5G UE Prototyping based on OpenAirInterface

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Nokia Bell Labs Murray Hill New Jersey

5G NR vs LTE: physical Layer

- Support of scalable waveforms
- Up to 100MHz system bandwidth for FR1
- Scalable numerology from 15kHz to 480 kHz

SCS [KHz]	15	30	60	120	240	480
BW [MHz]	20	40	80	160	320	640
OFDM Symb duration [us]	71.3	35.7	17.8	8.9	4.5	2.2

- Channel coding: LDPC and Polar codes
- Beam management

At least 5 times more stringent real-time requirement

5G NR vs LTE: synchronization signals

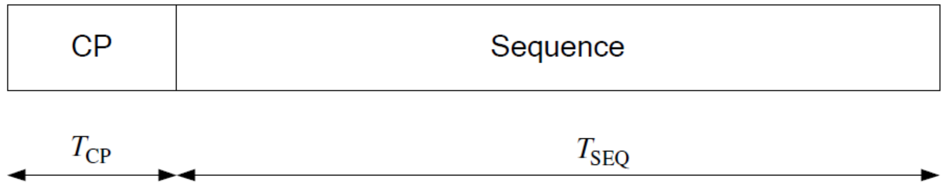
- Support more cell IDs than LTE
- Improve robustness of PSS w.r.t. frequency offsets
- Enable complete time-frequency synchronization and cell ID identification within one half-frame
- SS periodicity configurable per UE
- Different SS/PBCH blocks are associated with different beams

	LTE	NR
# CIDs	504	1008
SS length (SCs)	62	127
# PSS	3	
PSS	ZC with 3 roots	PN with 3 shifts
# SSS	168	336
SSS	PN	Longer PN
CID	3*SSS + PSS	

