QCON: Seamless QoE-Aware 5G Streaming via Multi-Connectivity

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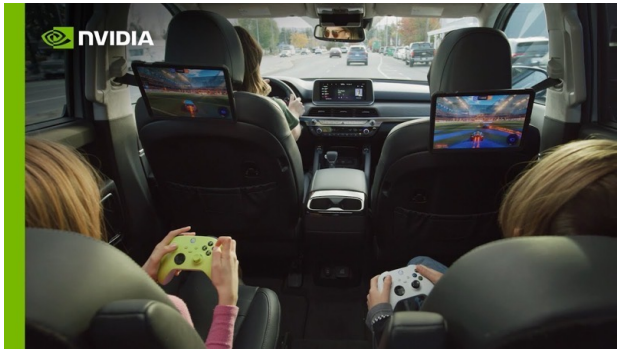
Mobile Real-Time Video Streaming (RTS)



Cloud gaming

VR/AR

Telesurgery

Requirements for High QoE*: **Consistent high throughput & low latency & high frame rates**
(e.g., Cloud gaming: > 25 Mbps , < 100 ms, 60 FPS)

*QoE: Quality of Experience

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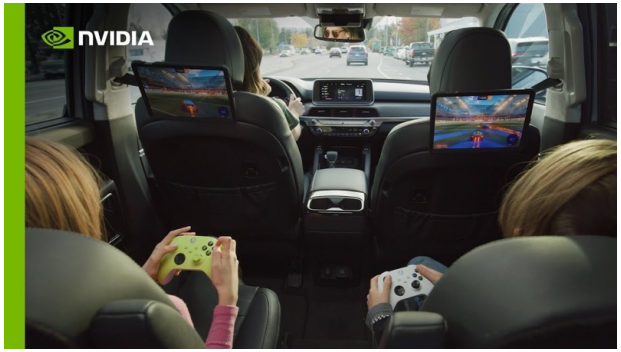

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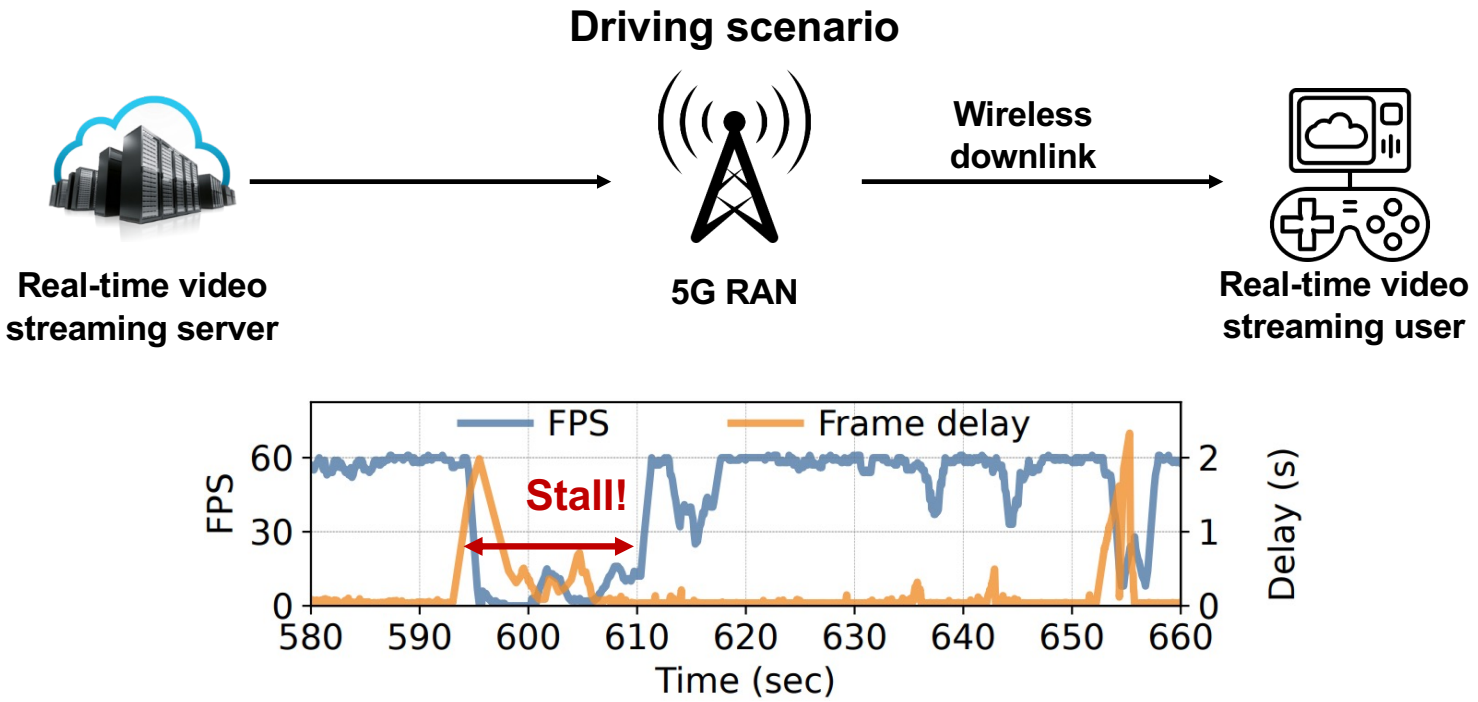
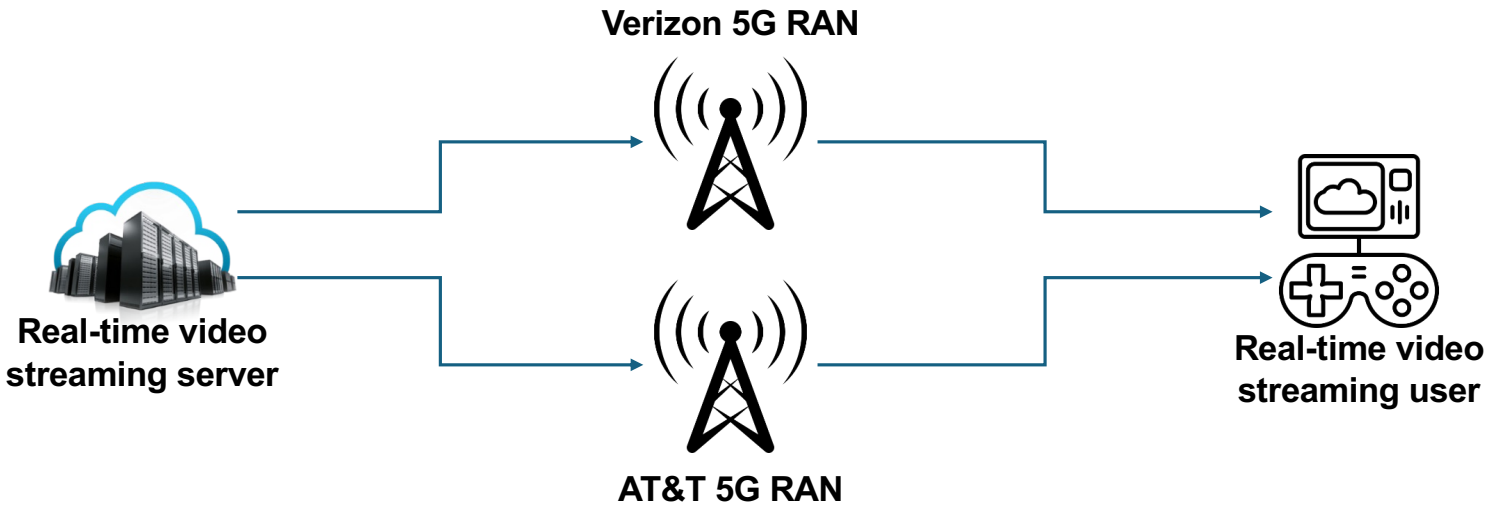
5G is the key technology to serve mobile real-time video streaming, from its **high bandwidth & low latency** link with **ubiquitous coverage**

Problem: Severe Wireless Fluctuations

- 5G offers **high average bandwidth** but suffers from **poor tail bandwidth**



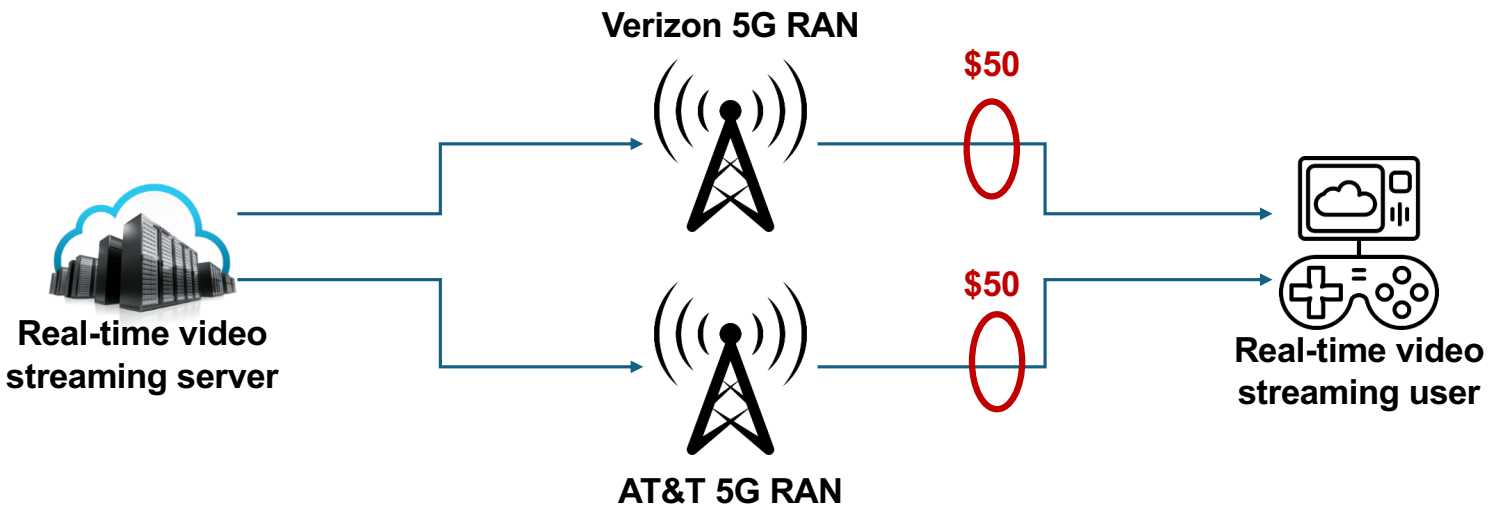
Promising Approach: Multi-Path Transport



