Nuberu: Reliable RAN Virtualization

Andres Garcia-Saavedra, Gines Garcia-Aviles, Marco Gramaglia, Xavier Costa, Pablo Serrano, Albert Banchs

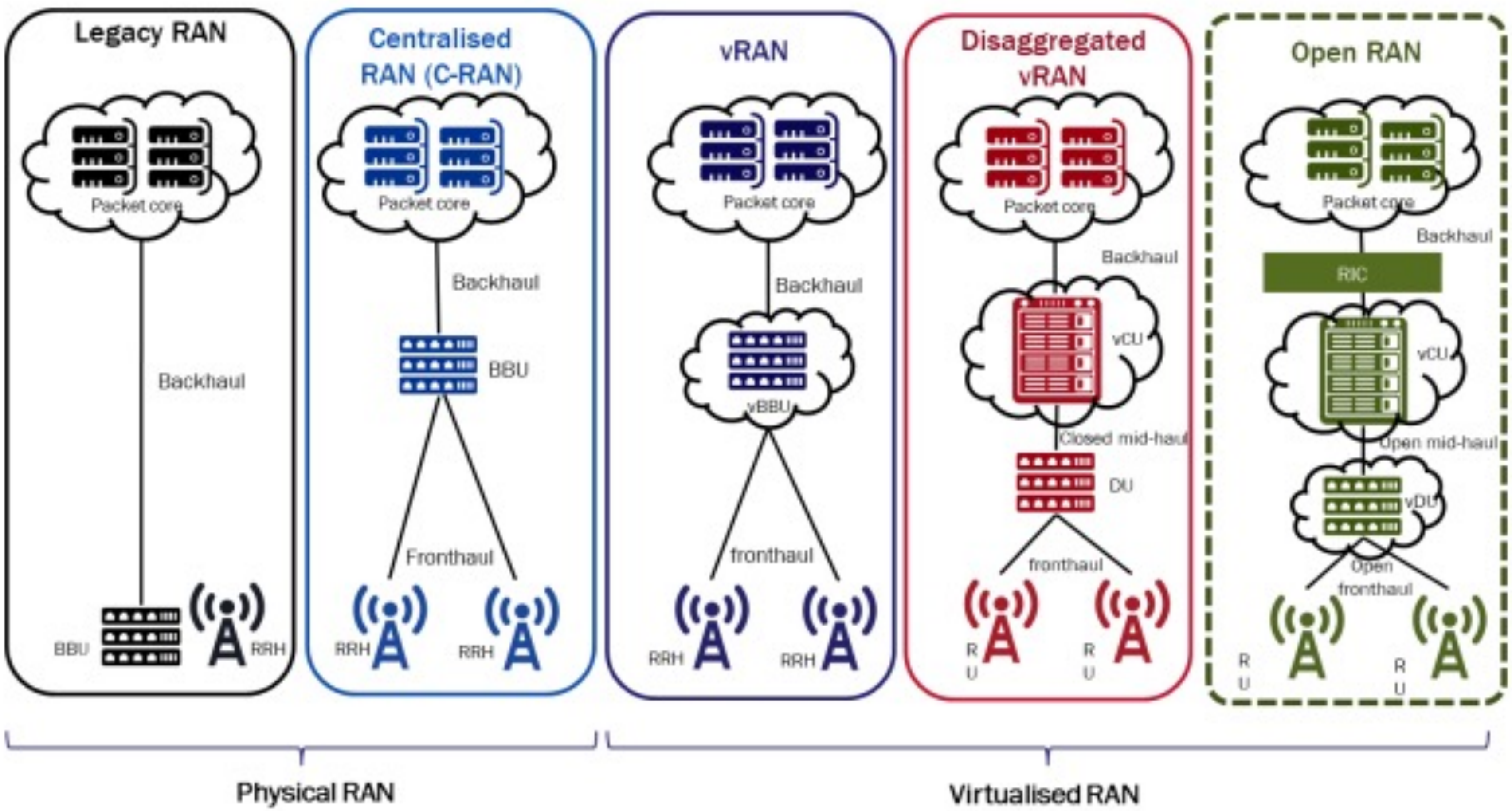
http://www.it.uc3m.es/pablo/

Università degli Studi di Brescia, Dec. 12nd 2022

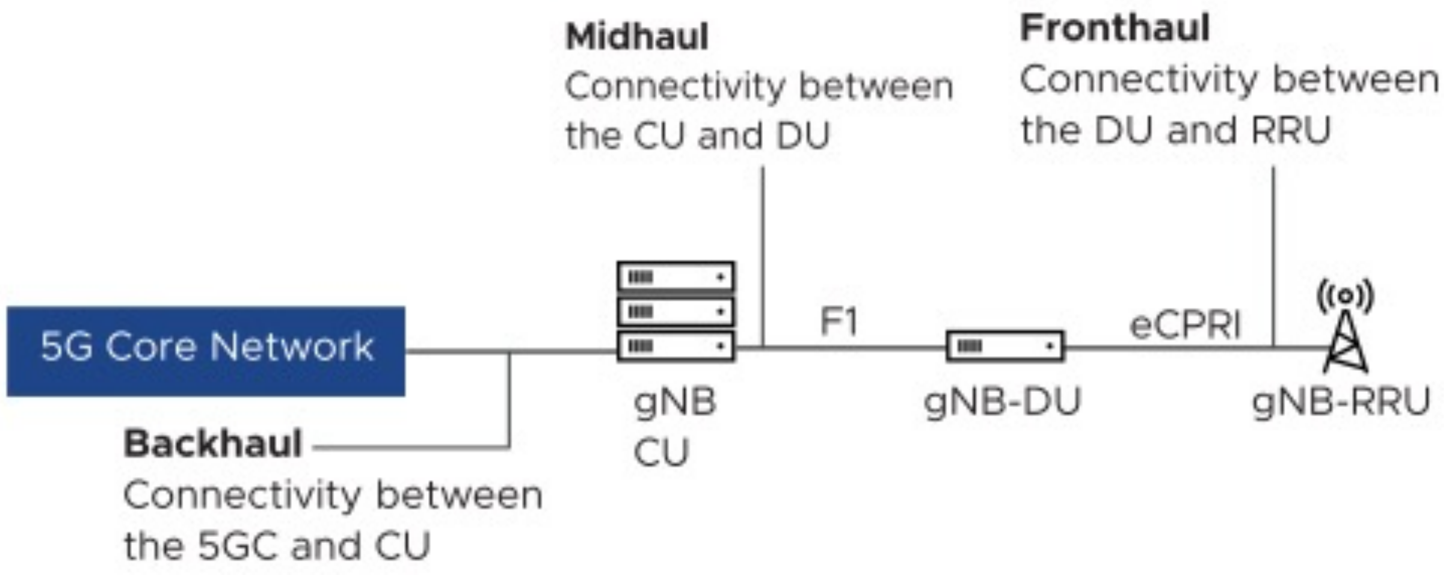
BACKGROUND

The evolution of RAN

- From fully integrated to Open



vRAN Architecture



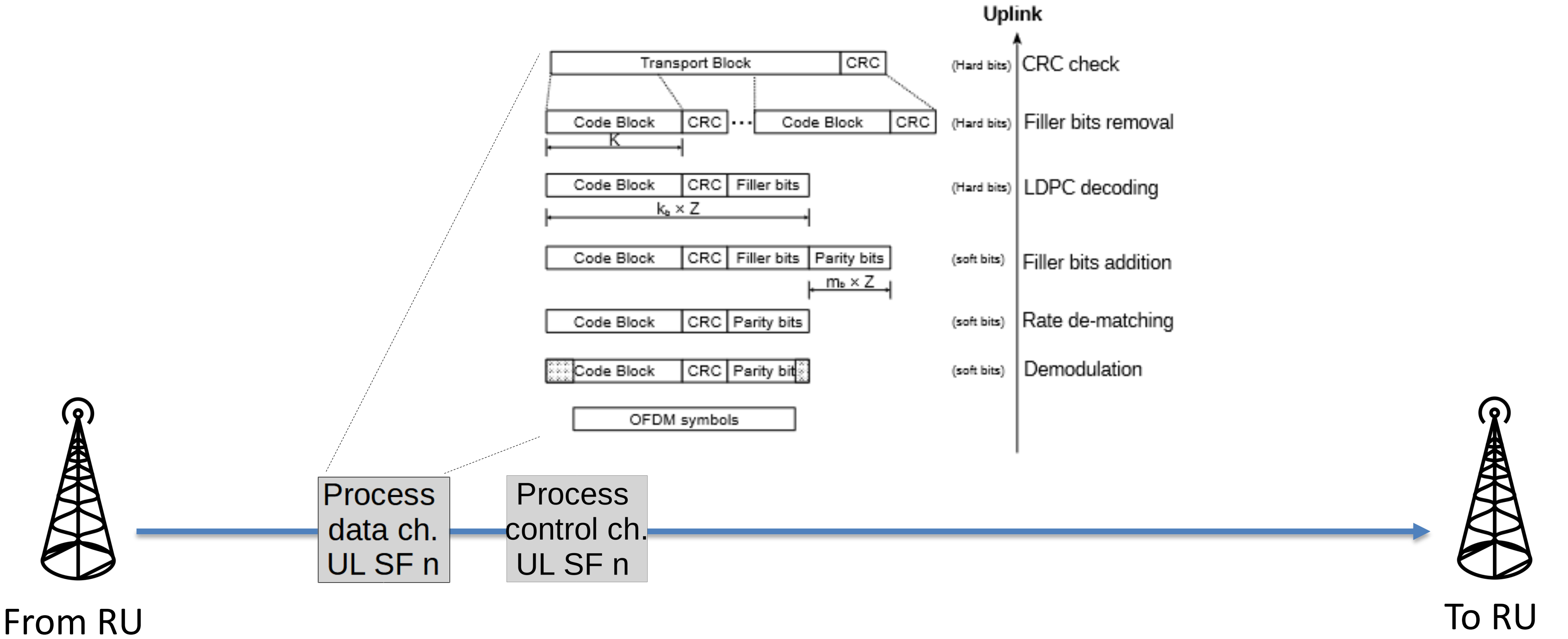
- Centralized Unit (CU): non-real-time processing
- Distributed Unit (DU): real-time processing and coordinates MAC, RLC and PHY
- Remote Radio Unit (RRU): amp. & sampling

