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## 1. Introduction

This paper deals with the situation when uplink ACK/NACK and/or CQI transmission is done via PUCCH or the situation when there is only downlink transmission and no uplink data transmission. In this case if UE wants to start data transmission it sends a scheduling request to eNB. We expect that dedicated SR channel will be specified for LTE e.g. as proposed in [1]. However, in order to maintain single carrier property of the uplink signal, simultaneous transmission of PUCCH and SR channel is not possible. In this paper we show how the SR bit can be included in the ACK/NACK and/or CQI on the PUCCH when dedicated SR channel can not be used.

It is possible to avoid the situation that ACK/NACK and SR are transmitted at the same time by introducing scheduler restrictions. Downlink transmission in sub-frames that cause ACK/NACK to be in the same uplink sub-frame as scheduling request, can be prohibited. These type of restrictions have a negative impact to flexibility of the system and create additional complexity to scheduler design, so it is not preferred method. Also periodic CQI reporting and SR may be allocated to different sub-frames. However, this can be difficult because, in general, periodicity of CQI and SR is not the same. Another thing that may be considered is to prioritize SR and CQI and/or ACK/NACK transmissions so that only one of them is transmitted if they occur at the same time. The problem with this approach is increased delay in CQI or SR signaling. SR delay will be an issue e.g., with VoIP. Also it is possible to generate additional multiplexing schemes for the cases when SR and ACK/NACK and/or CQI needs to be transported at the same time. However that would increase the complexity of the system unnecessarily.

The preferred approach is that data-non-associated control signalling and UL SR can be transmitted simultaneously in such a way that

- the existing single carrier properties (i.e. small cubic metric) could be maintained
- existing data-non-associated signalling could be kept as similar as possible (w/ and w/o SR)
- no additional signalling and scheduler limitations would be introduced
- the system would have minimum additional complexity with different multiplexing options
- the system would be robust against DL allocation grant signalling errors.

## 2. Multiplexing of Scheduling Request and ACK/NACK and/or CQI

It has been agreed that ACK/NACK transmission in the PUCCH is done by means of modulated CAZAC sequences. BPSK is used for 1-bit ACK/NACK and QPSK for 2-bit ACK/NACK, respectively. Block-wise spreading is applied to pilots (SF=3) and data (SF=4). Periodic CQI is transmitted similarly as ACK/NACK but without block-wise spreading.

Two schemes have been identified to transmit the scheduling request together with the existing data-non-associated control signalling transmitted on PUCCH.

### 1. Modulation scheme:

- Increased modulation order
  - i. Original modulation constellation of ZC sequence is used in the absence of scheduling request opportunity: i.e., BPSK is used for 1-bit (ACK/NACK) signaling, QPSK for 2 bit ACK/NACK signaling and for CQI, respectively.

- ii. QPSK is used for 1-bit ACK/NACK signaling and 8PSK is used for 2-bit ACK/NACK signaling and for CQI, in the presence of SR transmission opportunity. This arrangement will provide the room for signaling the additional SR bit.

- Modulation rotation

- i. It is also possible to indicate SR transmission by rotating the modulation constellation of ZC sequence compared to the original modulation constellation. In case of the QPSK modulation constellation can be rotated  $\pi/4$  radians in the presence of the SR transmission. The modulation constellation may be rotated in all data blocks or only in some of the blocks used according to a predetermined pattern (e.g., the constellation is rotated in every second data block).

We note that RS of PUCCH can be transmitted similarly with and without simultaneous scheduling request. In other words, modulation arrangement would apply only for the data blocks of PUCCH.

Increasing the order of modulation will decrease the link performance. However, decreased link performance can be compensated by applying higher PC target for those UEs which are transmitting control signals with increased modulation order.

## 2. Multi-code scheme

- Part of the cyclic shift resources of PUCCH are pre-allocated for SR usage: The possible SR is transmitted with ACK/NACK and/or CQI using multiple cyclic shift resources (multi-code transmission).
- Pre-coding can be used to reduce the PAR of multi-code transmission [2].
- On-off keying is applied for SR transmitted with ACK/NACK.

We note that RS of PUCCH can be transmitted similarly with and without simultaneous scheduling request. It is also noted that different code-specific power levels can be applied in the multi-code approach.

Table 1 shows an example of multi-code transmission related to the ACK/NACK signaling. There are 48 ACK/NACK data resources available in the current PUCCH resource. 12 implicit ACK/NACK resources have been allocated in Table 1. Each resource has a pre-assigned cyclic shift to be used with possible SR. Due to the interference issues (intra-cell orthogonality and inter-cell interference), only part of the code resources can be used in practice. However, is noted that interference-related issues with the SR is not as severe as with ACK/NACK due to the significantly lesser amount of activity.

Table 1. An example of cyclic shift allocation for ACK/NACK (A/N) and scheduling request (SR)

ACK/NACK data part				
Cyclic shift frequency	Cyclic shift, time			
	0	1	2	3
0	A/N0			SR11
1	SR0	A/N3		
2		SR3	A/N6	
3			SR6	A/N9
4	A/N1			SR9
5	SR1	A/N4		
6		SR4	A/N7	
7			SR7	A/N10
8	A/N2			SR10
9	SR2	A/N5		
10		SR5	A/N8	
11			SR8	A/N11

## 3. Summary

Scheduling request and PUCCH transmission may occur at the same. In this paper we have shown that SR bit can be included in the agreed PUCCH transmission structures with small modifications. With the proposed methods single carrier properties of the UL transmission can be maintained.

The proposed scheme allows SR to be included in the ACK/NACK and/or CQI transmission. This is done without significant PAR increase or performance degradation. There are no scheduler restrictions in the proposed method. Because SR and ACK/NACK and CQI can be transmitted simultaneously delay performance of those signals is not affected.

## References

- [1] R1-072307, "Uplink Scheduling Request for LTE", NSN, Nokia
- [2] R1-073000, "Increasing the size of CQI by means of enhanced sequence modulation", NSN, Nokia