3GPP TSG-RAN WG1 NR Ad Hoc Meeting #2 **R1-1711251**
Qingdao, China, 27th-30th June 2017

Source: **Cohere Technologies**
Title: **Design of Long-PUCCH for UCI of more than 2 bits**
Agenda item: **5.1.3.2.2.2**
Document for: **Discussion/Decision**

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1 Introduction

In recent past 3GPP RAN 1 meetings, the structure of PUCCH in long duration (PUCCH-LD) was discussed [1-4], and several relevant agreements were reached, as detailed in Appendix A. In particular, it is specified that a format must be defined for PUCCH in long duration for payloads of more than 2 bits. In this contribution, we propose a suitable PUCCH-LD format, and provide simulation results. The proposed PRACH format was also discussed in part in an earlier contribution [5].

2 PUCCH Format for Medium and Large Payloads

The PUCCH-LD needs to be scalable in duration (4 to 14 symbols), sub-carrier spacing, and payload size (1 to several hundred bits).

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.

For larger payloads, occupying multiple QPSK symbols, a similar structure may be used, in which each symbol uses a particular phase rotation of a base sequence combined with a DFT spreading code.

An illustration of the proposed PUCCH-LD format is provided in **Error! Reference source not found.**. A QPSK symbol $b_{k,l}$ is first multiplied by a DFT spreading code $[v_k(0) \dots v_k(M-1)]$, i.e. the k-th column of a size M DFT matrix. Each symbol is then multiplied by a length N sequence $[s(0) \dots s(N-1)]$, and subsequently by a length N orthogonal phase rotation $[w_l(0) \dots w_l(N-1)]$. 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 transmitting multiple symbols of one PUCCH-LD by selecting different indices k,l for each symbol.

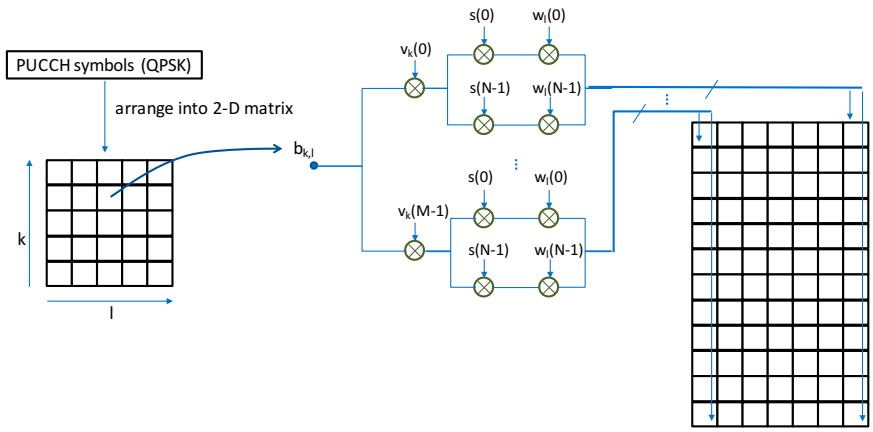


Figure 1. Illustration of proposed PUCCH design.

Observation 1: A PUCCH-LD format based on phase rotations or cyclic shifts of a base sequence, combined with DFT spreading codes, can support payloads larger than two bits by assigning a different shift and/or DFT spreading code to each symbol.

This structure has the following advantages:

- Each symbol energy is spread over all PUCCH-LD resources, ensuring a high degree of time and frequency diversity.
- The PUCCH-LD payload may be of arbitrary size, from 1 symbol to as many symbols are supported by the PUCCH resources and channel conditions.
- Multiple PUCCH-LD can be multiplexed in a given resource set (defined as *y* PRB and *z* slots).
- PUCCH-LD with small payload and large payload may be multiplexed in a given resource set.

Observation 2: The PUCCH-LD described in Section 2 of this document allows multiplexing different PUCCH-LD of arbitrary size, offering the highest degree of flexibility in PUCCH-LD resource allocation.

