

Agenda item: 6.4.2
Source: Motorola
Title: UCI Multiplexing on PUSCH in UL-MIMO Transmissions
Document for: Discussion/Decision

1. Introduction

At RAN1#61 the multiplexing of uplink control information on PUSCH for the case of uplink spatial multiplexing was discussed and the following conclusions agreed:

- *HARQ-ACK and RI:*
 - *Replicated across all layers of both CWs*
 - *TDM multiplexed with data such that UCI symbols are time-aligned across all layers*
 - *FFS: How to determine the number of UCI symbols on each CW and each layer*
- *CQI/PMI: transmitted only on 1 codeword*
 - *Reuse Rel-8 multiplexing and channel interleaving mechanisms*
 - *Extension: The input to data-control multiplexing $q_0, q_1, q_2, q_3, \dots, q_{Q_{CQI}-1}$, $f_0, f_1, f_2, f_3, \dots, f_{G-1}$ is grouped into column vectors $\underline{g}_0, \underline{g}_1, \underline{g}_2, \underline{g}_3, \dots, \underline{g}_{H'-1}$ of length $Q_m * L$*
 - *L (1 or 2) is the number of layers the CW is mapped onto*
 - *Enable time (RE) alignment across 2 layers for $L=2$*
 - *UCI symbol-level layer mapping: same as (treated as a part of) data*
 - *FFS: Mechanism for CW selection*

The requirement of a replication stage in the processing of HARQ-ACK and RI symbols ensures these symbols are transmitted with all antennas and layer with full transmit power [1]. The time alignment of UCI symbols across layers is motivated by simple symbol-level maximal ratio combining and the desire to reduce cross-layer interference between traffic data and control symbols. With these motivations in mind, this contribution addresses the problem of determining the number of UCI symbols to be allocated to HARQ-ACK and rank indication [2]. The assumptions on HARQ-ACK and rank indication symbol mapping are first reviewed followed by a discussion of three cases corresponding to different codeword/layer combinations. Proposals are given for all cases. The more interesting case of two codewords is discussed in depth and a proposal based on extending the Release 8 expression is derived for determining the resources for UCI symbol. A similar proposal is given in [3]. An alternative proposal is suggested in [4].

2. Rank and HARQ-ACK Symbol Mapping on PUSCH

The block diagram in Figure 1 illustrates mapping of HARQ-ACK and rank indication with the working assumption of symbol replication occurring at the output of the channel coder and prior to data/control multiplexing and interleaving. For both HARQ-ACK and rank indication symbols, codeword i 's replication stage repeats coded bits onto ν_i layers (i.e., the number of layers on codeword i), to give $Q_{i,RI}$ and $Q_{i,ACK}$ coded bits of rank indication and HARQ-ACK information respectively on codeword i .

The multiplexing and interleaving block time aligns UCI symbols across layers so that control and data symbols are not sent at the same time on different layers as shown in Figure 2. The details of how this is to

be performed still have to be decided however. Similarly, the exact operation of the scrambling block requires specification. One proposal based on scrambling each layer separately is given in [5]. The remaining blocks can be reused from Release 8.

