DETERMINISTIC6G

5G latency analysis and possible improvements

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Webinar on Architectural enhancements for 6G programmable and deterministic networks

DETERMINISTIC6G has received funding from the European Union's Horizon Europe programme under grant agreement No 101096504.

Speakers

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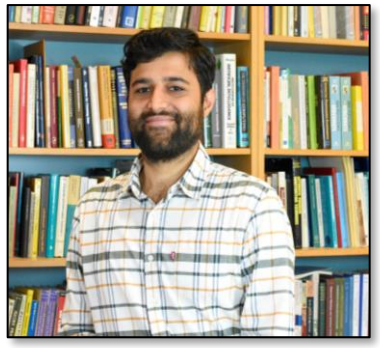
Senior Expert at Ericsson Research

>25 years experience in 2G to 6G



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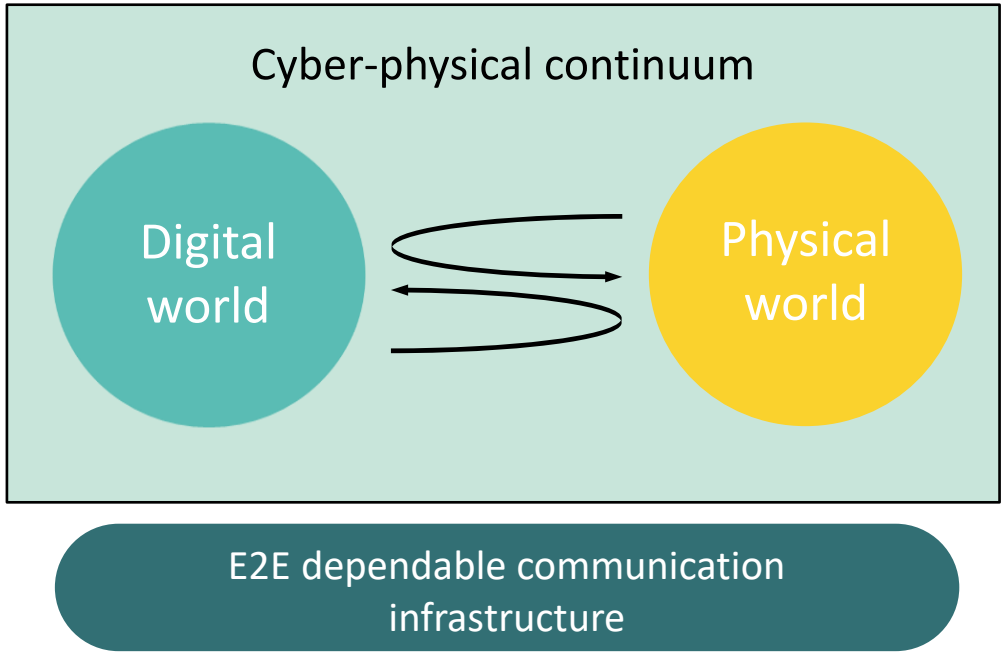
Outline

- Introduction
- Latencies in 5G Networks
- DETERMINISTIC6G Approach
- Summary

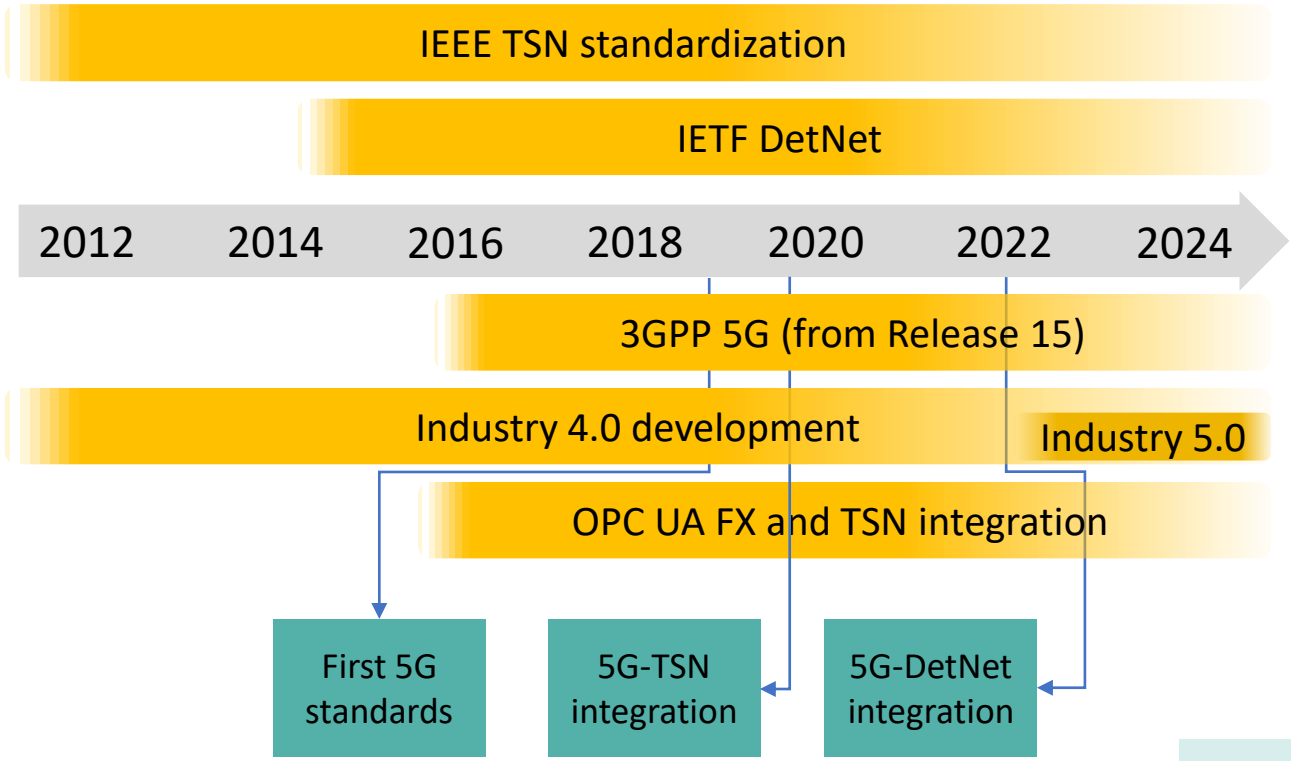
Moving towards a Cyber-Physical Continuum

- The digitalization is driving the transformation of the society and industries
- New forms of interactions will lead to a converged cyber-physical continuum spanning different communication technologies
- End-to-End (E2E) dependable communication infrastructure is a necessary requirement to support such interactions



Today's Dependable Communications Arena

- Over the last decade, the major pivot of the communications community has been towards low-latency and reliability
  - Digitalization of automation systems as a main driver
- Several communication technologies (TSN, DetNet, 5G, OPC UA) are independently evolving towards the support for wired/wireless dependable communication
  - So far only limited interworking (e.g., recent 5G-TSN integration architecture)

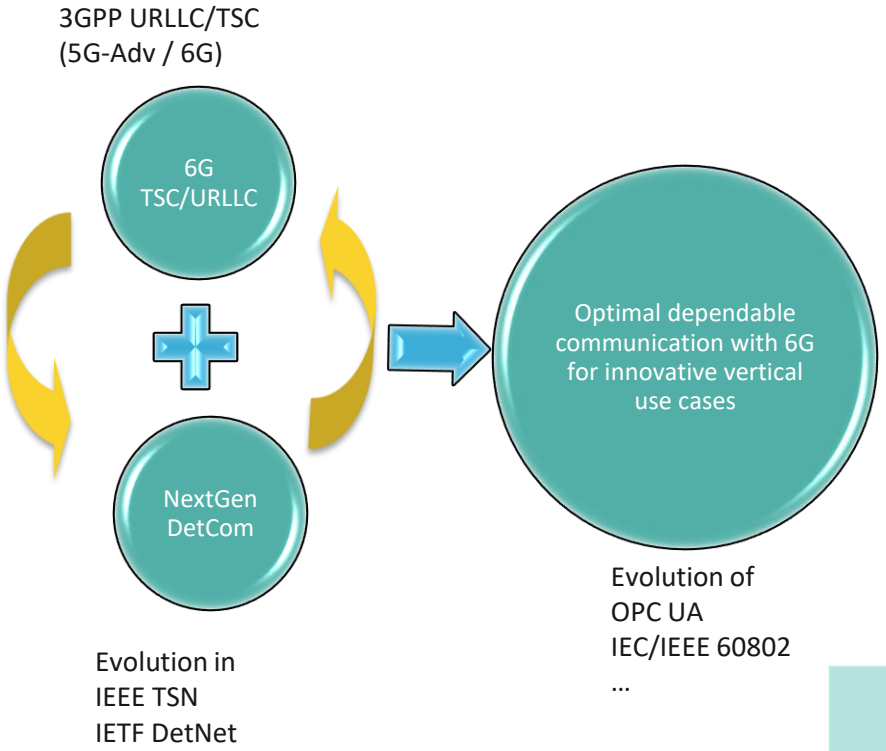


TSN : Time-Sensitive Networking
OPC UA : OPC Unified Architecture
DetNet: Deterministic Networking

