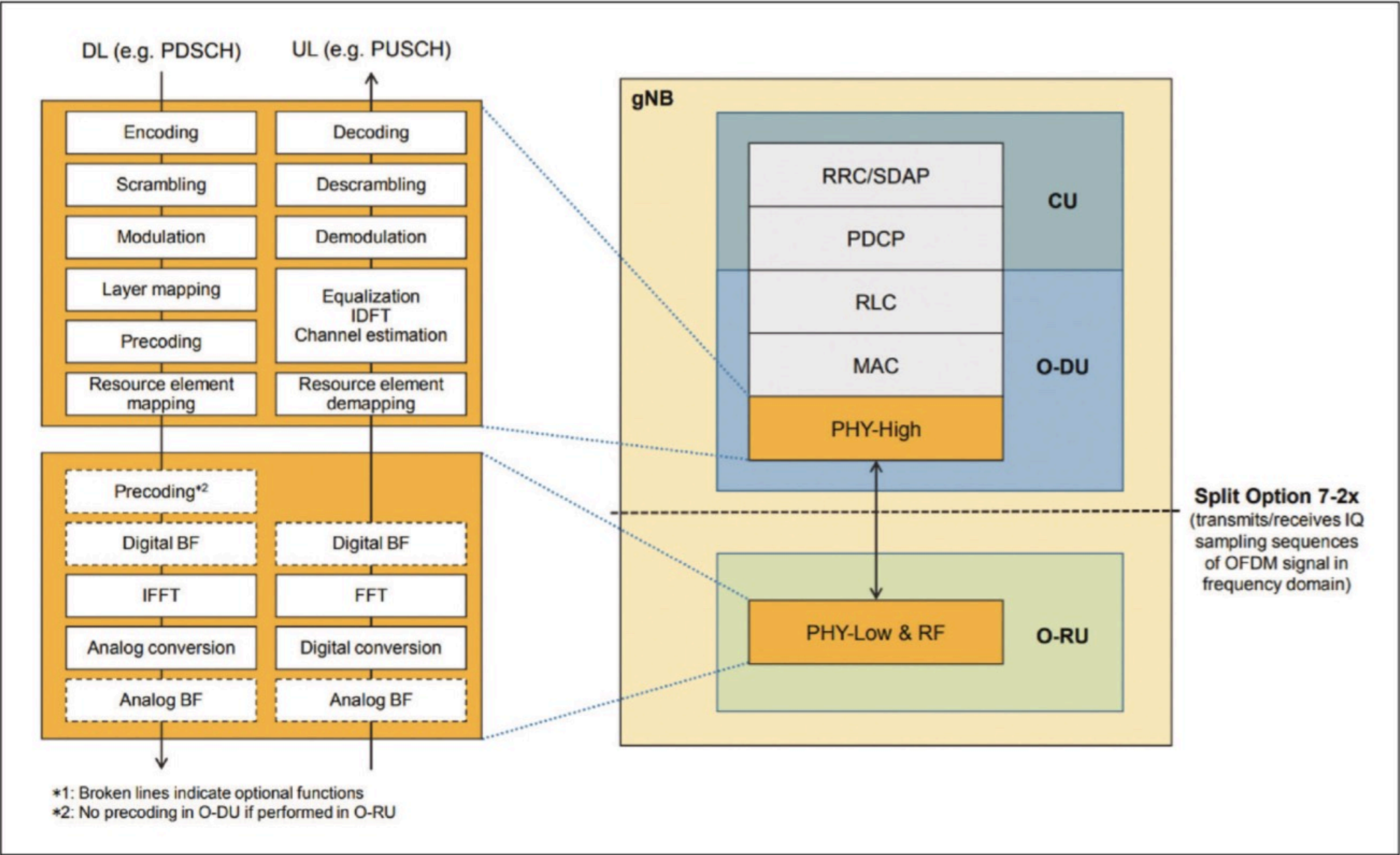


gNB Transceiver System Diagram

OAI (Directory)	(Layer)	function
openair1	Layer 1 (PHY)	signal Encoding 、 modulation 、 transmission
openair2	Layer 2 (Data Link) MAC, RLC, PDCP, SDAP	Radio resource management, scheduling
openair3	Layer 3 (Network) RRC	Connection control communication with the core network