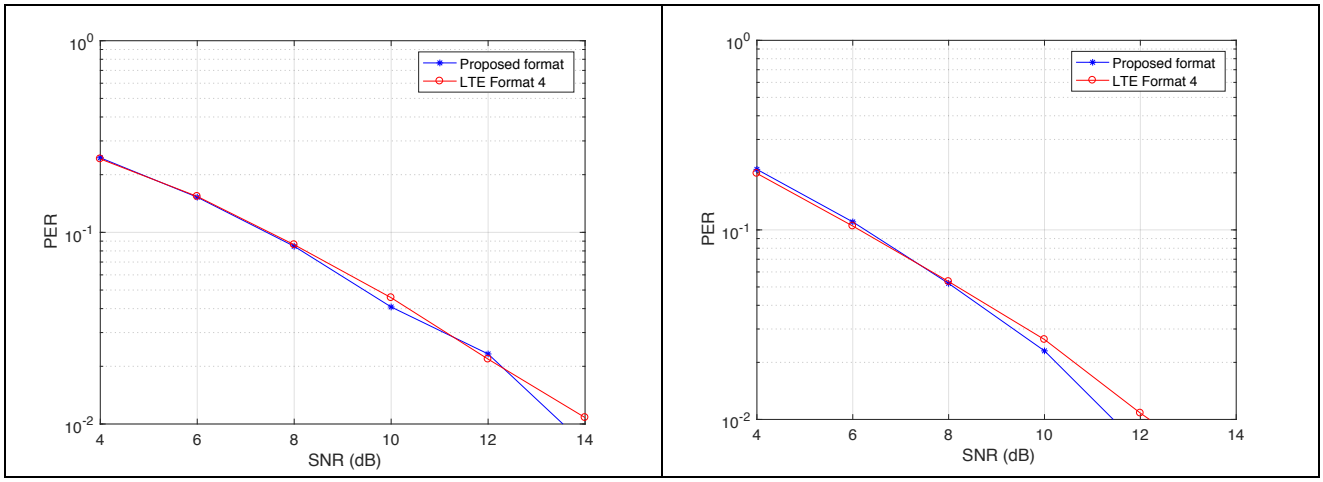
3 Simulation Results

The proposed PUCCH-LD format was simulated under the evaluation conditions described in Table 1.

Table 1. Evaluation Parameters

Parameter	Value
Carrier frequency	4 GHz
System bandwidth	10 MHz
Sub-carrier spacing	15 kHz
PUCCH resource allocation	1 PRB and 14 symbols
Slot hopping	Yes
Channel model	TDL-C, 300ns delay spread
Channel estimation	Ideal
UE speed	30kph, 120 kph, 240 kph, 500 kph
PUCCH payload size	100 bits
Modulation	QPSK
Channel coding	Rate 1/3 TBCC with generator polynomials [133, 171, 165], with bit interleaving
Receiver	MMSE

From the simulations, we note that the proposed scheme outperforms LTE format 4, particularly at higher mobility speeds, with differences up to 1.5 dB at 500 kph, for the 1% PER operating point. For lower speeds, performance is similar, since the channel is fairly static within the duration of the PUCCH-LD resources.