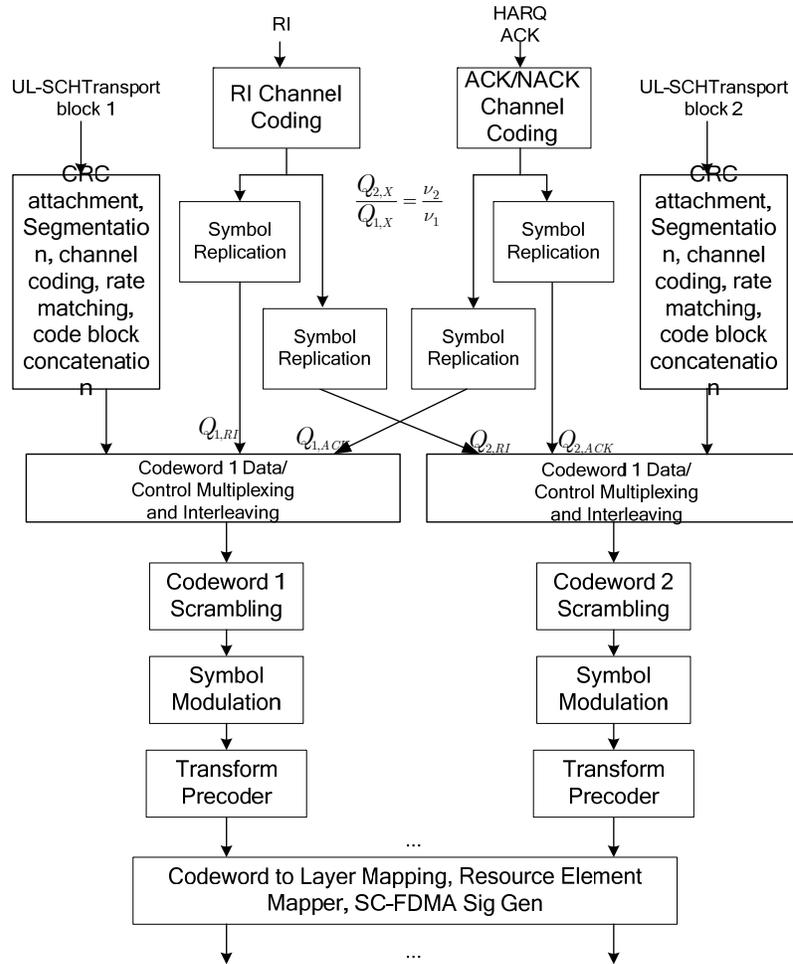


Figure 1: HARQ ACK and Rank Indication Mapping on PUSCH. Note: CQI not shown.

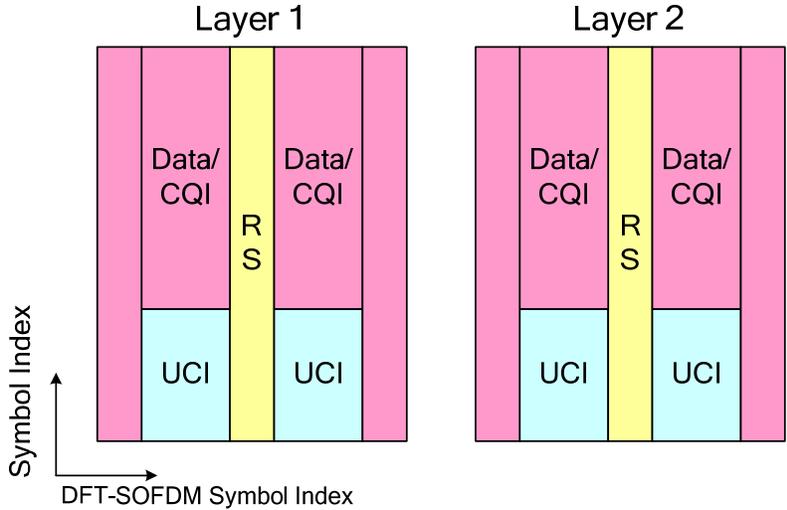


Figure 2: Time Alignment of UCI between layers. Due to the properties of SC-OFDM, the vertical axis (Symbol Index) corresponds to time.

2.1. Discussion on Control Symbol Allocation for Multi-Antenna Transmission

For the purposes of determining the number of UCI symbols with multilayer transmission, there are three cases of interest: 1) Single codeword and single layer transmission 2) Single codeword and multiple layers and 3) Two codewords and therefore multiple layers. Each case is discussed below.

2.1.1. Single Codeword and Single Layer Transmission

The first case can reuse the expression for determining the number of UCI symbols in Release 8 without modification:

Proposal: Reuse the Release 8 expression for the number of HARQ-ACK and rank indication symbols for single codeword single layer transmission.

2.1.2. Single Codeword and Multiple Layers

The second case occurs during a non-adaptive transmission of transport block which was originally transmitted along with another transport block on three or four layers. If the other transport block is correctly decoded after the first transmission, then according to the Release 8 downlink layer mapping rules which have been carried over multi-antenna transmission on the uplink, a single transport block two layer retransmission may be performed. While this case differs from single antenna Release 8 transmission in that multiple layers are involved, the same expression for number of HARQ-ACK and rank indication symbols can be reused with a UL spatial multiplexing specific rank 1 power offset factor $\beta_{1,offset}^{SM}$. A new offset is needed because the receiver performance in terms of received symbol SNR will not in general be the same for single and multiple layer receivers.

Proposal: Reuse the Release 8 expression for the number of HARQ-ACK and rank indication symbols with a power offset factor specific to single codeword multilayer transmission.

2.1.3. Two Codeword Case

The last case of multiple codewords is not as obvious. Several observations can be made however. First, the reliability of estimated UCI coded bits fed to the decoder is a function of the symbol SNRs on all layers and therefore both codewords' code rate and modulation order give information on the reliability of received control symbols. The associated fields in the uplink grant corresponding to both codewords should therefore be used to determine the number of HARQ-ACK and rank indication symbols.