support beam-sweeping requirements

5G NR vs LTE: PRACH

- LTE PRACH is supported length 839

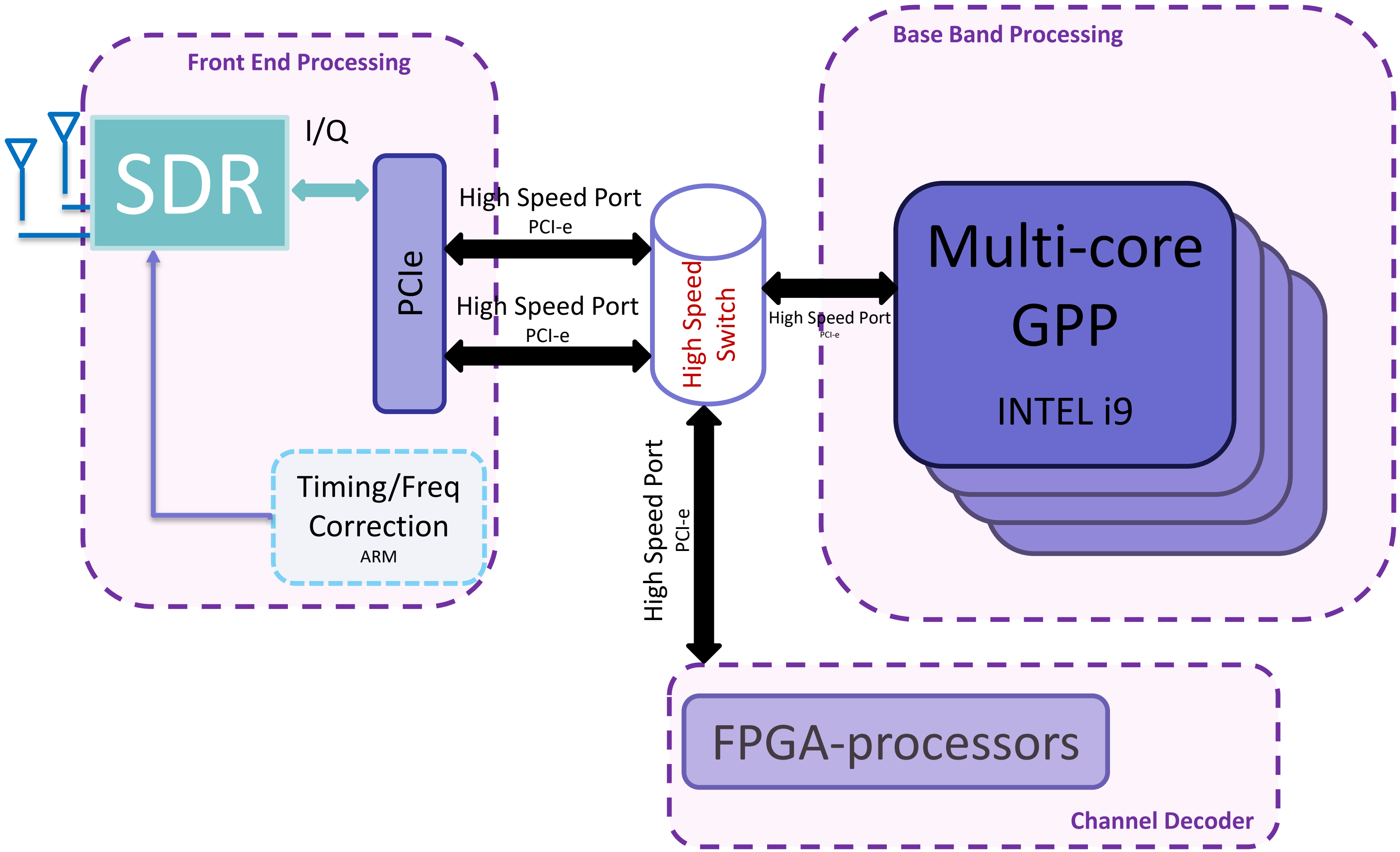


Format	L_{RA}	Δf^{RA}	N_u	N_{CP}^{RA}	Support for restricted sets
0	839	1.25 kHz	24576κ	3168κ	Type A, Type B
1	839	1.25 kHz	$2 \cdot 24576\kappa$	21024κ	Type A, Type B
2	839	1.25 kHz	$4 \cdot 24576\kappa$	4688κ	Type A, Type B
3	839	5 kHz	$4 \cdot 6144\kappa$	3168κ	Type A, Type B

- Additional restricted set TYPE B is introduced
- New PRACH option 1 is introduced with sequence length of 139

Format	L_{RA}	Δf^{RA}	N_u	N_{CP}^{RA}	Support for restricted sets
A1	139	$15 \cdot 2^{\mu}$ kHz	$2 \cdot 2048\kappa \cdot 2^{-\mu}$	$288\kappa \cdot 2^{-\mu}$	-
A2	139	$15 \cdot 2^{\mu}$ kHz	$4 \cdot 2048\kappa \cdot 2^{-\mu}$	$576\kappa \cdot 2^{-\mu}$	-
A3	139	$15 \cdot 2^{\mu}$ kHz	$6 \cdot 2048\kappa \cdot 2^{-\mu}$	$864\kappa \cdot 2^{-\mu}$	-
B1	139	$15 \cdot 2^{\mu}$ kHz	$2 \cdot 2048\kappa \cdot 2^{-\mu}$	$216\kappa \cdot 2^{-\mu}$	-
B2	139	$15 \cdot 2^{\mu}$ kHz	$4 \cdot 2048\kappa \cdot 2^{-\mu}$	$360\kappa \cdot 2^{-\mu}$	-
B3	139	$15 \cdot 2^{\mu}$ kHz	$6 \cdot 2048\kappa \cdot 2^{-\mu}$	$504\kappa \cdot 2^{-\mu}$	-
B4	139	$15 \cdot 2^{\mu}$ kHz	$12 \cdot 2048\kappa \cdot 2^{-\mu}$	$936\kappa \cdot 2^{-\mu}$	-
C0	139	$15 \cdot 2^{\mu}$ kHz	$2048\kappa \cdot 2^{-\mu}$	$1240\kappa \cdot 2^{-\mu}$	-
C2	139	$15 \cdot 2^{\mu}$ kHz	$4 \cdot 2048\kappa \cdot 2^{-\mu}$	$2048\kappa \cdot 2^{-\mu}$	

