3GPP TSG RAN WG1 Meeting #104-e R1-2101783

**e-Meeting, Jan. 25th – Feb. 5th, 2021**

**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*

Previous RAN1 agreements on these SRS enhancements are given in Section 6.1.

In this contribution, we summarize companies’ views on the above SRS enhancements submitted to RAN1#103e [2]-[25].

# Flexibility enhancements

## SRS triggering offset

### 2.1.1. Reference slot definition

Two options are given in last meeting’s agreement on the definition of reference slot. The following table summarizes companies’ views on three alternatives for SRS triggering offset enhancement.

Table 2-1

|  |  |  |
| --- | --- | --- |
|  | Number | Companies |
| Opt. 1 (Reference slot is the slot with the triggering DCI) | 10 | Nokia, NSB, Apple, NTT DOCOMO, ZTE, Futurewei, OPPO, Huawei, HiSilicon, LG |
| Opt. 2 (Reference slot is the slot indicated by the legacy triggering offset) | 12 | NEC, CMCC, Xiaomi, Qualcomm, Ericsson, Sharp, InterDigital, CATT, vivo, MediaTek, Intel, Spreadtrum |

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

Companies’ further views are collected as follows.

|  |  |
| --- | --- |
| Companies | Views |
| Ericsson | Option 2 is an add on to existing functionality instead of a replacement and gives more flexibility. |
| Samsung | We slightly support Option 2, since Option 2 can be implemented on top of the Rel-15/16 implementation with more flexibility. |
| CATT | Prefer option 2, which offers more flexibility. Option 1 can be seen as a special case of option 2 with legacy RRC configured slot offset set to 0. |
|  |  |

### 2.1.2. Available slot definition

One FFS point from last meeting is the detailed definition of available slot. One example is given in last meeting’s agreement, which is a good start point from most of companies’ view. Companies’ detailed views are given in the table below.

Table 2-2

|  |  |  |
| --- | --- | --- |
|  | Supporting companies | Other comments |
| **Definition:**“Available slot” are slots satisfying there are UL or flexible symbol(s) for the time-domain location(s) for all the SRS resources in the resource set and it satisfies the minimum timing requirement between triggering PDCCH and all the SRS resources in the resource set. | NEC, Samsung, Qualcomm, Ericsson, Sharp, ZTE, Futurewei, InterDigital, OPPO, Huawei, HiSilicon, vivo (12) | CMCC: Not to count flexible symbols due to DL channel/signals can be dynamically scheduled on flexible symbols.(FL: This can be addressed in the next row of this table.)Intel: Need to clarify whether to allow shift of SRS symbols in a slot.(FL: The definition says there should be UL or flexible symbols for the time-domain locations for the SRS resources, i.e., not just sufficient number of OFDM symbols. It is clear shift is not allowed.) |
| **Impact of dynamic event:**“Available slot” is determined only based on RRC configuration, i.e., * SFI or dynamic scheduling of DL channel/signals on flexible symbols does not impact the determination of available slots.
* Collision handling between the triggered SRS and any UL channels/signals does not impact determination of available slot.
 | NEC, CMCC, Samsung, Apple, Qualcomm, Ericsson, Sharp, ZTE, OPPO, vivo (10) |  |

Based on the majority of companies have a common understanding of available slot definition, and UE vendors have strong concern on dynamic signals impacting the determination of available slots, the following FL proposal is given.

***FL Proposal:*** *“Available slots” are slots satisfying there are UL or flexible symbol(s) for the time-domain location(s) for all the SRS resources in the resource set and it satisfies the minimum timing requirement between triggering PDCCH and all the SRS resources in the resource set.*

* *From the first symbol carrying the SRS request DCI and the last symbol of the triggered SRS resource set, UE does not expect to receive SFI indication or dynamic scheduling of DL channel/signal(s) on flexible symbol(s).*
* *Note: Collision handling between the triggered SRS and any other UL channel/signal is performed after the determination of available slot.*

Companies’ further views are collected as follows.

|  |  |
| --- | --- |
| Companies | Views |
| Ericsson | Support FL proposal. We also need to discuss collisions between two sets triggered by the same SRS trigger codepoint as they may have different “available slot” interpretations (see 2.1.4).  |
| Samsung | Support FL proposal. |
| CATT | We are OK with the FL proposal, except the 1st sub-bullet. The NW can refrain from sending SFI if so desired. Otherwise if SFI transmission makes the slot no longer available, Rel.16 dropping can apply. This is already in the current spec and doesn’t add to extra implementation. Also would suggest to add the clarification (“impact of dynamic event”) in table 2-2 in the proposal, otherwise we have several concerns and it becomes unacceptable to us.  |

### 2.1.3 Determination on the value of t

Based on last meeting’s agreement, candidate values of t are configured by RRC and indicated further in DCI. Detailed mechanism is still to be decided. Companies’ views are summarized in the following table.

