5G-NR Unlicensed with OAI

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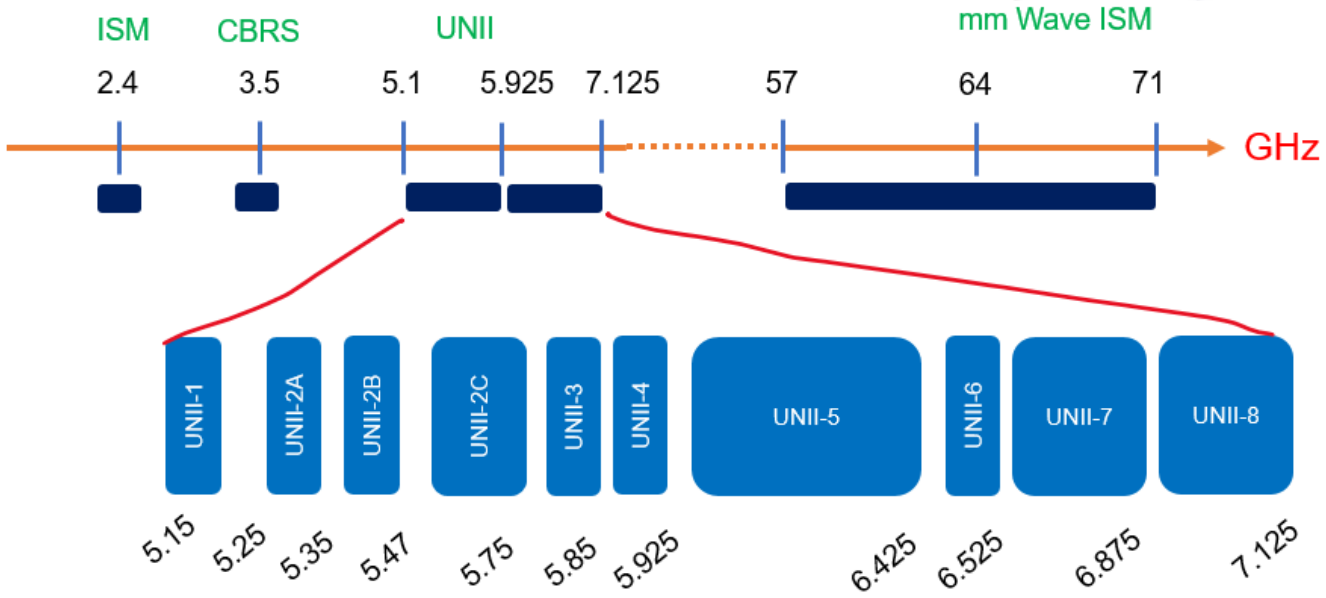
Why 5G Unlicensed?

- 5G capabilities over unlicensed spectrum
- No licensing effort or cost, sometimes no other option
  - But strict usage constraint, and regional differences
  - Limited by contention => Low contention environments
    - Factories, campuses
- 5G capabilities after channel acquisition
  - End-to-end QoS (5QI)
    - Per-flow scheduling from the 5G Core to the air interface
  - Network-controlled mobility
    - RRC-managed inter-cell handovers, not client-side roaming
  - Multi-connectivity
    - PDCP packet duplication for high reliability
  - 3GPP industrial features
    - URLLC, TSN integration, network slicing, AAA
  - Licensed/ shared anchor integration
    - Control plane on licensed spectrum, added capacity on unlicensed

Some Background

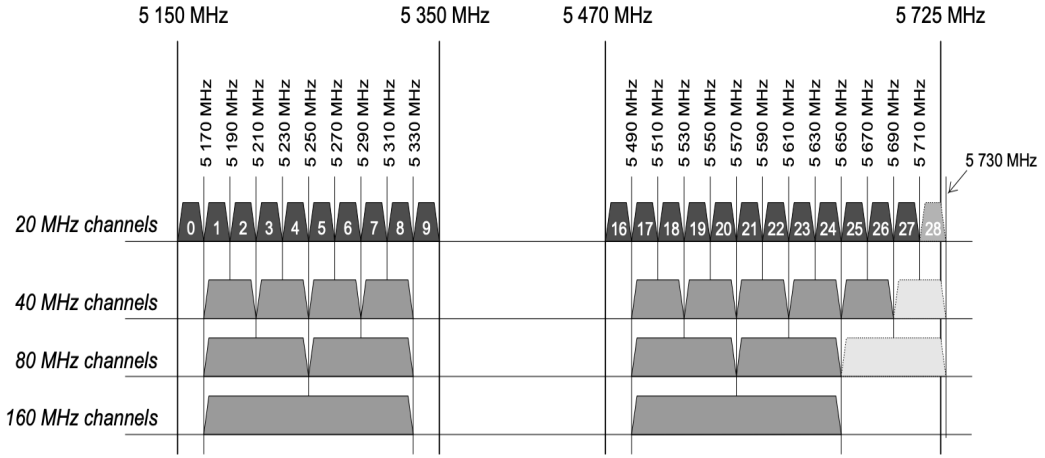
The Unlicensed Spectrum



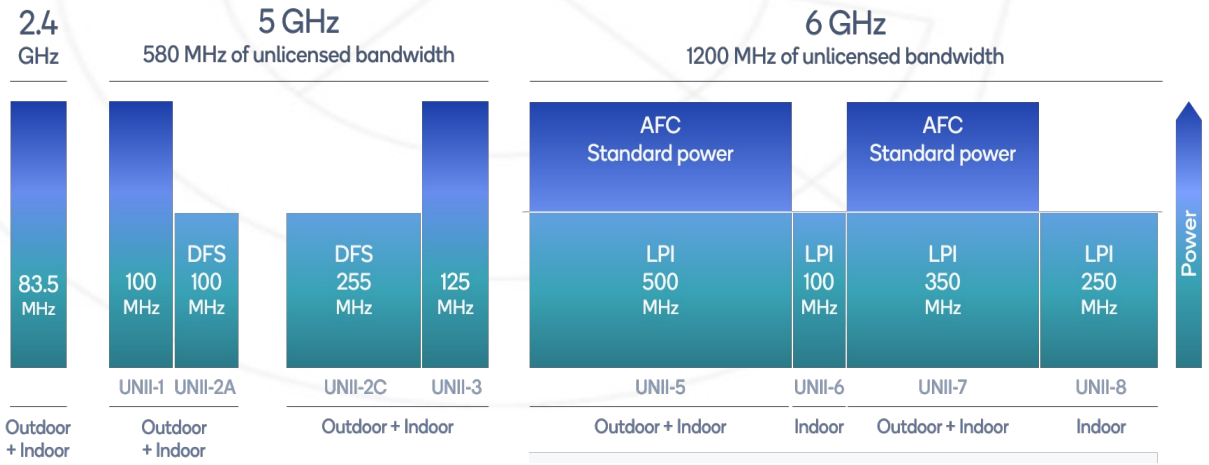
5G NR-U Frequency Bands. Source: Techplayon.