A DU has to perform many tasks

1. Receive Uplink (UL) subframe (SF) n (OFDM symbols, after FFT)

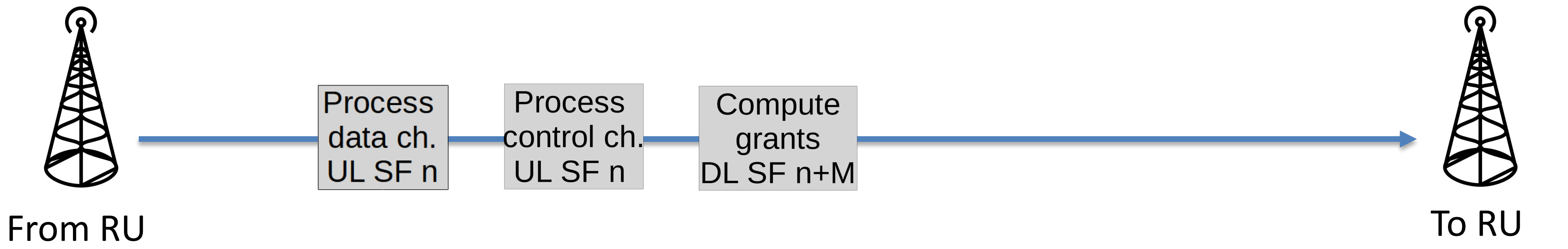
A DU has to perform many tasks

1. Receive Uplink (UL) subframe (SF) n (OFDM symbols, after FFT)
2. Process UL data channels in UL SF n
3. Process UL control channels in UL SF n



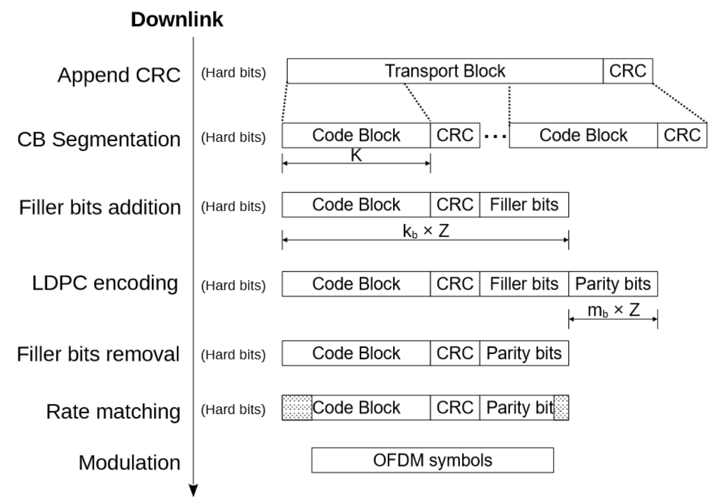
A DU has to perform many tasks

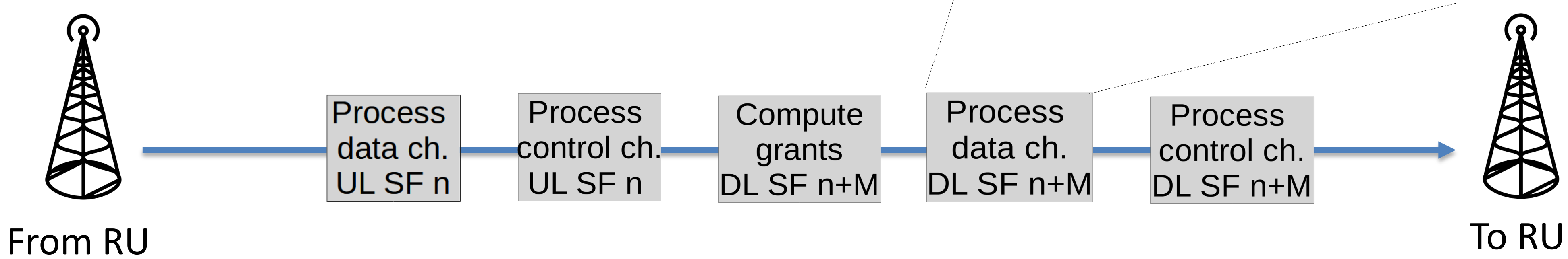
1. Receive Uplink (UL) subframe (SF) n (OFDM symbols, after FFT)
2. Process UL data channels in UL SF n
3. Process UL control channels in UL SF n
4. Prepare Downlink (DL) SF n + M (M=4)
   - Prepare basic synchronization signals
   - Compute radio scheduling grants



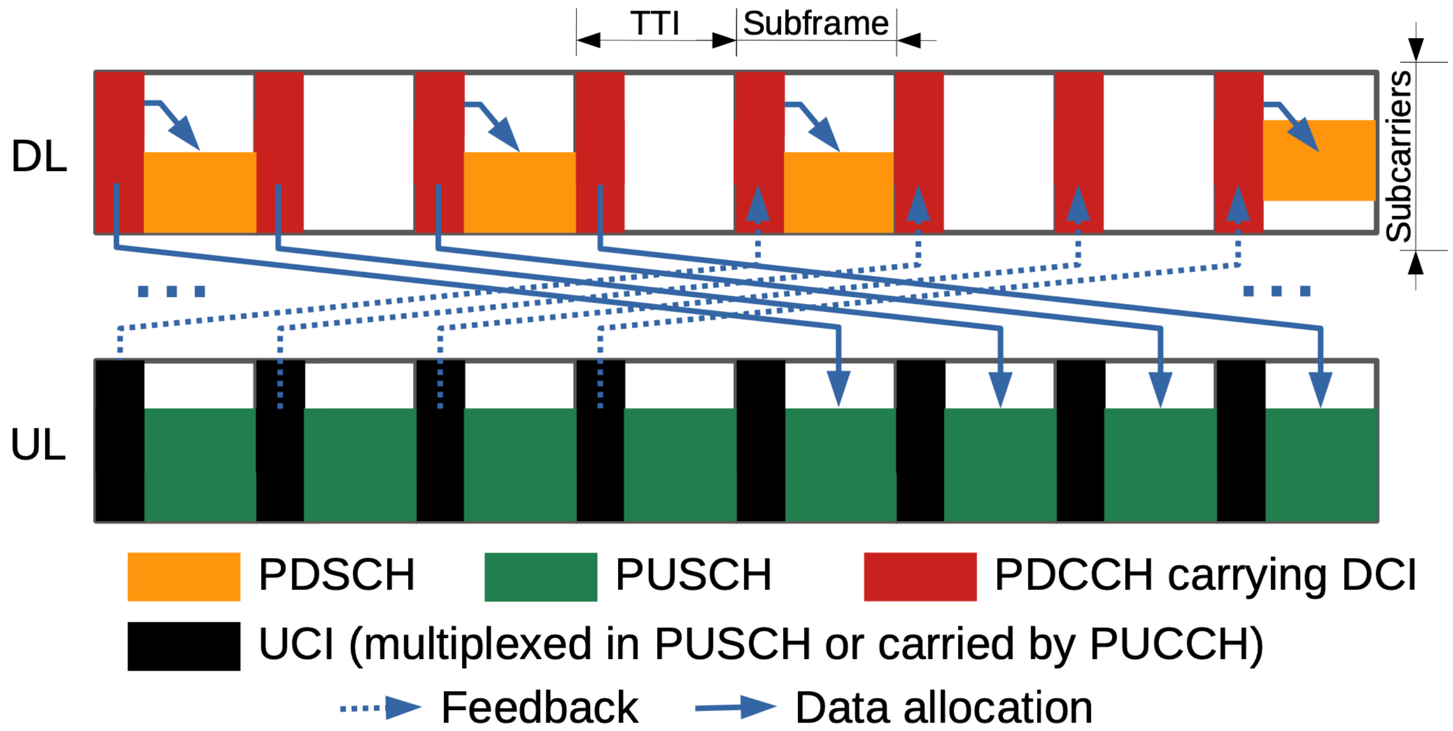
A DU has to perform many tasks

1. Receive Uplink (UL) subframe (SF) n (OFDM symbols, after FFT)
2. Process UL data channels in UL SF n
3. Process UL control channels in UL SF n
4. Prepare Downlink (DL) SF n + M (M=4)
5. Process DL data channels in DL SF n + M
6. Process DL control channels in DL SF n + M
7. Send DL SF n+M to RU (to perform IFFT)



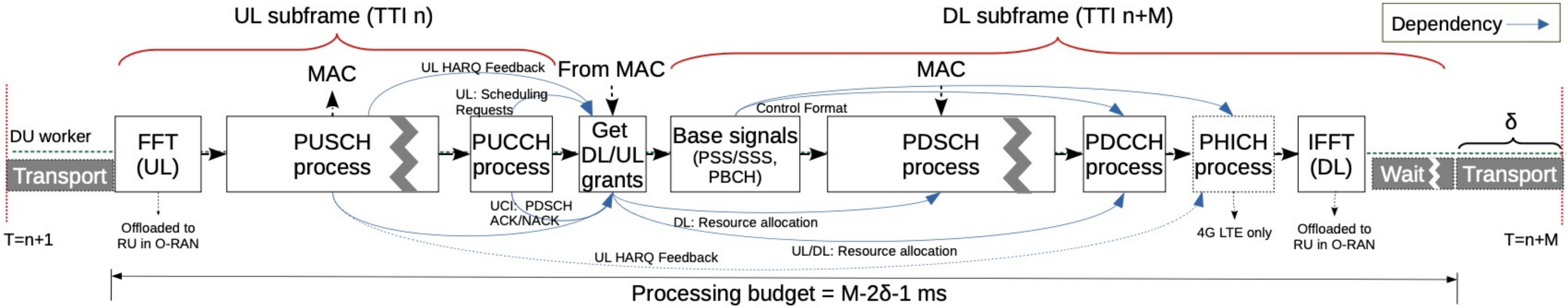


Dependencies



- DL and UL grants -> Downlink Control Information (DCI)
- HARQ feedback -> UL Control Information (UCI)

