Athena: Seeing and Mitigating Wireless Impact on Video Conferencing and Beyond

Fan Yi, Haoran Wan, Kyle Jamieson, Jennifer Rexford, Yaxiong Xie, Oliver Michel

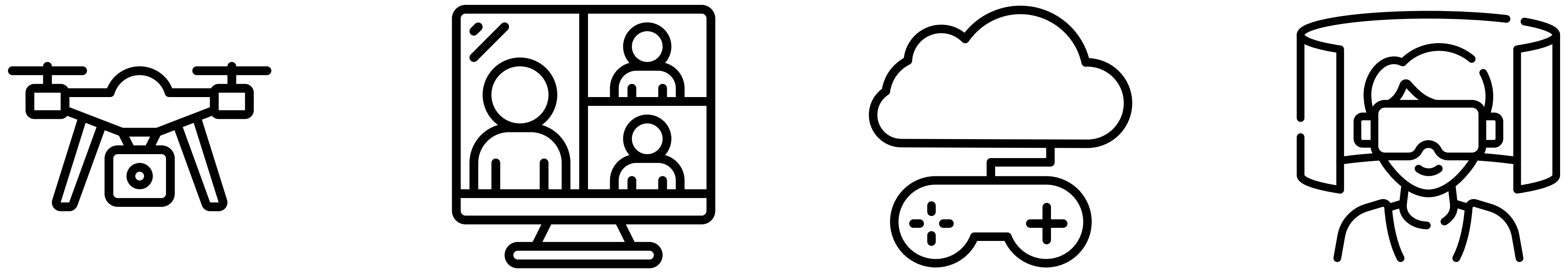
ACM HotNets '24

CAIDA GMI-AIMS-5, San Diego, CA, February 13, 2025.

PRINCETON UNIVERSITY

Application Requirements Outpace Network Evolution

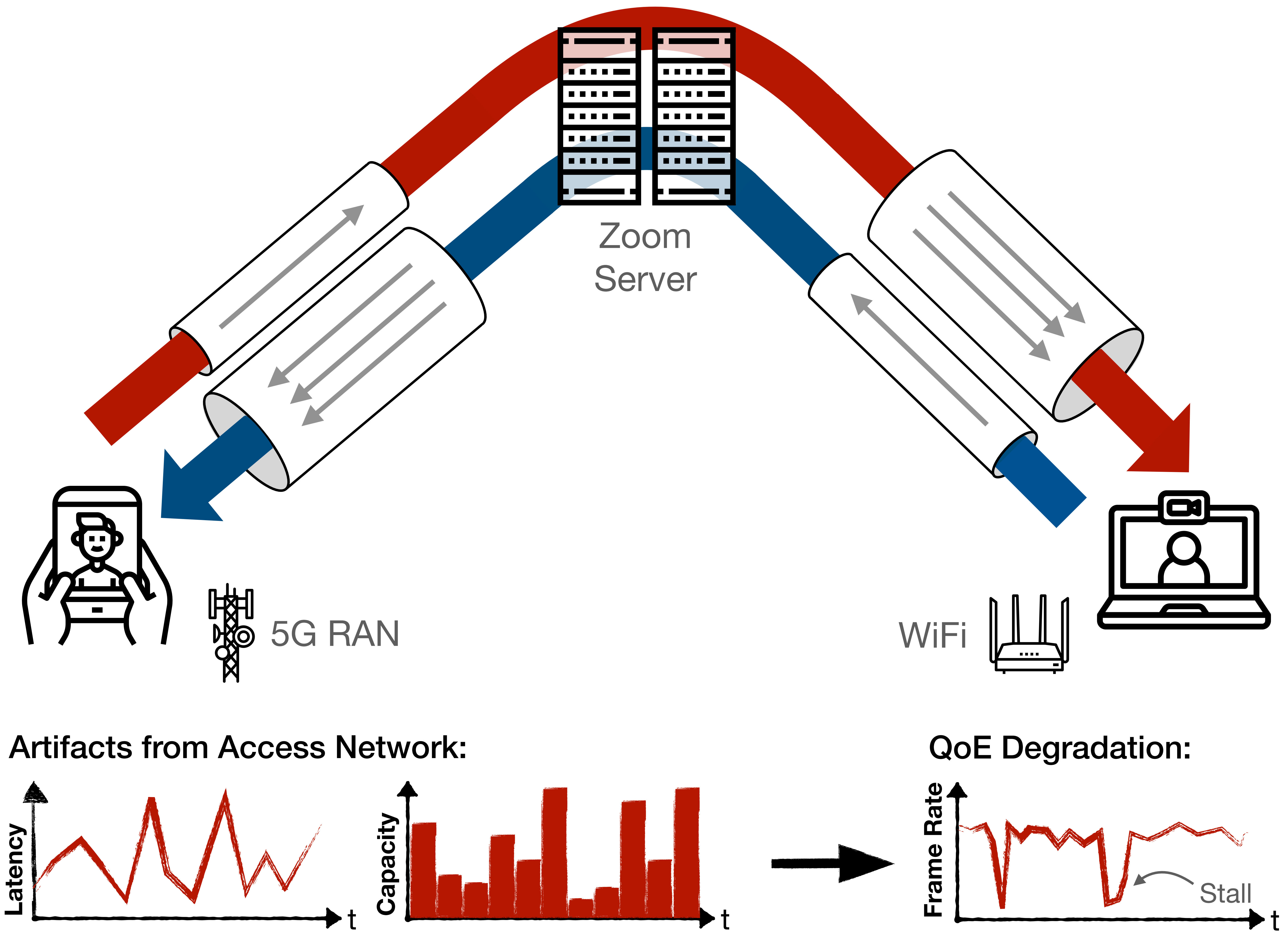
Massive rise in use over past decade across wide spectrum of use cases:



Real-Time Multimedia Applications

↗ Quality
↗ Interactivity → ↗ Network Performance Requirements → Requirements outpace network capabilities → ↘ QoE for users