The Unlicensed Spectrum in

Europe



US



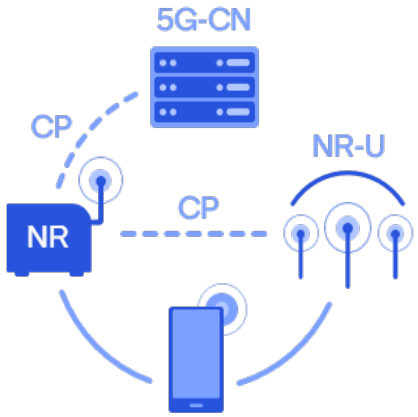
United States · FCC allocation.

5G NR-U: Anchored vs Standalone

Extend 5G capacity by combining licensed with unlicensed spectrum

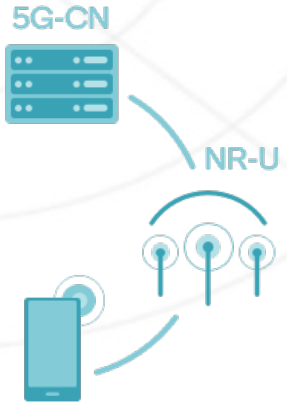
Deliver 5G capabilities over unlicensed spectrum without licensed anchors

Anchored NR-U



Scenario B
Carrier aggregation
NR with 5G-CN and NR-U

Standalone NR-U

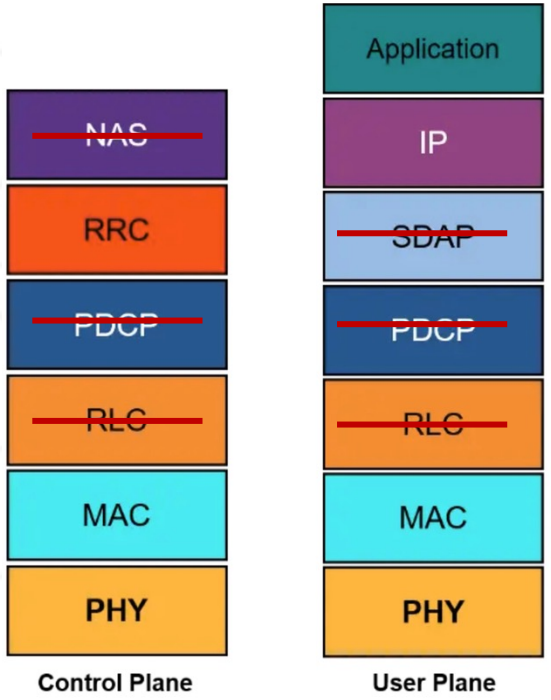


Scenario C
Standalone
NR-U with 5G-CN

Image Source: Qualcomm

NR-U in 3GPP Release 16

- Normative NR specs where NR-U behavior lives (Rel-16+):
  - TS 37.213: Physical layer procedures, including channel access for unlicensed bands
  - TS 38.321: MAC procedures
  - TS 38.331: RRC messages and parameters to configure NR-U behavior



Source: ShareTechnote

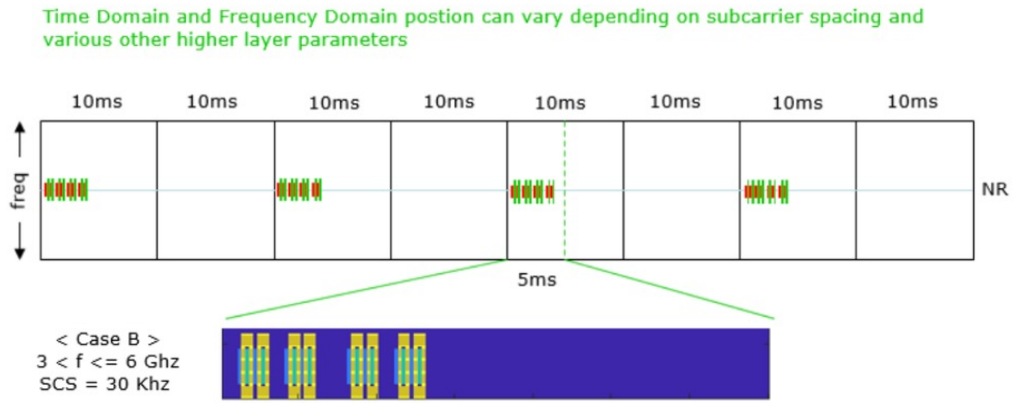
Physical Layer - TS 37.213

Sensing Slot	9 µs unit; the channel is idle if energy stays below the detection threshold for at least 4 µs
Type 1 access	random backoff with an adaptive contention window (Cat 1–4), to acquire the channel
Type 2 access	fixed short sensing (25 µs or 16 µs) or none, to continue inside an occupancy
Occupancy (MCOT)	held up to the Maximum Channel Occupancy Time (≈ 2–8 ms by class), then released; shareable gNB ↔ UE
Energy threshold	not fixed; adapts to bandwidth, transmit power and band

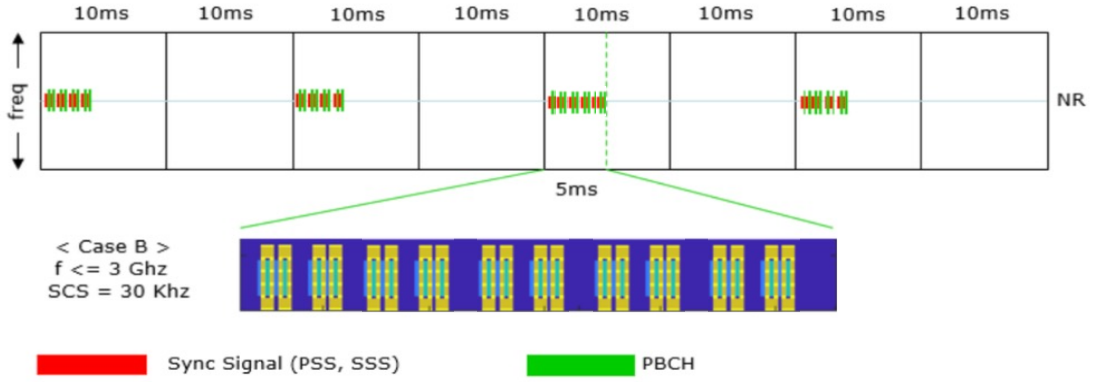
Physical Layer - TS 37.213

- Increase the Synchronization Signal Block (SSB) candidate slots per half-frame

5G



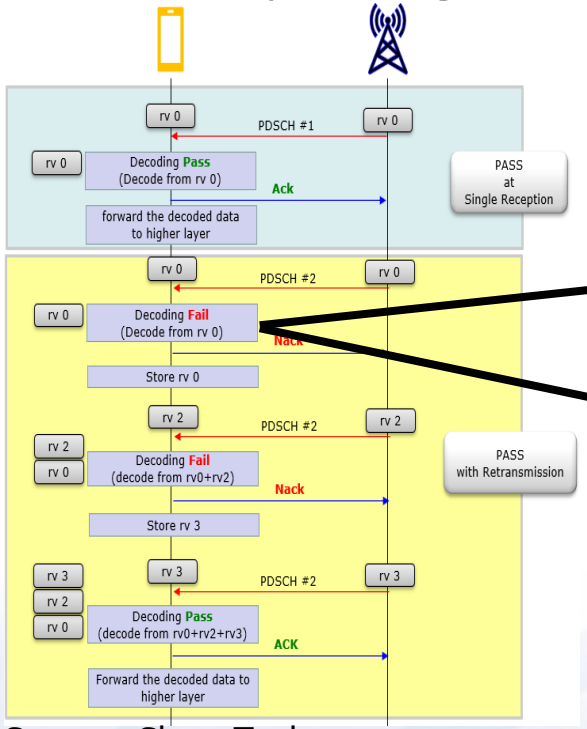
5G NR-U



- Only measure the energy of the resource blocks that are actually used for transmission
- Do not measure the energy of the entire channel bandwidth (e.g., 20 or 40 MHz)

