3GPP TSG-RAN Meeting #89 **R1-1708314**
Hangzhou, China, 13th - 20th May 2017

Source: **Cohere Technologies**
Title: **Structure of PUCCH in long-duration**
Agenda item: **7.1.3.2.2**
Document for: **Discussion and Decision**

---

1 Introduction

In recent past 3GPP RAN 1 meetings, the structure of PUCCH in long duration was discussed, and the following relevant agreements were reached [1-3]:

RAN1#88b (Spokane)

Agreements:

- For long duration NR-PUCCH in a given slot, FFS the detailed NR PUCCH formats. Companies are encouraged to provide the corresponding details.
  - Some examples as a starting point:
    - For small UCI payload with 1 or 2 bit(s), LTE PUCCH 1a/1b especially in light of # of symbols available for NR-PUCCH
      - FFS: Time domain OCC is applied over allocated multiple symbols.
    - For large UCI payload with X bits, LTE PUCCH format 4, or PUSCH
      - FFS on applicability of (virtual) frequency domain OCC
    - FFS for the value of X
    - FFS for medium UCI payload with less than X bits
    - Scalability of NR-PUCCH for different number of symbols available for NR-PUCCH
- The set of the number of symbols for long duration NR-PUCCH in a slot includes {4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14}
  - FFS whether or not it depends on the slot type, # of symbols per slot, etc.

Agreements:

- For DFTsOFDM in long-PUCCH, the following schemes are candidates for transmit diversity:
  - Low PAPR Alamouti-based transmit diversity applied in frequency or time domain, transparent transmit diversity (e.g. short delay CDD), time domain beam/precoder cycling or SORTD
  - FFS: for which PUCCH format and/or payload size
  - Other schemes with low PAPR are not precluded.
- Companies proposing a certain transmit diversity scheme are encouraged to jointly propose PUCCH structure and the transmit diversity scheme.

RAN1#88 (Athens)

Agreement: Both TDM and FDM between short duration PUCCH and long duration PUCCH are supported at least for different UEs in one slot

Agreements:

- For a given UCI payload, short-PUCCH is designed such that:
  - UE multiplexing capacity can be less than that of long-PUCCH
  - Performance including at least the following:
    - Frequency-diversity
    - Interference-diversity
    - PAPR/CM and emission
    - RS overhead
  - Interference randomization should be enabled
  - For more than 2 UCI bits, strive for scalable design with short-PUCCH
- For a given UCI payload, long-PUCCH is designed such that:
  - FFS: UE multiplexing capacity should be same/similar to LTE PUCCH
  - PAPR/CM should be same/similar to LTE PUCCH except for NR CP-OFDM case (if supported)
  - Frequency-diversity gain should be same/similar to LTE PUCCH
  - Interference randomization should be enabled

    - For more than 2 UCI bits, strive for scalable design with long-PUCCH with respect to the number of UCI bits
    - Strive for scalable design with long-PUCCH with respect to the number of symbols

Agreement:

- For PUCCH in long-duration, it may have variable number of symbols with a minimum of 4 symbols in a given slot
    - FFS the set of supported values

Agreements:

- 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

RAN1#AH1-NR (Spokane)

Agreements:

- For PUCCH in long-duration,
    - Long UL-part of a slot can be used for transmission of PUCCH in long-duration.
        - i.e., PUCCH in long-duration is supported for both UL-only slot and a slot with the number of uplink symbols greater than X (X >= 2).
            - FFS exact value of X
    - In addition to simultaneous PUCCH-PUSCH transmission, UCI on PUSCH is supported.
    - Intra-slot frequency-hopping is supported

Agreements:

- For further discussion of PUCCH in short-duration, UCI payload of 1 – at least a few tens of bits (or SR) is assumed.
- For further discussion of PUCCH in long-duration, UCI payload of 1 – at least a few hundreds of bits (or SR) is assumed.
- For PUCCH in long-duration, DFT-s-OFDM waveform is supported.
- For PUCCH in long-duration, transmit antenna diversity is supported.
    - FFS: PUCCH in short-duration

Agreements (updating RAN1 #87 agreements):

- A combination of semi-static configuration and (at least for some types of UCI information) dynamic signalling 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

2 Discussion

In this contribution, we focus on the format of the PUCCH in long duration (PUCCH-LD). The PUCCH-LD design should strive for high reliability and coverage, including low PAPR and diversity. In addition, it should be possible, for small payloads in particular, to multiplex many PUCCH-LD in each set of resources. In the following we propose solutions for the PUCCH-LD addressing these aspects.

