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Title: Long PUCCH over multiple slots
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1 Introduction

In the RAN1#88 meeting, the following agreements were made with regard to long PUCCH with one and multiple slot duration [2]:

- For PUCCH in long duration,
 - At least for 1 or 2 UCI bits, the UCI can be repeated within N slots ($N > 1$)
 - The N slots may or may not be adjacent in slots where PUCCH in long duration is allowed
 - Details are FFS, including repetition scheme including same or different formats, the possible value(s) N , the mechanism to determine the value of N , etc.
 - FFS for > 2 UCI bits
 - FFS the case of within a slot

In addition, in the RAN1#89 meeting, the following agreement was made with regard to support of OCC for long PUCCH [5]:

- Long duration NR-PUCCH for up to 2 bits in a given slot is composed as the followings:
 - HARQ ACK by BPSK or QPSK modulation is repeated in time domain and multiplied with sequence(s)
 - FFS: $\pi/2$ BPSK usage
 - Two states SR is based on on-off-keying
 - Time domain OCC can be applied over multiple UCI/DMRS symbols per frequency hop

In this contribution, we discuss resource allocation and frequency hopping for long PUCCH with multiple slot duration.

2 Long PUCCH with multiple slot duration

To achieve at least similar link budget as LTE, long PUCCH may span multiple slots. For instance, when 60 kHz subcarrier spacing is employed, 4 consecutive slots may be allocated for the transmission of long PUCCH with 1ms duration. The number of slots allocated for long PUCCH can be semi-statically configured by higher layers.

For long PUCCH spanning multiple slots, in case of dynamic TDD system, first and last symbols for the transmission of long PUCCH can be different for different slots within the aggregated slots. As illustrated in Figure 1, this may depend on DL control region sizes, GP duration or whether short PUCCH and SRS are present in the corresponding slot. In this case, certain mechanisms may need to be defined to signal the long PUCCH position in each slot within aggregated slots for proper decoding at gNB receiver.

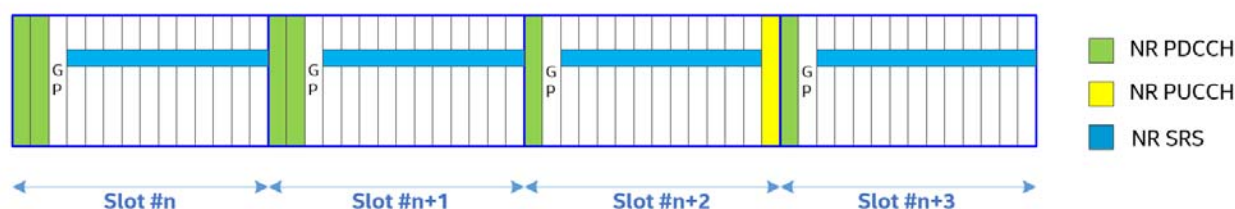
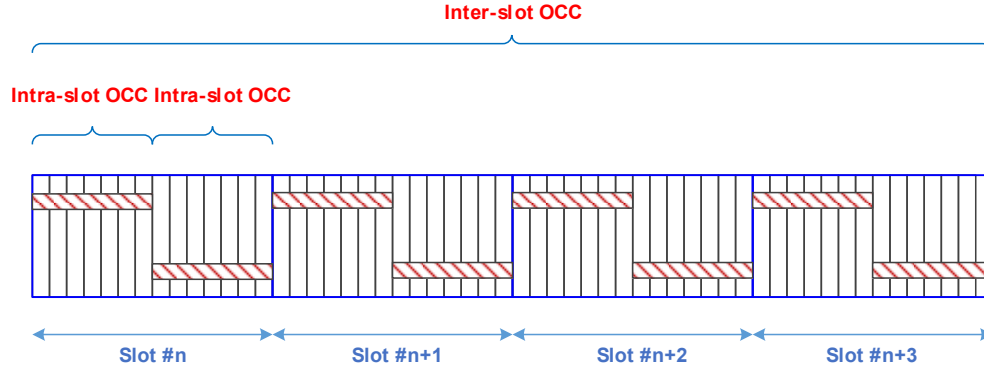