Observation: The number of HARQ-ACK and rank indication symbols should be a function of both codewords' resource allocation and MCS fields.

In order to maintain consistency between single and multiple codeword operation, it is desirable to try to extend the methodology used in Release 8 to the multiple codeword case. This allows the same interpretation to the expression for both cases thereby simplifying the design process. The derivation of the Release 8 expression for number of control symbols and how it can be extended to the multiple codeword case will be discussed below.

Observation: Extending the Release 8 expression for the number of UCI symbols to the multiple codeword case should be used as a baseline unless there is a compelling performance advantage to do otherwise

Although different eNB manufacturers could implement different type of receivers for UL MIMO, the performance of a reasonable receiver in a channel where the second codeword's layers have negligibly small gain (and therefore a TBS of near zero) should approach the performance with a single codeword case-either case 1 or case 2 above depending on the number of layers used for the dominant codeword. Since the expressions for the number of symbols in these cases was proposed to be the same as Release 8 with a possibly different offset factor, it is reasonable to assume that the expression for the number of UCI symbols in the two codeword case will approach the Release 8 expression (to within a scale factor) in the extreme case when one of the codeword's TB size goes to zero:

Observation: The number of UCI symbols required in the multi-codeword case should approach the number in Release 8 as the TB size indicated in the uplink approaches zero.

2.2. Extending the Release 8 Approach to Multiple Codewords

This section proposes an expression for the number of HARQ-ACK and rank indication symbols to be used with multiple codeword transmission. The proposal satisfies the three observations above: 1) It is a direct extension of the Release 8 expression 2) It is a function of both TBSs, and 3) It reduces to the Release 8 equation when one of the TBS goes to zero. The derivation of the Release 8 expression is given first to help motivate the multi-codeword case.

Release 8 Derivation of the Number of UCI Symbols

The approach taken in Release 8 was to allocate Q' control symbols such that the UCI energy-per-information bit, E_b^{UCI} was proportional to the energy-per information bit of the symbols corresponding to UL-SCH, E_b , with the proportionality constant being the higher-layer signaled parameter β_{offset}^{PUSCH} , i.e. $E_b^{UCI} = \beta_{offset}^{PUSCH} E_b$. With O bits of UCI, the total energy received in all UCI symbols is then

$$\begin{aligned}
\text{Received UCI Energy} &= O \cdot E_b^{UCI} = Q' \cdot E_s \\
&= Q' \cdot E_b \cdot (\text{code rate})_{UL_SCH}
\end{aligned}$$

where E_s^{rcvd} is the received energy per symbol which is assumed to be the same for a data or UCI symbol. Solving the above for Q' , limiting the number of UCI symbols to the symbols available in 4 SC-OFDM symbols, and using the approximation,

$$(\text{code rate})_{UL_SCH} = \frac{\sum_{r=0}^{C-1} K_r}{M_{sc}^{PUSCH-initial} \cdot N_{symb}^{PUSCH-initial}}$$

where

- M_{sc}^{PUSCH} is the scheduled bandwidth for PUSCH transmission in the current sub-frame for the transport block, expressed as a number of subcarriers,
- $N_{symb}^{PUSCH-initial}$ is the number of SC-FDMA symbols per subframe for initial PUSCH, transmission for the same transport block,
- The number of code blocks is C with sizes K_1, \dots, K_C ,
- β_{offset}^{PUSCH} is a higher layered signaled offset parameter.

gives the result in [6]:

$$Q' = \min \left(\left[\frac{O \cdot M_{sc}^{PUSCH-initial} \cdot N_{symb}^{PUSCH-initial} \cdot \beta_{offset}^{PUSCH}}{\sum_{r=0}^{C-1} K_r} \right], 4 \cdot M_{sc}^{PUSCH} \right)$$

The number of uplink resources is seen to nominally be inversely proportional to the codeword's spectral efficiency.