MAC Layer - TS 38.321

- **Hybrid Automatic Repeat Request (HARQ) process is marked pending if the channel is occupied**
  - Transport block waits in the buffer for the next valid transmission opportunity, after repeating LBT



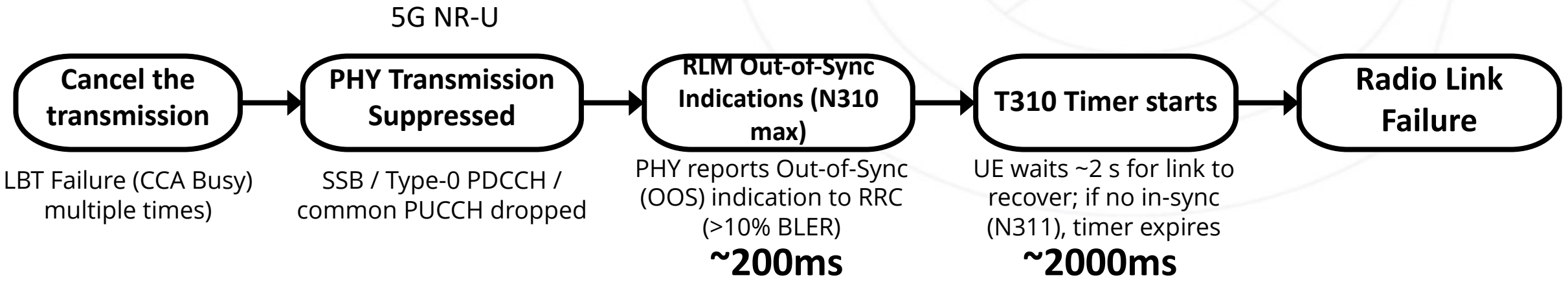
Low quality channel → Retransmit + Increase

Channel occupied → Pending state (wait until it's free)

Source: ShareTechnote

RRC Layer - TS 38.331

- Sets parameters for MAC and PHY execution
- RRCReconfiguration
  - UE's PHY capabilities for shared-spectrum access: Phy-ParametersSharedSpectrumChAccess
  - thresholds for declaring consistent uplink LBT failure, recovered in the MAC (TS 38.321): LBT-FailureRecoveryConfig
  - the BWP / carrier to fall back to when LBT keeps blocking transmissions

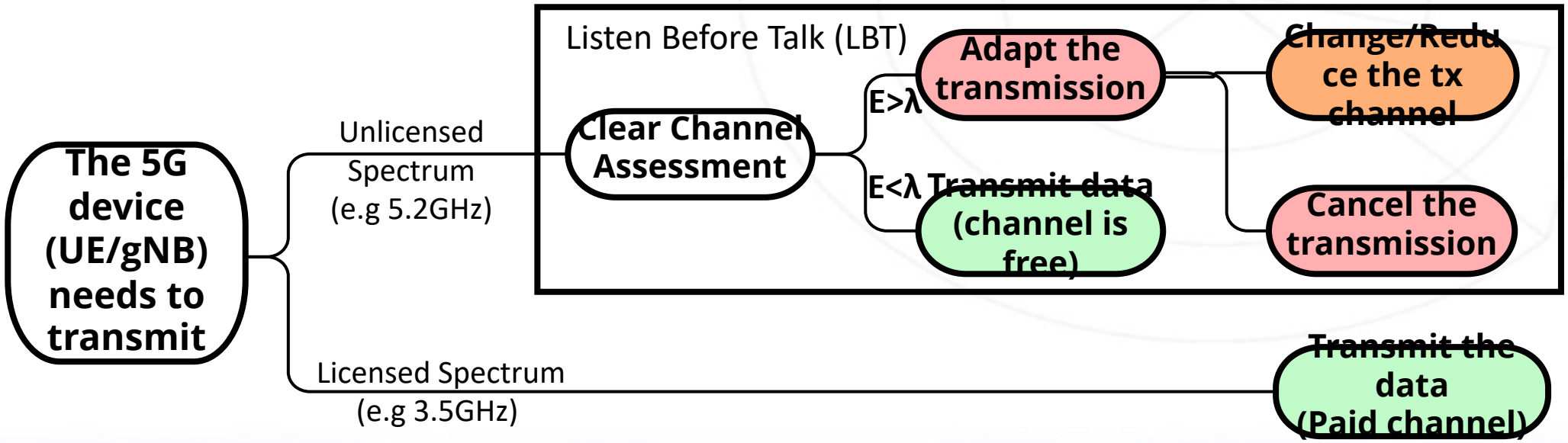


5G NR-U vs WiFi

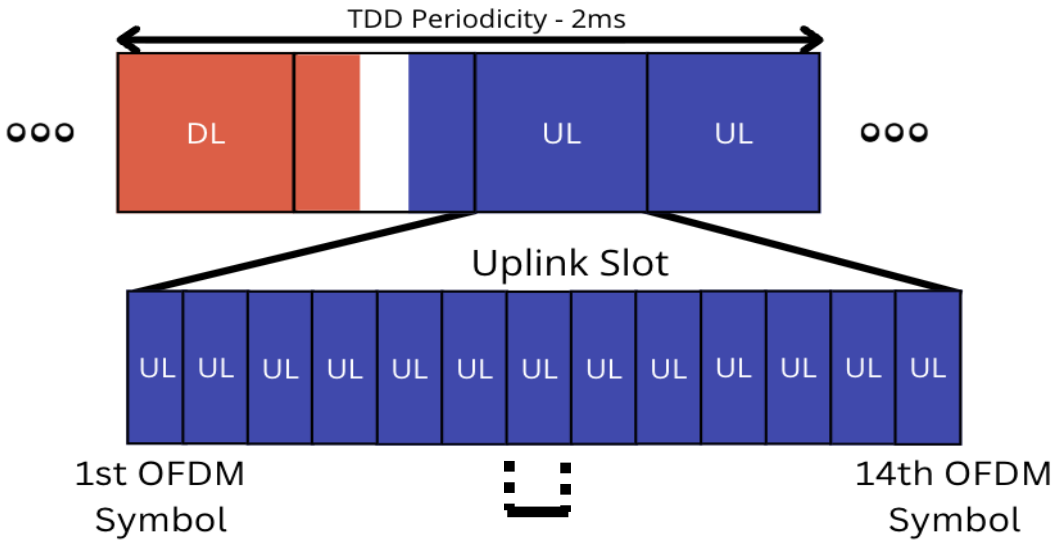
	Wi-Fi built for unlicensed	**5G NR-U** built for licensed
Frame & timing	no frame; transmits the instant backoff hits zero	transmits only on slot boundaries; sensing must fit in guard symbols, and the MCOT-bounded grant forces periodic re-contention
Reaction latency	defers and resumes within one slot time (µs)	per-slot decision; a granted PUSCH can't be cancelled, so reacting to a busy channel waits for the next downlink slot
Synchronisation	connectionless; a station can stay silent indefinitely	the UE tracks the gNB's SSB; if the gNB yields, the sync signals must stay on air or the link drops
Channel deferral	reads the preamble and duration field of a recognised frame, defers exactly that long	cross-technology, can't decode the neighbour; falls back to energy detection, blind to hidden nodes
Where LBT lives	CCA is in the 802.11 PHY/MAC by design	added across the OAI PHY (sensing) and MAC (per-slot reaction)