Table 2-3

|  |
| --- |
| **DCI** |
| Cases | Alternatives | Number | Companies |
| Non-scheduling DCI (DCI 0\_1/0\_2 without data and without CSI request) | Alt 1-1: Add a new configurable DCI field to indicate t | 4 | Apple, Huawei, HiSilicon, CATT |
| Alt 1-2: Re-purpose unused DCI field to indicate t | 7 | CMCC (TDRA), Qualcomm, ZTE (TDRA), Futurewei (TDRA), vivo, LG, Ericsson |
| Scheduling DCI (DCI that schedules a PDSCH or PUSCH) | Alt 2-1: Add a new configurable DCI field to indicate t | 8 | Nokia, NSB, Apple, Futurewei, Huawei, HiSilicon, vivo, CATT |
| Alt 2-2: t is indicated without adding DCI payload | 6 | CMCC, Qualcomm, ZTE, OPPO, Intel, Ericsson |

It can be observed in the case of non-scheduling DCI, the majority of companies support to repurpose unused fields. The benefit is clear as there is no need to add DCI overhead for such DCI. For scheduling DCI, slightly more companies prefer adding a configurable DCI format.

* Adding a new configurable field seems to be a simple solution.
* Some companies have concern on increasing DCI payload. If DCI payload is an issue, it’s better to keep the possibility to allow gNB not to configure the new DCI field, and re-purpose the unused fields in non-scheduling DCI.

Based on such observation, FL proposes the following to move forward.

***FL Proposal:*** *A list of t values is configured in RRC for each SRS resource set*

* *In DCI format 0\_1/0\_2/1\_1/1\_2, add a new configurable field to indicate the values of t*
* *For DCI format 0\_1/0\_2 without data and without CSI request, support to re-purpose an unused field for the indication of t*

Companies’ further views are collected as follows.

|  |  |
| --- | --- |
| Companies | Views |
| Ericsson | We support Alt.1-2 and 2-2.  |
| Samsung | Support FL proposal. |
| CATT | We support the FL proposal in the main bullet and the 1st sub-bullet. For the 2nd sub-bullet, whether unused field in the DCI format 0\_1/0\_2 without data and without CSI request is re-purposed for the indication of *t* depends on the solution of the indication of *t* for normal DCI format 0\_1/0\_2/1\_1/1\_2, it can be discussed later. |

Another FFS point in last meeting’s agreement is whether to support MAC CE as an inter-mediate step to update candidate values of t. Companies’ views are summarized as follows.

Table 2-4

|  |
| --- |
| **Whether to support MAC CE as an inter-mediate step** |
| Alternatives | Number | Companies |
| Support using MAC CE to update the candidate values of t | 8 | Nokia, NSB, Samsung, Qualcomm, NTT DOCOMO, MotM, Lenovo, MediaTek |
| Deprioritize or do NOT support | 5 | CMCC, Futurewei, OPPO, Ericsson, CATT |

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

Companies’ further views are collected as follows.

|  |  |
| --- | --- |
| Companies | Views |
| Ericsson | We prefer to deprioritize this |
| Samsung | To have more flexibility, we prefer to have MAC-CE based update. |
|  |  |

### 2.1.4 Collision handling among the triggered SRS resource sets

Two companies discuss the issue of supporting a mechanism to handle potential collision among the triggered SRS resource sets in the available slot, if multiple resource sets are triggered by one DCI. Their views are summarized as follows.

Table 2-5

|  |  |
| --- | --- |
|  | Companies |
| Support a mechanism to handle potential collision among triggered SRS resources in the same or different CCs in an available slot | vivo (an ordering principle of increased or decreased SRS resource set ID), Ericsson (details FFS) |

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

Companies’ further views are collected as follows.

|  |  |
| --- | --- |
| Companies | Views |
| Ericsson | This may need to be resolved, suggest to try to agree on the basic functionality first (2.1.1,2.1.2 and 2.1.3) |
|  |  |
|  |  |

## Flexible DCI format

Last meeting we have agreed to support DCI format 0\_1/0\_2 to trigger SRS without data and without CSI request. One remaining issue is whether to repurpose the unused fields. Companies’ views are summarized as follows.