Multi-path transport for real-time traffic

[NSDI'24] Augur,
[MobiCom'24] Chorus,
[SIGCOMM'23] Converge,
[SIGCOMM'23] Cellfusion,
[SIGCOMM'21] XLink

Limitations of Multi-Path Transport



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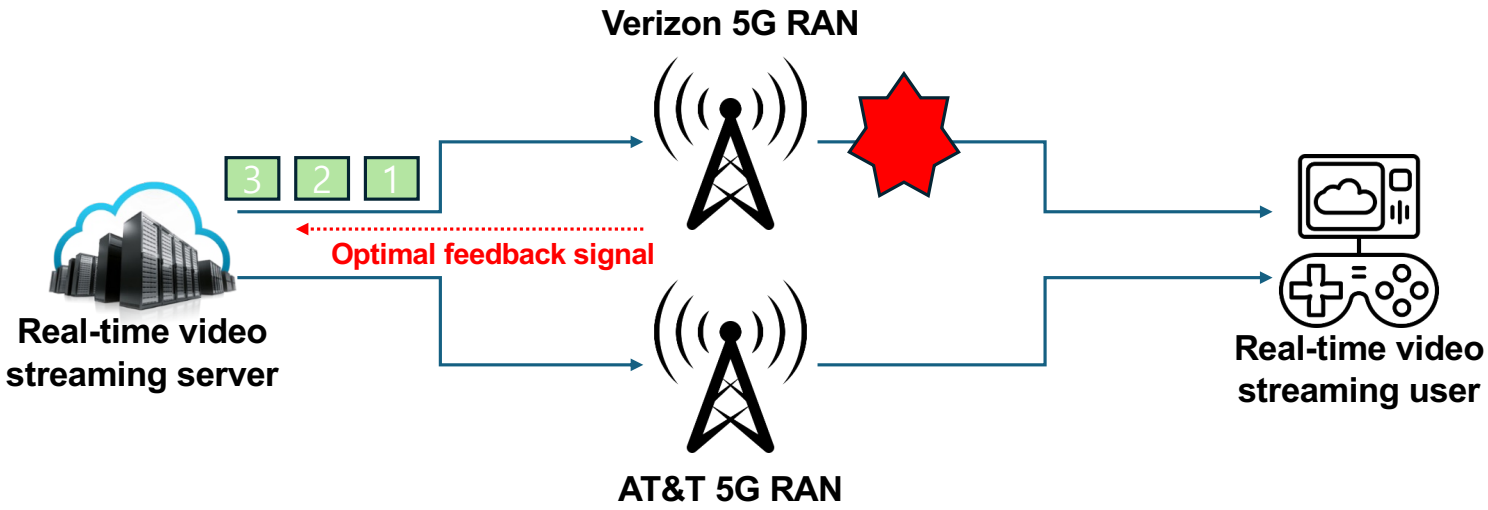
Limitation 1: Multiple cellular subscriptions required

Limitations of Multi-Path Transport



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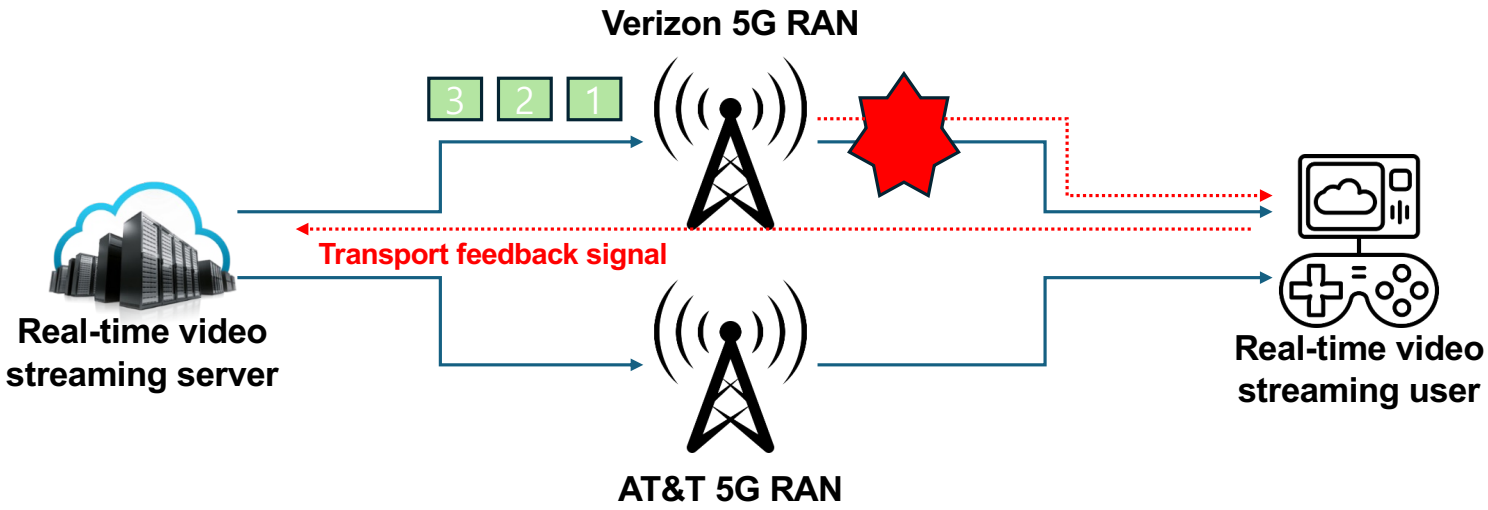
Limitation 2: Delayed reaction to wireless degradation

Limitations of Multi-Path Transport



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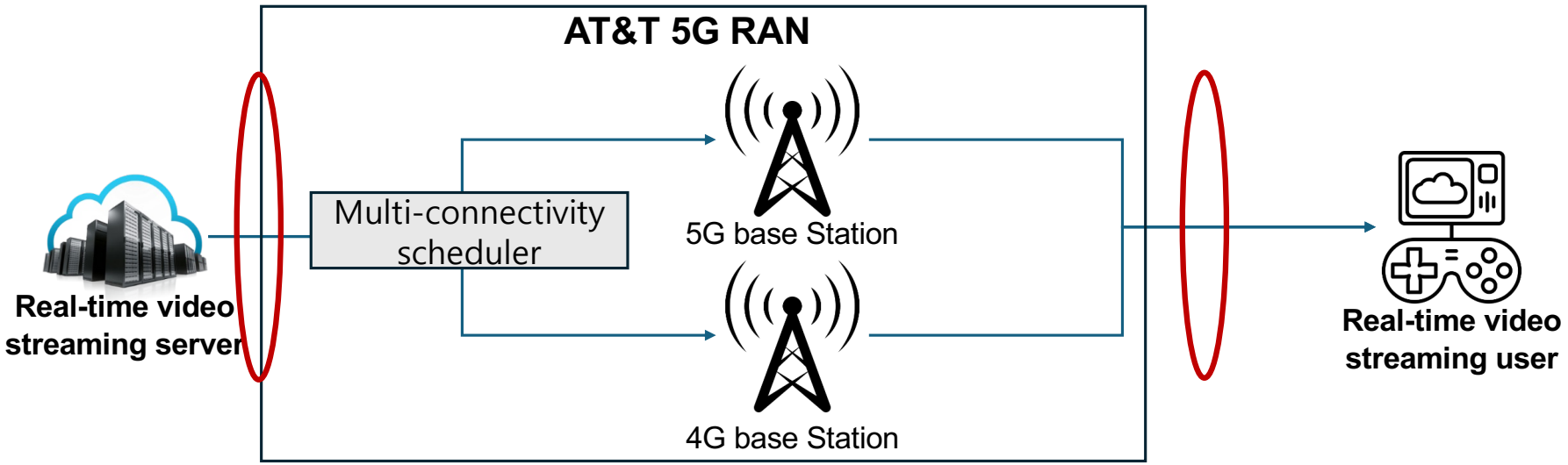
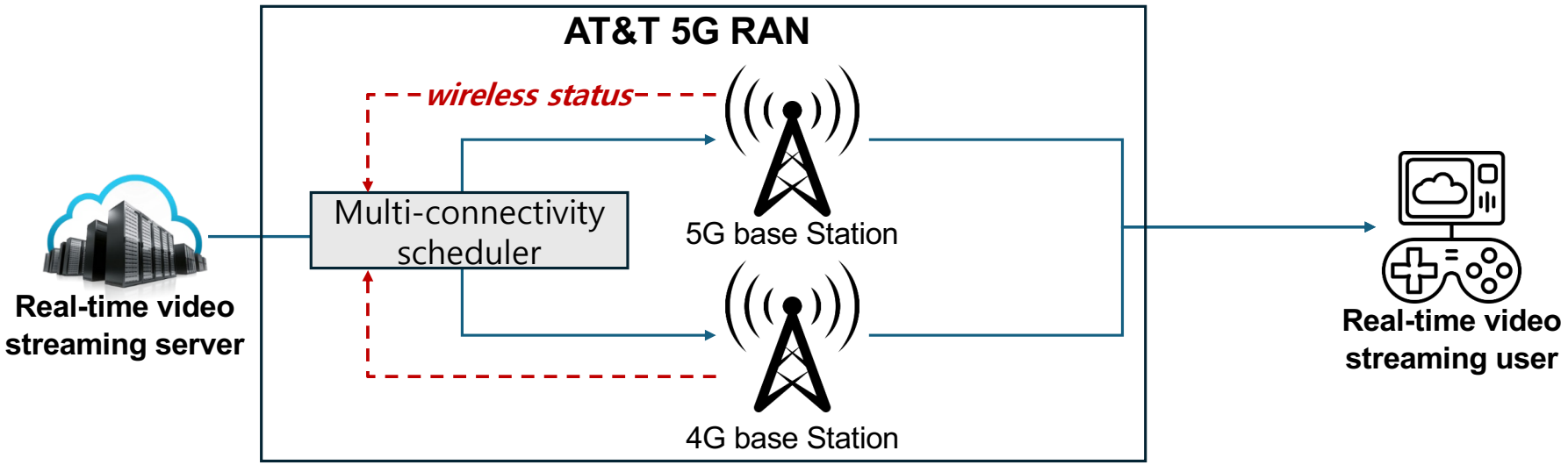
New Opportunity: 5G Multi-Connectivity

