3GPP TSG RAN WG1 Meeting #106bis-e R1-2110522

**e-Meeting, Oct. 11th – 19th, 2021**

**Source: Moderator (ZTE)**

Title: FL summary #3 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. Companies’ contributions submitted to RAN1#106bis are listed in [2]-[23].

In this contribution, we summarize companies’ views in the third round offline discussion for the above SRS enhancements in RAN1#106bis-e.

# Flexibility enhancements

## SRS triggering offset

### 2.1.1. Collision handling

One FFS point from RAN1#104e’s agreement on available slot definition is “rules to handle the case of multiple SRS resource sets with overlapping symbols and/or triggered by a same DCI”. Companies’ detailed views are given in the table below.

Table 2-1

|  |
| --- |
| **Collision handling** |
| Views | Companies | Priority rules |
| Introduce dropping rule when collision happens among aperiodic SRS resource sets | Huawei/HiSilicon, Futurewei (including collision between Rel-17 AP SRS with other UL channels/signals), ZTE, vivo, Lenovo/MotM, CATT, Xiaomi, Samsung, Intel, Nokia/NSB, Qualcomm, Ericsson, Apple (UE optional feature), NEC | * Rule 1 – Based on usage: Qualcomm, Nokia/NSB, Ericsson, vivo, Xiaomi,
* Rule 2 – Based on set ID and CC ID: vivo, Xiaomi, Huawei/HiSilicon, ZTE, NEC, Spreadtrum
* Rule 3 – Based on order of the triggering DCI: Lenovo/MotM, Samsung, CATT
* Rule 4 – Based on type of the aperiodic SRS and the UL channel/signaling: Futurewei
 |
| Do not introduce new dropping rule | OPPO, LGE |  |

***FL Proposal 2-1:*** *Introduce dropping rule when collision happens among multiple aperiodic SRS resource sets in a same CC or different CCs.*

* *~~Select one or more~~ Support a combination of the following priority rules*
	+ *Rule 1 – Based on usage*
	+ *Rule 2 – Based on set ID and CC ID*
	+ *~~Rule 3 – Based on order of the triggering DCI~~*
	+ *~~Rule 4 – Based on type of the aperiodic SRS (e.g., with Rel-17 offset or not)~~*
* *The new dropping rule is a UE optional feature*
* *FFS collision handling among Rel-17 flexible SRS and other UL channels/signals*

This has been discussed for many meetings. FL suggest to select both Rule 1 and Rule 2 based on companies’ views expressed in this previous rounds. **Please indicate whether you can agree on this proposal with Rule 1 and Rule 2 selected.**

Companies’ further views are collected as follows.

|  |  |
| --- | --- |
| Companies | Views |
| InterDigital | We could agree with Rule1 and Rule2. |
| MediaTek | Rule-1 is slightly preferred |
| Spreadtrum | We could agree both rules. |
| OPPO | Not support. The reasons have been inputted several times.Moreover, the use case of the current proposal is not clear: * For the SRS triggered by the same DCI?

For the SRS triggered by different DCIs? |
| LGE | Not support. We also provided the reasons in previous rounds. We are not convinced yet that the collision rule is critically needed. |
| LGE | Not support. We also provided the reasons in previous rounds.  |
| CATT | Support the combination of Rule 3 and Rule 2 with Rule 3 has higher priority, e.g. - if two collided aperiodic SRS resource sets are triggered by different DCIs, the SRS resource set triggered by the earlier DCI is dropped in overlapped symbols; - otherwise, if the two SRS resource sets are in different CCs, the SRS resource set with higher CC ID is dropped in overlapped symbols, and if the two SRS resource sets are in the same CC, the SRS resource set with higher set ID is dropped in overlapped symbols. “the earlier DCI” can be the DCI ended with earlier symbol. |
| Huawei, HiSilicon | Agree with Rule-2. For Rule-1, we have concern on priority of usage, how to decide the priority of usage. And also problems that, some usages will share the same SRS resource, it will be complicated to be handled.With set ID or cc ID, it is more easy for gNB to arrange the priority of SRS transmission. Even some usage of SRS want to be priority transmitted, gNB is also flexible arrange the proper IDs for such usage, i.e., Rule-1 can be implemented by Rule-2. |
| Ericsson | We can agree on Rule1+2. There is no issue on sharing of resource for Rule-1 since UE behaviour is anyway undefined if there is usage ambiguity and gNB has no clue what UE is choosing to do. Hence, resource sharing when ambiguity is created, is not recommended in practical networks.  |
| Docomo | If we go with Rule 1, then we will need to discuss which usage is prioritized.In that sense, Rule 2 and Rule3 are preferred, because we can simply prioritize based on “index”. |
| Intel | Ok with Rule 1 and Rule 2. |
| Futurewei | We support collision handling but we do not think Rule 1 or 2 are suitable. We only introduced a new offset, which affects only some SRS resource sets, and the collision handling should focus on those SRS resource sets with the new offsets. All other signals remain the same as before, so the collision handling should not change their behavior. But now Rule 1 or 2 does. We especially do not understand how Rule 1 may work: among beamManagement, codebook, nonCodebook, antennaSwitching, which usage has higher priority than the other and why? Should all R17 UEs follow the rule or only UE supporting the flexible triggering? |
| Lenovo/MotM | We support the collision handling but we prefer Rule 2 or rule 3 since only rule 1 cannot work for this feature. Multiple SRS resource sets used for beam management can be triggered by a same DCI with collision, how rule 1 works for this case? |
| Samsung | Similar view with CATT and Docomo, prefer rule 3 as first preference but if not convinced we are ok not to support dropping rule.  |
| vivo | Ok with rule1 and rule2 |
| Apple | If we agree to the FL proposal, we also need to discuss the cancellation timeline.  |
| CMCC | We have no problem with multiple CC cases. And current down-selected Rule 1 and Rule 2 or the combination is fine. We still have concern for the same CC issue. But please elaborate more, how cannot this be avoided through the scheduling.  |
| NEC | Support the proposal. |