Table 2-6

|  |
| --- |
| **Whether to repurpose unused fields in DCI format 0\_1/0\_2 without data and without CSI** |
| Alternatives | Detailed functionality | Companies |
| Yes | Indication of available slot position (cf. Section 2.1.3) | CMCC, Qualcomm, ZTE, Futurewei, vivo, LG |
| Indication of a group of CCs for SRS transmission | Qualcomm, ZTE |
| TPC command for each CC | Qualcomm |
| Indication of resource blocks for SRS transmission | Ericsson, Futurewei, LG |
| Indication of SRS port and beamforming | Futurewei |
| No | - | Apple, Huawei, HiSilicon |

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

Companies’ further views are collected as follows.

|  |  |
| --- | --- |
| Companies | Views |
| Ericsson | In our tdoc, we provide some motivation for indication of RBs for SRS |
|  |  |
|  |  |

Another remaining issue is whether to enhance group-common DCI in addition. Companies’ views are summarized as follows.

Table 2-7

|  |
| --- |
| **Whether group-common DCI enhancement is supported additionally** |
| Alternatives | Number | Companies |
| Yes | 7 | Xiaomi, Samsung, Qualcomm, Sharp, Futurewei, vivo, Intel |
| No | 5 | Nokia, NSB, Huawei, HiSilicon, CATT |

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

Companies’ further views are collected as follows.

|  |  |
| --- | --- |
| Companies | Views |
| Ericsson | Ok if benefits in performance can be shown and solutions is a simple modification to existing specification |
| Samsung | Group-common DCI is already used for the purpose of SRS carrier switching purpose. Hence we do not see why the other purposes are precluded. |
|  |  |

## Usage/overhead reduction

One remaining issue is whether to support configuring one SRS resource set with multiple usages explicitly in specification. Table 2-8 summarize companies’ views.

Table 2-8

|  |
| --- |
| **Whether to support configuring one SRS resource set with multiple usages explicitly** |
|  | Number | Companies |
| Support specification change | 5 | Nokia, NSB, Apple, Ericsson, vivoEricsson: Further support antenna selection for PUSCH with ceil(n/m)-bit SRI field. |
| Implementation can solve the issue | 6 | Xiaomi, Futurewei, OPPO, Huawei, HiSilicon, CATT |

***FL proposal:*** *TBD*

Companies’ further views are collected as follows.

|  |  |
| --- | --- |
| Companies | Views |
| Ericsson | Implementation cannot solve this as there will be ambiguity in power control parameters to use. Also, as discussed in our contribution, it is time to introduce closed loop antenna selection for PUSCH to catch up on LTE functionality which is yet another use case for multiple usages for SRS set |
|  |  |
|  |  |

## Flexible antenna switching

Multiple companies discuss the issue of indicating the number of antennas to support more flexible antenna switching in dynamic signaling. Their views are summarized in the following table.

Table 2-9

|  |  |  |
| --- | --- | --- |
|  | Number | Companies |
| Support indicating the number of Tx/Rx antennas for SRS antenna switching via MAC CE or DCI | 7 | Xiaomi, Qualcomm, Ericsson, ZTE, MotM, Lenovo, Intel |

***FL proposal:*** *Support indicating the number of Tx/Rx antennas for SRS antenna switching via MAC CE or DCI.*

Companies’ further views are collected as follows.

|  |  |
| --- | --- |
| Companies | Views |
| Ericsson | It seems no company oppose, or? 😉 |
| 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. |
|  |  |

## Others

The following are proposed by one company.

|  |  |
| --- | --- |
| Support TRP-specific SRS triggering in multi-TRP | Intel |
| Support one usage of SRS with multiple time-domain types | CMCC |

# Antenna switching up to 8Rx

## Resource set configurations

On the agreed set of antenna switching configurations {1T6R, 1T8R, 2T6R, 2T8R, 4T8R}, companies’ input on the supported SRS resource set configurations is summarized as the following table. Note that 4T6R is not included as the decision is pending.

