PBCH

Wednesday, August 7, 2024 2:20 PM

What is pbch?

In 5G, PBCH stands for Physical Broadcast Channel. It plays a crucial role in the 5G NR (New Radio) system.

The PBCH Transport Process encompasses a series of steps to prepare and transmit the Physical Broadcast Channel (PBCH) information. The PBCH is a key component in cellular communication networks, particularly in LTE and 5G systems. It serves as the primary channel through which a base station (eNodeB in LTE, gNodeB in 5G) transmits MIB to UEs.

The PBCH carries crucial information that a UE needs to decode other broadcast information and to establish a connection with the network.

- PBCH Transport Proces
  - (1) PBCH Payload Generation
  - (2) Scrambling
  - (3) CRC Attachment
  - (4) Channel Coding
  - (6) Scrambling
  - (7) Modulation
  - (8) Resource Element Mapping

- PBCH Transport Proces:

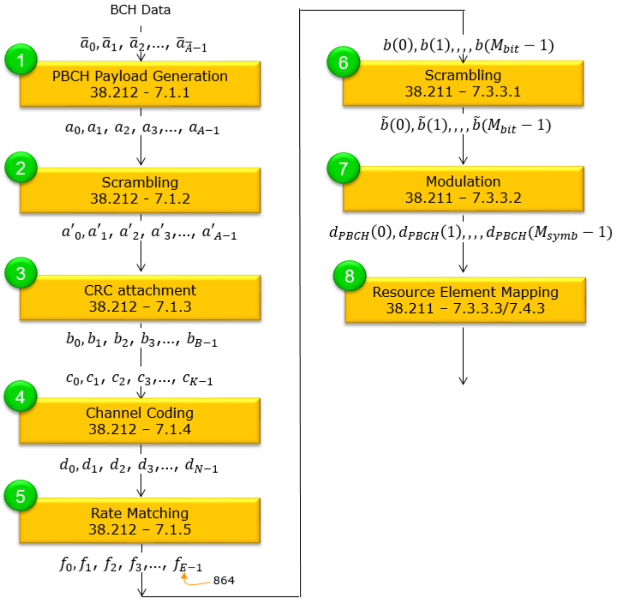


Diagram illustrates the PBCH Transport Process in a cellular communication system, detailing the sequence of steps involved in preparing and transmitting the PBCH from gNB to UE

I would not explain much in words for this process and I don't think I can make you understand the details of this process just by words.

The purpose of following description (illustrations) is to give you high level picture of the algorithm and let you know of what kind of lower layer, higher layer parameters are involved in each of the step.

PBCH Payload Generation: The broadcast channel (BCH) data is generated. This is the first step where the data that needs to be broadcasted is prepared.

Scrambling: The generated payload is scrambled. This step is crucial for mitigating interference and maintaining the integrity of the signal.

CRC Attachment: A Cyclic Redundancy Check (CRC) is attached to the scrambled data for error detection purposes.

Channel Coding: The data with the CRC is encoded to protect against potential errors during transmission.

Rate Matching: The encoded data is then processed through rate matching to ensure that it fits the available transmission resources.

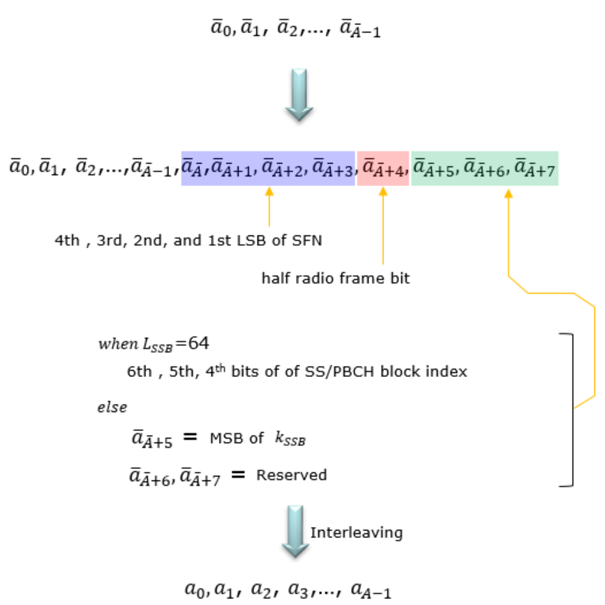
Scrambling: The rate-matched data undergoes a second scrambling process. This could be for additional security or interference mitigation.

Modulation: The scrambled data is then modulated, which means it is converted into a waveform suitable for transmission over the radio frequency spectrum.

Resource Element Mapping: Finally, the modulated data is mapped onto the resource elements in the frequency-time grid for actual transmission.

(1) PBCH Payload Generation:

The following illustration outlines the PBCH Payload Generation process, a crucial initial step in the PBCH Transport Process within cellular networks like 5G NR. This process is instrumental in creating the payload that will be transmitted over the Physical Broadcast Channel.