gNB v.s. UE

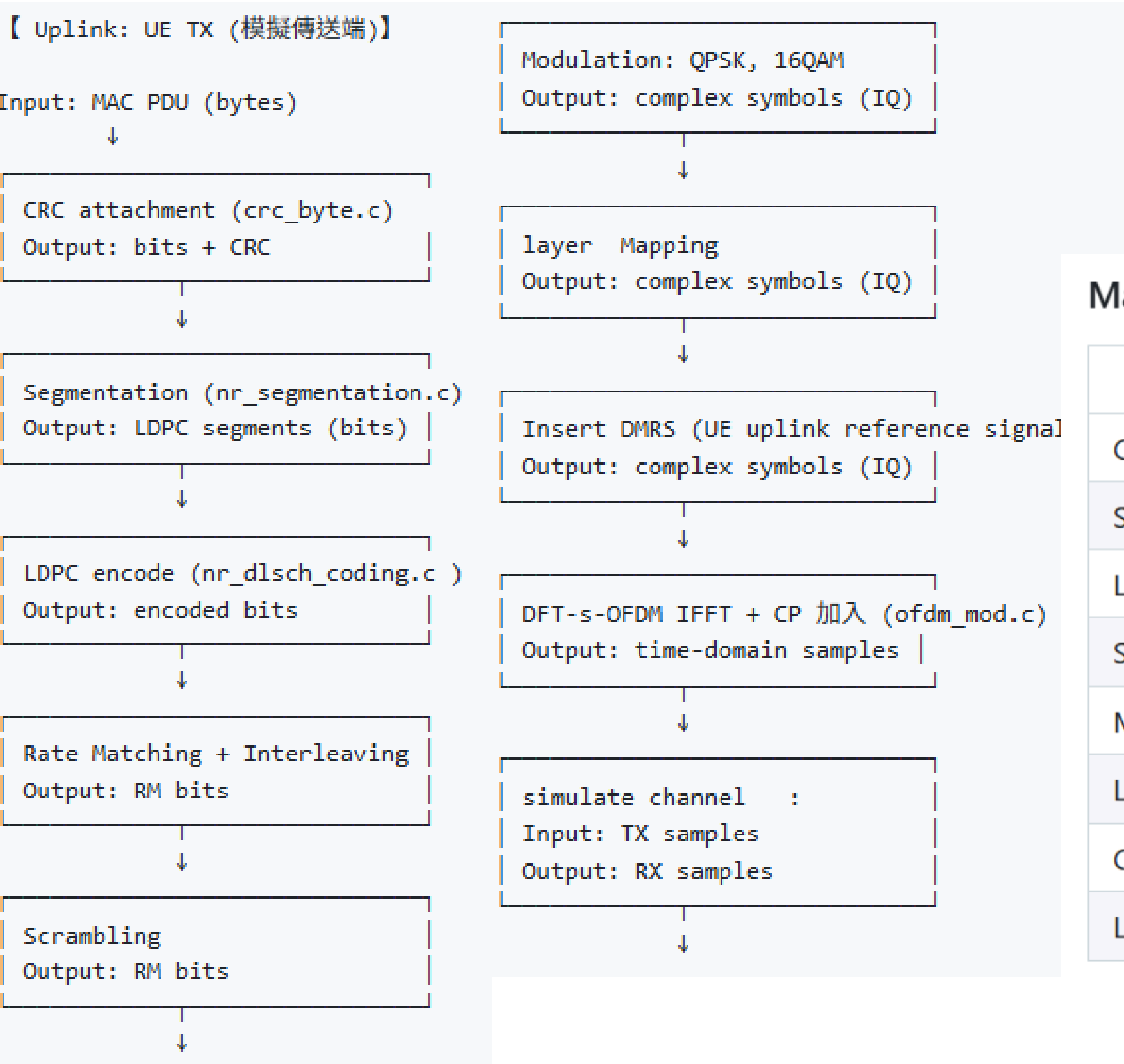
	gNB	UE
Role	Manages downlink (DL) transmission and receives uplink (UL) transmission. Controls scheduling and resource allocation.	Receives DL transmission and sends UL transmission. Provides feedback (e.g., CSI) to gNB.
Transmission Direction	Downlink: Uses MIMO, beamforming, or diversity based on CSI feedback.	Uplink: Transmits via PUSCH, supports single-antenna or low-order MIMO (e.g., 2x2). Follows gNB scheduling grants.
Scheduling & Control	Dynamically schedules resources based on UE' s CSI, BSR, and CQI. Supports flexible FDD/TDD and carrier aggregation.	Follows gNB' s scheduling instructions. Provides feedback (CQI, PMI, RI) for DL optimization.