DETERMINISTIC6G Vision

The DETERMINISTIC6G vision is to set the foundation for future global communication standards enabling 6G dependable communication for visionary use cases

- New concepts, features and solutions to
  - Evolve TSN & DetNet to become more wireless-friendly
  - Improve 5G-Advanced/6G to be better suited for dependable communication
  - Align with the main application middleware for dependable communication: OPC UA (with its features on OPC UA FX (Field eXchange) and the usage of TSN)



URLLC: Ultra-reliable and low-latency communications
5G-Adv: 5G-Advanced
TSN : Time Sensitive Networking
TSC: Time Sensitive Communication
DetNet: Deterministic Networking

DETERMINISTIC6G Consortium

Industrial application players bringing 6G visionary use cases

Key industrial players in 6G research and development

Key university and research institutes at the forefront for 6G fundamental research

12 partners (Coordinator: Ericsson GmbH)

Jan 2023 – Jun 2025 (30 months)

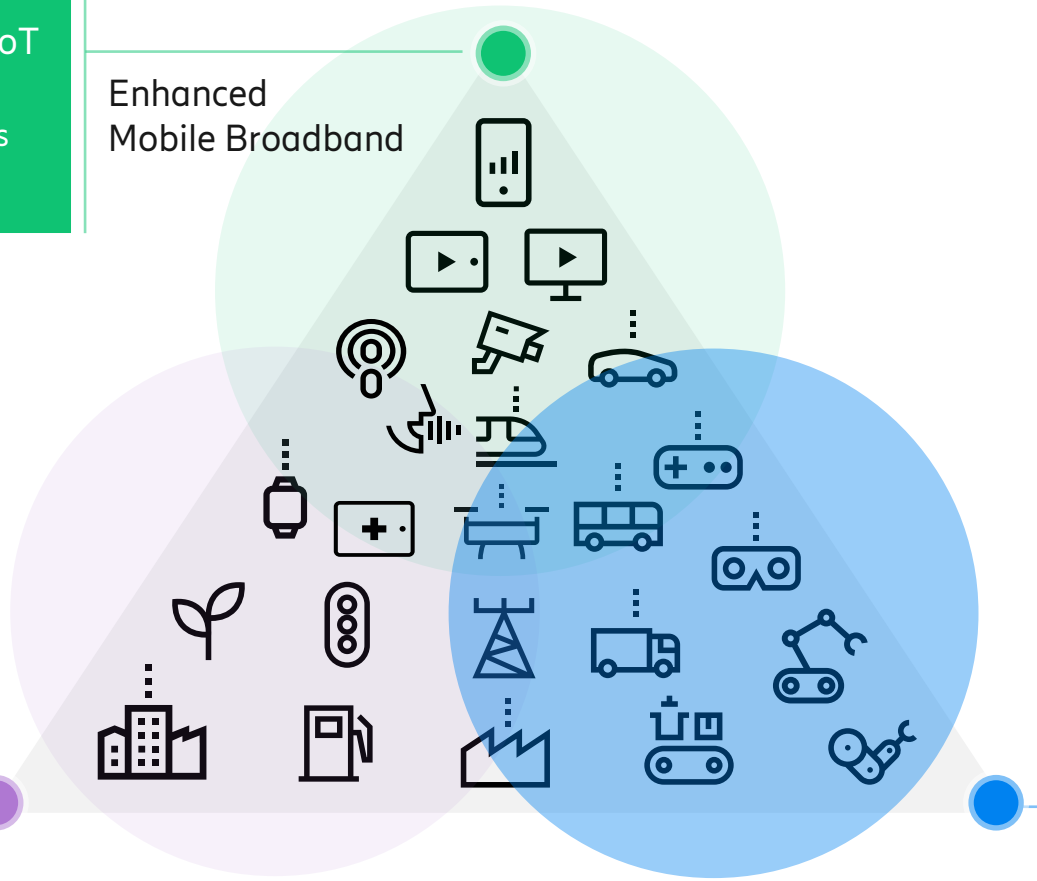
€ 5.8 M€

5G Ambitions

eMBB/Broaband IoT
- Extreme data rates
- Large data volumes
- Best effort latency

Enhanced Mobile Broadband

Massive IoT
- Low cost devices
- Extreme coverage
- Long device battery life



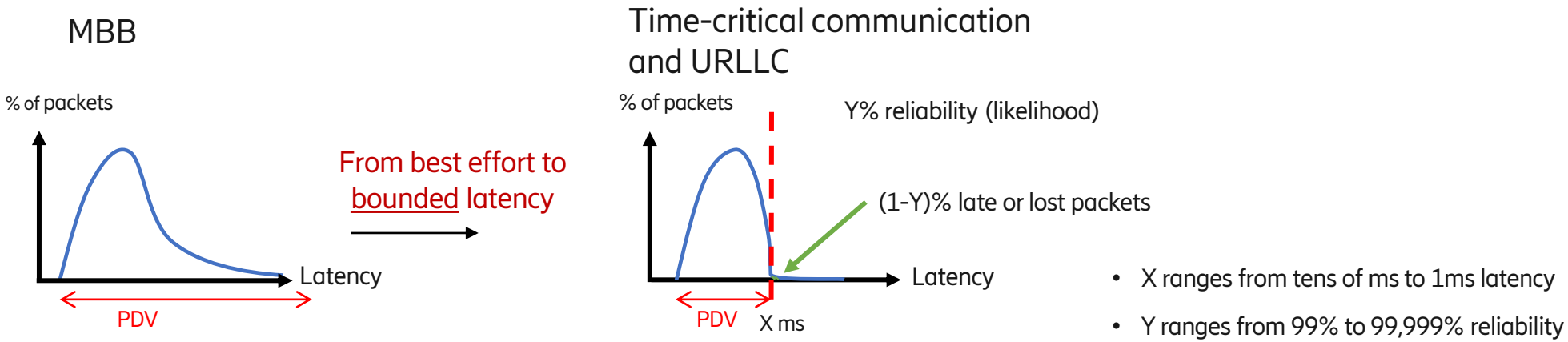
Massive machine type communications

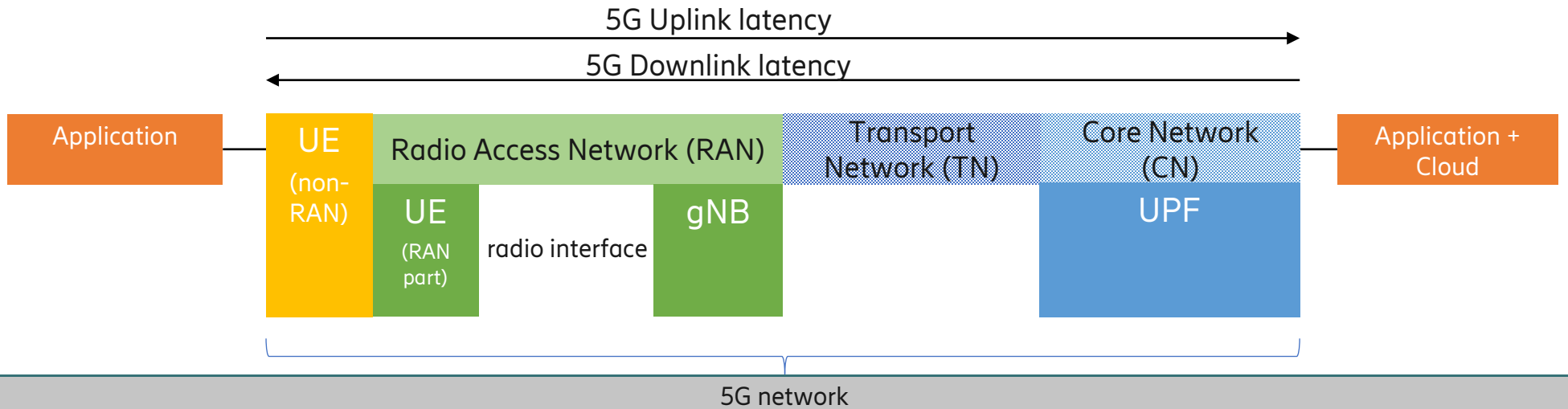
Critical IoT including Time-Critical Communication
- Consistent latency (low to ultra-low)
- High reliability
- High availability