Table 3-1

|  |  |  |
| --- | --- | --- |
|  | xTyR | Details/Companies |
| Define set distribution patterns | 1T6R | * 1 set, 6 resources: CMCC (periodic/semi-persistent), Xiaomi, Samsung, Qualcomm, Huawei, HiSilicon, CATT, Spreadtum
* 2 sets, 3+3: Nokia, NSB, CMCC (aperiodic), Xiaomi, Samsung, Qualcomm, CATT, Spreadtrum
* 3 sets, 1+2+3: CMCC (aperiodic), CATT
* 3 sets, 2+2+2: CMCC (aperiodic), Xiaomi, Samsung, CATT, vivo, Spreadtrum
* 3 sets, 1+1+4: Samsung, CATT
* 2 sets, 1+5: Samsung, CATT
* 2 sets, 2+4: Samsung, CATT
* 4 sets, 1+1+2+2: Samsung
* 6 sets, 1+1+1+1+1+1: vivo
 |
| 1T8R | * 1 set, 8 resources: CMCC (periodic/semi-persistent), Xiaomi, Samsung, Qualcomm (periodic/semi-persistent), Huawei, HiSilicon, CATT
* 2 sets, 4+4: Nokia, NSB, Xiaomi, Qualcomm, vivo, Spreadtrum, Sony
* 2 sets, 3+5: CATT
* 2 sets, 2+6: CATT
* 3 sets, 2+3+3: CMCC (aperiodic), CATT
* 4 sets, 1+1+3+3: CMCC (aperiodic), CATT
* 4 sets, 1+2+2+3: CMCC (aperiodic), CATT
* 4 sets, 2+2+2+2: CMCC (aperiodic), Xiaomi, CATT
* 8 sets, 1+1+1+1+1+1+1+1: vivo
 |
| 2T6R | * 1 set, 3 resources: Nokia, NSB, CMCC, Xiaomi, Samsung, Qualcomm, OPPO, Huawei, HiSilicon, CATT, Spreadtrum
* 2 sets, 1+2: CMCC (aperiodic), Xiaomi, Samsung, CATT, Spreadtrum
* 3 sets, 1+1+1: Xiaomi, Samsung, vivo
 |
| 2T8R | * 1 set, 4 resources: CMCC (periodic, semi-persistent), Xiaomi, Samsung, Qualcomm, Huawei, HiSilicon, Spreadtrum, Sony, CATT
* 2 sets, 2+2: Nokia, NSB, CMCC (aperiodic), Xiaomi, Samsung, CATT, vivo
* 2 sets, 1+3: CMCC (aperiodic), CATT
* 3 sets, 1+1+2: Samsung
* 4 sets, 1+1+1+1: Xiaomi, Samsung, vivo
 |
| 4T8R | * 1 set, 2 resources: Nokia, NSB, CMCC, Xiaomi, Samsung, Qualcomm, OPPO, Huawei, HiSilicon, CATT, Spreadtrum, Sony
* 2 sets, 1+1: Xiaomi, Samsung, vivo
 |
| Flexible configuration | Support RRC to flexibly configure the number of resource sets and distribute the SRS resources in the resource sets | Ericsson, ZTE, OPPO (for 1T6R (<=2 sets), 1T8R (<=4 sets) and 2T8R (<=2 sets)), Huawei, HiSilicon (for 1T8R), Intel (<=2 sets) |

It can be observed in the above table that companies have very divergent requests on the supported resource distribution patterns and number of resource sets, while flexible configuration can address most of (if not all) the requests. Further,

* For legacy 1T4R case, flexible distribution of 4 resources (1+3 or 2+2) in two sets has already been supported in the current specification.
* Along the direction of flexible configuration, a lot of discussion time can be saved. The only discussion point is the maximum number of sets for each xTyR.

Based on the above observation and principle, FL propose the following to progress.