Anatomy of a Video-Conferencing Session



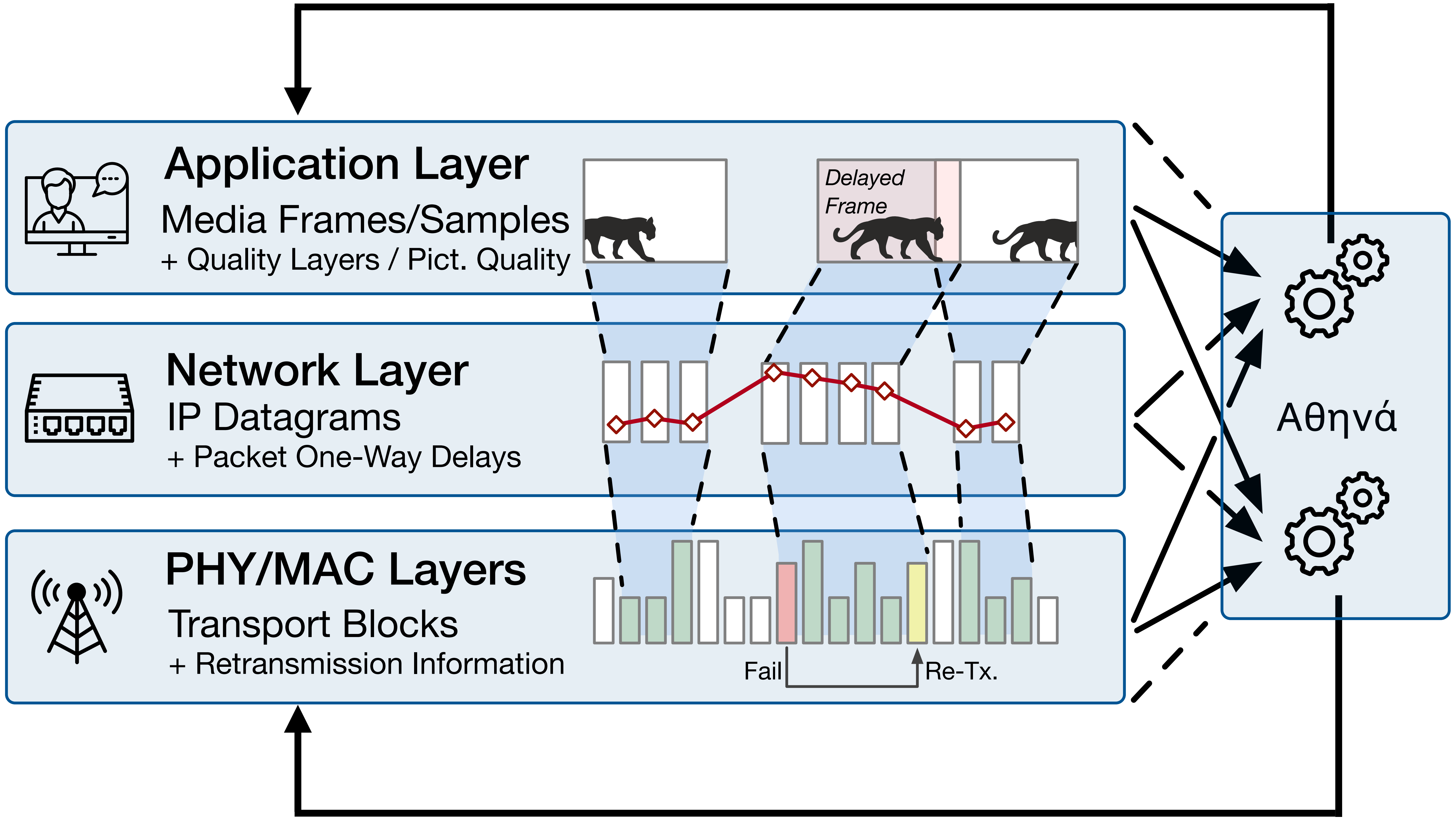
(1) Critical traffic on uplink

(2) Traversal of access networks

(3) Immediate QoE effects

Anatomy of video conferencing over wireless challenges QoE

Athena Cross-Layer Measurement & Optimization



Network state and information is siloed within each layer

→ Lost optimization opportunities

