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Title: NR PUCCH resource allocation
Agenda Item: 6.3.2.4
Document for: Discussion and Decision

1. Introduction

This contribution is revised and modified from contribution R1-1712454.

At the RAN1 #90 meeting, the following were agreed [1]:

Agreements:

- In order to identify PUCCH resource, **at least** following are known by the UE:
 - PUCCH format
 - Starting symbol in a slot
 - Which slot(s) the PUCCH is transmitted
 - PRB allocation within the UL BWP
 - For 1-symbol short-PUCCH for UCI of up to 2 bits,
 - ✧ Code/sequence index(es)
 - For 1-symbol short-PUCCH for UCI of more than 2 bits,
 - ✧ No additional parameters are identified
 - For 2-symbol short-PUCCH for UCI of up to 2 bits,
 - ✧ Code/sequence index(es)
 - ✧ Frequency-hopping pattern
 - For 2-symbol short-PUCCH for UCI of more than 2 bits,
 - ✧ Frequency-hopping pattern
 - For long-PUCCH for UCI of up to 2 bits,
 - ✧ Duration of the long-PUCCH within a slot
 - Note: take the case of multi-slot into account.
 - ✧ Sequence/code index
 - OCC and, e.g., cyclic-shift
 - ✧ Frequency-hopping pattern
 - For long-PUCCH for UCI of more than 2 bits with no multiplexing capacity,
 - ✧ Frequency-hopping pattern
 - ✧ Duration of the long-PUCCH within a slot
 - Note: take the case of multi-slot into account.
 - For long-PUCCH for UCI of more than 2 bits with multiplexing capacity,
 - ✧ FFS: details
- FFS: for transmit diversity
- FFS: signaling aspects, e.g., implicit, explicit, table, etc.

Based on the existing agreements, further considerations about the PUCCH are made in this contribution. SR resources are also discussed.

2. PUCCH resource allocation

2.1. PUCCH resource set

It has been agreed to support ARI-based PUCCH resource allocation for HARQ-ACK transmission in RAN1#88 meeting [2]. That is a PUCCH resource set is configured by high layer signaling, and the physical layer signaling indicates the one PUCCH resource from the set.

In RAN1#90 meeting, the resource elements of the resource set for each PUCCH format are identified. It can be found that different PUCCH formats may require different resource elements. For example, cyclic shift index is not applicable to PUCCH format with more than 2 bits. Therefore, it is reasonable to define a separate PUCCH resource set for different PUCCH formats. On the other hand, in some transmission modes based on the current payload size, UE may know which PUCCH format should be used between formats with 2bits UCI and formats with more than 2bits UCI. It seems unnecessary to define a separate set for PUCCH format supporting the same number of UCI bits.

Proposal 1: For the PUCCH resource set

- **Define two PUCCH resource sets, one set is for PUCCH format carrying up to 2 bits UCI and another set is for PUCCH format carrying more than 2 bits UCI.**
- **Each PUCCH resource in the PUCCH resource set can contain: PRB index, start symbol, duration, and corresponding slot. They can be independent, joint-coded or represented by tables.**

In Table 1, an example is shown for PUCCH resource set definition for formats carrying up to 2bits UCI. Resource parameter including format types, PUCCH length, PUCCH resource value, time domain OCC (if any) and cyclic shift index, etc. 4 bits in DCI is used to indicate one PUCCH resource group index to the UE.

The PUCCH resource value in Column #3 corresponds to a specific RB index and starting symbol index. For short PUCCH format, each CS set contains multiple CS. For example, CS set #0 and CS set #1 are {0, 6}, CS set #2 is {0, 3, 6, 9} and CS set #3 is {1, 4, 7, 11}. If 2 bits UCI are to be transmitted while the corresponding CS index set only contains two CS, the UE will automatically use another RB, which can be explicitly indicated by the configured RB index. For long PUCCH format, each CS set contains only one CS. In addition, the time domain OCC is only applied to long PUCCH format.