## Flexible DCI format

**Re-purpose**

***FL Proposal 2-3A:*** *No consensus to support repurpose of DCI field(s) for SRS parameter indication in Rel-17.*

Supported by Apple, OPPO, Qualcomm, Samsung, Spreadtrum, CATT, Xiaomi, Lenovo/MotM, vivo (2nd), NEC, Nokia/NSB, InterDigital, Huawei/HiSilicon, Ericsson

***FL Proposal 2-3B:*** *Further discuss and decide if the existing TPC command field, bandwidth part indicator field, and FDRA field in the DCI configured for data transmission apply to the AP SRS or not.*

Supported by Intel, vivo (1st), NTT DOCOMO, Futurewei

FL would like to ask the proponents of 2-3B **whether 2-3A is acceptable** considering it is hard to achieve consensus on 2-3B.

Companies’ further views are collected as follows.

|  |  |
| --- | --- |
| Companies | Views |
| InterDigital | Support FL proposal 2-3AGiven the limited time, do not support FL proposal 2-3B |
| QC | Support FL proposal 2-3A, agree with InterDigital. |
| Xiaomi | Support FL proposal 2-3A |
| Huawei, HiSilicon | OK to stop the discussion at this stage. |
| Ericsson | Although we see benefits of some of the proposals in 2-3B, we also understand that time is running out. We are ok to stop discussion here as well.  |
| Docomo | Support Proposal 2-3B. We agree with Futurewei’s 2nd round comment that the listed enhancements can be achieved with small specification impact, while its benefit is large.  |
| Intel | Support Proposal 2-3B. When aperiodic SRS is triggered by DCI 0\_1/0\_2 without scheduling data, the UE behavior is not clear regarding some existing DCI field and should be clarified. For example, whether the UE should switch BWP according to the BWP indicator field. |
| Futurewei | Support Proposal 2-3B. The benefit is seen as obvious to quite some companies. The spec impact is basically already described in the proposal itself. No other spec change is needed to support Proposal 2-3B and hence we don’t see the time limit is an issue. |
| Lenovo/MotM | Support proposal 2-3A. |
| Apple | We prefer 2-3A |
| CMCC | Support proposal 2-3A. |
| NEC | Support 2-3A. |

## Flexible antenna switching

The following proposal is given based on the discussion in the second round.

***FL proposal 2-4:*** *Support gNB indicating the used SRS resources from the configured SRS resources in SRS resource set(s) for antenna switching via MAC CE.*

* *Applicable to at least one of the following two cases*
	+ *Case 1: all of aperiodic, periodic and semi-persistent SRS*
	+ *Case 2: only periodic or semi-persistent SRS*
	+ *Case 3: only for aperiodic SRS*
* *Support UE reporting of one preferred antenna switching configuration in MAC CE*
* *The gNB indicated or UE reported antenna switching configuration belongs to the supported antenna switching reported by UE capability signaling*
* *FFS whether DCI can be additional used to indicate the used antenna switching configuration*
* *FFS the application timing of the MAC CE activation*
* *Note: Any change on the configured number of Tx antennas in each SRS resource is precluded in either the gNB indication or UE reporting*

The contentious points are still **whether to use DCI or MAC CE for the indication, whether/how UE reporting is performed, and whether additional application timing is needed if MAC CE is used.** Companies are encouraged to share your further views on these aspects.

Companies’ further views are collected as follows.

|  |  |
| --- | --- |
| Companies | Views |
| Apple | Again, to make this feature useful, the more important change that gNB can provide is the number of ports in SRS since the most use case of this feature is switching between 2T4R and 1T2R.  |
| InterDigital | A question about the second bullet, how a UE can report preferred antenna switching configuration, when the note says, “*Any change on the configured number of Tx antennas in … is precluded in either the gNB indication or UE reporting*” |
| MediaTek | Clarification of this proposal is required. For example, if gNB originally configure 2 SRS Resources in an SRS Resource Set, each with 2 ports, intending for 2T4R. gNB later indicates one of the resource, then UE interprets it as to switch to 1T2R (and which T/R antennas is up to UE’s implementation). Is that the correct understanding of the proposal? In addition, UE can report in MAC CE which SRS resource ID is preferred OR which xTyR configuration is preferred?In terms of MAC-CE or DCI, we think MAC-CE should be enough.We are open to further discuss if any additional application timing is needed. |
| OPPO | As we commented before, one note is needed to avoid the potential different understanding:* Note: This proposal does not impact the number of Rx antenna(s) for DL data reception

We think MAC CE is sufficient. Regarding the application time of MAC CE, we feel it is not necessary, but we are open to discuss it. To MTK:* In your example, my understanding is 2T2R.

