

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

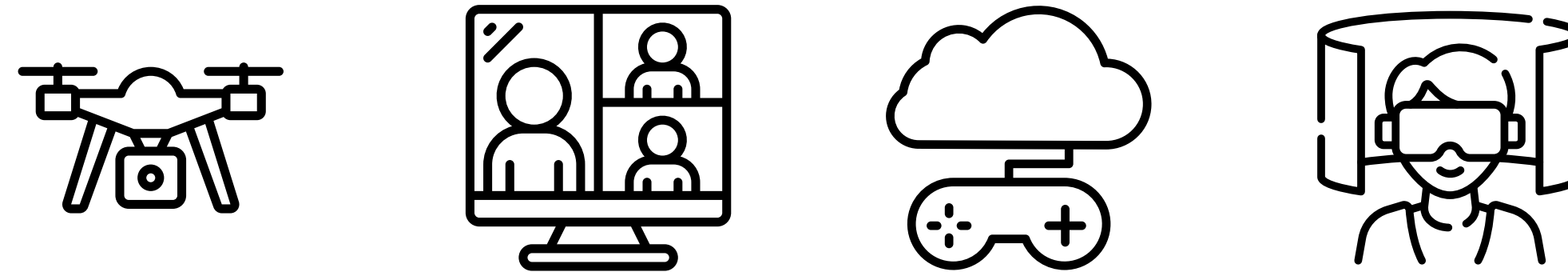
Fan Yi, Haoran Wan, Kyle Jamieson, Jennifer Rexford, Yaxiong Xie, [Oliver Michel](#)

HotNets '24, Irvine, CA, November 18, 2024



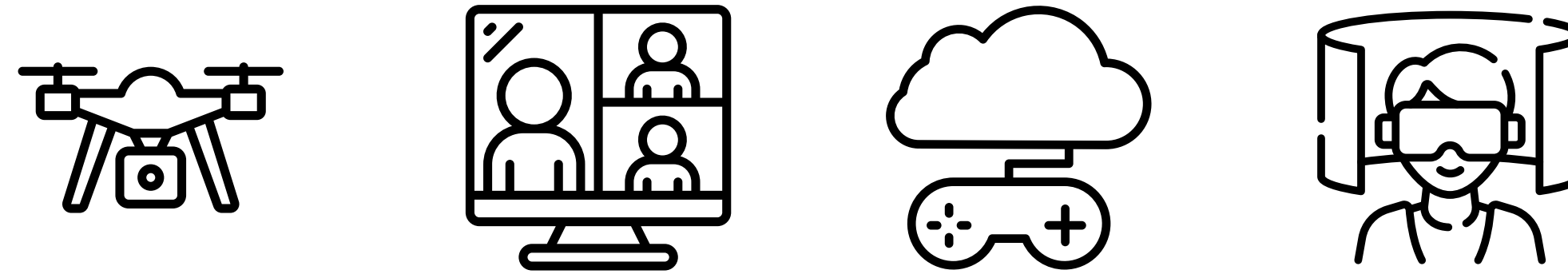
Application Requirements Outpace Network Evolution

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



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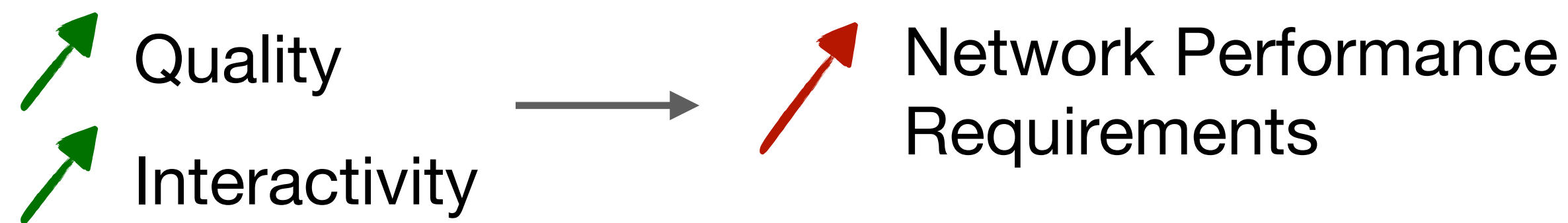
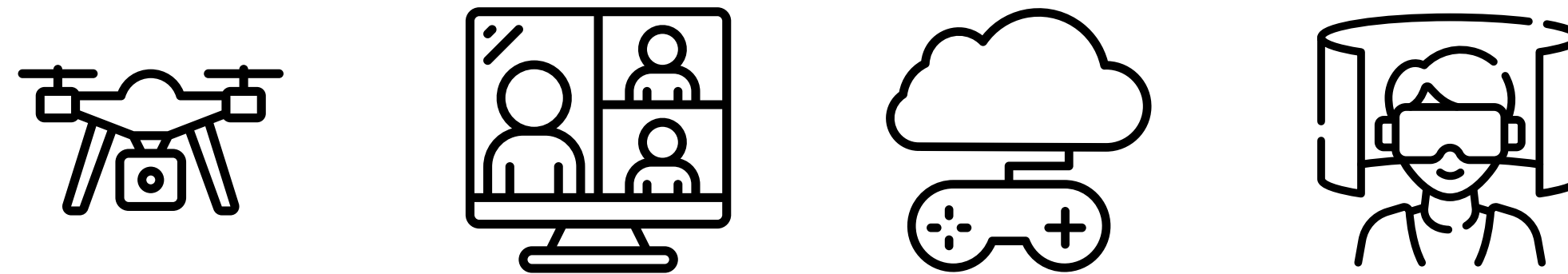
Massive rise in use over past decade across wide spectrum of use cases:



↗ Quality
↗ Interactivity

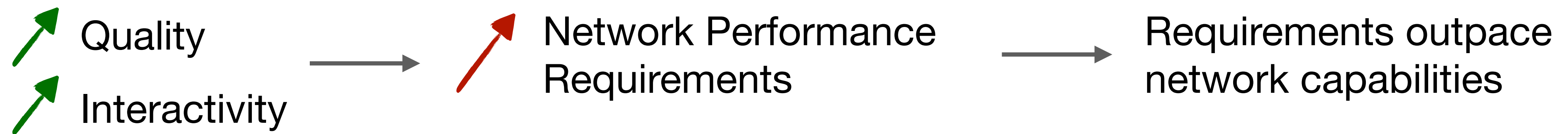
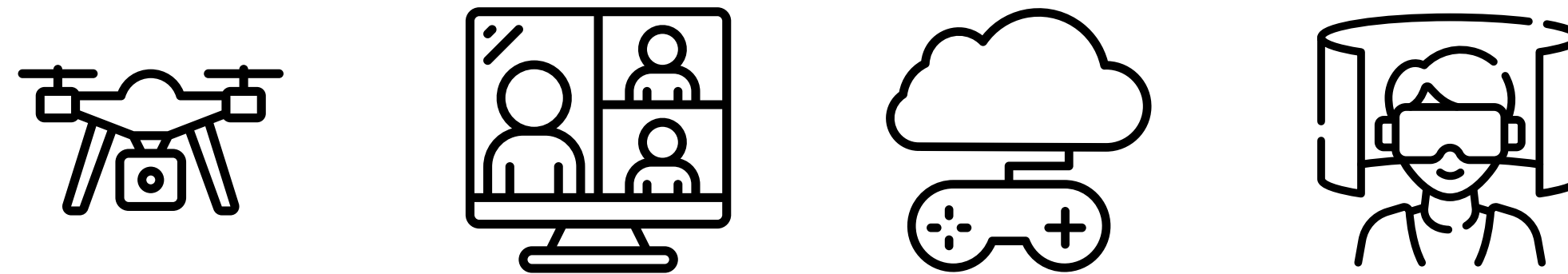
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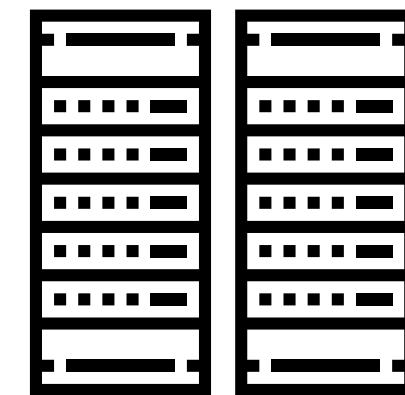


Application Requirements Outpace Network Evolution

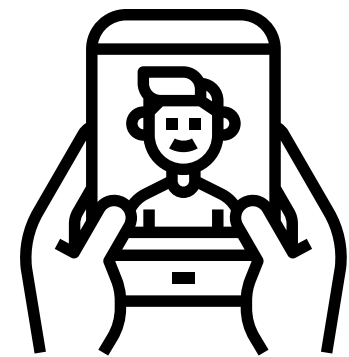
Massive rise in use over past decade across wide spectrum of use cases:



Anatomy of a Video-Conferencing Session

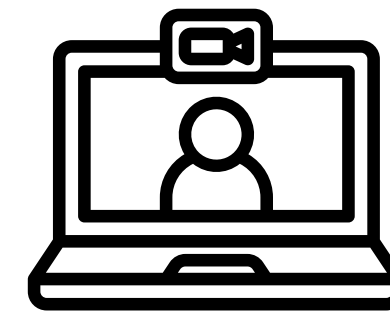
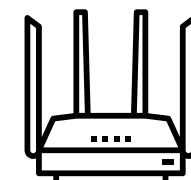


Zoom
Server

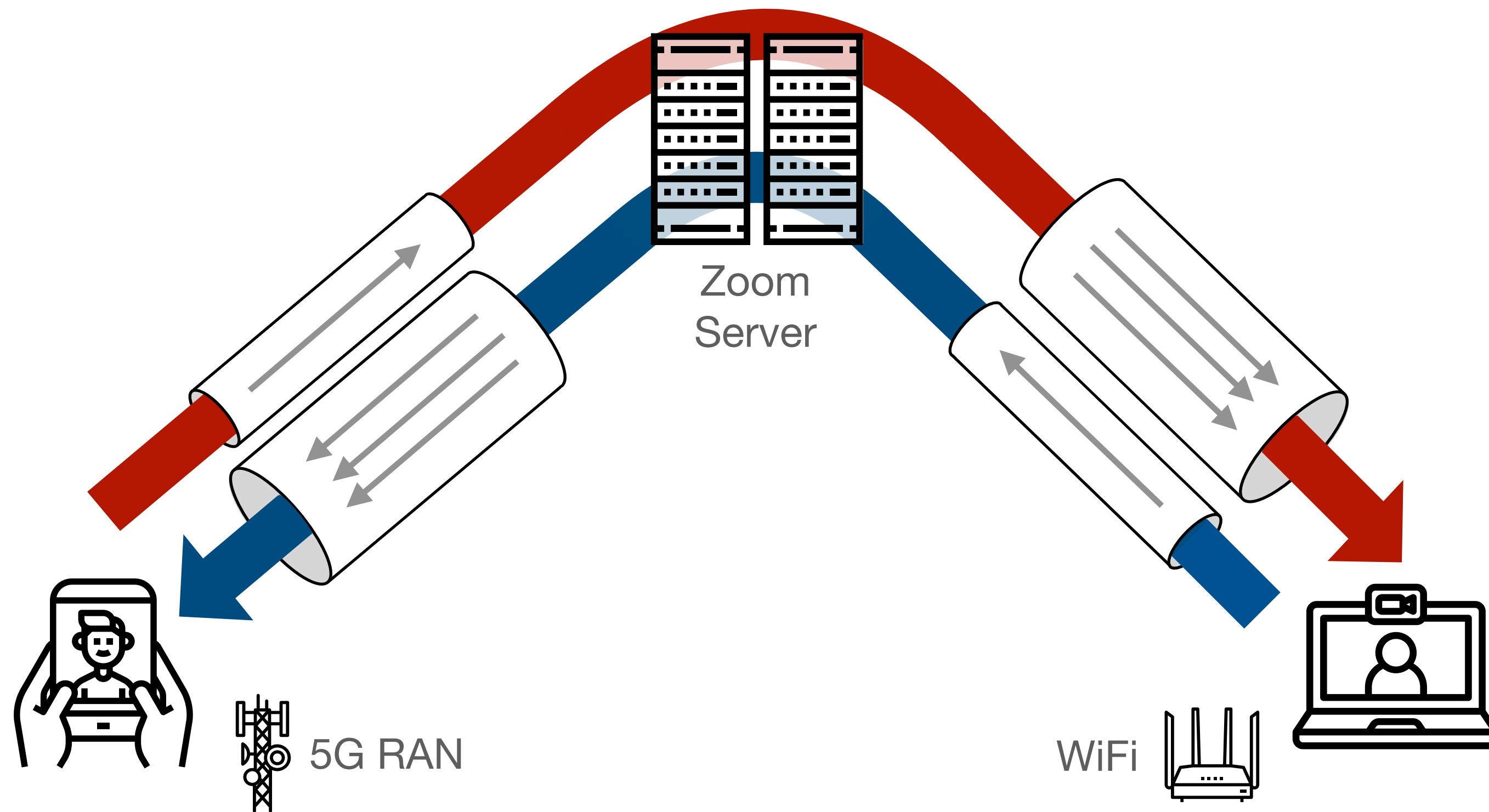


5G RAN

WiFi

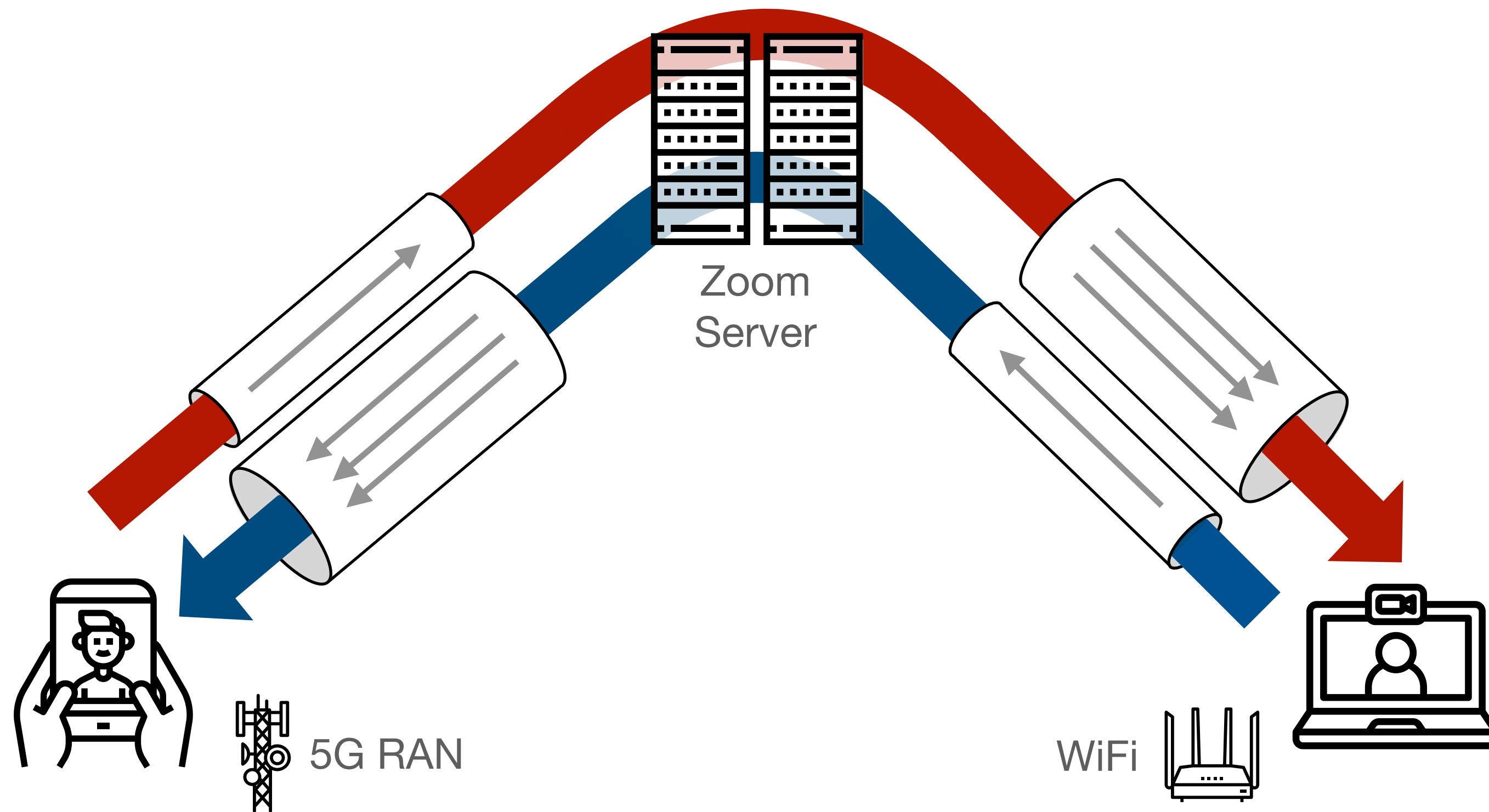


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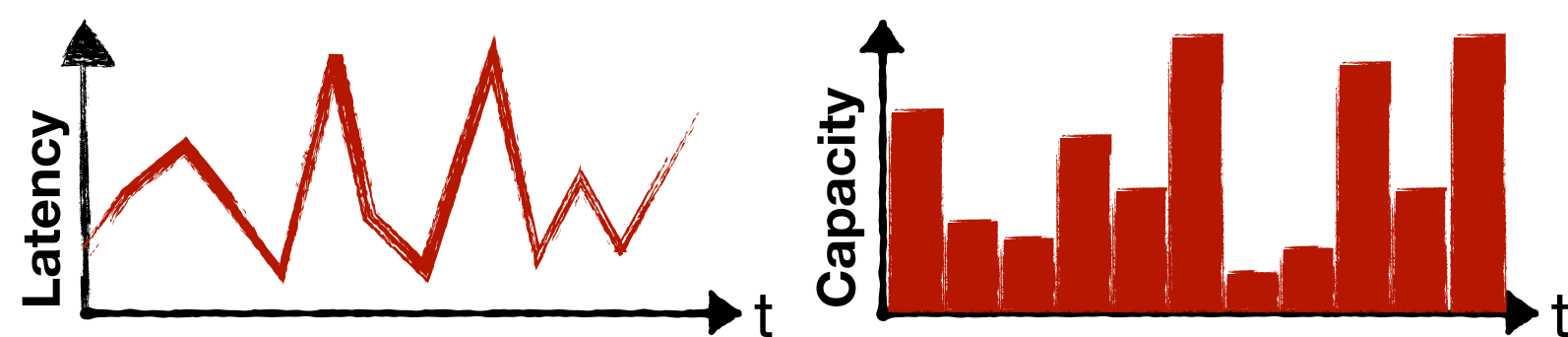
(1) Critical traffic on uplink