Table 1– PUCCH resource set for formats carrying up to 2 bits

PUCCH format	PUCCH length	PUCCH resource value	Time domain OCC	Cyclic shift index	PUCCH resource group index
Short Format 0	1	a0	-	CS set #0	0
		a1	-	CS set #1	1
	1	a2	-	CS set #2	2
		a3	-	CS set #3	3
	2	a4	-	CS set #4	4
		a5	-	CS set #5	5
	2	a6	-	CS set #6	6
		a7	-	CS set #7	7
Long Format 0	4	a8	OCC #0	CS set #8	8
		a9	OCC #1	CS set #9	9
	8	a10	OCC #0	CS set #10	10
		a11	OCC #1	CS set #11	11
	8	a12	OCC #0	CS set #12	12
		a13	OCC #1	CS set #13	13
	14	a14	OCC #0	CS set #14	14
		a15	OCC #1	CS set #15	15

For PUCCH formats with more than 2 bits, a similar resource set like Table 1 would be introduced. It use 'the number of RBs' in Column #5 instead of 'cyclic shift index'.

Proposal 2: The resource parameters, for PUCCH resource set should configured by predefined table.

2.2. Frequency resource allocation for PUCCH resource set

2.2.1 Analysis and simulation for short PUCCH performance

In NR, the PUCCH is divided into a long and short format. The short PUCCH contains only 1~2 OFDM symbols. In 3GPP there is a consensus about that compared to the LTE PUCCH, the performance of the short PUCCH in NR is decreased due to the lower number of symbols being used. These drawback should be mitigated and it should be studied how to improve the performance of the short PUCCH in NR.

In LTE, the PUCCH resources are pre-allocated and placed at both ends in the frequency domain. Although the LTE-PUCCH does not make full use of the channel quality information, the application of more OFDM symbols can guarantee the performance requirements. In NR, in order to achieve a better performance of the short PUCCH, it should be studied how to utilize channel quality information for the PRB selection of the PUCCH transmission.

A system simulation result is provided as an indication that a significant gain can be obtained for a short PUCCH when utilizing the channel quality. The system simulations have taken into account the impact of

neighbouring cell interference, scheduling algorithms and CQI effectiveness (CQI measurement is in subframe n and CQI measurement result is used in subframe $n+6$). More detailed parameters are provided in the appendix.

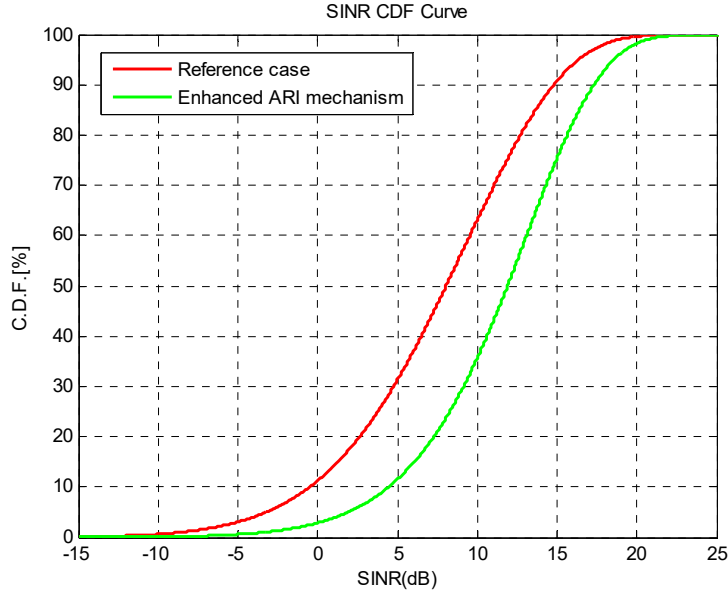


Figure 1 – CDF for SINR of two PUCCH transmission schemes

In Figure 1, two PUCCH SINR curves are provided. One is for a reference case and the other is for an improved mechanism, which is introduced as Enhanced ARI mechanism in section 2.2 below. The reference case always uses randomly assigned PRBs for the short PUCCH transmission, no channel quality information is considered. Enhanced ARI mechanism, on the other hand, takes advantage of the channel quality when selecting suitable PRBs. A SINR gain between 3.5-5 dB compared to the reference case can be observed.