2.1 PUCCH-LD Design Principles

The PUCCH-LD needs to be scalable in duration (4 to 14 symbols), sub-carrier spacing, and payload size (1 to several hundred bits). At the same time, it needs to provide multiplexing capability for smaller UCI payloads, while achieving low PAPR.

For the smaller payloads, multiplexing capability may be achieved by using a structure similar to LTE, based on phase rotations of a base sequence, combined with DFT spreading codes (the columns of a Discrete Fourier Transform or DFT matrix) in the time domain. The advantage of such spreading structure is that it affords a great deal of flexibility, since it can support different sequence lengths (the number of available phase rotations will depend on the sequence length and channel conditions) as well as different length of the PUCCH-LD in terms of number of symbols, while maintaining orthogonality, or a good degree of separation, under different channel conditions.

An illustration of the PUCCH-LD spreading structure is provided in Figure 1. A BPSK or QPSK symbol $b_{k,l}$ is first multiplied by a DFT spreading code [$v_k(0)$ ... $v_k(M-1)$], i.e. the k-th column of a size M DFT matrix. Each symbol is then multiplied by a length N sequence [s(0) ... s(N-1)], and subsequently by a length N orthogonal phase rotation [$w_l(0)$ ... $w_l(N-1)$]. Note that phase rotation vectors are also columns of a size N DFT matrix. Alternatively, cyclic shifts of a base sequence may also be used. As a base sequence, a CAZAC sequence, such as Zadoff-Chu, may be chosen. The resulting symbols are then loaded on a size N*M grid of PUCCH-LD resources. The process allows multiplexing of multiple PUCCH-LD by selecting different indices k,l.

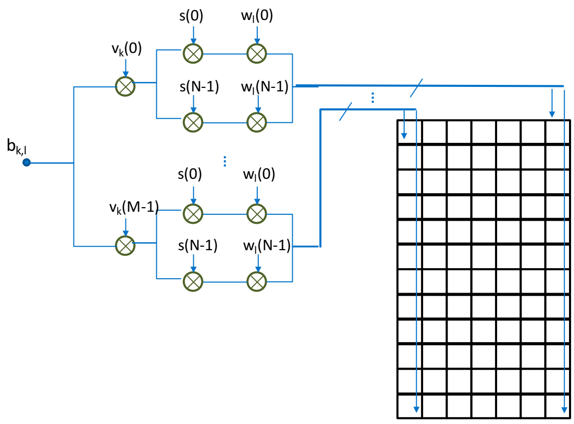

Figure 1. Illustration of 2-dimensional spreading for PUCCH.

Interference randomization may also be used as an additional measure to increase the robustness of PUCCH-LD transmission.

In the following we elaborate further on the PUCCH-LD structure for particular payload sizes.

2.2 PUCCH-LD Design for Small Payloads (1 or 2 bits)

For small UCI payloads of 1 or 2 bits, a single BPSK or QPSK symbol is sufficient for transmission. In this case, a large degree of multiplexing can be achieved. For a PUCCH-LD allocation (in one slot) of N_{SC} subcarriers and N_S symbols (of which N_{RS} are RS symbols), up to N_{SC} phase rotations of a length N_{SC} sequence are possible and up to (N_S-N_{RS}) different DFT codes may be obtained, resulting in N_{SC}* (N_S-N_{RS}) multiplexed PUCCH-LD. Depending on propagation conditions and the channel delay and Doppler spreads, a smaller number of multiplexed PUCCH-LD may be feasible, since only a smaller subset of phase rotations and DFT codes may provide sufficient separation. The subset of phase rotations and DFT codes may be determined semi-statically, by means of upper layer signaling, or dynamically, with implicit or explicit indication in the PUCCH-LD grant.

Using the scheme described to transmit reference signals, up to N_{SC}*N_{RS} reference signals may be multiplexed.

Proposal 1: A combination of phase rotations (or cyclic shifts) of a base sequence and spreading across symbols with DFT codes should be considered for the PUCCH-LD.

For the smallest UCI payload sizes, a PUCCH channel structure consisting of alternating data and RS symbols may be adopted (Figure 2). This structure provides a sufficient number of RS and maximizes channel estimation quality by distributing RS evenly across the slot. Such a structure can also be easily adapted to different PUCCH lengths in number of symbols.