Their transmission processes are similar, the difference lies in hardware and the RS.

As the master control device on the network side, gNB is mainly responsible for sending downlink RS (such as SSB, CSI-RS) and configuring RS parameters,

while UE mainly receives these RS and sends uplink RS (such as SRS, DM-RS) to provide feedback or support uplink transmission.

UE in UPLINK Tx



Mapping to 3GPP specifications and OAI functions

Function	3GPP Spec Section	OAI Function
CRC attachment	38.212 §5.1	crc24a() 、crc24b().....
Segmentation	38.212 §5.2	nr_segmentation()
LDPC encoding	38.212 §5.2	LDPCencoder(), nr_ulsch_encoding()
Scrambling	38.211 §6.3.1.1	nr_pusch_codeword_scrambling()
Modulation	38.211 §6.3.2	nr_modulation()
Layer Mapping	38.211 §6.3.1.2	nr_ue_layer_mapping
Channel Estimation	38.211 §6.4.1.1.2 (DMRS)	nr_pbch_channel_estimation()
LLR Calculate	38.212 attachment A	nr_dlsch_qpsk_llr() , nr_dlsch_16qam_llr() ...

PHY/CODING/ nrLDPC_coding/crc_byte.c

- TS 38.212 | 5.1
- Declare multiple crc functions, such as crc24a(), crc24b()...

PHY/CODING/nr_segmentation.c

- TS 38.212 | 5.2.2
- Divide the data into segments and send to LDPC ENCODER for processing

Functions definition in PHY/CODING/coding_defs.h

PHY/CODING/nrLDPC_coding/nrLDPC_coding_segment/nr_rate_matching.h

- Declare nr_interleaving_ldpc() 、 nr_rate_matching_ldpc()

PHY/CODING/nrLDPC_coding/nrLDPC_coding_segment/nr_rate_matching.c

- TS 38.212 | 5.3.2 PUSCH/PDSCH LDPC Interleaving
- TS 38.212 | 5.4 PUSCH/PDSCH rate matching

PHY/CODING/ nrLDPC_coding/nrLDPC_coding_segment

- nrLDPC_coding_encoder
 - └─ nrLDPC_launch_TB_encoding
 - └─ ldpc8blocks
- nrLDPC_coding_encoder : Performs LDPC encoding for all Transport Blocks (TBs) in a slot and writes the encoded output to the corresponding buffer.
- nrLDPC_launch_TB_encoding : Controls the LDPC encoding task flow for a complete Transport Block (TB), creating and dispatching thread tasks to ldpc8blocks() to process every 8 segments.
- ldpc8blocks() : Handles up to 8 LDPC segments in a single thread.
 - Processes all Transport Blocks (TBs) in a slot according to 5G NR standards:
 - LDPC Encoding: LDPCencoder(c, d, impp)
 - Rate Matching: nr_rate_matching_ldpc()
 - Bit Interleaving: nr_interleaving_ldpc()
 - Output Result
 - Each task processes 8 segments.

PHY/CODING/ nrLDPC_encoder

ldpc_encoder.c

Main controller of the LDPC encoding process.

LDPCencoder()

Follow TS 38.212 5.2.2 for LDPC Encoding

PHY/MODULATION/

<code>modulation_UE.h</code>	Defines core function interfaces for modulation/demodulation front-end processing at the UE physical layer
<code>modulation_eNB.h</code>	Defines key function interfaces related to modulation and beamforming at the base station physical layer
<code>nr_modulation.c</code>	Handles modulation, layer mapping, DFT (Discrete Fourier Transform), and precoding

TS 38.211 I5.1 : MODULATION method (QPSK、16QAM、64QAM、256QAM、1024QAM)

TS 38.211 I 6.3.1.3 Layer Mapping (Uplink)