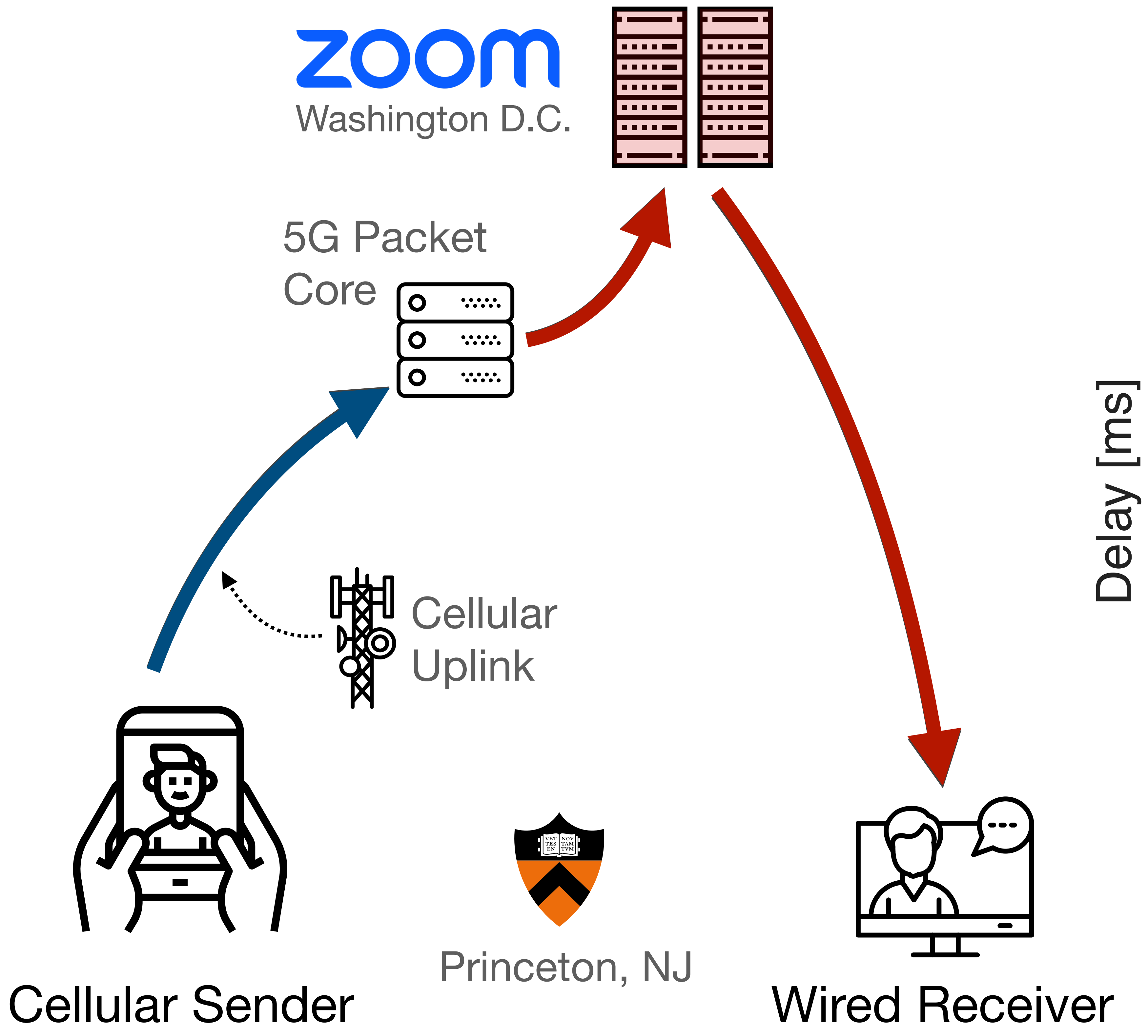
ATHENA …

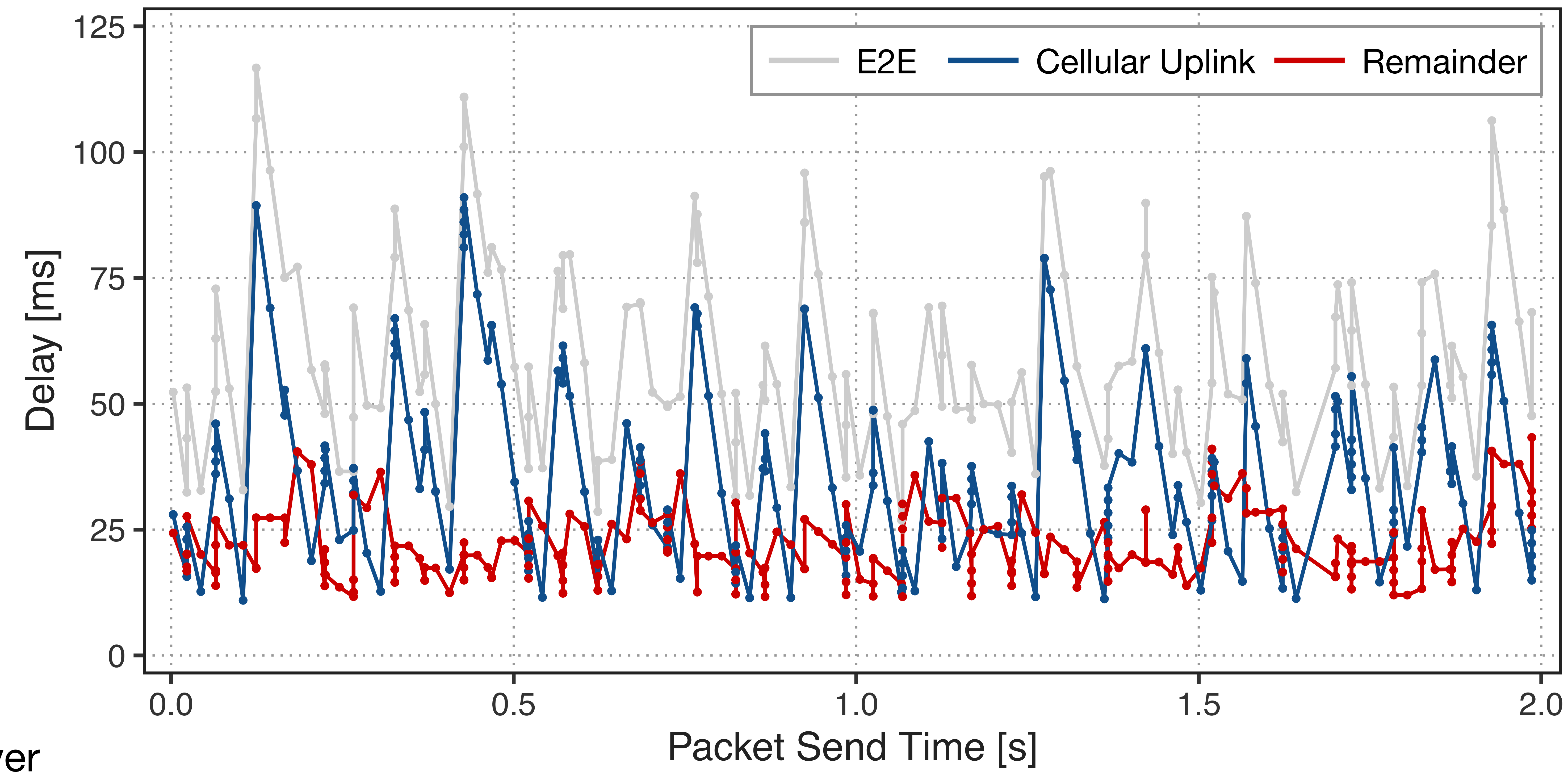
(1) Sees across layers

(2) Correlates data across layers

(3) Enables cross-layer optimization

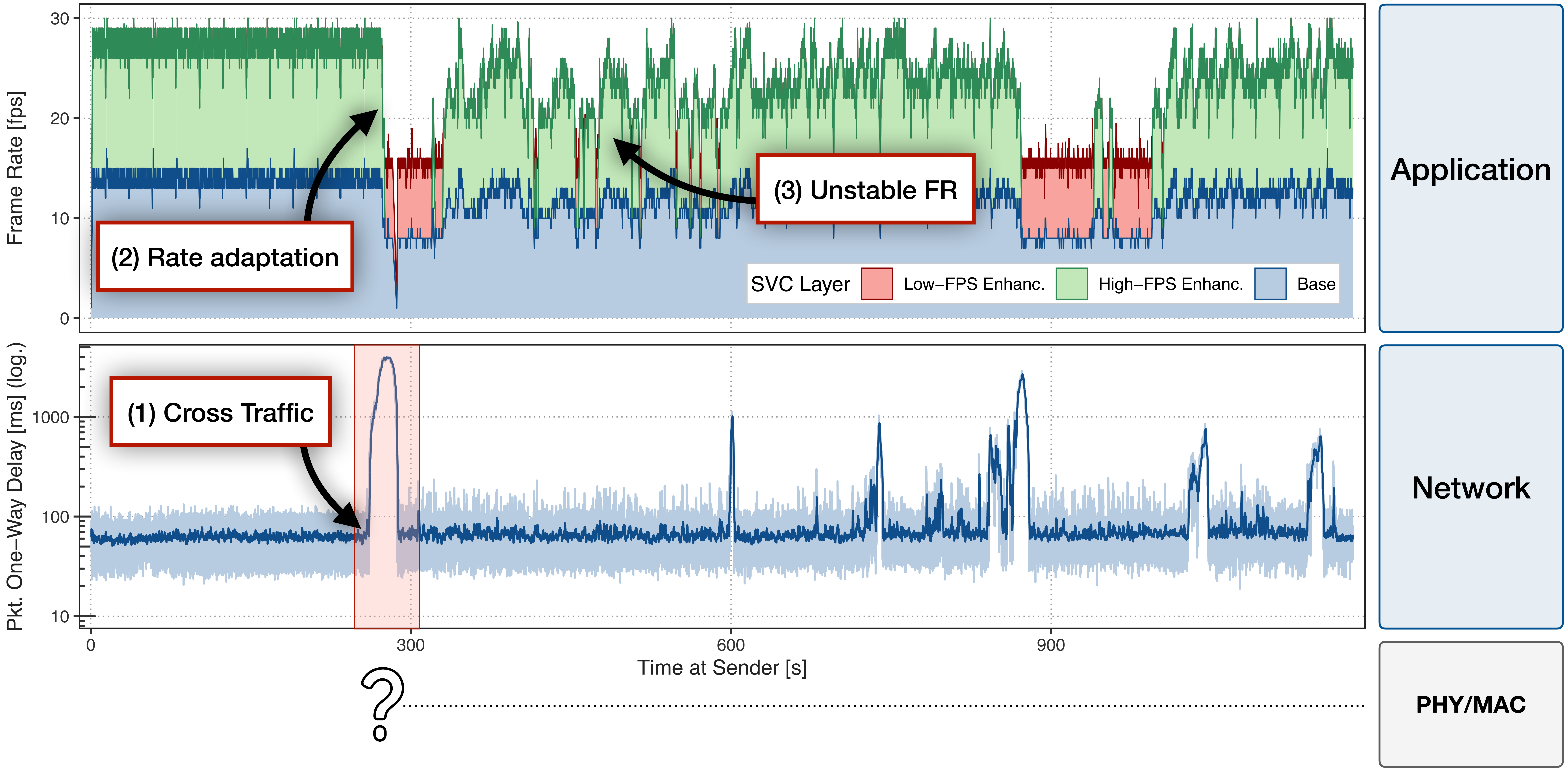
5G Uplink causes high Latency and Jitter



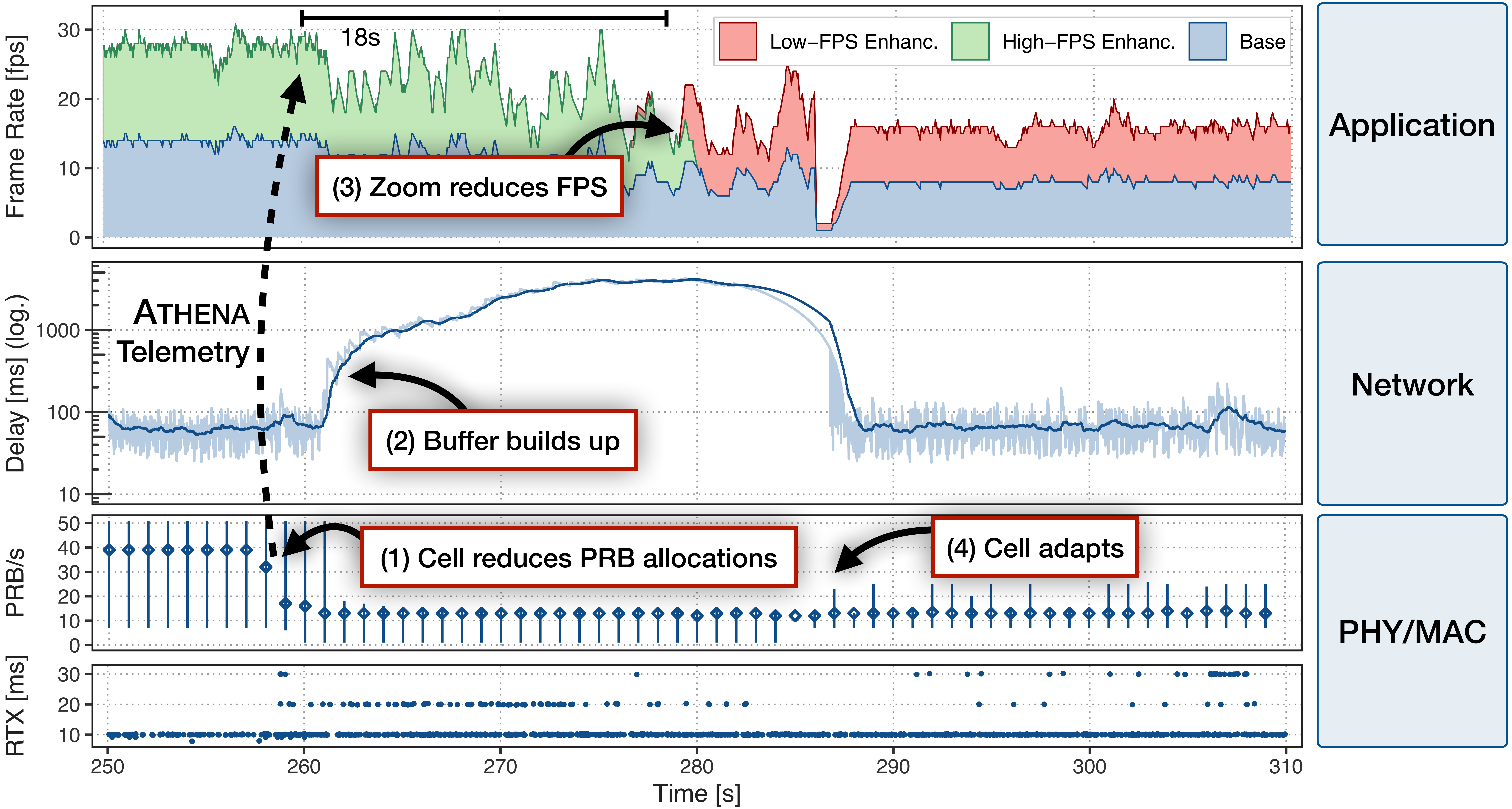


→ Cellular uplink is primary contributor to high delay and jitter.

