PDCCH

Wednesday, August 7, 2024 3:05 PM

PDCCH (Physical Downlink Control Channel):

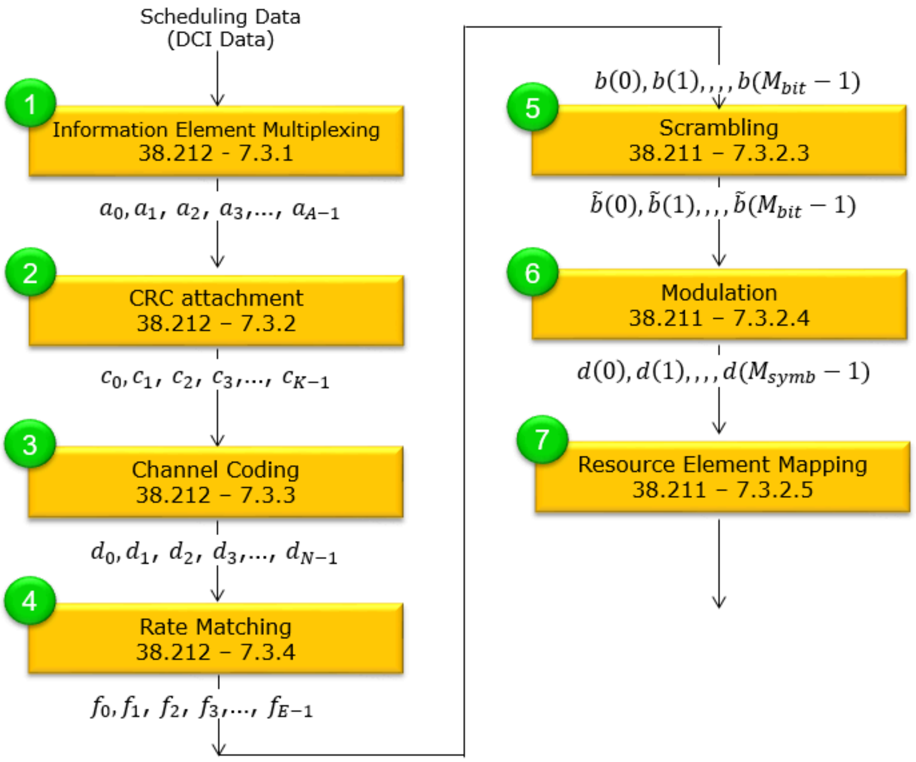
As in LTE, NR PDCCH is the physical channel that carries DCI and this would be one of the most important channel which is supposed to be very robust and easily decoded even in harsh radio condition.

Overall channel coding and physical layer process is also similar to LTE PDCCH as listed below with a few differences like channel coding.

- PDCCH Transport Process
    - (1) Information Element Multiplexing
    - (2) CRC Attachment
    - (3) Channel Coding
    - (4) Rate Matching
    - (5) Scrambling
    - (6) Modulation
    - (7) Resource Element Mapping

PDCCH Transport Process:

The PDCCH Transport Process in a cellular communication system, detailing the sequence of steps involved in preparing and transmitting the PDCCH from gNB to UE



Information Element Multiplexing: This stage involves combining different control information elements such as Downlink Control Information (DCI) formats into a single data stream for processing.

CRC Attachment: A Cyclic Redundancy Check is added to the multiplexed information to enable error detection at the receiver's end.

Channel Coding: The data stream with CRC is encoded to protect against potential data corruption during transmission. This typically involves error correction coding techniques like Polar code.

Rate Matching: The encoded data is adjusted to match the allocated resource blocks. This step may involve puncturing or repeating bits to fit the data into the available transmission space.

Scrambling: The rate-matched data is scrambled to minimize interference and ensure data security. Scrambling is performed using a sequence known to both the transmitter and receiver.

Modulation: The scrambled data is then modulated, which means converting the bits into symbols that can be transmitted over a radio frequency channel.