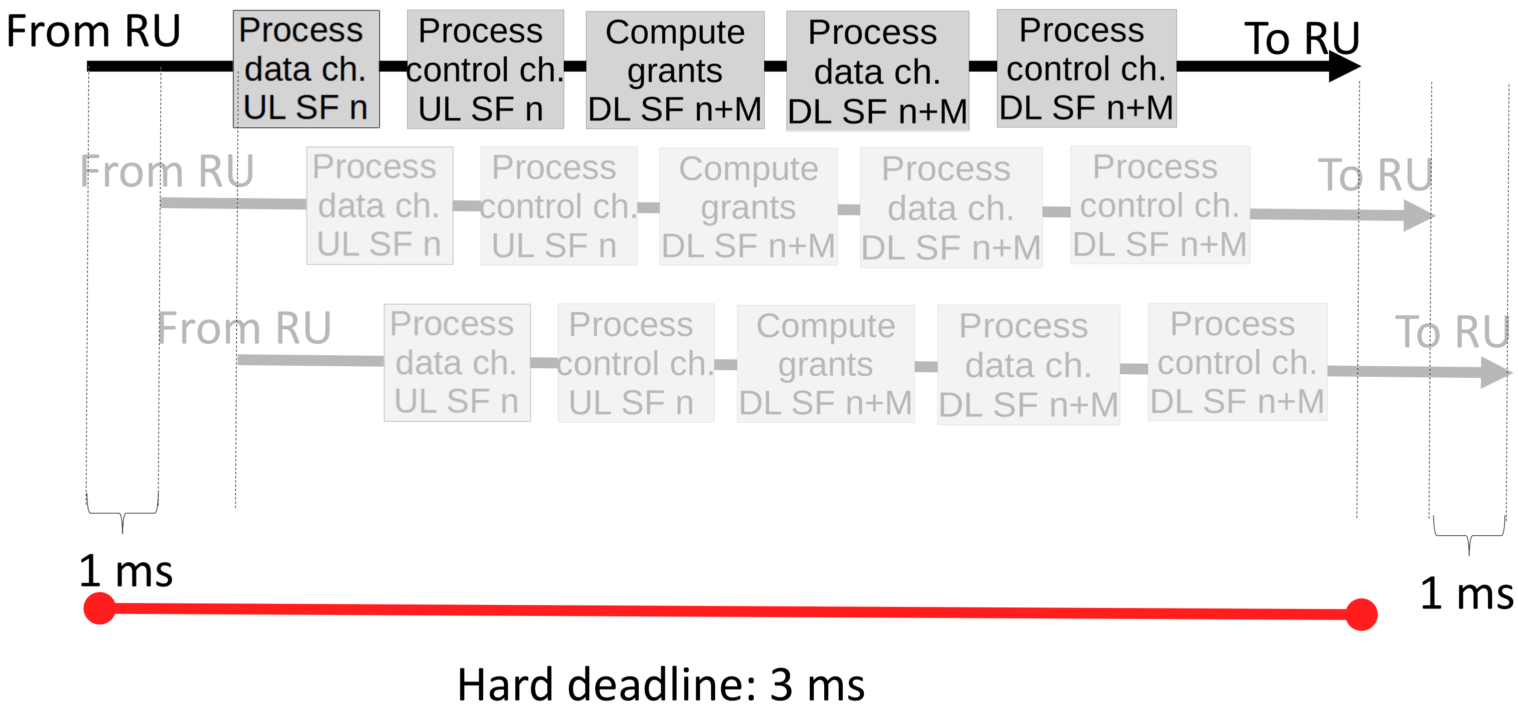
Dependencies (in more detail)

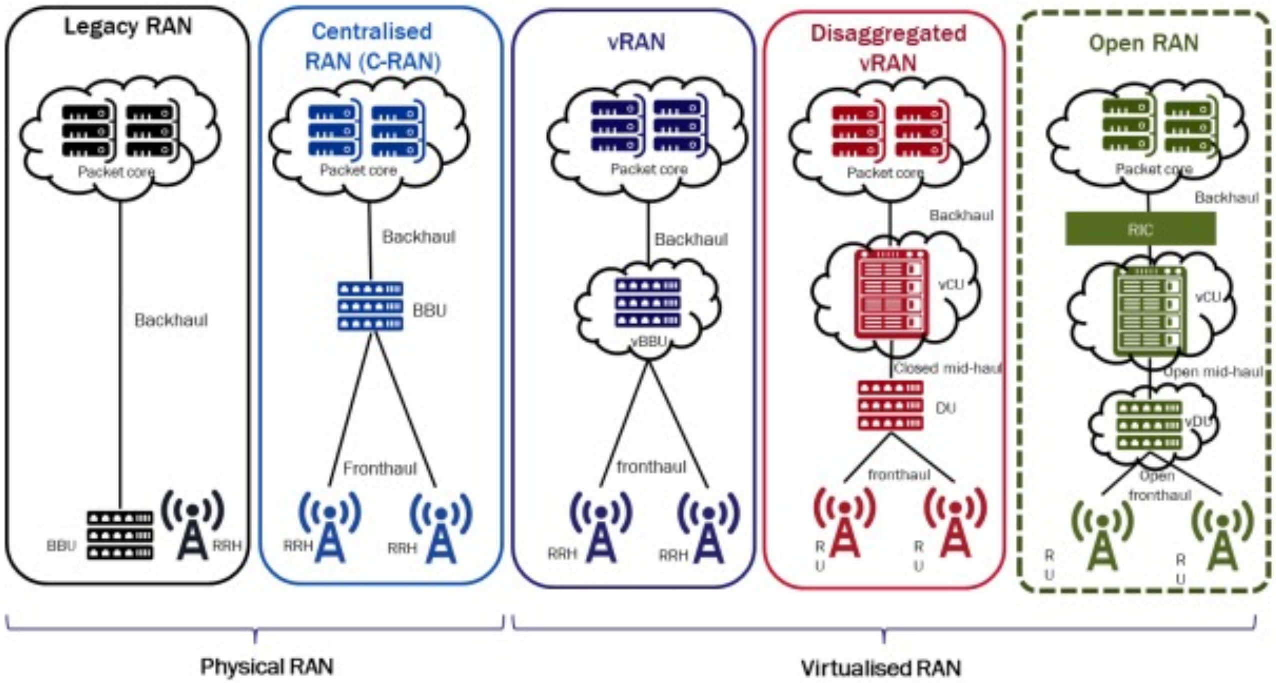


- DL grants must be computed before PDSCH because they carry information required to encode and modulate DL
- PUSCH and PUCCH must be processed before computing DL grants because they carry users' feedback (DL HARQ, channel quality, etc.) in UCI messages (dotted arrows in Fig. 7), which is required to schedule DL data appropriately;
- UL HARQ feedback can only be computed after processing PUSCH; and this feedback is required to schedule UL grants within the same job to satisfy 3GPP timing constraints;
- UL grants must be computed before processing PDCCH, which carries those grants, and (in case of LTE) before processing PHICH, which carries UL HARQ feedback.

Timing is critical

- Tight deadline to process each DU job
  - Otherwise sync is lost

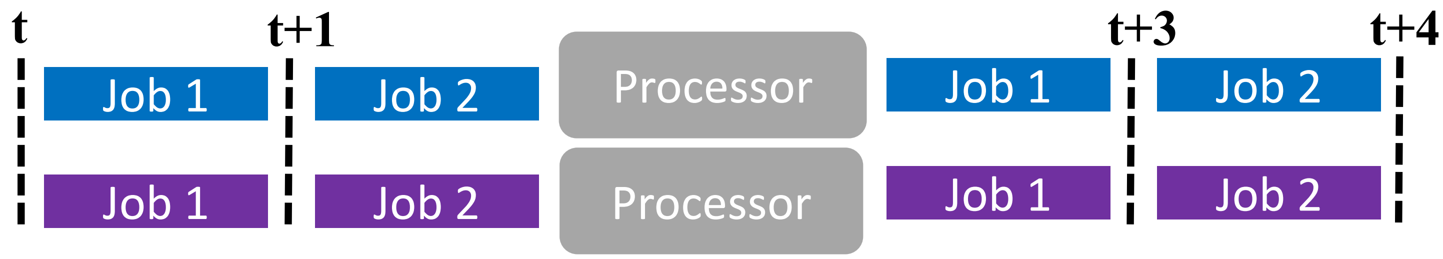




VIRTUALIZING THE VIRTUAL RAN: APPROACHES AND CHALLENGES

Over-dimensioning

- Virtualizing a base station (eNB/gNB) is hard
  - Distributed Unit (DU) pipeline has tight computing deadlines
  - Violating deadlines loses UE-DU synchronization (network collapse)
- Industry today: over-dimensioning
  - Offload some tasks (FEC) to dedicated hardware accelerators
  - Intel FlexRAN (FPGA) or NVIDIA Aerial (GPU)