Anatomy of a Video-Conferencing Session

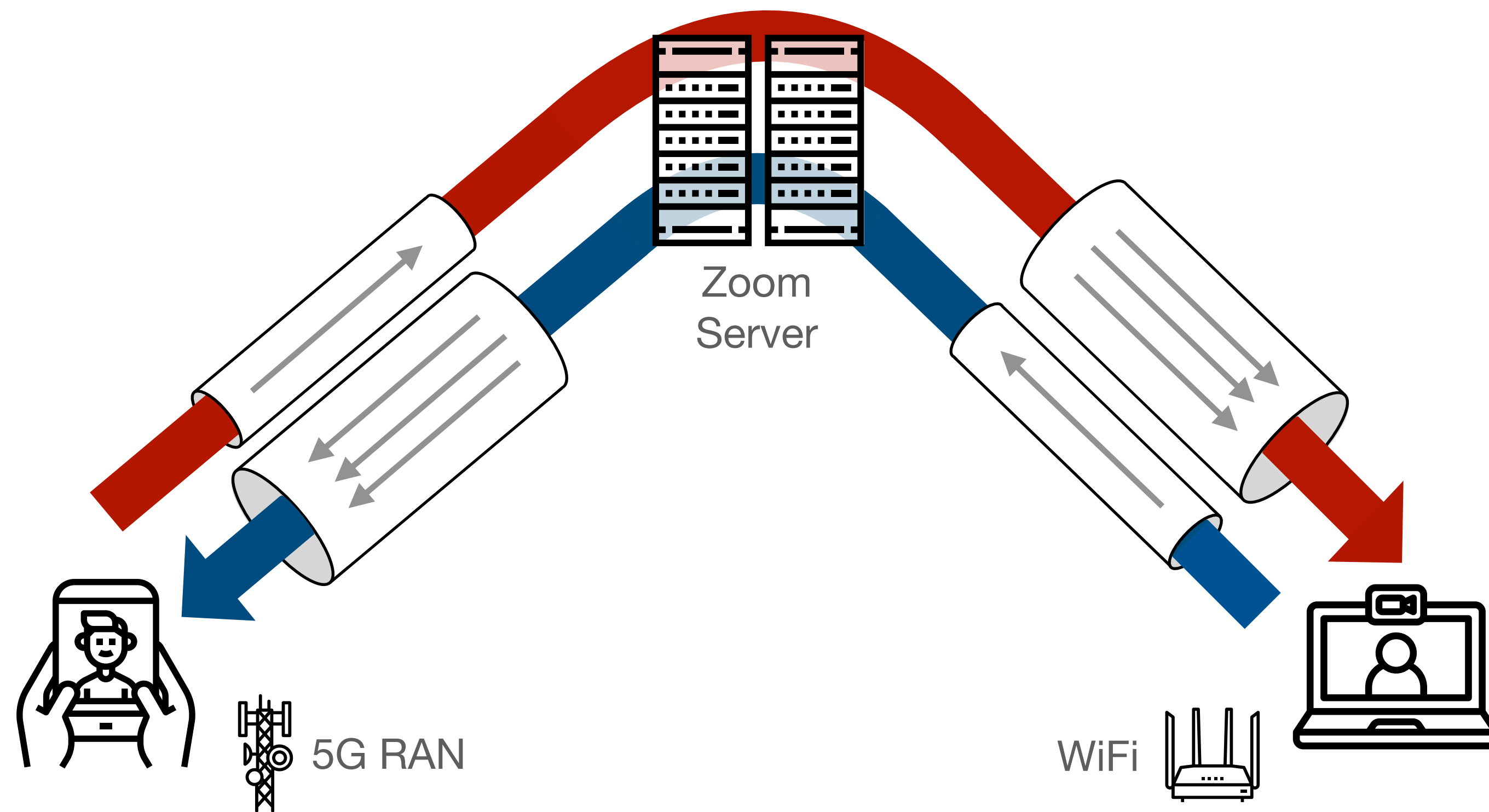


- (1) Critical traffic on uplink
- (2) Traversal of access networks

Artifacts from Access Network:

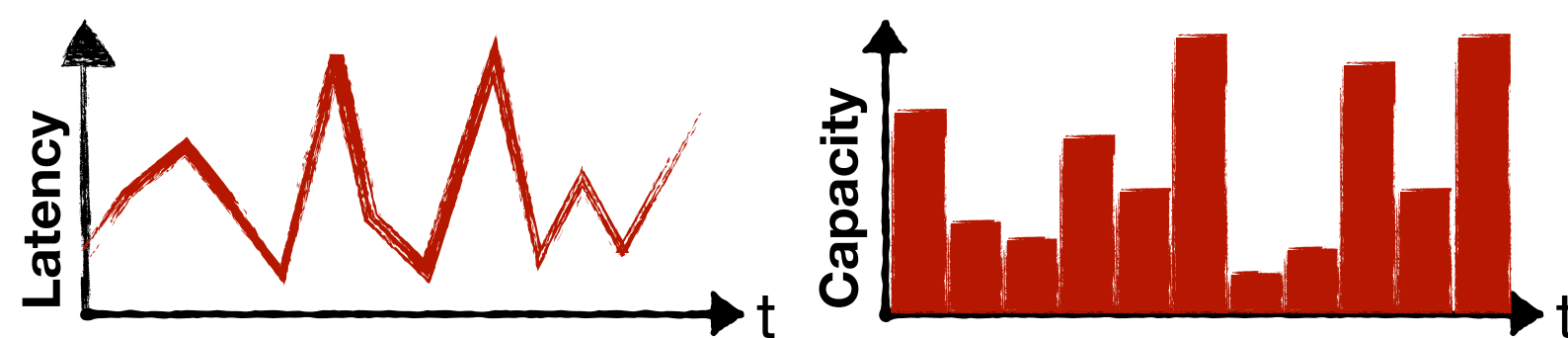


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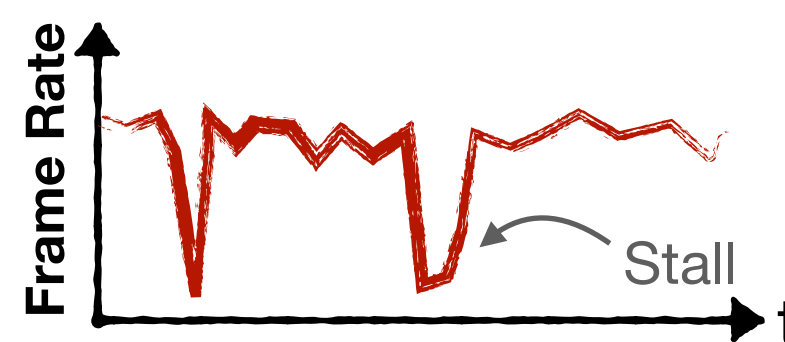


- (1) Critical traffic on uplink
- (2) Traversal of access networks
- (3) Immediate QoE effects

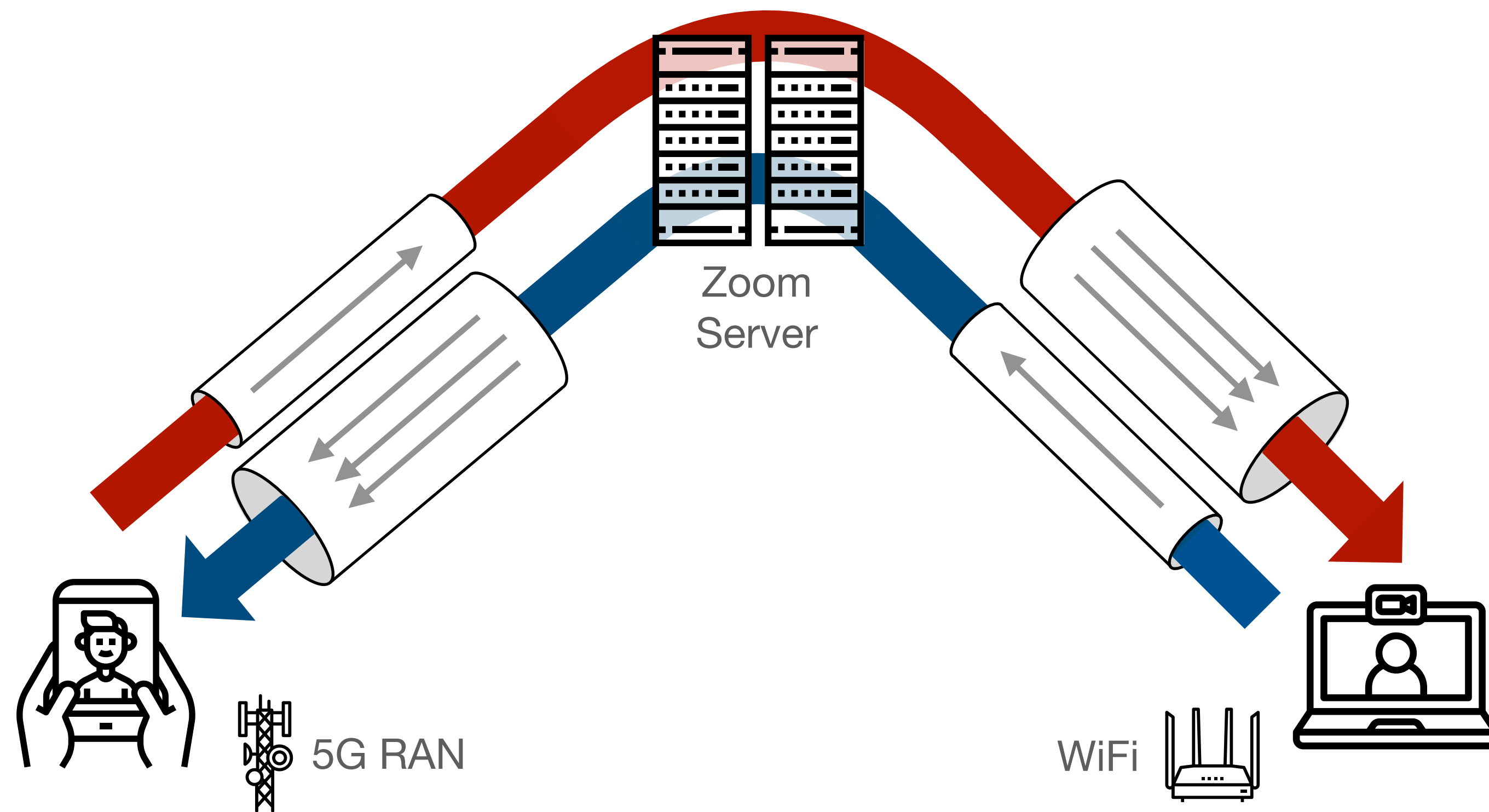
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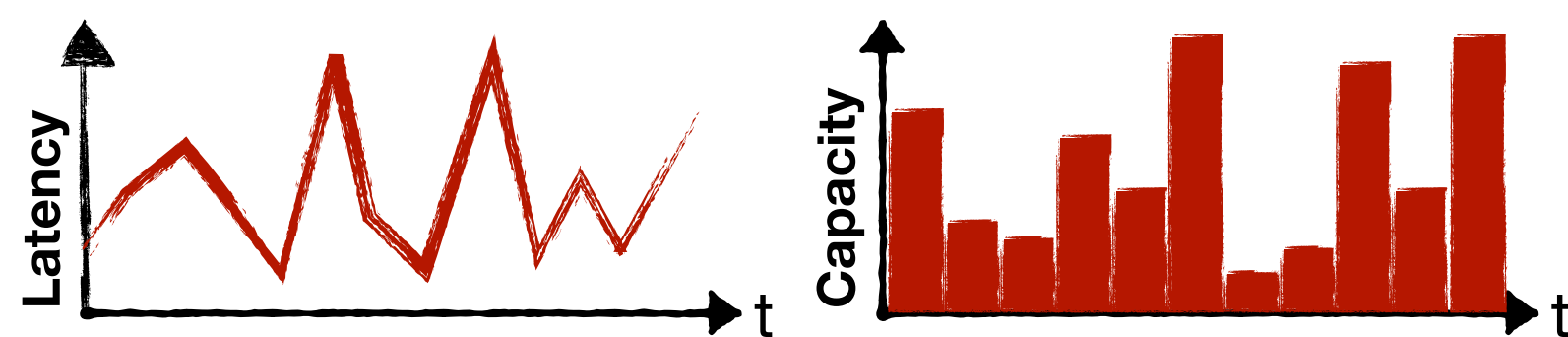
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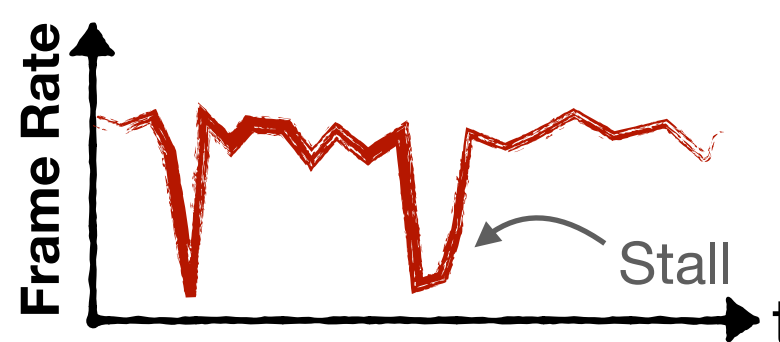
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Anatomy of video conferencing over wireless challenges QoE

Artifacts from Access Network:



QoE Degradation:



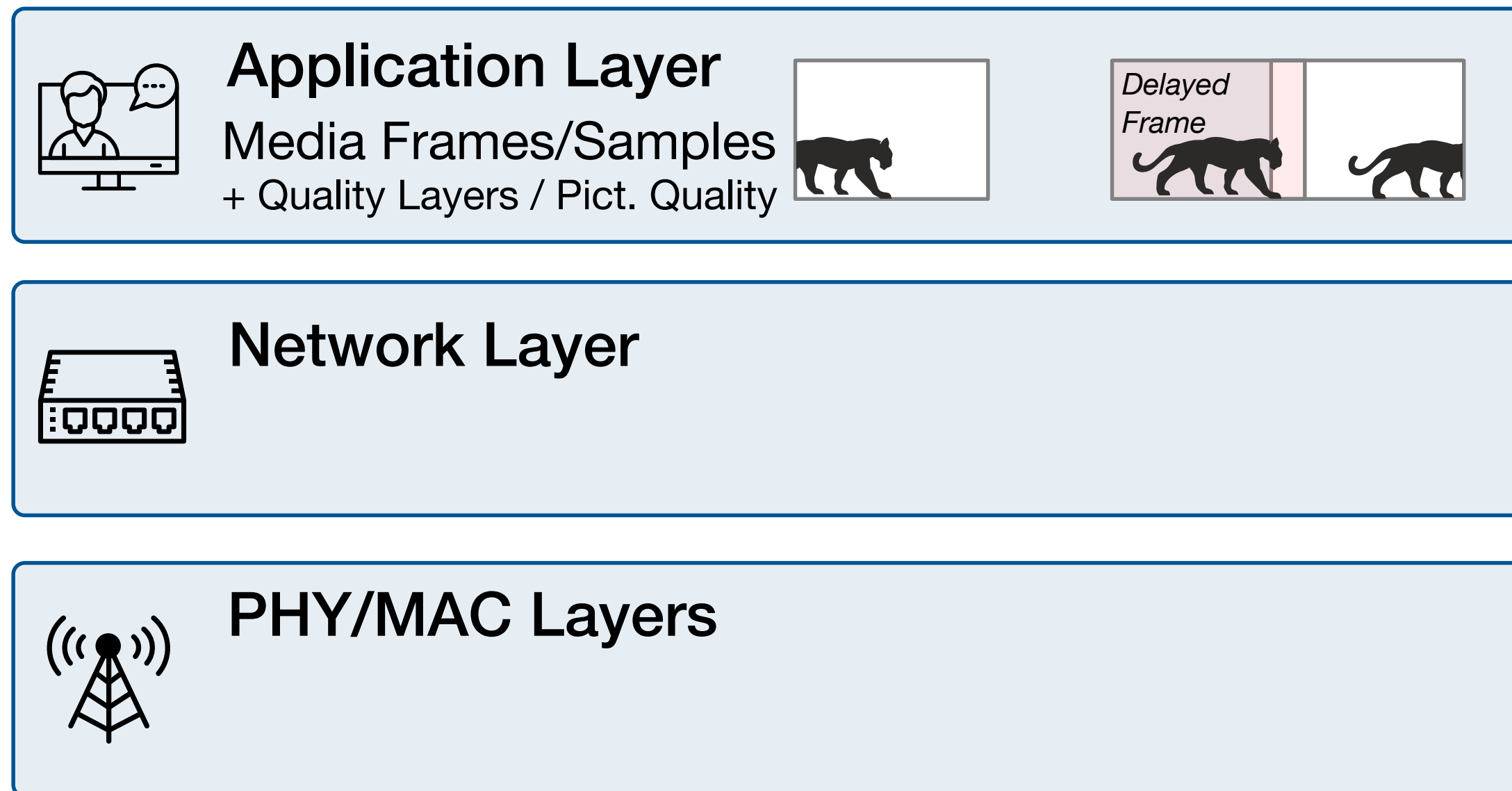
Athena Cross-Layer Measurement & Optimization

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Network state and information
is siloed within each layer

