A Dynamic HARQ Feedback Method in NR Communication Systems

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***Abstract*— In NR (New Radio), Hybrid automatic repeat request (HARQ) feedback type is statically configured as either transport block based feedback or code block group based feedback when the serving cell is established. This paper proposes a method to dynamically indicated the HARQ feedback type based on the channel state. To achieve this, the paper suggests adding a HARQ feedback type indicator field to the downlink DCI. The HARQ feedback type indicator instructs the HARQ feedback type for the transmitted DL data. The HARQ feedback type can be changed based on the channel state for each HARQ codebook period. By dynamically indicating the HARQ feedback type, efficient utilization of PUCCH resources for the HARQ codebook transmission and PDSCH resources for retransmissions can be achieved.**

***Keywords*— NR, HARQ, Feedback**

I. Introduction

HARQ plays an important role providing a certain quality of service (QoS) requirements, including packet error rate (PER) and data transfer delay. HARQ is a combination of forward error correction (FEC) coding and automatic repeat request (ARQ) to support fast error recovery. In NR, a TB which is received from MAC layer is divided into multiple code blocks (CB). For FEC coding, low density parity check (LDPC) based channel coding is performed on each CB [1]. Error correction relies on retransmission methods such as ARQ. Also, retransmission methods are determined by feedback information. In NR, there are two types of HARQ feedback type, transport block (TB) based and code block group (CBG) based. The TB-based feedback method transmits a 1-bit information indication the HARQ acknowledgment (ACK) or negative acknowledgment (NACK) for a single TB. On the other hand, the CBG-based feedback method divides a single TB into multiple CBs, then bundles a few CBs to form a single CBG and transmits the HARQ ACK or NACK information per CBG [2-3].

The TB-based feedback method utilizes physical uplink control channel (PUCCH) resources for transmitting a 1-bit HARQ feedback for a single TB. This allows for reducing the PUCCH resources required for HARQ feedback, but it increases the physical downlink shared channel (PDSCH) resources needed for retransmissions. The CBG-based feedback method performs retransmissions only for the CBGs where errors occurred, which can reduce PDSH resources. However, it involves performing HARQ feedback at the CBG level, resulting in an increase in PUCCH resources required. In NR, the HARQ feedback method is statically configured at serving cell level.

In this paper, we propose a novel method that dynamically selects the HARQ feedback method based on the channel conditions. The proposed method uses downlink control information (DCI) to indicate a HARQ feedback method and applies the HARQ feedback method to slots that share the same PUCCH resources for transmitting HARQ feedback information.

The rest of the paper is organized as follows. In section II, we describe HARQ feedback methods in NR. We propose a HARQ feedback method in section III. A performance evaluation is presented in section IV. Finally, conclusions are drawn in section V.

II. HARQ Feedback Methods in NR

In NR, the necessary procedures for downlink (DL) HARQ are as follows.

A. Channel Coding Procedure

As shown in Figure 1, a CRC is appended to the TB received from MAC. After selecting the LDPC base graph, the maximum CB size is determined. The TB is segmented into multiple CBs, which are smaller than the maximum CB size, and a CRC is added to each code block. Channel coding is then performed on each code block [4].

B. HARQ Feedback Methods in NR

The HARQ feedback method for each serving cell is indicated through the RRC signaling procedure. During the slot interval for HARQ feedback transmission using the same PUCCH resources, the serving cell retains the HARQ feedback information for the received data in each slot. As shown in Figure 2, the HARQ codebook is constructed by combining the HARQ feedback information from the serving cell that share the same PUCCH resources. The HARQ feedback information from each serving cell can be either TB-based or CBG-based. TB-based HARQ feedback conveys a 1-bit information, whereas CBG-based HARQ feedback is equal to the number of CBGs comprising the TB.

