Multiplexing Periodic CSI with HARQ-ACK on PUCCH Format 3 in LTE-A

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***Abstract* — In order to avoid dropping the periodic CSI report frequently in case of collision between a periodic CSI report and HARQ-ACK feedback in LTE-Advanced system, this paper gives two coding schemes for multiplexing periodic CSI (Channel State Information) with HARQ-ACK (Hybrid Automatic Repeat request Acknowledgement) feedback on PUCCH (Physical Up Control Channel) format 3. The result of simulation shows that both of the two coding schemes can effectively support simultaneous transmission periodic CSI and HARQ-ACK feedback on PUCCH format 3. What's more, with joint coding scheme, periodic CSI and HARQ-ACK feedback have the same performance, while HARQ-ACK feedback has better performance than periodic CSI with separate coding scheme. Hence through the separate coding scheme, we can not only enhance simultaneous transmission of periodic CSI and HARQ-ACK feedback, but also guarantee the similar performance of HARQ-ACK feedback as transmitting it alone.**

***Index Terms* — Periodic CSI, HARQ-ACK, Multiplexing, PUCCH format 3**

I. Introduction

Along with the 4rd generation mobile communication technology appearance, the LTE-Advanced is researched and standardized by 3GPP organization. One of the most important technologies introduced in LTE-Advanced is the carrier aggregation (CA) of multiple Component Carriers (CCs) [1, 2], which is introduced to LTE-Advanced to support peak data rates of 1 Gbps in the downlink and 500 Mbps in the uplink, facilitate efficient use of fragmented spectrum and support heterogeneous networks. However, some technical challenges for implementing CA technique in LTE-Advanced [3] system still remain highlighted. One of the challenges is the HARQ-ACK bits with huge increase compared with LTE [4, 5] system. In carrier aggregation, a UE (User Equipment) have to feedback HARQ-ACK bits for all configured downlink CCs [6-8] on uplink PCC (Primary Component Carriers) which can be as much as 90 bits at most. However, LTE was not designed to carry such large numbers of HARQ-ACK bits from multiple downlink CCs. In order to solve this problem, PUCCH format 3 [9, 10] is applied in LTE-Advanced in support of carrier aggregation.

The PUCCH format 3 supports transmission of 48 coded bits. The actual number of bits of HARQ-ACK is determined from the number of configured CCs, the configured transmission modes on each of them, and, in TDD, the HARQ-ACK bundling window size (the number of downlink subframes associated with a single uplink subframe). For TDD, PUCCH format 3 supports a HARQ-ACK payload size of up to 20 bits. If the number of HARQ-ACK bits to be fed back for multiple downlink subframes from multiple CCs is greater than 20, 'spatial bundling' of the HARQ-ACK bits corresponding to the two codewords within a downlink subframe is performed for each of the configured CC to reduce the HARQ-ACK bits. Thus, the HARQ-ACK bits may be less than 20 bits and can be fed back on PUCCH format 3. However, a UE not only need to feedback HARQ-ACK bits from multiple downlink CCs, but also should report CSI about each configured CC. So, when HARQ-ACK bits collide with CSI [11, 12], a new challenge appears.

For TDD and for a UE that is configured with one CC and with PUCCH format 3, in case of collision between a periodic CSI report and an HARQ-ACK feedback [13-15] in the same subframe without PUSCH, if we drop the periodic CSI report, the system performance will be degraded. As more configured CCs are aggregated, its dropping will occur more frequently and thus lead non-negligible downlink throughput loss [16, 17]. Therefore, to avoid downlink throughput loss, it should be considered that simultaneous transmission of HARQ-ACK feedback and periodic CSI on PUCCH format 3 is introduced for LTE-Advanced.

This paper focuses on the feasibility and application scenarios of multiplexing periodic CSI with HARQ-ACK

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feedback on PUCCH format 3, then proposes two channel coding schemes, such as joint coding scheme and separate coding scheme, for simultaneous transmission periodic CSI and HARQ-ACK feedback on PUCCH format 3. Simulation results demonstrated that with joint coding scheme the performance of periodic CSI and HARQ-ACK feedback are similar whereas the performance of HARQ-ACK feedback [18] is better than it of periodic CSI and close to it of HARQ-ACK feedback as transmitting it alone with separate coding scheme. Thus through the separate coding scheme, we can not only enhance simultaneous transmission of periodic CSI and HARQ-ACK feedback, but also guarantee the similar performance of HARQ-ACK feedback as transmitting it alone.