→ Lost optimization
opportunities

Athena Cross-Layer Measurement & Optimization

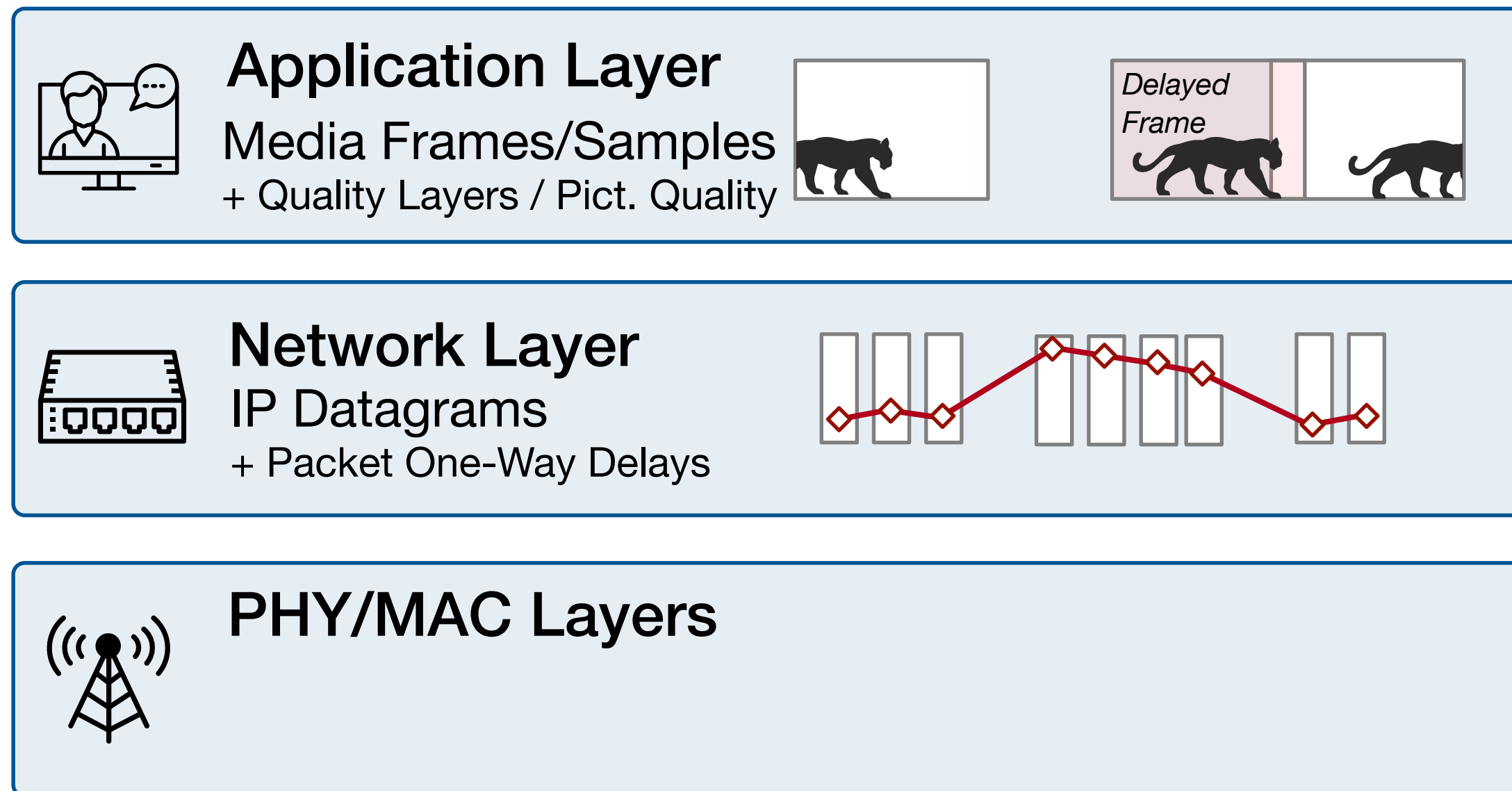


Network state and information is siloed within each layer



Lost optimization opportunities

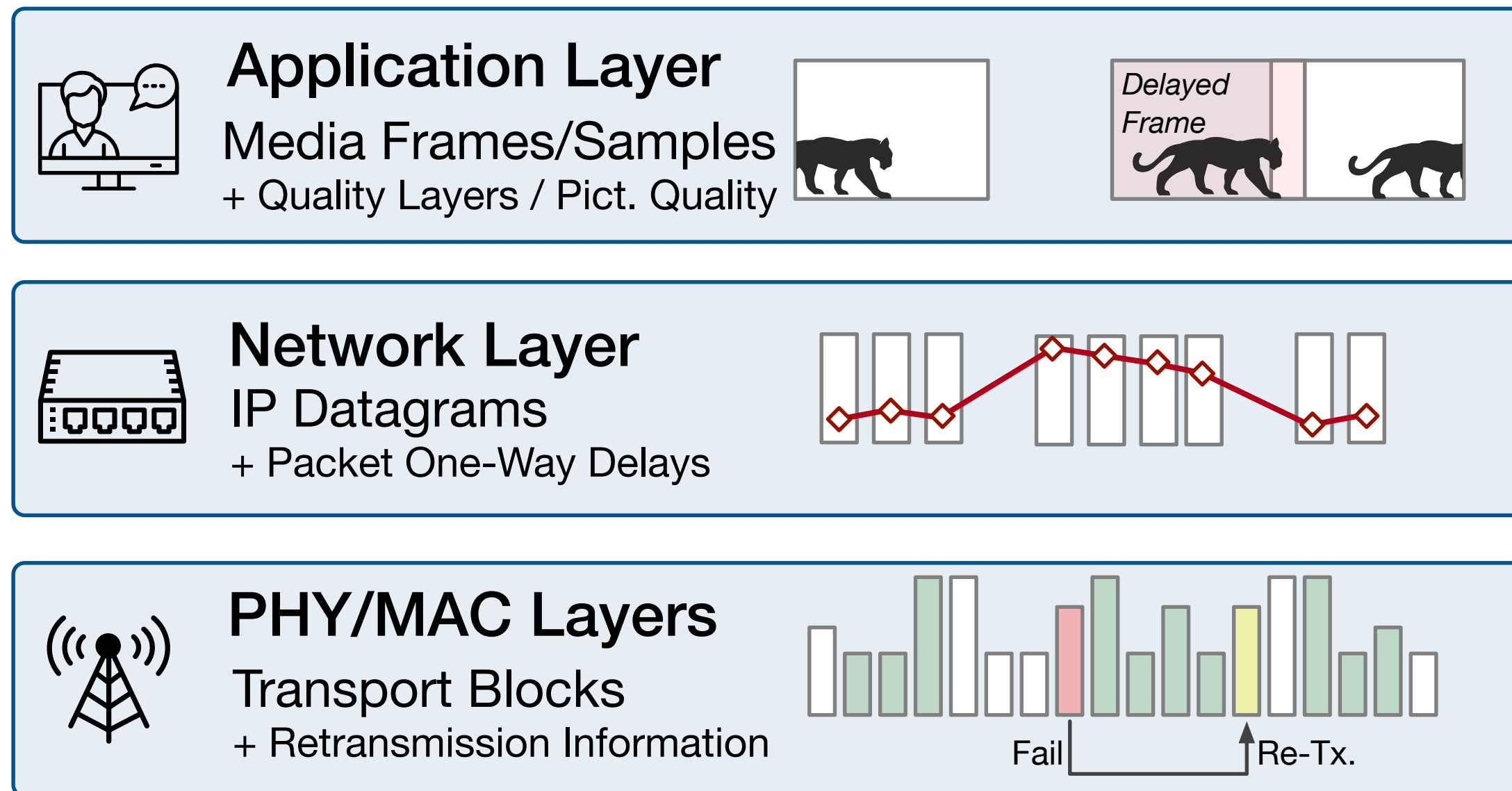
Athena Cross-Layer Measurement & Optimization



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→ Lost optimization opportunities

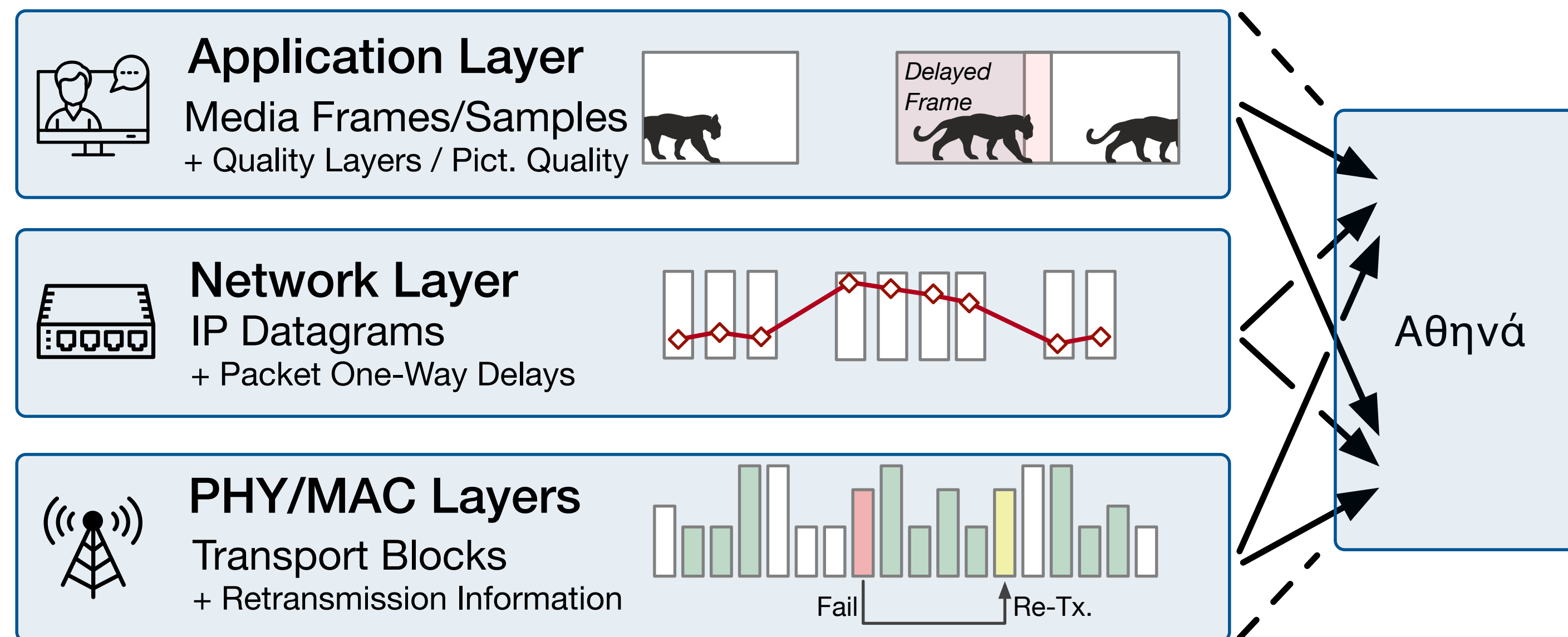
Athena Cross-Layer Measurement & Optimization



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Athena Cross-Layer Measurement & Optimization



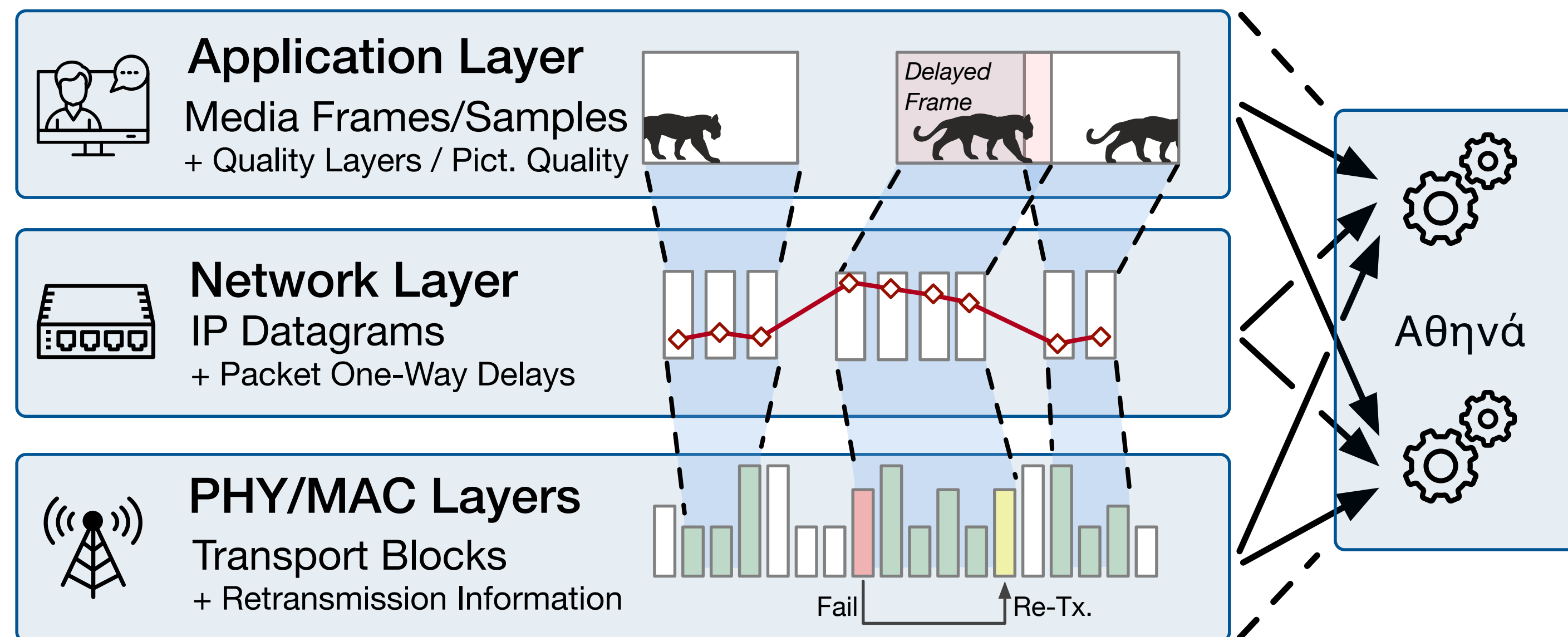
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ATHENA...

(1) Sees across layers

Athena Cross-Layer Measurement & Optimization



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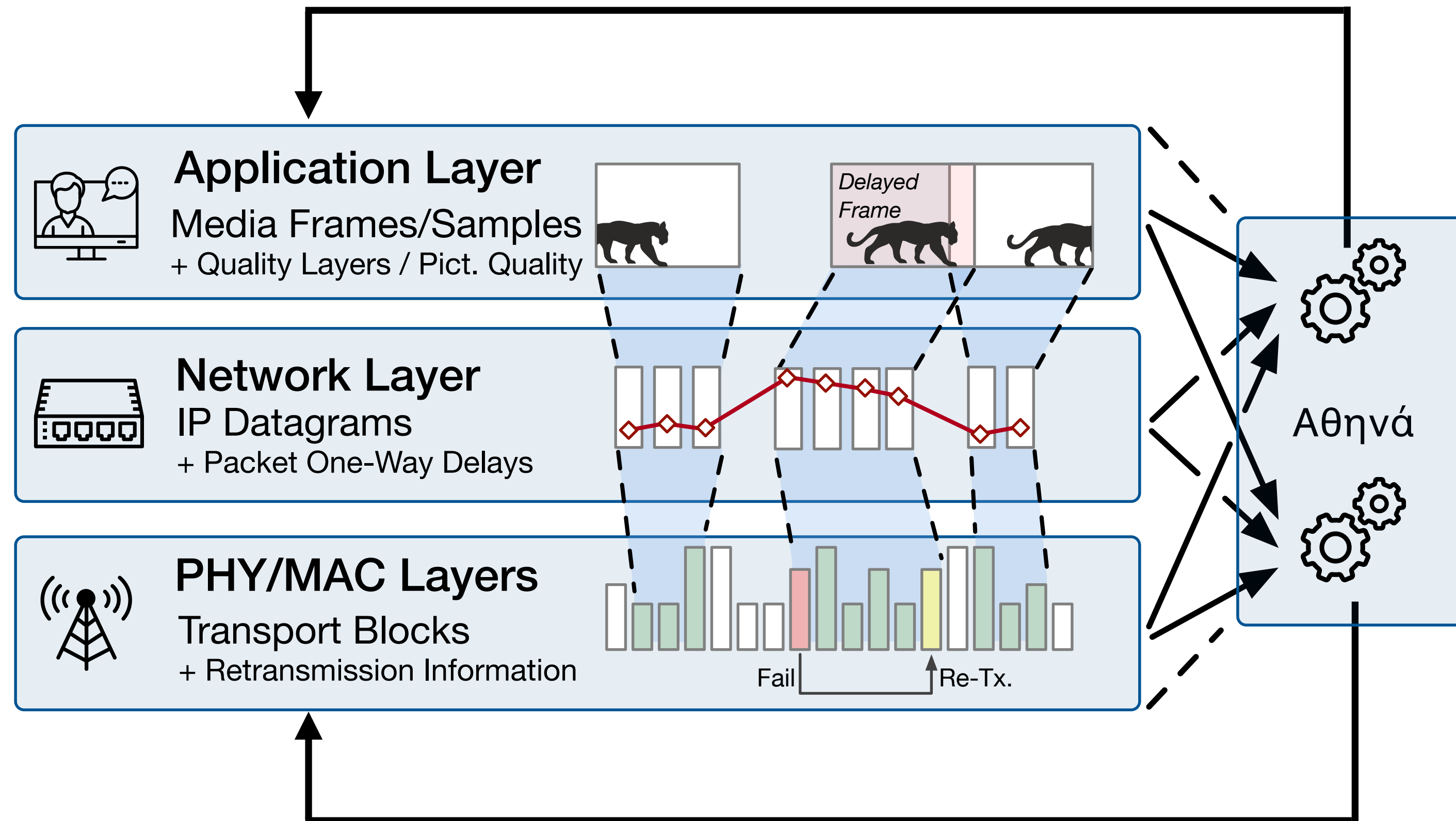
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(1) Sees across layers