5G UE Architecture



(*) Offload channel decoder is optional

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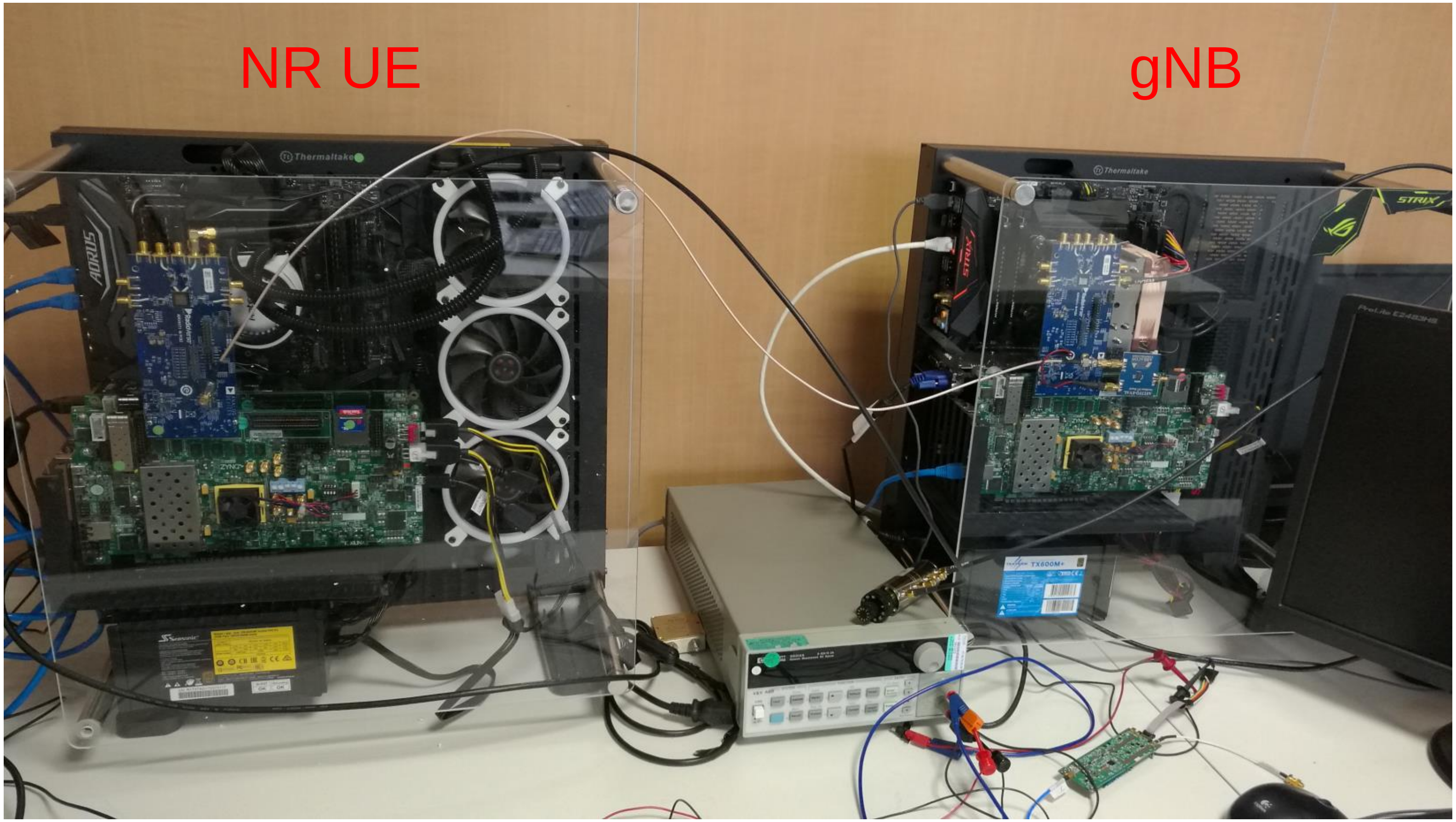
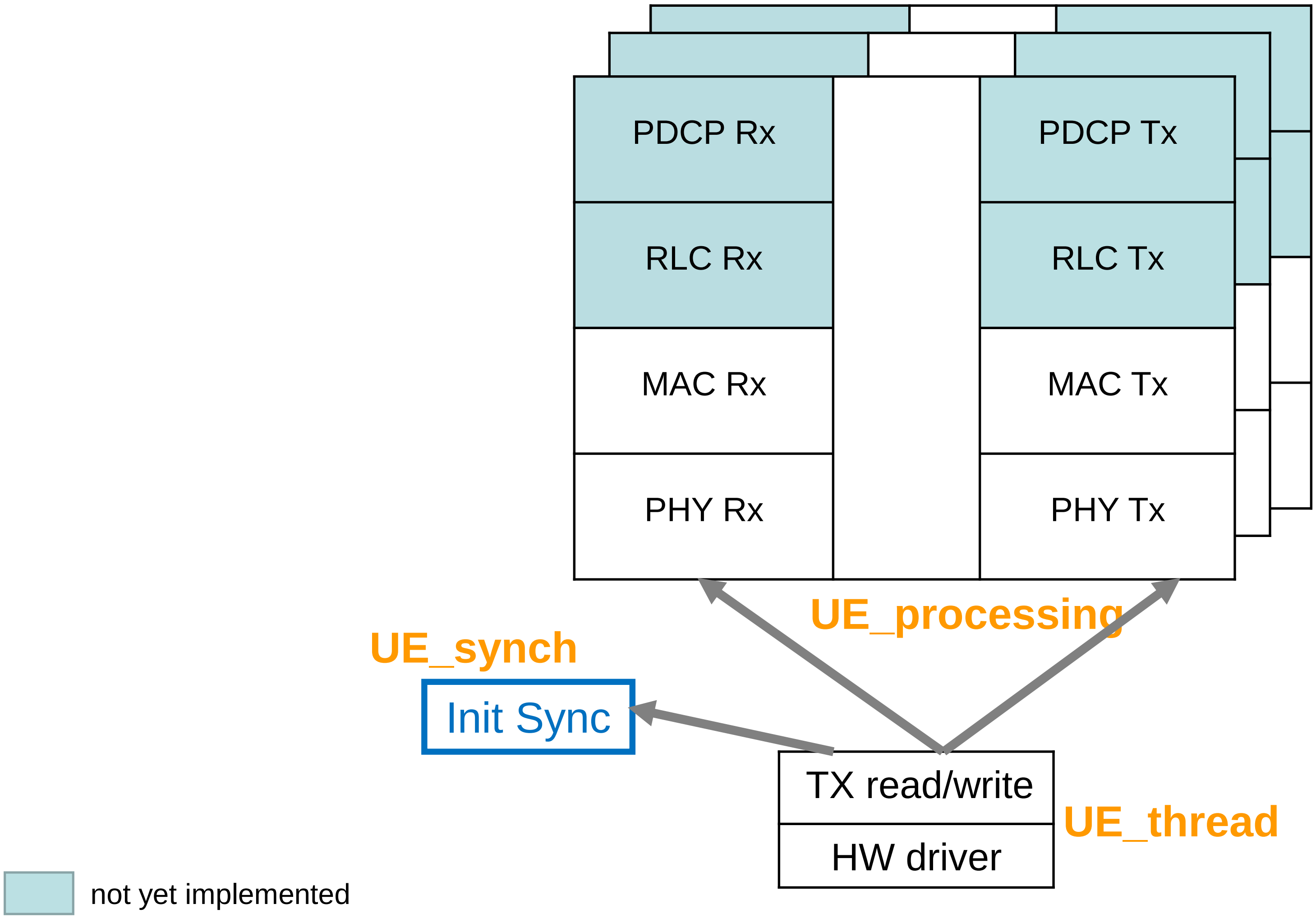
5G NR Platform