Proposal 3: In NR, in order to enhance the performance of the short PUCCH, it should be studied how to use the PRB(s) with a good channel quality at least for PUCCH with ACK/NACK.

Obviously, in an uplink slot, the UE might simultaneously transmit the PUCCH and the PUSCH, or the UE only transmits the PUCCH. Therefore, when discussing PUCCH frequency-domain resource allocation, it should be considered whether or not the UE simultaneously transmits PUSCH.

2.2.2 Semi-static + Dynamic PRB allocation for UE with simultaneous PUCCH and PUSCH

In LTE, a combination of a semi-static configuration and dynamic signalling is used to determine the PUCCH resource for ACK/NACK in the frequency domain. This is called the ARI (ACK/NACK

Resource Indicator) mechanism. A similar concept could be envisioned for NR. A set containing four PUCCH candidate resources is configured through semi-static signalling, and then the specific PUCCH resources to be used are indicated via the physical layer DCI. This ARI concept could also be used for transmitting PUCCH based on channel quality measurements, but the efficiency would be very low. Since four PUCCH candidate frequency resources are always pre-allocated through higher layer signalling, they cannot be adjusted in time to accurately track the change in channel quality.

We recommend a new method to achieve semi-static + dynamic PUCCH frequency resource allocation, an enhanced ARI mechanism which can overcome the above mentioned drawbacks.

An example for the enhanced ARI mechanism is shown in Figure 2 below. In one slot, when a UE's PUSCH and PUCCH are to be transmitted simultaneously, then at least one PUCCH candidate resource of the UE is located within the frequency domain for the PUSCH/PDSCH. The other candidate PUCCH frequency resources are configured through higher layer signalling. It is assumed that in total 4 candidates for PUCCH resources are contained in a configured set for the UE in a semi-static state. The base station always configures 3 candidate PUCCH resources for the UE through higher layer signalling and implicitly assumes that 1 candidate PUCCH resource is located within the frequency domain of the PUSCH / PDSCH of the UE. Then, physical layer signalling is used to indicate the specific PUCCH resource to be used out of the set from the four PUCCH candidate resources.

In most cases, the specific PUCCH resources of different UEs do not collide with each other when the PUCCH candidate resource within the UE's PUSCH resources is used. However, for rare events that it will happen, the base station can indicate one of the other PUCCH candidate resources (e.g., outside the UE's PUSCH resources) by physical layer signalling.

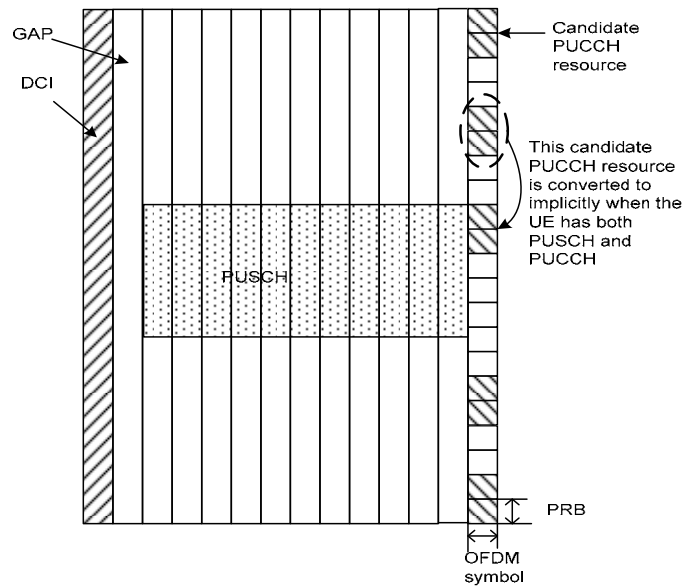


Figure 2 - Example for enhanced ARI mechanism

The enhanced ARI mechanism (dynamic + semi-static method) can promptly adjust at least one PUCCH candidate frequency resource to immediately follow the channel quality. Therefore, it can make full use of channel quality to transmit PUCCH.