Resource Element Mapping: Finally, the modulated symbols are mapped onto specific resource elements in the frequency-time grid of the carrier signal. This step positions the control information correctly for transmission within the broader signal frame.

(1) Information Element Multiplexing:

This is a process of generating a bit string of DCI carrying various control and scheduling information. Refer to DCI page to see the details of the contents.

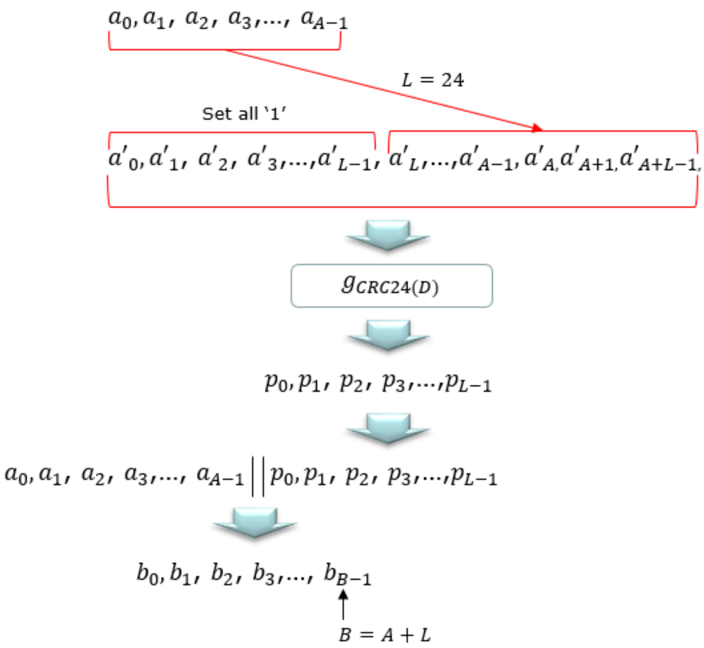
If the size of DCI is less than 12 bit, it will be zero padded until it become 12 bits .

This stage involves combining different control information elements such as Downlink Control Information (DCI) formats into a single data stream for processing

(2) CRC Attachment:

< CRC Attach >

The CRC Attachment process for the 5G PDCCH (Physical Downlink Control Channel). As you see here, 24 bits CRC is appeded to DCI data.



Initially, DCI (Downlink Control Information) data is presented as a sequence of bits a_0, a_1, a_2, ..., a_{A-1}. A 24-bit CRC is appended to this DCI data.

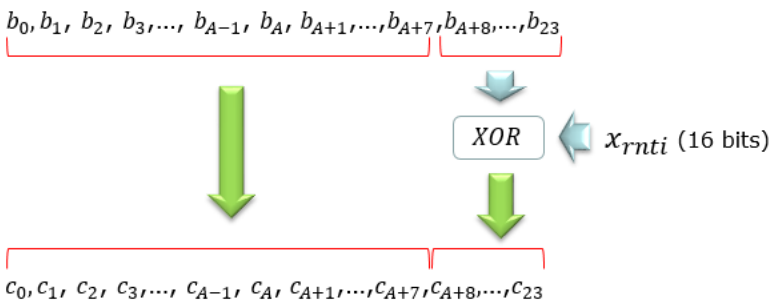
To prepare for CRC attachment, a sequence is extended by setting all bits following the DCI data to '1' for a length L of 24, resulting in an extended sequence a'_0, a'_1, a'_2, ..., a'_{L-1}, a'_L, ..., a'_{A+L-1}. This sequence is processed using a generator polynomial $G_{CRC24}(D)$, producing a CRC of bits p_0, p_1, p_2, ..., p_{L-1}.

The DCI data and CRC are then concatenated, forming a complete sequence a_0, a_1, a_2, ..., a_{A-1} | p_0, p_1, p_2, ..., p_{L-1}, which is denoted by b_0, b_1, b_2, ..., b_{B-1}. The total length of the sequence after CRC attachment is B = A + L.

This CRC attachment process is a crucial step in ensuring the integrity of the control information as it allows the receiver to detect any errors that may have occurred during the transmission.