Challenge: cost

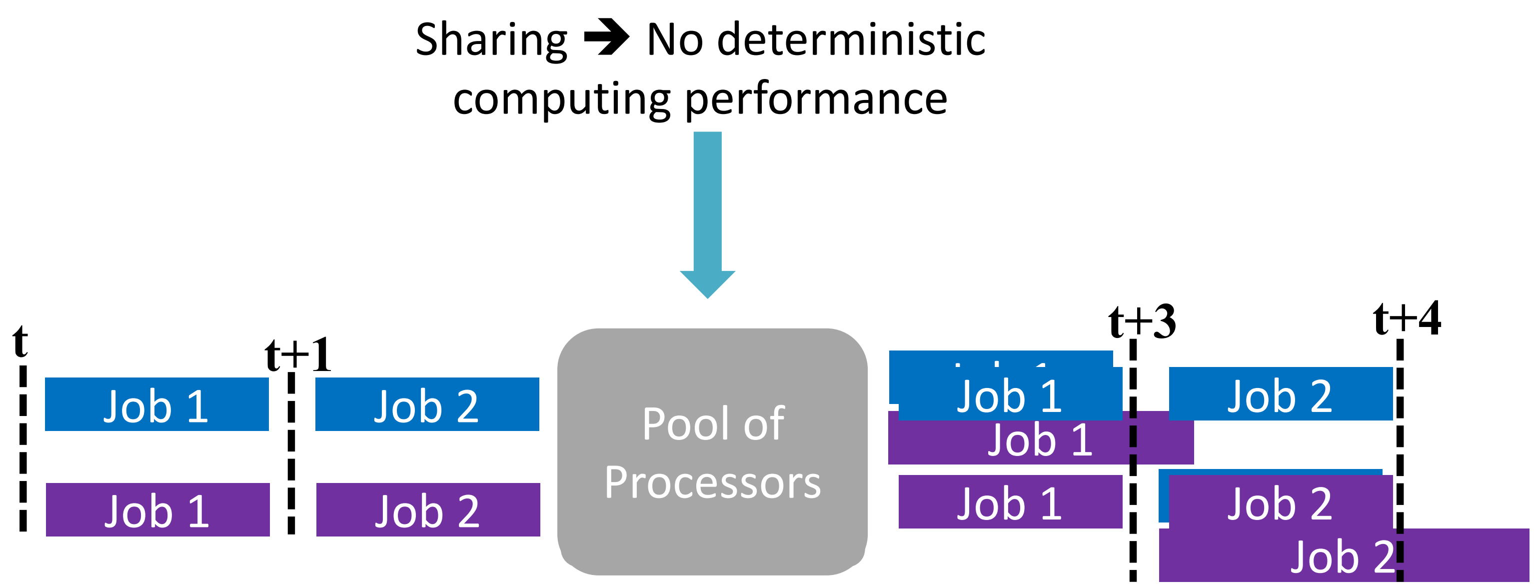
“Dedicated custom ASIC [application-specific integrated circuit] processors that vendors design for their base stations cannot currently be matched by general purpose processors (GPP), when it comes to supporting advanced RAN functions. **If a chip supplier surrounds the CPU with enough accelerators - FPGAs, GPUs (graphical processor units) or ASICs -to offload the most demanding tasks, the solution becomes very expensive and potentially power-hungry**”

Fredrik Jejdling,
Executive Vice President and Head of Business Area Networks at Ericsson
Pre-MWC 2020

“They [FPGAs] give you flexibility, they give you time-to-market advantage, but then **they’re expensive**.”

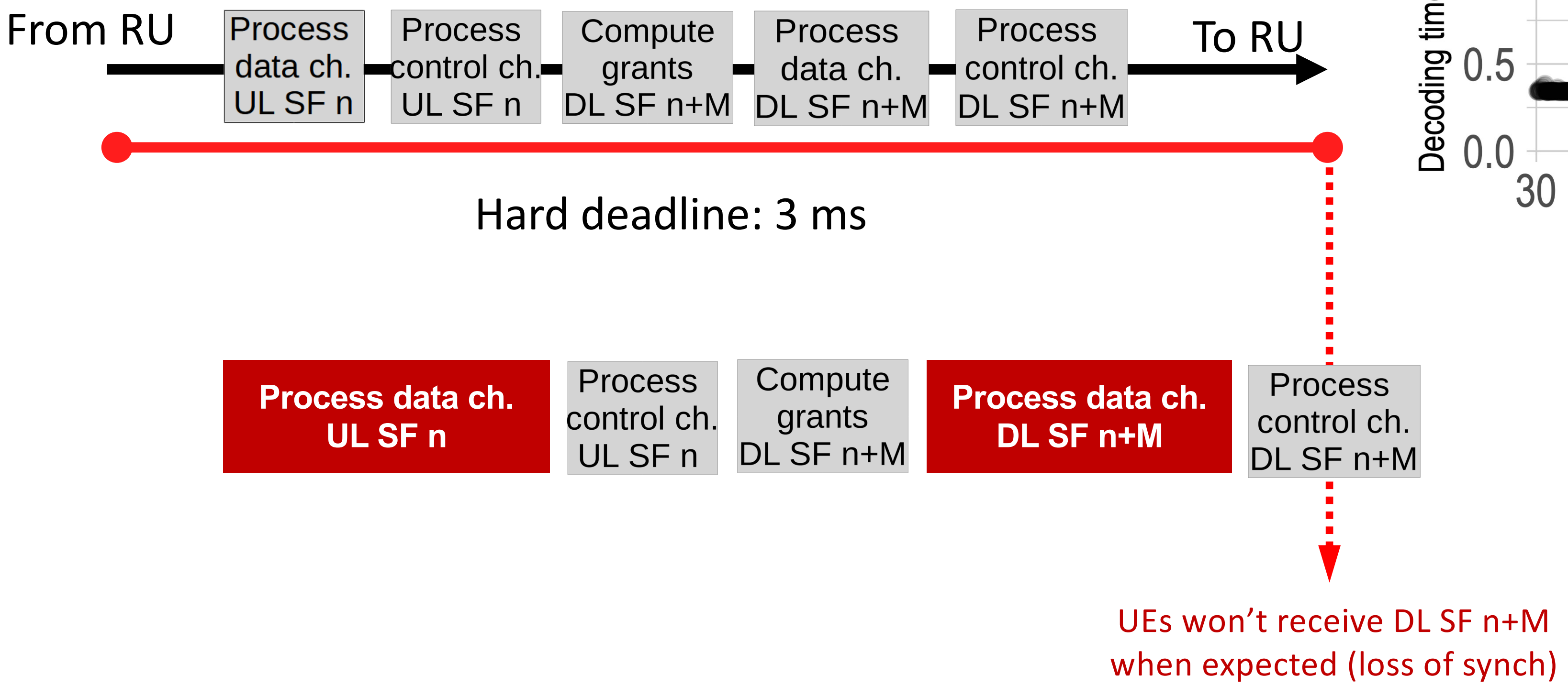
Rajeev Suri,
CEO, Nokia (till 2020)
Q3 2019 Results Conference Call October 24

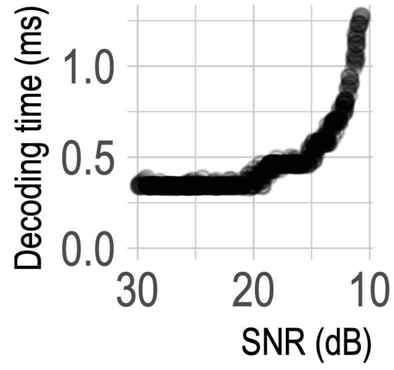
Sharing computing resources



Challenge: timing

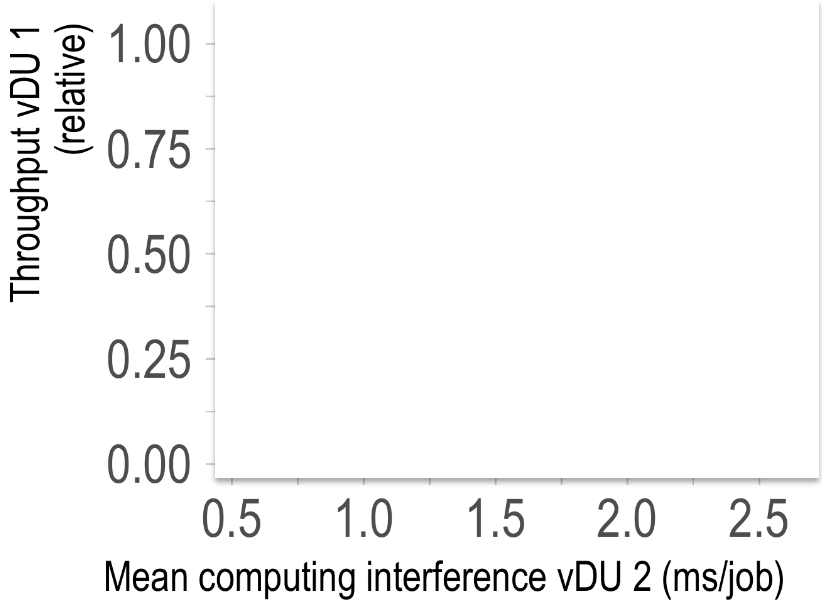
- Variable capacity **and** variable demand





Toy experiment

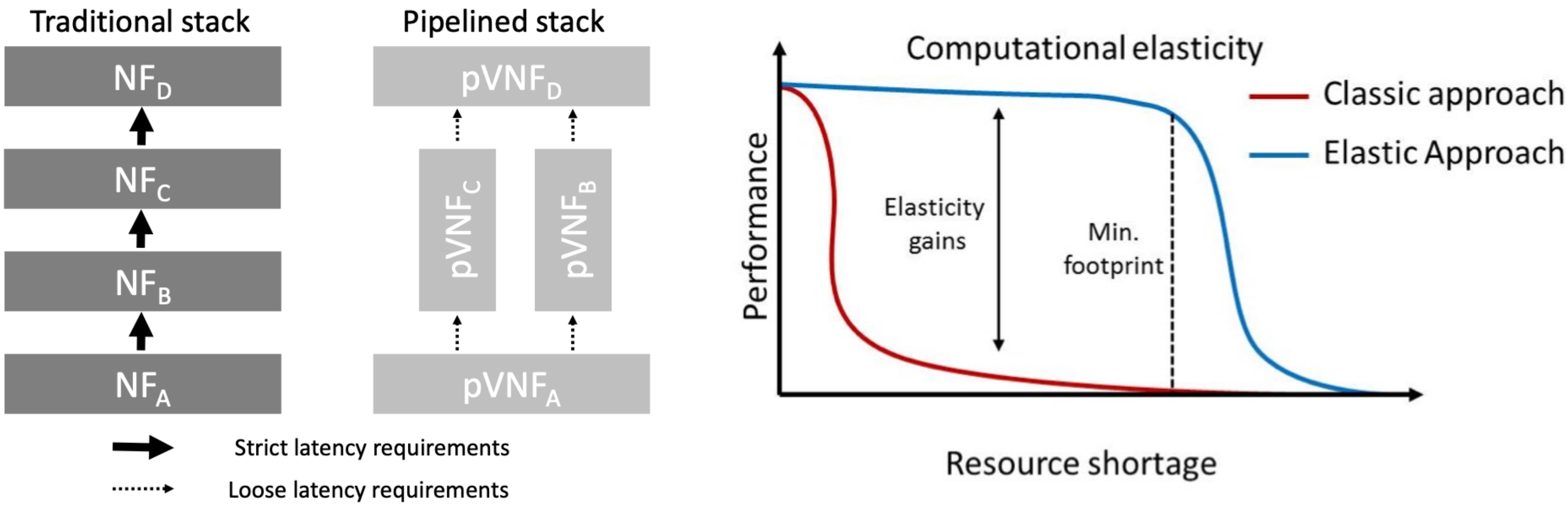
- 5x CPUs @ 1.9 GHz, 2x vDUs sharing platform
  - vDU 1 (y-axis): Max. load uplink and downlink
  - vDU 2 (x-axis): Increasing load (noisy neigh.)