In some well-known cases, the frequency resources of the PUSCH are allocated through the interference coordination between neighbouring cells. If the enhanced ARI mechanism is used, the specific PUCCH resources for the UE are dynamically adjusted to coincide with the PUSCH frequency resources, and then the interference of the other cells to the PUCCH can also be simultaneously reduced.

Obviously, dynamic frequency resource allocation and the enhanced ARI mechanism can be used simultaneously for long/short PUCCHs.

Proposal 4: Frequency resource allocation for PUCCH resource set:

- **In one slot, at least one PUCCH resource is located or implied within the frequency domain of the PUSCH/PDSCH (if any) of the UE, the other PUCCH resources can be configured through higher layer signalling.**

3 SR resource design for multiple beams

In NR, multiple beams are introduced to gNB and UE for data transmission and reception, to fight rapid fading in high frequency, e.g. above 6GHz. Similarly, the gNB cannot predict the actual beam for UE to

transmit or for gNB to receive SR. If only one fixed SR resource is allocated to UEs for all beams, when the serving BPL (beam pair link) especially the receiving beam of gNB is changed, gNB cannot receive the SR due to the fact that gNB needs to receive the signal from the other frequency band by original receiving beam. A straightforward way is to allocate one SR resource for each receiving beam of gNB to UE as shown in Figure 1. It means that multiple resources corresponding to different receiving beams of gNB are configured for each UE within one SR period. However, UE only uses serving beam to transmit SR and the remaining SR resources will not be used because the corresponding BPL quality is too weak. Considering that a large number of beams in gNB and UE result in a lot of corresponding SR resources, the waste SR resource may be considerable and cannot be ignored. Therefore, the resource efficiency of SR should be further studied.

Observation 1: *In multiple-beam scenarios, the overhead of SR resources is considerable if each receiving beam of gNB corresponds to one SR resource.*

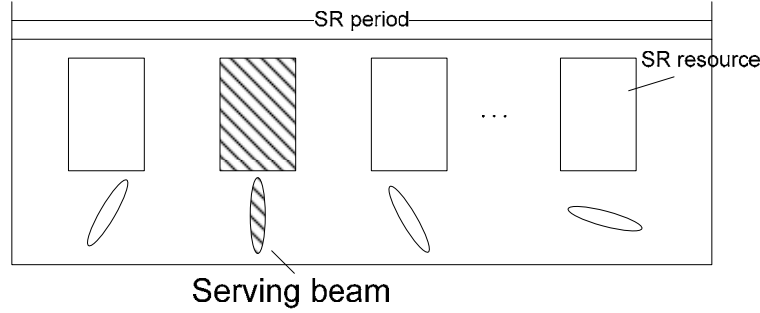


Fig. 1 Correspondence between SR resource and the receiving beam of gNB

It is obvious the SR resource selection is tightly related to the actual BPL, especially the receiving beam of gNB. Since UE only uses one SR resource within a SR period, the gNB can allocate only one resource for UE according to the current BPL. When the receiving beam of gNB is changed, the SR resource in the original beam can be released and a new SR resource for current beam is then allocated. Generally, the BPL of UE always changes due to the equipment movement. If SR resource is indicated by RRC signaling as in LTE, the latency is too large so that SR resource cannot follow the change of beam pair. Therefore, when gNB informs UE of the change of beam pair, the corresponding SR resource should also be indicated and the remaining resource can be scheduled for another purpose to improve resource efficiency, e.g. data transmission.

Proposal 5: *In multiple-beam scenarios, SR resource should bundle with the BPL, especially the receiving beam of gNB, within a SR period.*

The SR resource is changed according to the serving beam pair between UE and gNB. It means at least the time domain resource should be changed when the serving BPL is changed. However, for frequency domain and code domain resource, there are two kinds of options:

- Option 1: frequency domain and code domain resource keep unchanged
- Option 2: frequency domain and code domain resource are also changed