The BCH data sequence begins with bits labeled from ā0 to ā(A-1). This sequence is then augmented with additional bits that encode specific system information:

- The bits ā(A-1), ā(A+1), ā(A+2), and ā(A+3) correspond to the 4th, 3rd, 2nd, and 1st LSBs of the System Frame Number (SFN).
- The bit ā(A+4) denotes a half radio frame bit.
- When L_{SSB} equals 64, the bits ā(A+5), ā(A+6), and ā(A+7) are the 6th, 5th, and 4th bits of the SS/PBCH block index, respectively.
- If L_{SSB} is not equal to 64, then ā(A+5) is the MSB of KSSB, with ā(A+6) and ā(A+7) being reserved.

After these bits are inserted, an interleaving process is applied, reordering the sequence into a0 to a(A-1), which completes the payload generation phase ready for subsequent transmission steps.

(2) Scrambling:

The scrambling process for cellular communication data, which is a critical step in the PBCH Transport Process. The process begins with the generation of an initialization sequence cinit that is dependent on the cell ID NCELLID and the System Frame Number (SFN). The sequence is specifically generated at the start of each SFN where mod(SFN, 8) equals 0.

$c_{\text{init}} = N_{ID}^{cell}$ at the start of each SFN satisfying $\mathrm{mod}(SFN, 8) = 0$

$$x_1(n+31) = \left(x_1(n+3) + x_1(n)\right)\mathrm{mod}2$$

$$x_2(n+31) = \left(x_2(n+3) + x_2(n+2) + x_2(n+1) + x_2(n)\right)\mathrm{mod}2$$

$$c(n) = \left(x_1(n+N_C) + x_2(n+N_C)\right)\mathrm{mod}2$$

$$a'_i = \left(a_i + s_i\right)\mathrm{mod}2$$

$$s_i = c(j + vM)$$

$M = A - 3$ for $L = 4$ or $L = 8$
$M = A - 6$ for $L = 64$

38.212 - Table 7.1.2-1

(3rd LSB of SFN, 2nd LSB of SFN)	Value of v
(0, 0)	0
(0, 1)	1
(1, 0)	2
(1, 1)	3

The scrambling sequence c(n) is formulated using two sequences $x_1(n)$ and $x_2(n)$. These sequences are recursively updated using the relationships:

- $x_1(n+31) = (x_1(n+3) + x_1(n)) \bmod 2$
- $x_2(n+31) = (x_2(n+3) + x_2(n+2) + x_2(n+1) + x_2(n)) \bmod 2$

The data bit a_i is scrambled with the bit s_i from the scrambling sequence c(n), resulting in the scrambled bit $a'_i = (a_i + s_i) \bmod 2$.

The value of s_i is derived from the pseudo-random sequence generated by c(j + vM), where M is defined as A - 3 for L = 4 or L = 8, and A - 6 for L = 64.

The accompanying table maps the third and second LSB of the SFN to the value of v, which influences the pseudo-random sequence generation:

- For (0,0) and (1,1), v is 0.
- For (0,1) and (1,0), v is 1.
- For (1,0) and (0,1), v is 2.
- For (1,1) and (0,0), v is 3.

This scrambling ensures the transmitted signal's clarity, distinguishing it from noise and other signals for precise reception and decoding.

(3) CRC Attachment:

The CRC Attachment process, which is the third step in the PBCH Transport Process.

$$a'_0, a'_1, a'_2, a'_3, \dots, a'_{A-1}$$

$$\boxed{g_{CRC24}(D)}$$

$$a'_0, a'_1, a'_2, a'_3, \dots, a'_{A-1} \,||\, p_0, p_1, p_2, p_3, \dots, p_{L-1}$$

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$$b_0, b_1, b_2, b_3, \dots, b_{B-1}$$

A sequence of scrambled bits is represented as $a'_0, a'_1, a'_2, \dots, a'_{A-1}$. A CRC polynomial, represented as $G_{CRC24}(D)$, is applied to this data sequence, producing a set of CRC bits $p_0, p_1, p_2, \dots, p_{L-1}$, with L being the length of the CRC which is 24 bits.

These CRC bits are then appended to the original data sequence, resulting in an concatenated data string $a'_0, a'_1, a'_2, \dots, a'_{A-1} \mid p_0, p_1, p_2, \dots, p_{L-1}$. This appended sequence serves as a checksum for error detection at the receiver's end. The combined sequence, now including the CRC, is denoted as $b_0, b_1, b_2, \dots, b_{B-1}$.

The CRC attachment is essential for maintaining data integrity during transmission and is a common practice in digital communication systems for error detection and correction.