- **As a link-layer solution,** multi-connectivity leverages **multi-path features**
  - With a **single operator subscription**



New Opportunity: 5G Multi-Connectivity

- **As a link-layer solution,** multi-connectivity leverages **multi-path features**
  - With a **single operator subscription**
  - With **explicit wireless status**



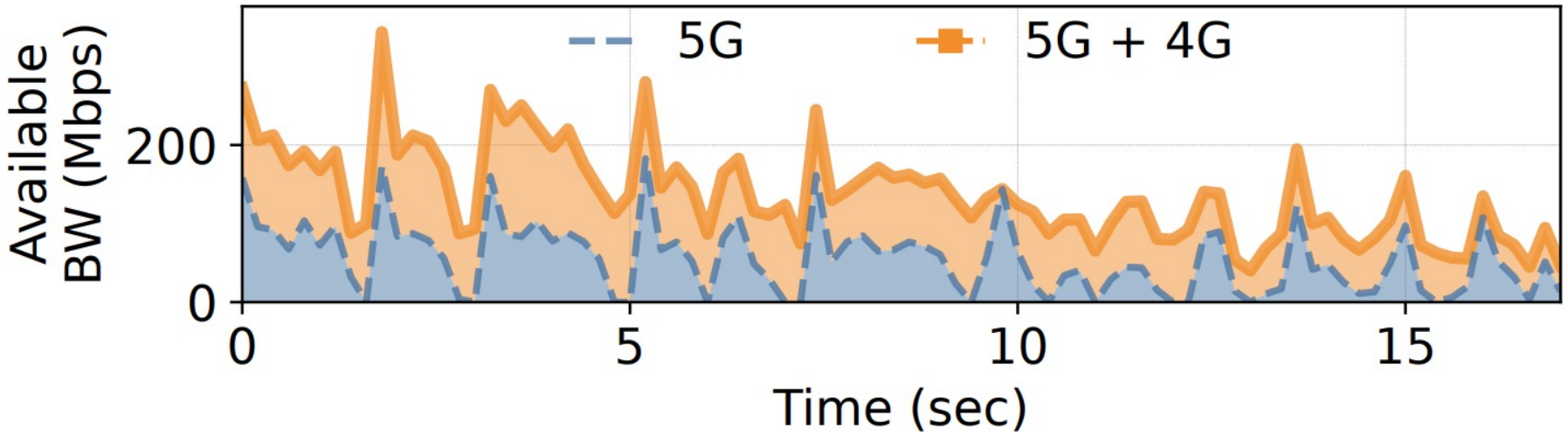
New Opportunity: 5G Multi-Connectivity

Multi-connectivity is already deployed in commercial 5G!

	Verizon	AT&T	T-Mobile
NSA (Non-standalone)	✓	✓	✓
SA (Standalone)	✗	✗	✓
Multi-connectivity enabled	✓	✓	✓