Ultra-Reliable and Low Latency Communication

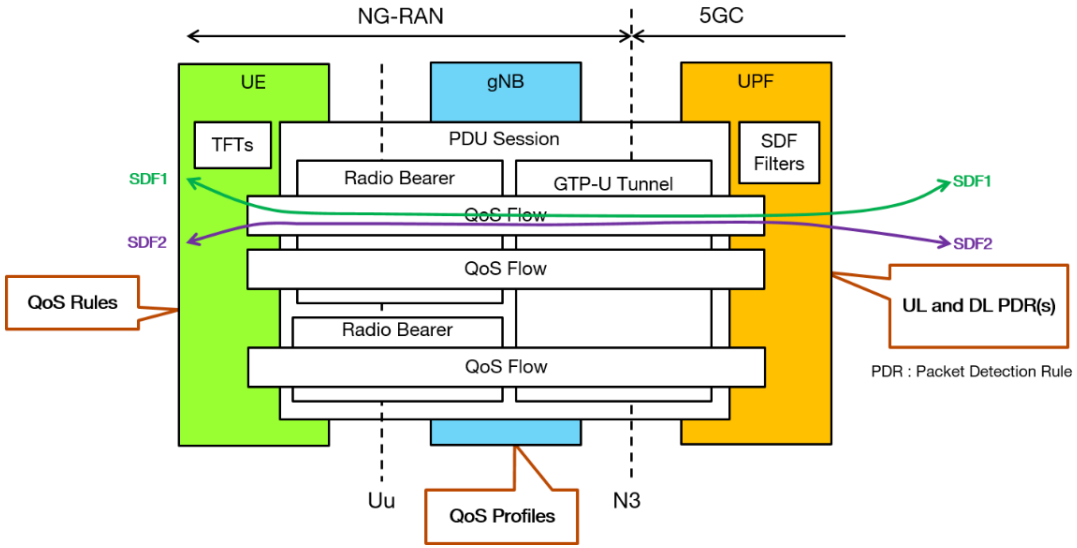
Source: Ericsson Based on: ITU's vision for IMT 2020 & beyond