TS 38.211 I 6.3.1.4 Transform Precoding (DFT-spread OFDM)

TS 38.211 I 6.3.1.5 Precoding for PUSCH (Uplink)

```
void nr_modulation(const uint32_t *in,
                  uint32_t length,
                  uint16_t mod_order,
                  int16_t *out);

void nr_ue_layer_mapping(const c16_t *mod_syms, const int n_layers, const int n_syms, c16_t tx_layers[][n_syms]);

c16_t nr_layer_precoder(int sz, c16_t datatx_F_precoding[][sz], const char *prec_matrix, uint8_t n_layers, int32_t re_offset);
```


OPENAIR1/PHY/

Subfolder	Function	Notes
NR_TRANSPORT/	5G NR gNB Transport	
NR_UE_TRANSPORT/	UE Transport functions	
NR_REFSIG/	NR reference signal module	Includes DMRS, PTRS, PRACH, SSB waveform generation and insertion
MODULATION/	OFDM IFFT/FFT, MODULATION, MAPPING	
TOOLS/	Channel estimation, vector ops, FFT tools, phase noise	
INIT/	Layer 1 variable initialization	Called in <code>phy_init_nr_ue()</code>
CODING/	LDPC, Polar ENCODING/DECODING, CRC, SEGMENT	
defs.h , extern.h , vars.h	Global definitions and variable references	Shared across modules, depends on these three files

PHY/NR_UE_TRANSPORT/ (Uplink)

MAIN FUNCTION :

nr_ulsch_coding.c	Implements ULSCH encoding: CRC, segmentation, LDPC encode, rate matching
nr_ulsch_ue.c	Handles UE ULSCH PHY procedures (encoding, modulation, etc.)

Where functions are stored :

nr_transport_proto_ue.h	Declares functions related to DL SCH, UL SCH, PUCCH, PBCH, PRACH, PSBCH in PHY.
-------------------------	---

eg.

```
void nr_pusch_codeword_scrambling(uint8_t *in,
                                   uint32_t size,
                                   uint32_t Nid,
                                   uint32_t n_RNTI,
                                   bool uci_on_pusch,
                                   uint32_t* out);

int nr_ulsch_encoding(PHY_VARS_NR_UE *ue,
                     NR_UE_ULSCH_t *ulsch,
                     const uint32_t frame,
                     const uint8_t slot,
                     unsigned int *G,
                     int nb_ulsch,
                     uint8_t *ULSCH_ids);

void nr_ue_ulsch_procedures(PHY_VARS_NR_UE *UE,
                            const uint32_t frame,
                            const uint8_t slot,
                            nr_phy_data_tx_t *phy_data,
                            c16_t **txdataF,
                            bool was_symbol_used[NR_NUMBER_OF_SYMBOLS_PER_SLOT]);
```