It is obvious that option 2 is more flexible but the signaling overhead of option 1 is lower than option 2. As illustrated in figure 2, the units filled with pattern denote the SR resources used by different UEs and the blank units denote unused SR resource. Note that the units just denote the smallest time and frequency resource granularity for SR, which can be code division multiplexed by two UEs. Different orthogonal code resources are denoted by different filled patterns. In option 1, since the frequency domain and code domain resource for SR keep unchanged, different UEs cannot use the same frequency domain and code domain resource in different time. So after allocating proper SR resource for all UEs, the remaining unused resource is irregular as shown in Figure 2, which is not beneficial for resource allocation. Meanwhile, considering multiple SR can be code division multiplexed, option 2 which allow changing frequency domain and code domain resource for SR is more beneficial for resource efficiency. For example, UE 1 and UE 5, UE 4 and UE 7 can be code division multiplexed in same frequency resource in option 2 respectively. However, in option 1, they have to use different frequency resource and the code domain resources are wasted.

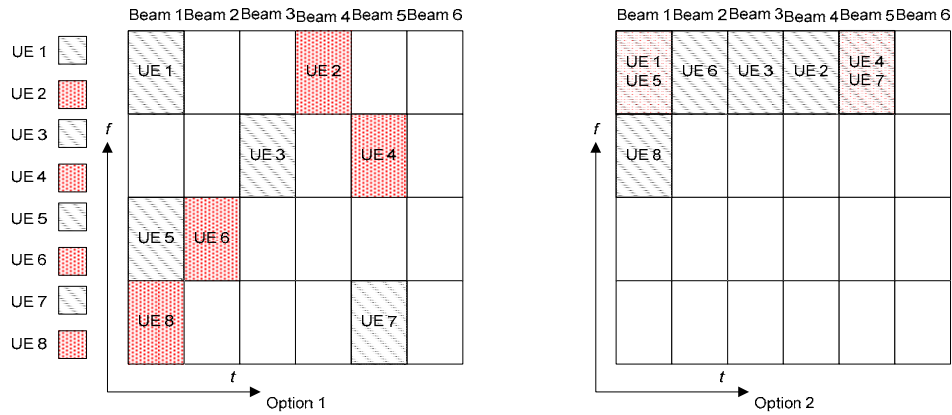


Fig. 2 Resource allocation examples of option 1 and option 2

Proposal 6: When the beam pair is changed, a new SR resource along with a new beam pair should be indicated by gNB.

3. Conclusion

Based on the analysis given above, we have the following proposals:

Proposal 1: For the PUCCH resource set

- Define two PUCCH resource sets, one set is for PUCCH format carrying up to 2 bits UCI and another set is for PUCCH format carrying more than 2 bits UCI.
- Each PUCCH resource in the PUCCH resource set can contain: PRB index, start symbol, duration, and corresponding slot. They can be independent, joint-coded or represented by tables.

Proposal 2: The resource parameters, for PUCCH resource set should configured by predefined table.

Proposal 3: In NR, in order to enhance the performance of the short PUCCH, it should be studied how to use the PRB(s) with a good channel quality at least for PUCCH with ACK/NACK.

Proposal 4: Frequency resource allocation for PUCCH resource set:

- In one slot, at least one PUCCH resource is located or implied within the frequency domain of the PUSCH/PDSCH (if any) of the UE, the other PUCCH resources can be configured through higher layer signalling.

Proposal 5: In multiple-beam scenarios, SR resource should bundle with the BPL, especially the receiving beam of gNB, within a SR period.

Proposal 6: When the beam pair is changed, a new SR resource along with a new beam pair should be indicated by gNB.

4. Reference

[1] 3GPP RAN1#90 Meeting, Chairman's Notes RAN1_#90_final.

[2] 3GPP RAN1#88 Meeting, Chairman's Notes RAN1_#88_final.

5. Appendix – System Simulation Parameters

Parameters	Assumption
Deployment scenario	Urban micro
Link direction	Uplink
Carrier Frequency	2 GHz

system bandwidth	10 MHz
Layout	Single layer: - Hex. Grid
ISD	200m
BS antenna elements	2 Rx antenna elements
UE antenna elements	1 Tx antenna element
Number of Users per cell	10 users
Traffic model	Full buffer traffic
Scheduler algorithm	PF
Scheduling unit	Subframe (1ms)
CQI effectiveness	The CQI measurement is in subframe n and the CQI measurement result is used in subframe $n + 6$.