Another advantage of the alternating RS-data structure is that it can easily accommodate a repeated PUCCH-LD pattern, to be used to send PUCCH-LD over multiple beams. To that effect, a single DFT code (i.e. the “all ones” code) may be used, resulting in a repetition of a basic PUCCH-LD and RS transmission. In that case, only phase rotations can be used to multiplex multiple PUCCH-LD.

Proposal 2: The PUCCH-LD structure within a slot should alternate data and RS symbols in order to maximize channel estimation quality.

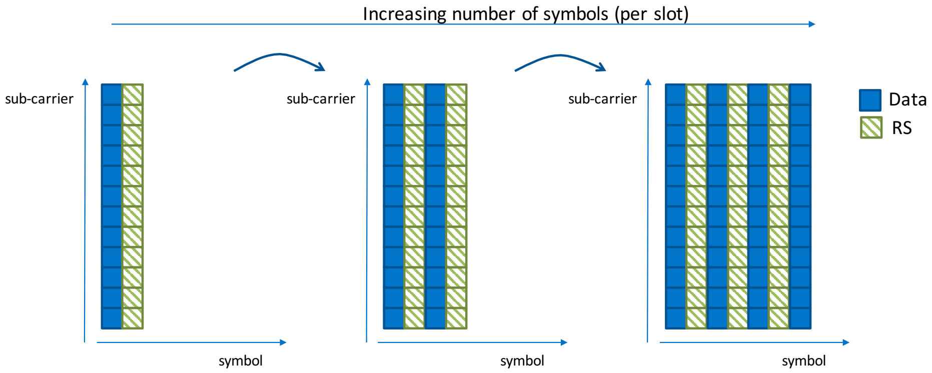

Figure 2. Multiplexing of data and RS for PUCCH-LD with small payload (1 or 2 bits), using a scalable structure for varying number of symbols.

2.3 PUCCH-LD Design for Larger Payloads

For larger UCI payload sizes, the number of RS symbols can be reduced, since the amount of multiplexed RS signals also diminishes (Figure 3). Eventually, for large UCI payload sizes, the structure used for NR PUSCH may be adopted.

Proposal 3: For larger UCI payload sizes, the number of RS symbols can be reduced by replacing some of the RS symbols used for smaller payload size with data symbols.

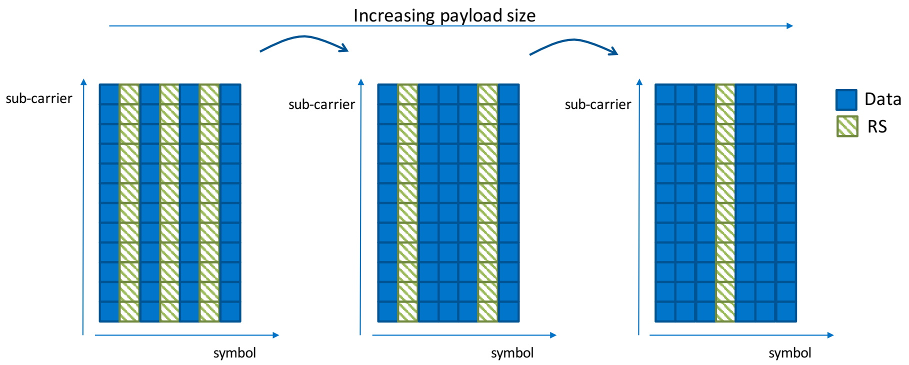

Figure 3. RS and data placement for larger PUCCH-LD payloads. Example for a 7-symbol slot.

Regarding PUCCH multiplexing for larger payloads, phase rotation and DFT spreading may not be necessary. In general, the following options are possible:

1. Eliminate DFT spreading across symbols and maintain phase rotations. In that case, more than one symbol of a given PUCCH can be multiplexed in time.
2. Reduce the amount of phase rotations, by using shorter sequences, or eliminate phase rotations, while keeping DFT spreading across symbols. More than one symbol can then be multiplexed in frequency. In this case, DFT spreading in the frequency domain (DFT-s-OFDM) may be employed to reduce PAPR. For example, two length 6 sequences may be mapped onto 6 sub-carriers each in a comb fashion, while phase rotations are applied for each sequence, allowing for the multiplexing of two symbols.
3. For larger payloads, eliminate DFT spreading and phase rotations completely, allowing for multiplexing of symbols in both time and frequency domains. Also in this case DFT spreading in the frequency domain (DFT-s-OFDM) may be used to reduce PAPR.
4. Maintain the same number of phase rotations/cyclic shifts and DFT spreading codes regardless of payload size, and assign multiple symbols with different rotations/cyclic shifts and/or DFT codes to one PUCCH-LD. This solution allows for multiplexing of symbols in the rotation/shift and DFT spreading domains.