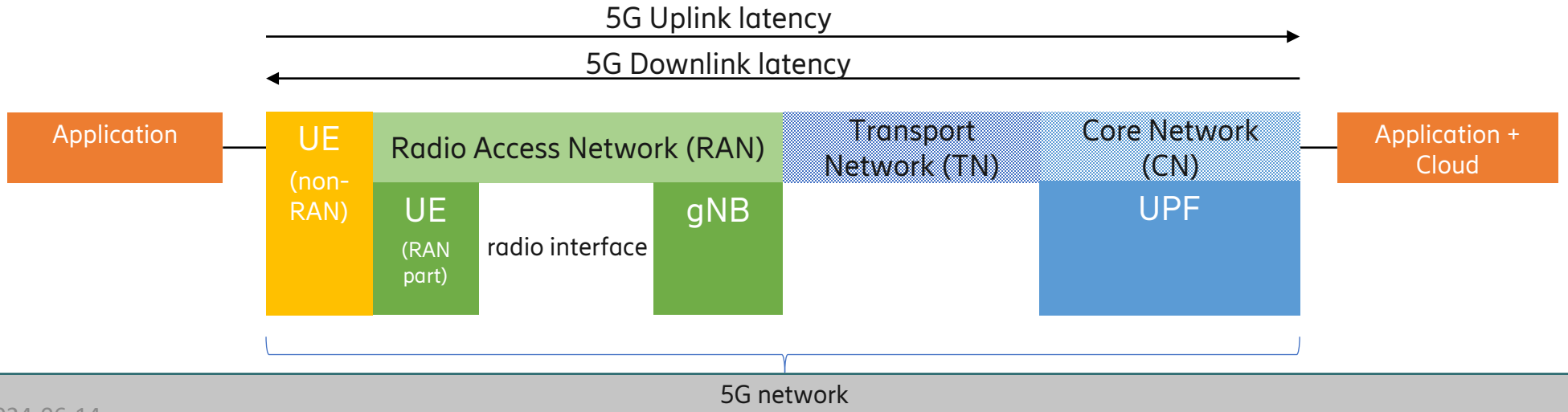
Time-critical Communication



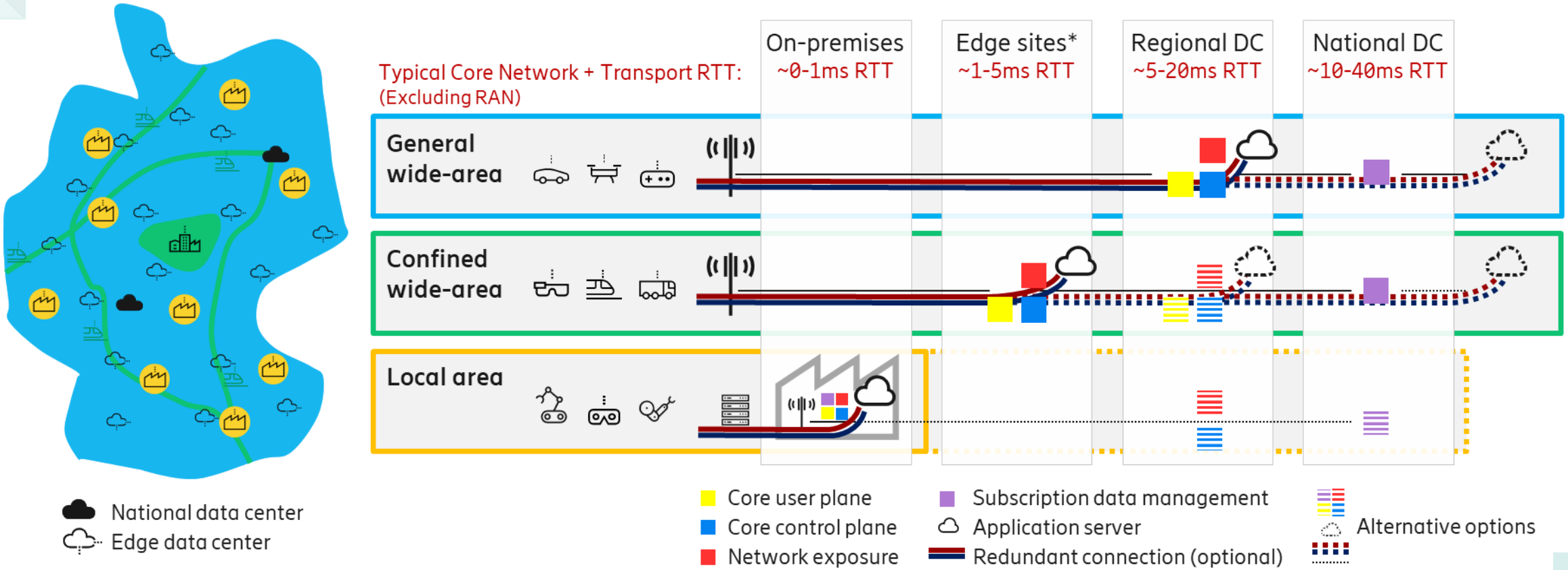


Time-critical Applications



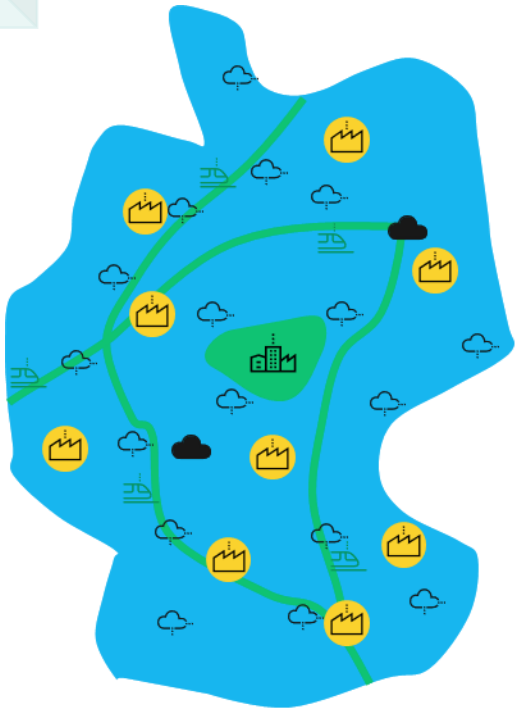


Latency Induced by Distance

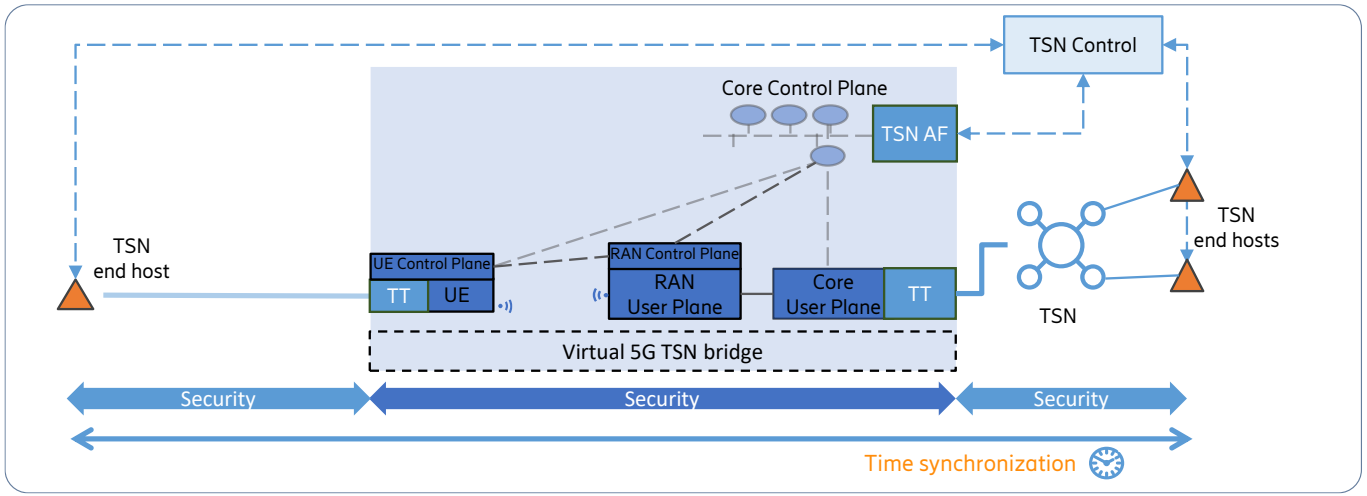


F. Alriksson, L. Boström, J. Sachs, Y. . -P. E. Wang and A. Zaidi, "Critical IoT connectivity Ideal for Time-Critical Communications," in Ericsson Technology Review, vol. 2020, no. 6, pp. 2-13, June 2020, doi: 10.23919/ETR.2020.9905508

5G Non-public (private) Networks



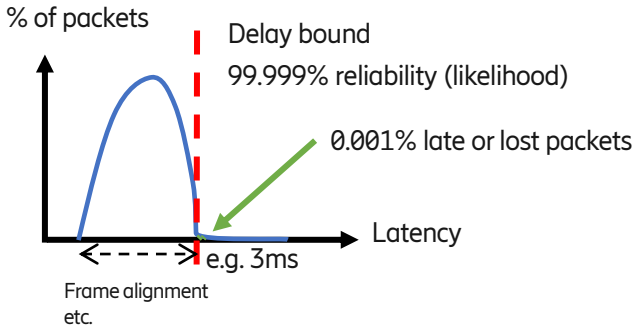
National data center
Edge data center

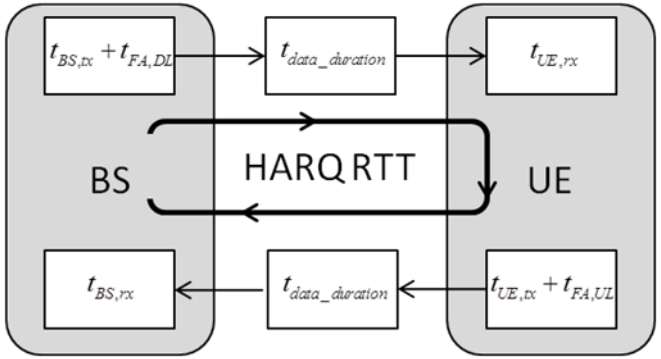


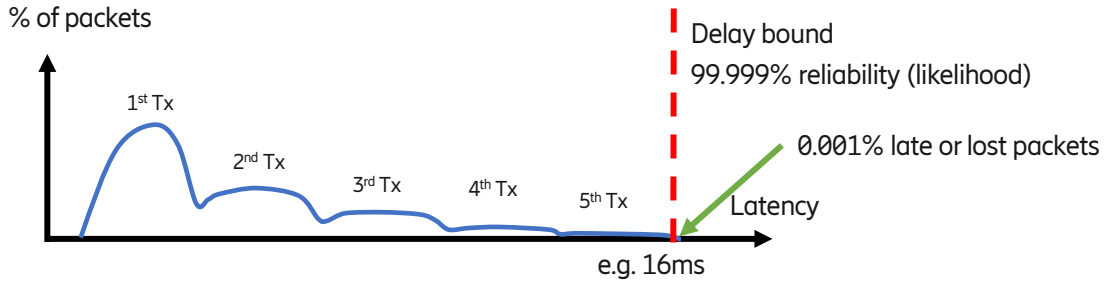
Core user plane
Core control plane
Network exposure
Subscription data management
Application server
Redundant connection (optional)
Alternative options

* Edge sites include local access sites, hub sites and radio access sites

Reliability vs. Latency

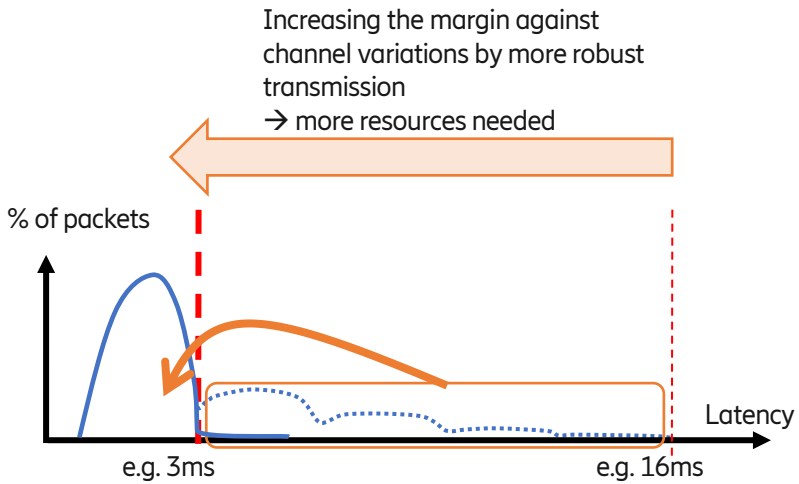


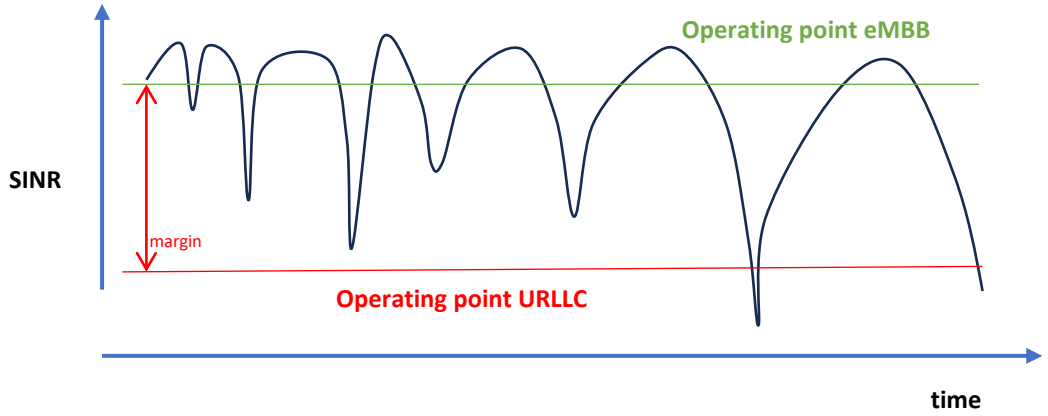




DETERMINISTIC6G, Deliverable 2.1, "First report on 6G centric enablers," Dec. 2023, https://deterministic6g.eu/index.php/library-m/deliverables

Reliability vs. Spectral Efficiency





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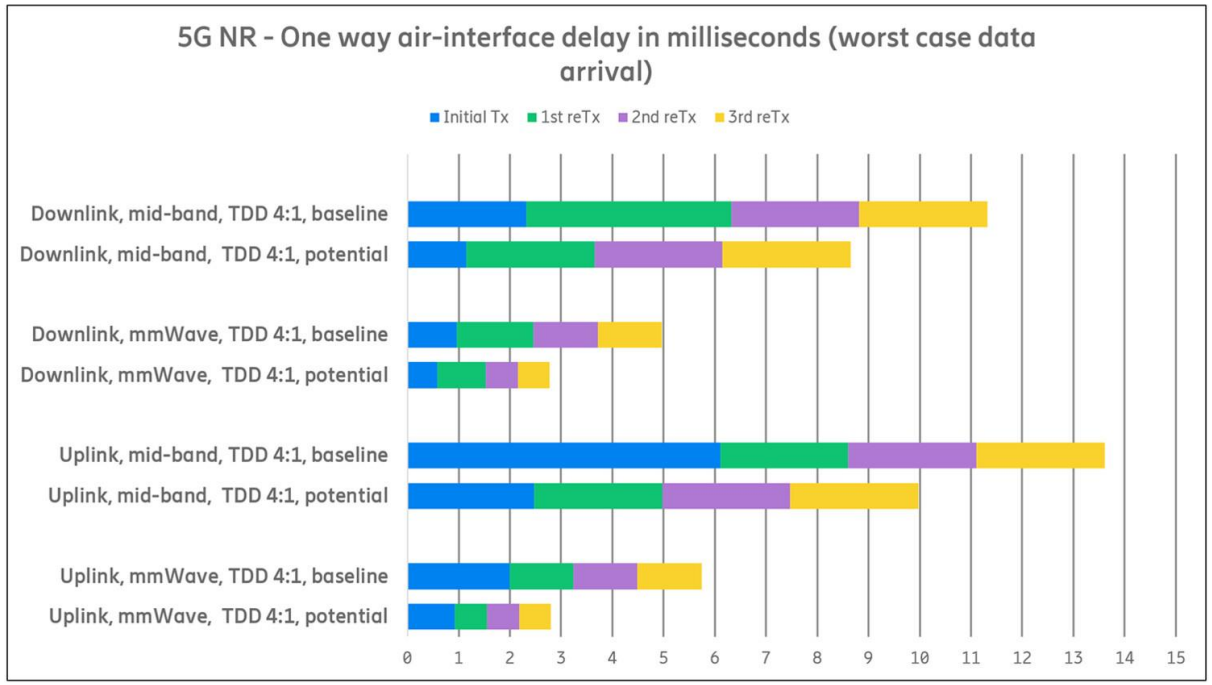
URLLC with 5G

