3GPP TSG RAN WG1 Meeting #93 R1-1808255

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Agenda Item: 7.2.6.1
Source: TCL Communication
Title: PDCCH combining strategy
Document for: Discussion and decision

1. Introduction

The requirements of URLLC have been specified in [1]:

"A general URLLC reliability requirement for one transmission of a packet is 10^{-5} for 32 bytes with a user plane latency of 1ms."

In last RAN1 meeting, the following agreements about PDCCHs and PDSCH were made [2]:

Agreements:

- *To ensure the reliability requirement of NR-PDCCH for URLLC, at least the following aspects should be supported*
    - *Defining a compact DCI format targeting low BLER operation*
    - *The highest aggregation level should target a BLER of Y for this compact DCI format*
        - *FFS Y, Y<1%*
        - *FFS highest aggregation levels, e.g., 16, 32*
    - *FFS other enhancements*

[3] gives the topics that will be studied in the next release and one item about control channel design is:

- *Study and specify if gains are identified*
    - *Define a new DCI format(s) that has a smaller DCI payload size than DCI format 0-0 and DCI format 1-0 unicast data*
    - *For a given carrier, PDCCH repetitions over same or multiple PDCCH monitoring occasion(s) of the same or multiple CORESET and search space*

2. PDCCH & PDSCH repetitions combining

2.1. Transmission scheme

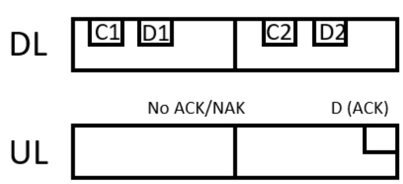

Figure 1: PDCCH & PDSCH repetition

The conventional transmission scheme with HARQ process is shown in Figure 1. The gNB starts to transmit PDCCH (C1) and PDSCH (D1) in the downlink. The UE fails to decode PDCCH so PDSCH also cannot be decoded because its location is unknown to the UE so the gNB will not receive ACK/NACK. After detecting the missing HARQ response in the resource, the gNB knows that PDCCH is not detected by the UE. Thus, it reschedules data by sending again both PDCCH and PDSCH. It causes very sub-optimal resource usage because both control and data need to be transmitted again and most probably with lower code rate. Moreover, it leads to increase of data latency when the UE needs to wait for the retransmission. This latency can be a big issue for URLLC type of services.

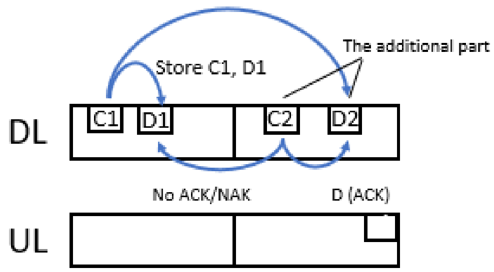

Figure 2:Reliable transmission of DL assignment information

The retransmission of complete PDCCH and PDSCH as if it's a fresh transmission can be avoided by repeating PDCCH and PDSCH partially and combining these multiple transmitted PDCCHs and PDSCHs. In this scheme as shown in Figure 2, for the original transmission, the gNB transmits PDCCH (C1) and PDSCH (D1). When no HARQ response is received at the gNB for PDSCH at the expected time, it retransmits special versions of PDCCH and PDSCH in the next transmission occasion (explained in 2.2). The two transmissions of control (C1 and C2) are designed such that they can be combined for joint detection as proposed earlier. Additional to this, the decoded PDCCH enables the UE to locate the two transmissions of PDSCH, the original transmission (D1) and the retransmission (D2) in order to combine them. This allows the network to enhance the reliability of both PDCCH and PDSCH for URLLC users in a very timely manner which can be a key to meet their latency and reliability requirements in harsh environments.

Proposal 1: The gNB retransmits a special version of PDCCH and PDSCH if it does not receive any HARQ response for the previous transmission (PDCCH and PDSCH). The UE combines two repetitions of PDCCH and two repetitions of PDSCH to have the codewords with lower code rate, resulting in improved detection probability.

The applicability of this idea requires that the UE keeps the samples of the previous control occasion (including control and data portions) in the buffer to be able to combine.