NR UE: Intel Core i9 7980EX (18 cores)
gNB : Intel Core i7 6900K (8 cores)
SDR : Xilinx EVALUATION KIT ZYNQ-7000 ZC706 + ADRV9371
https://gitlab.eurecom.fr/oai/openairinterface5g/wikis/5g-nr-development-and-releases

NR UE threading structure(1)



Branch: https://gitlab.eurecom.fr/oai/openairinterface5g/tree/develop-nr

UE Threading architecture(2)

- UE multi-threading is introduced to control the processing delay
- Three Parallelized threads can be running on physical layer
  - Each RX/TX Thread for one slots processing
  - Each Thread “UE_processing” is responsible of :
    - downlink slot decoding (#Slot N)
    - uplink slot encoding (#Slot N+4, flexible in NR)
- Four Cores are fully used for the whole PHY processing
  - Core 0: Samples Acquisition
  - Core 1-3: Processing of one Slot
- Number of threads is flexible to adapt different time constraint

	slot N+1	slot N+2	slot N+3	slot N+4	slot N+5	slot N+6	
core 0	I/Q Acquisition Subframe N+1	I/Q Acquisition Subframe N+2	I/Q Acquisition Subframe N+3	I/Q Acquisition Subframe N+4	I/Q Acquisition Subframe N+5	I/Q Acquisition Subframe N+6	I/Q Acqu
core 1	Phy Processing	Channel Decoding	UL	Phy Processing	Channel Decoding	UL	P
core 2		Phy Processing	Channel Decoding	UL	Phy Processing	Channel Decoding	
core 3			Phy Processing	Channel Decoding	UL	Phy Processing	Channel