URLLC toolbox

- ❑ Pre-scheduling and configured grant
- ❑ Mini-slots and flexible numerology
- ❑ Fast HARQ
- ❑ Preemptive transmission
- ❑ Robust control and data channels
- ❑ Redundant connectivity
- ❑ Multi-antenna diversity



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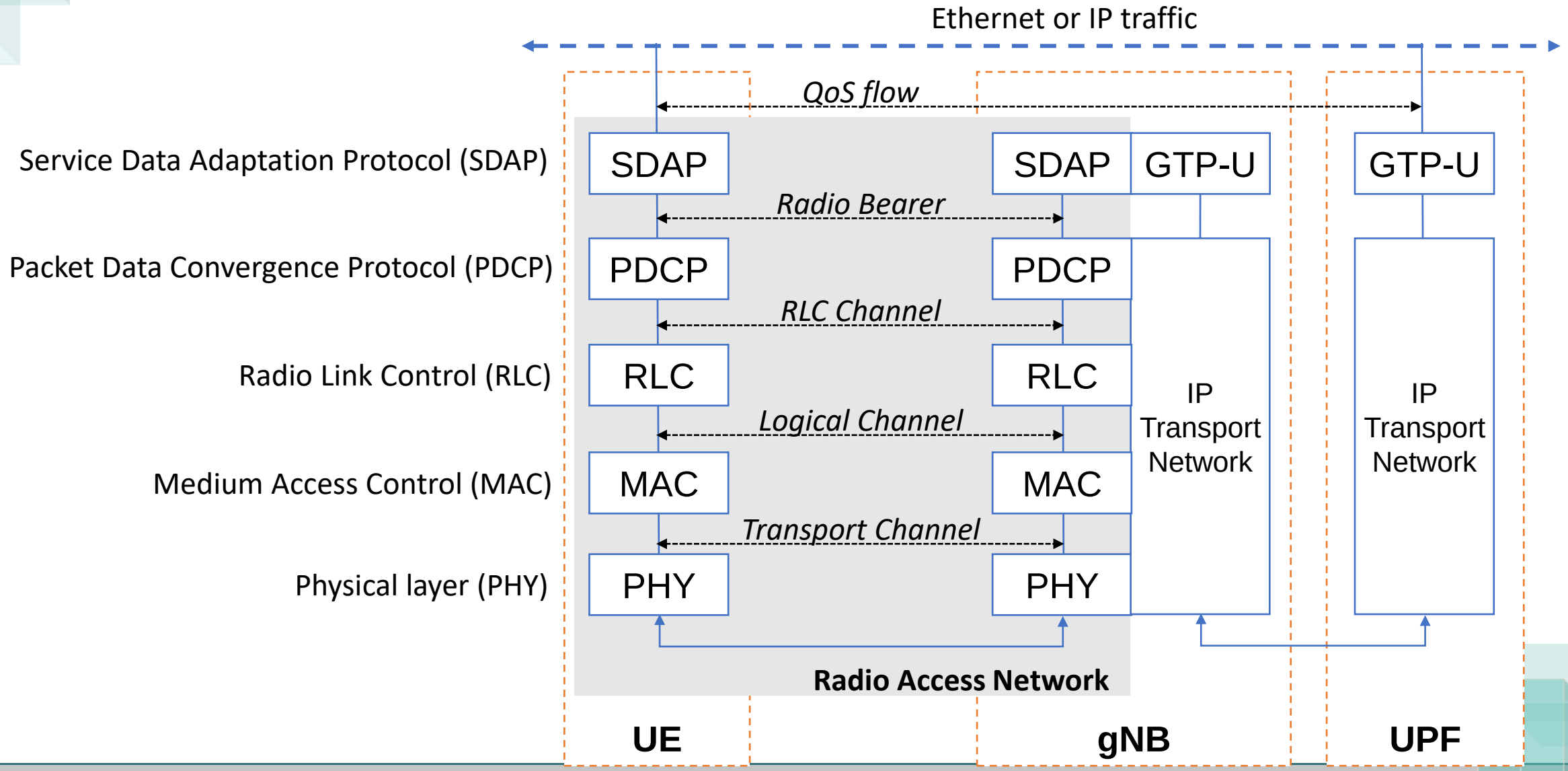
5G RAN Latency Contributors



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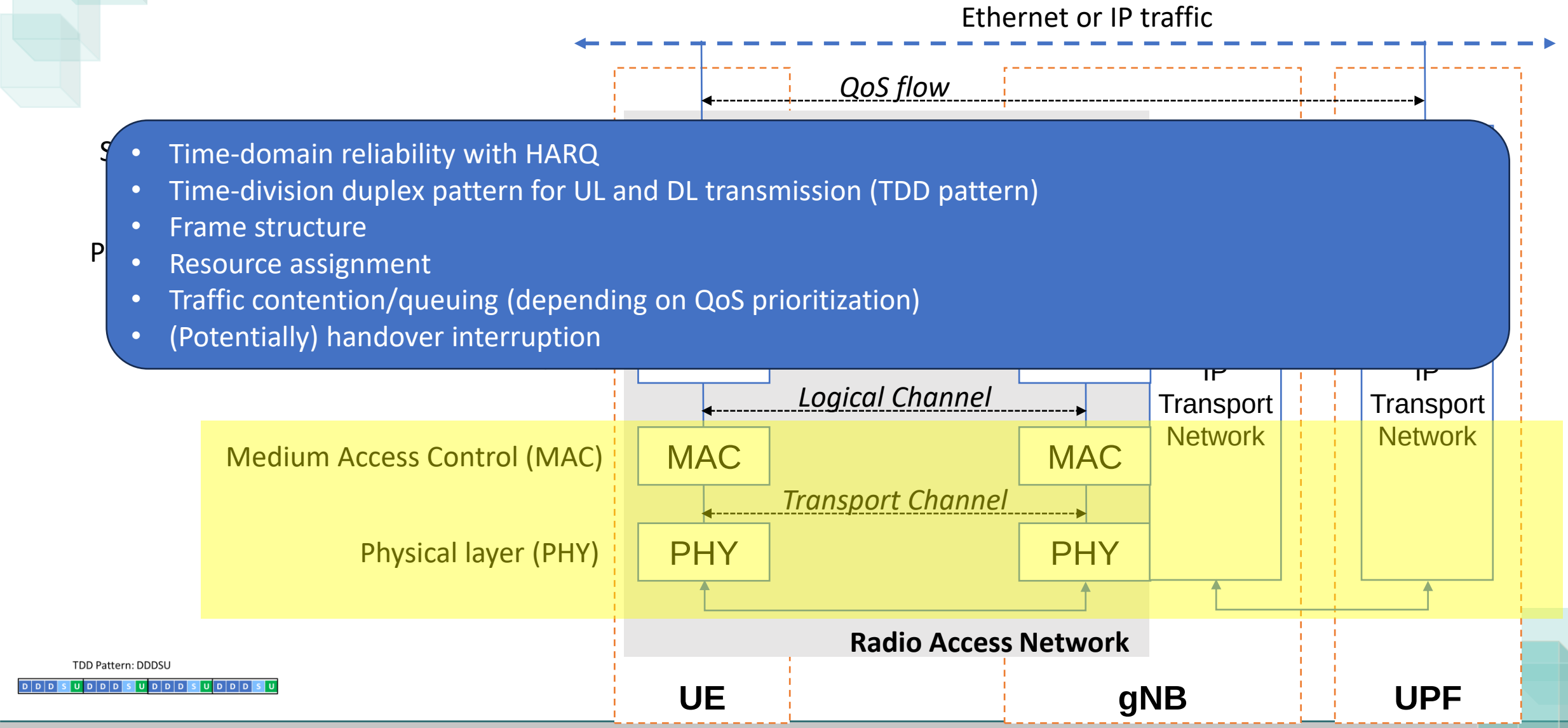

