Hardware Emulations

using 5G Toolkit and SDRs: Hands-on

GIGAYASA

For academia only

Contributors:

Editor:	Simulator Design Team, GIGAYASA
Contributing Authors:	Aman Mishra, Vijaya Mareedu and Vikram Singh, GIGAYASA

Grants and Funding

Gigayasa is supported by:

- Indian Institute of Technology, Madras Incubation Center (IITM-IC).
- Startup India.
- Department of Telecommunication (DoT), India.
- Center of Excellence in Wireless Technology (CEWiT), IITM.
- Ministry of Electronics and Information Technology (MEITy), India.

Contents

1 | Implementation of PBCH Chain in 5G Networks

The Physical Broadcast Channel (PBCH) carries the Master Information Block (MIB). The MIB contains essential information for downlink synchronization of user equipment, such as cell identity, system bandwidth, and configurations of other channels. In this experiment, the complete implementation of the PBCH chain is discussed in detail.

1.1 | What is PBCH Chain?

PBCH chain encompasses a series of steps to prepare, transmit and receive the PBCH information. The PBCH chain consists of: PBCH encoder(processed at base station), PBCH decoder(processed at user equipment).

Table 1.1: Content of master information block (MIB)

–	Parameter	Data-type	Range of Values
MIB	Choice bit	bool	$\{0, 1\}$
	Subcarrier spacing common (Δf)	enum	$\{15\_or\_120\text{kHz}, 30\_or\_240\text{kHz}\}$
	DMRS-Type-A Position	enum	{DMRS-Type-A, DMRS-Type-B}
	PDCCH-Config-SIB1:CORESET-0	int	$\{0, 1, \ldots, 15\}$
	PDCCH-Config-SIB1:SearchSpace-0	int	$\{0, 1, \ldots, 15\}$
	Cell barred	bool	$\{0, 1\}$
	Intra-frequency reselection	bool	$\{0, 1\}$
	Spare bit	bool	0
MIB/ATI	System frame number (SFN)	int	$\{0, 1, \ldots, 1023\}$
	SSB-subcarrier offset (k_{SSB})	int	$\{1, 23\}$ for FR-1 ($f_c <$ 6GHz)
			$\{0, 11\}$ for FR-2 ($f_c >$ 6GHz)
ATI	Half radio frame bit (n_{HRF})	bool	$\{0, 1\}$
	SSB-PBCH index (L_{SSB})	int	$\{0, 3\}$ for FR-1 ($f_c <$ 2GHz)
			$\{0, 7\}$ for FR-1 ($2 < f_c$(GHz) < 6)
			$\{0, 63\}$ for FR-2 ($f_c >$ 6GHz)

1.2 | Design of PBCH Chain

1.2.1 | PBCH Chain: Transmitter

The PBCH encoder is shown in figure 1.1 below.
PBCH processing at base station is explained below:

- **PBCH payload generation**: This is the first stage of processing at base-station wherein payload data intended for broadcast is prepared. The size of PBCH payload generation is 32 bits.
- **PBCH Interleaver**: The objective of PBCH interleaver is to achieve time diversity. The interleaver disperses bits to minimize effect of burst error. The size of output of interleaver is 32 bits.
- 1^{st} **Scrambling**: The purpose of scrambler is to break long sequence of 0's and 1's. Scrambling is achieved by ex-oring the input sequence with scrambling sequence. The length of scrambling sequence and input sequence both are 32 bits, which produces a 32 bits scrambled sequence.
- **CRC addition**: 24 bits of CRC bits are added to the scrambled payload to enable error detection at user-equipment. The size of payload along with CRC bits are 56 bits.