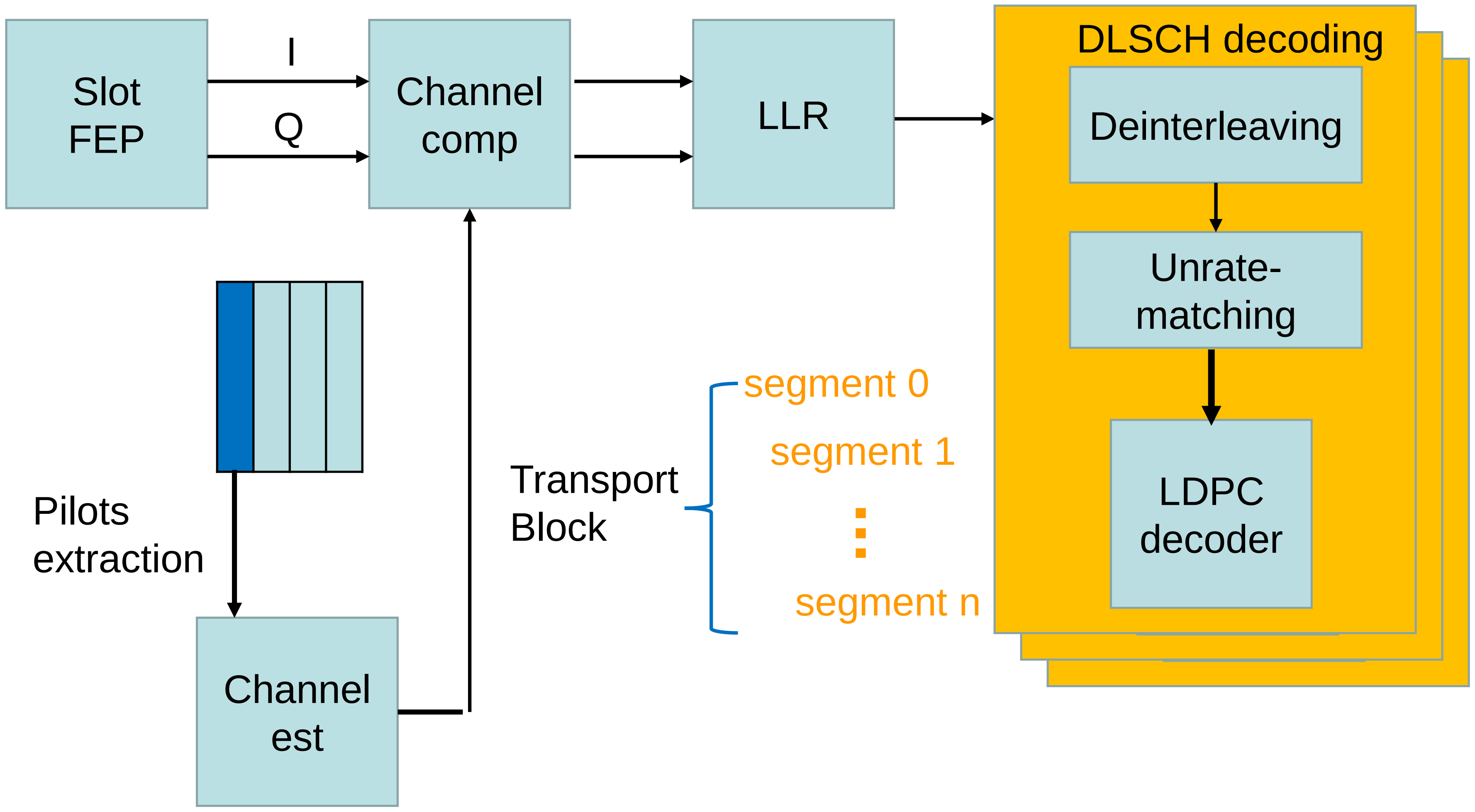
Timing Measurement

Single core slot processing

	100MHz SCS30KHz @4GHz clock 100 PRB MCS 25 SISO
PDCCH slot_fep + channel est	12 us
PDCCH Decoding	38 us
PDSCH slot_fep + channel est	70 us
PDSCH procedure	350 us
DLSCH decoding	450 us
Sum	920 us