- Time-domain reliability with HARQ
- Time-division duplex pattern for UL and DL transmission (TDD pattern)
- Frame structure
- Resource assignment
- Traffic contention/queuing (depending on QoS prioritization)
- (Potentially) handover interruption

DETERMINISTIC6G, Deliverable 2.1, "First report on 6G centric enablers," Dec. 2023, https://deterministic6g.eu/index.php/library-m/deliverables

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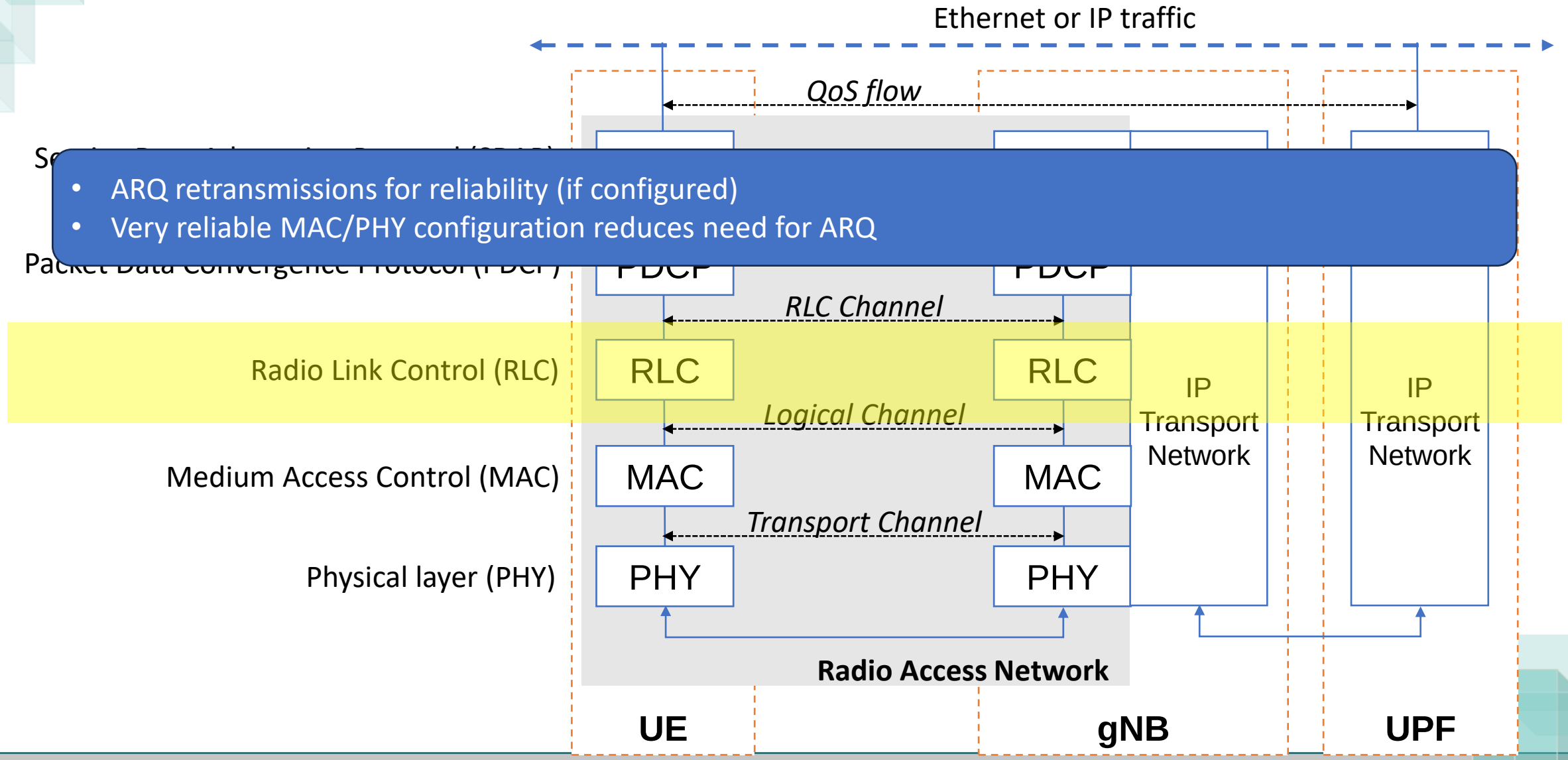

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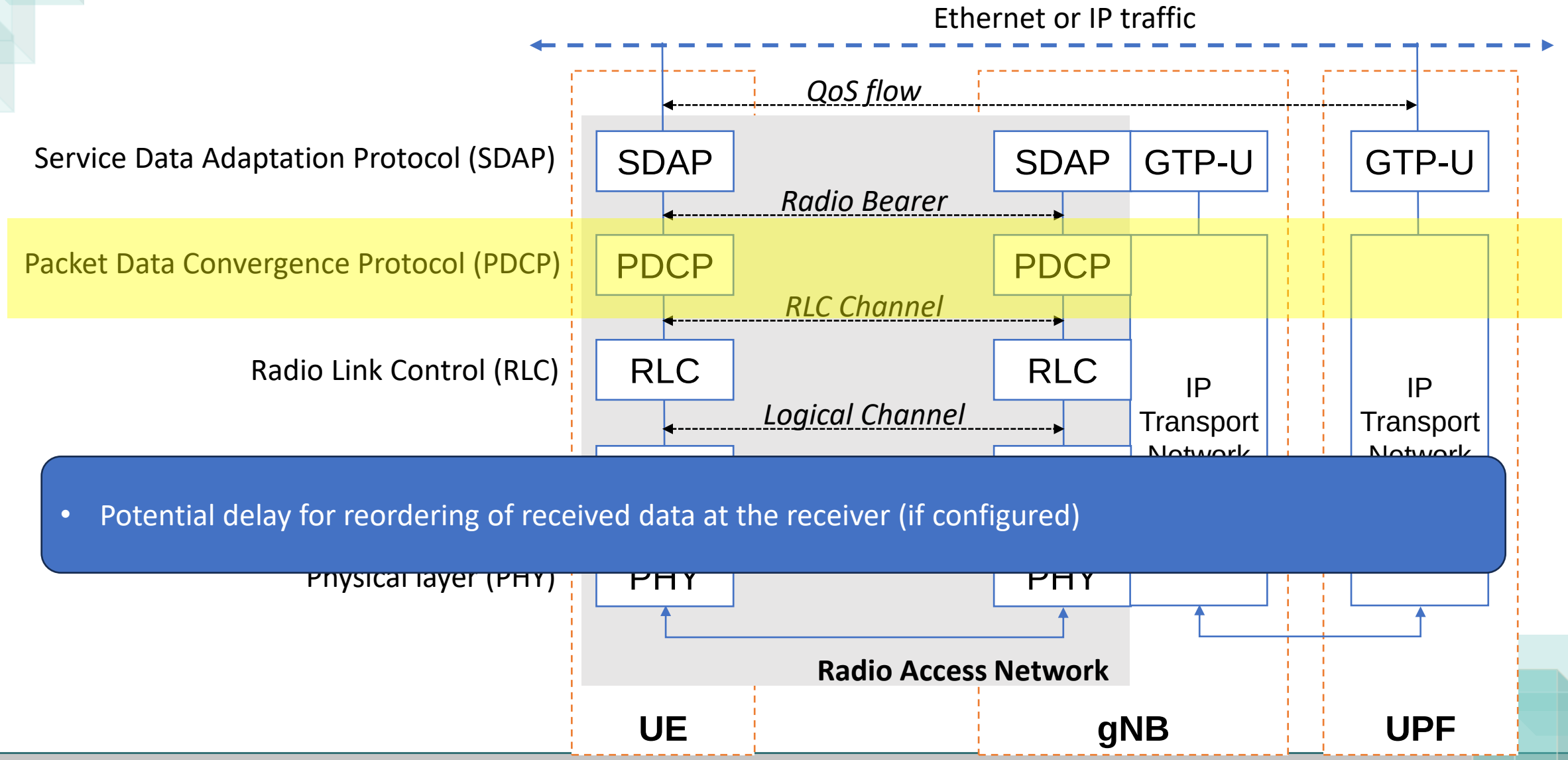
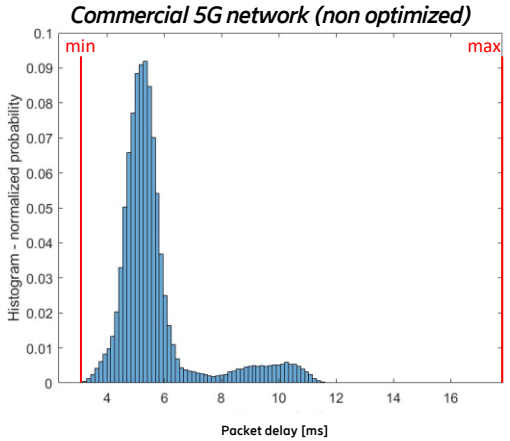


- Potential delay for reordering of received data at the receiver (if configured)