< Masking with RNTI >

After CRC Attach, the last 16 bit is masked with a specific RNTI. Using this RNTI, UE figures out which UE the DCI is for and what is the usage of the DCI.



After the CRC is appended to the DCI data, resulting in the sequence b_0, b_1, b_2, ..., b_{A-1}, b_A, ..., b_{23}, the last 16 bits are masked with a specific RNTI (Radio Network Temporary Identifier).

This masking is performed by XORing the last 16 bits of the sequence with the 16-bit RNTI, denoted as x_{RNTI}. The RNTI is a unique identifier that enables the User Equipment (UE) to determine which DCI is intended for it and understand the usage of the DCI.

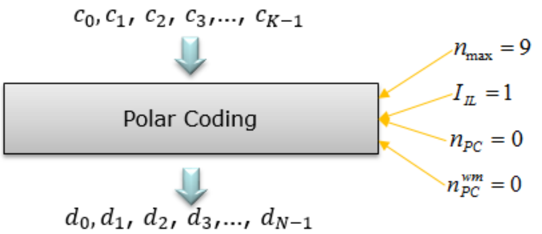
The output of this process is a new sequence c_0, c_1, c_2, ..., c_{A-1}, c_A,...,c_{A+7},c_{A+B}, ..., c_{23}, where the last 16 bits have been modified by the RNTI masking. This step is crucial for directing the DCI to the correct UE and for protecting the information's integrity.

< Interleaving >

After RNTI masking, the data is interleaved so that CRC bits are distributed among information bits. This inter leaver supports a max input size of 164 bits meaning that DCI without CRC can be max 140 bits.

(3) Channel Coding:

The image shows the Channel Coding step, which is part of the PDCCH channel coding processing.



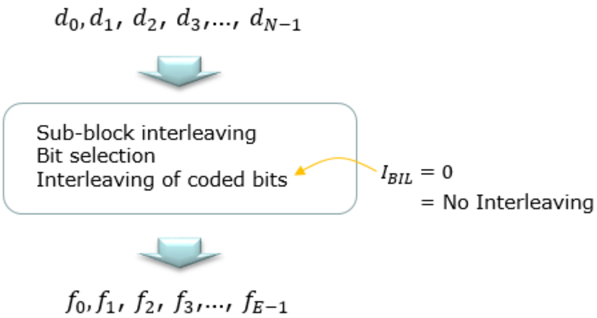
In this step, the sequence c_0, c_1, c_2, ..., c_{K-1} undergoes Polar Coding, a method known for its efficiency in error correction capabilities.

The Polar Coding process is characterized by several parameters: n_{max} represents the maximum number of reliable sequence indices and is set to 9; I_{IL} denotes the list size used in decoding, given as 1; n_{pc} is the number of parity check bits, which is 0 in this case; and n_{pc}^{wm} is another parity check parameter, also set to 0 here.

After Polar Coding, the data sequence is transformed into d_0, d_1, d_2, ..., d_{N-1}, which is ready for subsequent transmission steps. This coded sequence is more resistant to errors during transmission over the communication channel.

(4) Rate Matching

This diagram illustrates the Rate Matching step in PDCCH channel processing, which is essential for adapting the coded data to the correct size for transmission.

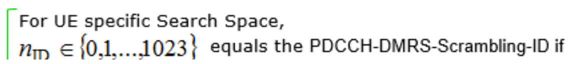


Starting with the coded data sequence d_0, d_1, d_2, ..., d_{N-1}, the process involves sub-block interleaving and bit selection. Interleaving of coded bits is indicated, but with I_{BIL} set to 0, this implies that there is no interleaving applied to the data.

Following this, the data sequence is adjusted to match the transmission rate, resulting in a new sequence f_0, f_1, f_2, ..., f_{E-1}. This rate matching process ensures that the data fits into the allocated transmission resources and is correctly received and decoded by the User Equipment.