The rest of this paper is organized as follows. In Section Ⅱ, the feasibility and application scenarios of multiplexing periodic CSI with HARQ-ACK feedback on PUCCH format 3 are discussed. Two coding schemes to realize it are described in detail in Section Ⅲ. Simulation results are presented and discussed in Section Ⅳ. This paper is concluded in Section Ⅴ at last.

II. Feasibility and Application Scenarios

A. Feasibility

From 3GPP Rel-11, the maximum payload size carried by PUCCH format 3 is 22 bits in TDD, this corresponds to 21 HARQ-ACK bits plus 1 SR bit where the SR is appended to the HARQ-ACK bits [10]. According to Rel-11, the periodic CSI report is 11 bits at most. If there is up to 10 HARQ-ACK bits plus 1 SR bit, the PUCCH format 3 can in principle be used for multiplexing HARQ-ACK bits with any of the PUCCH periodic CSI reporting modes. For example, this could be done by using a dual $(32, O)$ RM coding for a total of 22 payload bits. However, we should expect the number of configured downlink CCs for a UE to be less than the nominal maximum of 5 CCs for many cases. If the number of the HARQ-ACK bits is more than 10 bits and the SR need to be transmitted in the same subframe, a much simpler approach for this case is to drop the periodic CSI report on the PUCCH format 3.

B. Application Scenarios

For TDD, it's feasible to multiplex periodic CSI report with HARQ-ACK feedback on PUCCH format 3 [13]. However, we should not increase PUCCH overhead and complicate the PUCCH format 3 too much. So it is not preferred to use PUCCH format 3 for simultaneous transmission of periodic CSI and HARQ-ACK if extra resource for PUCCH format 3 is needed. For example, for the case that PUCCH format 1b with channel selection is used for HARQ-ACK only feedback and PUCCH format 2 is configured for periodic CSI only reporting, eNB (evolved Node Base) needs to assign extra resource for PUCCH format 3 to support simultaneous transmission of periodic CSI and HARQ-ACK on PUCCH format 3, which will increase the PUCCH overhead. Thus, multiplexing periodic CSI report with HARQ-ACK bits on PUCCH format 3 has the following two possible application scenarios.

(1) Scenario 1: PUCCH format 3 is used for HARQ-ACK only feedback but not configured for periodic CSI only reporting.
(2) Scenario 2: PUCCH format 3 is configured for periodic CSI only reporting.

III. Two Channel Coding Schemes

With simultaneous transmission of periodic CSI and HARQ-ACK on PUCCH format 3, the channel coding scheme needs to be simple, flexible and effective. According to this, we propose two coding schemes for periodic CSI and HARQ-ACK feedback on PUCCH format 3.

A. Joint Coding of Periodic CSI and HARQ-ACK

In joint coding scheme, periodic CSI bits are concatenated next to HARQ-ACK bits, and then the concatenated bits are encoded by Reed-Muller (RM) code and rate matching. The processing is the same as in the case if there are only HARQ-ACK bits on PUCCH format 3. An example for the case of dual RM code is shown in Fig. 1.

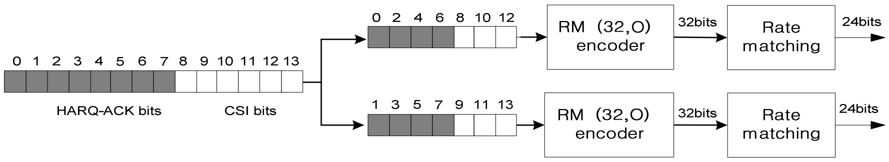

Figure 1. An example for joint coding scheme

The coding processing of this scheme is the same as in the case if there is only HARQ-ACK feedback without CSI. So it is fully compatible with the earlier version and can be implemented with little modification. However, in joint coding scheme, the HARQ-ACK bits and periodic CSI bits are treated like the same. Thus the performance of HARQ-ACK and periodic CSI is always the same. From Fig. 1, both of them are punched by rate matching, so the performance of them will be all degraded.

As we known, the HARQ-ACK feedback has the higher priority than periodic CSI bits. As the communication environment getting worse, the performance of HARQ-ACK will be serious degraded, which will inevitably decrease downlink throughput heavily. So, it is not necessary to sacrifice the performance of HARQ-ACK for periodic CSI. Thus, periodic CSI and HARQ-ACK feedback should be treated differently.

B. Separate Coding of Periodic CSI and HARQ-ACK

To multiplex periodic CSI with HARQ-ACK and control their performance separately, it is preferred to use separate coding scheme. The processing of separate coding scheme is shown in Fig. 2.

