-level capacity.
* Class 3 has either gain or similar performance compared with baseline on link-level performance, and it brings gain on system-level capacity.

Hence FL suggests the following proposal for further discussion.

***FL proposal 6:*** *In Rel-17 SRS coverage and capacity enhancement, support at least one scheme from Class 2 and Class 3, and deprioritize Class 1.*

Companies’ further views are collected as follows.

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| Companies | Views |
| FL | Add offline input from companies: NEC, Futurewei. |
| NEC | Support the FL proposal. |
| Nokia/NSB | Support FL’s proposal and we prefer Class 2 |
| Huawei, HiSilicon | OK for the proposal for this stage.  For repetition solutions, we want to emphasize that, the interference issues, especially inter-cell interference should be addressed in the repetition cases, while purely increasing the repetition numbers is no gain can be obtained.  Then, for subcarrier-level partial sounding, since the CS will be impacted by delay spread, so increasing the subcarrier spacing for SRS transmission will reduce the orthogonality for cyclic shift for SRS, i.e., the multiplexing capacity. So, the system performance for subcarrier-level partial sounding should be carefully checked. |
| Qualcomm | Support FL’s proposal and prefer to keep both Class 2 and Class 3 as there are beneficial schemes to enhance SRS capacity and coverage in both classes. |
| ZTE | Support FL’s proposal. |
| OPPO | Support FL’s proposal |
| Samsung | Support FL proposal. We also support class 3-1 and 3-2 for the second level details. |
| Xiaomi | Support the proposal, and agree with QC to keep class 2 and class 3 as different approaches for the enhancement as they can be applied for different scenarios. |
| Intel | Fine with FL’s proposal. |
| Fraunhofer IIS, Fraunhofer HHI | Support FL’s proposal. |
| LGE | Support the FL’s proposal and we slightly prefer Class 2. |
| Apple | Fine with FL proposal |
| InterDigital | Support the FL proposal. |
| Ericsson | **Support the FL proposal, except that extensions to frequency hopping should be clarified.**  Given that we have SRS in any symbol in Rel-16, increased SRS occupancy within a slot is the natural starting point. This means that Classes 2 and 3 are also natural starting points. We have observed from system simulations that repetition does not necessarily increase SINR, therefore mechanisms to control interference are needed to gain from the larger SRS resource. Frequency hopping is one such way to increase SRS SINR while avoiding interference. Can we have a note like the following?   * Note: Extensions of Rel-15/16 frequency hopping are supported in Classes 2 and 3, e.g. where UE hops once per symbol within a Rel-17 SRS resource. |
| MediaTek | Okay with deprioritizing Class 1 when there is a discontinuous transmission between SRS symbols. However, consecutive symbols across slots can still be useful and falls into the scope of Class 2. By which, it can increase potential sounding opportunities if repetition is needed. For example, it can configure a SRS with 8 symbols starting from 10-th symbol in a slot.  We also prefer to keep both Class2 and Class3. Also, we think co-schedule different repetition SRS in the same time/frequency resource is important for system flexibility and backward compatibility. Variable length scheme (see R1-2008959) for both Class2 and Class3 need to be considered. |
| Futurewei | Support the FL’s proposal |