If 1T2R is expected, the possible way is that gNB indicates another set or the SRS ports for these resource in the same set. |
| Xiaomi | Support the FL proposal. Agree with MTK and Oppo that MAC-CE is sufficient for the frequency of changing antenna switching configurations from UE implementation point of view.DCI is not preferred due to the additional RRC signaling overhead because SRS resource sets according to multiple SRS antenna switching configurations need to be configured, and the spec workload for DCI design in RAN1.@MediaTek, UE can report in MAC CE which xTyR configuration is preferred.  |
| CATT | Based on the discussion in last round, different companies have different interpretations on “*gNB indicating the used SRS resources from the configured SRS resources in SRS resource set(s) for antenna switching*”. We’d better let the proposal be clear.As we mentioned before, flexible SRS triggering via DCI is more preferred than via MAC-CE, since it has less spec efforts. For example, different xTyR schemes can be configured with different trigger states, then aperiodic SRS resource set(s) for an xTyR scheme can be triggered by configuring SRS request field to be the value corresponding to its trigger state.  |
| Huawei, HiSilicon | Thanks for the discussion, we are supportive on this feature. Some view on this discussion:* This feature only change the number of Rx, but not for number of Tx, since the change on Tx is some impact on RF chains, which need RAN4 discussion. The current wording is fine.
* Only MAC-CE is necessary. The feature is for resource and power saving, we do not see the requirement with DCI to change the configurations. By the way, DCI design and DCI overhead is another problem at this stage.

For the cases, we only support Case-2, i.e., for P- and SP-SRS. As mentioned, the benefits of the feature is for power saving and resource saving, if only once transmission for AP-SRS, we do not see the necessity support the feature. |
| Ericsson | Do not support the FL proposal since this is not a useful feature as it is currently described. The switching needs to be fast to be useful and pass the bar for implementation. Hence, what we see as a useful feature is:* DCI based switching by associating different trigger states to different AS configurations xTyR. Hence, no need for new DCI field
 |
| Docomo | * On whether to use DCI or MAC CE, we think MAC CE is prefered as captured in FL proposal.
* On whether/how UE reporting is performed, we do not see a significant need to support such reporting, but we are open to discuss. We’d like to clarify that gNB can enable/disable such a reporting. Also, we’d like to clarify the gNB is not required to follow the reporting.
* On whether additional application timing is needed if MAC CE is needed, we’d like to clarify the MAC CE is DL MAC CE, because there are both DL/UL MAC CE in the proposal. We think general timeline (i.e. 3ms after ACK transmission) is enough, but we are open to discuss.
 |
| Intel | Do not support the FL proposal.1. For aperiodic SRS, we share similar view as Ericsson and CATT that DCI based solution should be supported, which is more important. Introducing MAC-CE to indicate some resources just introduce additional signaling overhead.The switching between xTyR could be achieved by associating different trigger state with the aperiodic SRS resource sets for corresponding xTyR. For example, trigger state #1 could be associated with SRS set #A for 2T4R, and trigger state #2 could be associated with SRS set #B for 1T2R.The spec impact is much less and there is no need to introduce new DCI field.2. For periodic SRS, we don’t see the need to have MAC-CE based solution at all. The RRC reconfiguration is sufficient.3. Regarding semi-persistent SRS, in previous meeting, it was agreed that two semi-persistent SRS resource sets could be supported. Therefore, the existing MAC-CE to activate/deactivate semi-persistent SRS can be used to enable flexible switching between xTyR.For example, the UE could be configured with one semi-persistent resource set for 2T4R and another semi-persistent SRS resource set for 1T2R. In this way, the gNB can use the existing MAC-CE to activate corresponding semi-persistent SRS resource set for 1T2R or 2T4R operation.Comparing with introducing new MAC-CE, re-using the existing MAC-CE is the simplest way and has minimum spec impact. In addition, re-using the existing MAC-CE can also support changing the number of ports of SRS.Therefore, we have the following proposal:***Proposal:**** *For antenna switching with aperiodic SRS, DCI is used to switch between different xTyR*
	+ *The aperiodic SRS resource sets for different xTyR are associated with different trigger state*
	+ *No new DCI field is needed*
 |
| Futurewei | Agree with OPPO to add the note for clarification. We saw companies previously discussing turning on/off PA / RF front end / RF chain, etc.Agree with Docomo that gNB is not required to follow the reporting. In addition, since there is only a very small set of antenna configurations, we doubt the reporting is needed. |
| Lenovo/MotM | We support this feature.1. Only the number of Rx antennas can be changed, while the number of Tx antennas should not be changed.2. MAC CE based approach is enough.3. Fine to further study on the MAC CE application timing. |
| vivo | Similar question as InterDigital on 2nd bullet, additionally since gNB configures the xTyR from reported combo of values, UE reporting one out of the combo is meaningless, gNB will configure based on overall system performance, gNB can also utilize CQI and other information at hand to configure antenna switching SRS resources. We can only accept MAC CE based on activation with following revision* *~~FFS~~ the application timing of the MAC CE activation*
 |
| Apple | In general, we support the proposal. Some of the comments to finish this feature * We are also open to change the #SRS ports, since in the field, the typical use case for UE power saving is switching between 2T4R and 1T2R
* We prefer MAC-CE, but the design principle should be
	+ All SRS resource sets configured for AS, including P/SP/AP, should have the same xTyR configuration
* This feature is only useful if UE can report UE preference
 |
|  |  |

# Antenna switching up to 8Rx

## 4T6R configurations

Based on the first-round discussion, it seems the first two alternatives attract higher interest than the other two. Hence FL recommends to focus on these two in Round 3 and try to select one.