(2) Correlates data across layers

Athena Cross-Layer Measurement & Optimization



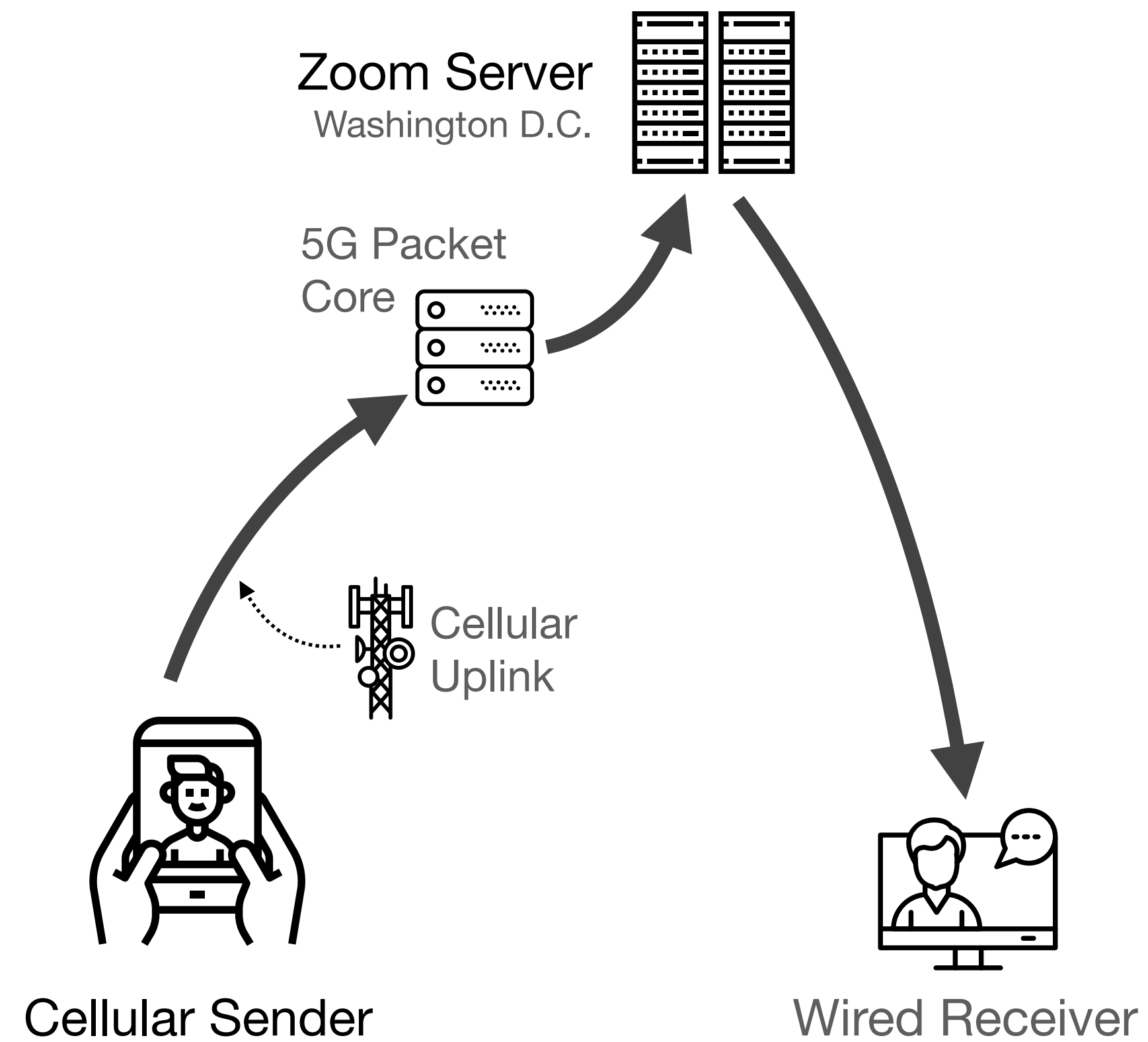
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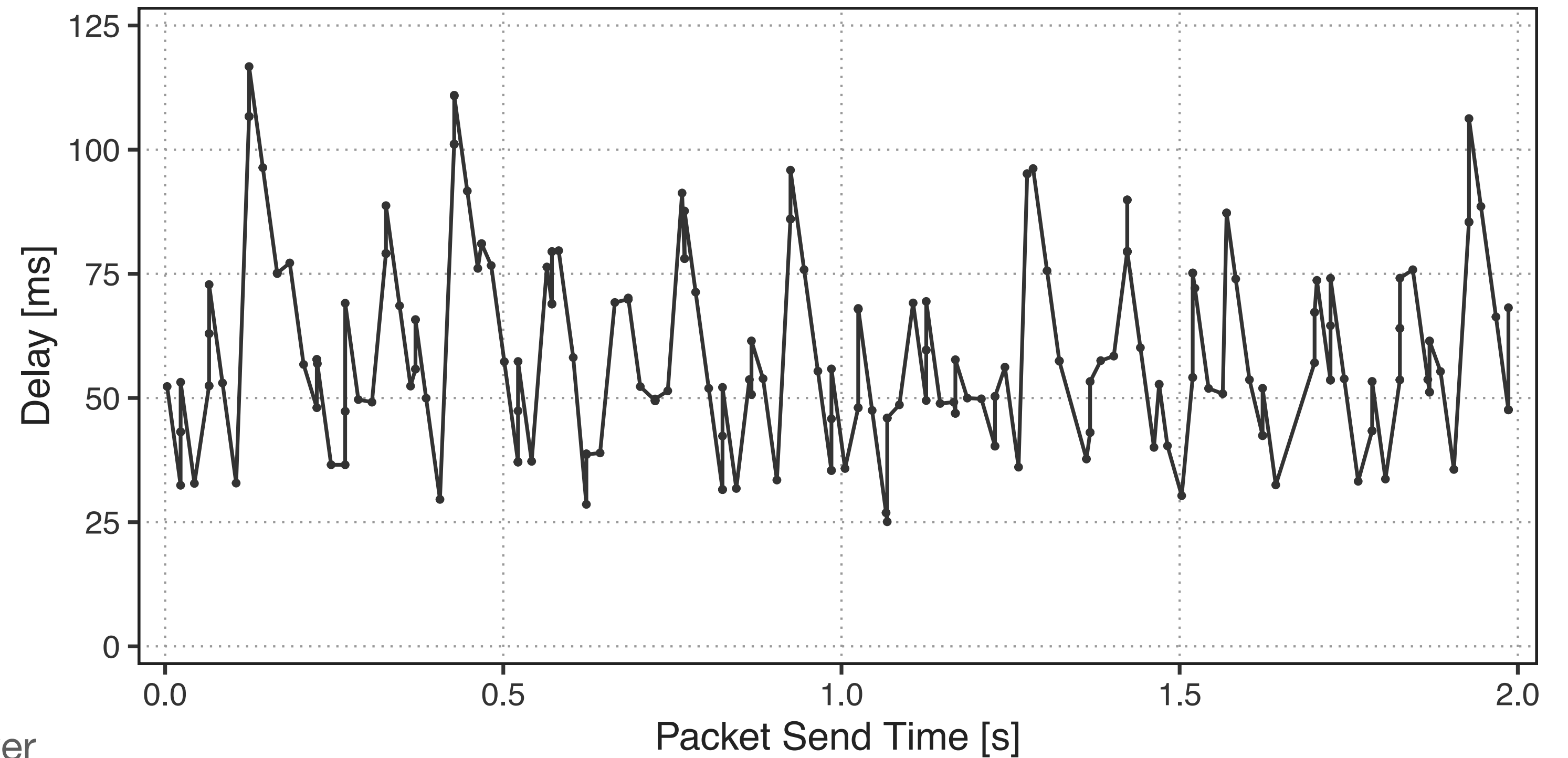
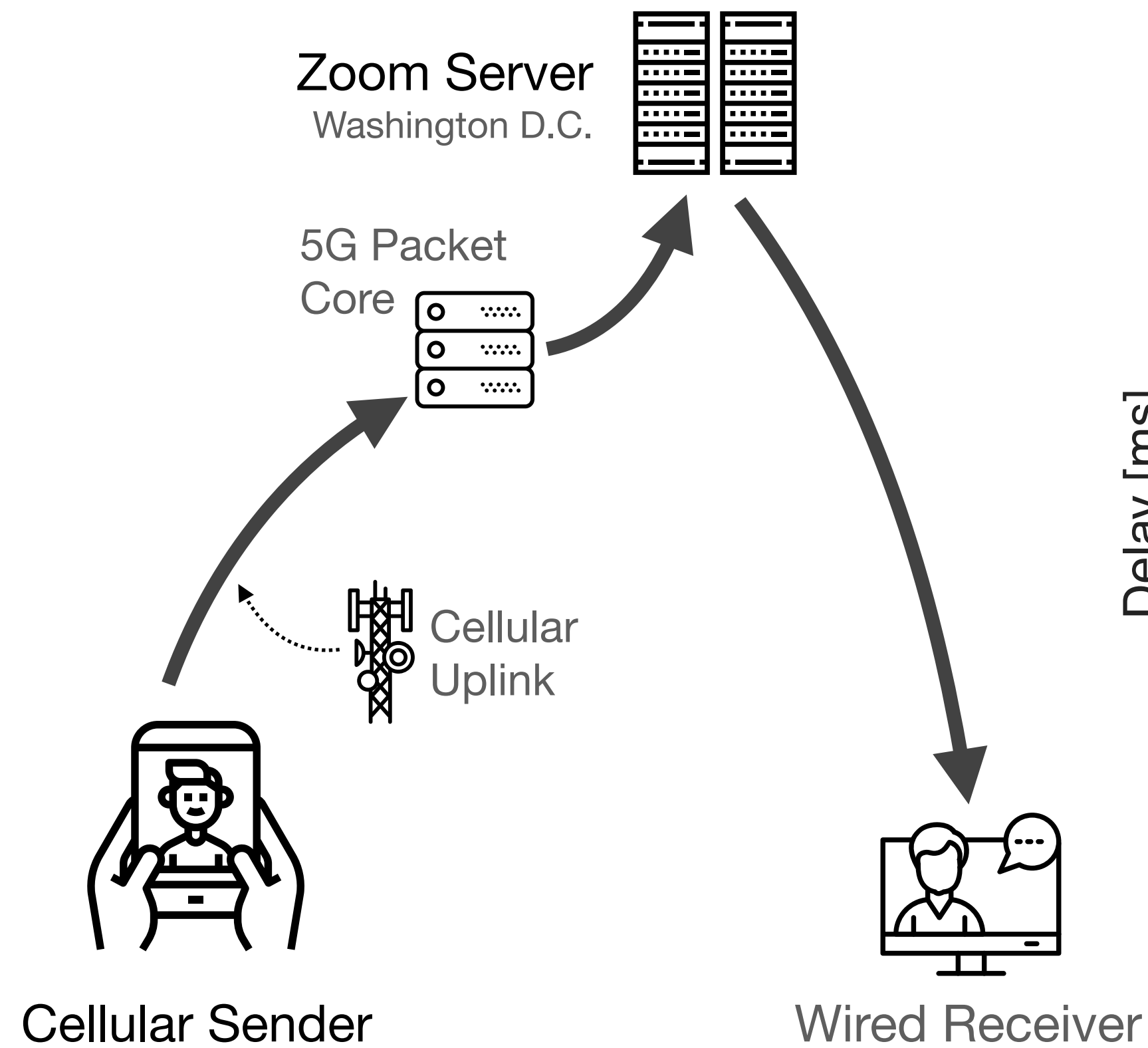
ATHENA...

- (1) Sees across layers
- (2) Correlates data across layers
- (3) Enables cross-layer optimization

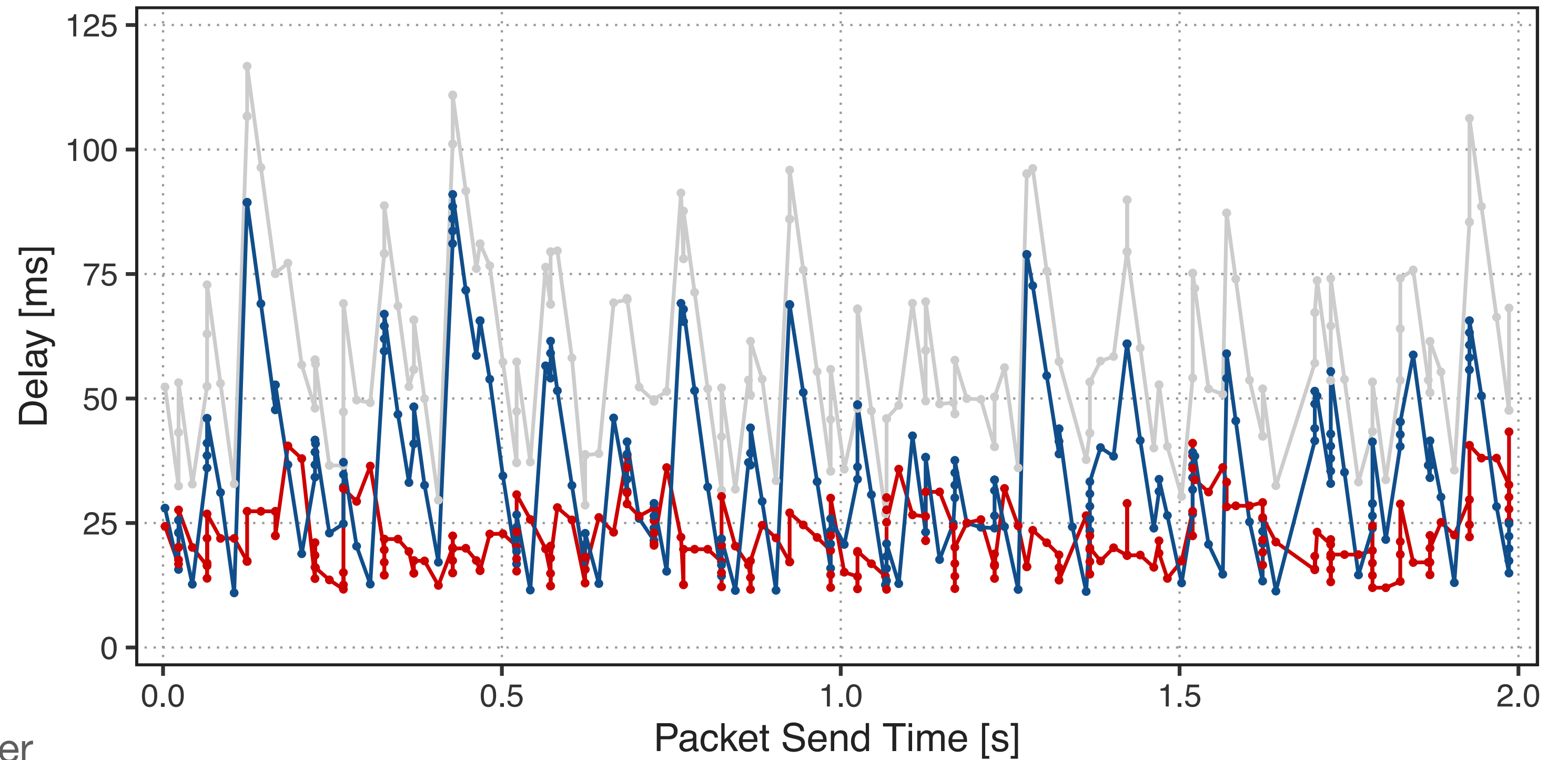
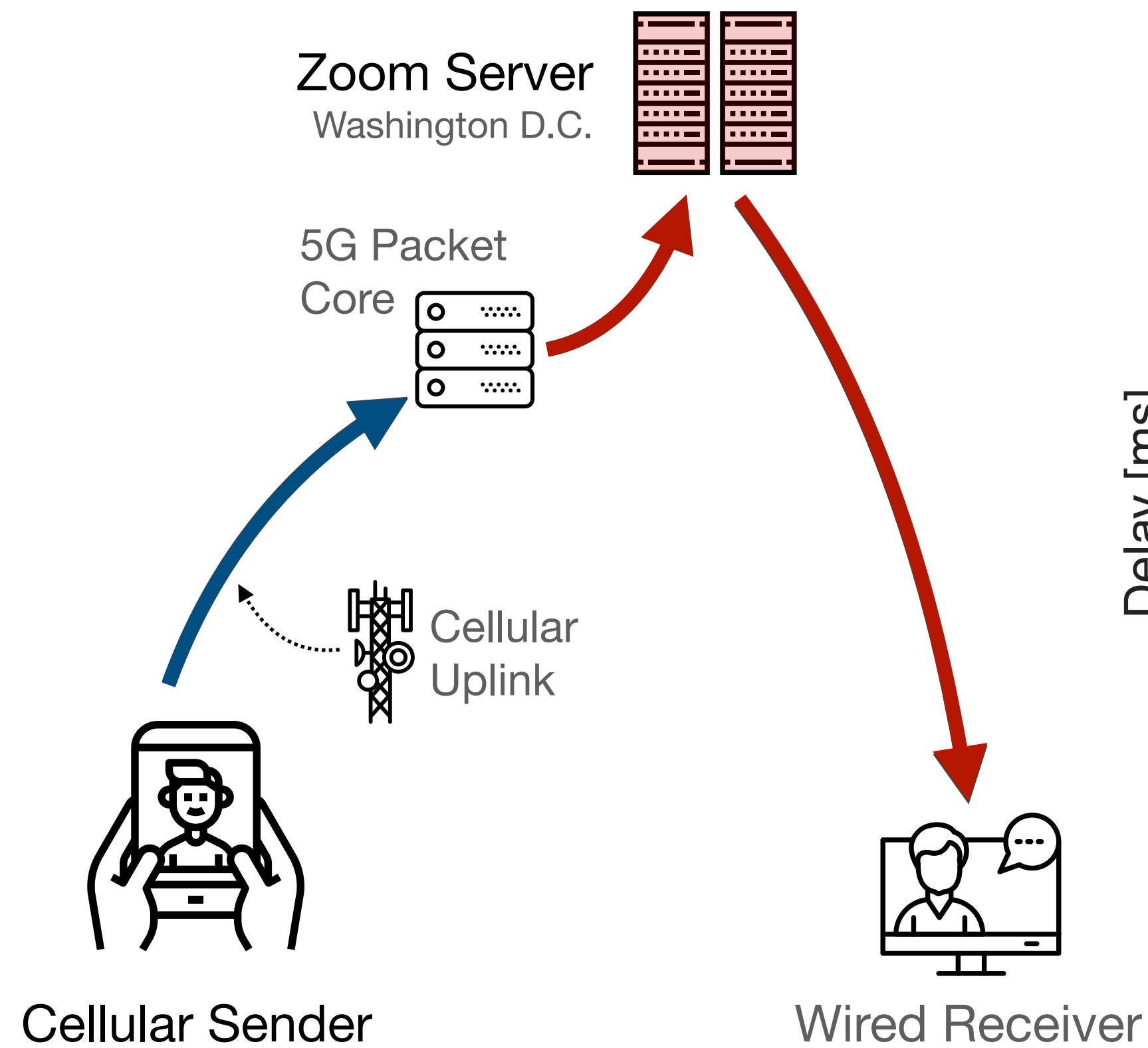
5G Uplink causes high Latency and Jitter