Simulations should be provided for different payload sizes and channel conditions, and for different UE speeds, in order to determine the best solution.

Proposal 4: Simulations should be carried out to determine the best number of phase rotations/cyclic shifts and DFT spreading code lengths for larger payloads. Different payload sizes and UE speeds should be considered.

2.4 Slot Hopping

For the PUCCH-LD, slot-based hopping may be used to achieve diversity in multiple slot PUCCH-LD. With slot-based hopping, all symbols in a particular sub-band are closer together in time, which should provide higher channel estimation quality. The PUCCH-LD structure may be defined for one slot and repeated in consecutive slots in order to achieve diversity. Other non-repeated structures may be considered if they provide a performance advantage. If the PUCCH-LD is only transmitted in one slot, intra-slot hopping should be allowed. In this case, the PUCCH-LD allocation should be divided into two parts with equal number of consecutive symbols, each transmitted on a different sub-band. An illustrative example is provided in Figure 4.

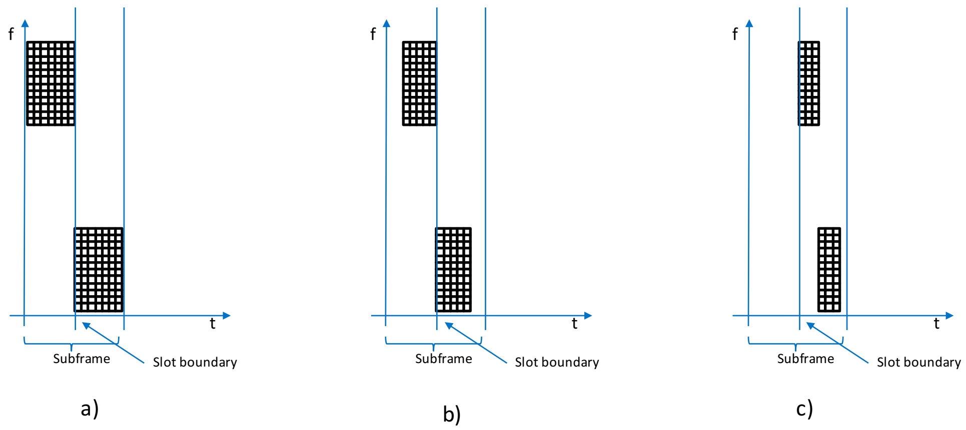

Figure 4. PUCCH-LD hopping examples: a), b), inter-slot hopping; and c) intra-slot hopping with consecutive symbol blocks.

Proposal 5: Inter-slot hopping should be considered for PUCCH-LD spanning multiple slots. Intra-slot hopping with consecutive symbol blocks should be considered for PUCCH-LD spanning a single slot.

3 Conclusion

In this contribution, we addressed the design of the NR PUCCH in long format. The following proposals are made:

Proposal 1: A combination of phase rotations (or cyclic shifts) of a base sequence and spreading across symbols with DFT codes should be considered for the PUCCH-LD.

Proposal 2: The PUCCH-LD structure within a slot should alternate data and RS symbols in order to maximize channel estimation quality.

Proposal 3: For larger UCI payload sizes, the number of RS symbols can be reduced by replacing some of the RS symbols used for smaller payload size with data symbols.

Proposal 4: Simulations should be carried out to determine the best number of phase rotations/cyclic shifts and DFT spreading code lengths for larger payloads. Different payload sizes and UE speeds should be considered.

Proposal 5: Inter-slot hopping should be considered for PUCCH-LD spanning multiple slots. Intra-slot hopping with consecutive symbol blocks should be considered for PUCCH-LD spanning a single slot.

4 References

[1]. Draft Report of 3GPP TSG RAN WG1 #88bis v0.1.0 (Spokane, USA, 3rd – 7th April 2017).
[2]. Final Report of 3GPP TSG RAN WG1 #88 v1.0.0 (Athens, Greece, 13th – 17th February 2017).
[3]. Final Report of 3GPP TSG RAN WG1 #AH1_NR v1.0.0 (Spokane, USA, 16th – 20th January 2017).