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, 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 |

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:*** *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.*

* *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*

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. |

## 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:*** *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., for triggering offset(s), on which carrier(s), on which subbands/PRBs, 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 |

## 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 | 9 | MediaTek (for only T=R), Intel (for only T=R, and Full power mode 1 and 2 are 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 |
| Do not support or need further study | 6 | Futurewei, Huawei, HiSilicon, Qualcomm, OPPO, ZTE |

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

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.  |
|  |  |
|  |  |

## 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 | 3 | Qualcomm, ZTE, Intel |

It seems more discussion and input are needed.

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. |
|  |  |
|  |  |

## Others

The following are proposed by one or two companies.

|  |  |
| --- | --- |
| Enhance cross-carrier SRS triggering | Qualcomm, Intel |
| 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 |

Companies’ further views are collected as follows.

|  |  |
| --- | --- |
| Companies | Views |
| FL | Add offline input from Futurewei. |
|  |  |
|  |  |

# 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:*** *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 |
|  |  |

# 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 | LG, vivo, Spreadtrum, Futurewei |

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:*** *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.

|  |  |
| --- | --- |
| 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 |

# Conclusion

# Appendix

## Previous agreements

|  |
| --- |
| **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

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

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

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

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