Design & Implementation in OAI

Listen Before Talk

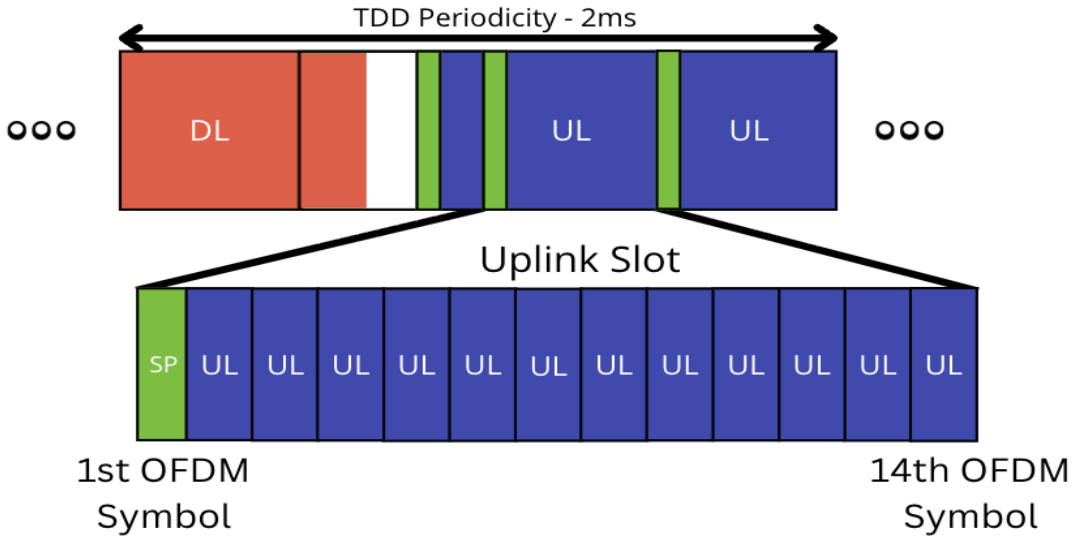


Clear Channel Assessment – When



1 Symbol = 36µs

Assuming SCS 1 = 30Khz

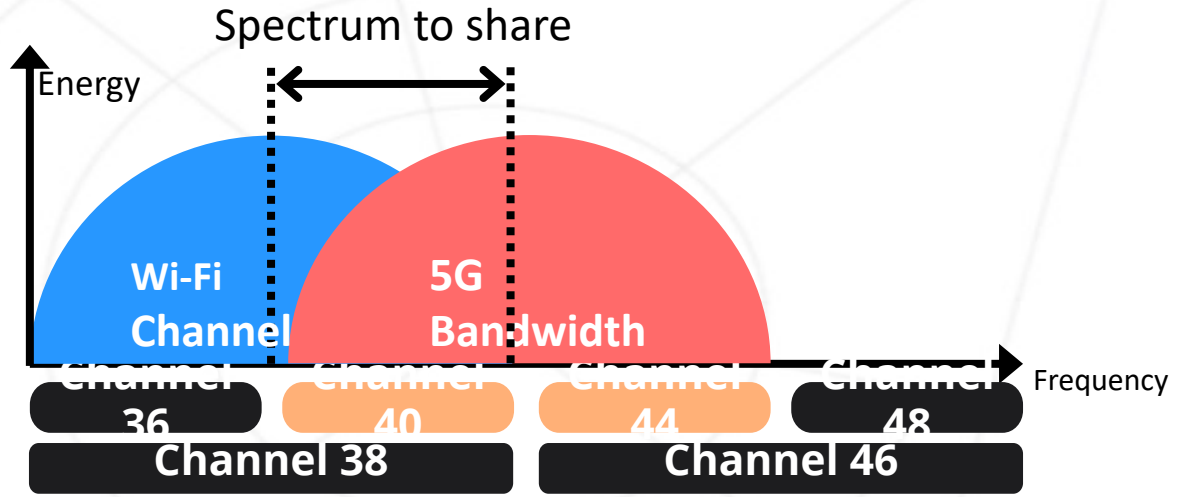


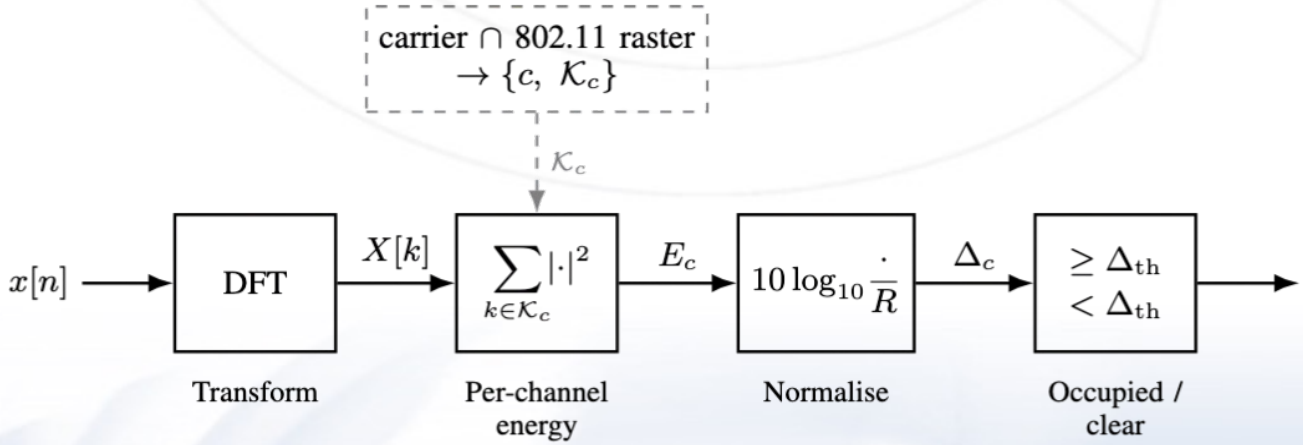
SLIV (Start and Length Indicator Value)