Extension to Multiple Codewords

The method of determining the number of control symbols described above can easily be extended to multilayer transmission. Assume that codeword i contains Q'_i control symbols distributed among ν_i layers with each symbol having an average received symbol energy of $E_{s,i}$. The received UCI energy is then

$$\begin{aligned}
\text{Received UCI Energy} &= O \cdot E_b^{UCI} = Q'_1 \cdot E_S^1 + Q'_2 \cdot E_S^2 \\
&= Q'_1 \cdot E_b \cdot \left(\text{cw 1 code rate} \right)_{UL_SCH} + Q'_2 \cdot E_b \cdot \left(\text{cw 2 code rate} \right)_{UL_SCH} \\
&= \frac{E_b}{M_{sc}^{PUSCH-initial} \cdot N_{symp}^{PUSCH-initial}} \left(\frac{Q'_1}{\nu_1} \sum_{r=0}^{C_1-1} K_{r,1} + \frac{Q'_2}{\nu_2} \sum_{r=0}^{C_2-1} K_{r,2} \right)
\end{aligned}$$

Because the UCI is time-aligned across layers, the number of UCI symbols mapped to the codeword 2's layer(s) is ν_2/ν_1 times the number of UCI symbols mapped to codeword 1's layers and therefore $Q'_1/\nu_1 = Q'_2/\nu_2$ which, when substituted into the above equation, gives the proposed expression:

$$Q'_i = \min \left(\left[\frac{O \cdot \nu_i \cdot M_{sc}^{PUSCH-initial} \cdot N_{symp}^{PUSCH-initial} \cdot \beta_{offset}^{SM,PUSCH}}{\sum_{r=0}^{C_1-1} K_{r,1} + \sum_{r=0}^{C_2-1} K_{r,2}} \right], 4 \cdot \nu_i \cdot M_{sc}^{PUSCH} \right). \quad (1)$$

Several Observations.

- In the multi-codeword case, the number of UCI symbols is inversely proportional to the average per-layer spectral efficiency.
- A new offset factor higher-layer signaled offset $\beta_{offset}^{SM,PUSCH}$ has been assumed.
- The number of symbols Q'_i is defined on a per-codeword basis and not a per-layer basis and this accounts for the number of layers, ν_i , appearing in the numerator.
- When one codeword's size approaches zero (say codeword 2) and codeword 1 has $\nu_1 = 1$ layer, the expression reduced to the Release 8 equation.

Proposal: The number of symbols for either HARQ-ACK or rank indication be given by (1) where $\beta_{offset}^{SM,PUSCH}$ is a higher layer signaled parameter.

3. Conclusions

Expressions were derived for the number of symbols to be used for either HARQ-ACK or rank indication when multi-transmit antennas are used on the uplink. Three cases were discussed : 1) Single codeword and single layer transmission 2) Single codeword and multiple layers and 3) Two codewords and therefore multiple layers. Proposals based on the Release 8 expressions were given for each case.

Proposal (Single Codeword and Single Layer): Reuse the Release 8 expression for the number of HARQ-ACK and rank indication symbols for single codeword single layer transmission.

Proposal (Single Codeword and Multiple Layers): Reuse the Release 8 expression for the number of HARQ-ACK and rank indication symbols with a power offset factor specific to single codeword multilayer transmission.

Proposal (Multiple Codewords): The number of symbols for either HARQ-ACK or rank indication on codeword i is given by

$$Q'_i = \min \left(\left[\frac{O \cdot \nu_i \cdot M_{sc}^{PUSCH-initial} \cdot N_{ymb}^{PUSCH-initial} \cdot \beta_{offset}^{SM,PUSCH}}{\sum_{r=0}^{C_1-1} K_{r,1} + \sum_{r=0}^{C_2-1} K_{r,2}} \right], 4 \cdot \nu_i \cdot M_{sc}^{PUSCH} \right).$$

4. References

- [1] R1-102631, "Design Principles for UCI on PUSCH", Ericsson, ST-Ericsson, RAN1#61, Montreal, Canada, 10-14 May 2010.
- [2] R1-103180, "UCI Multiplexing on PUSCH in UL-MIMO Transmissions", Motorola, RAN1#61, Montreal, Canada, 10-14 May 2010.
- [3] R1-102762, "UCI multiplexing for SU-MIMO transmission", Qualcomm Incorporated, RAN1#61, Montreal, Canada, 10-14 May 2010.
- [4] R1-102827, "Data and Control Multiplexing for UL Multi-Antenna Transmission", Texas Instruments, RAN1#61, Montreal, Canada, 10-14 May 2010.
- [5] R1-102962, "Performance evaluation of UCI multiplexing schemes on PUSCH in case of SU-MIMO", Nokia Siemens Networks, Nokia, RAN1#61, Montreal, Canada, 10-14 May 2010.
- [6] 36.211, v8.8.0, "Physical Channels and Modulation", 3GPP.