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1. Introduction

UL control channel design is one of the fundamental works in NR, including the structure of long and short PUCCH format, the PUCCH resource allocation and also how to multiplex UCI with data. This contribution discusses several aspects of the PUCCH resource allocation, while the PUCCH structure and UCI transmission in PUSCH are treated in our companion contributions [1] ~ [5].

Up to RAN1 NR ad-hoc meeting, following agreements related to PUCCH resource allocation were made:

Agreements (updating RAN1 #87 agreements):

- A combination of semi-static configuration and (at least for some types of UCI information) dynamic signaling is used to determine the PUCCH resource both for the 'long and short PUCCH formats'
  - The PUCCH resource includes time, frequency and, when applicable, code domains.
    - FFS details e.g., if the time in the PUCCH resource includes both slot and symbol, or only symbol in a slot

Agreements:

- At least semi-static configuration for the following is supported.
  - A PUCCH resource of a given UE within a slot.
    - i.e., short-PUCCHs of different UEs can be TDM'ed within the given duration in a slot.
- The PUCCH resource includes time, frequency and, when applicable, code domains.
  - FFS details e.g., if the time in the PUCCH resource includes both slot and symbol, or only symbol in a slot

Agreements:

- Timing between DL assignment and corresponding DL data transmission is indicated by a field in the DCI from a set of values
  - The set of values is configured by higher layer
- Timing between UL assignment and corresponding UL data transmission is indicated by a field in the DCI from a set of values
  - The set of values is configured by higher layer
- Timing between DL data reception and corresponding acknowledgement is indicated by a field in the DCI from a set of values
  - The set of values is configured by higher layer
- Timing(s) is (are) defined at least for the case where the timing(s) is (are) unknown to the UE
  - FFS the value for the timing

2. Discussion

2.1 Multiple PUCCH formats

To enable more flexible operation and dynamic slot structure, NR will support flexible/configurable HARQ-ACK timing. Due to flexible HARQ-ACK timing, the number of DL slots with PDSCH(s) corresponding to one PUCCH/PUSCH for HARQ-ACK transmission can be variable and UE-specific. In some cases, the DL slot of PDSCH reception and the corresponding HARQ-ACK feedback can have a one-to-one mapping (similar to LTE FDD) while in other cases, there can be a many-to-one mapping (similar to LTE TDD). Thus, the HARQ-ACK payload may vary with

the bundling window size (note: it depends on HARQ-ACK codebook determination [6]). If more than one bit per TB such as CBG-based feedback is to be supported in NR, the HARQ-ACK payload also changes with CBG/TB-level feedback. Furthermore, same as LTE, the UCI payload also varies with the UCI contents (i.e., HARQ-ACK/CSI/SR) and the number of configured/scheduled DL cells in CA.

Therefore, similar to the LTE PUCCH formats 1~5 which are designed to optimally support different UCI payloads, different PUCCH formats in NR are also needed for the same reason. Considering the maximum payload of different PUCCH duration (long or short PUCCH) is different, the supported PUCCH formats for short and long PUCCH would be different. To avoid a large number of combination of PUCCH formats and PUCCH durations, it is desirable fewer PUCCH formats than in LTE be supported in NR.

A PUCCH format determination can be either explicit by DCI or, similar to LTE, implicit based on the HARQ-ACK payload.

Proposal 1: NR supports multiple PUCCH formats for HARQ-ACK transmission based on HARQ-ACK payload. Consider down-selection from LTE PUCCH format based structures.

2.2 PUCCH resource indication

UEs with different HARQ-ACK timing can transmit HARQ-ACK in a same slot while associated PDSCHs can be received in same or different slots. Then, the implicit determination of PUCCH resources (implicit link between a lowest CCE index of the PDCCH and PUCCH resource) in LTE can lead to collisions.

One way to avoid the collision is fully explicit indication (from a set of configured PUCCH resources) similar to ARI in LTE as was agreed in RAN1#87. The other possible way is the implicit indication complemented by explicit signaling in DCI. In LTE, 2 bits ARO indicative of one of four offsets on top of PUCCH resource derived by CCE index is introduced to alleviate the PUCCH resource collision between UEs with same CCE index within respective EPDCCH search space or one in EPDCCH search space while the other in PDCCH search space. In NR, ARO could still be an effective way to resolve the PUCCH resource collisions from UEs with PDSCH(s) transmitted in different DL slots. It can be considered at least for small HARQ-ACK payloads as in LTE to reduce the PUCCH resource reservation overhead.