Configuration sent from the gNB to the UE: which symbols to use from each slot

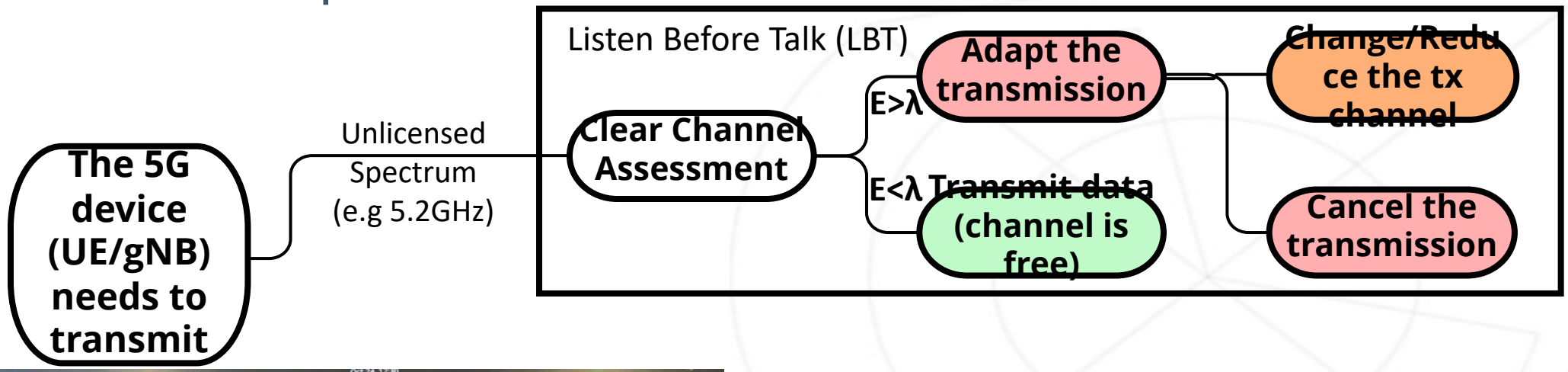
Clear Channel Assessment – How

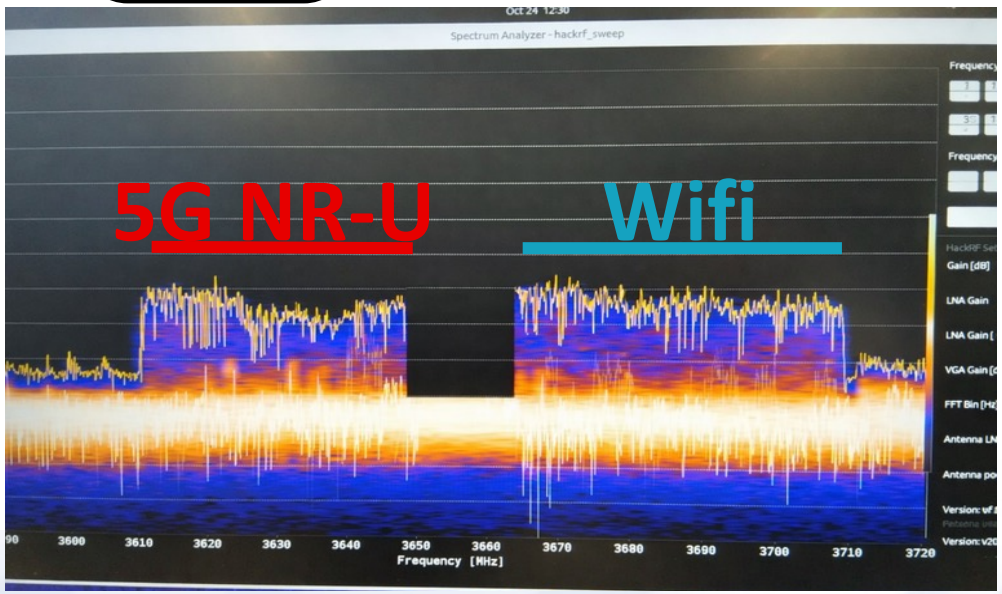
- Energy detector
  - Sense only overlapping channels
  - Identify occupied channels
  - Trade-off: footprint, speed and accuracy