***FL Proposal 3-3:*** *Select one of the following SRS configurations for 4T6R*

* *Alt 1: 4 + 2*
	+ Supported byZTE, CATT, CMCC, Samsung, Intel, Qualcomm, OPPO, Lenovo/MotM, NTT DOCOMO, Xiaomi, Apple, MediaTek, LGE
* *Alt 2: 2+2+2*
	+ *For SCS=15, 30 and 60KHz: No guard symbols*
	+ *For SCS=120 KHz: No guard symbols between the 1st and the 2nd transmission, and 1 guard symbol between the 2nd and 3rd transmission*
	+ Supported by Huawei/HiSilicon, InterDigital, CMCC, vivo, Ericsson, NTT DOCOMO
* *Clarification on the notation:* $x\_{1}+\cdots +x\_{K}$ *means totally K resources are needed, where the k-th resource contains* $x\_{k}$ *ports, 1<=k<=K*

Companies are encouraged to indicate which alternative you prefer **between these two alternatives**.

Companies’ further views are collected as follows.

|  |  |
| --- | --- |
| Companies | Views |
| Apple | We prefer Alt 1. Alt 2 seems to be 2T6R. Why UE needs to report 4T6R then? Anyway, we do not even think 4T6R is something that realistic. |
| InterDigital | Our preference is Alt2, for the following reasons: 1- it supports an equal power for chnnel sounding across the ports, 2- it requires less overhead and therefore, it takes less time for completing sounding of the channel.In regard to the question about its difference with 2T6R, in 2T6R we only have 2 TX chains. Therefore, the sounding must be done with the same pair of TX chains, and because of that we need to have guard symbols between every SRS transmission. But when UE reports 4T6R, we have two pair of TX chains, therefore we can alternate between the two pairs of TX chains without requiring guard symbols.Since some of details are not captured in the existing proposal, we would like to suggest the following updated proposal,***FL Proposal 3-3:*** *Select one of the following SRS configurations for 4T6R** *Alt 1: 4 + 2*
	+ Supported byZTE, CATT, CMCC, Samsung, Intel, Qualcomm, OPPO, Lenovo/MotM, NTT DOCOMO, Xiaomi
* *Alt 2: 2+2+2*
	+ For SCS=15, 30 and 60KHz: No guard symbols
	+ For SCS=120 KHz: No guard symbols between the 1st and the 2nd transmission, and 1 guard symbol between the 2nd and 3rd transmission
	+ Supported by Huawei/HiSilicon, InterDigital, CMCC, vivo, Ericsson, NTT DOCOMO
* *Clarification on the notation:* $x\_{1}+\cdots +x\_{K}$ *means totally K resources are needed, where the k-th resource contains* $x\_{k}$ *ports, 1<=k<=K*
 |
| MediaTek | prefer Alt 1 |
| OPPO | Our first preference is Alt.1, but we can support both.In the last GTW, we extended the configuration of SRS resource sets for 1T2R and 2T4R. Following the similar logic, we can support more than one configuration of SRS resource sets for 4T6R as well.  |
| QC | We support Alt 1. There are few concerns with Alt 2.1. Alt 2 doesn’t enable SRS resource sharing between antenna switching and codebook sets for 4Tx UE which has been commonly used since Rel-15. For Alt 1) gNB can configure two SRS resources, one resource with 4 ports and another one with 2 ports. The 4ports SRS resource is shared between ‘antennaSwtiching’ set and the codebook set. This is not possible for Alt 1 especially for full coherent UE.

1. Alt 2 results into cross talk between (signal coupling) which results into mixed port sounding. The antenna switching is not instantaneous and requires transition time to turn trun OFF the PA (take few microseconds as per RAN4 spec), perform RF antenna switching, then turn on the PA. This procedure will be done while the other PAs are ON. During the transition periods of PA (ON 🡨🡪 OFF), the PA is still radiating which will result into coupled signal from the turned off to the ON ports. This will results into gNB estimation of mixed channel of two ports.

To further explain, given the figure from InterDigital contribution, where during the 2nd SRS symbol, PA3 and PA4 are connected to antenna 2,3 while UE switch PA1/2 from (p0,p1) to (p4,p5). The ordering as explain in figure below is 1) UE turn off PA1/2, then 2) change switch state of the RF switches, then 3) turn back the PA1/2 on. This needs to happen while PA3/4 is ON. During the transition period of PA1/2 from ON to OFF, there will transmitted power from p0, and 1. In addition, during transition from OFF to ON, there will be transmitted powr from p4,p5.

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| --- | --- |
| Transmission of the 2nd SRS resource |  |

1. Regarding the power imbalance claims across the 4+2 ports. We don’t see any issue here. If two sets are configured for the two resources, gNB can configure different power control parameter such that it guarantees same power is used for the different power. Even, if single set is used, gNB is aware of power delta (3dB) and can be compensated.