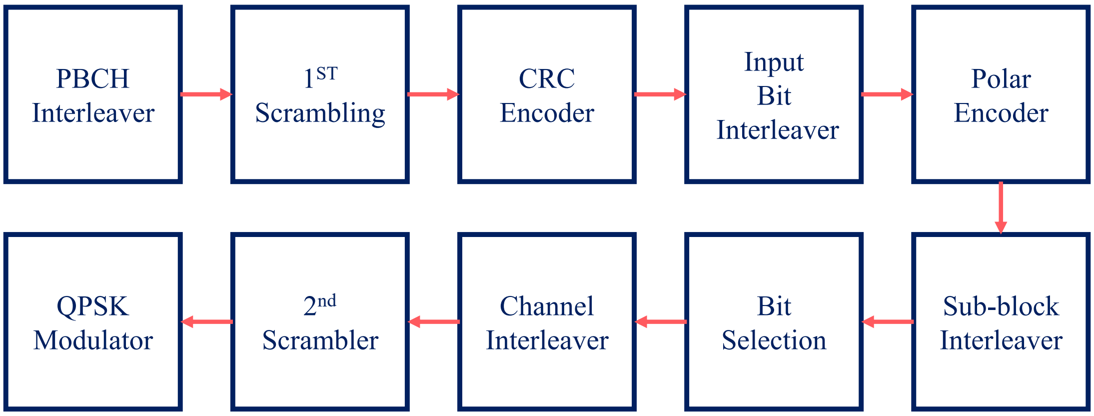

Figure 1.1: PBCH chain: Transmitter

- **Input bit Interleaver**: Bit interleaver is a crucial component used in the physical layer to enhance the reliability of data transmission over the air interface. The purpose of the bit interleaver is to disperse consecutive bits of information across time and frequency domains, thereby mitigating the effects of burst errors and improving the system's ability to recover from transmission impairments like fading, noise, and interference. The size at output of bit interleaver is 56 bits.
- **Polar Encoder**: Polar coding is forward error correction (FEC) technique used to improve the reliability of data transmission over the wireless channel. The polar coded adds the redundant bits to information bits. The output of polar coder has 512 bits.
- **Rate Matching**: Rate matching primarily has two functions, control the code rate (redundancy) and enable hybrid-ARQ. The output size of rate matching is such that it is equal to numbers of available resources. The output size of rate matching is 864 bits.
- **Scrambling**: Scrambling breaks the long sequence of consecutive 1's or/and 0's. The output of rate matching is ex-ored with the scrambling sequence of same length. The output size remains 864 bits.
- **QPSK modulator**: Upon QPSK modulation, which has modulation order of 2, the 864 bits converts into 432 symbols.
- **DMRS generator and resource mapping**: The PBCH DMRS sequence are generated and mapped on the resource grid.

1.2.2 | PBCH Chain: Receiver

The PBCH decoder is shown in figure 1.2 below.

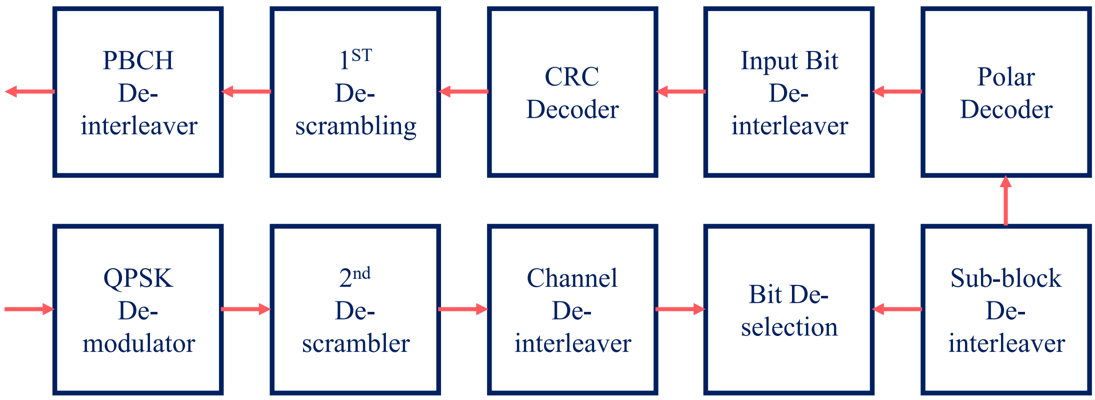

Figure 1.2: PBCH chain: Receiver

PBCH processing at user equipment is explained below:

- **Estimate SSB grid**: Upon receiving samples from base-station SDR, time synchronization is performed by detecting PSS, followed by CFO estimation and OFDM demodulation. Upon OFDM demodulation the SSB grid is extracted.
- **Channel Estimation**: Upon extracting the SSB, the channel across PBCH is estimated using PBCH DMRS. The **ChannelEstimationAndEqualization** class has two parameters 'estimatorType' and 'interpolatorType'. 'estimatorType' specifies the channel estimation technique used, for SSB only Zero-Forcing (ZF) is employed. 'interpolatorType' specifies channel interpolation type used, for SSB 'nearest neighbour' interpolator is used. Channel is estimated using relation:

$$\hat{H} = Y/X \tag{1.1}$$

- **Equalization**: Transmitted symbols is retrieved using:

$$\hat{X} = Y/\hat{H} \tag{1.2}$$

  Equalization return 432 QPSK modulated symbols.
- **QPSK De-modulator**: The QPSK demodulator is used to demodulate the PBCH and extract its content the MIB information. The demodulation converts 432 QPSK modulated symbols into 864 bits.
- **De-Srambling**: The demodulated bits are ex-ored with the scrambling sequence. This step is done to nullify the effect of scrambling. The size of de-scrambling output remains 864 bits.
- **Rate De-matching**: The rate de-matching reverses the effect of rate matcher. The size of de-matching output is 512 bits.
- **Polar Decoder**: Polar decoder removes the redundant bits added at the base station. The redundant bits added at base station are removed to obtain 56 bits at the output of polar decoder.
- **Input bit de-interleaver**: The bit de-interleaver is the counterpart of a bit interleaver. While a bit interleaver rearranges bits in a specific pattern before transmission to mitigate burst errors, a bit de-interleaver is used at the receiving end to revert the rearranged bits back to their original order. The size of output remains 56 bits.
- **CRC Decoder**: At this step, the CRC bits of 24 bits is checked for any presence of error. These 24 bits CRC bits are removed to obtain 32 bits at the output.
- 1^{st} **De-srambling**: The 32 bits from CRC decoder is ex-ored with scrambling sequence of 32 bits to reverse the effect of 1^{st} scrambling at the base station.
- **PBCH De-interleaver**:Another de-interleaving operation is performed. The output size remains 32 bits.
- **Decoded PBCH payload**: Finally, the PBCH payload of 32 bits is obtained.

1.3 | Results

The general simulation parameters are given below,

Table 1.2: General simulation parameters.

Name of parameter	Value
center frequency/carrier frequency	1000 MHz
Bandwidth	5 MHz
FFT size	1024
subcarrier spacing	15 KHz
Transmitter-receiver separation	1 m

The above parameters holds for every results unless otherwise specified.

Observation:1- To verify whether Master Information Block(MIB) parameters at transmitter and receiver are same.
The PBCH contains Master Information Block(MIB), which contains necessary information (*SystemFrameNumber, subCarrierSpacingCommon, ssb-SubCarrierOffset, etc.*) for initial cell selection procedure. Firstly, UE needs to successfully detect the SSB, detect and decode PBCH. The contents of MIB should be matched at both transmitter(base-station) and receiver(user-equipment) end to ensure successful receipt of MIB.
The MIB parameters at transmitter(base station) is shown in figure 1.3 below.

```
pbchObject.mib.displayParameters(0)

Carrier Frequency:       1000000000.0
ChoiceBit:               1
nSsbCandidatesInHrf:     4
subCarrierSpacingCommon:30000
DMRSTypeAPosition:       typeB
controlResourceSet0:     5
searchSpace0:            13
cellBarred:              notBarred
intraFreqReselection:    notAllowed
systemFrameNumber:       315
ssbSubCarrierOffset:     0
HRFBit:                  1
iSSBindex:               0
```

Figure 1.3: MIB parameters: Transmitter

After successful detection of SSB, detection and decoding of PBCH, the MIB is extracted as shown in figure 1.4.

```
pbchDecoder.mibRx.displayParameters(0)

Carrier Frequency:       1000000000.0
ChoiceBit:               1
nSsbCandidatesInHrf:     4
subCarrierSpacingCommon:30000
DMRSTypeAPosition:       typeB
controlResourceSet0:     5
searchSpace0:            13
cellBarred:              notBarred
intraFreqReselection:    notAllowed
systemFrameNumber:       315
ssbSubCarrierOffset:     0
HRFBit:                  1
iSSBindex:               0
```

Figure 1.4: MIB parameters: Receiver

Observation:2- The distance between transmitter and receiver are dynamic in nature. It becomes important to determine the impact of distance between the transmitter and receiver SDRs on detection and decoding of PBCH (which contains the MIB information).

Table 1.3: MIB decoding at UE

Transmitter-Receiver distance	Whether MIB information is decoded correctly at UE
10 cm	Yes
50 cm	Yes
1 m	Yes

From table 1.3, it is clearly observed that for distances 10 cm, 50 cm and 1 m the MIB information is decoded correctly at UE.

2 | References