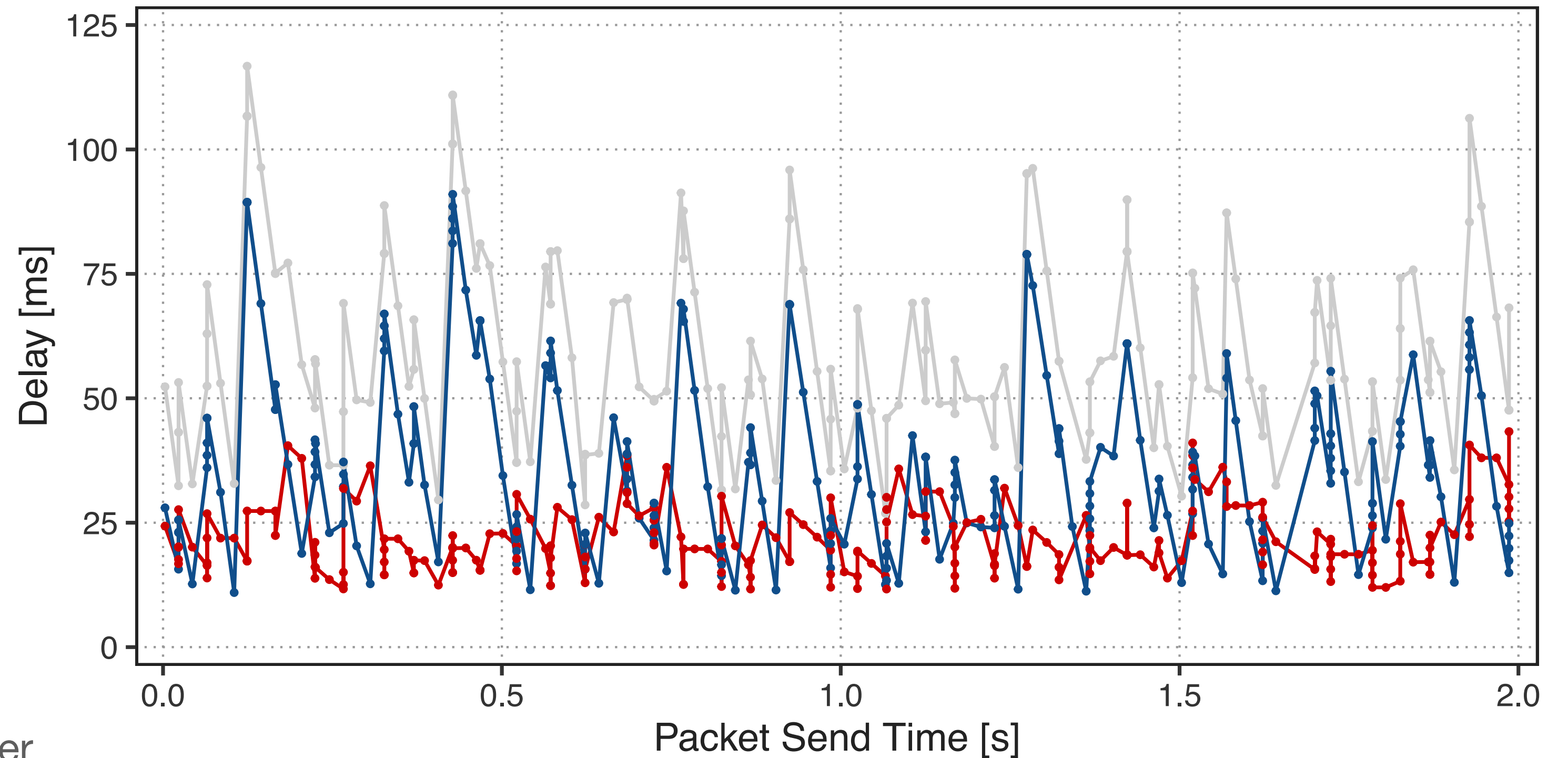
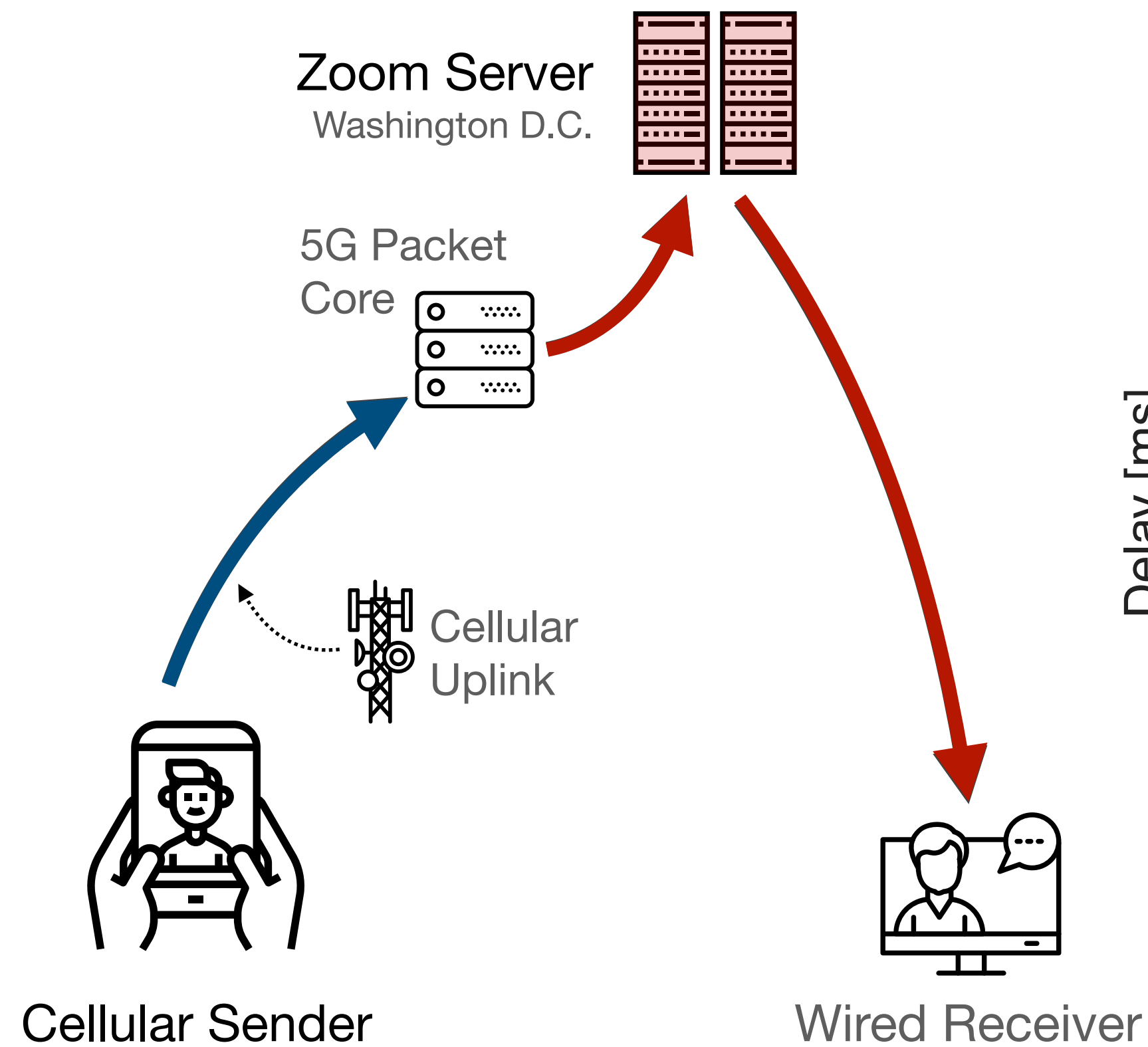
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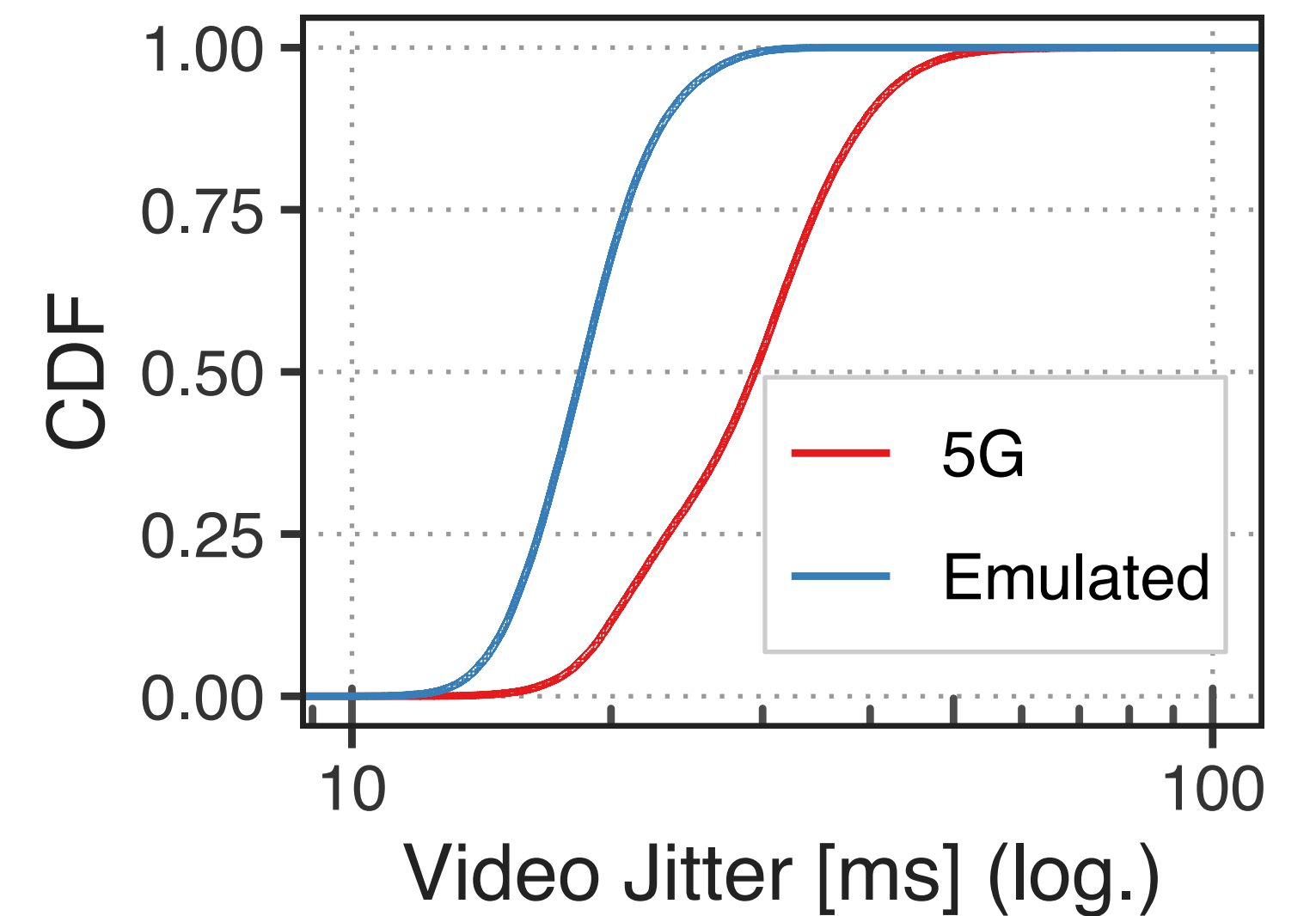
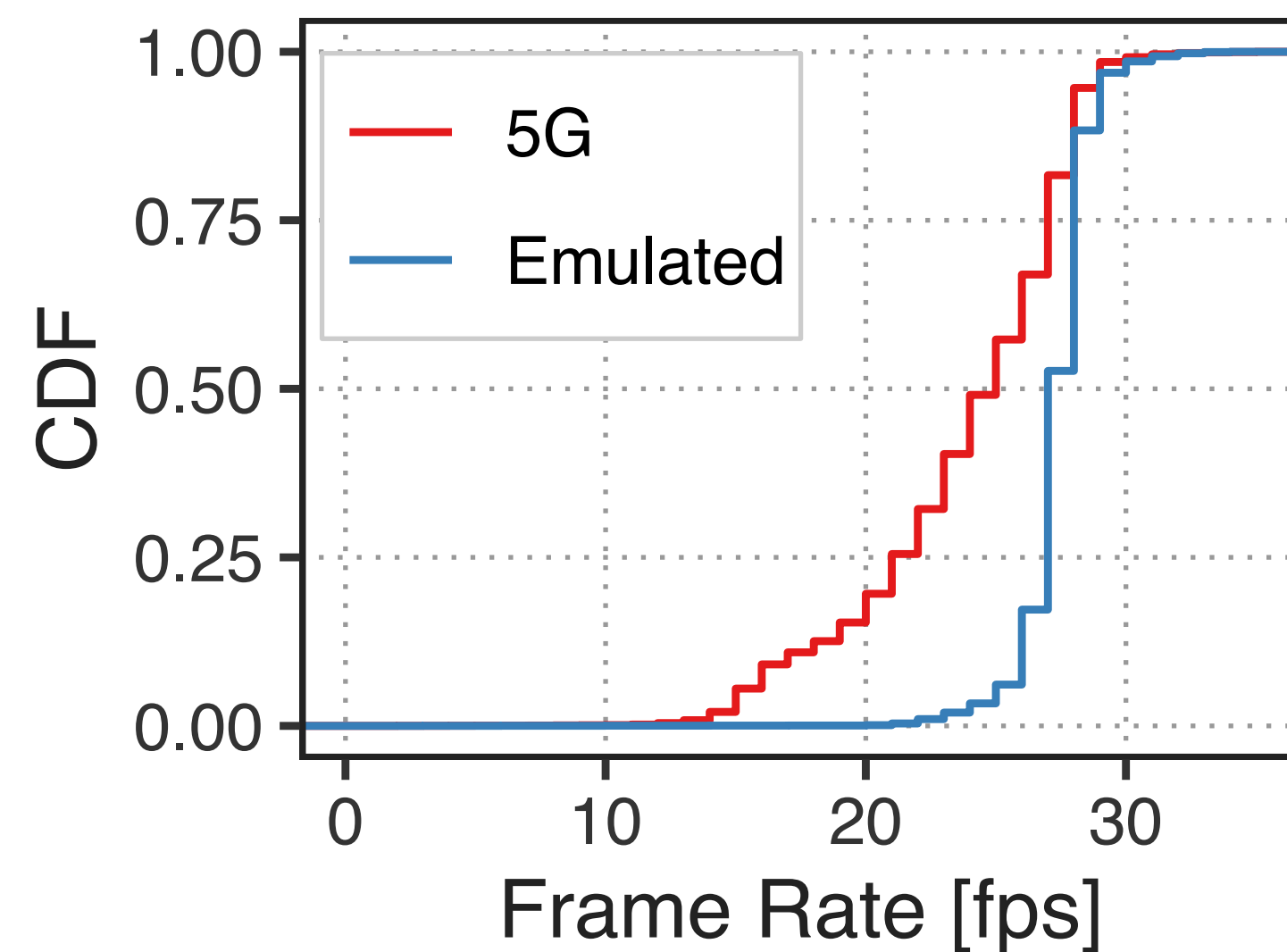
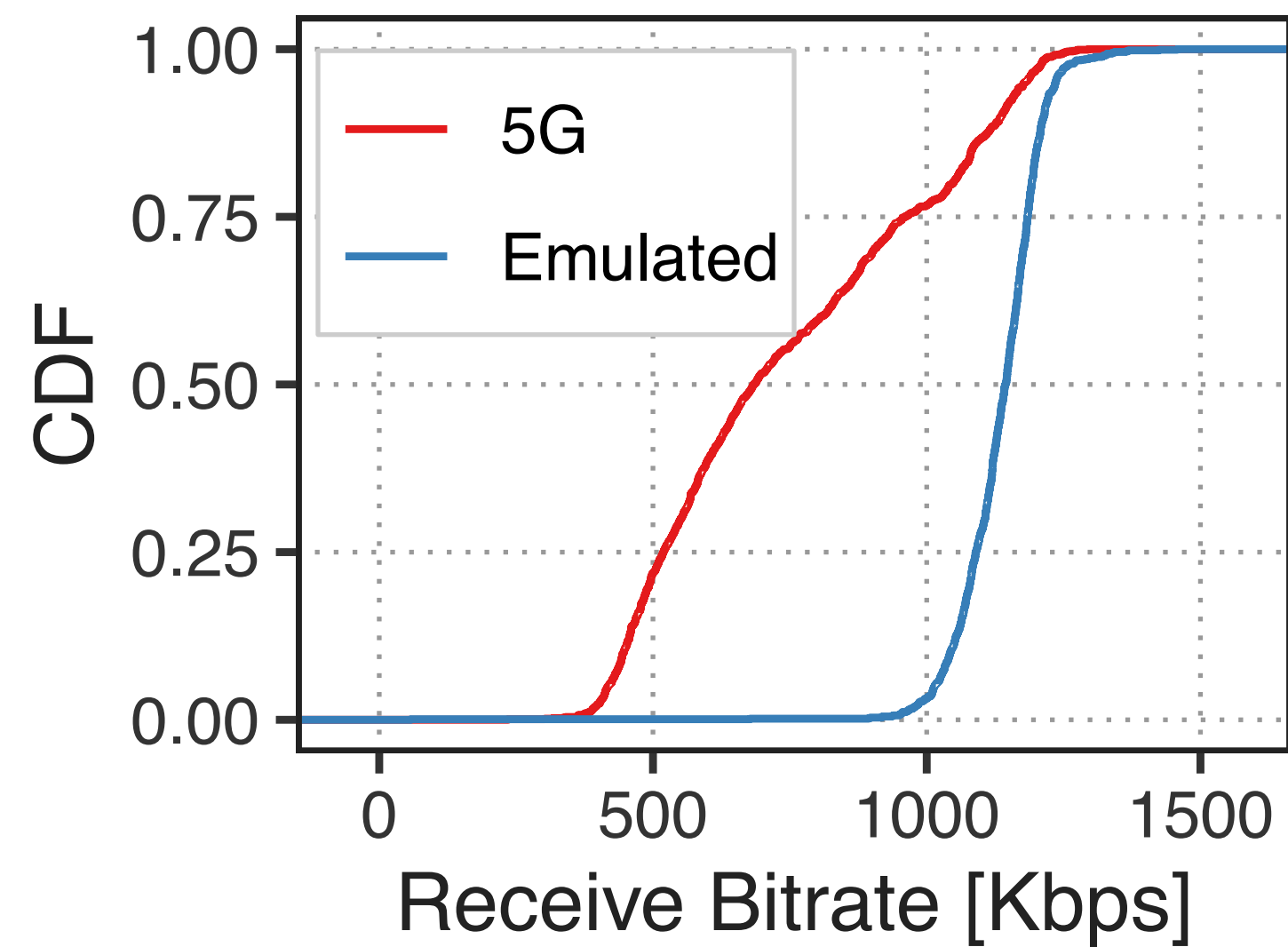