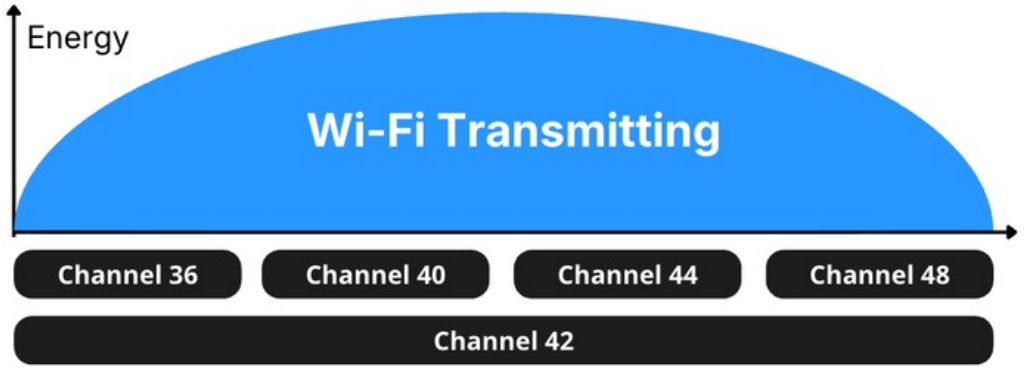


LBT – Adapt Transmission



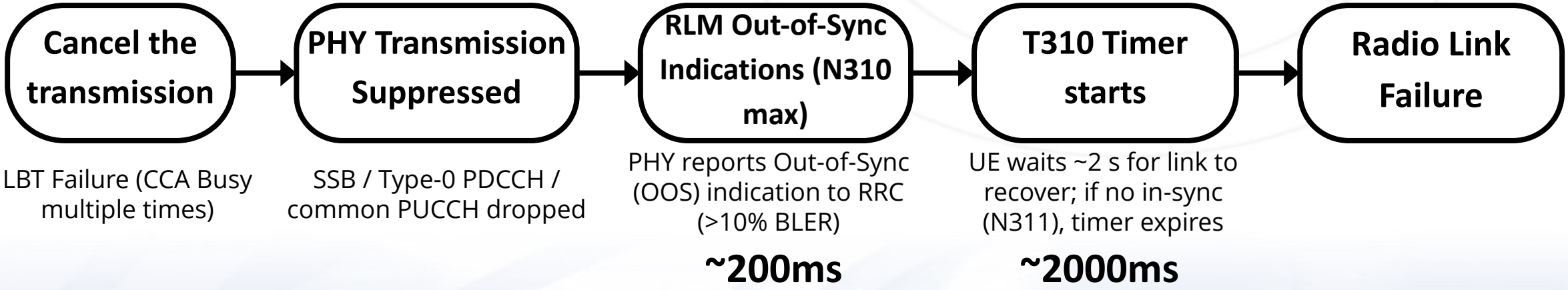


TX Canceled



Keeping the UE in Synch

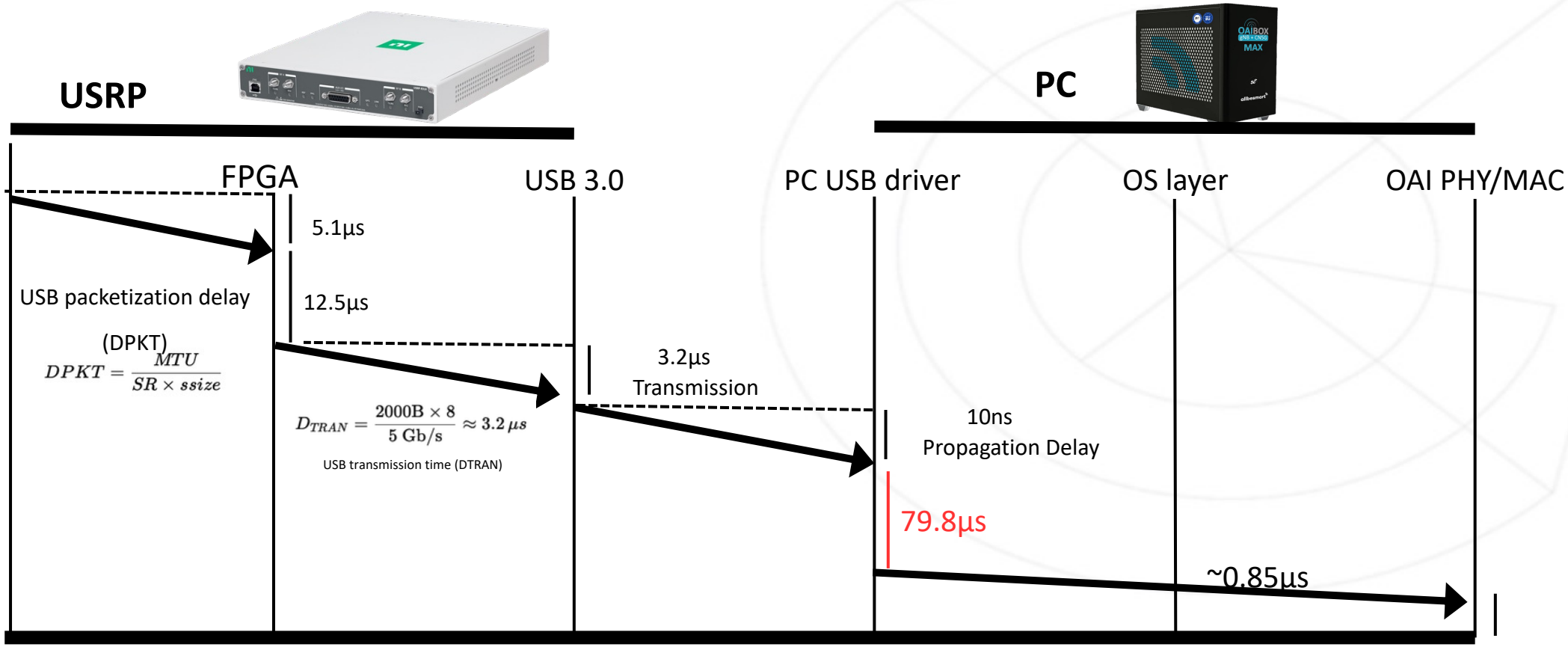
- Dynamic PRB allocation keeps 24 RB on air
  - SSB — the synchronisation signal block the UE locks onto (20 PRBs)
  - Type-0 PDCCH — carries the system information (24 PRBs)
  - Common PUCCH — carries the UE's feedback (often 1–2 PRBs for a given transmission)
- Frequent transmission cancellation may lead to radio link failure



Adapting HARQ & Integrating with OAIBox

- HARQ cannot distinguish transmission cancellation from lost packet
  - Leads to MCS collapse and HARQ retransmissions
- MAC signals tx cancellation
- HARQ adapted to not update BLER => does not trigger HARQ or MCS adaptation
- Integrated with OAIBOX™