***FL proposal:*** *For antenna switching SRS with 1T6R, 1T8R, 2T6R, 2T8R or 4T8R, support to configure N <=N\_max resource sets, where totally K resources are distributed in the N resource sets flexibly based on RRC configuration.*

* *For 1T6R, K=6, N\_max = [4], and each resource has 1 port.*
* *For 1T8R, K=8, N\_max = [4], and each resource has 1 port.*
* *For 2T6R, K=3, N\_max = [3], and each resource has 2 ports.*
* *For 2T8R, K=4, N\_max = [4], and each resource has 2 ports.*
* *For 4T8R, K=2, N\_max = [2], and each resource has 4 ports.*

Companies’ further views are collected as follows.

|  |  |
| --- | --- |
| Companies | Views |
| Ericsson | We would like to ask RAN1 companies for support to extend this FL proposal based on our feedback from real life deployments of NR. As discussed in our contribution, 1T4R and 2T4R, 1T2R antenna switching for some operators using special slots with 2 UL symbols is not possible by current spec. By enabling using special slot with only 2 UL symbols for SRS antenna switching transmissions would increase TDD efficiency and throughput significantly in their networks as UL slots can then fully be used for PUSCH/PUCCH. Hence, we think this FL proposal can be straightforwardly be extended to also include 1T4R, 2T4R and 1T2R cases, i.e.* *For 1T4R, K=4, N\_max = 4, and each resource has 1 port.*
* *For 2T4R, K=2, N\_max = 2, and each resource has 2 ports.*
* *For 1T2R, K=2, N\_max = 2, and each resource has 1 port.*
 |
| Samsung | Support FL proposal. |
| CATT | Support FL proposal. |

## Whether 4T6R is supported

One remaining issue from last meeting is whether 4T6R is supported. Companies’ views are summarized as follows.

Table 3-2

|  |
| --- |
| **Whether to support 4T6R SRS antenna switching** |
|  | Number | Companies |
| Yes | 10 | NEC, Nokia, NSB, CMCC, Xiaomi, Samsung, Qualcomm, NTT DOCOMO, InterDigital, Spreadtrum |
| No or deprioritize | 4 | Ericsson, Futurewei, Huawei, HiSilicon |

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

Companies’ further views are collected as follows.

|  |  |
| --- | --- |
| Companies | Views |
| Samsung | Since some products can have larger form factor such as CPE-type future product than a normal smart phone, we think that 4T6R can be also a case to consider. Also, if 4T8R is supported, we think that 4T6R should support the same. |
|  |  |
|  |  |

## Others

The following is proposed by one company.

|  |  |
| --- | --- |
| Enhance SRS resource set configuration for 1T2R, 1T4R and 2T4R | Ericsson |

# Coverage and capacity enhancements

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

Table 4-1

|  |  |  |  |
| --- | --- | --- | --- |
|  | Schemes | Number | Companies |
| Class 2 | Scheme 2-0: Increase the number of repetition symbols in one slot | 20 | NEC, Nokia, NSB, CMCC, Xiaomi, Samsung, Apple, Qualcomm, Sharp, ZTE, Futurewei, MotM, Lenovo, CATT, vivo, MediaTek, LG, Intel, Spreadtrum, Sony |
| Scheme 2-1: Inter-slot repetition | 7 | Nokia, NSB, Futurewei, OPPO, vivo, MediaTek, Intel |
| Scheme 2-2: Repetition with TD-OCC | 4 | NEC, ZTE, MediaTek, Intel |
| Scheme 2-3: Repetition with CS hopping | 3 | Huawei, HiSilicon, MediaTek |
| Class 3 | Scheme 3-1: RB-level partial frequency sounding | 18 | NEC (Reducing subband size for frequency hopping), CMCC, Xiaomi, Qualcomm (with only contiguous RBs), Ericsson (frequency hopping enhancements that allow contiguous portions of the band to be sounded in each slot), NTT DOCOMO, Fraunhofer IIS, Fraunhofer HHI, ZTE (contiguous RBs in a hop), Futurewei (a unified design of partial frequency sounding with granularity of N PRBs), Huawei, HiSilicon (for SRS hopping BW > 4 RBs), MotM, Lenovo, vivo, MediaTek, Intel, Spreadtrum |
| Scheme 3-2: Subcarrier-level partial frequency sounding | 13 | NEC, CMCC, Xiaomi, Samsung, Qualcomm, OPPO, MotM, Lenovo, CATT, vivo, MediaTek, Spreadtrum, Sony |
| Scheme 3-3: Subband-level partial frequency sounding | 8 | NEC (Reducing the number of hoppings), Sharp, Fraunhofer IIS, Fraunhofer HHI, MotM, Lenovo, vivo, MediaTek |
| Scheme 3-4: Partial-frequency sounding schemes assisted with CSI-RS | 2 | CMCC, Qualcomm |
| Scheme 3-5: Dynamic change of SRS bandwidth with RB-level subband size scaling | 2 | vivo, LG |

Relevant simulation observations submitted to RAN1#104e are summarized in Table 6-2 in Appendix.