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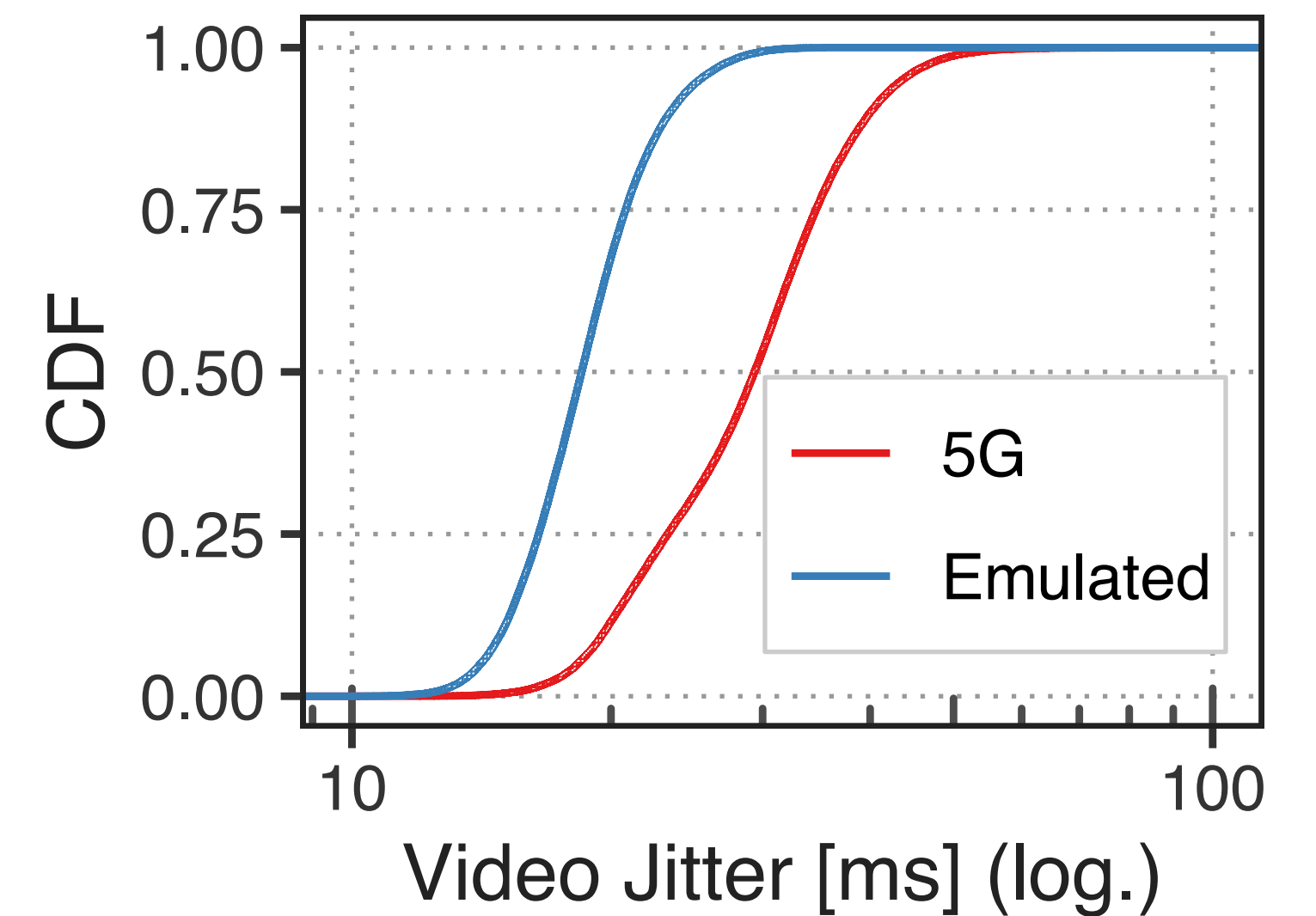
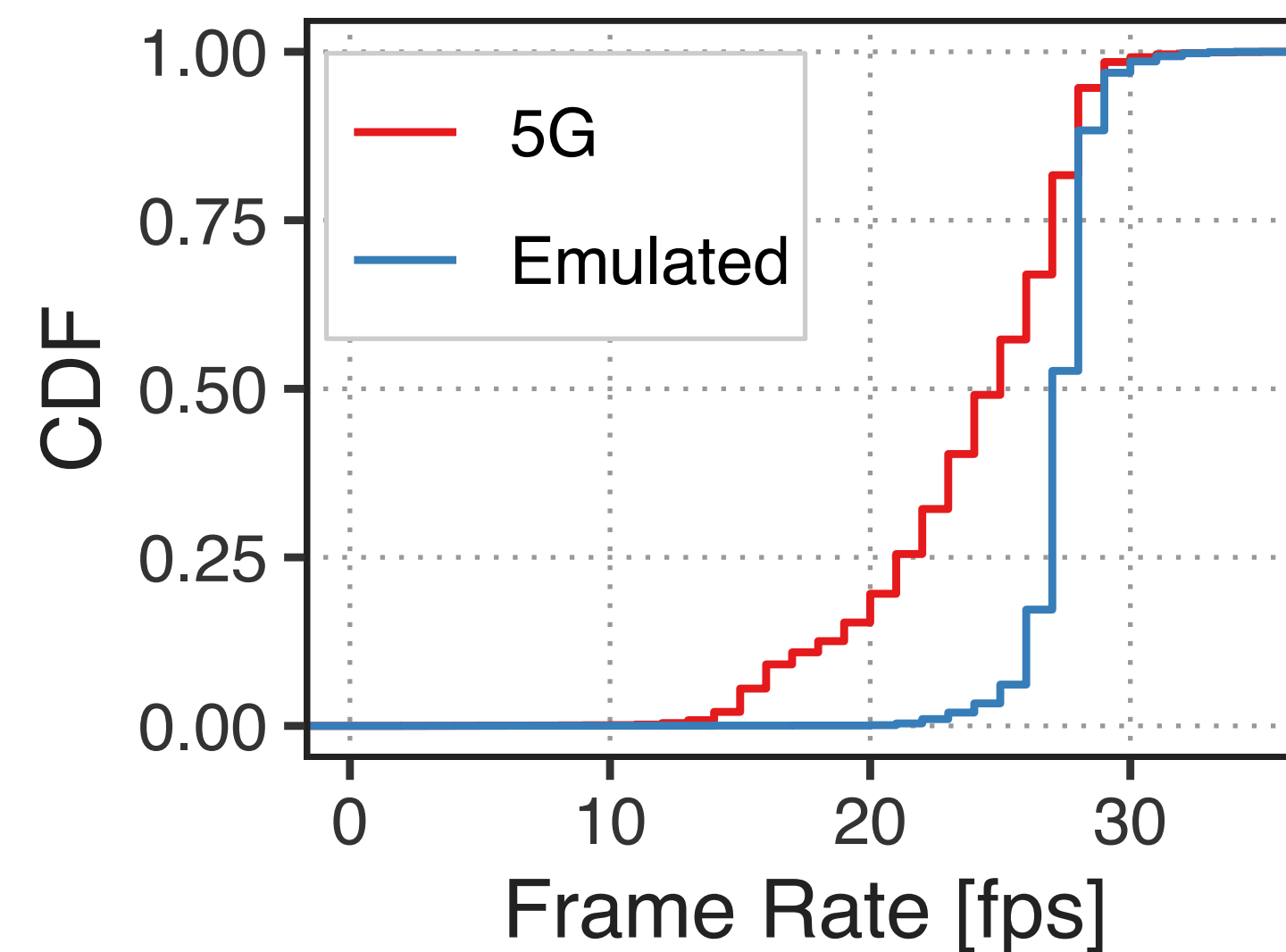
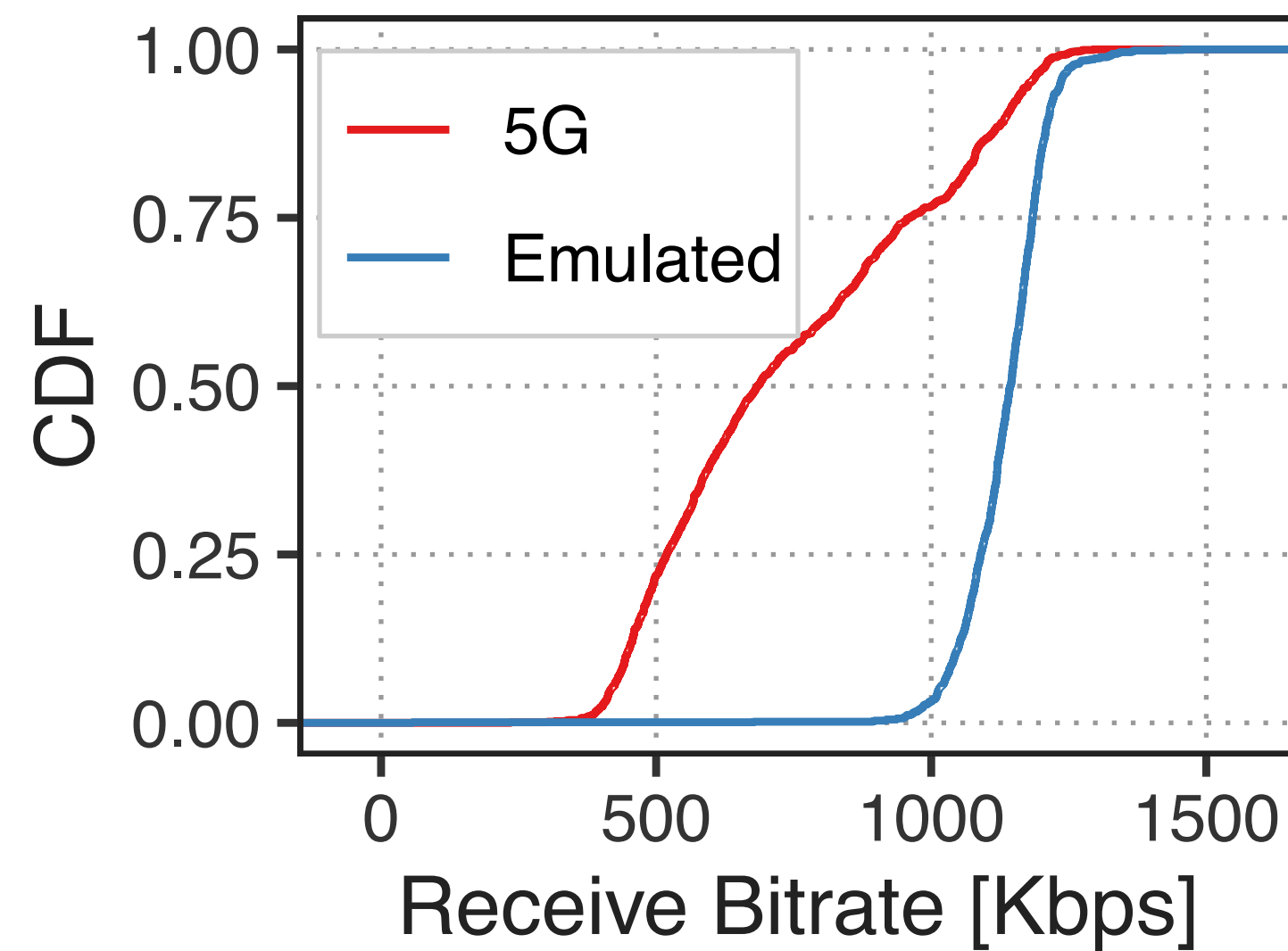


→ Cellular uplink is primary contributor to high delay and jitter.

5G Latency and Jitter Considered Harmful

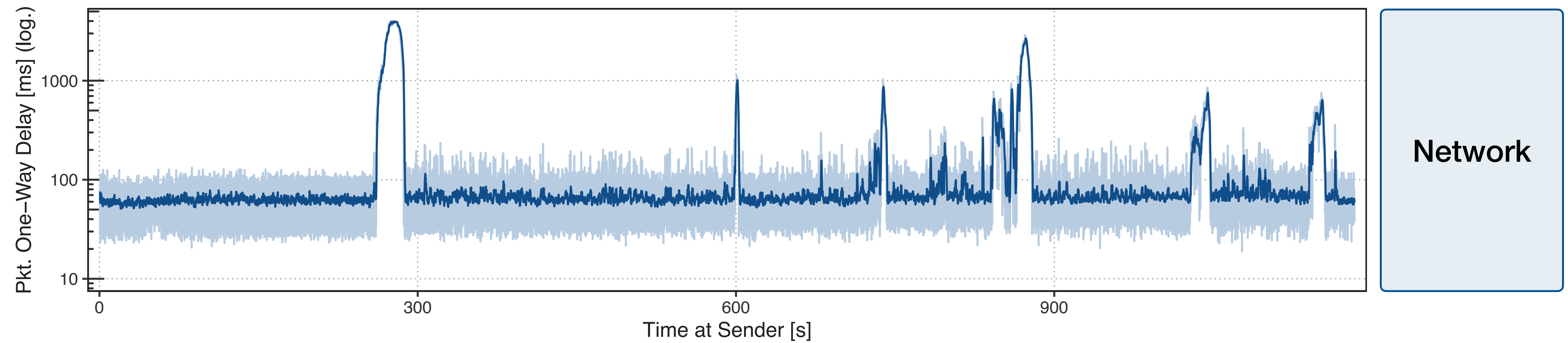


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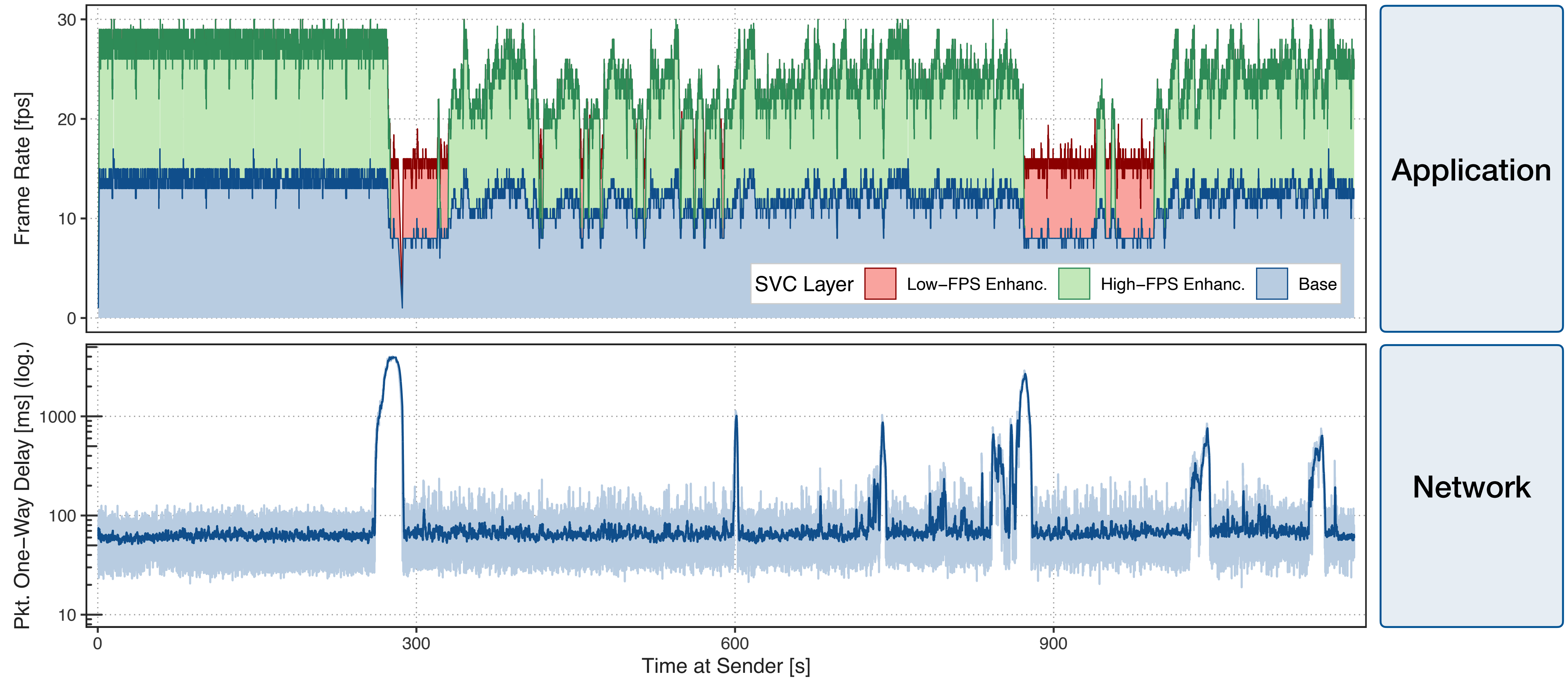


→ Latency and Jitter cause degraded performance.