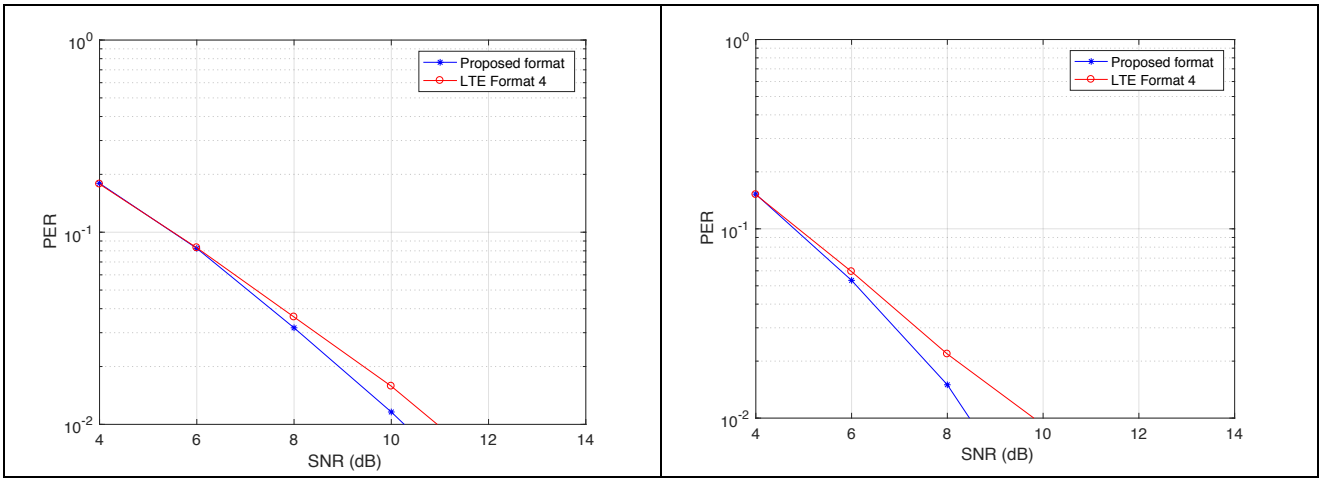


Figure 2. PUCCH-LD performance, payload size 100 bits, rate 1/3; 30 kph (upper left), 120 kph (upper right), 240 kph (lower left), 500 kph (lower right).

Observation 3: The PUCCH-LD format described in Section 2 of this document outperforms LTE PUCCH format 4 for moderate to high speeds, and has similar performance at low speed.

Proposal 1: Adopt the PUCCH-LD format described in Section 2 of this document for PUCCH-LD for UCI of more than 2 bits.

4 Conclusion

In this document, a format for PUCCH-LD for UCI of more than 2 bits was proposed. The following observations and proposals were made:

Observation 1: A PUCCH-LD format based on phase rotations or cyclic shifts of a base sequence, combined with DFT spreading codes, can support payloads larger than two bits by assigning a different shift and/or DFT spreading code to each symbol.

Observation 2: The PUCCH-LD described in Section 2 of this document allows multiplexing different PUCCH-LD of arbitrary size, offering the highest degree of flexibility in PUCCH-LD resource allocation.

Observation 3: The PUCCH-LD format described in Section 2 of this document outperforms LTE PUCCH format 4 for moderate to high speeds, and has similar performance at low speed.

Proposal 1: Adopt the PUCCH-LD format described in Section 2 of this document for PUCCH-LD for UCI of more than 2 bits.

5 References

[1]. Draft Report of 3GPP TSG RAN WG1 #89 v1.0.0 (Hangzhou, China, 15th – 19th May 2017).
[2]. Final Report of 3GPP TSG RAN WG1 #88bis v1.0.0 (Spokane, USA, 3rd – 7th April 2017).
[3]. Final Report of 3GPP TSG RAN WG1 #88 v1.0.0 (Athens, Greece, 13th – 17th February 2017).
[4]. Final Report of 3GPP TSG RAN WG1 #AH1_NR v1.0.0 (Spokane, USA, 16th – 20th January 2017).
[5]. R1-1708314 "Structure of PUCCH in long-duration, Cohere Technologies," 3GPP TSG RAN WG1 #89, Hangzhou, China, May 15th – 19th 2017.

6 Appendix A: Relevant RAN1 Agreements

RAN1#89 (Hangzhou)

Agreements:

- 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

Agreements:

- NR supports following long-PUCCH:
  - One PUCCH format for UCI with up to 2 bits with high multiplexing capacity
  - One PUCCH format for UCI with large payload with no multiplexing capacity
- FFS: One PUCCH format for UCI with moderate payload with some multiplexing capacity
  - Note: this could be a variation of one of the former PUCCH formats.

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 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