# Conclusion

# Appendix

## Previous agreements

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| **RAN1#102e**  **Agreement**  Enhance the determination of aperiodic SRS triggering offset, with at least one of the following alternatives   * + Alt 1: Delay the SRS transmission to an available slot later than the triggering offset defined in current specification, including possible re-definition of the triggering offset   + Alt 2: Indicate triggering offset in DCI explicitly or implicitly   + Alt 3: Update triggering offset in MAC CE   + Further consideration aspects may include the cost v.s. the total combinations PDCCH and SRS locations for gNB to choose, DCI overhead, multi-UE SRS multiplexing, CA aspect, whether to have multiple opportunities to transmit SRS, etc.   **Agreement**  Study the following two alternatives in the scope to enhance at least one DCI format for aperiodic SRS triggering   * + Alt 1: Use UE-specific DCI, e.g., extending DCI 0\_1 without uplink data and without CSI   + Alt 2: Use group-common DCI, e.g., extending DCI 2\_3 for cases other than carrier switching   + Further consideration aspects may include simultaneous or CC-specific SRS triggering for multiple CCs, dynamic indication of SRS frequency resources, etc..   **Agreement**  For SRS overhead reduction, study reusing same resources among multiple usages, at least for “codebook” and “antenna switching”. Study aspects include   * + Whether implementation approach based on legacy SRS configuration is sufficient     - If not, and if there are benefits other than RRC overhead reduction, study further on the case that antenna switching and PUSCH have different number of Tx antennas, whether UL BWP for different SRS usages is the same or different, whether and how to ensure UE to use same virtualization, the set of applicable usages, UE implementation complexity and overhead, etc..   **Agreement**  For SRS antenna switching up to 8Rx, study the configuration of {1T6R, 1T8R, 2T6R, 2T8R, 4T6R, 4T8R}.   * + Study points may include CSI latency, performance considering aspects like insertion loss, use cases, antenna structure, UE power saving, SRS resource configuration, etc..   **Agreement**  For SRS coverage/capacity enhancements, evaluate and, if needed, specify one or more from three categories based on the following definition.   * + Class 1 (Time bundling): Utilize relationship among two or more occasions of one or more SRS resources in one or more slots to enable joint processing within time domain.     - Study aspects include the issue of phase discontinuity, interruption of SRS transmission by other UL signals, etc..   + Class 2 (Increase repetition): Change the legacy SRS pattern in one resource and one occasion from time domain by increasing SRS symbols for repetition.     - Study aspects include to use TD-OCC to compensate the negative impact on SRS capacity, inter-cell interference randomization, whether these SRS symbols are in one slot or consecutive slots, etc..   + Class 3 (Partial frequency sounding): Support more flexibility on SRS frequency resources to allow SRS transmission on partial frequency resources within the legacy SRS frequency resources.     - Study aspects include the partial frequency resources are with RB level or subcarrier level (e.g., larger comb, partial bandwidth), PAPR issue, etc.. |

# References

[1] RP-193133, New WID: Further enhancements on MIMO for NR, Samsung

[2] R1-2007544, Enhancements on SRS flexibility, coverage and capacity, FUTUREWEI

[4] R1-2007591, Discussion on SRS enhancements for Rel-17, Huawei, HiSilicon

[5] R1-2007631, Discussion on SRS Enhancements, InterDigital, Inc.

[6] R1-2007649, Further discussion on SRS enhancement, vivo

[7] R1-2007768, Enhancements on SRS flexibility, coverage and capacity, ZTE

[8] R1-2007829, On enhancements on SRS flexibility, coverage and capacity, CATT

[9] R1-2008005, Enhancements on SRS flexibility, coverage and capacity, CMCC

[10] R1-2008153, Enhancements on SRS, Samsung

[11] R1-2008222, Enhancements on SRS flexibility, coverage and capacity, OPPO

[12] R1-2008351, Considerations on SRS flexibility, coverage and capacity, Sony

[13] R1-2008443, Views on Rel-17 SRS enhancement, Apple

[14] R1-2008578, Enhancements on SRS flexibility, coverage and capacity, LG Electronics

[15] R1-2008900, Enhancements on SRS for coverage and capacity, Fraunhofer IIS, Fraunhofer HHI

[16] R1-2008908, Enhancements on SRS flexibility, coverage and capacity, Nokia, Nokia Shanghai Bell

[17] R1-2008914, Enhancements on SRS, Lenovo, Motorola Mobility

[18] R1-2008948, Discussion on SRS enhancement, NEC

[19] R1-2008959, Enhancements on SRS flexibility, coverage and capacity, MediaTek Inc.

[20] R1-2008982, Discussion on SRS enhancements, Intel Corporation

[21] R1-2009031, Discussion on SRS enhancements, Xiaomi

[22] R1-2009131, Enhancements on SRS, Sharp

[23] R1-2009146, Considerations on SRS enhancement, Spreadtrum Communications

[24] R1-2009179, Discussion on SRS enhancement, NTT DOCOMO, INC.

[25] R1-2009211, SRS Performance and Potential Enhancements, Ericsson LM

[26] R1-2009255, Enhancements on SRS flexibility, coverage and capacity, Qualcomm Incorporated

[27] R1-2009286, Discussion on enhancement of SRS in Rel. 17 further enhanced MIMO, CEWiT