5G Latency and Jitter Considered Harmful

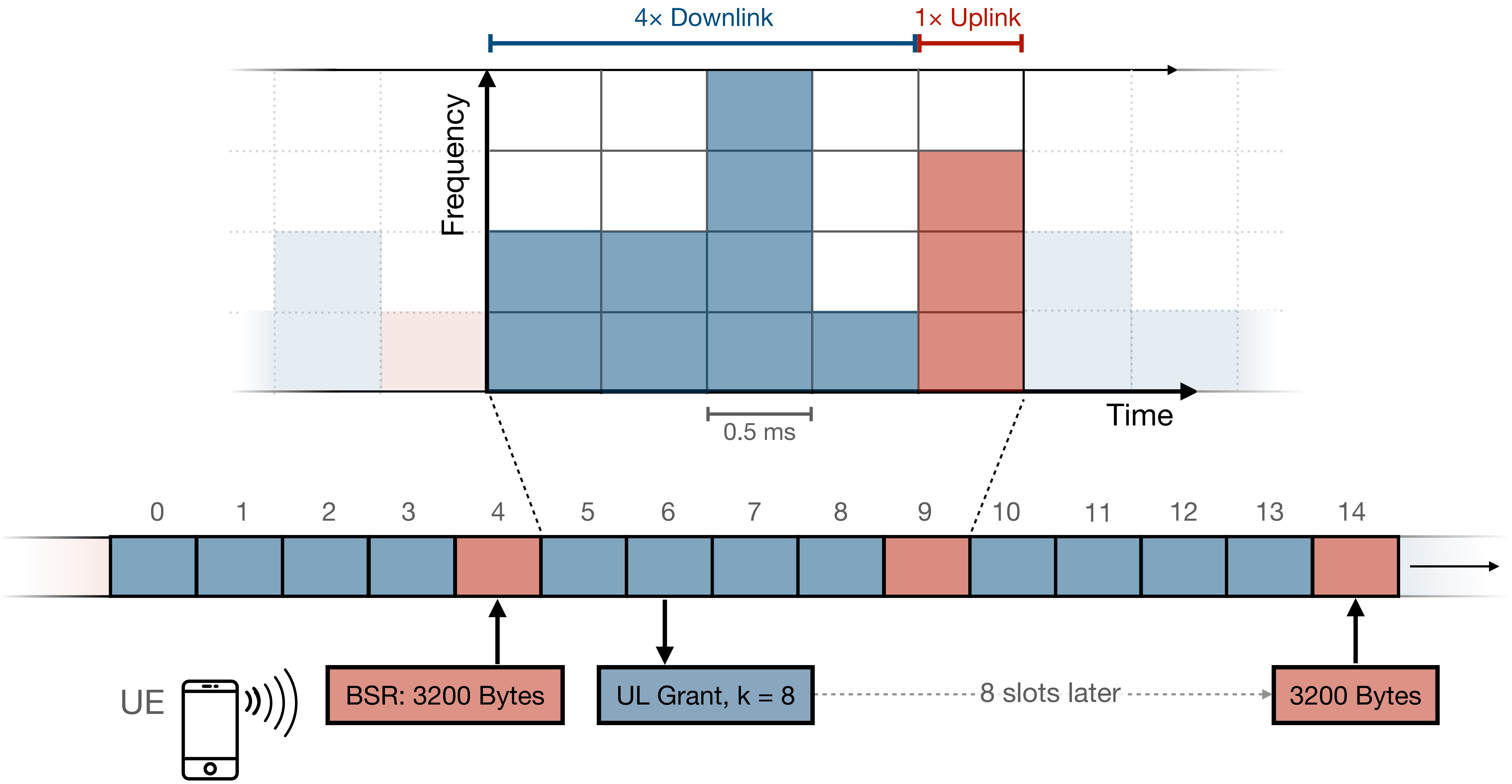


5G Capacity Changes Inflate Delay

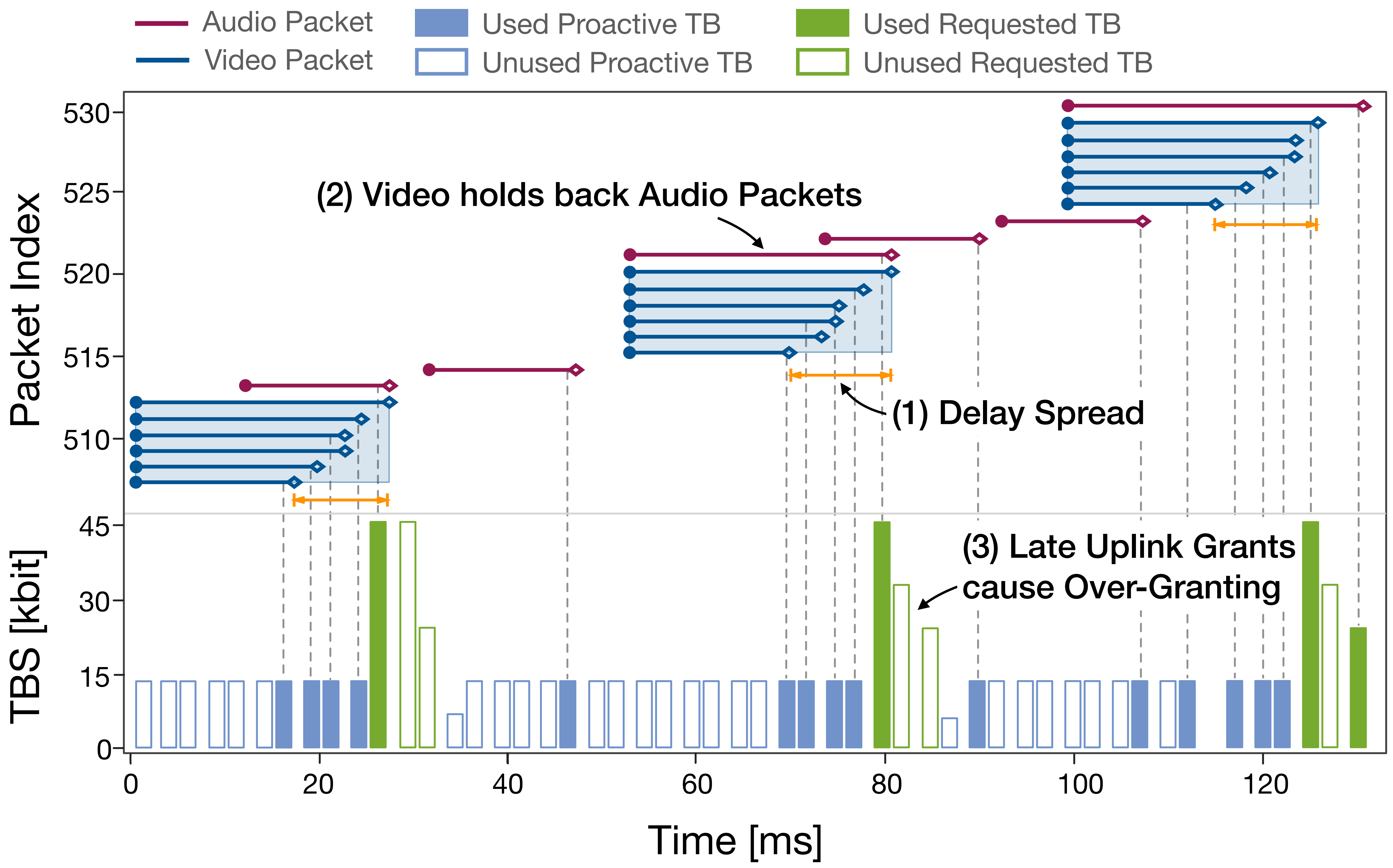


Expanding to the Physical Layer

5G Time-Division Duplex and Uplink Transmission



5G Uplink Scheduling Causes Jitter

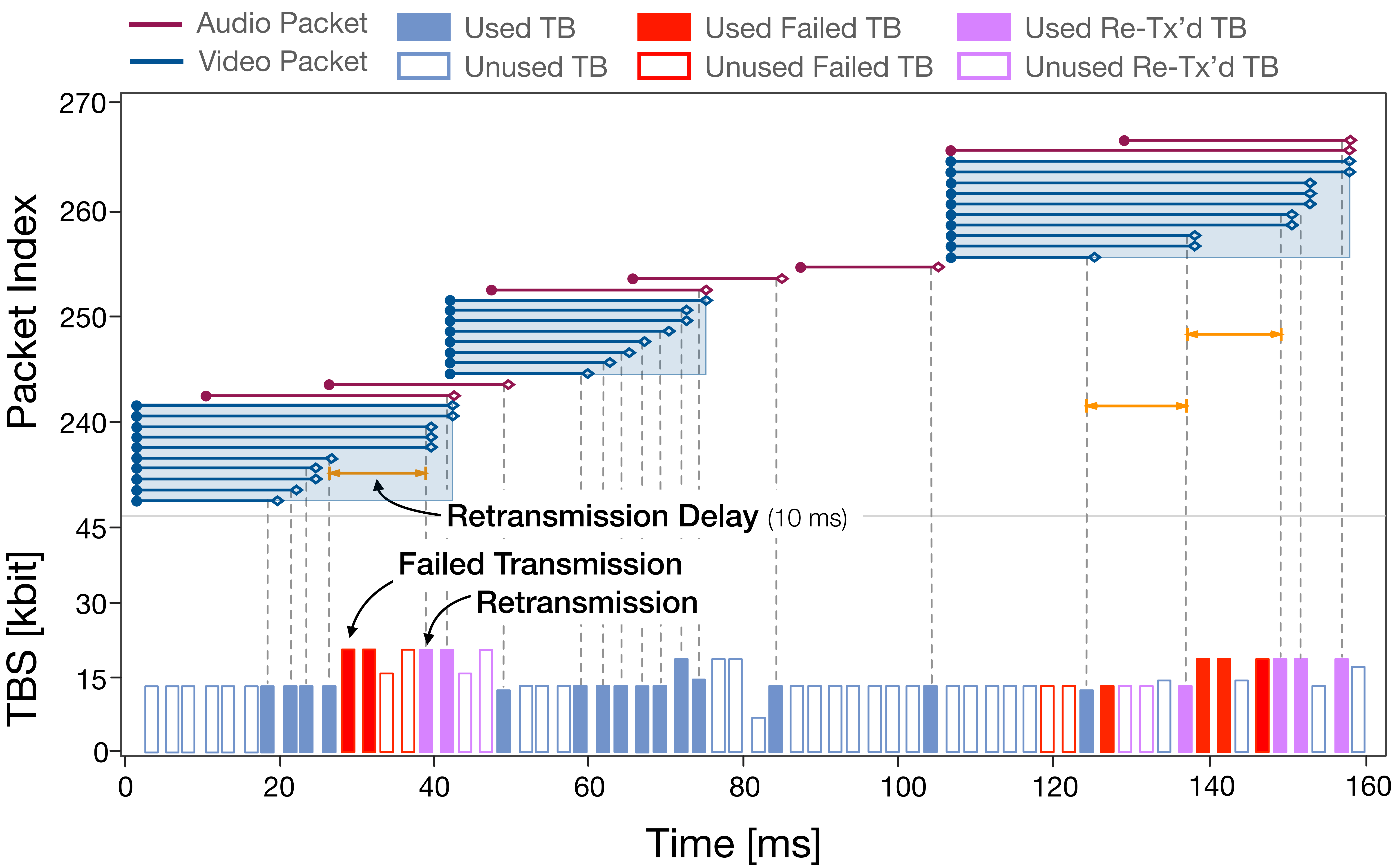