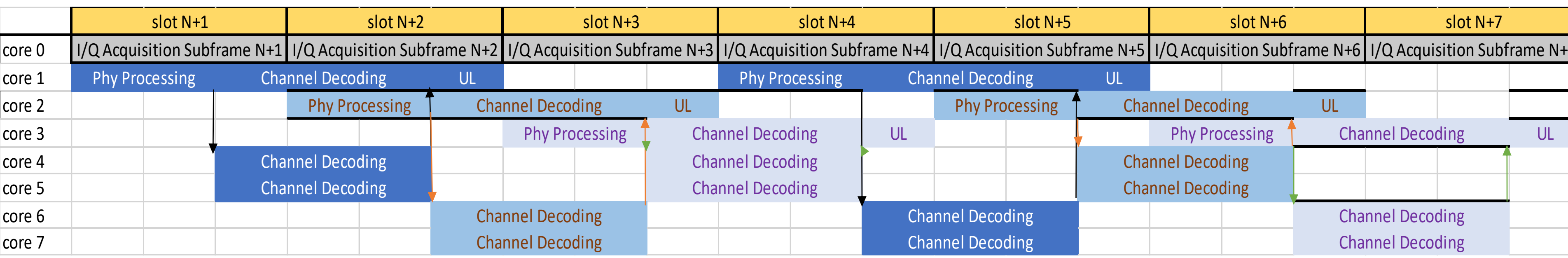
- 3 UE threads in parallel, timing budget 3x500us = 1.5ms
- TBS 65576 MCS25 PRB 100 -> ~130Mbps
- DLSCH Decoding takes around 50 % of full downlink processing
- TBS 131176 MCS25 PRB 200 estimated processing time ~1.8ms -> ~260Mbps
  need 4 UE threads if UL can be scheduled in N+5

DLSCH Threading structure(1)



DLSCH Threading structure(2)

- UE DLSCH multi-threading is used when transport block has more than 1 segment
- First segment is performed in the main ue_processing thread
- Two more DLSCH threads are running in parallel in this example
- Each DLSCH thread is responsible of one segment decoding of transport block
- Number of threads is flexible for different transport block size