To guarantee the combination of PDCCHs, the content of DCI must be the same for both the initial transmission and the retransmission. One way is to make the (initial) PDCCH indicate the resource allocation information for both two transmissions as illustrated in Figure 2. This does not necessarily mean that all the fields in the DCI relevant to scheduling of resources, precoding, layers, MCS etc are doubled up. One possibility could be to pre-define what would be the resources for the retransmission PDSCH (D2) as a function of resources indicated for the original transmission (D1). The transmission parameters, like MCS, RV etc can be kept same and may not need any indication separately for the retransmission PDSCH.

Proposal 2: The (first) PDCCH includes the resource allocation information for multiple PDSCH transmissions.

If the UE can decode PDCCH but encounters an error in decoding PDSCH, PDSCH can be retransmitted independently in the next transmission occasion without a request of another PDCCH because the resource allocation information of this repetition is known by the UE by decoding the initial PDCCH. After that, the UE combines these two transmissions to obtain PDSCH.

Proposal 3: If PDCCH is decoded but PDSCH is not correctly decoded, PDSCH can be retransmitted in the next transmission occasion without another PDCCH.

When one PDCCH indicates PDSCH in both the current slot and the next transmission occasion, it means that the resource for the data retransmission is configured. It can lead to a waste of resource in case PDCCH and PDSCH are decoded successfully by the UE. Therefore, this configured resource can be dynamically allocated to other UEs if the gNB receives ACK and a retransmission is not necessary anymore.

Proposal 4: The configured resource of PDSCH repetition can be dynamically allocated to other UEs if no retransmission is required.

2.2. Design of PDCCH repetitions

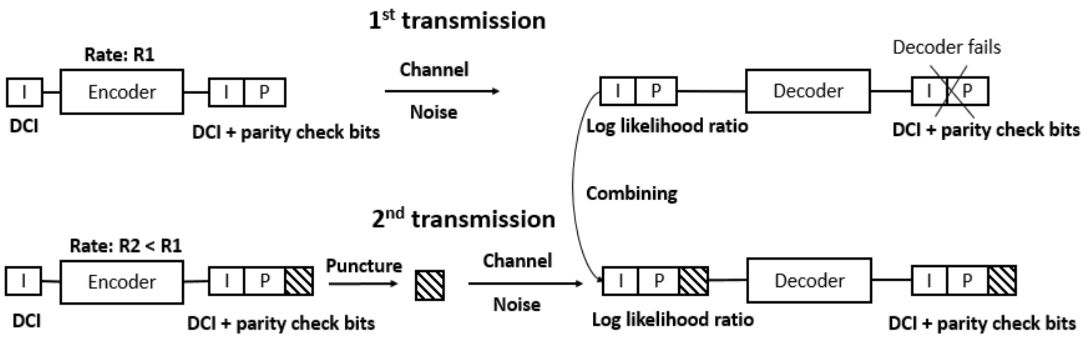

Figure 3: Combining of multiple PDCCHs

The contents of the multiple transmissions of same PDCCH are explained in detail as illustrated in Figure 3 (the same mechanism for PDSCH repetition). When the transmission starts, the gNB encodes the control signal (DCI) using Polar code with the code rate R1 to generate PDCCH containing DCI and parity check bits. Subsequently, PDCCH is transmitted from the gNB to the UE. The UE is responsible for calculating the log likelihood ratio (LLR) of the incoming codeword. After that, the UE decodes the incoming codeword to find the codeword sent by the gNB. If the decoder fails to find the correct codeword, the UE will store the current slot containing PDCCH to combine with PDCCH repetition in the next transmission occasion, in case the gNB indeed does a retransmission of PDCCH. The buffered slot also consists of PDSCH that will be back indicated and decoded if the PDCCH repetition is decoded successfully. On the transmitter side, the gNB does not receive ACK/NACK from the UE, thus initiating the second transmission of DCI that has the same content with the first DCI because both DCIs indicates the same PDSCH as in Figure 2. In this retransmission, a lower code rate R2 (R2 < R1) is used in order to increase the reliability of PDCCH. However, the bits that are already transmitted in the first transmission are punctured, only the additional bits due to the lower code rate are transmitted to the UE. The UE combines the current slot with the previous stored slot to build a codeword with lower code rate. Due to the lower code rate, BLER becomes smaller in comparison to the first transmission so the UE has better chance to decode the transmitted DCI.

