Individual ACK/NACK Performance Equalization for Carrier Aggregation in LTE-A Systems

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***Abstract*— Carrier Aggregation (CA) is an important feature for 3GPP Long-Term-Evolution-Advance (LTE-A). Up to five Component Carriers (CC) can be configured and Physical Downlink Shared Channel (PDSCH) can transmit at most two codeword at each CC. Therefore, for Frequency Division Duplex (FDD), at most ten ACK/NACK bits have to be reported in HARQ process. PUCCH Format 3 can be used when the Reed-Muller (RM) code is adopted. Due to the uneven Hamming distance between the basis sequences in RM code, each ACK/NACK bits would have different error performance thus cause unfairness. A Dynamic bits ordering is proposed to equalize the individual error performance. The simulation result shows that the variance between individual error performances can be reduced.**

Keywords— **LTE-A, Carrier Aggregation, HARQ, Reed-Muller code, PUCCH**

1. INTRODUCTION

In LTE-A systems, Carrier Aggregation is used in increase the bandwidth of the systems. Up to five Component Carriers (CC) can be configured. Physical Downlink Shared Channel (PDSCH) can transmit at most two codeword at each CC. Therefore, for Frequency Division Duplex (FDD), at most ten ACK/NACK bits have to be reported in HARQ process.

At 3GPP RAN1 #62 meeting, it was agreed that slow codebook adaptation is adopted for PUCCH Format 3 0. That is the codebook selection is based on configured CCs and configured transmission modes for each CC. At 3GPP RAN1 #62bis [2][3], it was further agreed that the ordering and coding of ACK/NACK bits for PUCCH Format 3 is according to section 5.2.3.1 in [3].

If one ACK is decoded by the UE as a NACK, one useless retransmission will happen and thus system throughput performance decreases. For the case of NACK to ACK error, when a NACK is mistaken as an ACK, this will trigger an RLC retransmission which would increases the maximum delay. For PUCCH Format 3, Reed-Muller (RM) Code is adopted as its channel coding. The performance of the Reed-Muller code depends on the weights of the RM basis sequences [3]. Therefore, depending on the activated Component Carrier (CC), the deviation of the ACK/NACK performance between codewords would yield unequal performance and cause unfairness. In addition, if bundling is configured, the performance deviation between different ACK/NACK bits would affect more than one codewords thus make the situation of unfairness worse.

In this paper, a method aims to equalize the individual ACK/NACK error performance for PUCCH Format 3 is proposed and simulation result shows that the proposed scheme can effectively reduce the variance between individual error probabilities.

2. SLOWLY ADAPTIVE REED-MULLER CODING

In order to avoid the error in CC activation/deactivation process, the slowly adaptive codebook is adopted for PUCCH Format3. The ACK/NACK bits input to the channel coding block are denoted by

$a_0, a_1, a_2, a_3, ..., a_{N-1}$. The ACK/NACK inputs bits are obtained by concatenate the ACK/NACK bits for each configured CC. By reporting the ACK/NACK bits for configured CC, the error in CC activation/deactivation process can be avoided. ACK bits are encoded as '1' and NACK or the ACK/NACK bits for the codewords that correspond to de-activated CCs are encoded as '0'. For example, if the configured CC is 5 and the activated CC is CC1 and CC3, then the concatenated ACK/NACK bits are $0,0,a_2,a_3,0,0,a_6,a_7,0,0$. The ACK/NACK message is first encoded using a RM(32, O) block code. The code words of the RM(32, O) block code are a linear combination of the O basis sequences denoted $M_{i,n}$ and defined in Table 5.2.2.6.4-1 of [5]. The encoded block is denoted by $\tilde{b}_0, \tilde{b}_1, \tilde{b}_2, \tilde{b}_3, ..., \tilde{b}_{B-1}$ where $B = 32$ and

$$\tilde{b}_i = \sum_{n=0}^{O-1} \left(a_n \cdot M_{i,n}\right) \bmod 2 , \qquad (1)$$

where i = 0, 1, 2, …, B-1. (1)