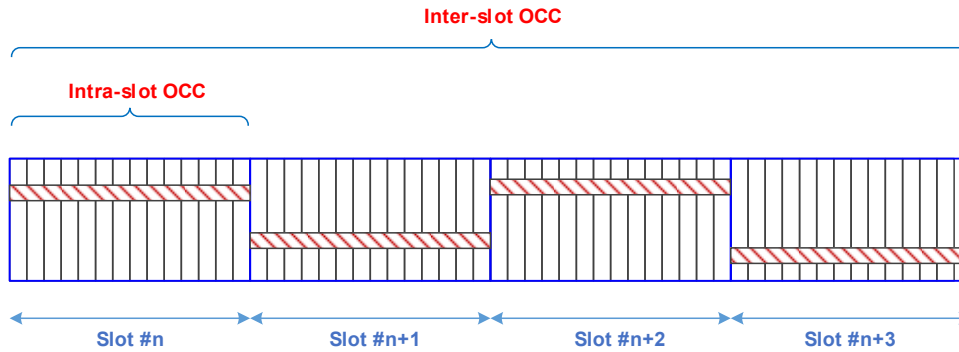
Figure 1. Different sizes for long PUCCH within aggregated slots

Similar to long PUCCH with 1 slot duration, frequency hopping can be applied for the transmission of long PUCCH spanning multiple slots. In particular, inter-slot frequency hopping may be employed to further improve the link budget for long PUCCH. Note that frequency hopping pattern needs to be carefully investigated with considerations of cross-slot channel estimation performance and frequency diversity gain. In one option, UE may transmit the long PUCCH in one frequency resource in K consecutive slots before switching to another frequency resource, where K is defined as half of the number of slots allocated for long PUCCH.

In another aspect, Figures 2(a) and 2(b) illustrate intra-slot and inter-slot OCC for cases that inter-slot hopping is applied for NR PUCCH with and without intra-slot frequency hopping, respectively. Intra-slot or/and inter-slot OCC can be applied for the transmission of NR PUCCH, which allows to increase UL control channel capacity. Also, it can improve robustness by providing protection against potential orthogonality breakdown between the UEs sharing the same PRB using different cyclic shifts in frequency selective channels.



(b) Inter-slot hopping with intra-slot hopping.



(a) Inter-slot hopping without intra-slot hopping.

Figure 2. Intra-slot and inter-slot frequency hopping of long PUCCH with OCC.

For long PUCCH carrying relatively small UCI payload, multiple UEs can be multiplexed in a CDM manner in a same physical resource, including cyclic shift in frequency domain and OCC in time domain. As agreed in the RAN1#88 meeting [2], at least for 1 or 2 UCI bits, UCI can be repeated within N slots. Hence, the design principle can be further extended to the case when long PUCCH spans multiple slots. For instance, both intra-slot and inter-slot OCC can be applied for the transmission of long PUCCH with multiple slot duration, which can help to further increase UL control channel capacity.

Proposal:

- For long PUCCH spanning multiple slots:
 - The number of slots allocated for long PUCCH can be semi-statically configured by higher layers.
 - Inter-slot frequency hopping can be employed to exploit the benefit of frequency diversity.
 - Inter-slot OCC can be applied for robustness and larger capacity along with intra-slot OCC.

3 Conclusions

In this contribution, we shared our view on resource allocation and frequency hopping for long PUCCH with multiple slot duration. Based on the discussion, we propose as follows:

Proposal:

- *For long PUCCH spanning multiple slots:*
 - *The number of slots allocated for long PUCCH can be semi-statically configured by higher layers.*
 - *Inter-slot frequency hopping can be employed to exploit the benefit of frequency diversity.*
 - *Inter-slot OCC can be applied for robustness and larger capacity along with intra-slot OCC.*

References

- [1] Chairman's notes, RAN1 #88bis, Spokane, USA, April, 2017.
- [2] Chairman's notes, RAN1 #88, Athens, Greece, February, 2017.
- [3] Chairman's notes, RAN1 NR Ad-Hoc, Spokane, USA, January, 2017.
- [4] R1-1707392, "Structure of 1~2 bits HARQ-ACK long PUCCH with TDM DMRS", Intel Corporation, RAN1#89, Hangzhou, P. R. China, May, 2017.
- [5] Chairman's notes, RAN1 #89, Hangzhou, China, May, 2017.