Finally, want to highlight, that RAN4 allows some margins of power variation across antenna ports which can be as large as 7.5 dB. Any other Rx chain other than the “primary” RX chain can have reduced maximum output power defined by **of ∆TRxSRS.** So claims of power imbalance is washed out within this margin if it exits.  Excerpt of 38.101-1 16.8.0 below. 6.2.4 Configured transmitted powerThe UE is allowed to set its configured maximum output power PCMAX,f,c for carrier f of serving cell c in each slot. The configured maximum output power PCMAX,f,c is set within the following bounds:PCMAX\_L,f,c ≤ PCMAX,f,c ≤ PCMAX\_H,f,c with PCMAX\_L,f,c = MIN {PEMAX,c– ∆TC,c, (PPowerClass – ΔPPowerClass) – MAX(MAX(MPRc+∆MPRc, A-MPRc)+ ΔTIB,c + ∆TC,c +∆TRxSRS, P-MPRc) }PCMAX\_H,f,c = MIN {PEMAX,c, PPowerClass – ΔPPowerClass }… ∆TRxSRS is applied when a) UE transmits SRS to other than first SRS port when the *SRS-TxSwitch* capability is indicated as ‘1T2R', '1T4R' or, '1T4R/2T4R'b) UE transmits SRS to other than first or second SRS port when the *SRS-TxSwitch* capabilityis indicated as‘2T4R' or '1T4R/2T4R', orc) UE transmits SRS to a DL-only carrier **The value of ∆TRxSRS is 4.5dB for n79 and 3 dB for bands whose FUL\_high is lower than the FUL\_low of n79 when the device is capable of power class 3 in the band. The value of ∆TRxSRS is 7.5dB for n79 and 6 dB for bands whose FUL\_high is lower than the FUL\_low of n79 when the device is capable of power class 2 in the band**. |
| LGE | Between the two alts, we prefer Alt 1. We tend to agree with QC. In addition, we would like to propose to optionally support Alt 3(4+4) for when the time gap between the two SRS resources is relatively large or for time-variant channel environment. |
| CATT | Alt 1 is preferred since it has lower SRS overhead. |
| Huawei, HiSilicon | Support 2+2+2, i.e., Alt2.**We have concerns on Alt.1**:1. With Alt.1, it is clear that channel estimation is loss 3dB due to the unbalanced SRS resource configuration with 4-port resource and 2-port resource. ***The channel estimation of 4-port SRS resource is 3dB SINR less than 2-port SRS resource, due to the less power at the transmitter. We do not understand how does receive side (gNB) to complement the 3dB SINR loss on channel estimation?***2. Alt.1 has the Power balance issue as we mentioned before. As explained by QC, there is already some tolerance on antennas’ power. But, we should know the power tolerance in RAN4 discussion for different insertion loss. ***If antenna switching structure from 4-port and 2-port is already 3dB difference, how to guarantee the total power difference within 3dB for power class-3? How can guarantee no any insertion loss for different antennas?*** For sure, Alt.1 is problems on power imbalance in RAN4 design. **Some replies for the comments on Alt.1**:1. Fine with IDC’s revision, which is no requirement on guard period due to the 4Tx transmission capability.2. For QC’s comment on cross-talk, after some checking, we do not see there is such problem. During antenna switching in the guard period, there is no any signals on the PAs/antennas, so we do not see there is interference on the another PAs’ SRS transmission. 3. For QC’s comment on SRS sharing, it is not always required for the different type of SRS resources should be shared for different usages. Resource sharing is not the design principle for antenna switching. But anyway, if like, 2-ports SRS resource still could be reused for two port transmission.  |
| Ericsson | Alt.2 |
| Docomo | We are not sure the down selection is needed. We can support the both configuration.  |
| Intel | Support Alt 1. We don’t see the need to support both configurations. |
| Lenovo/MotM | We support Alt1. Alt 2 seems to 2T6R configuration.  |
| Samsung | Prefer Alt.1 |
| vivo | Support alt2. 2+2+2 is SRS configuration, it doesn’t restrict on any hardware implementation. |
| Apple-2 | By adding no guard symbol to Alt2, now, we object Alt2. |
| NEC | Support Alt 1. |

# Coverage and capacity enhancements

## RB-level partial frequency sounding (RPFS)

This section summarizes companies’ views on remaining issues for RPFS.

### 4.1.1 PF values

***FL Proposal 4-1:*** *No consensus to support PF values other than {2, 4} for RPFS in Rel-17.*

Supported by LGE, OPPO, Samsung, Qualcomm, CATT, Ericsson, Spreadtrum, Intel, Xiaomi, Nokia/NSB, MediaTek, Lenovo/MotM, NEC, InterDigital, Apple, ZTE

Concerned by NTT DOCOMO, Futurewei, vivo

Considering the majority of companies can accept this proposal, FL encourages companies to consider the limited time we have now. Please indicate whether FL proposal 4-1 is acceptable.

Companies’ further views are collected as follows.

|  |  |
| --- | --- |
| Companies | Views |
| Apple | We support  |
| InterDigital | Support FL proposal |
| MediaTek | Support |
| Spreadtrum | Support |
| OPPO | Support FL proposal |
| QC | Support FL proposal. |
| LGE | Support. |
| Xiaomi | Support |
| CATT | Support  |
| Huawei, HiSilicon | Add a value more, i.e., 3 is more beneficial. |
| Ericsson | Support |
| Docomo | Not support, because of the same comment in the 2nd round. *Our comment in round2:**We believe larger value should be introduced. Introducing larger value of P F have more benefit to improve coverage/capacity. Moreover, we don’t understand the problem to introduce the larger values than P F =4. For example, when we have 8, and limit the number of exact RBs with Alt 2 (or Alt 3) in 4.1.4, we see few (or no) issue remains. What is the problem to introduce the larger value e.g. PF = 8?* |
| Intel | Support FL proposal. |
| Futurewei | Not support. We agree with Docomo.If only 2 and 4 are supported, the resulting SRS BWs can be alternatively configured based on existing R15 specs. We are not sure how useful this feature is. |
| Lenovo/MotM | We prefer to add *Pf*=8 in addition. |
| vivo | Not support, agree with views from DOCOM and Futurewei |
| CMCC | Support FL proposal |
| NEC | Support the proposal. |

# Conclusion

The following proposals are recommended.