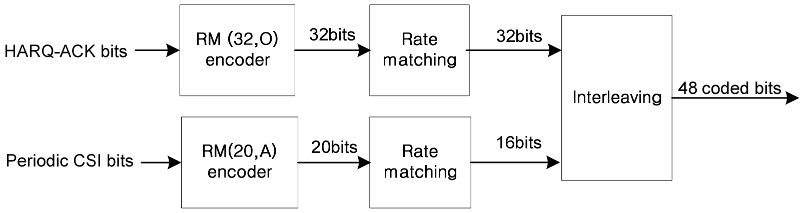

Figure 2. Basic processing for separate coding

In separate coding scheme, HARQ-ACK and periodic CSI are encoded by RM $(32, O)$ encoder and RM $(20, A)$ encoder separately. As HARQ-ACK and periodic CSI are coded separately, the performance of HARQ-ACK and periodic CSI can be controlled. To make the performance of the HARQ-ACK bits better than periodic CSI, rate matching is adopted. Interleaving of the coded bits from the encoders is needed to obtain time and frequency diversity gain for both HARQ-ACK and periodic CSI. The processing of separate coding scheme is as follows.

(1) Encoding: HARQ-ACK is encoded by RM $(32, O)$ encoder and periodic CSI is encoded by RM $(20, A)$ encoder separately. The HARQ-ACK sequence and periodic CSI sequence are $a_0, a_1, \cdots, a_{N_{A/N}-1}$ and $o_0, o_1, \cdots, o_{N_{CSI}-1}$ respectively. The output bit sequences of encoders are $\tilde{b}_0, \tilde{b}_1, \cdots, \tilde{b}_{31}$ and $\tilde{\tilde{b}}_0, \tilde{\tilde{b}}_1, \cdots, \tilde{\tilde{b}}_{19}$ respectively, as Fig. 2 shows.

(2) Rate matching: PUCCH format 3 can carry 48 coded bits, which are distributed among the HARQ-ACK and periodic CSI. One or multiple parameter(s) signaled by eNB can be used to adjust the coding rate. In this paper, among the 48 encoded bits, 32 bits are distributed to HARQ-ACK and 16 bits are distributed to periodic CSI. The output bit sequences of rate matching are $\tilde{b}_0, \tilde{b}_1, \cdots, \tilde{b}_{31}$ and $\tilde{\tilde{b}}_0, \tilde{\tilde{b}}_1, \cdots, \tilde{\tilde{b}}_{15}$ respectively, as Fig. 2 shows.

(3) Interleaving: Both the HARQ-ACK coded bits and periodic CSI coded bits should be mapped to both slots. So as to obtain time and frequency diversity gain. In this paper, the interleaving is executed as follows: every four HARQ-ACK bits, there should be two periodic CSI bits. The output bit sequence of interleaving $b_0, b_1, \cdots, b_{B-1}$ where $B=48$ is obtained by the concatenation of the bit sequences $\tilde{b}_0, \tilde{b}_1, \cdots, \tilde{b}_{31}$ and $\tilde{\tilde{b}}_0, \tilde{\tilde{b}}_1, \cdots, \tilde{\tilde{b}}_{15}$, the processing is shown in Fig. 3.

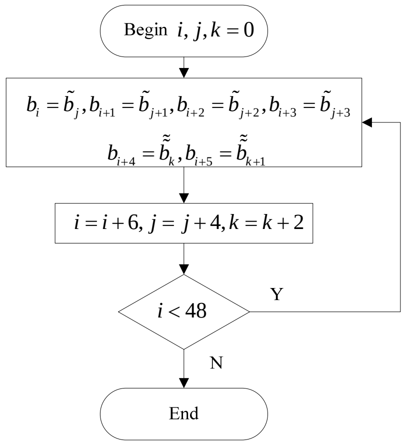

Figure 3. Basic processing of interleaving

From Fig. 2, it is obvious that the basic processing for separate coding scheme is a little bit complicated than joint coding and has more impact on the specification and implementation. But it is more flexible in controlling the performance of HARQ-ACK feedback and periodic CSI separately to meet the different performance requirements of periodic CSI and HARQ-ACK. Through rate matching, only CSI will be punched heavier than the joint coding scheme but HARQ-ACK not need to be punched. Obviously, we can obtain better HARQ-ACK performance.

With separate coding scheme, the performance of HARQ-ACK feedback will be very close to the case of transmitting it alone. At the same time, it can enhance simultaneous transmission of periodic CSI and HARQ-ACK feedback. As a result, periodic CSI dropping will be avoided and thus downlink throughput will be increased without sacrificing the performance of HARQ-ACK feedback too much.