- vDU 1's throughput collapses
- Reason: Processing deadlines are violated

Our Approach: Cloud Awareness

- A cloud-aware re-design of the stack
  - Relax the tight interactions between functions
  - Support a graceful degradation

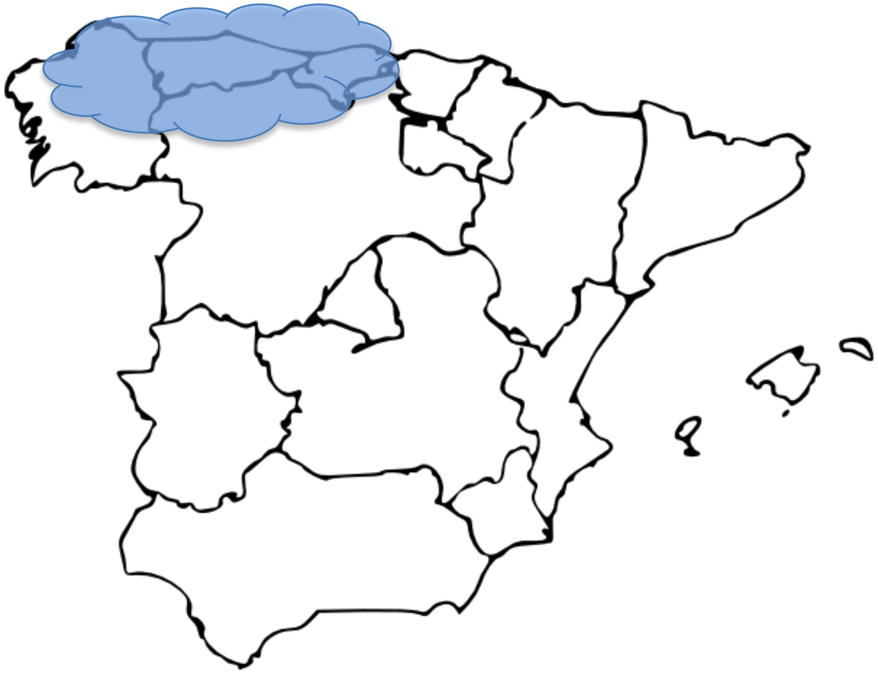


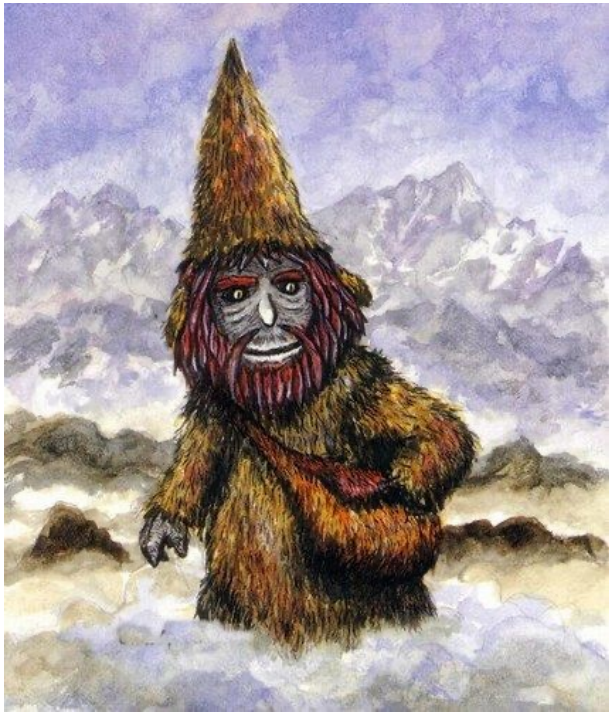
P. Serrano, "The path towards a cloud-aware mobile network protocol stack," Transactions on Emerging Telecom. Tech. Technologies, Vol. 25, Issue 5, May 2018

OUR SOLUTION: NUBERU

Nuberu

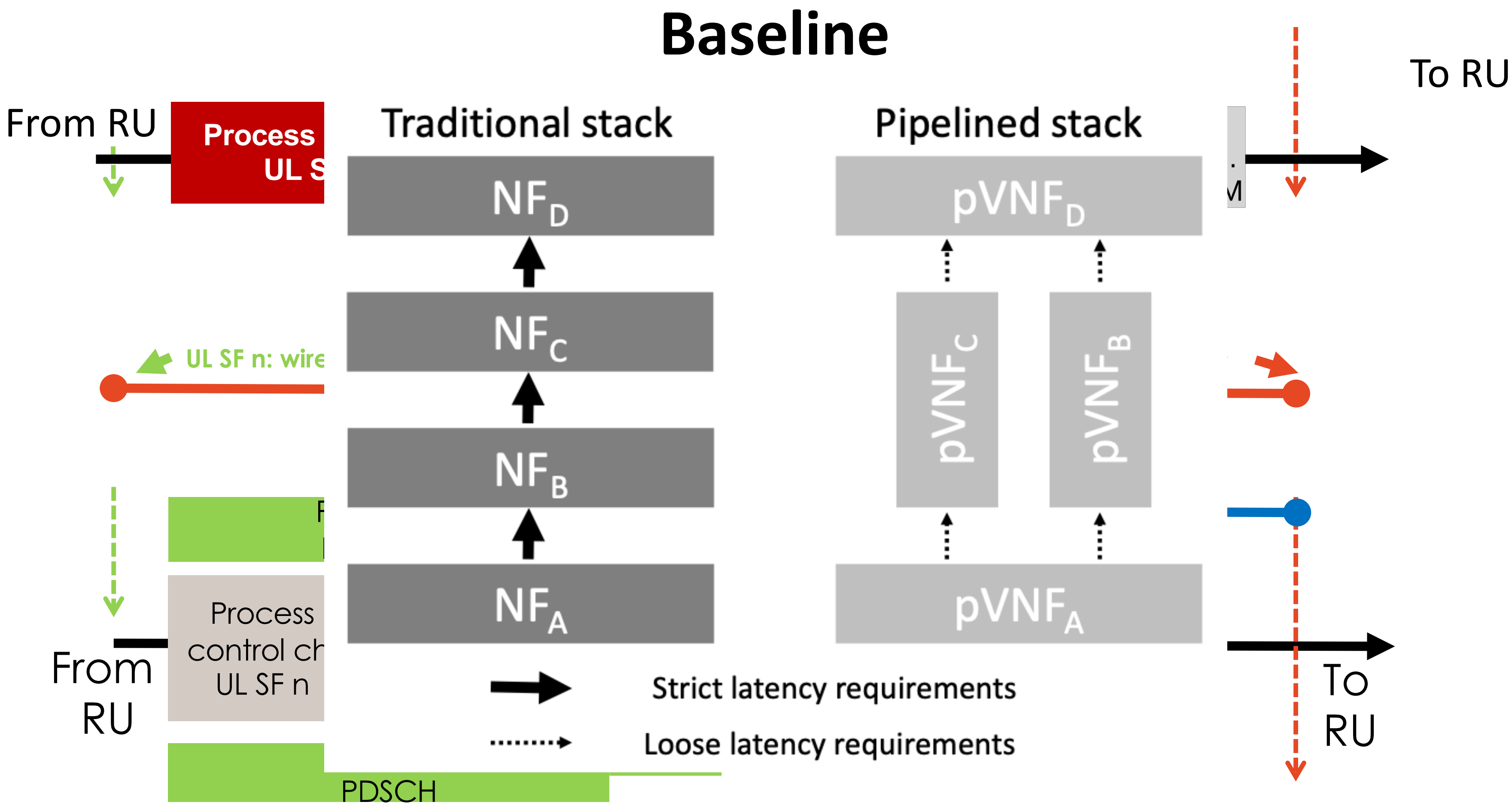
- "The Clouder": the divinity of clouds (and storms)





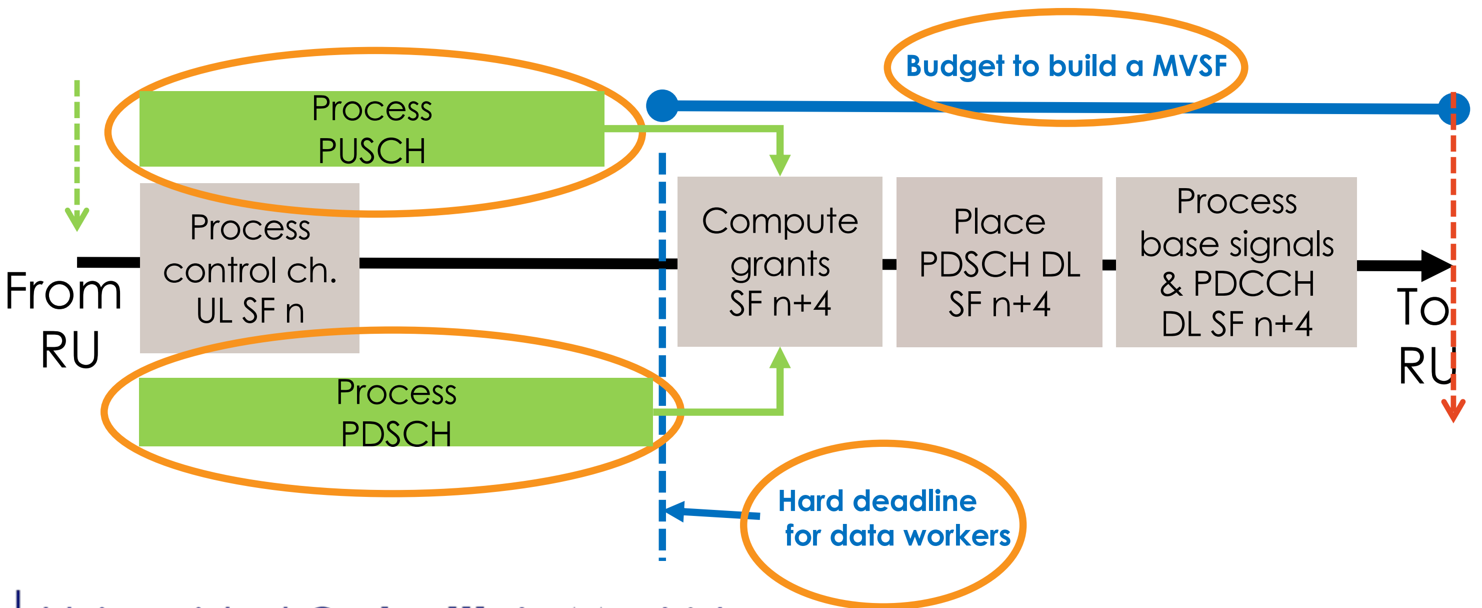
“Their appearance changes from region to region but they are usually elderly, winged, dark and **terribly ugly**.”