# Appendix

## Previous agreements

Table 6-1

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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..

**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}.**RAN1#104e****Agreement**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, 10, 12, 14}
		- FFS other candidate values
* Support to transmit SRS only in $\frac{1}{P\_{F}}m\_{SRS,B\_{SRS}}$ contiguous RBs in one OFDM symbol, where$m\_{SRS,B\_{SRS}}$  indicates the number of RBs configured by BSRS and CSRS
	+ Support at least one PF value from {2, [3], 4, 8}
		- FFS other candidate values, e.g., non-integer values for PF
	+ Note: SRS sequence shorter than the minimum length supported in the current specification is not pursued.
	+ No new sequence including length is introduced
	+ FFS it is applicable to frequency hopping and non-frequency hopping
	+ FFS detailed signaling mechanism to determine PF and the location of the $\frac{1}{P\_{F}}m\_{SRS,B\_{SRS}}$ RBs
* Support Comb 8
	+ Note: SRS sequence shorter than the minimum length supported in the current specification is not pursued.
* FFS whether and if needed, how to use harmonized approach to define the three supported schemes
* Note: other schemes for SRS capacity and coverage enhancements are not supported in Rel-17.

**Agreement*** For aperiodic antenna switching SRS, 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.
	+ (Working Assumption) For 4T8R, K=2, N\_max = [2], and each resource has 4 ports.
	+ FFS the number of supported candidate values of N for each xTyR.
* FFS extension to increase N\_max for 1T4R, 2T4R, T=R and 1T2R cases for aperiodic, periodic and semi-persistent SRS resources
* FFS the number of resources and resource sets for semi-persistent and periodic antenna switching SRS
* Note: SRS could be transmitted over the last 6 OFDM symbols, or over any OFDM symbols within the slot subject to UE capability.

**Agreement**Further study whether and if needed, how to achieve further enhancements on aperiodic SRS triggering and resource management based on repurposing unused fields in DCI format 0\_1/0\_2 without data and without CSI. Consider the following examples* CAT A: Time-domain parameters
	+ A-1: Indication of available slot position, i.e., the t values
	+ A-2: Indication of slot offset
	+ A-3: Indication of SRS symbol-level offset
	+ A-4: Indication of time-domain behavior for SRS transmission over multiple OFDM symbols, e.g., repetition, hopping, and/or splitting
* CAT B: Frequency-domain parameters
	+ B-1: Indication of a group of CCs for SRS transmission
	+ B-2: Indication of frequency domain resource in a BWP for SRS transmission
	+ B-3: Indication of whether DL/UL BWP is applied for SRS transmission
* CAT C: Power control parameters
	+ C-1: Re-purpose ‘TPC command for PUSCH’ as ‘TPC command for SRS’
		- FFS impact on power control, impact from triggering a group of CCs for SRS
	+ C-2: Indication of open loop power control parameter e.g., p0.
* CAT D: Spatial-domain parameters, i.e., indication of SRS port and beamforming
* CAT E: Extend the number of DCI codepoints for aperiodic SRS trigger states
* Other examples are not precluded

**Agreement**A list of t values is configured in RRC for each SRS resource set. Adopt at least one of the following for DCI indication of t.* In DCI format 0\_1/0\_2 without data and without CSI request,
	+ Alt 1-1: Reuse the same scheme used for DCI format 0\_1/0\_2/1-1/1-2 that schedules a PDSCH or PUSCH
	+ Alt 1-2: Re-purpose unused DCI field to indicate t
	+ Alt 1-3: t is indicated by a configurable DCI field, where the DCI field may contain bits from unused fields and additional bits configured by gNB
		- FFS design details with other potential field(s)
	+ FFS: whether t can be slot offset
* In DCI format 0\_1/0\_2/1-1/1-2 that schedules a PDSCH or PUSCH
	+ Alt 2-1: t is indicated by adding a new configurable DCI field
	+ Alt 2-2: t is indicated without adding DCI payload
* Note: The size of DCI payload does not change dynamically
* Note: RAN1 should strive for unified solution for different DCI formats.
* FFS: The number of RRC configured t values per SRS resource set and DCI bit field size.

**Agreement**Confirm the following working assumption with modificationsAn “available slot” is a 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 UE capability on 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, UL cancellation indication or dynamic scheduling of DL channel/signal(s) on flexible symbol(s) that may change the determination of “available slot”.
* Note: Collision handling between the triggered SRS and any other UL channel/signal is performed after the determination of available slot.
* FFS: Rules to handle the case of multiple SRS resource sets with overlapping symbols and/or triggered by a same DCI

**RAN1#104bis-e****Agreement**For increased repetition in Rel-17, support the following N\_symbol (number of OFDM symbols in one SRS resource) and R (repetition factor) values* N\_symbol = 8, R = {1, 2, 4, 8}
* N\_symbol = 12, R = {1, 2, [3], 4, 6, 12}
* FFS the following configurations
	+ N\_symbol = 10, R = {1, 2, 5, 10}
	+ N\_symbol = 14, R = {1, 2, 7, 14}
* FFS options to reduce SRS BW for R>1

**Agreement**On aperiodic SRS configuration for antenna switching with > 4Rx, support the following N\_max values* 1T6R: N\_max = 3
* 1T8R: N\_max = 4
* 2T6R: N\_max = 3
* 2T8R: N\_max = 4
* [4T8R: N\_max = 2]
* The support of N\_max value does not imply the support of N value that is smaller than N\_max. This is FFS.
* FFS whether further enhancement for single-DCI or multi-DCI based MTRP is needed