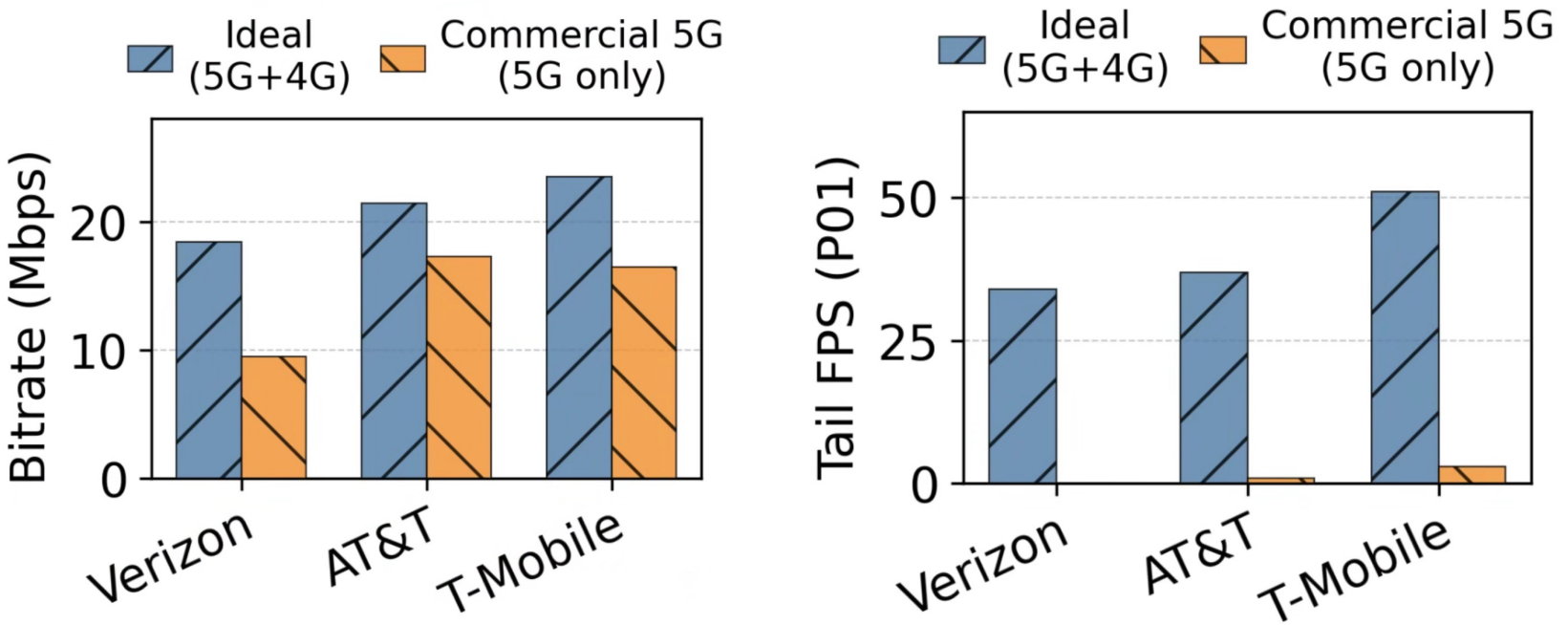
New Opportunity: 5G Multi-Connectivity

Multi-connectivity can improve tail bandwidth of 5G

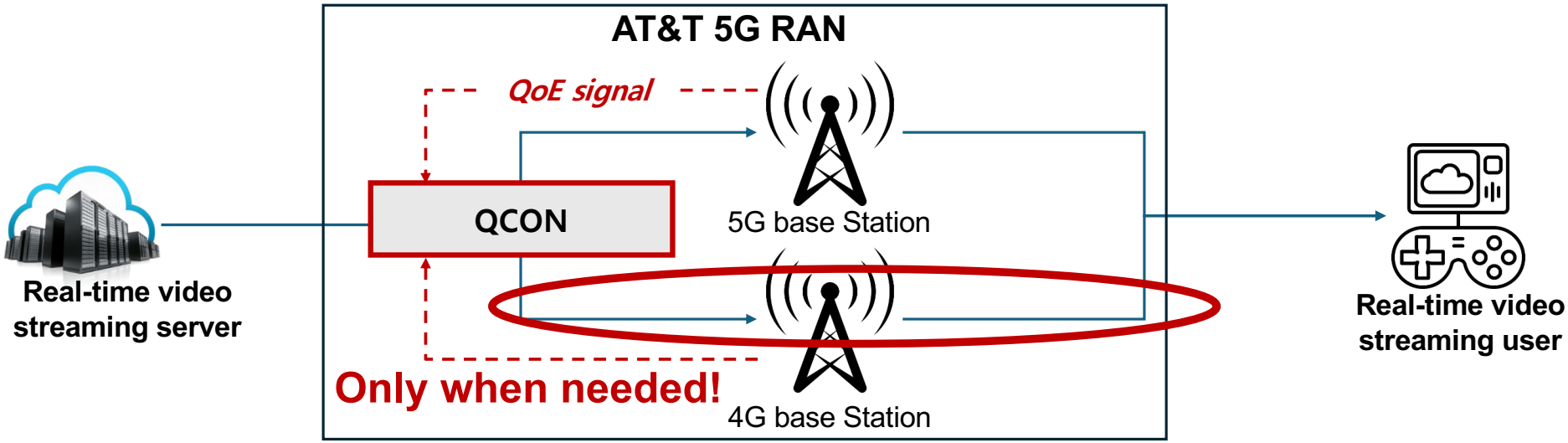


Reality: QoE-Agnostic Multi-Connectivity

Multi-connectivity is not fully utilized for app QoE

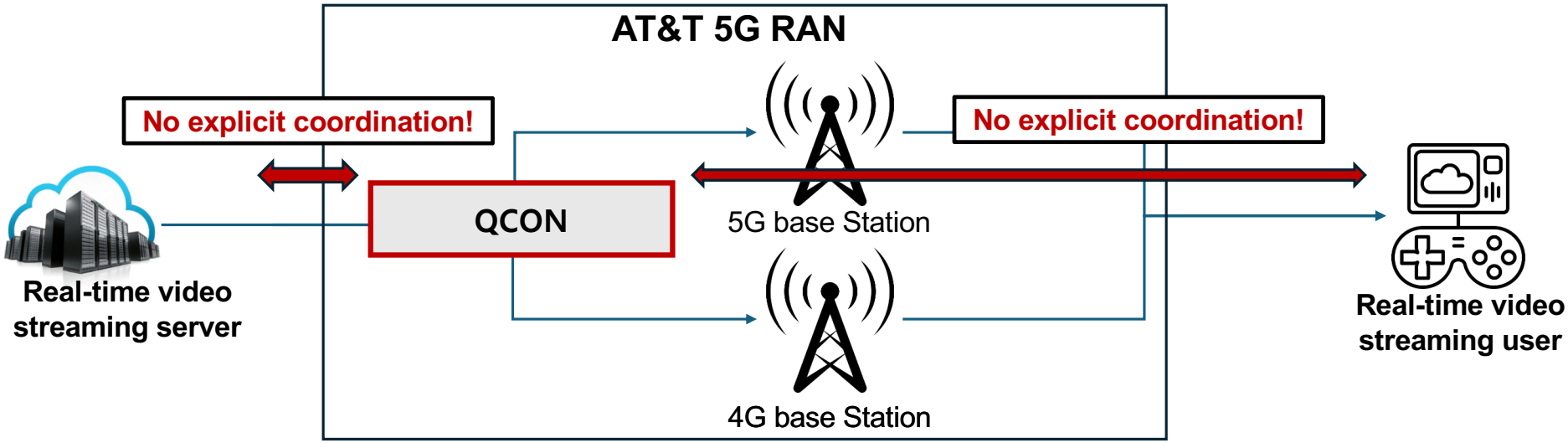


QCON: QoE-Aware Multi-Connectivity



Goal 1: Multi-link scheduling based on QoE

QCON: QoE-Aware Multi-Connectivity

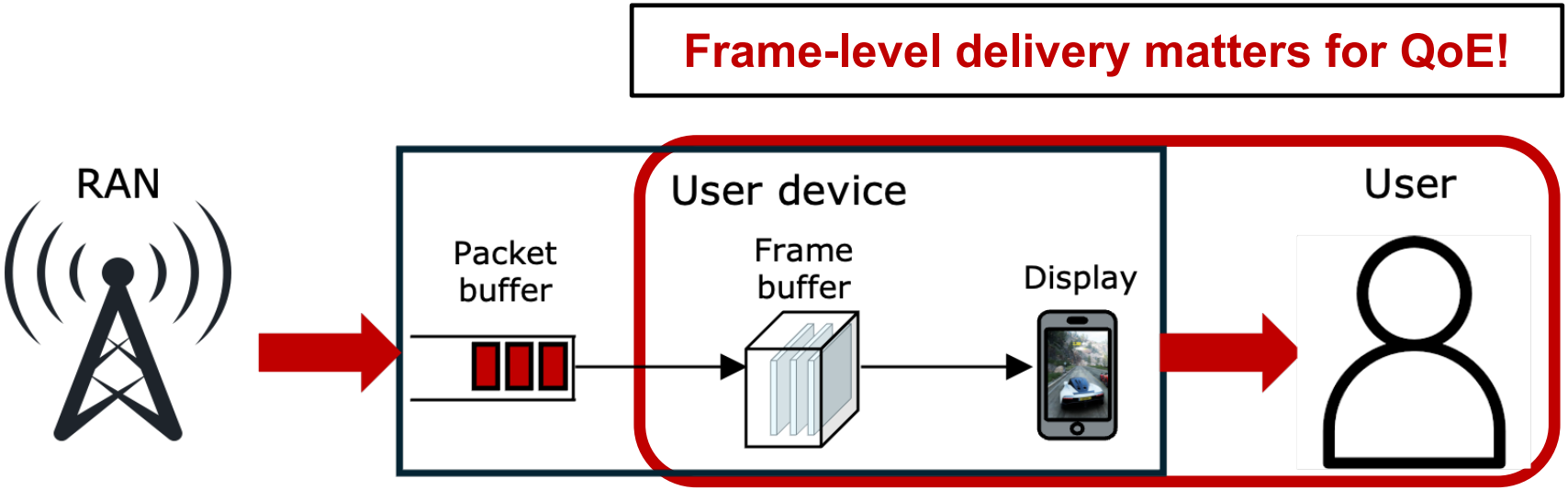


Goal 1: Multi-link scheduling based on QoE

Goal 2: Widely deployable solution

QCON Design: QoE Monitor

- Challenge #1: How to understand user QoE in the link-level RAN?
- Solution: Frame-level insights into app QoE



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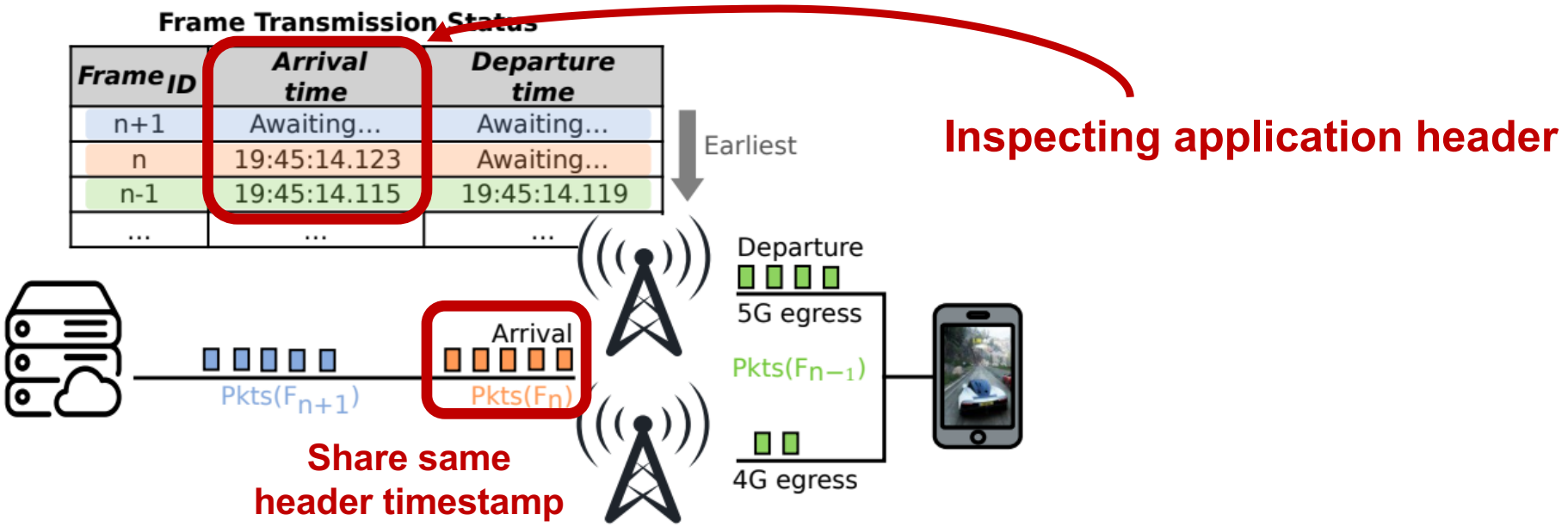