It can be observed that the majority of companies support Scheme 2-0, Scheme 3-1 and Scheme 3-2. Further, based on companies’ evaluation results,

* Scheme 2-0 can provide link-level gain, but it has negative impact on SRS capacity;
* Scheme 3-1 can provide either similar or better link-level performance compared with Rel-15 baseline, and it can provide SRS capacity gain;
	+ Non-contiguous RBs in one OFDM symbol has negative impact on PAPR;
* Scheme 3-2 can provide similar link-level performance compared with Rel-15 baseline, and it can provide SRS capacity gain.

Considering the majority views and simulation observations, FL proposes the following (support all three schemes: Scheme 2-0, Scheme 3-1 and Scheme 3-2) to progress.

***FL Proposal:*** *For Rel-17 SRS capacity and coverage enhancement, support the following*

* *Increase the maximum number of repetition symbols in one slot and one SRS resource to S*
	+ *Support at least one S value from {8, 12, 14}*
* *When frequency hopping is enabled, support to transmit SRS only in* $\frac{1}{P\_{F}}m\_{SRS, B\_{SRS}}$ *contiguous RBs in one frequency hop, where* $m\_{SRS, B\_{SRS}}$ *indicates the number of RBs in a frequency hop as configured by BSRS and CSRS*
	+ *Support at least one PF value from {2, 3, 4}*
* *Support Comb 8*

Companies’ further views are collected as follows.

|  |  |
| --- | --- |
| Companies | Views |
| Samsung | Support FL proposal. We support increasing the maximum number of repetition symbols based on scheme 2-0 which is an intuitive way to enhance coverage without minimal impact on implementation. We also support Comb 8 which can be based on scheme 3-2. For the case of scheme 3-1, we are not okay with non-contiguous case since subcarriers with unequal spacing would request a complex channel estimation and would not be good for PAPR as FL mentioned, but we can support the contiguous case as mentioned in the second bullet of FL proposal. |
|  |  |
|  |  |

# Conclusion

# Appendix

## Previous agreements

Table 6-1

|  |
| --- |
| **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..

**RAN1#103e****Agreement**A given aperiodic SRS resource set is transmitted in the (t+1)-th available slot counting from a reference slot, where t is indicated from DCI, or RRC (if only one value of t is configured in RRC), and the candidate values of t at least include 0. 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” considering UE processing complexity and timeline to determine available slot, potential co-existence with collision handling, etc., e.g.,
	+ Based on only RRC configuration, “available slot” is the slot satisfying: there are UL or flexible symbol(s) for the time-domain location(s) for all the SRS resources in the resource set and it satisfies the minimum timing requirement between triggering PDCCH and all the SRS resources in the resource set
* FFS explicit or implicit indication of t
* FFS whether updating candidate triggering offsets in MAC CE may be beneficial

**Agreement**Support at least DCI 0\_1 and 0\_2 to trigger aperiodic SRS without data and without CSI.* FFS whether/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

**Agreement**In Rel-17 SRS coverage and capacity enhancement, support at least one scheme from Class 2 and Class 3, and deprioritize Class 1.* Note: Extensions of Rel-15/16 frequency hopping are included in Classes 2 and 3, e.g. where UE hops once per symbol within a Rel-17 SRS resource.

**Agreement**Candidate schemes for Class 2:* Scheme 2-0: Increase the number of repetition symbols in one slot
* Scheme 2-1: Inter-slot repetition on consecutive symbols or non-consecutive symbols across slots
* Scheme 2-2: Repetition with TD-OCC
* Scheme 2-3: Repetition with CS hopping

Candidate schemes for Class 3:* Scheme 3-1: RB-level partial frequency sounding
* Scheme 3-2: Subcarrier-level partial frequency sounding
* Scheme 3-3: Subband-level partial frequency sounding
* Scheme 3-4: Partial-frequency sounding schemes assisted with CSI-RS, where SRS is transmitted in a subset of RBs of the original SRS frequency resource
* Scheme 3-5: Dynamic change of SRS bandwidth with RB-level subband size scaling
* Note: Consider issues like gNB receiver complexity, PAPR, etc., with above schemes
* Note: Joint operation between Class 2 and Class 3 schemes can be considered