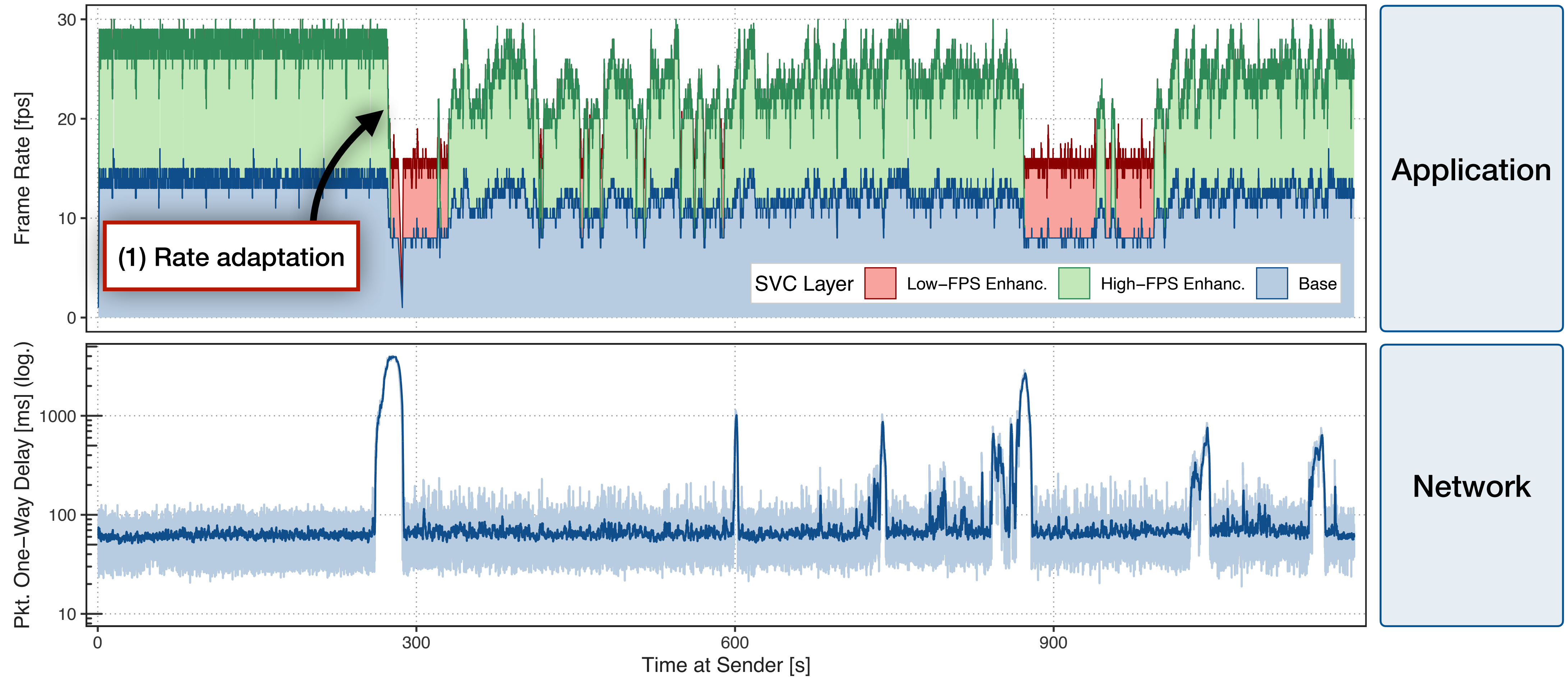
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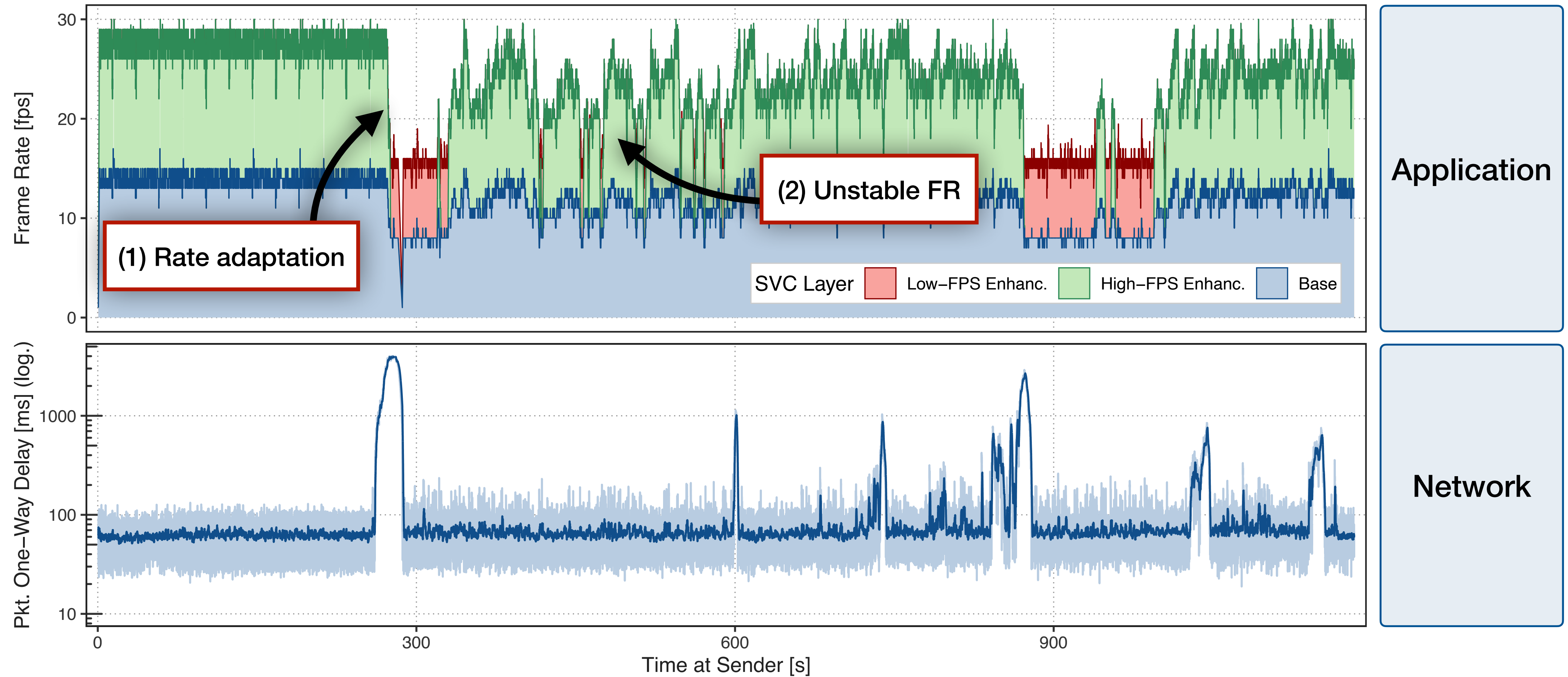
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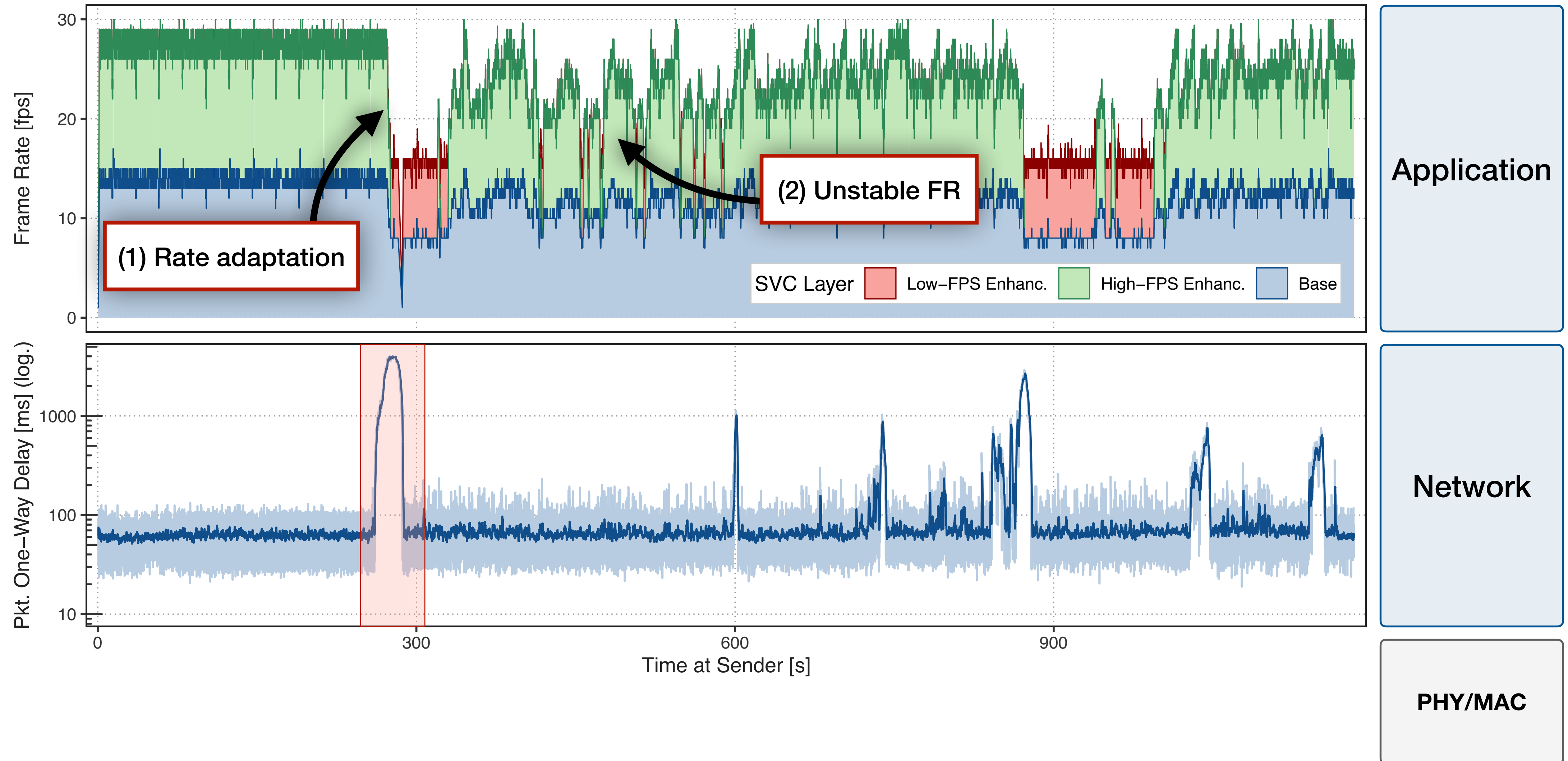
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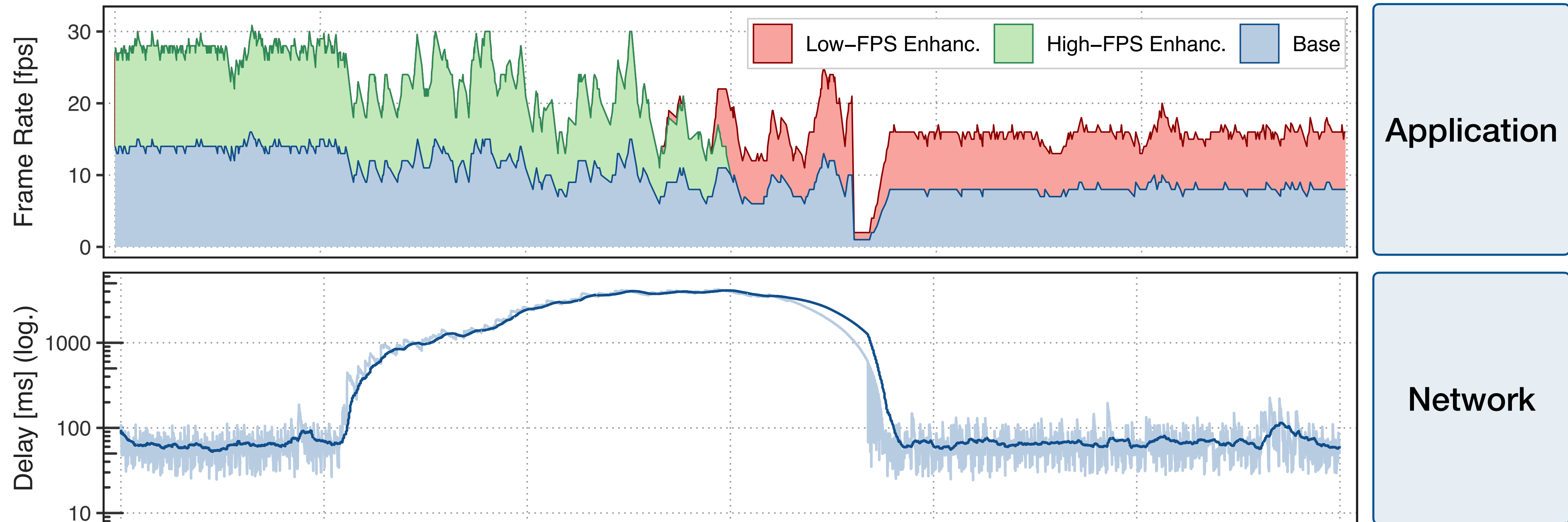
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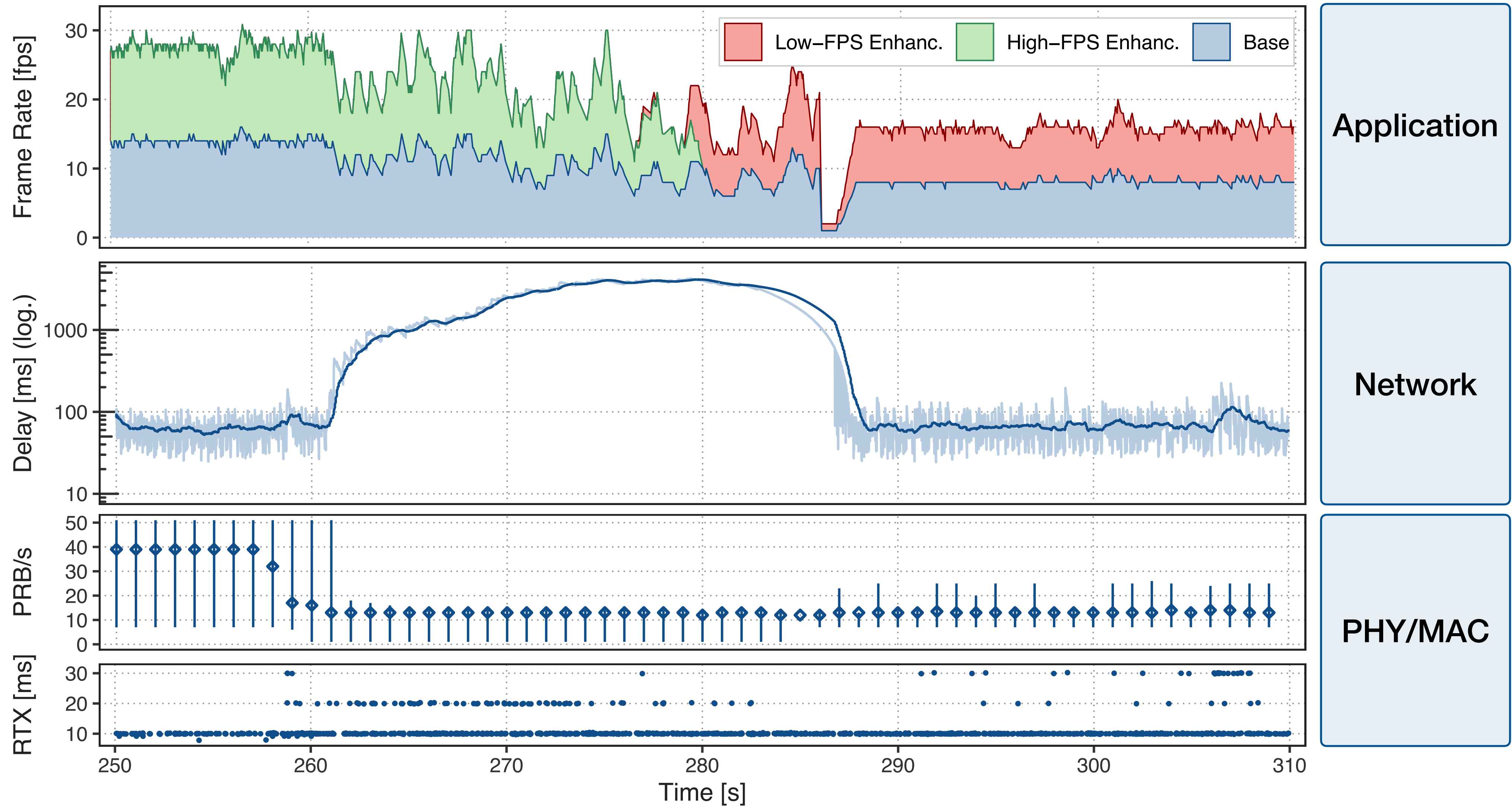
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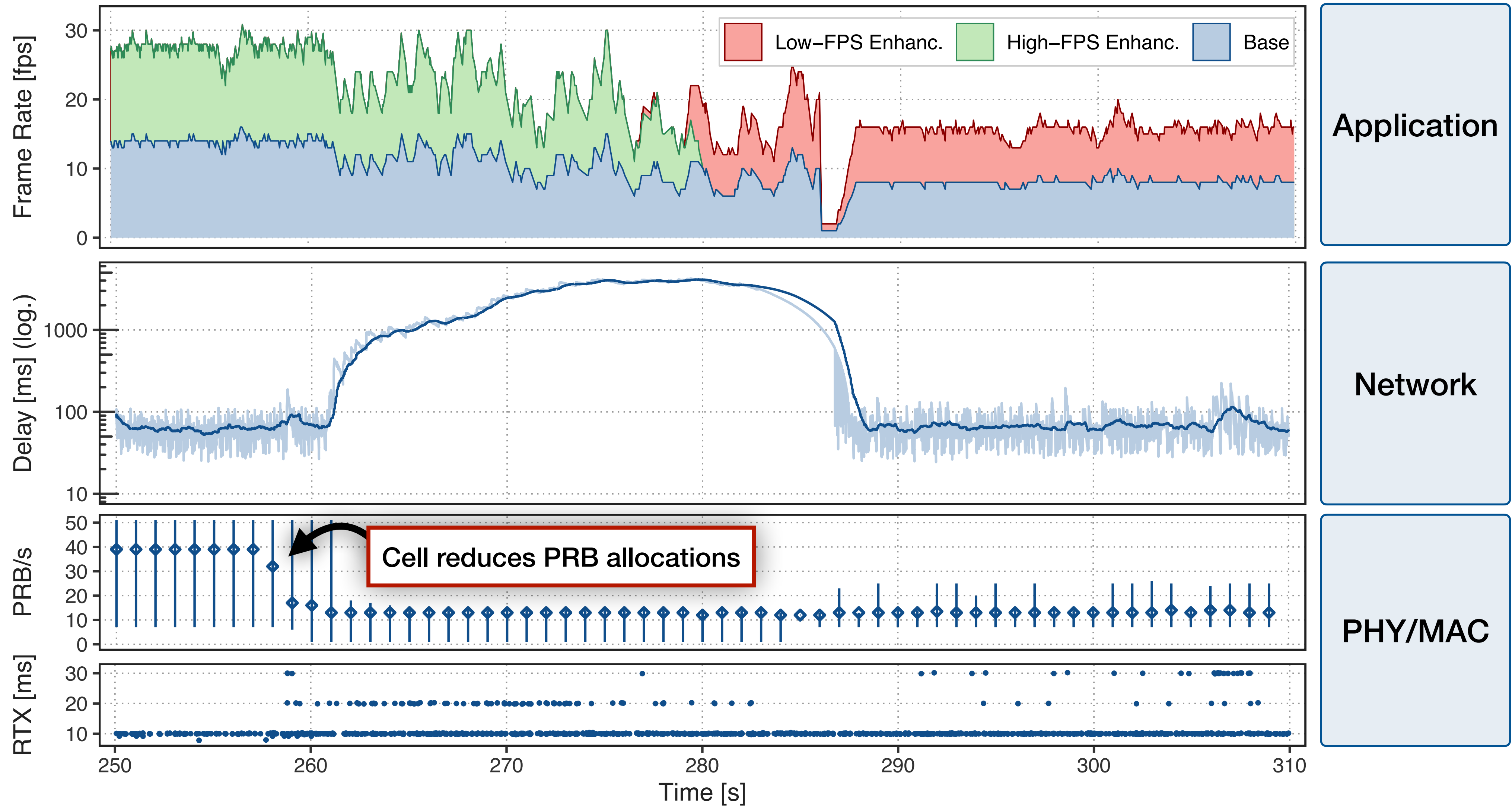
5G Capacity Changes Inflate Delay