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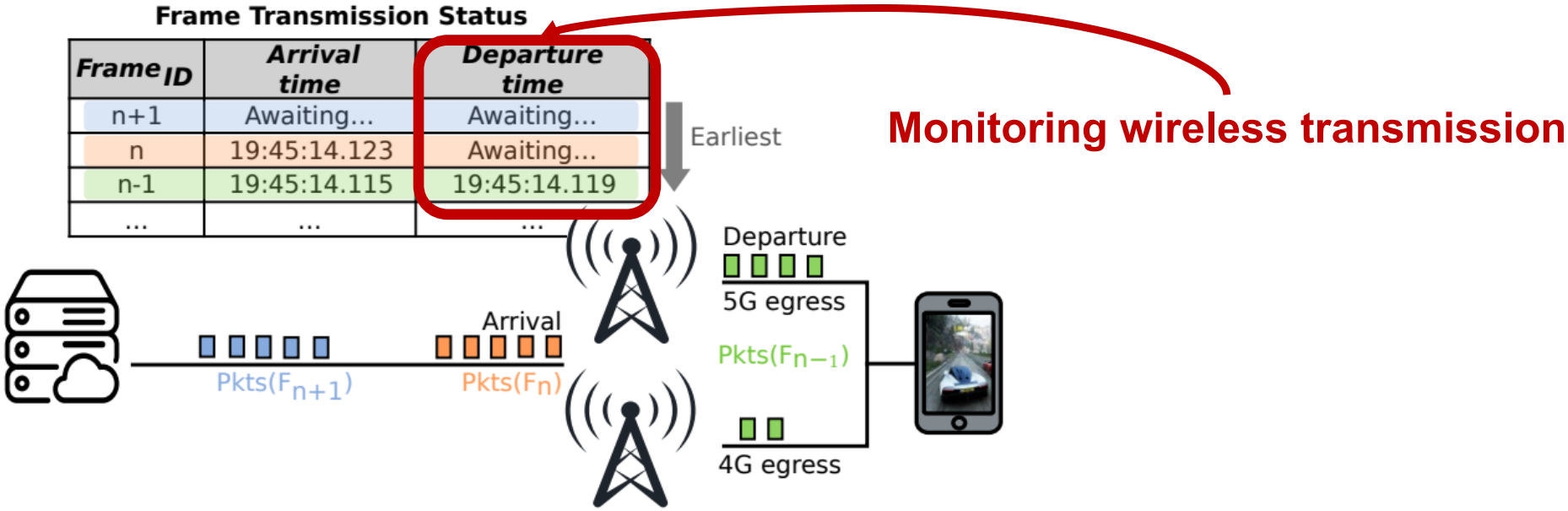
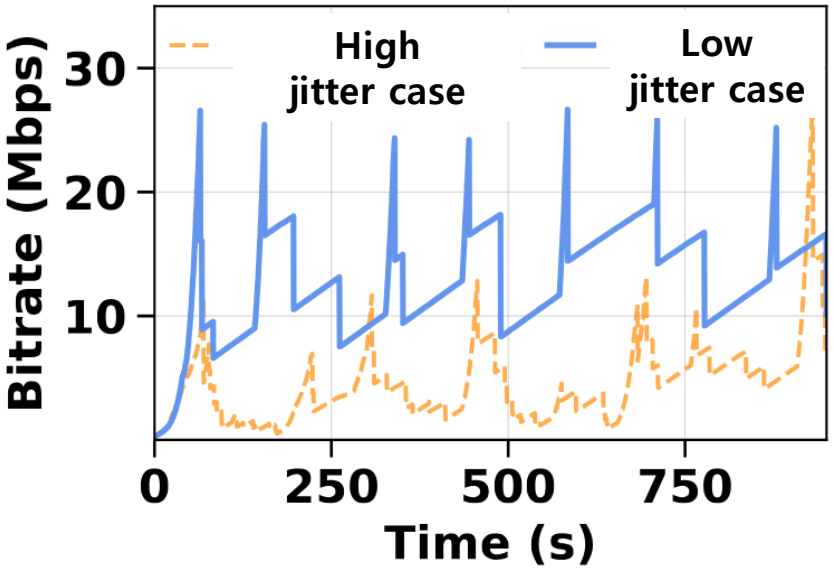
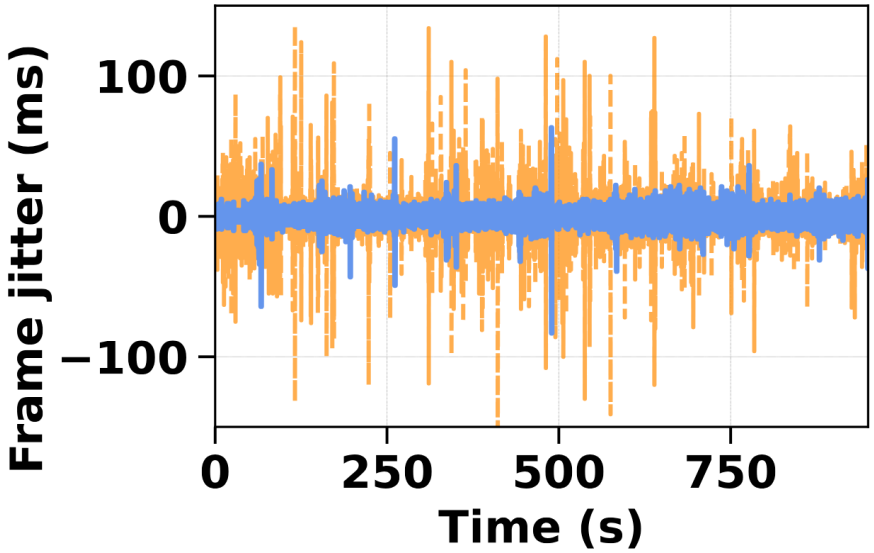


QCON Design: Multi-Link Scheduler

- Challenge #2: How to ensure high bitrates in radio resource efficient manner?

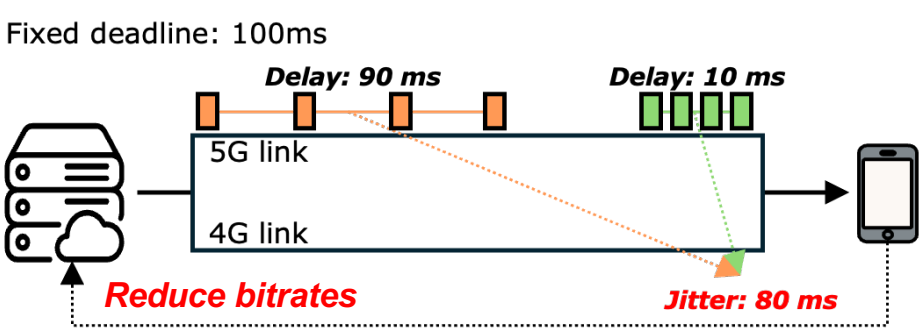
Congestion signal (i.e., jitter) matters!



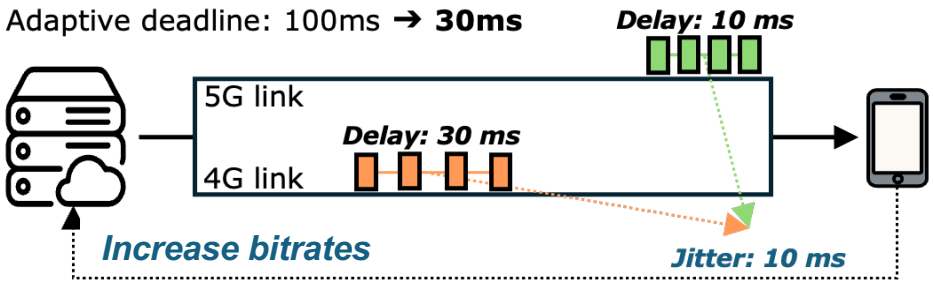


QCON Design: Multi-Link Scheduler

- Challenge #2: How to ensure high bitrates in radio resource efficient manner?
- Solution: Jitter-adaptive multi-link scheduling