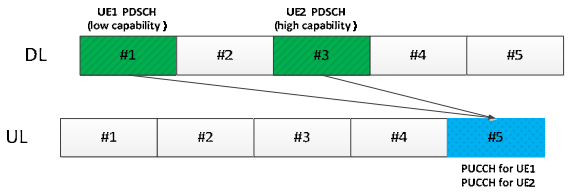

Figure 1 ACK/NACK collision between UEs with different ACK/NACK timing

Proposal 2: Further study the combination of implicit and ARO-like explicit indication of PUCCH resource in terms of DCI overhead and UL resource efficiency.

It is clarified in RAN1 NR ad-hoc meeting that the PUCCH resource consists of a time-domain component and frequency/code-domain component. Regarding the time-domain component, the granularity of time resource for long and short PUCCH is different. For the long PUCCH, the unit of time resource is UL slot, while the unit of time resource is UL symbol for short PUCCH.

Both separate indication of PUCCH time resource and frequency/code-domain resource or joint indication of all resources can be considered in terms of efficient UL resource utilization and reduced DL signaling overhead. In the case of separate indication of time and frequency/code resource, the set of HARQ-ACK timing values is configured by higher-layer and one of values is dynamically indicated by HARQ-ACK timing bit in DCI, and meanwhile, the set of frequency/code resource is configured by a separate higher-layer signaling and one of values is indicated by ARI/ARO-like bit in DCI. For long PUCCH, PUCCH time resource can be fully derived from the slot-level HARQ-ACK timing indication. For the short PUCCH, in addition to HARQ-ACK timing indication, semi-static configuration or dynamic indication in DCI is needed to identify the UL symbol index. In the case of beamformed system, UL symbols within one UL slot may be associated with receiving beams at gNB. The UL symbol to transmit short PUCCH could be implicitly derived from the gNB-side Rx beam indication. On the other hand, if there is no determinate relation between Rx beam and PUCCH transmission, explicit indication of UL symbol index should be applied. In the case of joint indication, for long PUCCH format, the UL slot is configured together with frequency/code resource in the PUCCH resource set, i.e., by a single higher-layer signaling. Then, the HARQ-ACK timing bit field can be omitted. For short

PUCCH format, UL symbol index and UL slot can be configured together with frequency/code resource in PUCCH resource set, or UL slot is configured in PUCCH resource set while UL symbol index is implicitly derived from beam indication or explicitly indicated by additional bit field in DCI, or the UL symbol is configured in PUCCH resource set and UL slot is derived by HARQ-ACK timing in DCI.

Proposal 3: Consider both separate indication of PUCCH time resource and frequency/code-domain resource or joint indication of all resources.

2.3 PUCCH duration indication

Multiple PUCCH duration (long and short PUCCH) is supported in NR to cope with different transmission latency, different link budget and probably for the different UCI payload. Since the link budget may change slowly and the latency of a certain service type is pre-defined, it seems sufficient to semi-statically configure the PUCCH duration. For the UCI payload, it may vary dynamically with number of DL slots/scheduled DL cells (with dynamic HARQ-ACK codebook determination). It might be beneficial to enable dynamic switching between long PUCCH and short PUCCH, at least for UEs with relatively good link budget. For example, when there is only one or few HARQ-ACK bits reported by a cell center UE, short PUCCH can still meet the performance requirement and improve scheduling flexibility by enabling either full UL/UL centric or DL centric slot. The dynamic switching could be implemented by either explicit indication in DCI (i.e., adding one bit) or ARI-like indication wherein long/short PUCCH is included in PUCCH resource set configuration.

Proposal 4: Further study the dynamic switching between long and short PUCCH in addition to semi-static configuration.

3. Conclusion

This contribution considered the design aspects for PUCCH resource allocation, and proposes the following.

Proposal 1: NR supports multiple PUCCH formats for HARQ-ACK transmission based on HARQ-ACK payload. Consider down-selection from LTE PUCCH format based structures.

Proposal 2: Further study the combination of implicit and explicit indication of PUCCH resource in terms of DCI overhead and UL resource utilization efficiency.

Proposal 3: Consider both separate indication of PUCCH time resource and frequency/code-domain resource or joint indication of all resources.

Proposal 4: Further study the dynamic switching between long and short PUCCH in addtion to semi-static configuration.

Reference

[1] R1-1702979, UL Control Channel Design: Short Format, Samsung.

[2] R1-1702981, UL Control Channel Design: Long Format, Samsung.

[3] R1-1702980, Multiplexing Short NR-PUCCH with Data or SRS, Samsung.

[4] R1-1702982, Consideration of Variable Slot Length, Samsung.

[5] R1-1702984, On UCI Multiplexing in PUSCH, Samsung.

[6] R1-1700957, HARQ-ACK feedback with flexible timing, Samsung.