(4) Channel Coding:

The Channel Coding step, which is the fourth stage in the PBCH Transport Process.

$$c_0, c_1, c_2, c_3, \dots, c_{K-1}$$

$$\boxed{\text{Polar Coding}}$$

$n_{max} = 9$
$I_{IL} = 1$
$n_{PC} = 0$
$n_{PC}^{wm} = 0$

$$d_0, d_1, d_2, d_3, \ldots, d_{N-1}$$

1. It begins with a sequence of bits, represented as $c_0, c_1, c_2, \ldots, c_{K-1}$, which are then fed into a Polar Coding scheme.
2. Polar Coding transforms the original bits into a new set of coded bits that have properties making them more robust against errors over a noisy communication channel. Parameters such as $n_{max} = 9$, $I_L = 1$, $n_{pc} = 0$ and $n^{wm}_{pc} = 0$ are related to the specific configuration of the Polar Coding process.
3. The output from the Polar Coding block is a new sequence of coded bits $d_0, d_1, d_2, \ldots, d_{N-1}$, which are ready for the subsequent steps in the transmission process. This encoded sequence is designed to be more resilient to the effects of noise and interference when transmitted over the air interface.

(6) Scrambling:

The scrambling process which is step six in the PBCH Transport Process, essential for data preparation in cellular networks

$c_{init} = N_{ID}^{cell}$ at the start of each SS/PBCH block

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

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

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

$$\tilde{b}(i) = (b(i) + c(i + vM_{bit}))\bmod 2$$

- for $L_{max} = 4$, v is the two least significant bits of the SS/PBCH block index
- for $L_{max} = 8$ or $L_{max} = 64$, v is the three least significant bits of the SS/PBCH block index

NOTE : Lmax is the maximum number of SS/PBCH blocks in an SS/PBCH period. This value is determined by subcarrier spacing and frequency range. See this table to see the specific Lmax value for each cases.

It begins with the initialization of the sequence c_{init} based on the cell's N_{ID}^{cell} at the start of each SS/PBCH block.

Two sequences, $x_1(n)$ and $x_2(n)$, are used to generate the scrambling sequence c(n). These sequences are updated for each n using a linear feedback shift register, with updates performed as follows:

- $x_1(n+31) = (x_1(n+3) + x_1(n)) \bmod 2$
- $x_2(n+31) = (x_2(n+3) + x_2(n+2) + x_2(n+1) + x_2(n)) \bmod 2$

The data bits $\tilde{b}(i)$ are scrambled by XORing with the bits from the sequence $c(i + vM_{bit})$, where M_{bit} is a variable that depends on the length L_{max} of the SS/PBCH block index:

- For $L_{max} = 4$, v is the two least significant bits of the SS/PBCH block index.
- For $L_{max} = 8$ or $L_{max} = 64$, v is the three least significant bits of the SS/PBCH block index.

This step is crucial to ensure that the transmitted signal is robust against interference, enabling accurate decoding by the receiver.

(7) Modulation:

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

QPSK : 2 bits → 1 symbol (complex number)

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

The process starts with a binary sequence $\tilde{b}(0), \tilde{b}(1), \ldots, \tilde{b}(M_{bit} - 1)$. This binary sequence is then modulated using QPSK, which maps every two bits of the binary sequence to one complex number symbol, thereby creating a complex number sequence $d_{PBCH}(0), d_{PBCH}(1), \ldots, d_{PBCH}(M_{symb} - 1)$.

QPSK is a type of modulation that is particularly efficient in terms of spectrum usage because it transmits two bits per symbol, which is represented as a complex number. After modulation, the data is represented in a format suitable for transmission over a radio frequency channel, with the sequence now prepared to be mapped onto the resource elements of the carrier frequency.

(8) Resource Element Mapping:

1. **Resource Grid:**
   - The resource grid is a time-frequency matrix where each cell represents a Resource Element (RE).
   - Each RE is defined by a specific subcarrier (frequency domain) and an OFDM symbol (time domain).
   1. **PBCH Mapping:**
      - PBCH data is mapped onto specific REs within the resource grid.
      - This mapping is done within the SS/PBCH block, which consists of 4 OFDM symbols and a certain number of subcarriers, typically 240 subcarriers for 30 kHz subcarrier spacing.
      - The PBCH occupies the same four OFDM symbols as the SS block.
      1. **OFDM Symbols:**
         - The SS/PBCH block consists of four OFDM symbols, and PBCH data is interleaved with the Synchronization Signals (PSS and SSS).
         1. **Subcarriers:**
            - In the frequency domain, PBCH data is spread across 48 subcarriers within the SS/PBCH block.

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+-------------------------------+
| SS    | PBCH  | PBCH  | SS    |   <- 48 Subcarriers (Frequency Domain)
+-------------------------------+
| PBCH  | PBCH  | PBCH  | PBCH  |
+-------------------------------+
| PBCH  | PBCH  | PBCH  | PBCH  |
+-------------------------------+
| SS    | PBCH  | PBCH  | SS    |
+-------------------------------+
  ^       ^       ^       ^
  |       |       |       |
OFDM Symbol 1  Symbol 2  Symbol 3  Symbol 4
```

- "SS" represents the synchronization signals (PSS and SSS).
- "PBCH" represents the Resource Elements carrying PBCH data.