(1) Proactive grants cause delay spread at receiver side resulting in jitter

(2) Audio packets sent alongside video frames are delayed by video

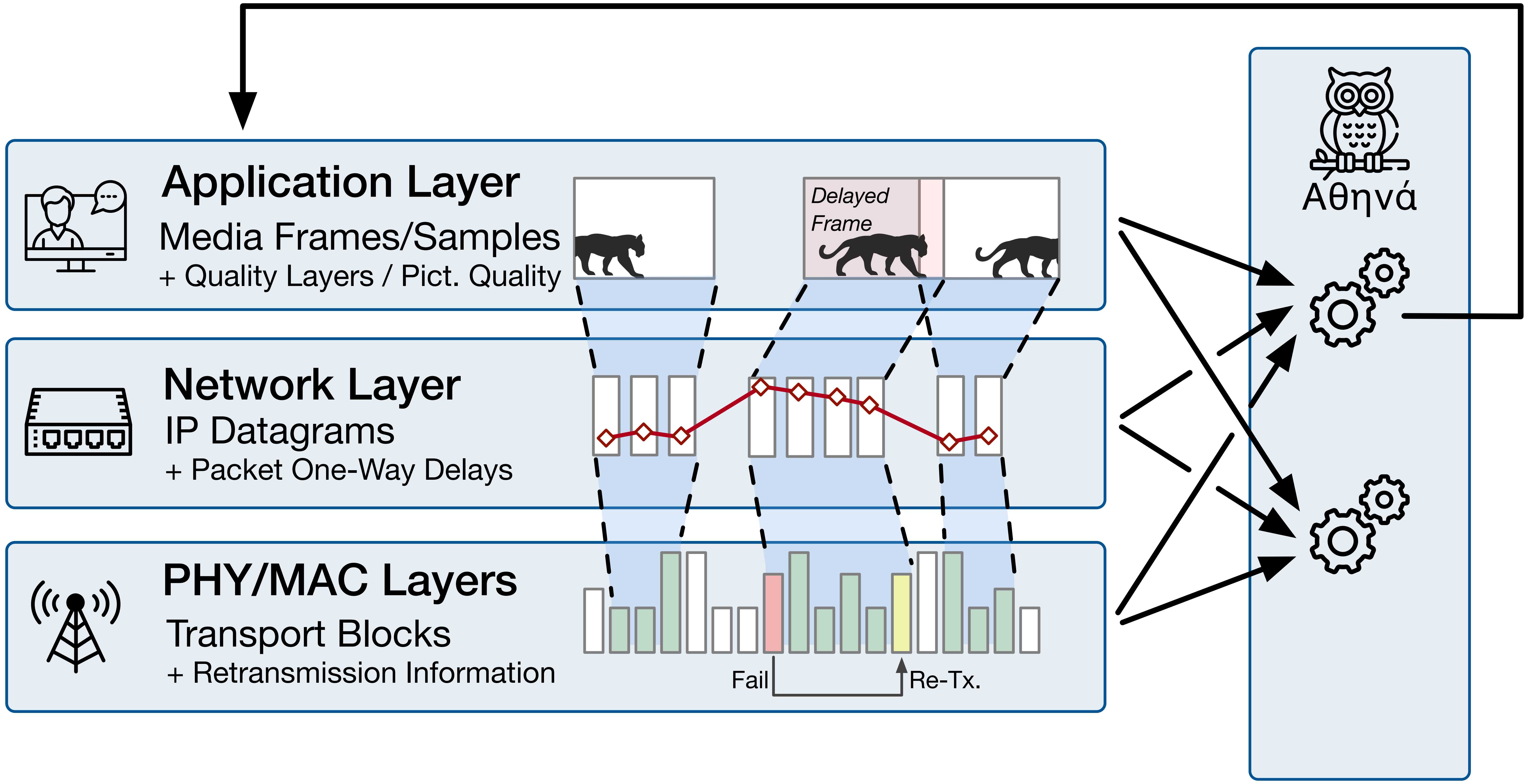
(3) Late BSR-triggered uplink grants waste capacity

5G Retransmissions Cause Jitter



→ Athena can explain per-packet latency: link-layer retransmissions further inflate delay by 10 ms