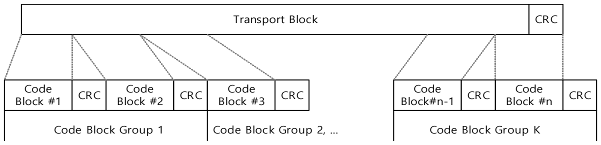

Figure 1. Code block segmentation

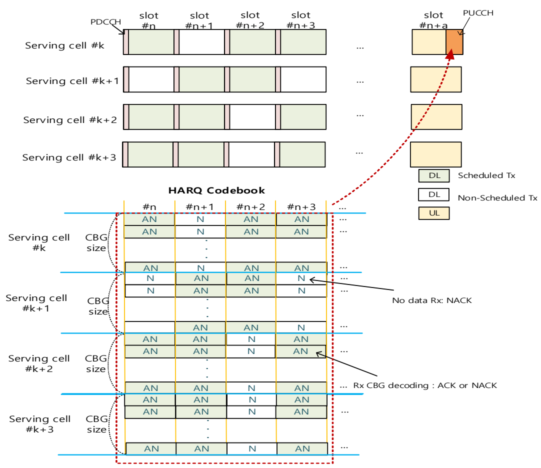

Figure 2. CBG based HARQ feedback

III. The Proposed Adaptive HARQ Feedback

In NR, HARQ feedback is performed using two types: TB-based or CBG-based. For TB-based HARQ feedback, 1-bit feedback information is transmitted, utilizing smaller PUCCH resources. However, this leads to an increase in the PDSCH resources required for retransmissions. On the other hand, CBG-based HARQ feedback generates 1-bit feedback information per CBG. Although this requires more PUCCH resources, it allows for a reduction in the PDSCH needed for retransmissions. The HARQ feedback type assigned to each serving cell in NR is statically configured, meaning it remains fixed and does not dynamically change based on channel conditions or other factors.

We propose a method to dynamically select the HARQ feedback type based on channel conditions or other factors in order to efficiently utilize PDSCH and PUCCH resources. The proposed approach performs TB-based HARQ feedback when the channel conditions are stable and error-free, while it switches to CBG-based HARQ feedback when the channel conditions are unstable and errors occur.

In order to dynamically instruct the HARQ feedback type to the UE, we introduce a new field called the HARQ feedback type indicator in the DCI. The DCI includes information required for the UE to receive DL data. The HARQ feedback type indicator indicates the HARQ feedback type for the currently transmitted DL data. After decoding the received data, the UE constructs the feedback information based on the instructed HARQ feedback type. A value of 0 indicates TB-based feedback, while a value of 1 indicates CBG based feedback.

In the case of supporting carrier aggregation (CA), the UE can configure multiple serving cells. A PUCCH group

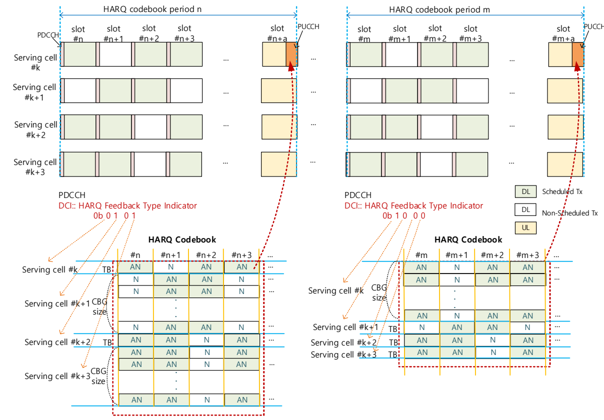

Figure 3. Dynamic HARQ feedback

represents a group of serving cells that share a common PUCCH resource. The size of the HARQ feedback type indicator field is equal to the number of serving cells sharing one PUCCH resource. Each bit of the HARQ feedback type indicator is associated to the serving cell index within the PUCCH group in ascending order. The serving cell performs TB-based feedback when the associated bit value is 0, or CBS-based feedback when the value is 1.

In a TDD (Time Division Duplex) configuration as shown in Figure 3, the HARQ feedback information for the DL data received in multiple DL slots is transmitted using a single PUCCH. In other words, the feedback information for DL data received in multiple DL slots is collected to form single HARQ codebook. We define this duration as the HARQ codebook period. The HARQ feedback type of the serving cell can be changed on a per HARQ code book period basis. During the HARQ codebook period, the HARQ feedback type indicator within DCI is transmitted with the same value, indicating a specific feedback type. This enables the determination of the feedback type based on the received DCI information from other slots, even if the DCI transmission fails in a particular slot. Additionally, by transmitting the same information to all serving cell within the PUCCH group, if the DCI is lost in one serving cell, the HARQ feedback type can be determined based on the received HARQ feedback indicator from other serving cells.