**Agreement**For RB-level partial frequency sounding (RPFS) in Rel-17* The start RB index of the $\frac{1}{P\_{F}}m\_{SRS, B\_{SRS}}$ RBs in the $m\_{SRS, B\_{SRS}}$ RBs is $N\_{offset}=\frac{k\_{F}}{P\_{F}}m\_{SRS, B\_{SRS}}$, where kF = {0, …, PF-1}
	+ FFS support start RB location (Noffset) hopping in different SRS occasions, symbols or frequency hopping periods, and if supported, detailed hopping pattern
* Support to determine PF and Noffset at least via RRC configuration per SRS resource.
	+ FFS whether to introduce DCI and/or MAC CE in addition

**Working Assumption**For DCI indication of “t” in Rel-17 SRS triggering offset enhancement* For both DCI that schedules a PDSCH/PUSCH and DCI 0\_1/0\_2 without data and without CSI request
	+ t is indicated by adding a new configurable DCI field (up to 2 bits)
		- Applies only when there are multiple candidate values of t configured
	+ No further enhancement to indicate “t” for DCI 0\_1/0\_2 without data and without CSI request at least when the new DCI field is configured

**Agreement**On supported values of N for Rel-17 aperiodic SRS antenna switching with >4Rx, down-select at least one of the following alternatives in RAN1#105e* Alt 1: All the non-zero integer values <= N\_max are supported for N
* Alt 2: Support N=N\_max only
* Alt 3: Support specific N values <= N\_max
* FFS whether different alternatives may be selected for the same xTyR configuration subject to the UE capability on maximum number of symbols that can be used for SRS in a slot
* FFS: whether different alternatives may be selected for different xTyR configuration

**Agreement**Study the maximum number of cyclic shifts for Comb-8 in Rel-17, with the following alternatives as starting points* Alt 1: The maximum number of CSs for Comb-8 is 6
* Alt 2: The maximum number of CSs for Comb-8 is 12, and introduce a rule to restrict applicable CSs when SRS sequence is shorter than the maximum number of CSs

**Agreement*** Up to 4 “t” values can be configured per SRS resource set.

**Agreement*** For RPFS in Rel-17, support PF = {2, 4}.
* FFS 3, 8, 12, 16 or fractional numbers
* Support at least one of the following alternatives (to be decided in RAN1#105-e)
	+ Alt 1: $\frac{1}{P\_{F}}m\_{SRS, B\_{SRS}}$$\frac{1}{P\_{F}}m\_{SRS, B\_{SRS}}$ is an integer value
	+ Alt 2: $\frac{1}{P\_{F}}m\_{SRS, B\_{SRS}}$$\frac{1}{P\_{F}}m\_{SRS, B\_{SRS}}$ is an integer value with minimum value 4
	+ Alt 3: $\frac{1}{P\_{F}}m\_{SRS, B\_{SRS}}$ is a multiple of 4
	+ Alt 4: Round $\frac{1}{P\_{F}}m\_{SRS, B\_{SRS}}$$\frac{1}{P\_{F}}m\_{SRS, B\_{SRS}}$ to a multiple of 4 in case of Alt 1 or Alt 2

**Agreement**On aperiodic SRS configuration for antenna switching with 4T8R, support N\_max = 2**Agreement**For RPFS SRS in Rel-17, adopt one of the following alternatives for sequence generation, where no new sequence length other than the ones supported in the current spec is introduced (to be decided in RAN1#105-e)* Alt 1: Generate length- $\frac{12}{Comb⋅P\_{F}}m\_{SRS, B\_{SRS}}$$\frac{\frac{12}{P\_{F}}m\_{SRS, B\_{SRS}}}{Comb}$ ZC sequence
* Alt 2: Truncate from legacy length-$\frac{12}{Comb}m\_{SRS, B\_{SRS}}$$\frac{12⋅m\_{SRS, B\_{SRS}}}{Comb}$ sequence according to the location of RPFS SRS

**Agreement**For antenna switching, support one of the following * Alt 1: Support maximum one SRS resource set for periodic SRS and maximum one SRS resource set for semi-persistent SRS
* Alt 2: Support up to two semi-persistent SRS resource sets in addition to a periodic SRS resource set
	+ Note: the two SP-SRS resource sets are not activated at the same time.
* FFS whether further enhancement for single-DCI or multi-DCI based MTRP is needed
* FFS whether configurations on SRS repetitions have impact
* FFS relevant UE capability design

**RAN1#106-e****Agreement**Confirm the following WA:For DCI indication of “t” in Rel-17 SRS triggering offset enhancement* For both DCI that schedules a PDSCH/PUSCH and DCI 0\_1/0\_2 without data and without CSI request
	+ t is indicated by adding a new configurable DCI field (up to 2 bits)
		- Applies only when there are multiple   candidate values of t configured
	+ No further enhancement to indicate “t” for DCI 0\_1/0\_2 without data and without CSI request at least when the new DCI field is configured