A resilient pipelined stack

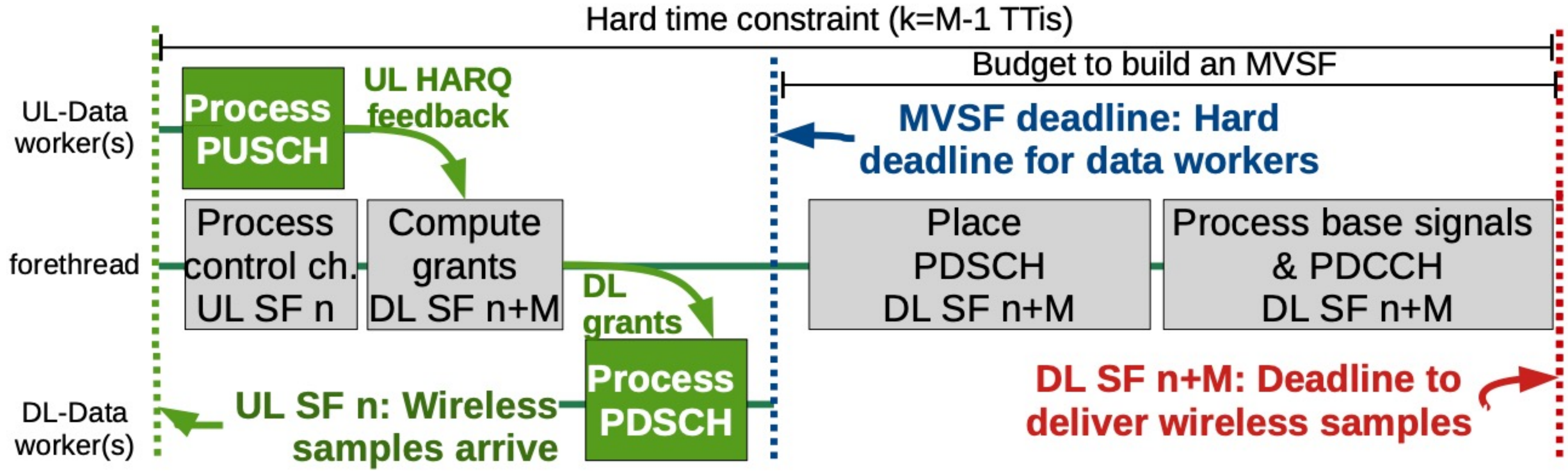


A resilient pipelined stack

- Decouple heavy tasks (PUSCH, PDSCH), which alleviates head-of-line blocking)
- Hard deadline for data processing workers
  - This guarantees sufficient residual time to build a **minimum viable SF** (MVSF), which preserves sync

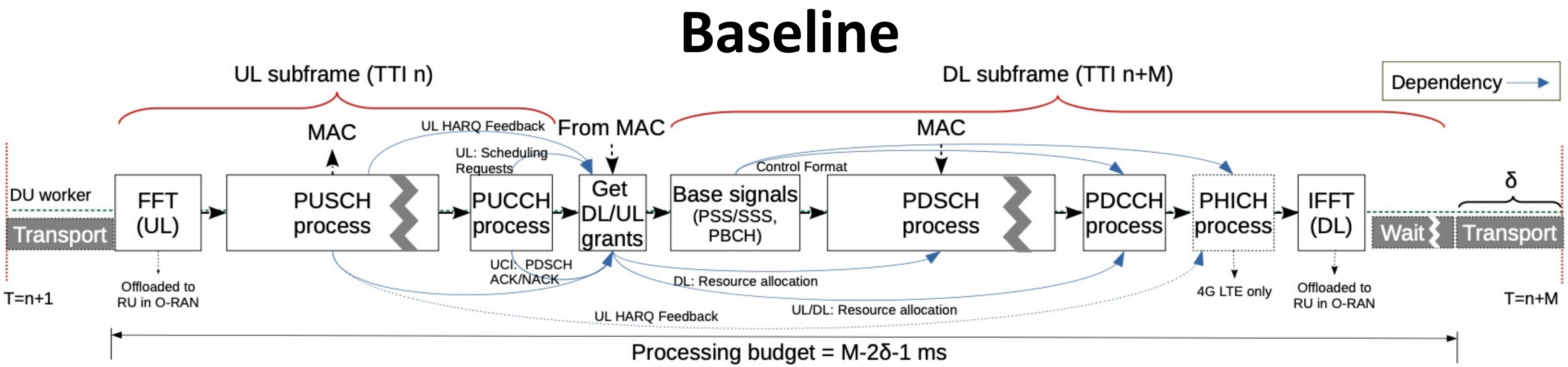


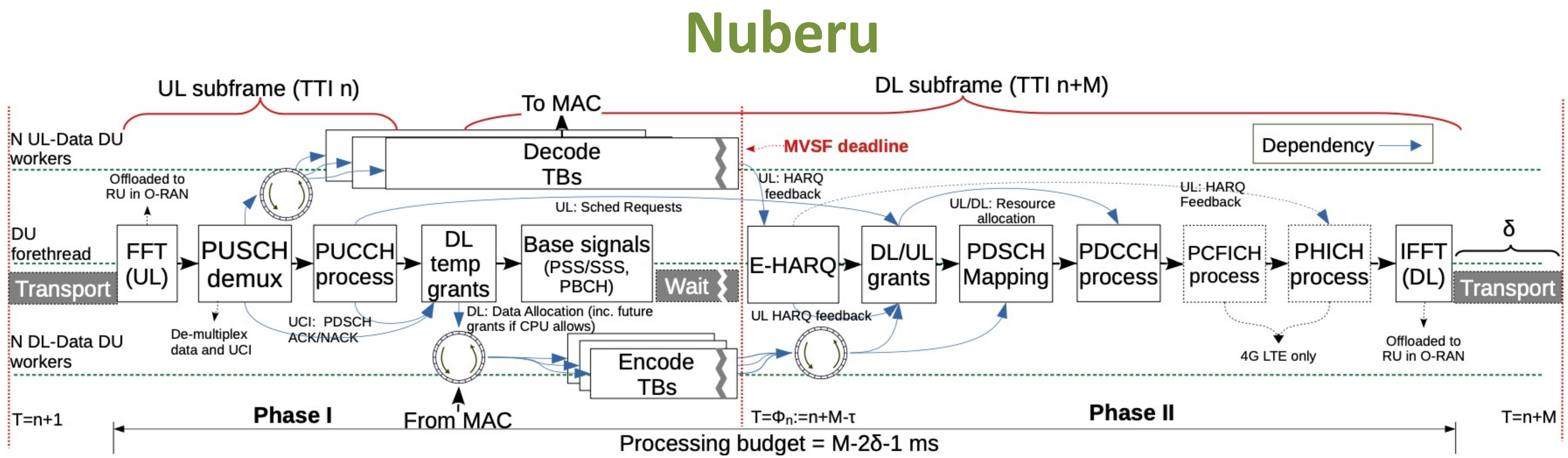
Approach: Three families of workers



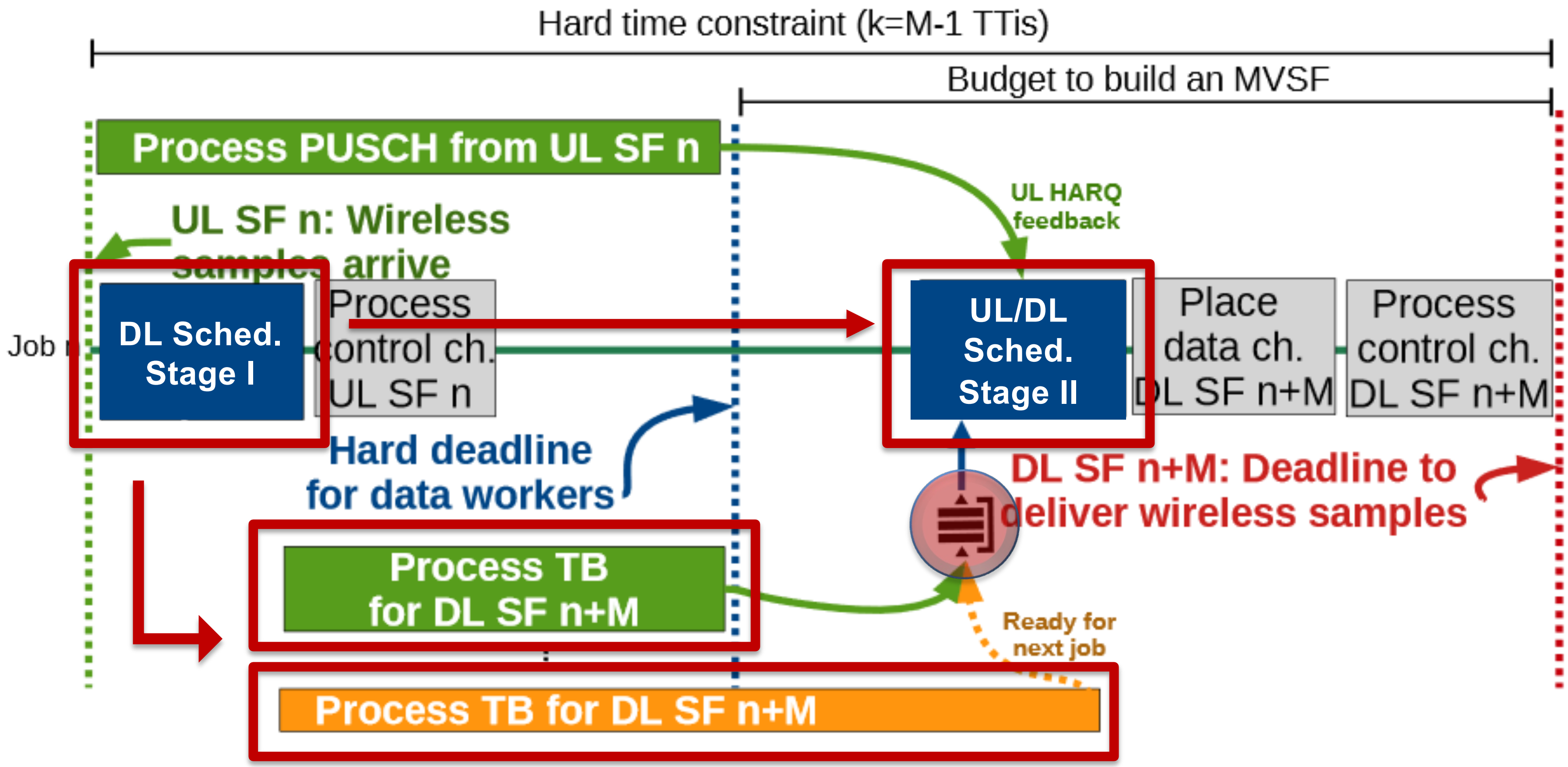
- DU forethread
  - (i) building the MVSF;
  - (ii) coordinating the remaining workers
- DL-Data DU workers: process PDSCH tasks
- UL-Data DU workers: process PUSCH tasks