DETERMINISTIC6G, Deliverable 2.1, "First report on 6G centric enablers," Dec. 2023, https://deterministic6g.eu/index.php/library-m/deliverables

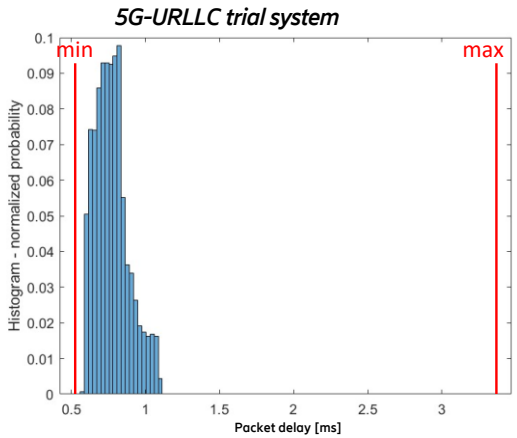
5G Networks: From Trials to Reality

- 5G networks show comparatively large packet delay variation (PDV), even with URLLC



(a)

Ansari et al. Electronics 2022



(b)

Ansari et al., TSNA 2022
Kehl et al. Electronics 2022

[1] J. Ansari, C. Andersson, P. de Bruin, J. Farkas, L. Grosjean, J. Sachs, J. Torsner, B. Varga, D. Harutyunyan, N. König, R. H. Schmitt, “Performance of 5G Trials for Industrial Automation. Electronics”, 2022; 11(3):412. https://doi.org/10.3390/electronics11030412

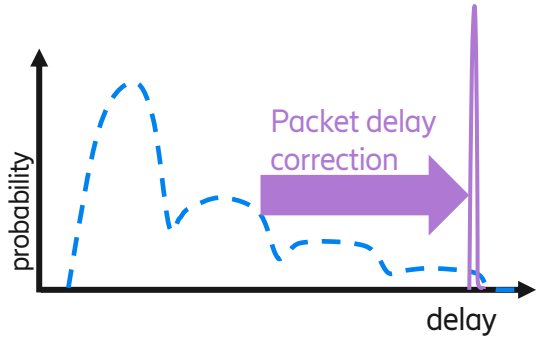
[2] P. Kehl, J. Ansari, M. H. Jafari, P. Becker, J. Sachs, N. König, A. Göppert, R. H. Schmitt, “A Prototype of 5G Integrated with TSN for Edge-Controlled Mobile Robotics" Electronics 11, no. 11: 1666, 2022. https://doi.org/10.3390/electronics11111666

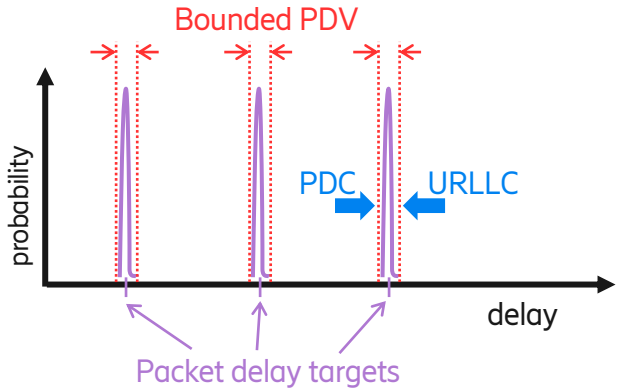
[3] DETERMINISTIC6G, “Digest on First DetCom Simulator Framework Release”, deliverable D4.1, Dec. 2023, https://deterministic6g.eu/index.php/library-m/deliverables

[4] DETERMINISTIC6G, “Report on 6G convergence enablers towards deterministic communication standards”, deliverable D3.1, Dec. 2023, https://deterministic6g.eu/index.php/library-m/deliverables

Packet Delay Variation (PDV)

- Time-sensitive / deterministic transmission
  - Receiving the right packet at the right time
- Packet-delay variation creates uncertainty on packet arrivals
  - Can be problematic for e.g. Time-Sensitive Networking (TSN) time-scheduled transmission [D3.1]
- Correction of PDV via packet delay correction (PDC) in 6G can remove uncertainty of packet delays [D2.1]

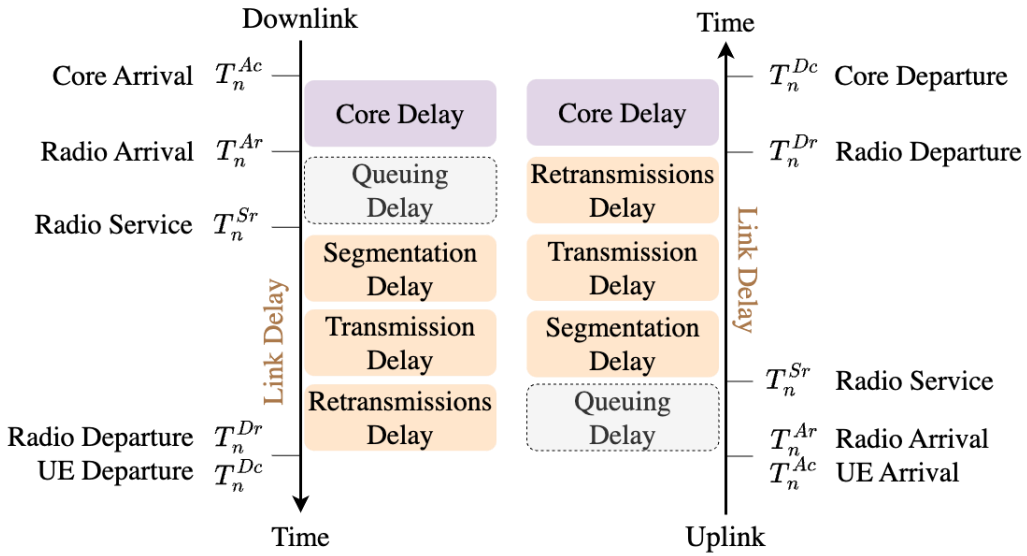




[D2.1] DETERMINISTIC6G, Deliverable 2.1, "First report on 6G centric enablers," Dec. 2023, https://deterministic6g.eu/index.php/library-m/deliverables
[D3.1] DETERMINISTIC6G, Deliverable 3.1, "Report on 6G convergence enablers towards deterministic communication standards," Dec. 2023, https://deterministic6g.eu/index.php/library-m/deliverables

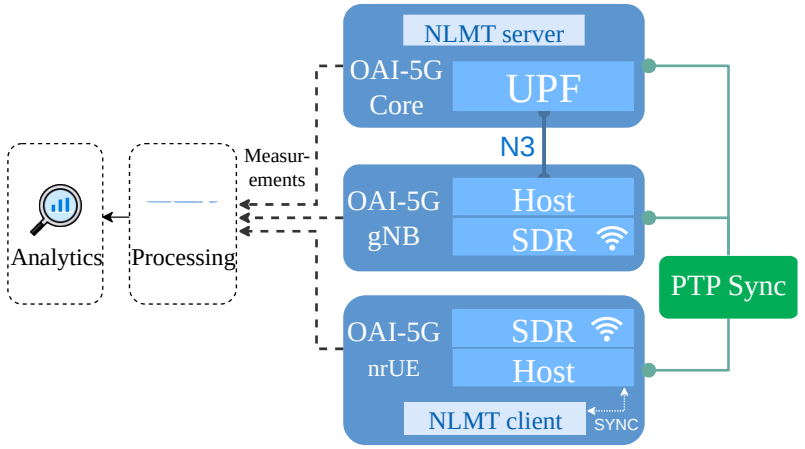
5G Delay Decomposition Model

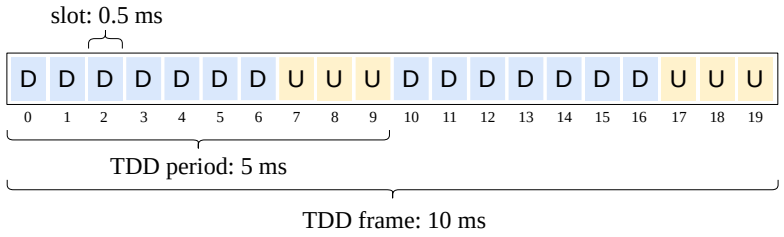
- High-level components: Core delay and RAN delay
- Core delay
  - N3 interface (between RAN and UPF)
  - Industrial scenarios: small and fixed
- RAN delay
  - Dominates in end-to-end delay variations
  - Further split: Queuing Model
    1. Queuing delay (RLC buffer)
       - previous packets, frame-alignment + scheduling
    2. Link delay
       - Segmentation delay
       - Transmission delay
       - Retransmission delay



Experimental Setup

- Implementation on Openairinterface5G with SDRs; hosts were synced with PTP
- Measurement points inserted in the OAI user plane in both UE and gNB for the UL path
- NMLT packet generator that can align send time offset wrt 5G frame boundaries
- Each packet journey is reconstructed using recorded timestamps and stored in a DB