During the HARQ codebook period, the UE collects the ACK or NACK information according to the decoding result of the received DL data from each serving cell. It then forms a HARQ codebook and transmits it to the gNB using PUCCH resources. The gNB performs HARQ retransmission based on the HARQ codebook information. As a method to dynamically the HARQ feedback type at the gNB, it can be inferred from the presence or absence of errors in the received data within the serving cell during the HARQ codebook period. If all the feedback information for the DL data transmitted during the HARQ codebook period is received as ACK, the TB based feedback type is indicated for the next HARQ codebook period. This can reduce the codebook size and allows for the transmission of the HARQ codebook using smaller PUCCH resources. On the other hand, if errors occur in the DL data transmitted during the HARQ codebook period and a NACK is received, the CBG based feedback type is indicated for the next HARQ period. This enables HARQ retransmissions using fewer PDSCH resources.

IV. PERFORMANCE ANALYSIS

In NR, the HARQ feedback type is statically configured during serving sell setup. When the CBG based feedback type is configured, the HARQ codebook size, S within one PUCCH group during the HARQ codebook period can be calculated as follows.

$$S = N * C * D \tag{1}$$

where N is the number of CBGs configured per TB, C is the number of serving cells within the PUCCH group, and D represents the number of DL slots during the HARQ codebook period.

The proposed method dynamically determines the HARQ feedback type to be used during the HARQ codebook period. If ACK is received for all DL data transmitted from any serving cell during the HARQ codebook period, the TB-based feedback type is indicated for the next HARQ codebook period. Otherwise, the CBG-based feedback type is indicated. When the probability of successfully receiving the transmitted data during the HARQ codebook period is denoted as P, the HARQ code size generated for a PUCCH group during the HARQ codebook period can be calculated as follows.

$$Sp = \{(1-p)(N * D) + p * D\} * C \tag{2}$$

In NR, the HARQ feedback type is determined when the serving cell is configured and remains unchanged. Therefore, the HARQ codebook size in NR is fixed. Under the conditions depicted in Figure 4, the HARQ codebook size generated for a PUCCH group during the HARQ codebook period is 168 bits in CB based feedback type.

The proposed method allows for dynamic changes of the feedback type on a HARQ codebook period basis, based on the channel conditions. By checking the received HARQ codebook, if all DL data transmitted in the previous period are successfully received, the TB based feedback type is instructed for the next period. This approach generates 1-bit feedback information per TB, reducing the HARQ codebook size and utilizing smaller PUCCH resources for transmission. Figure 4 illustrates the HARQ codebook size according to the probability of successful reception, p. In case errors occur in the DL data transmitted in the previous period, the CBG based feedback type is instructed for the next period, resulting in an increased HARQ codebook size. However, this allows for efficient utilization of PDSCH resources through CBG based retransmissions.

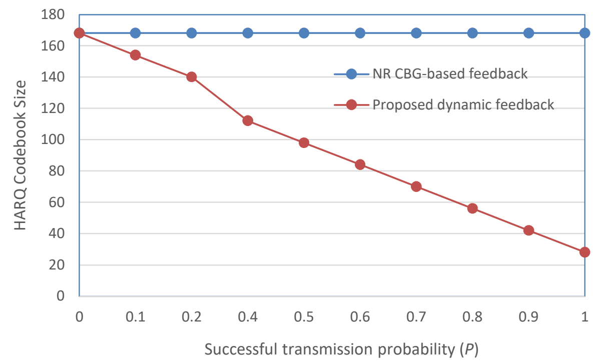

Figure 4. HARQ Codebook Size according to successful Rx probability ***(N: 6, C: 4, D: 7)***

V. CONCLUSIONS

We have proposed a method for dynamically indicating the HARQ feedback type depending on the channel state. The proposed method includes the HARQ feedback type indicator in the DCI along with the resource allocation information for DL data transmission. The HARQ feedback type indicator instructs the HARQ feedback type during the HARQ codebook period. If the channel state is stable and no errors occur, the TB based feedback type is indicated. On the other hand, if the channel is unstable and errors occur, the CBG based feedback type is indicated. This approach can achieve efficient utilization of PUCCH resources for HARQ codebook transmission and PDSCH resources for CBG based retransmission.

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