IV. SIMULATIONS

In order to demonstrate the feasibility of multiplexing the periodic CSI report with HARQ-ACK bits on PUCCH format 3 and the effectiveness of the two coding schemes under different moving speed of user equipment, simulations will be provided in this section. In this paper, the extended typical urban model (ETU) [19] is chosen as the channel model, and the Doppler frequency cases are 200 Hz and 300 Hz, corresponding moving speed of user equipment are $105km/h, 160km/h$ respectively. The performance is represented by bit error rate (BER). PUCCH format 3 adopts SORTD transmit diversity [20, 21], and both of the length of HARQ-ACK bits and periodic CSI report are 10. The simulation parameters are listed in Table Ⅰ.

TABLE I.
SIMULATION PARAMETERS

Parameters	Values
Carrier frequency	2GHz
Bandwidth	5MHz
Cyclic prefix	Normal
FFT size	2048
MIMO configuration	2T×2R
Channel model	ETU
Length of HARQ-ACK/periodic CSI bits	10/10
Number of simulations for each SNR	1000
Mobile speed	105/160 Km/h

In Fig. 4 and Fig. 5, both the BER of simultaneous transmitted periodic CSI and HARQ-ACK feedback with the two coding schemes are shown respectively. What's more, the BER of transmitted HARQ-ACK feedback alone is also studied. From them, if joint coding has been adopted, no significant difference is observed between the BER of periodic CSI and HARQ-ACK feedback, whereas if separating coding scheme has been adopted, the BER of HARQ-ACK feedback is bigger than it of the periodic CSI significantly. Due to code the periodic CSI and HARQ-ACK feedback independently in separate coding scheme, the BER of periodic CSI is worse than the it with joint coding scheme and the BER of HARQ-ACK feedback is better than it with joint coding scheme at all range of SNR. The most impressive achievement of separate coding scheme is that the BER of HARQ-ACK feedback with separate coding scheme is very close to the BER of HARQ-ACK feedback as transmitting it alone.

Comparing Fig. 4 with Fig. 5, it can be concluded that Doppler frequency 200 and Doppler frequency 300 have little impact to the BER of periodic CSI and HARQ-ACK feedback in the two coding schemes. The BER of periodic CSI and HARQ-ACK feedback with two coding schemes in the environment of Doppler frequency of 200 Hz are almost the same as the BER in the environment of 300 Hz respectively at each SNR.

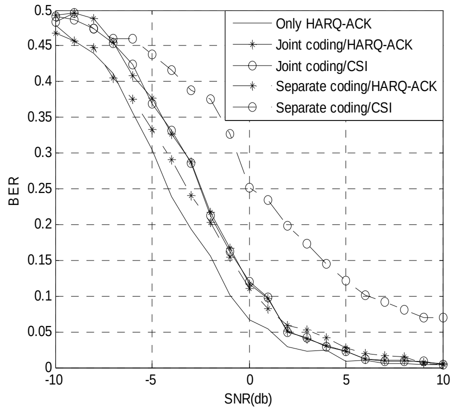

Figure 4. Simulation performance of Doppler frequency 200 Hz

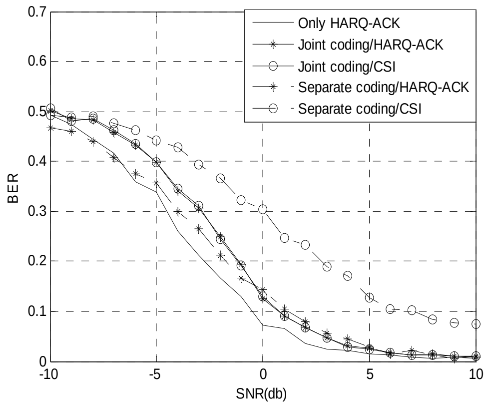

Figure 5. Simulation performance of Doppler frequency 300 Hz

V. CONCLUTION

In this paper, the feasibility and application scenarios of multiplexing periodic CSI with HARQ-ACK feedback are introduced first. Then two coding schemes to realize simultaneous transmission of periodic CSI and HARQ-ACK feedback are described in detail. The simulation results indicate that both of the two coding schemes can effectively support simultaneous transmission periodic CSI and HARQ-ACK feedback on PUCCH format 3. But from joint coding, periodic CSI and HARQ-ACK feedback have the same performance while from separate coding, HARQ-ACK feedback has better performance than periodic CSI. Furthermore, the performance of HARQ-ACK feedback with separate coding scheme is very close to the performance of HARQ-ACK feedback as transmitting it alone. Hence through the separate coding scheme, we can not only enhance simultaneous transmission of periodic CSI and HARQ-ACK feedback, but also guarantee the similar performance of HARQ-ACK feedback as transmitting it alone.

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