Multiple channel decoding threads for higher throughput

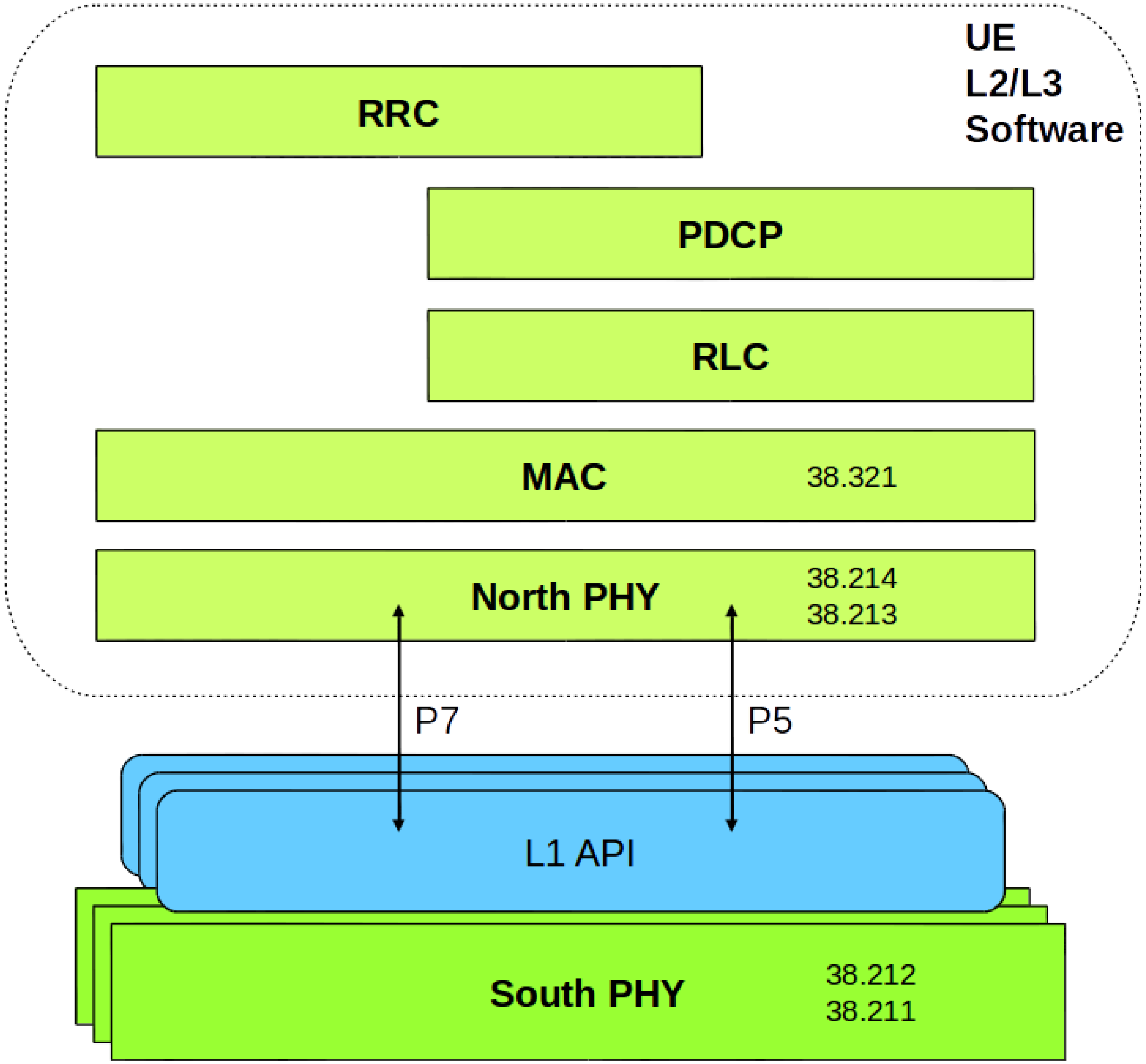
Timing Measurement

Multi-threads DLSCH and offloading LDPC

BW 100MHz SCS60Khz @4GHz clock SISO	100 PRB MCS 25 Multi-threads DLSCH (estimated)	100 PRB MCS 25 Offloading LPDC (estimated)
PDCCH slot_fep + channel est	12 us	12 us
PDCCH Decoding	38 us	38 us
PDSCH slot_fep + channel est	70 us	70 us
PDSCH procedure	350 us	350 us
DLSCH decoding	258 us	250 us
Sum	728 us	720 us
Throughput	260Mbps	260Mbps

- 3 UE threads for slot processing time budget 3*250us = 750us
- 8 DLSCH decoding threads for 8 segments running in parallel
- Multi-threads DLSCH decoding can achieve similar performance to offloading LDPC