**Agreement**For antenna switching up to 8Rx, support SRS resource configurations for {1T6R, 1T8R, 2T6R, 2T8R, [4T6R], 4T8R}. |

## Simulation observations on coverage and capacity enhancement

Table 6-2

|  |  |
| --- | --- |
| Companies | Observations |
| Lenovo, MotM | * 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 performance degradation of up to 0.4dB compared with comb 2, while increasing the SRS capacity a factor of 8.
* The performance loss of all three partial frequency band sounding schemes are not obvious in the given channel condition.
 |
| 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 | * 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.
* Increased SRS repetition shows only marginal gains in system-level simulations where SRS interference is taken into account.
* Increasing the number of frequency hops per slot is a more effective way of increasing DL throughput than increasing the repetition factor, especially in interference-limited scenarios.
 |
| Qualcomm | * SRS repetition more than 4 symbols improves the quality of the channel estimates which reflect to better DL throughput.
* SRS repetition with TD-CC can recover some of capacity loss as compared to SRS repetition, however, it comes at the cost of losing some of SRS coverage gain.
* 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
* SRS Frequency hopping similar or higher DL throughput as compared to SRS Repetition.
* TD-OCC performance is inferior as compared to SRS repetition or SRS frequency hopping.
* For a given capacity assumption, partial frequency sounding shows better throughput performance compared with full-band sounding scheme due to the faster sounding periodicity and power boosting effect.
* 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.
* For a given capacity assumption, comb 8 shows better DL throughput performance compared to comb 4 and comb 2 due to the faster sounding periodicity and power boosting effect.
* For different comb size configurations, 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.
* For a given capacity assumption, RB level partial frequency schemes show better DL throughput performance compared to full-band sounding scheme due to the faster sounding periodicity and power boosting effect. Meanwhile RB level partial frequency sounding with pattern 0101 shows similar throughput performance compared with the one of pattern 0110.
* For RB level partial frequency schemes, 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.
* RB level partial frequency sounding increases the channel capacity while preserving a similar performance to full band sounding.
* Both of the RB level partial frequency schemes (including continuous sounding bandwidth and non-continuous sounding bandwidth) and subcarrier level partial frequency sounding (larger comb size) can bring system-level performance gain compared with the baseline scheme due to the faster sounding periodicity and power boosting effect.
* Considering the same capacity improvement, RB level partial frequency sounding and subcarrier level partial frequency sounding show similar throughput performance, and the sounding pattern of the RB level partial frequency sounding has small influence on the throughput.
* 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
 |
| Huawei, HiSilicon | * Increasing SRS repetitions has the similar performance with reducing hopping bandwidth, but SRS multiplexing capacity will decrease by increasing SRS repetitions.
* Larger comb means shorter sampling duration, which reduce the number of available cyclic shift per comb. Subcarrier-level partial frequency sounding can’t improve SRS capacity.
* 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 | * The performance of comb 2 with 1100 is slightly worse than that of comb 4 with 1100.
* Large comb value as well as comb 4 with pattern-based mechanism with SRS hopping achieves some performance gain compared with others in both of UL BLER and UL throughput.
* The DL performance of comb 4 achieves visible gain compared with comb 2 with pattern-based scheme, while DL performance of comb 8 is almost same with that of comb 4 with 1100 pattern, if no repetition SRS enabled.
* Although an extra 1 dB gain is achieved in comparison with non-repetition case, the DL performance of comb 8 with half SRS resource costs is better than comb 2 with 1100 with enabling SRS repetition.
* The DL performance of comb 8 with repetition is worse than comb 4 with 1100 and repetition, while almost same performance between the two schemes are achieved without repetition.
* Along with the increasing of intra-slot repetition factor, DL BLER performance is also increased for both case of repetition without SRS hopping and with SRS hopping.
* Significant repetition gain is achieved from each R=x to R=2x with per about 1dB gain increasing in metric of DL BLER for repetition scheme with SRS hopping.
* DL BLER performance of R = 8 increases over 2.5 dB gain compared with that of R = 1 under SRS hopping condition.
* For inter-slot repetition, almost same DL BLER performance is obtained from R = 8 with intra-slot repetition and R = 8 with two different inter-slot repetition schemes.
* For the performance metric of DL throughput, similar performance tendency is achieved compared with performance results in DL BLER.
 |
| ZTE | * The following is observed from LLS results for coverage enhancement
* 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.
* Comb8 does not have gain compared with baseline, due to reduced detection window in time domain.
* 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.
* Based on the above LLS and SLS results, we can conclude the following.
* Scheme 3-1 has gain on both single-link performance and system-level throughput.
* Scheme 2-0 have gain on single-link performance.
* From system level, it is crucial to use Scheme 2-2 (TD-OCC) or Scheme 3-1 to compensate the loss of SRS capacity if Scheme 2-0 is supported.
 |
| OPPO | * Considering the influence of capacity and BLER performance, RE-level method is the optimal option in DL BLER comparison.
 |
| Futurewei | * BiT based on flexible A-SRS triggering with dynamically indicated partial frequency sounding can provide substantial SE performance gains over baseline ZF in a TDD system.
* TDD ZF performance can be significantly improved by flexible A-SRS triggering with dynamically indicated partial frequency sounding.
 |
| CATT | * The PAPR of SRS transmission on uneven frequency resource by using RB-level partial frequency sounding is increased compared to the SRS transmission on uniform frequency resource as do as SRS transmission in Rel-15.
* For the same SRS transmission bandwidth, the PAPR of larger comb size, e.g., 8 or 12 is smaller than that of comb 4 with pattern‘0101’which belongs to RB-level partial frequency sounding.
 |
| Nokia, NSB | * Scheme 2-0 with repetition factor of R=8,12 outperform existing Rel-15 solutions (R= up to 4)
* For Scheme 2-0 the impact of antenna port coherence impairments are marginal.
* Scheme 3-1 w/ TX power boosting can achieve nearly same PDSCH throughput as the Scheme 2-0 with three times smaller resource overhead.
* Scheme 3-1 provides robust PDSCH throughput performance in the presence of antenna port incoherence impairments.
* Existing Rel-15 (Scheme 3-1) with TX power boosting can provide nearly same PDSCH throughput performance as the Scheme 2-1 w/ and w/o antenna port phase incoherence impairments.
 |