Proposal 5: Only the additional bits due to a lower code rate are transmitted in the PDCCH and PDSCH repetitions.

In order to combine PDCCHs, the content of DCI in the transmission and retransmission must be the same and the codewords of the encoded DCI are punctured from a mother codeword with a fixed rate to obtain a higher code rate.

Proposal 6: The gNB generates codeword of PDCCH with a mother code of lower rate. It can select suitable bits to be transmitted in the original PDCCH transmission and the repetition by applying puncturing. In this way, it does not need to encode PDCCH twice for multiple repetitions.

2.3. Containing the complexity of blind decode for PDCCH Combining

The proposals in the previous sections requires the UE to combine multiple repetitions of PDCCH from different control transmission occasions. This will present as a challenge to UE blind decoding complexity if no additional constraints on PDCCH mapping are enforced. In principle, the location of PDCCH is unknown to a UE so each UE must perform blind decode until it finds a DCI that passes the CRC. When a

UE is not able to decode PDCCH, it is not certain if it failed to decode PDCCH or there was no PDCCH destined to it to start with.

In the PDCCH combining, the complexity of blind decode becomes more severe when the number of blind decodes grows remarkably. As shown in Figure 4, in a fully exhaustive scheme, the number of combinations is the product of the number of PDCCH candidates in two control occasions.

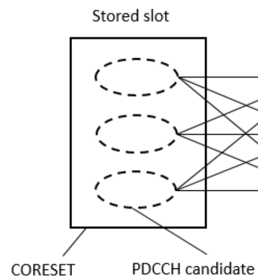

Figure 4: Blind PDCCHs combining

The number of blind decodes when the UE combines the slots can decrease further when the gNB is configured to transmit PDCCH and the repetitions in the candidates with a one-to-one correspondence mapping. As shown in Figure 5, the number of combinations in two slots falls significantly in comparison to the conventional method in Figure 4. There could still be different mapping possibilities which can be defined. This can be defined a-priori by making it a part of the 3GPP specification or this could be configured by the gNB to the user.

Proposal 7: To contain the blind decode complexity of PDCCH combining, the association can be defined such that which PDCCH candidates in one occasion can be mapped to which candidates in the repletion occasion.

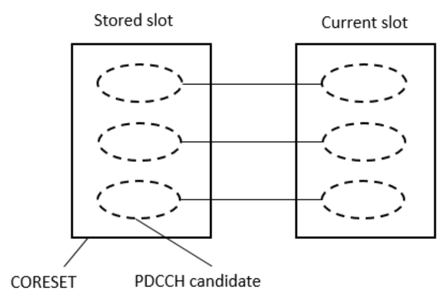

Figure 5: Associated PDCCH combining

Based on the same principle of one-to-one correspondence of PDCCH combining, the improvement of URLLC's service quality through interference cancellation and frequency diversity in PDCCH transmission can be achieved by frequency hopping.

In one method the PDCCH repetitions are in the same CORESET, over the same set of PRBs, at different time instant. The mapping is defined in such a manner so as to exploit the frequency diversity as much as possible within the resources configured for the CORESET.

Proposal 8: PDCCH candidates can be in different CORESETs in the same band and over the same set of PRBs but these candidates are hopped over different frequency.

In another method to allow additional frequency diversity advantage in PDCCH combining, the initial transmission and repetitions are allocated to the disjoint frequencies with large frequency distance. As NR does not allow a single COREEST to change its frequency allocation with time, one way to achieve this would be that the gNB configures two CORESETs at disjoint frequency locations as illustrated in . The gNB configures 2 CORESETs for 2 transmissions in the disjoint bands.

Proposal 9: Frequency hopping may be used in PDCCH repetition to achieve frequency diversity. The PDCCH candidates can be repeated in different CORESETs at different frequency locations to be combined by the UE.