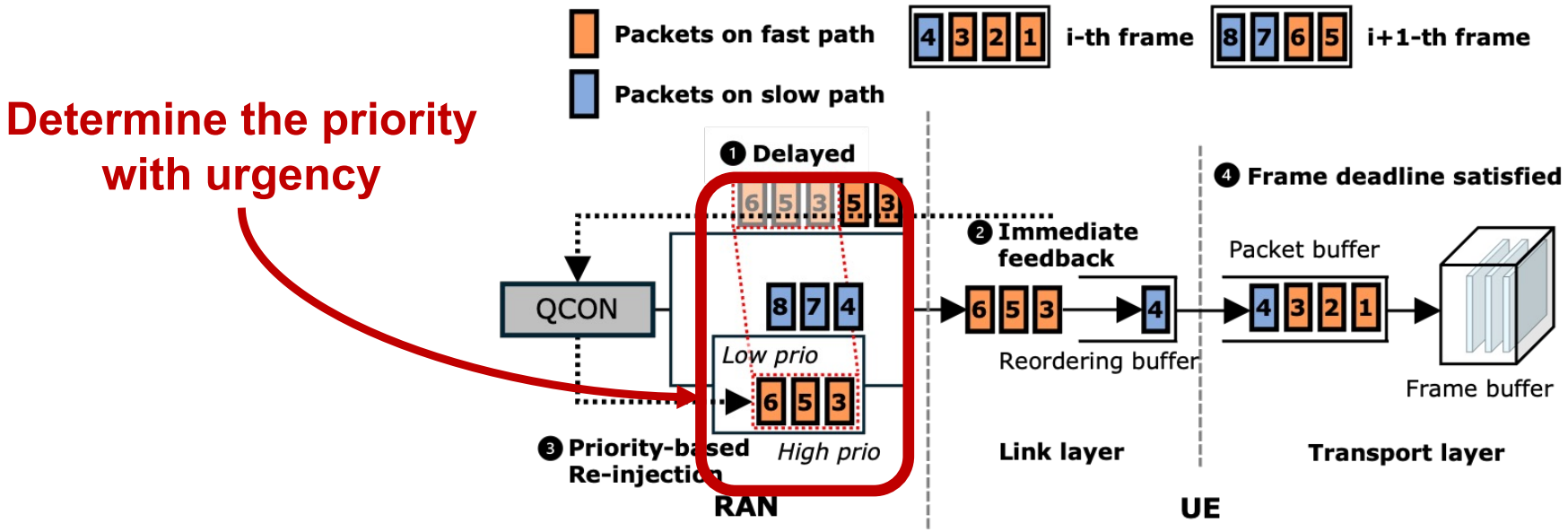
Jitter-agnostic scheduling



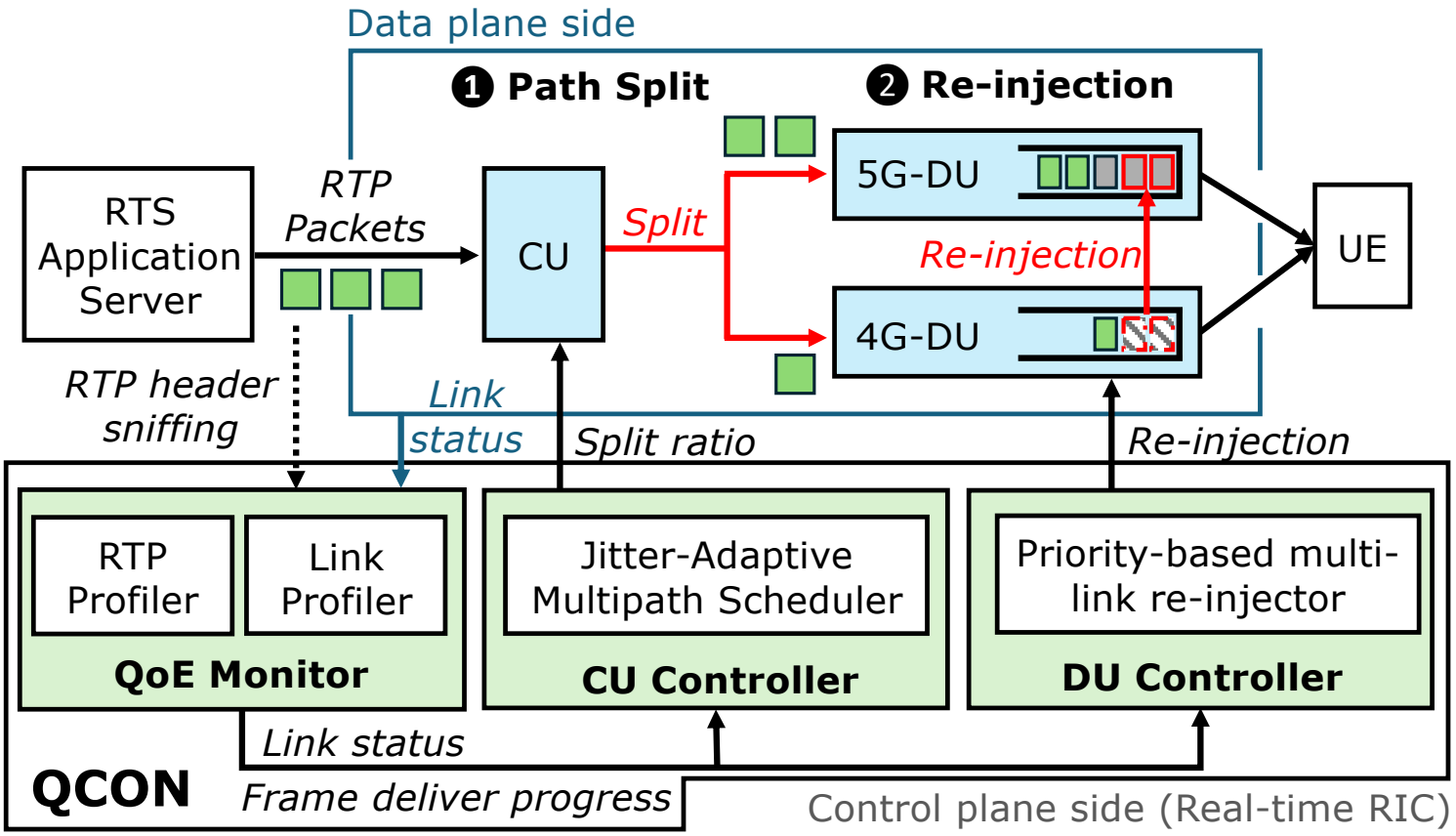
Jitter-adaptive scheduling

QCON Design: Multi-Link Re-Injection

- Challenge #3: How to tackle unexpected link disruption?
- Solution: Priority-based multi-link re-injection



QCON as a System



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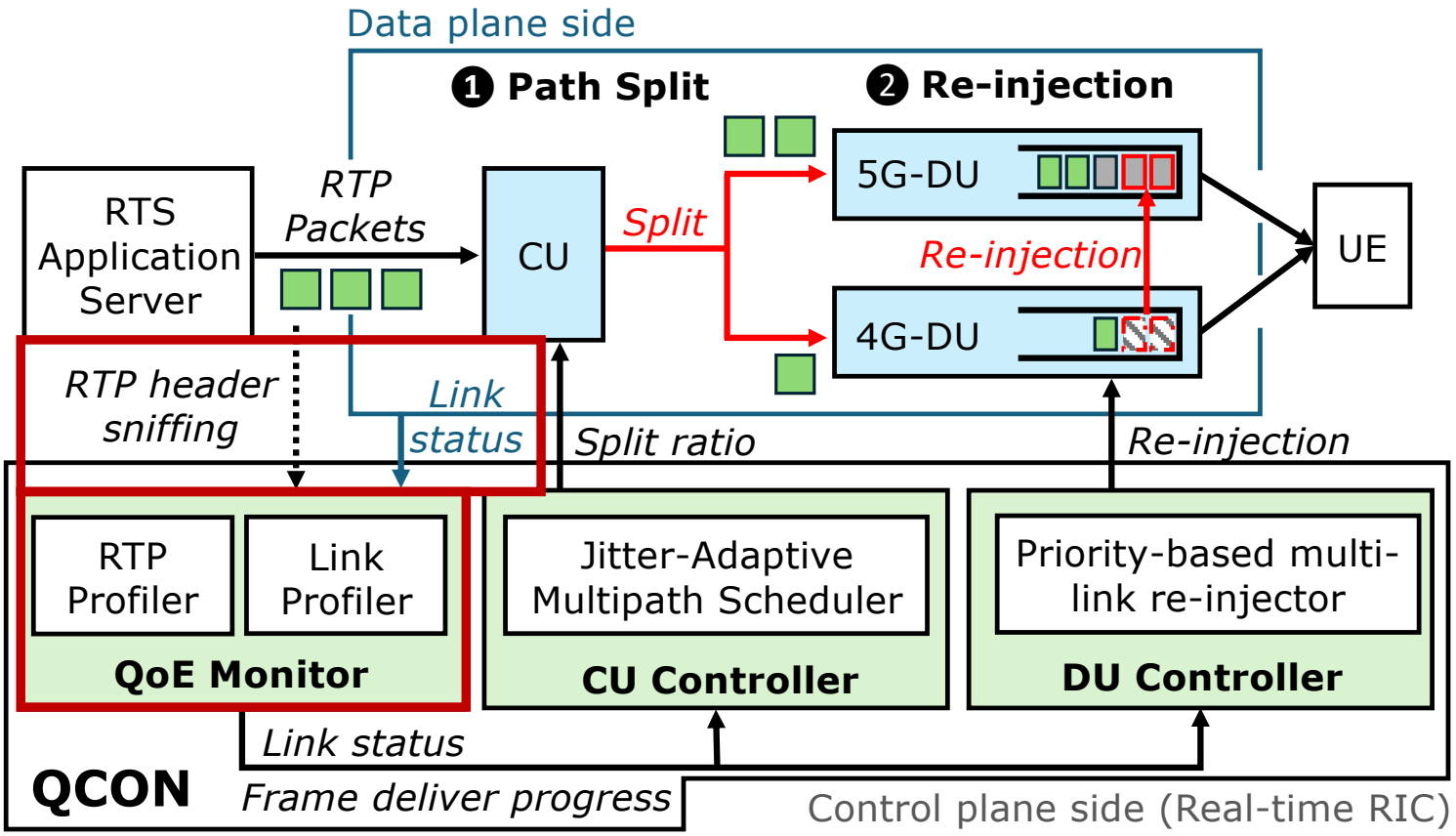