Approach: Two phases

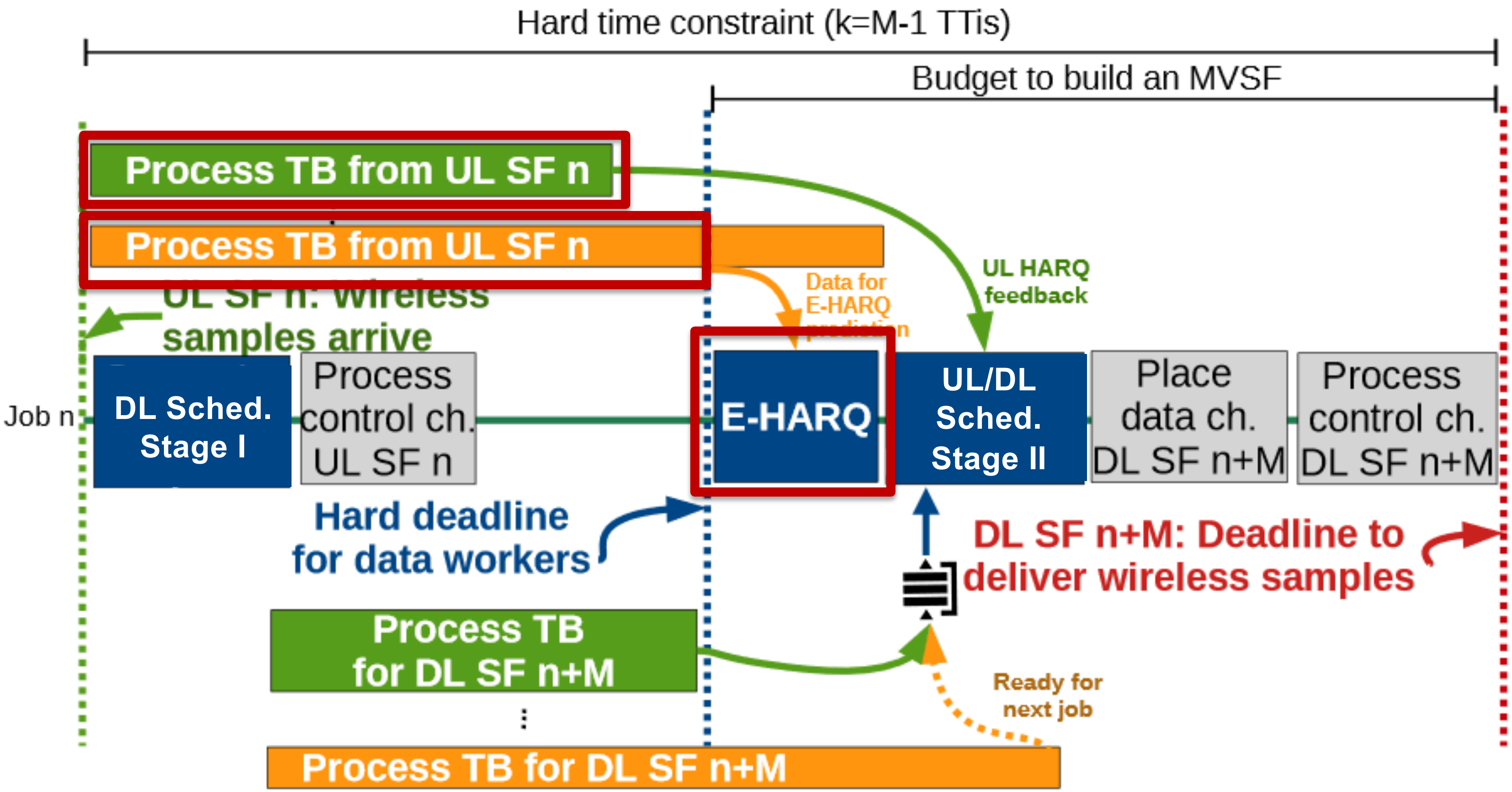




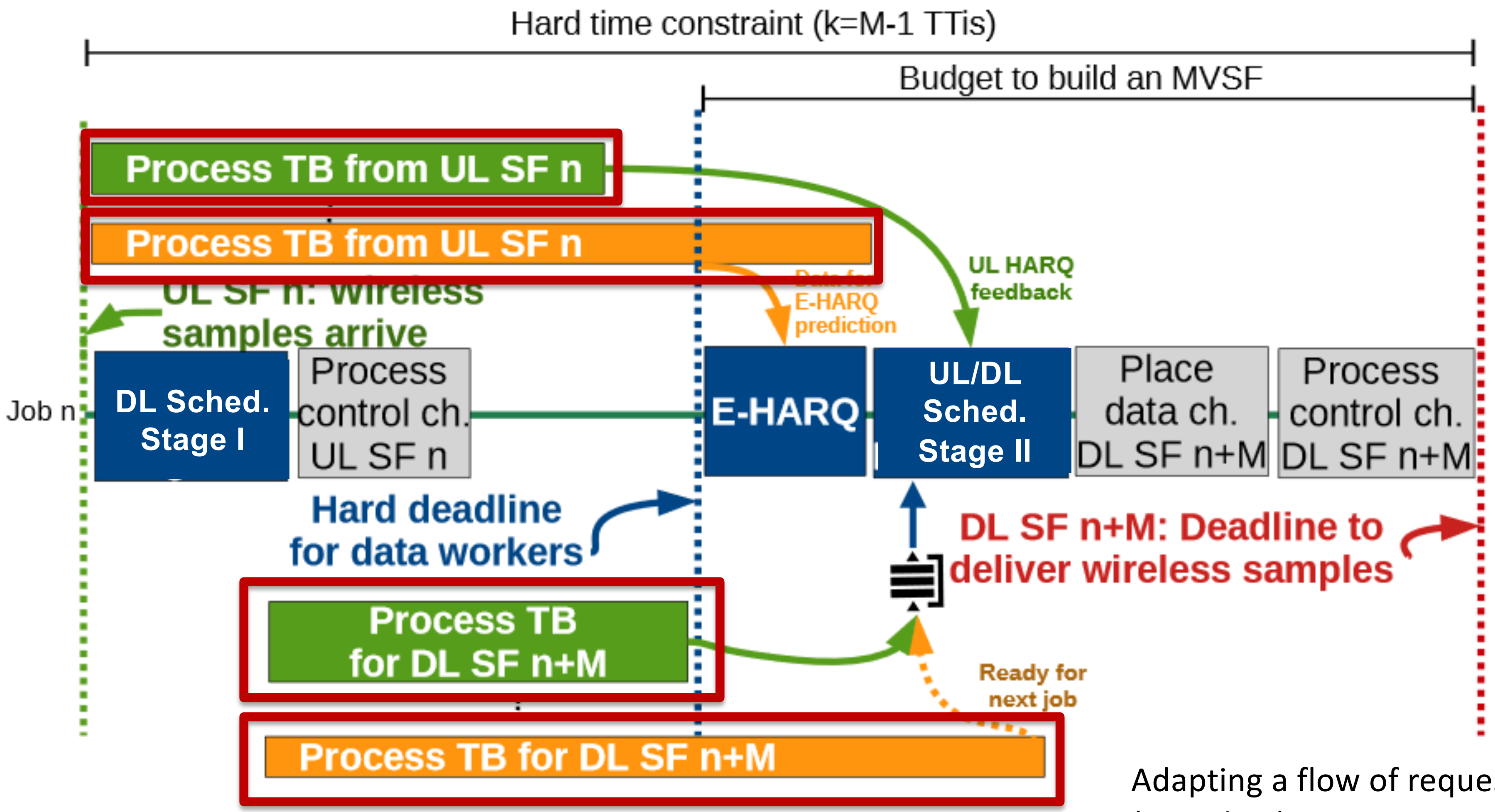
DL: Two stage scheduling



UL: Early Hybrid-ARQ (E-HARQ)



Adapt DL/UL grants to capacity



Adapting a flow of requests (encoding) to a server capacity (computing platform): cong. control

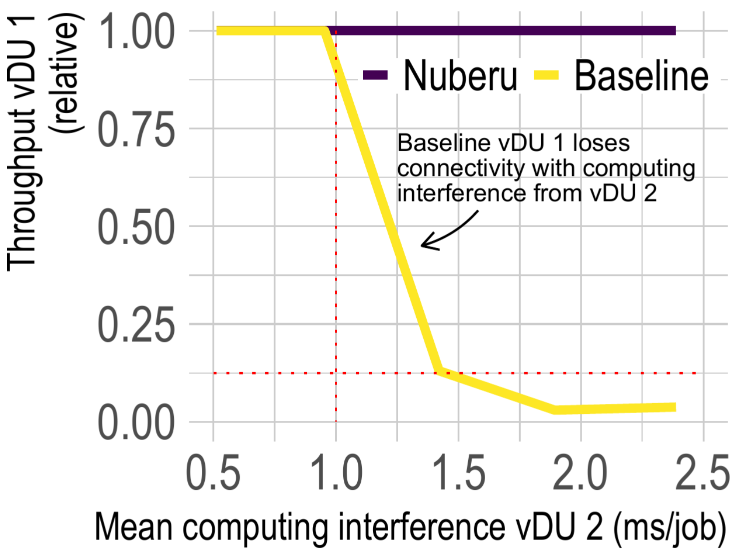
Two Congestion Control Algs.