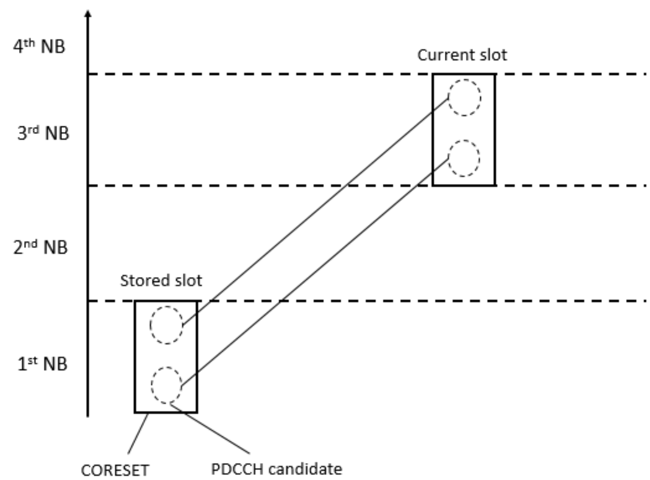

Figure 6: Frequency hopping PDCCH repetition with one-to-one correspondence

3. Simulation result

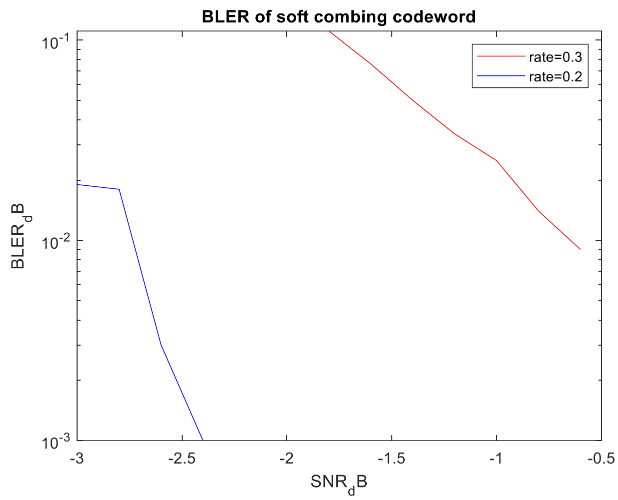

Figure 7: BLER of two PDCCH transmissions

The simulation of PDCCH combining is shown in Figure 7 in comparison to the legacy NR scheme. In this simulation, the encoder uses Polar code to encode the input codeword and the decoder is Successive cancellation list (SCL) decoder with list size 8. In the first transmission, the codeword with the rate 0.3 is transmitted. In the second transmission, the information bits are encoded with the rate 0.2 to generate a longer codeword but only the additional bits due to a lower code rate are transmitted. At the decoder, the LLRs of the first transmission and the second transmission are combined and the decoder decodes the codeword with the rate 0.2. As can be seen in Figure 7, the performance of the combined codeword represented by the blue curve is remarkably better than that of the first transmission as in the legacy NR scheme represented by the red curve with a margin being about 2dB. This means that the information of the additional bits in the second transmission increases the reliability of PDCCH transmission without consuming much resources for the second transmission of the whole PDCCH with a higher AL as in the conventional scheme.

4. Conclusion

Proposal 1: The gNB retransmits a special version of PDCCH and PDSCH if it does not receive any HARQ response for the previous transmission (PDCCH and PDSCH). The UE combines two repetitions of PDCCH and two repetitions of PDSCH to have the codewords with lower code rate, resulting in improved detection probability.

Proposal 2: The (first) PDCCH includes the resource allocation information for multiple PDSCH transmissions.

Proposal 3: If PDCCH is decoded but PDSCH is not correctly decoded, PDSCH can be retransmitted in the next transmission occasion without another PDCCH.

Proposal 4: The configured resource of PDSCH repetition can be dynamically allocated to other UEs if no retransmission is required.

Proposal 5: Only the additional bits due to a lower code rate are transmitted in the PDCCH and PDSCH repetitions.

Proposal 6: The gNB generates codeword of PDCCH with a mother code of lower rate. It can select suitable bits to be transmitted in the original PDCCH transmission and the repetition by applying puncturing. In this way, it does not need to encode PDCCH twice for multiple repetitions.

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Proposal 9: Frequency hopping may be used in PDCCH repetition to achieve frequency diversity. The PDCCH candidates can be repeated in different CORESETs at different frequency locations to be combined by the UE.

References

[1] "TR 38.913".

[2] "Chairman's Notes RAN1 NR Ad-Hoc #1".

[3] "RP-172817 – “NR High-Reliability URLLC scope for RAN1/RAN2”, Ericsson, RAN78".