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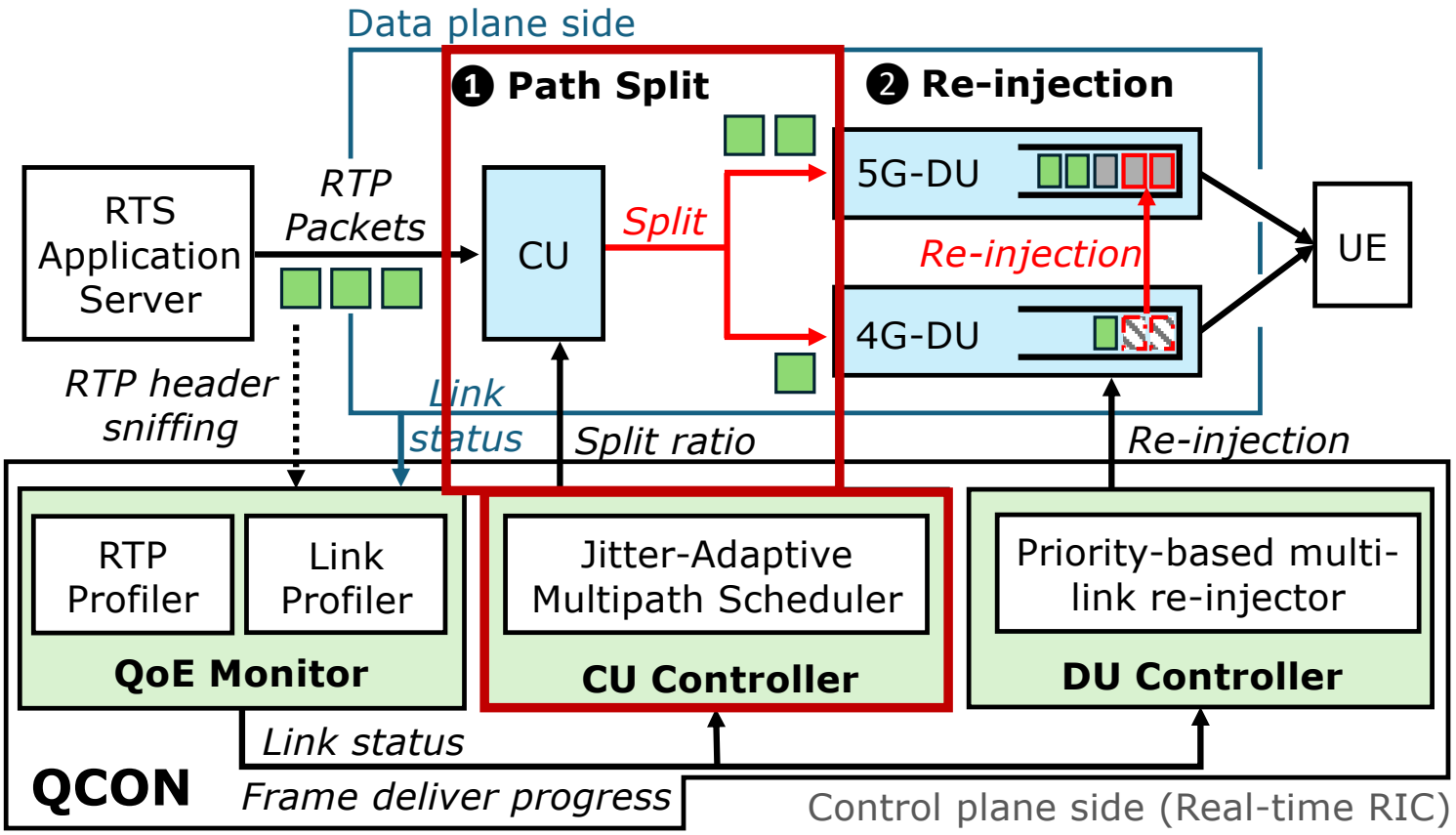

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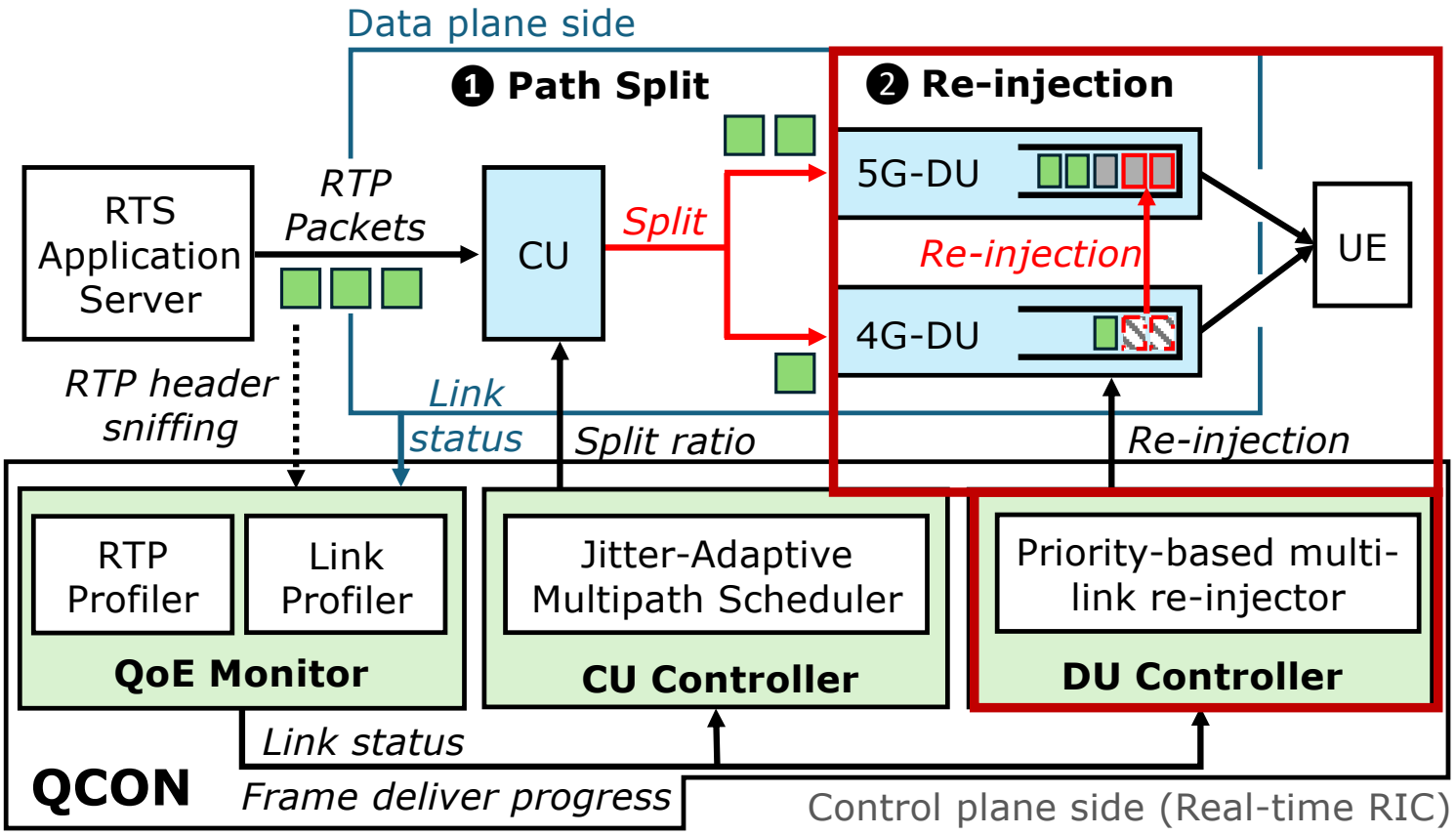
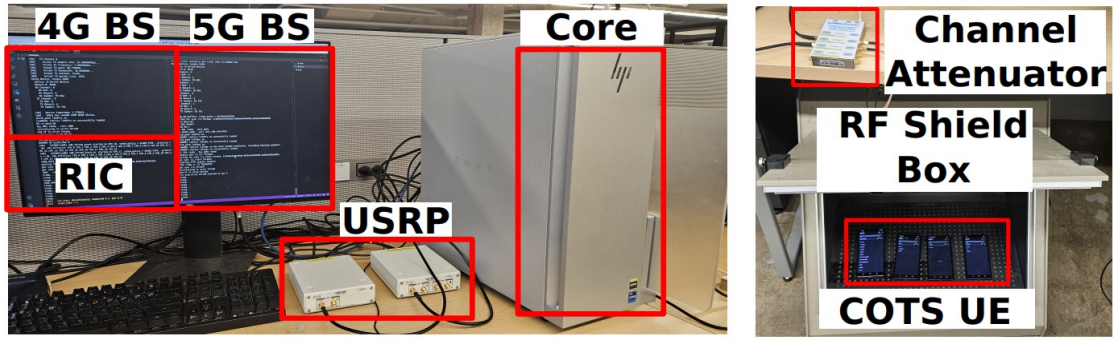