Implementation in the DU: Limitation



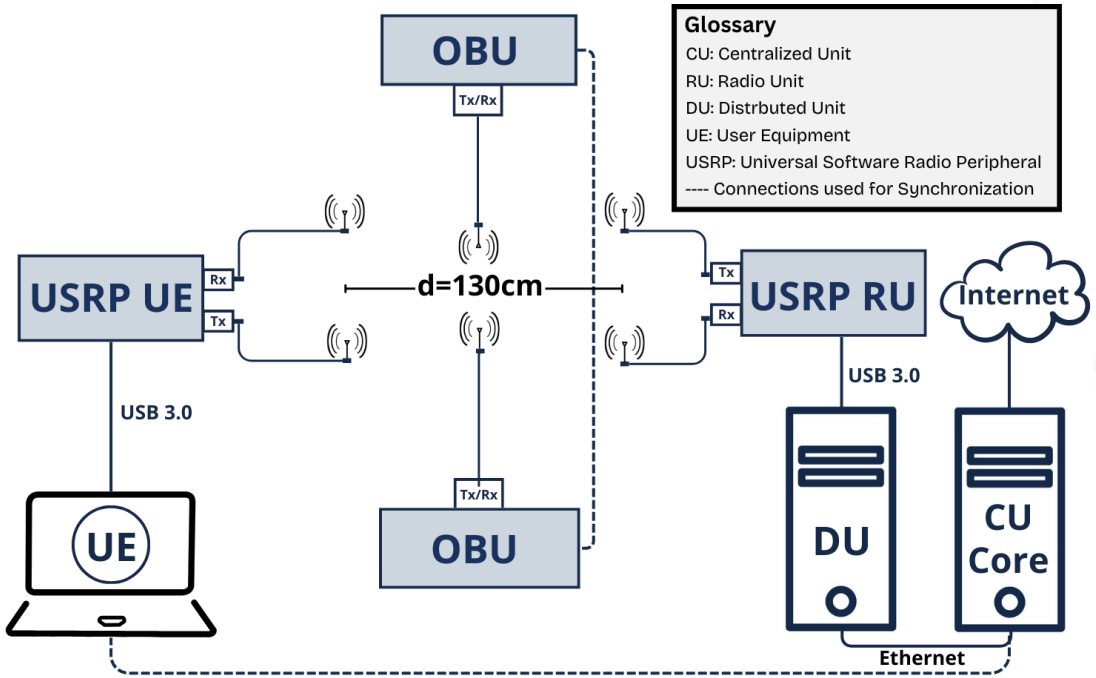
RTT ~ 203µs, so one-way ~ 101.5µs

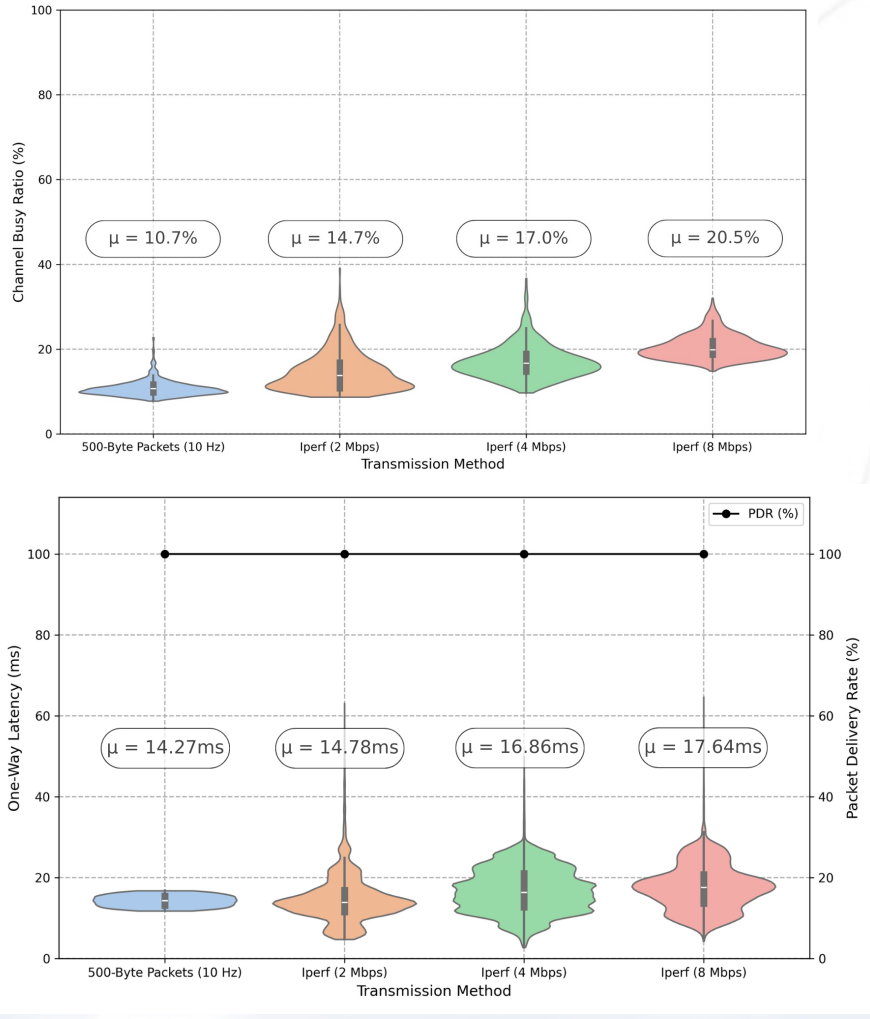
Assuming USRP X310, Maximum Transmission Unit (MTU) 2000B and 40MHz. → RTT (min / median / max): (104 µs, 203 µs, 257 µs)

Source: Laskos, C., Zubow, A., & Dressler, F. (2025, June). Latency Analysis of SDR-based Experimental C-RAN / O-RAN Systems. In Proceedings of the IEEE International Conference on Communications (ICC 2025) – Workshop on Tactile Internet with Human-in-the-Loop (TIHL 2025) (pp. 893-898). Montréal, Canada.

Some Results

5G NR-Unlicensed Operation





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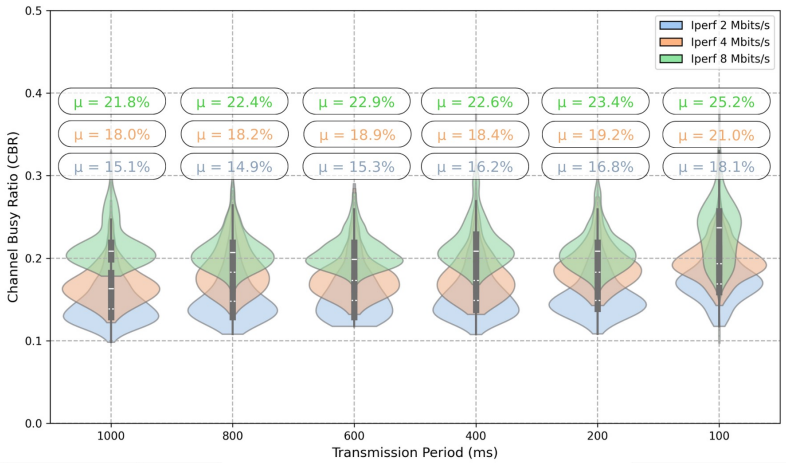
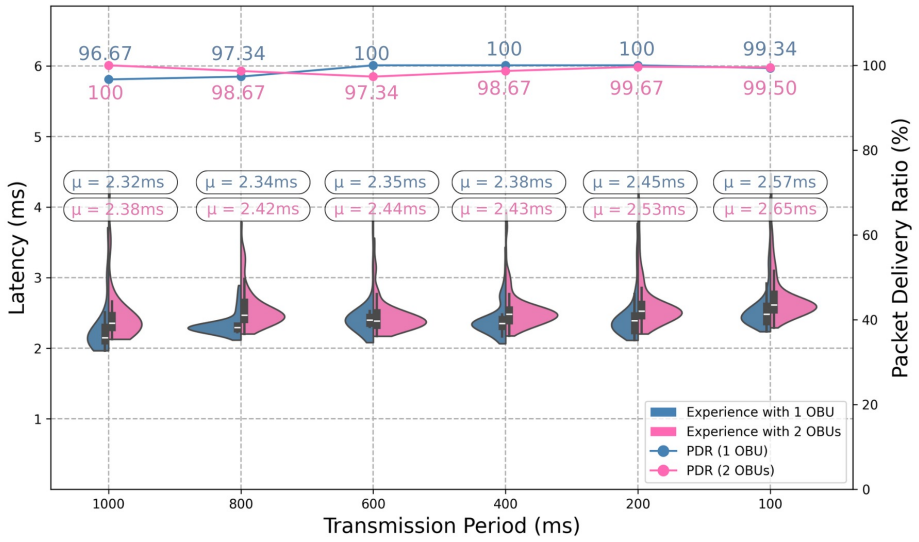
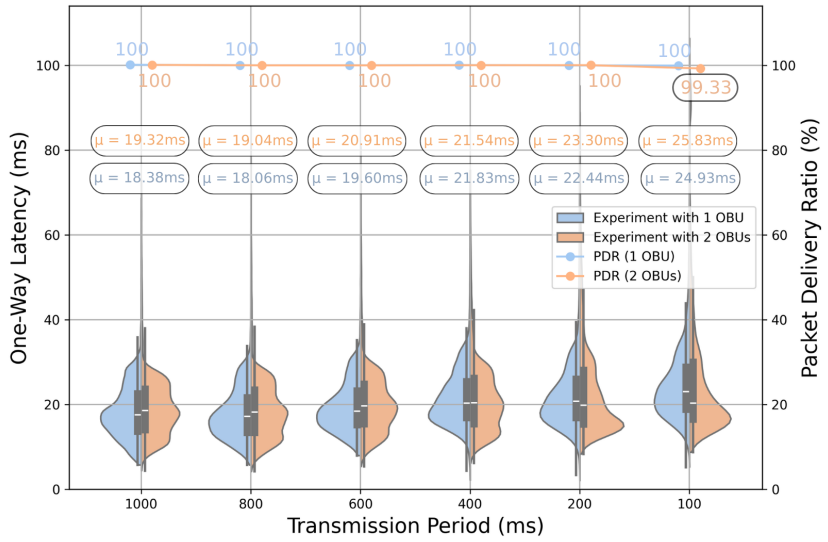
5G NR-Unlicensed Co-Existence with ITS-G5