Athena Cross-Layer Optimization Opportunities

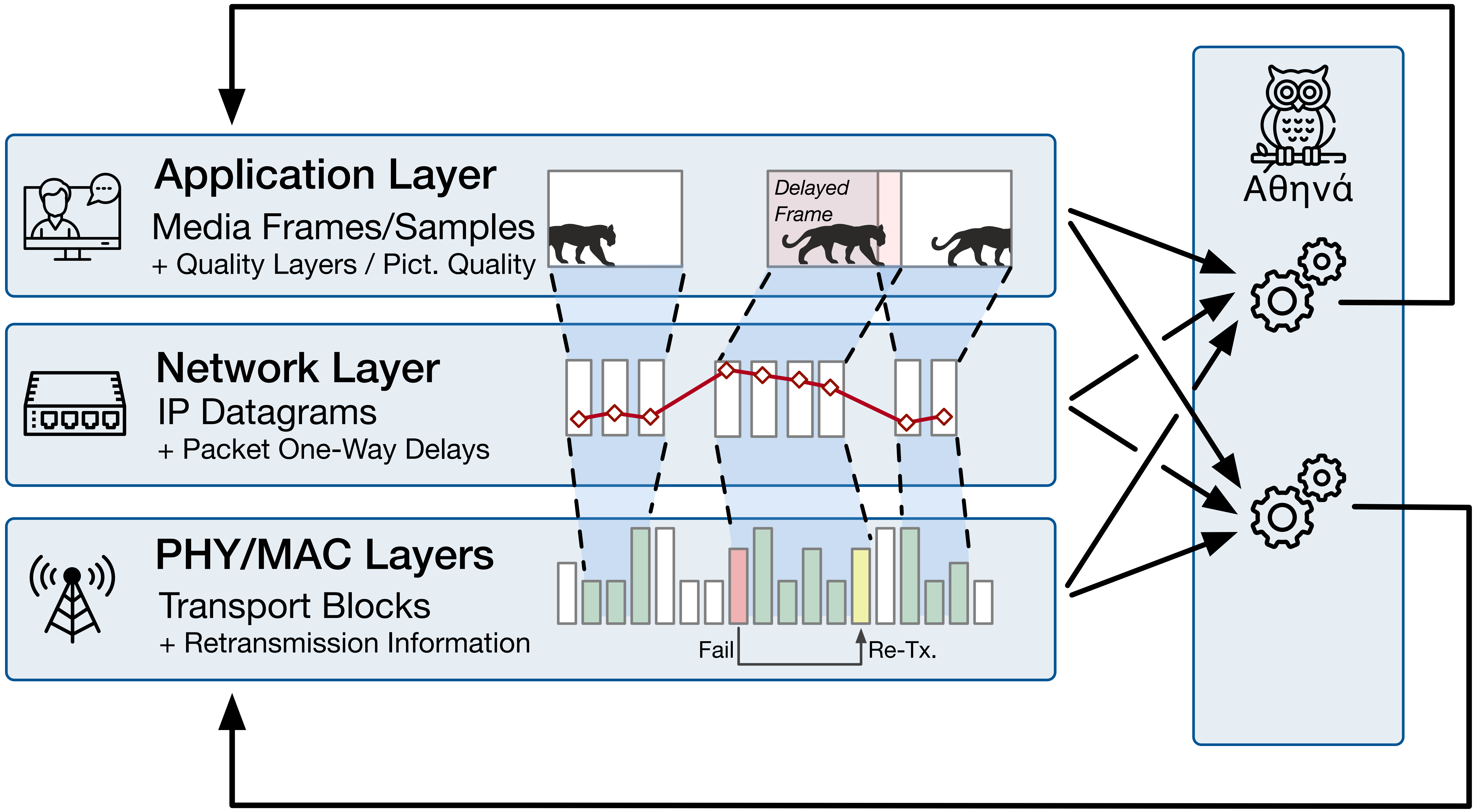


Network to Application

Telemetry about network, e.g.,

- Available capacity
- Cause of delay increase

Athena Cross-Layer Optimization Opportunities



Network to Application

Telemetry about network, e.g.,

- Available capacity
- Cause of delay increase

Application to Network

Use application semantics in network, e.g.,

- Intelligent dropping of frames
- Application-aware scheduling

ATHENA: starting point for long arc of research uncovering and addressing the intricacies of cutting-edge access networks

Q&A

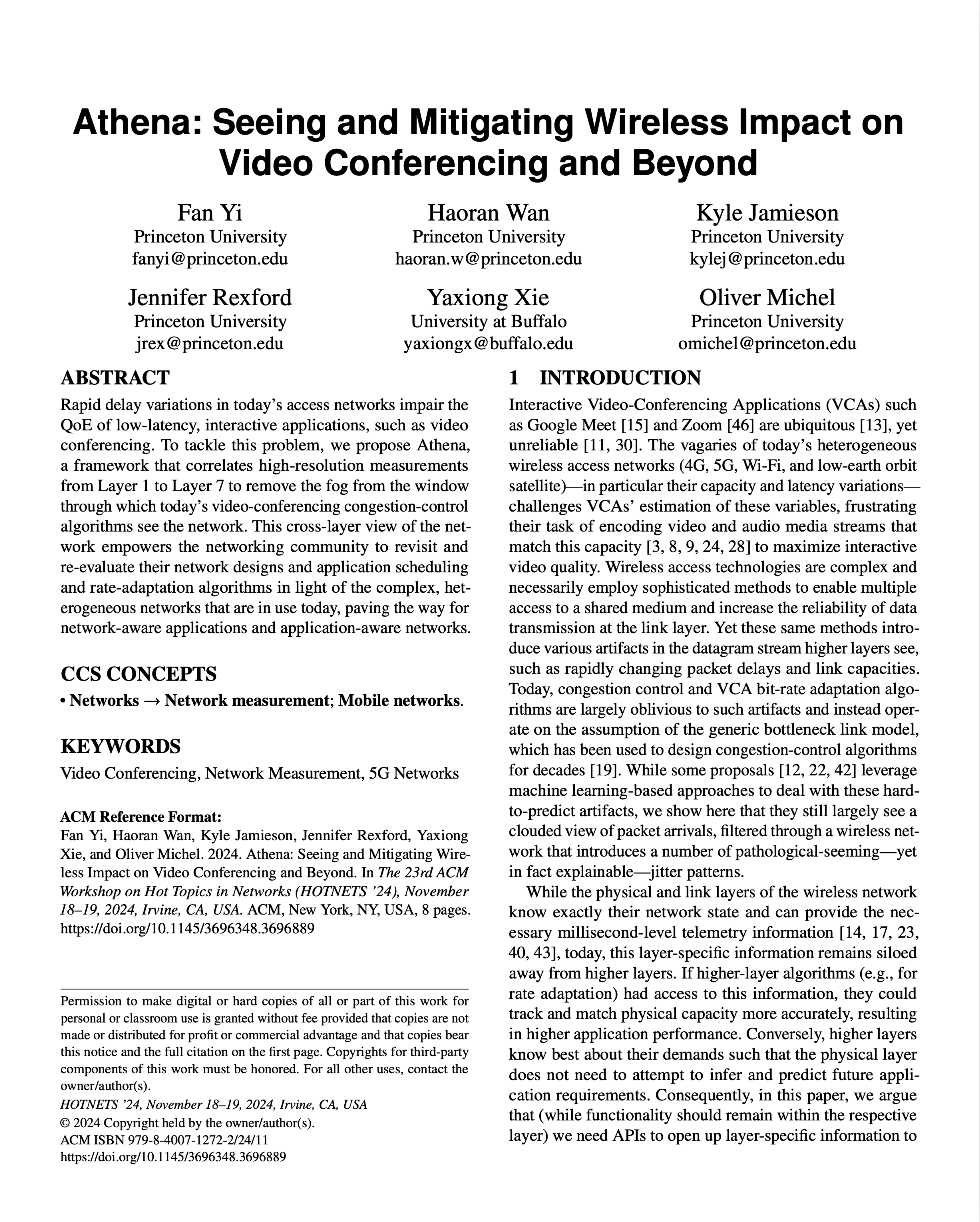
omichel@princeton.edu

https://olivermichel.github.io

Fan Yi, Hoaran Wan, Kyle Jamieson, Jennifer Rexford, Yaxiong Xie, Oliver Michel. 2024
Athena: Seeing and Mitigating Wireless Impact on Video Conferencing and Beyond
In 23rd ACM Workshop on Hot Topics in Networks *(HotNets ’24)*

Oliver Michel, Satadal Sengupta, Hyojoon Kim, Ravi Netravali, and Jennifer Rexford. 2022
Enabling Passive Measurement of Zoom Performance in Production Networks
In 22nd ACM Internet Measurement Conference *(IMC ’22)*

Haoran Wan, Xuyang Cao, Alexander Marder, and Kyle Jamieson. 2024
NR-Scope: A Practical 5G Standalone Telemetry Tool
In 20th ACM Conf. on emerging Networking EXperiments and Technologies *(CoNEXT ’24)*



Athena: Seeing and Mitigating Wireless Impact on Video Conferencing and Beyond

Fan Yi, Princeton University, fanyi@princeton.edu
Haoran Wan, Princeton University, haoran.w@princeton.edu
Kyle Jamieson, Princeton University, kylej@princeton.edu
Jennifer Rexford, Princeton University, jrex@princeton.edu
Yaxiong Xie, University at Buffalo, yaxiongx@buffalo.edu
Oliver Michel, Princeton University, omichel@princeton.edu

ABSTRACT

Rapid delay variations in today’s access networks impair the QoE of low-latency, interactive applications, such as video conferencing. To tackle this problem, we propose Athena, a framework that correlates high-resolution measurements from Layer 1 to Layer 7 to remove the fog from the window through which today’s video-conferencing congestion-control algorithms see the network. This cross-layer view of the network empowers the networking community to revisit and re-evaluate their network designs and application scheduling and rate-adaptation algorithms in light of the complex, heterogeneous networks that are in use today, paving the way for network-aware applications and application-aware networks.