Experimental Setup

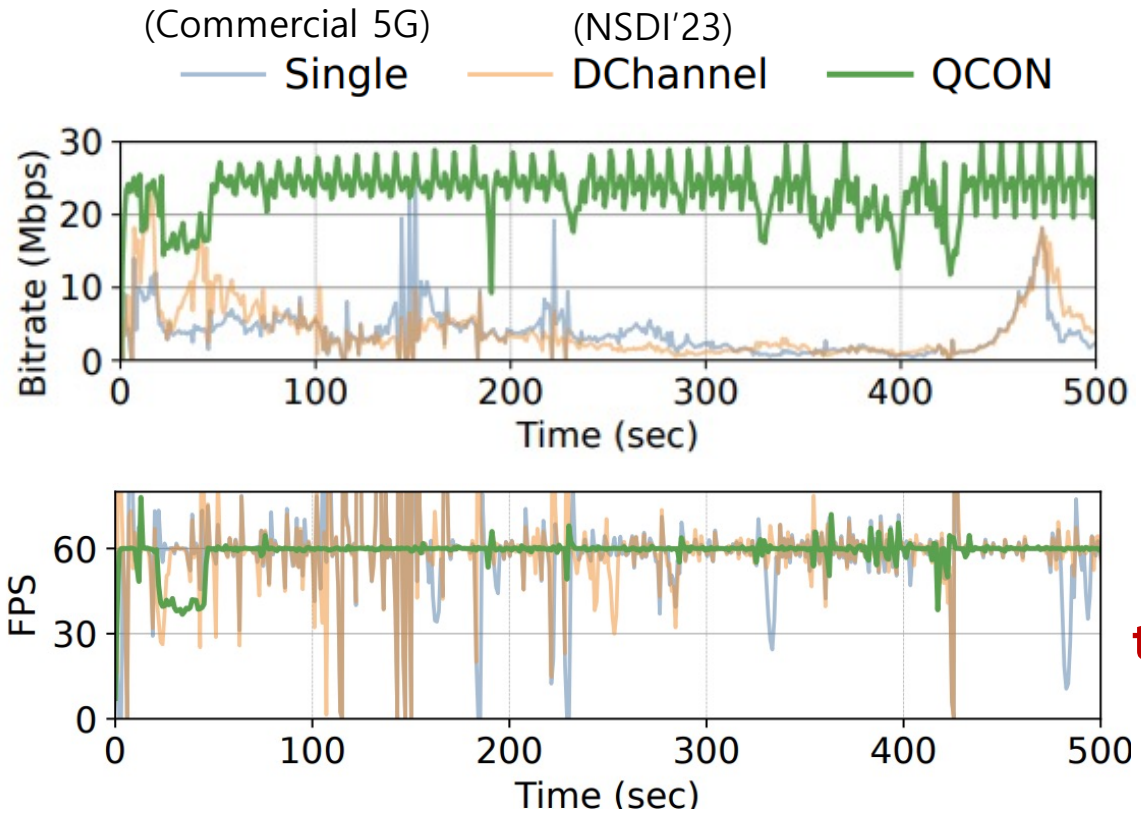
- Trace-driven emulation
  - WebRTC
  - Driving channel traces from AT&T/Verizon/T-Mobile

- Real-world experiment
  - Radio software
    - Openairinterface5G
  - Radio hardware
    - USRP B210
  - COTS UE
    - Google Pixel Phones
  - Channel environment
    - RF shield box + Channel attenuator
  - Commercial cloud gaming apps
    - Xbox Cloud Gaming
    - Nvidia GeForce Now
    - Boosteroid



In-lab Open-RAN testbed

Evaluation over Trace-Driven Emulation (WebRTC)

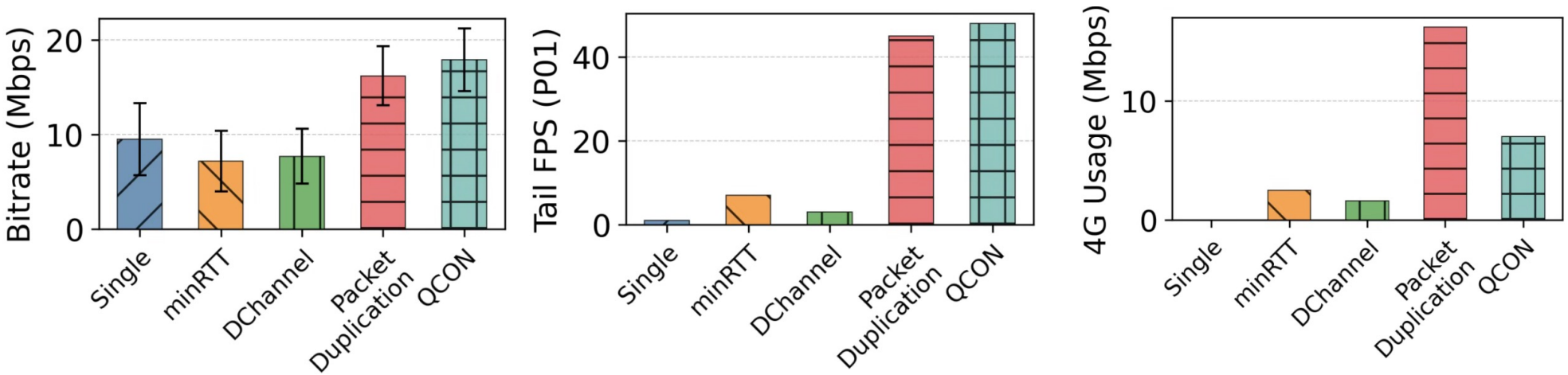


6X avg bitrate

2.5X tail FPS

With only 24% of 4G usages (47% in DChannel)

Evaluation over Real-World Testbed (Xbox Cloud Gaming)



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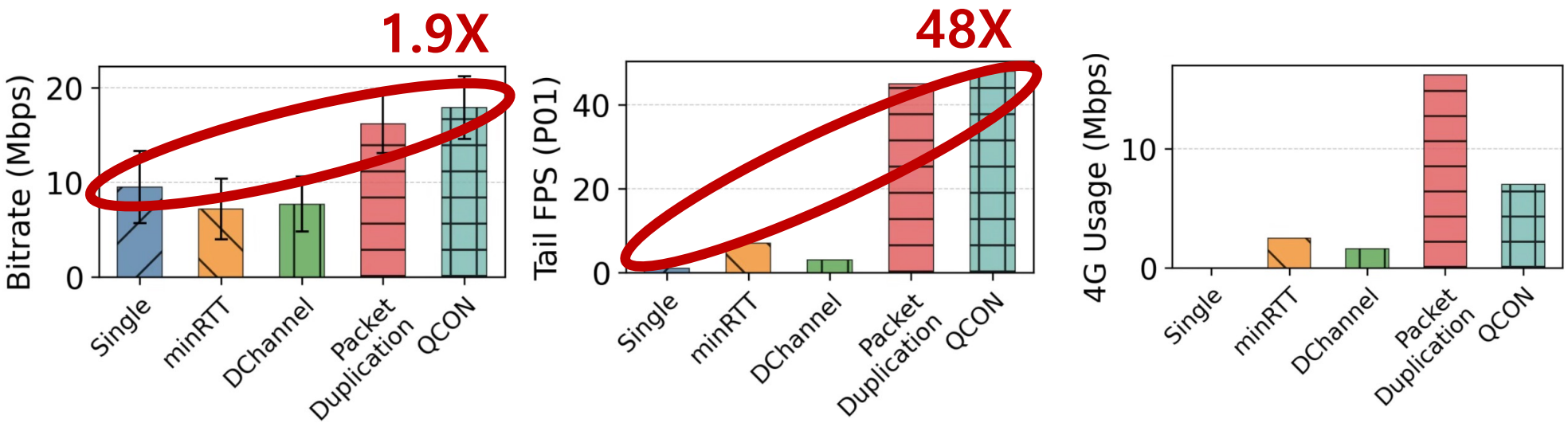

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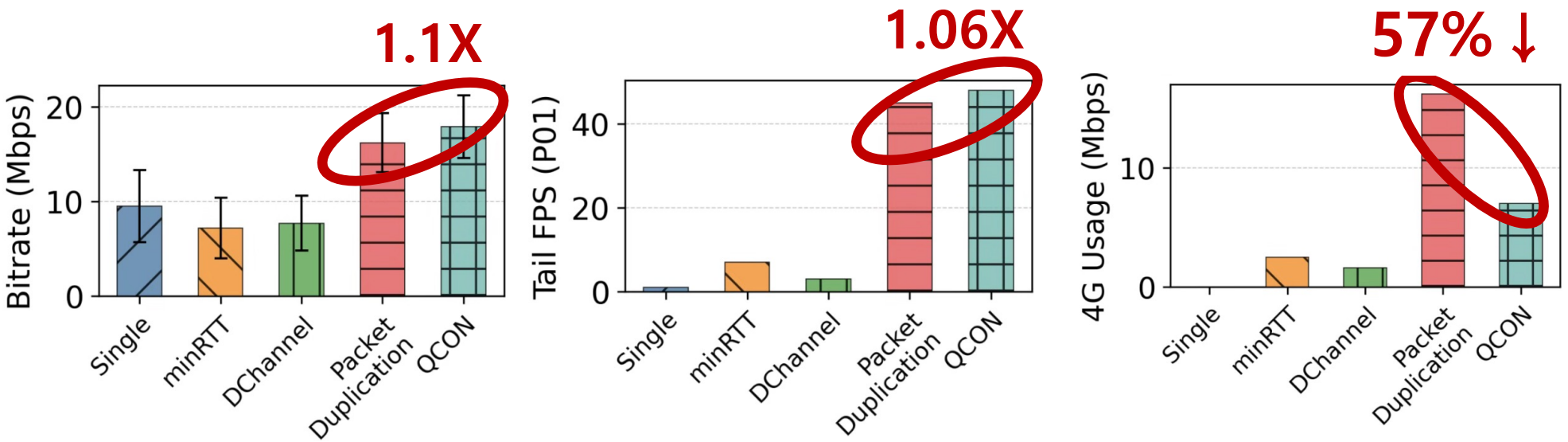

Conclusions & Takeaway

- Motivation
  - Mobile real-time video streaming suffers from **5G wireless fluctuations**
- Existing approach
  - **Multi-path transport solutions** show **deployment & performance issues**
- Innovation
  - **QCON** enables **seamless mobile real-time video streaming** with **QoE-aware multi-connectivity** that is **widely deployable and radio-resource efficient**
- Takeaway
  - **Multi-path link** can be the **better alternative** of multi-path transport
  - **Real-time video QoE can be estimated in RAN** with only RAN modifications

Thank you! Q&A

Email: goodsolusa@gmail.com
Homepage: https://goodsollee.github.io/
QCON source code: https://github.com/goodsollee/qcon-nsdi26