ITS-G5



5G NR-U



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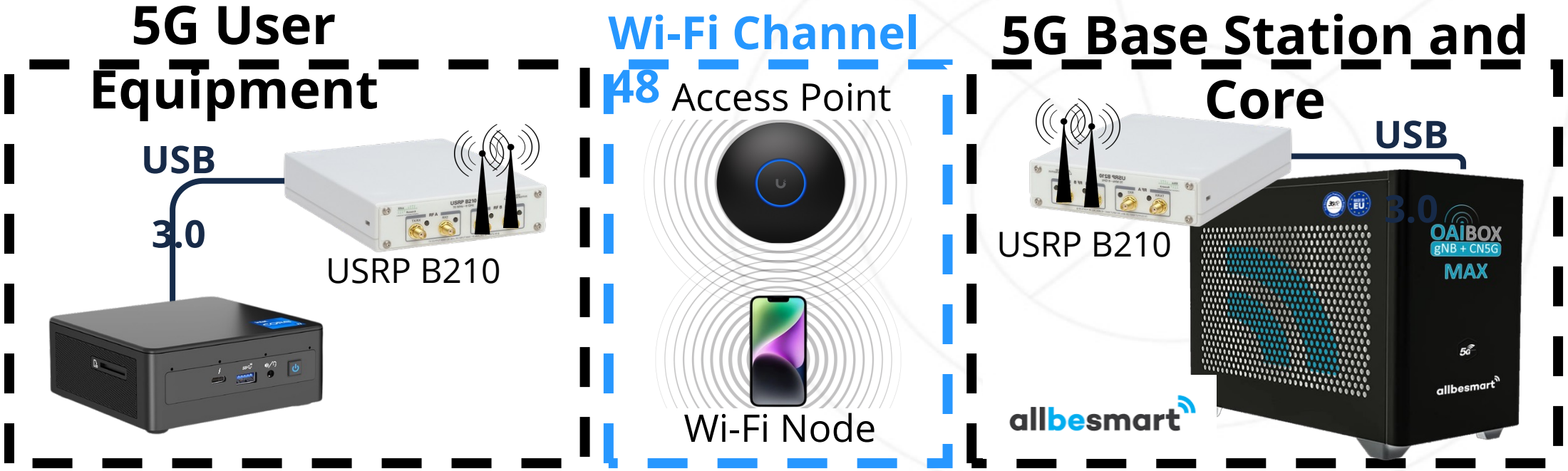
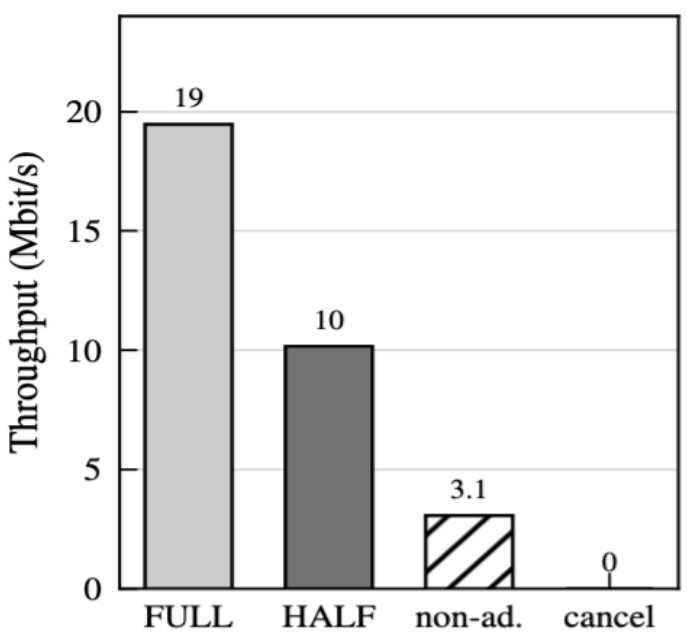
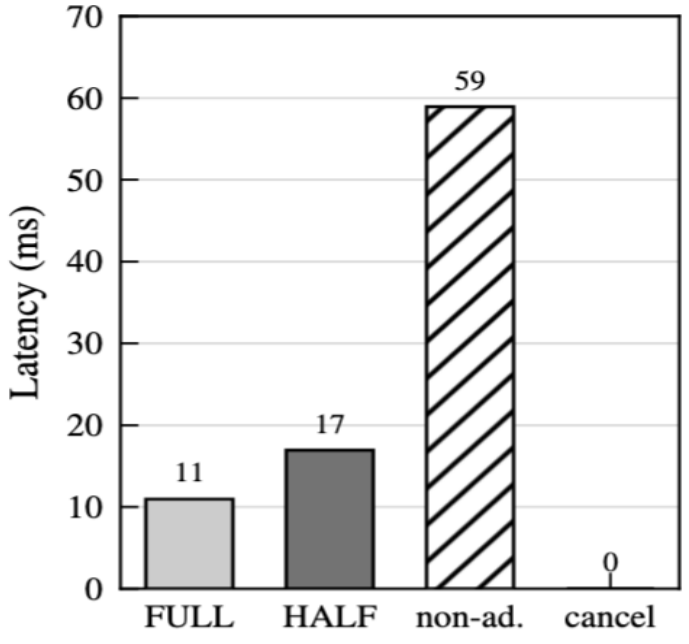
Co-Existence with WiFi

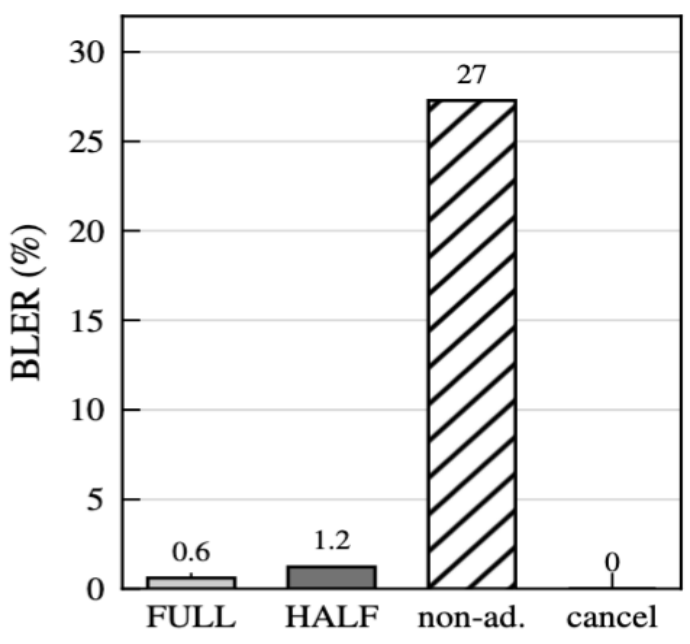


(Preliminary) Performance Evaluation

- Full: no WiFi
- Half: sharing with WiFi
- Non-adapt: not adapting scheduled RB







Take-aways & Look ahead

- Developed and validated components for 5G NR Unlicensed
  - No licensing costs, usable in controlled occupation environments, e.g. industrial
  - No contention between 5G-Unlicensed devices
  - Digital Networks Act (DNA) mandates that operators enable spectrum sharing
  - Lack of COTS devices/ device flexibility
- Code available online 
- Next steps
  - Add unlicensed branch to OAI development codebase
  - Publish a skill for unlicensed/ dynamic spectrum access development
  - Validation of FPGA CCA implementation for reduced reaction time
  - Deterministic communications over 5G NR-U

Thank you! Questions?

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