CCS CONCEPTS

• **Networks → Network measurement**; **Mobile networks**.

KEYWORDS

Video Conferencing, Network Measurement, 5G Networks

ACM Reference Format:
Fan Yi, Haoran Wan, Kyle Jamieson, Jennifer Rexford, Yaxiong Xie, and Oliver Michel. 2024. Athena: Seeing and Mitigating Wireless Impact on Video Conferencing and Beyond. In *The 23rd ACM Workshop on Hot Topics in Networks (HOTNETS ’24), November 18–19, 2024, Irvine, CA, USA.* ACM, New York, NY, USA, 8 pages. https://doi.org/10.1145/3696348.3696889

Permission to make digital or hard copies of all or part of this work for personal or classroom use is granted without fee provided that copies are not made or distributed for profit or commercial advantage and that copies bear this notice and the full citation on the first page. Copyrights for third-party components of this work must be honored. For all other uses, contact the owner/author(s).
HOTNETS ’24, November 18–19, 2024, Irvine, CA, USA
© 2024 Copyright held by the owner/author(s).
ACM ISBN 979-8-4007-1272-2/24/11
https://doi.org/10.1145/3696348.3696889

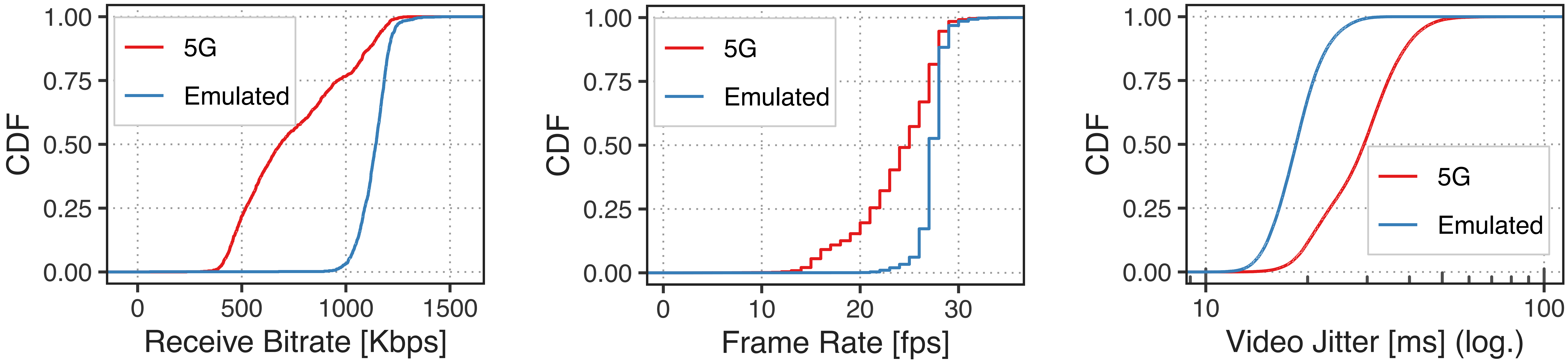
1 INTRODUCTION

Interactive Video-Conferencing Applications (VCAs) such as Google Meet [15] and Zoom [46] are ubiquitous [13], yet unreliable [11, 30]. The vagaries of today’s heterogeneous wireless access networks (4G, 5G, Wi-Fi, and low-earth orbit satellite)—in particular their capacity and latency variations—challenges VCAs’ estimation of these variables, frustrating their task of encoding video and audio media streams that match this capacity [3, 8, 9, 24, 28] to maximize interactive video quality. Wireless access technologies are complex and necessarily employ sophisticated methods to enable multiple access to a shared medium and increase the reliability of data transmission at the link layer. Yet these same methods introduce various artifacts in the datagram stream higher layers see, such as rapidly changing packet delays and link capacities. Today, congestion control and VCA bit-rate adaptation algorithms are largely oblivious to such artifacts and instead operate on the assumption of the generic bottleneck link model, which has been used to design congestion-control algorithms for decades [19]. While some proposals [12, 22, 42] leverage machine learning-based approaches to deal with these hard-to-predict artifacts, we show here that they still largely see a clouded view of packet arrivals, filtered through a wireless network that introduces a number of pathological-seeming—yet in fact explainable—jitter patterns.

While the physical and link layers of the wireless network know exactly their network state and can provide the necessary millisecond-level telemetry information [14, 17, 23, 40, 43], today, this layer-specific information remains siloed away from higher layers. If higher-layer algorithms (e.g., for rate adaptation) had access to this information, they could track and match physical capacity more accurately, resulting in higher application performance. Conversely, higher layers know best about their demands such that the physical layer does not need to attempt to infer and predict future application requirements. Consequently, in this paper, we argue that (while functionality should remain within the respective layer) we need APIs to open up layer-specific information to

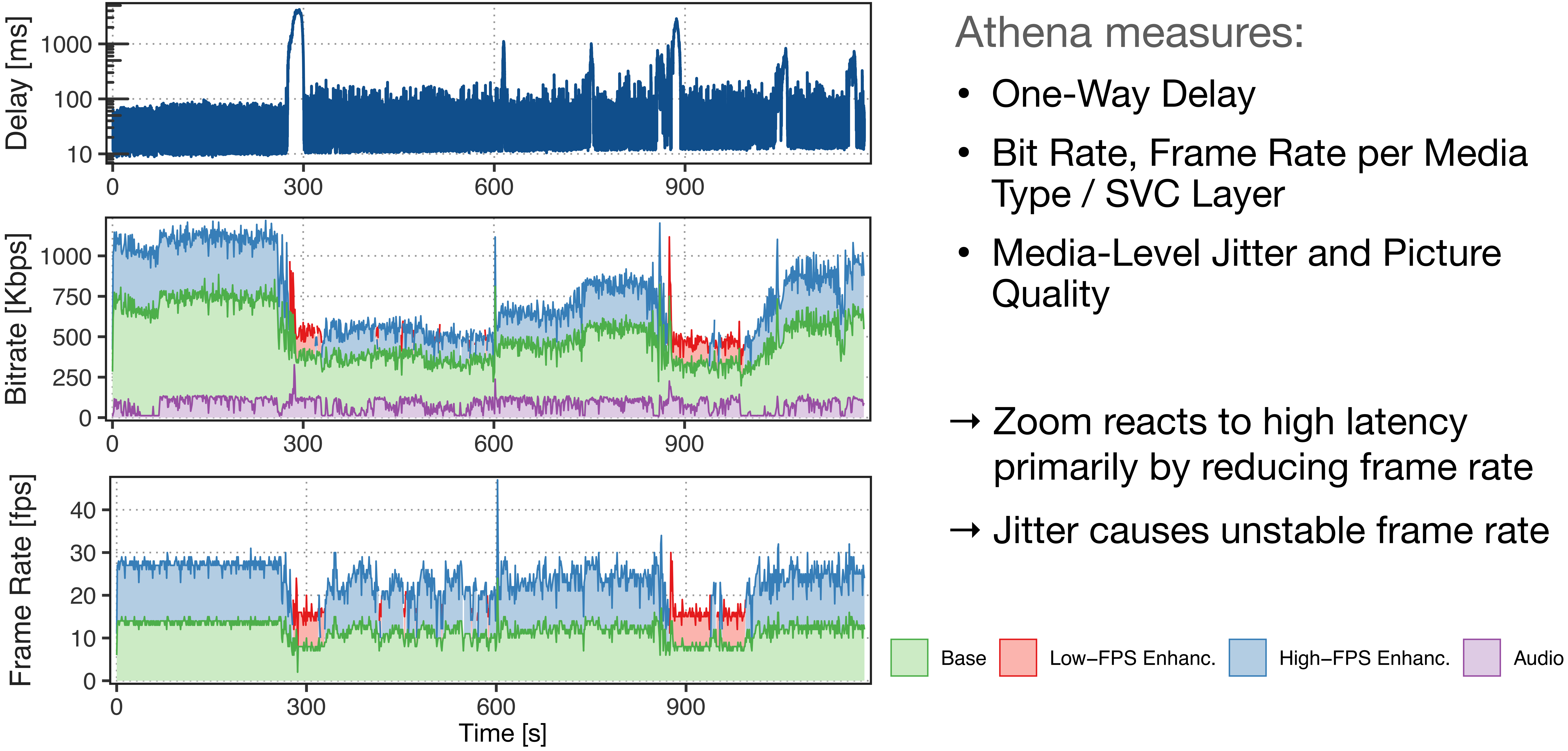
Backup Slides

5G Latency and Jitter Considered Harmful



→ Latency and Jitter cause degraded performance.