Reference Signal in tx & rx

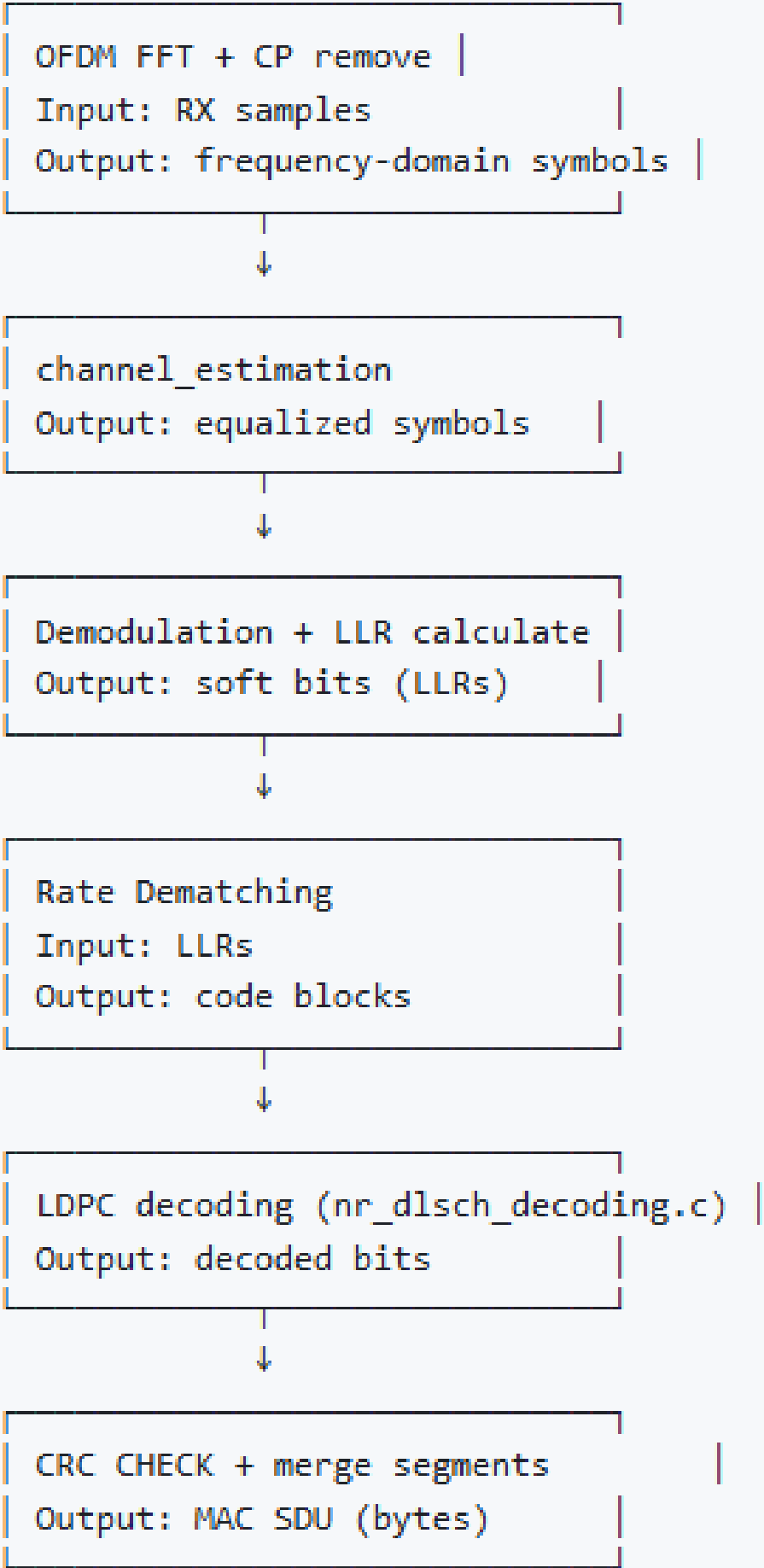
Reference Signal	Function	gNB	UE	Key Differences
SSB(Synchronization Signal Block)	Cell search, time/frequency synchronization, initial beam selection, MIB delivery.	Broadcasts SSB (PSS, SSS, PBCH) with beam sweeping for DL coverage.	Detects SSB for cell ID, synchronization, beam selection, and initial access.	SSB is only sent by gNB; UE only receives and processes.
CSI-RS(Channel State Information Reference Signal)	Cell search, time/frequency synchronization, initial beam selection, MIB delivery.	Sends CSI-RS (periodic/semi-persistent/aperiodic) for UE to measure channel state and beams.	Receives CSI-RS, measures channel state, and reports CSI (CQI, PMI, RI).	CSI-RS is sent by gNB; UE only receives and measures.
SRS(Sounding Reference Signal)	UL channel estimation, DL channel estimation (TDD reciprocity), beam management.	Receives SRS to estimate UL channel and configure UL/DL transmission (TDD). Configures SRS parameters.	Sends SRS (periodic/semi-persistent/aperiodic) for gNB channel estimation and beam management.	SRS is sent by UE; gNB only receives and processes.
DM-RS(Demodulation Reference Signal)	Channel estimation for PDSCH/PUSCH, PDCCH/PUCCH demodulation, MIMO support.	Sends DM-RS for DL PDSCH/PDCCH; receives DM-RS for UL PUSCH/PUCCH. Configures DM-RS parameters.	Receives DM-RS for DL demodulation; sends DM-RS for UL PUSCH/PUCCH.	Both send/receive DM-RS, but gNB supports complex configurations; UE is limited.