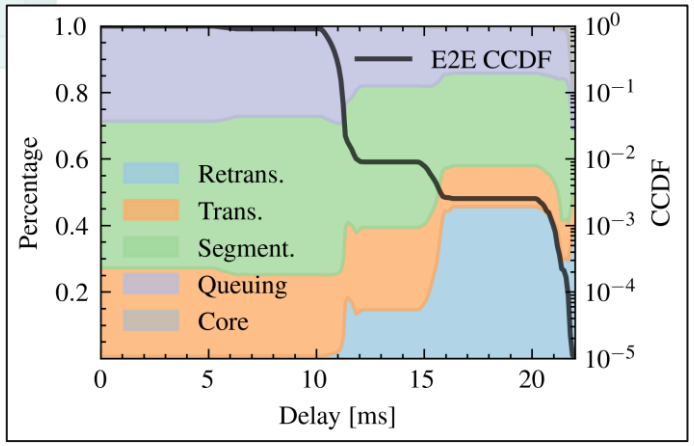


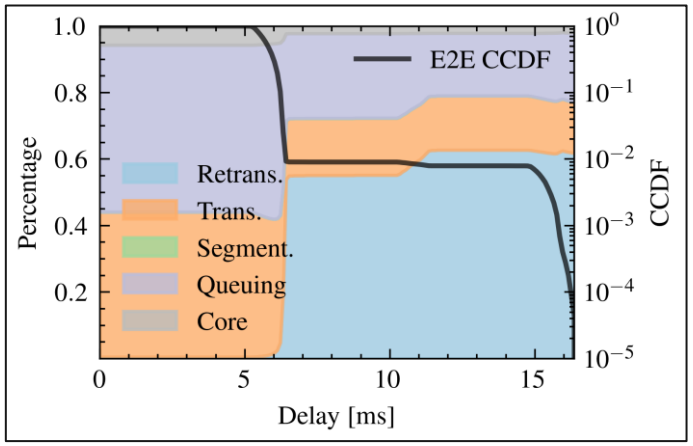
Parameters	Value/Ranges
OAI config	Band 78, TDD, 106 RBs, 40 MHz, SCS of 30kHz (slot size=0.5ms)
Traffic	500B UDP @ 100 Hz

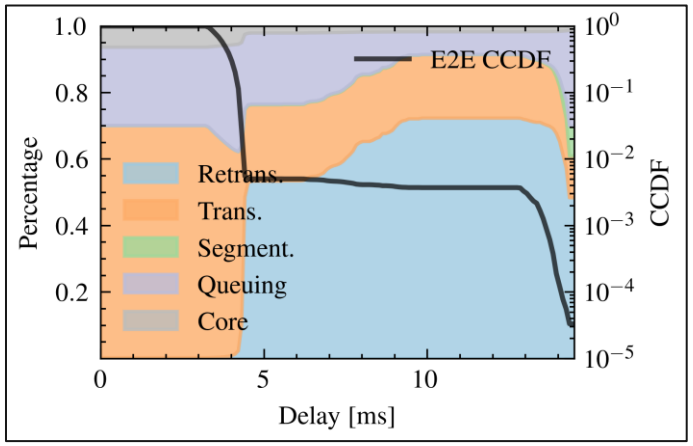
5G Delay Decomposition

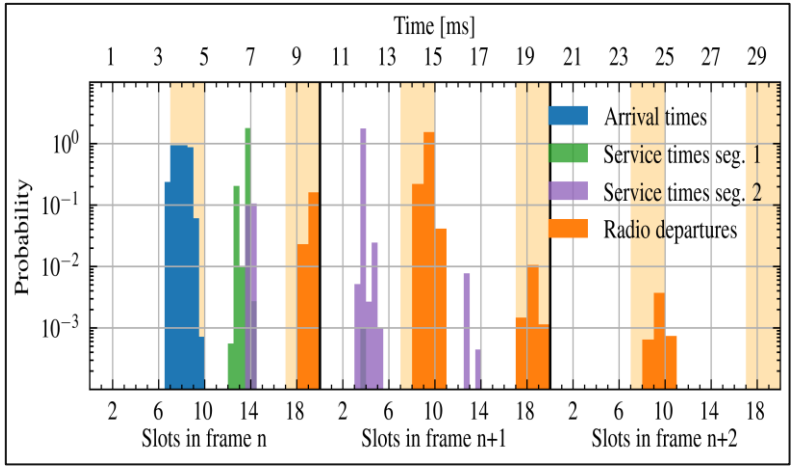
5G Delay Decomposition

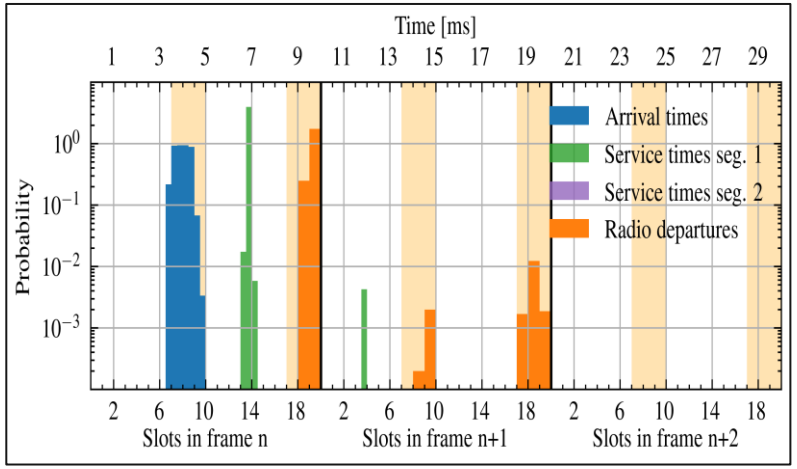
Data-driven Delay Optimization

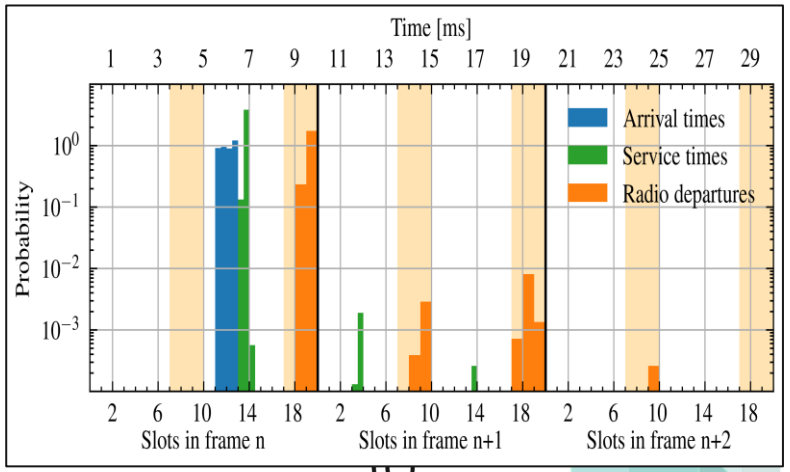












Baseline

Addressing segmentation delay

Addressing frame-alignment delay

Requirements of Time-critical Applications

- Time-sensitive applications typically have critical (lower and upper) delay bounds
  - Avoid failure or degradation of experienced application quality

- Deterministic network and application characteristics (claimed to be) a necessity
  - But challenging in several digitalization enablers
    - Cloud computing
    - wireless communication
    - (adaptive) applications
  - Include stochastic variations

From Deterministic Communication to Dependable Communication

- Strict review of *determinism:*
  - a system without or with negligible stochastic variations
  - a system behaves in a pre-determined way from a certain state with a given input
- Eliminating stochastic elements not always feasible,
  - ➔ Embrace stochastic elements that are not pre-determined
  - ➔ … make them predictable and plannable,
  - ➔ … manage them to fullfill the requirements of the applications and utilize flexibility and adaptability
  - Provide *dependable communication* for time-critical services (➔ the service can rely on the communication)

[1] DETERMINISTIC6G, "DETERMINISTIC6G use cases and architecture principles", deliverable D1.1, Dec. 2023, https://deterministic6g.eu/index.php/library-m/deliverables

[2] DETERMINISTIC6G, "Report on 6G convergence enablers towards deterministic communication standards", deliverable D3.1, Dec. 2023, https://deterministic6g.eu/index.php/library-m/deliverables

Dependable Mobile Networks for Time-Critical Applications

Dependable communication :

Be able to quantitatively ascertain the delivery of required service performance for the communication as it has been agreed.

- ❑Builds on time-critical communication enabled with Ultra-reliable and low latency communication capabilities
- ❑Requires service specification with application requirements via network exposure
- ❑Requires observability for service performance monitoring and prediction
- ❑Potential for feedback to the application domain and enabling application-network coordination

Summary

- Convergence of digital and physical worlds will requires support for time-critical communications
- Data-driven latency assesement provides an oppurtunity for designing enablers for end-to-end delay optimization
- DETERMINISTIC6G aims to realize end-to-end dependable time-critical communication with 6G

Further References

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