UE FAPI interface



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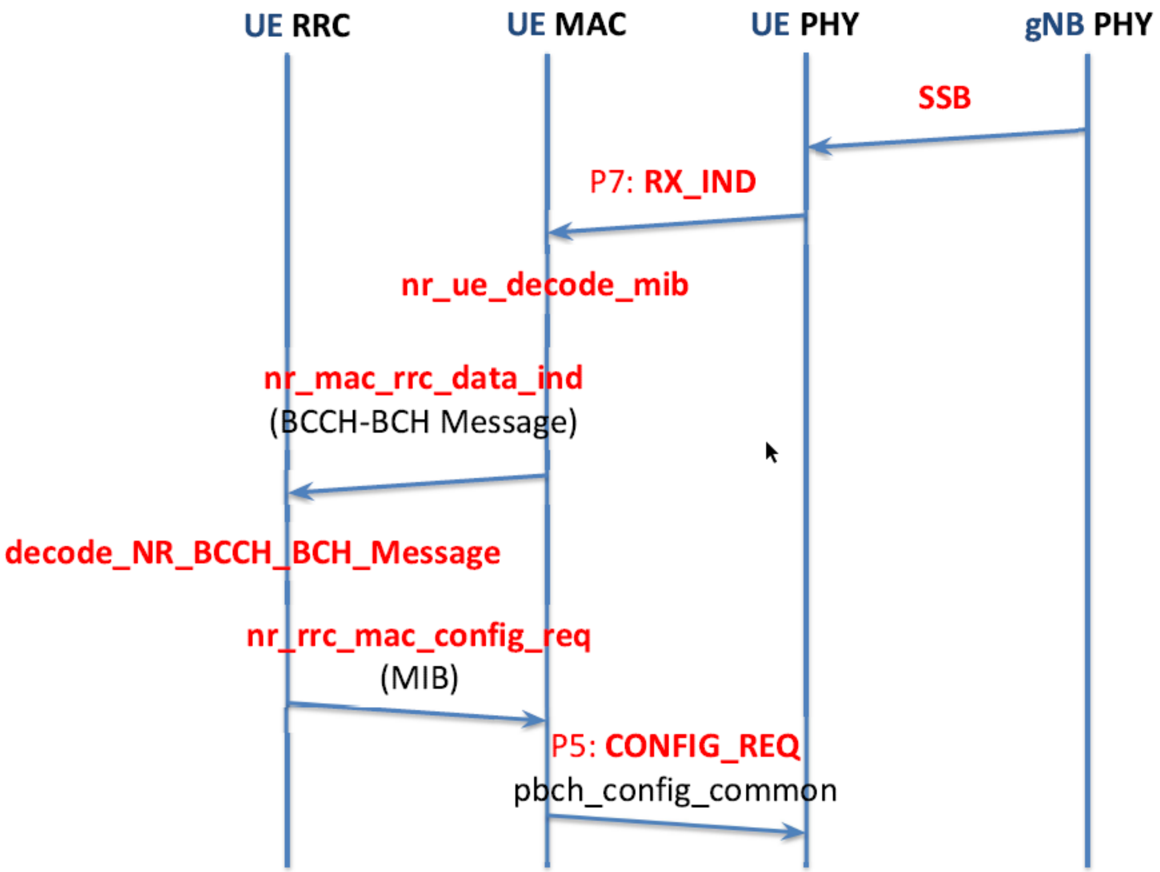
MIB reception



https://trello.com/c/CaC9BvfU/52-ue-fapi

OAI 5G UE development status (1)

Items	Sub Items	Status
Cell search	PSS/SSS	PSS/SSS sequence is mapped to 127 subcarriers Center frequency is aligned with PBCH
	PBCH	PBCH TTI: 80 ms , SCS 30KHz PBCH channel coding scheme: Polar Code
NR PRACH	wo beam sweeping	All format supported Zadoff-Chu based sequence Two preamble lengths supported
Numerology	40 and 80 MHz BW	done
Framing	slot-based	done
	minislot	not supported
Duplex	slot level TDD	Static configuration
NR PDSCH	DM-RS	configuration type 1 PDSCH mapping type A (front loaded) Single symbol DMRS
	PT-RS	not supported
	segmentation and rate-matching and interleaving for LDPC	segmentation done rate-matching and interleaving done LDPC BG1 and BG2 supported
	Channel estimation and compensation	Done

OAI 5G UE development status (2)

Items	Sub Items	Status
NR PDCCH	DCI	Type0-PDCCH common search space/CORESET Format 0_0 and 0_1 for the scheduling of PUSCH Format 1_0 and 1_1 for the scheduling of PDSCH
	DMRS	Done
	segmentation and rate-matching for Polar code	Done
HARQ		dynamic grant on PDCCH Asynchronous HARQ uplink
NR SRS		periodic mode, 1 antenna port 1 symbol duration No SRS-CarrierSwitching
NR PUCCH	UCI	ALL format supported CSI, ACK/NACK, Scheduling Request (SR) code block group CBG=OFF Type2-HARQ-ACK codebook = dynamic
NR PUSCH	LDPC for Transport Block	Done (Fraunhofer)
2 layers MIMO	IA decoder	Done

3 people working on OAI NR UE development at TCL in the past 2 years

NR UE SW roadmap

- real-time performance tests on 40MHz 80MHz SISO (ongoing)
- TDD semi static config
- Algos for OTA (AGC, freq tracking)
- 3.5GHz OTA test
- PUCCH validation with gNB (ongoing with Eurecom and IISc)
- PRACH validation with gNB (ongoing with Eurecom and IISc)
- RAR procedure
- 2 layers MIMO validation on simulation with gNB
- 2 layers MIMO real-time optimization and performance tests
- Periodic SRS validation with gNB

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