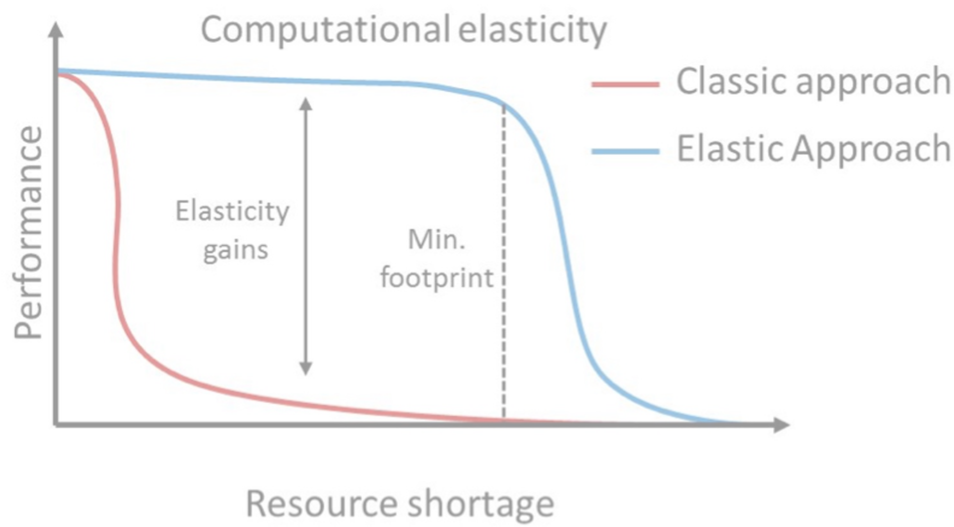
- Predict & schedule DL/UL grants that can be processed in time
- Simple AIMD approach with a CW that limits the size of grants
  - DL: if the buffer of encoded grants > λ times the BS's bandwidth -> reduce CW
  - UL: Failed E-HARQ predictions -> reduce CW

RESULTS

It works!

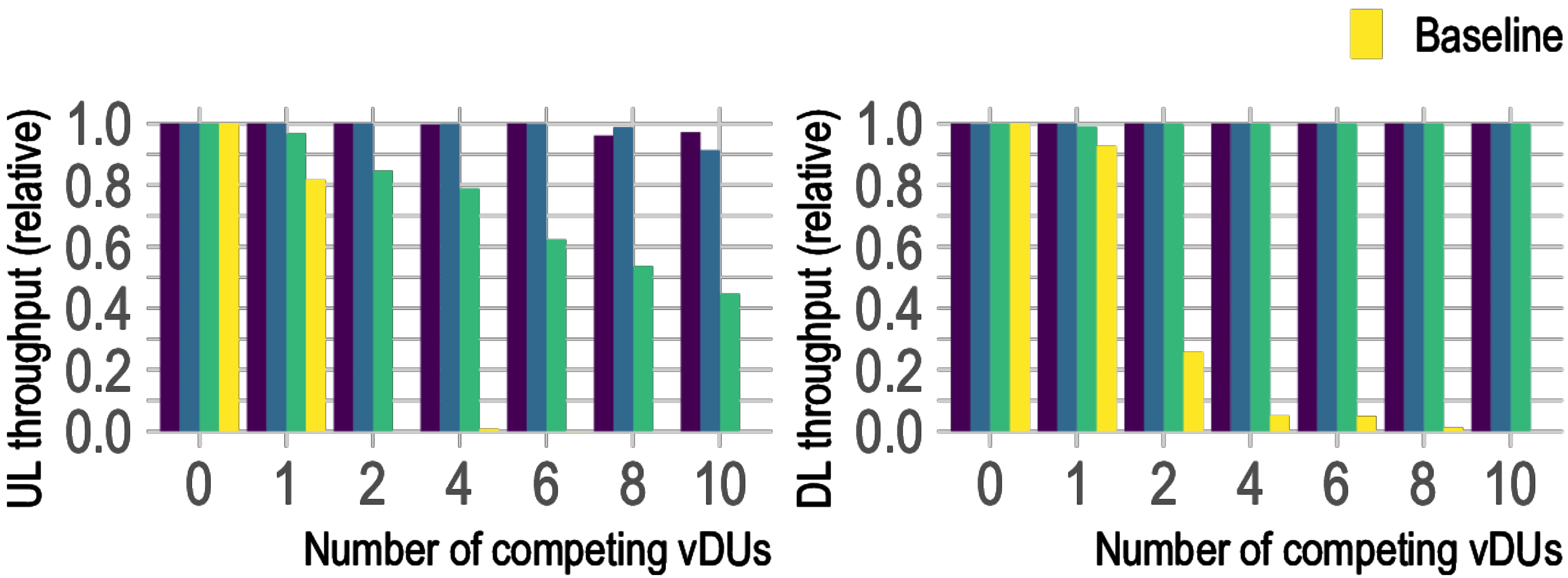
- Same toy experiment as before





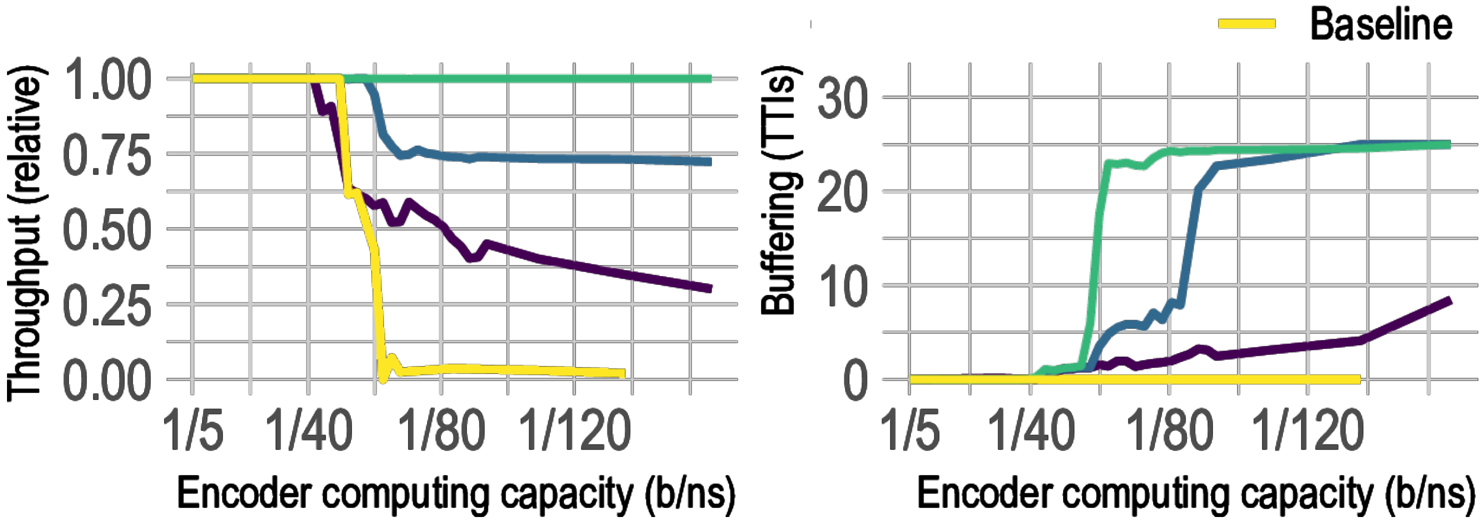
Evaluation: Multiple DUs

- We emulate the presence of competing vDUs
  - A small test program with a thread pool that spawns instances of Intel FlexRAN decoding TBs



Throughput-delay trade-off

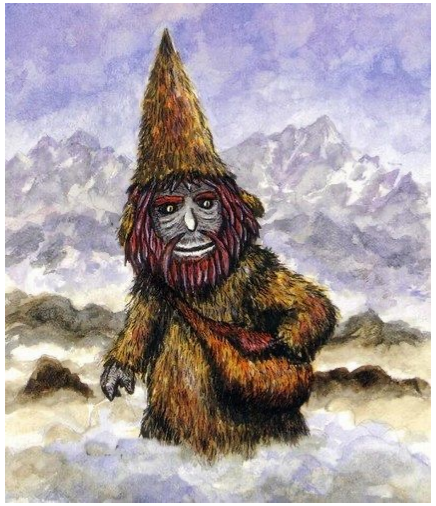
- Artificially slow down the CPU processor



Summary

- The success of vRAN depends on the ability to use shared computing platforms
- The Distributed Units (DU) of vRANs are sensitive to non-deterministic performance due to hard time constraints
- Nuberu: a re-design of the baseline DU pipeline for vRANs over clouds of shared resources
  - Preserves synchronization with the users to provide reliability regardless of computing fluctuations
  - Congestion control, predictive HARQ, and jitter-absorbing buffers to maximize performance

Nuberu: Reliable RAN Virtualization



A. Garcia-Saavedra, G. Garcia-Aviles, M. Gramaglia, X. Costa, P. Serrano, A. Banchs, “Nuberu: Reliable RAN Virtualization," MobiCom ‘21, https://doi.org/10.1145/3447993.3483266

Pablo Serrano
Univ. Carlos III de Madrid (UC3M)
pablo@it.uc3m.es
http://www.it.uc3m.es/pablo/

uc3m | Universidad Carlos III de Madrid