PHY/NR_UE_TRANSPORT/ (RS)

TS 38.211 7.4.2.2	pss_nr.c	Detect PSS (Primary Synchronization Signal, time sync)
TS 38.211 7.4.2.3	sss_nr.c	Detect SSS (Secondary Synchronization Signal) and decode
TS 38.212 6.3.1	pucch_nr.c	Handles UCI (e.g., SR, HARQ-ACK, CSI)
	pucch_nr.h	Defines UE-side PUCH-related data structures and functions for UCI transmission
TS 38.211 6.4.1.4	srs_modulation_nr.c	Implements SRS generation and processing at UE side
	srs_modulation_nr.h	Defines UE-side SRS-related data structures and functions

```
static void nr_uci_encoding(uint64_t payload,          int ue_srs_procedures_nr(PHY_VARS_NR_UE *ue,
    uint8_t nr_bit,                                const UE_nr_rxtx_proc_t *proc,
    int fmt,                                       c16_t **txdataF,
    uint8_t is_pi_over_2_bpsk_enabled,           nr_phy_data_tx_t *phy_data,
    uint8_t nrofSymbols,                         bool was_symbol_used[NR_NUMBER_OF_SYMBOLS_PER_SLOT])
    uint8_t nrofPRB,
    uint8_t n_SF_PUCCH_s,
    uint8_t intraSlotFrequencyHopping,
    uint8_t add_dmrs,
    uint64_t *b,
    uint16_t *M_bit) {
```

UE in DOWNLINK RX



UE DOWNLINK

Function	Specification	OAI Function / File
Channel Estimation	TS 38.211 §7.4.1.1 (DM-RS)	nr_pbch_channel_estimation.c nr_pdsch_channel_estimation.c
Demodulation + LLR calculate	TS 38.211 §7.3.1.4 (modulation) TS 38.212 §7.1.4 (LLR calculate)	nr_dlsch_llr_computation.c nr_qpsk_llr.c , nr_qam16_llr.c
Rate Dematching	TS 38.212 §5.4.1 (DL)	nr_rate_matching_ldpc.c nr_dlsch_decoding.c
LDPC decoding	TS 38.212 §5.3.2	nrLDPC_decoder.c ldpc_decode.c called in nr_dlsch_decoding.c
CRC check + merge Segments	TS 38.212 §5.1 (CRC) §5.2.2 (Code block segmentation merge)	crc_byte.c , check_crc.c Merged inside nr_dlsch_decoding.c

PHY/NR_UE_TRANSPORT/nr_dlsch_demodulation.c

```
nr_rx_pdsch()  
|  
├─ nr_dlsch_channel_level()          ← Executed only for the first symbol of the entire PDSCH, calculates the average channel :  
|  
├─ nr_dlsch_channel_compensation()  ← Equalization core: Multiplies frequency-domain symbols by the channel conjugate + calcul.  
|                                   Output is rxdataF_comp[]: Compensated frequency-domain data for subsequent processing.  
|  
├─ nr_dlsch_detection_mrc()         ← If MRC is used, performs multi-antenna combining (non-spatial multiplexing).  
|  
├─ Modulation LLR Calculation: Calls based on modulation type  
|   ├─ nr_dlsch_qpsk_llr()  
|   ├─ nr_dlsch_qam16_llr()  
|   └─ nr_dlsch_qam64_llr()  
|   (Calculates soft-decision LLRs for the transport layer buffer based on modulation type: QPSK, 16QAM, 64QAM, or 256QAM.)  
└─ LLR Output → Softbuffer → LDPC Decoding
```

PHY/NR_UE_TRANSPORT/nr_dlsch_decoding.c

- Including UNSCRAMBLING
- main function: nr_dlsch_decoding

gNB Rx VS UE RX

(Pipeline Step)	UE Rx (Downlink)	gNB Rx (Uplink)	Sensing
1. convert to frequency domain	FFT + CP Removal	FFT + CP Removal	same
2. Reference Signal (RS)	receive DL DMRS (demodulation) receive CSI-RS (channel estimate)	receive UL DMRS (demodulation) receive SRS (channel estimate)	different
3. channel estimating	nr_pdsch_channel_estimation	nr_ulsch_channel_estimation	same
4. Equalization	Channel Compensation	Channel Compensation	same
5. Decoding	LDPC Decoder (PDSCH)	LDPC Decoder (PUSCH)	same LDPC, different config