(5) Scrambling:

The image illustrates the scrambling process, which is essential for ensuring data integrity and security.



configured in ControlResourceSet in RRC

$$n_{\mathrm{ID}} = N_{\mathrm{ID}}^{\mathrm{cell}} \text{ otherwise}$$

$$c_{\mathrm{init}} = \left(n_{\mathrm{RNTI}} \cdot 2^{16} + n_{\mathrm{ID}}\right) \bmod 2^{31}$$

$$x_1(n+31) = \left(x_1(n+3) + x_1(n)\right) \bmod 2$$

$$x_2(n+31) = \left(x_2(n+3) + x_2(n+2) + x_2(n+1) + x_2(n)\right) \bmod 2$$

$$c(n) = \left(x_1(n+N_C) + x_2(n+N_C)\right) \bmod 2$$

$$\tilde{b}^{(q)}(i) = \left(b^{(q)}(i) + c^{(q)}(i)\right) \bmod 2$$

The scrambling process uses an initialization sequence c_{init} that is derived from the RNTI (Radio Network Temporary Identifier) and an identifier n_{ID}.

For UE specific search spaces, n_{ID} is set to a value defined by the PDCCH-DMRS-Scrambling-ID if configured in ControlResourceSet in the RRC (Radio Resource Control) layer, which can range from 0 to 1023. Otherwise, n_{ID} equals N_{ID}^{cell}, the physical cell ID.

The initialization sequence is calculated as c_{init} = (RNTI * 2^{16} + n_{ID}) mod 2^{31}. Two sequences $x_1(n)$ and $x_2(n)$ are generated and used to produce the scrambling sequence c(n) through a defined polynomial relationship.

Finally, the data bits b(i) are scrambled with c(n) to produce the scrambled bits b~(i) = (b(i) + c(i)) mod 2. This scrambled sequence is more resistant to interference and unauthorized interception, enhancing the overall security and reliability of the communication.

(6) Modulation:

$\tilde{b}(0), \tilde{b}(1),,, \tilde{b}(M_{bit} - 1)$: Binary Sequence

QPSK : 2 bits → 1 symbol (complex number)

$d(0), d(1),,, d(M_{symb} - 1)$: Complex Number Sequence

The process starts with a binary sequence represented as b~(0), b~(1), ..., b~(M_{bit} - 1). This sequence undergoes Quadrature Phase Shift Keying (QPSK) modulation, which is a method that maps every two bits of the binary sequence to one symbol, represented as a complex number. Thus, two binary bits are converted into a single QPSK symbol.

After modulation, the sequence of binary bits is transformed into a sequence of complex numbers, d(0), d(1), ..., d(M_{symb} - 1), where each symbol in this new sequence corresponds to a pair of binary bits from the original sequence. The result of this modulation is a complex number sequence suitable for transmission over the radio frequency spectrum.

(7) Resource Element Mapping:

This is putting the ecoded and modulated PDCCH bits into each resource elements in NR resource grid.

The gNB should assume a block of complex-valued symbols d(0), ..., d(M_{symb} - 1) is to be scaled by a factor β_{PDCCH} and then mapped to resource elements $(k, l)_{p, u}$ that are designated for the monitored PDCCH and not used for the associated PDCCH DMRS. The mapping order should follow an increasing sequence of first k, then l. The specified antenna port for this operation is p = 2000.

The process can be described in step by step as follows:

- The gNB prepares a block of complex-valued symbols represented as d(0), d(1), ..., d(M_{symb} - 1).
- Each symbol in the block is scaled by a predefined factor, β_{PDCCH}.
- The scaled symbols are mapped onto resource elements, denoted as $(k, l)_{p,u}$, where k is the subcarrier index and l is the OFDM symbol index within a slot.

- This mapping follows an ascending order, first by subcarrier index k, then by OFDM symbol index l.
- It is ensured that the resource elements used for PDCCH do not overlap with those allocated for the associated PDCCH DMRS.
- The antenna port used for this operation is specified as p = 2000.

Through these steps, the gNB systematically assigns the PDCCH symbols to the appropriate resources on the frequency-time grid for effective transmission.