The output bit sequence $b_0, b_1, b_2, ...,, b_{M-1}$ is obtained by circular repetition of the sequence $\tilde{b}_0, \tilde{b}_1, \tilde{b}_2, ...,, \tilde{b}_{31}$, i.e. $b_i = \tilde{b}_{(i \bmod 32)}$. For DFT-S-OFDM based CA PUCCH with SF=5, M=48 coded bits are needed thus the effective codebook is RM(48, O).

When eNB decode PUCCH, it can utilize its scheduling information to reduce the number of hypothesis of decoding. For example, if eNB scheduled 2CCs each with 2 codeword, then the hypothesis in decoding can be reduced from $2^{10} = 1024$ to $2^4 = 16$.

3. DYNAMIC HARQ BITS ORDERING

In order to equalize the ACK/NACK Bit-Error-Rate (BER), the ordering of the concatenated ACK/NACK bits is dynamically reordered/shuffled before the RM encoder. This would map the ACK/NACK bits to different RM basis sequences dynamically. Since the synchronization between eNB and UE, eNB can decode the ACK/NACK bits then perform de-ordering using corresponding de-ordering patterns. There could be many alternatives for the reordering/shuffling. One example is shown in Fig. 1 where a cyclic shuffling pattern is performed across activated CCs. The shuffling pattern depends on the subframe number thus is dynamically changed. In this example, 5 CCs are configured and each CC has 2 ACK/NACK bits. The activated CCs are CC1 and CC3.