Athena Application and Network Layer Measurements



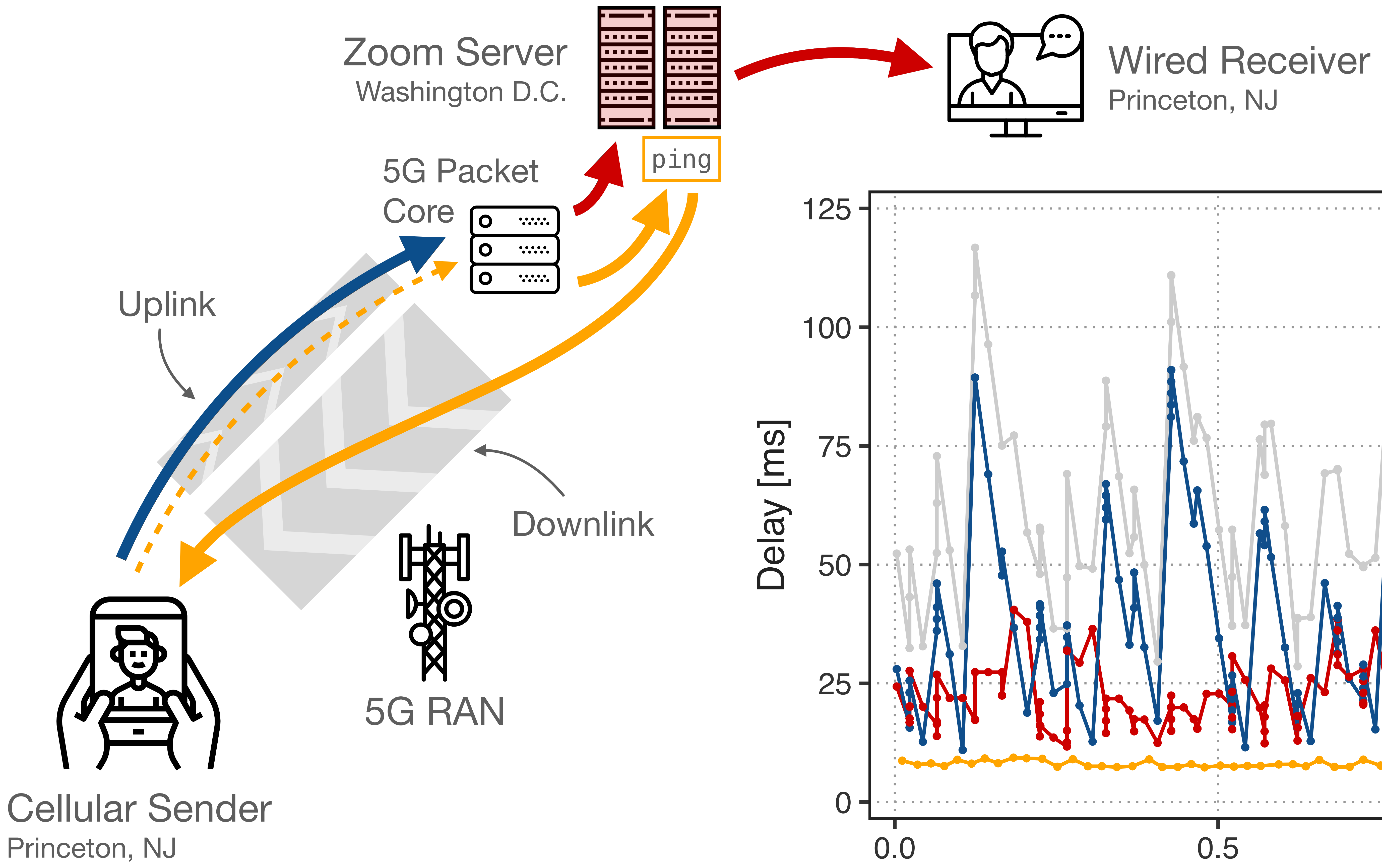
Athena measures:

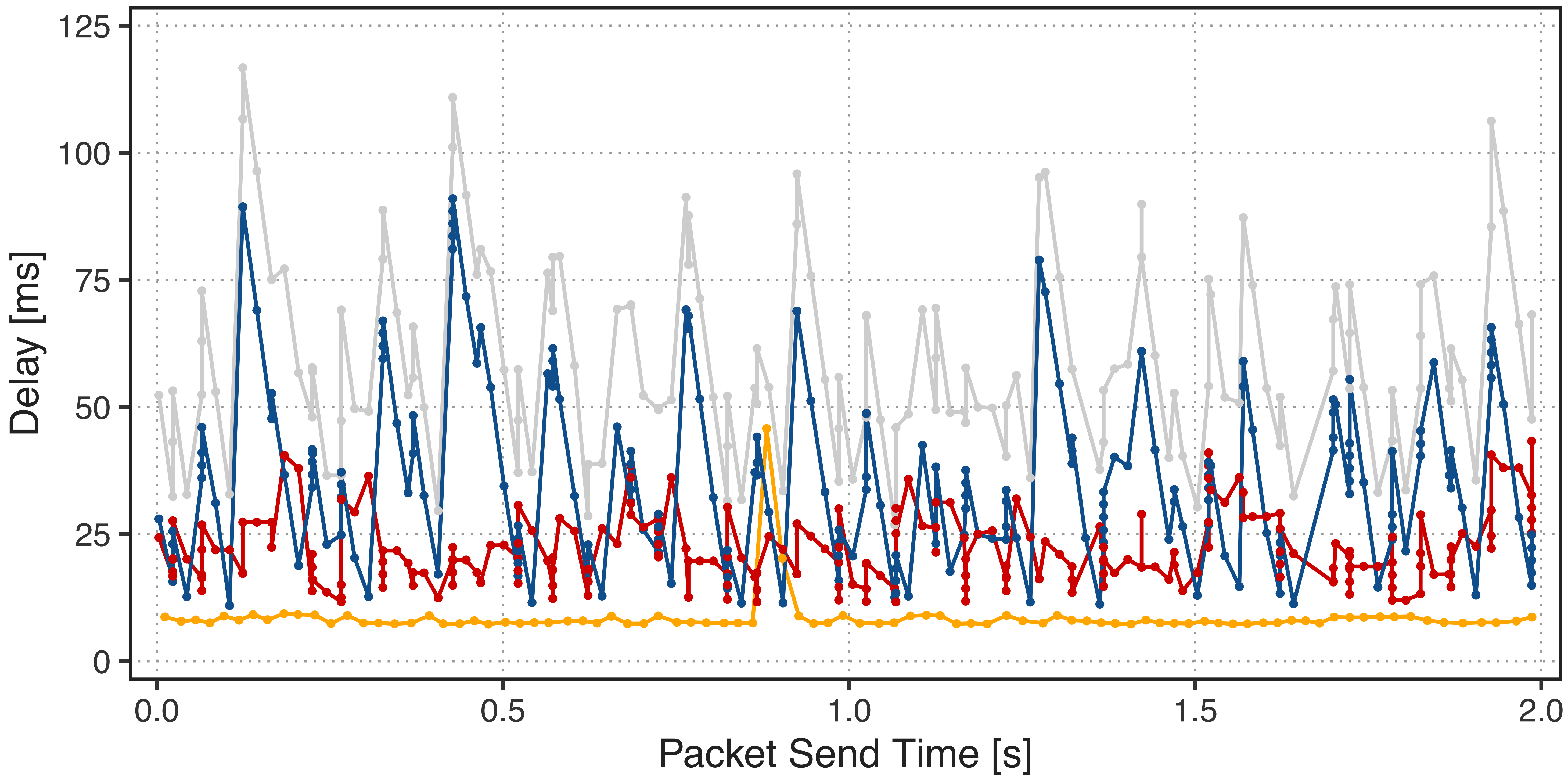
- One-Way Delay
- Bit Rate, Frame Rate per Media Type / SVC Layer
- Media-Level Jitter and Picture Quality

→ Zoom reacts to high latency primarily by reducing frame rate

→ Jitter causes unstable frame rate

5G Uplink causes high Latency and Jitter





→ **Cellular uplink is primary contributor to high delay and jitter.**