# References

1. RP-193133, New WID: Further enhancements on MIMO for NR, Samsung
2. R1-2100042, Enhancements on SRS flexibility, coverage and capacity, FUTUREWEI
3. R1-2100068 , Flexible SRS Transmission and Antenna Switching, InterDigital, Inc.
4. R1-2100123, Enhancements on SRS flexibility, coverage and capacity, OPPO
5. R1-2100213 , Enhancements on SRS for Rel-17, Huawei, HiSilicon
6. R1-2100277, Enhancements on SRS, Lenovo, Motorola Mobility
7. R1-2100290, Enhancements on SRS flexibility, coverage and capacity, ZTE
8. R1-2100348, Discussion on SRS enhancement for Rel-17 , CATT
9. R1-2100426, Further discussion on SRS enhancement, vivo
10. R1-2100590 , Enhancements on SRS flexibility, coverage and capacity, MediaTek Inc.
11. R1-2100623 , Enhancements on SRS flexibility, coverage and capacity, LG Electronics
12. R1-2100641 , Discussion on SRS enhancements, Intel Corporation
13. R1-2100788, Considerations on SRS enhancement, Spreadtrum Communications
14. R1-2100849 , Considerations on SRS flexibility, coverage and capacity, Sony
15. R1-2100953, Discussion on SRS enhancement, NEC
16. R1-2101010, Enhancements on SRS flexibility, coverage and capacity, Nokia, Nokia Shanghai Bell
17. R1-2101037, Enhancements on SRS flexibility, coverage and capacity, CMCC
18. R1-2101096 , Discussion on SRS enhancements, Xiaomi
19. R1-2101191, Enhancements on SRS, Samsung
20. R1-2101355 , Views on Rel-17 SRS enhancement, Apple
21. R1-2101451 , Enhancements on SRS flexibility, coverage and capacity, Qualcomm Incorporated
22. R1-2101519 , SRS Performance and Potential Enhancements, Ericsson
23. R1-2101538, Enhancements on SRS flexibility, coverage and capacity, Sharp
24. R1-2101602, Discussion on SRS enhancement, NTT DOCOMO, INC.
25. R1-2101684 , Enhancements on SRS for coverage and capacity, Fraunhofer IIS, Fraunhofer HHI