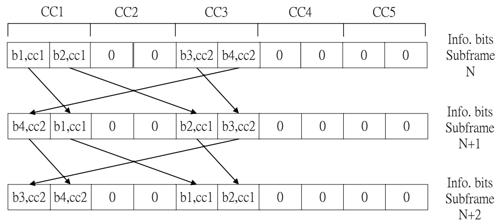


Figure 1, Dynamic ACK/NACK bits ordering

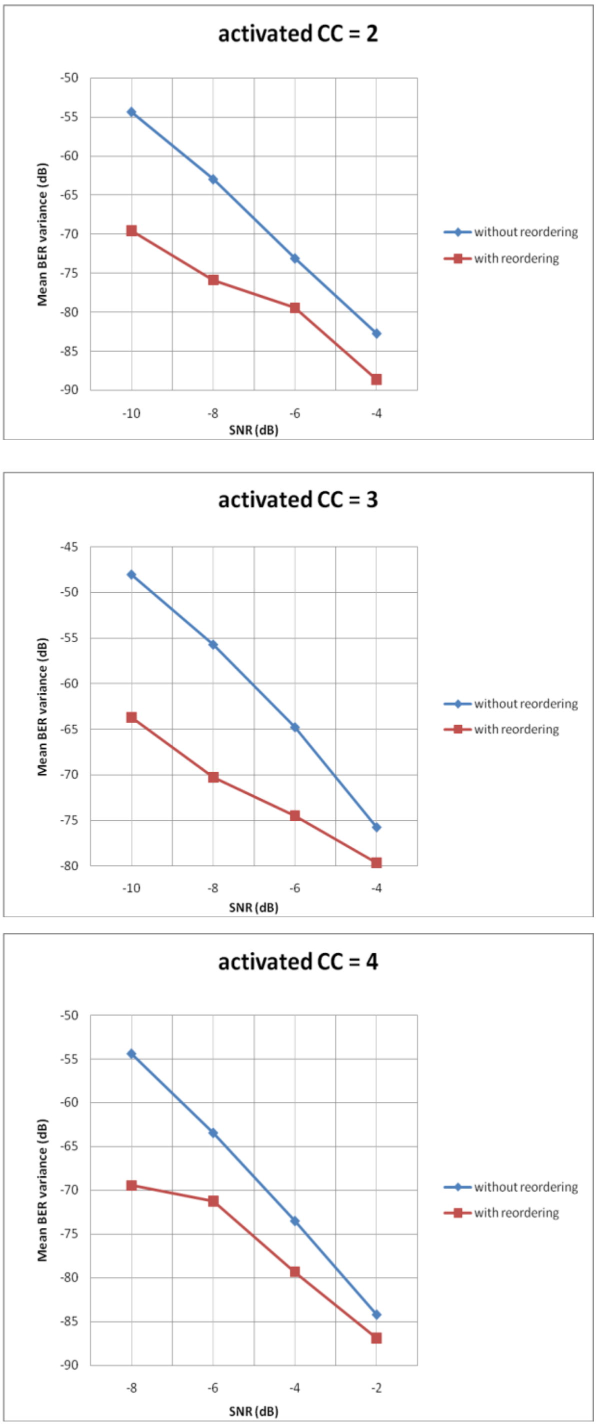
4. SIMULATION RESULT

In this contribution, we compare the performance of the link-level HARQ-ACK BER w/o ACK/NACK performance equalization. Simulation assumptions are provided in Table 1. In order to compare the ACK/NACK BER w/o performance equalization, the BER variance in dB scale is first computed across individual ACK/NACK bits for a given RM basis then Mean BER variance in dB scale is obtained by averaging BER variance across all possible choices of RM basis sequences. Fig. 2 shows the Mean BER variance w/o reordering for activated CC = 2, 3, 4 and 5 respectively. The required operating SNR is determined based on the following criterions: (1) Freq(DTX→ACK bits) $\leq$ 1%, (2) Pr(NACK/DTX→ACK) $\leq$ 0.1% and (3) Pr(ACK→NACK/DTX) $\leq$ 1%. It can be seen that, after the ACK/NACK performance equalization, the Mean BER variance can be reduced by approximately 5 dB at the operating SNR points for EPA 3km/hr channel. The simulation parameters are list in Table 1.

Table 1, Simulation Parameters

Parameters	Value
carrier frequency	2.0 GHz
Bandwidth	10 MHz
channel model	EPA
UE speed (km/h)	3 km/h
frequency hopping	at slot boundary
antenna setup	1Tx 2Rx
RX antenna correlation	uncorrelated
channel estimation	practical
CP type	normal CP
transmission schemes	DFT-S-OFDM with SF=5

signal bandwidth	180 kHz
Configured CC	5
ACK/NACK bits per CC	2
Detection Threshold	Freq(DTX → ACK bits) = 10^{-2}



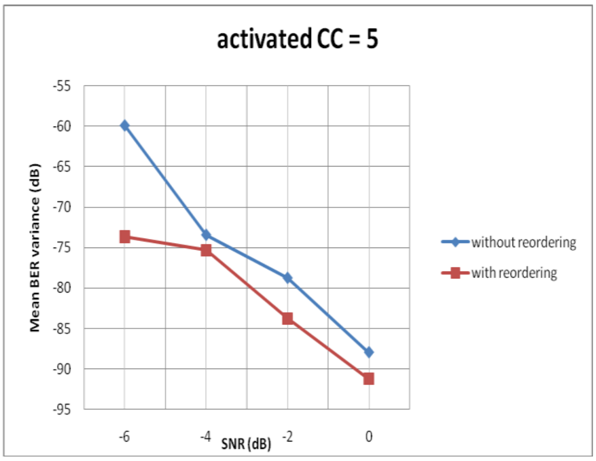


Figure 1, BER ratio comparisons w/o HARQ-ACK equalization

5. Conclusions

In this paper, the performance of PUCCH Format 3 HARQ-ACK bits w/o performance equalization is evaluated and compared. Based on the evaluation results, it is shown that, with the HARQ-ACK bits performance equalization scheme proposed in the paper, the BER deviation of each TBS can be reduced.

References

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