**Agreement**Support start RB location (Noffset) hopping in different SRS frequency hopping periods for RPFS and at least periodic/semi-persistent SRS, where Noffset is the start RB index of the $\frac{1}{P\_{F}}m\_{SRS, B\_{SRS}}$ RBs in the $m\_{SRS, B\_{SRS}}$ RBs.* For a given SRS transmission occasion, $N\_{offset}=\frac{\left(k\_{F}+k\_{hopping}\right) mod P\_{F}}{P\_{F}}m\_{SRS, B\_{SRS}}$ , where khopping is same for all SRS occasions within a legacy FH period but changes across legacy FH periods, kF and PF are at least configured by RRC signaling (kF = {0, 1, …, PF-1}).
* Support at least one pattern for khopping in time domain, FFS detailed pattern
* Note: the legacy FH period is the period to sound the full SRS hopping bandwidth across the different subbands of $m\_{SRS, B\_{SRS}}$ RBs each.
* This start RB location hopping is enabled or disabled by RRC signaling.
* FFS whether MAC CE or DCI can be additionally used
* When this start RB location hopping is disabled,$k\_{hopping}$ khopping is fixed to be 0 for all SRS symbols
* This start RB location hopping is UE optional.
* FFS whether start RB location hopping is also applicable on SRS occasion(s) within one FH period (e.g., when R>1) and/or on aperiodic SRS, if so, how

**Agreement**For aperiodic xTyR antenna switching SRS, where xTyR is from {1T6R, 1T8R, 2T6R, 2T8R, 4T8R}, support all the non-zero integer values N<=N\_max except N=1 for 1T8R * For each xTyR configuration, UE does not expect multiple SRS resource sets are configured or triggered in one slot
* UE does not expect that the OFDM symbols contained in one SRS resource set exceed UE capability on which OFDM symbols can be used for SRS taking guard period into account

**Agreement**Support Opt. 2: Reference slot is the slot indicated by the legacy triggering offset.* If DCI is transmitted in slot n, and k is the legacy triggering offset, reference slot is slot n+k.
* Note: the legacy triggering offset can be 0, if slotOffset is absent.

**Conclusion**MAC CE for t value update in Rel-17 is not supported.**Agreement**For antenna switching SRS, support maximum one SRS resource set for periodic SRS and maximum 2 SRS resource sets for semi-persistent SRS.* Note: the two SP-SRS resource sets are not activated at the same time
* For xTyR where y>4, if UE does NOT support this feature, support maximum one SRS resource set for periodic SRS and maximum one SRS resource set for semi-persistent SRS
* Applies for all supported xTyR where y<=8
* For each xTyR antenna switching (except for 4T6R if supported), each periodic or semi-persistent resource set contains y/x resources.

This feature is UE optional: For UEs that do not support this feature, follow Rel-15 on the number of resource sets for periodic and semi-persistent SRS**Agreement*** Support 4T6R SRS antenna switching in Rel-17.

**Agreement**For RPFS SRS sequence generation, support * Alt 1: Generate length-$\frac{\frac{12}{P\_{F}}m\_{SRS, B\_{SRS}}}{Comb}$ ZC sequence.

**Agreement**For SRS increased repetitions in Rel-17, support the following configurations, and no other values are supported.* (N\_symbol, R) = {(8, 1), (8, 2), (8, 4), (8, 8), (12, 1), (12, 2), (12, 3), (12, 4), (12, 6), (12, 12), (10, 1), (10, 2), (10, 5), (10,10), (14, 1), (14, 2), (14, 7), (14, 14)}
* Note: N\_symbol SRS symbols are adjacent in a slot.

**Agreement*** On the presence of guard symbols in Rel-17 for SRS antenna switching, down-select one of the following
	+ Alt 1-0: Guard symbols are always-on, which is same as Rel-15
	+ Alt 1-1: Guard symbols are configurable subject to UE capability
* On whether to introduce guard symbols between SRS resource sets for antenna switching, down-select one of the following
	+ Alt 2-0: Do not introduce guard symbols between SRS resource sets, i.e., guard symbols only appears between SRS resources in a resource set
	+ Alt 2-1: Introduce guard symbols between two sets mapped to consecutive slots
* Note: Rel-15 guard period symbols are supported if none of the above enhancements is agreed

**Agreement**For Comb-8 SRS in Rel-17, down-select one of the following in RAN1#106bis-e* Alt 1: The maximum number of CSs for Comb-8 is 6
* Alt 2: The maximum number of CSs for Comb-8 is 12, and introduce a rule to restrict applicable CSs when SRS sequence is shorter than the maximum number of CSs

**RAN1#106bis-e****Agreement**For two SRS resource sets of an xTyR antenna switching located in two consecutive slots, if UE is capable of transmitting SRS in all symbols in one slot, a minimum gap period of Y symbols exists between the last OFDM symbol occupied by the SRS resource set in the first slot and the first OFDM symbol occupied by the SRS resource set in the second slot* The value of Y is same as the inter-resource GP defined in Rel-15
* FFS: Whether or not the minimum GP exists can be RRC configurable subject to UE capability
* Whether this inter-set GP is needed for 4T6R can be discussed later per the decision on 4T6R configuration.
* FFS: How/Whether to handle the case where the interval between SRS resource sets is larger than Y

**Agreement**For the detailed pattern of $k\_{hopping}$ when start RB location hopping across legacy FH periods is enabled, support the following* For PF = 2, $k\_{hopping}$ = {0, 1}
* For PF = 4, $k\_{hopping}$ = {0, 2, 1, 3}
* Note: $k\_{hopping}=\{x\_{0},\cdots x\_{P\_{F}-1}\}$ means $k\_{hopping}=x\_{n mod P\_{F}}$ for the (n+1)-th legacy FH period, where n = {0, 1, 2, 3, …}
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