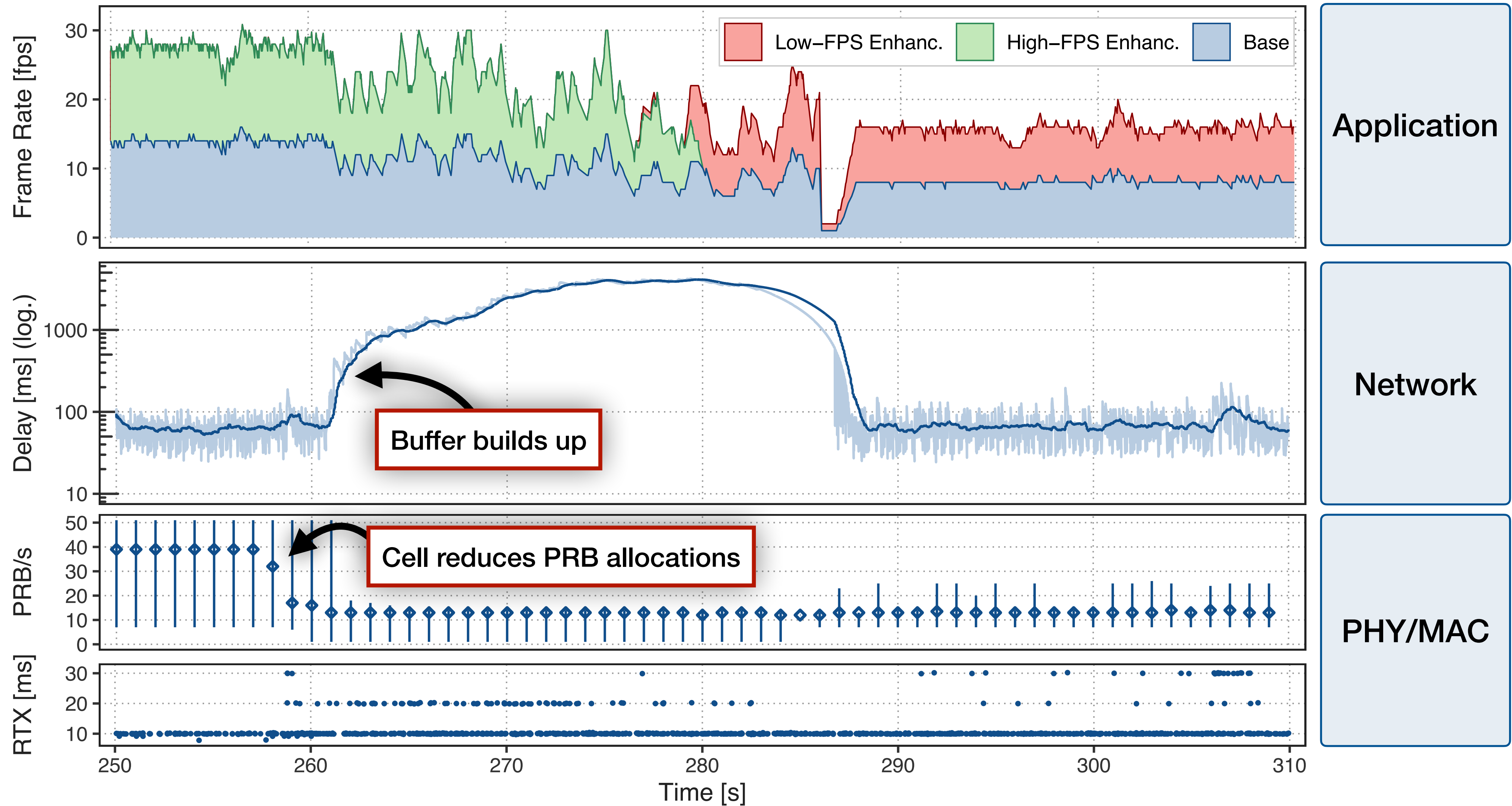
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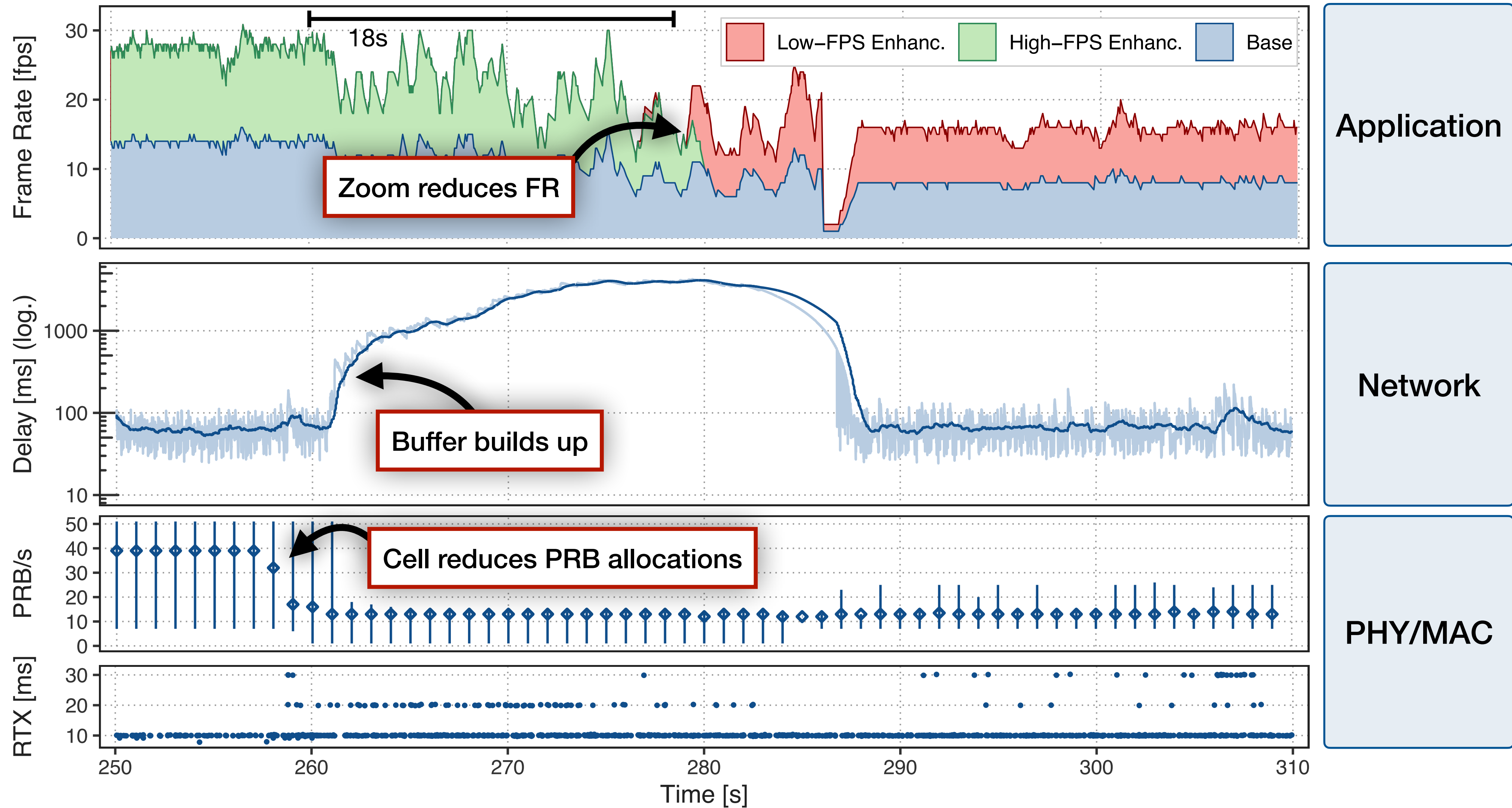
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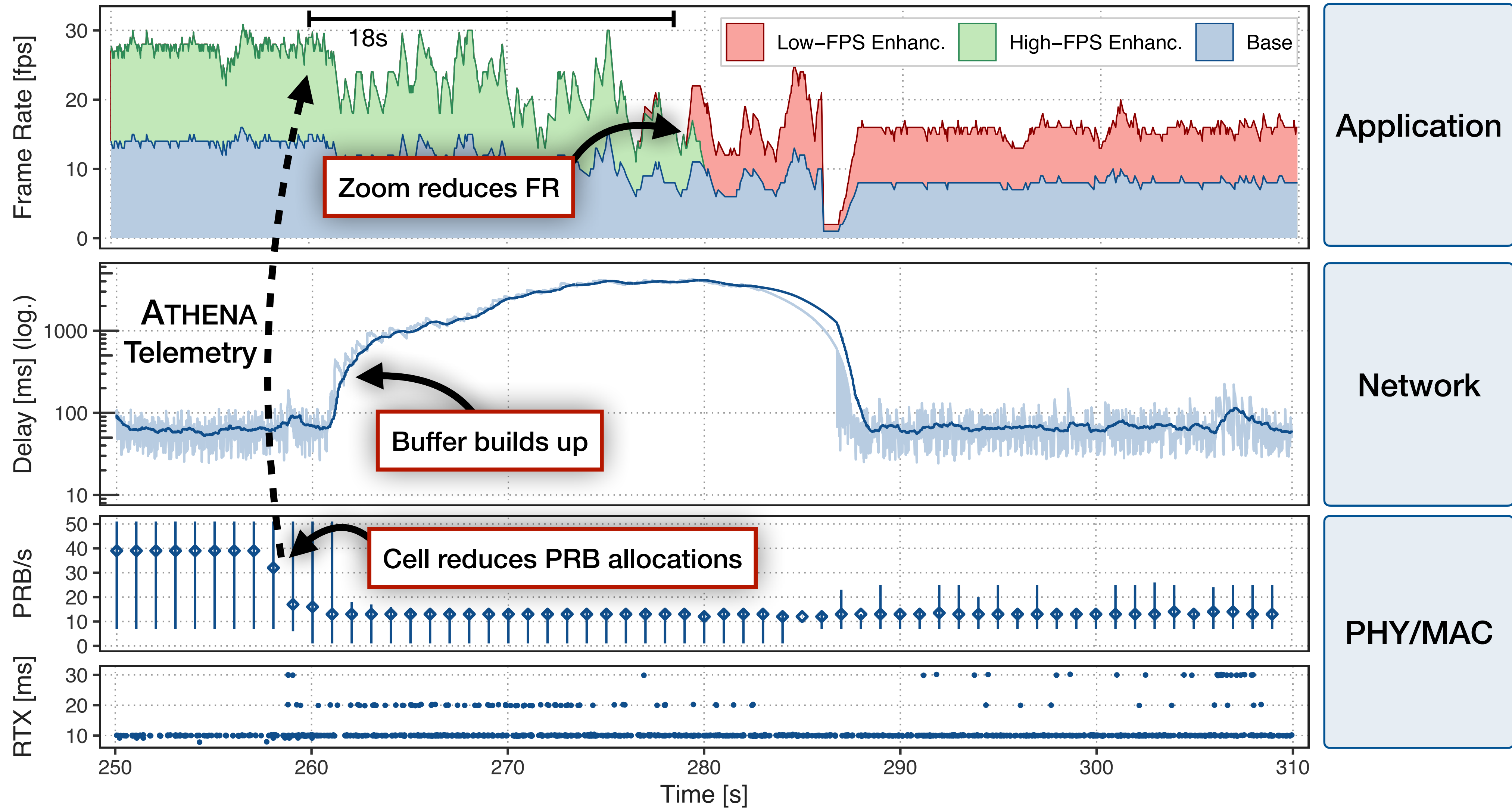
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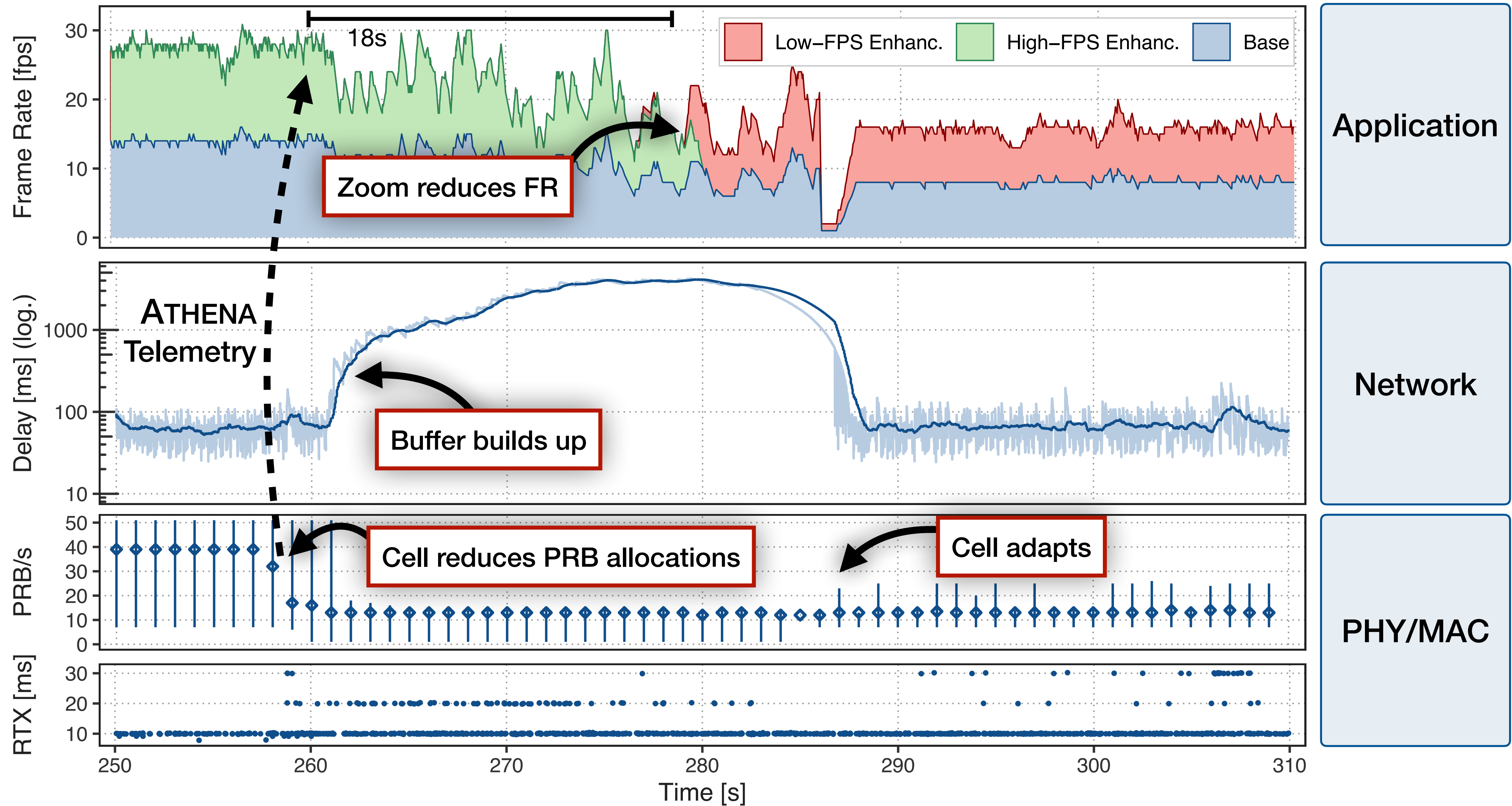
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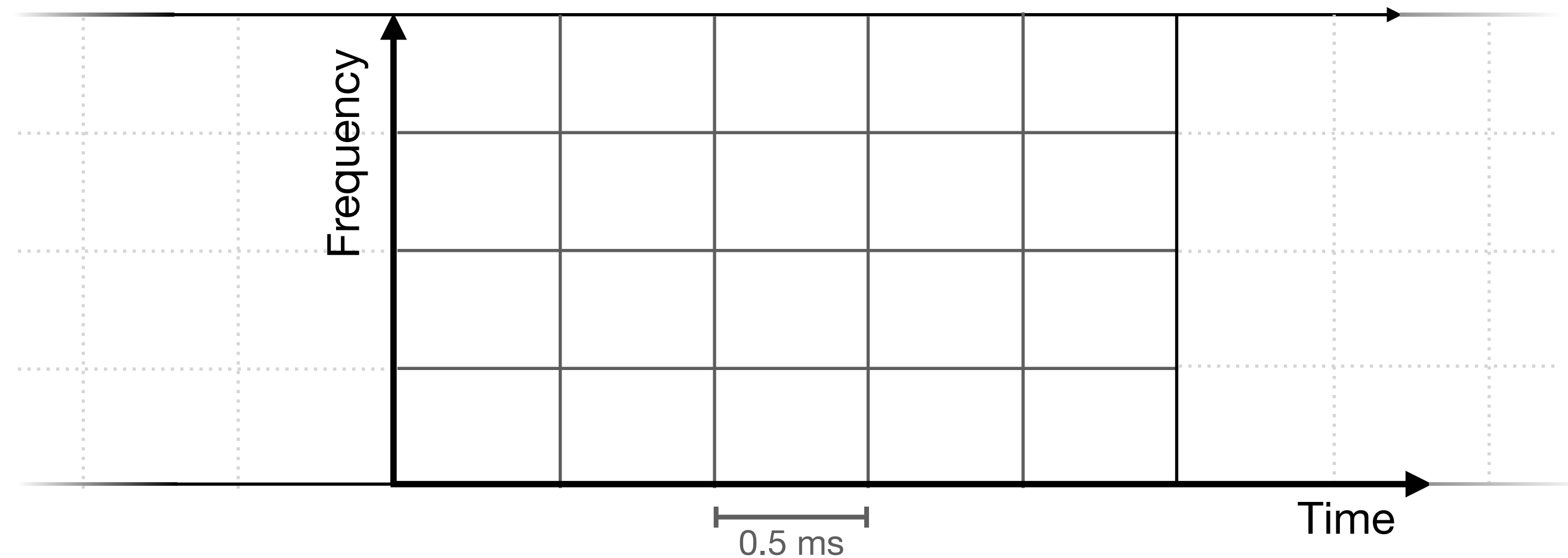


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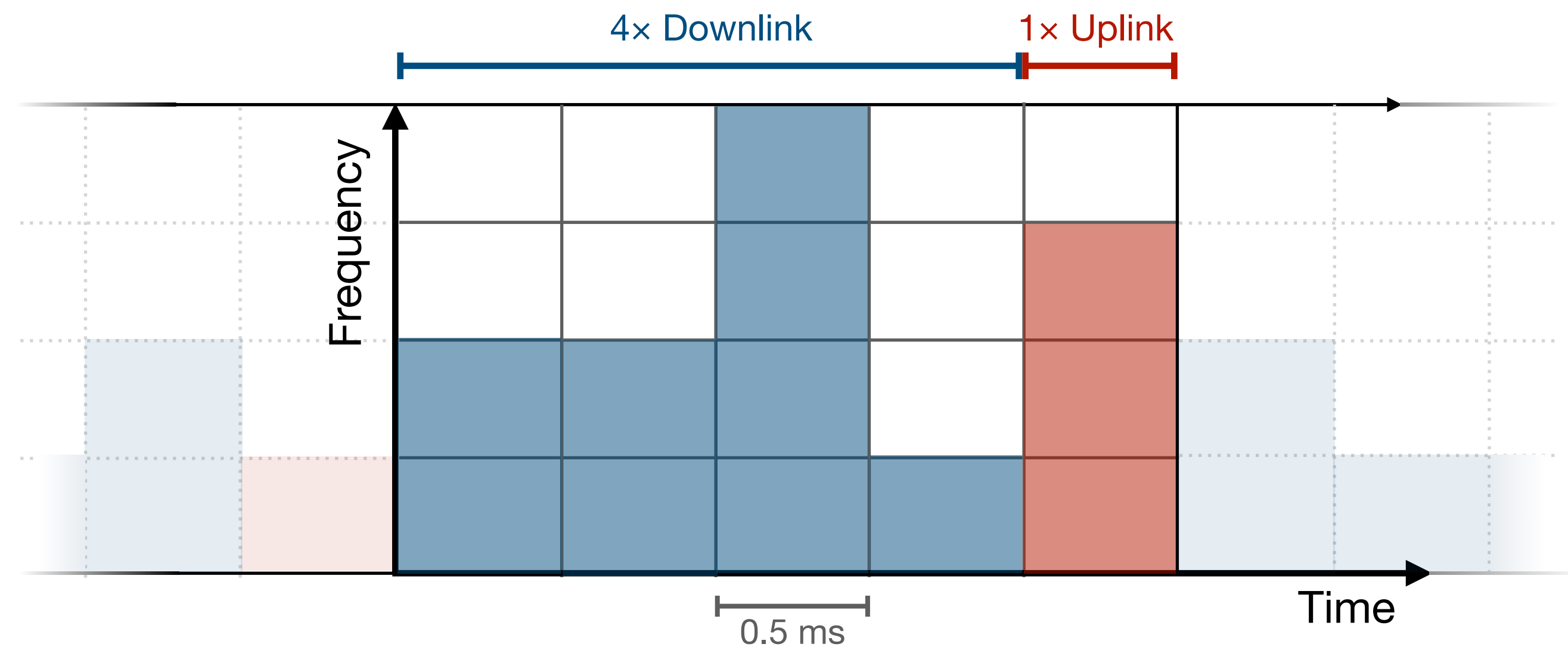
Expanding to the Physical Layer

5G Time-Division Duplex and Uplink Transmission



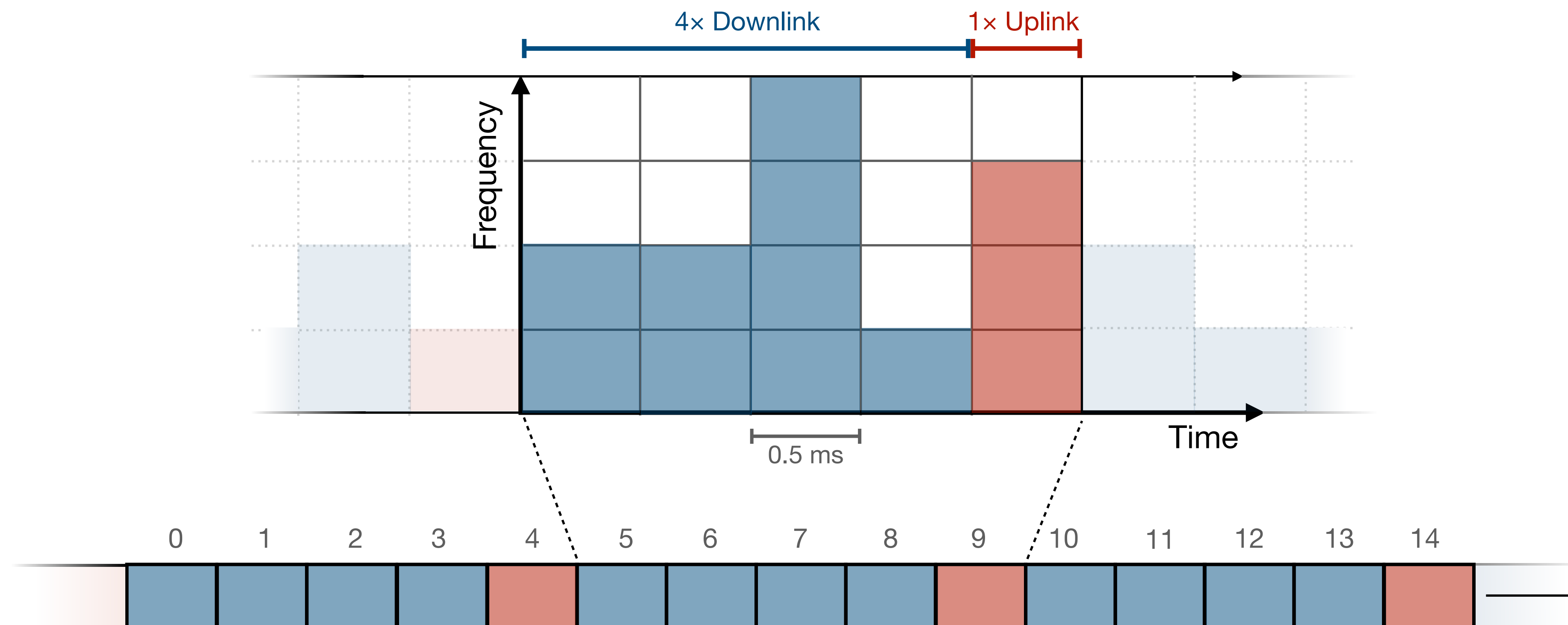
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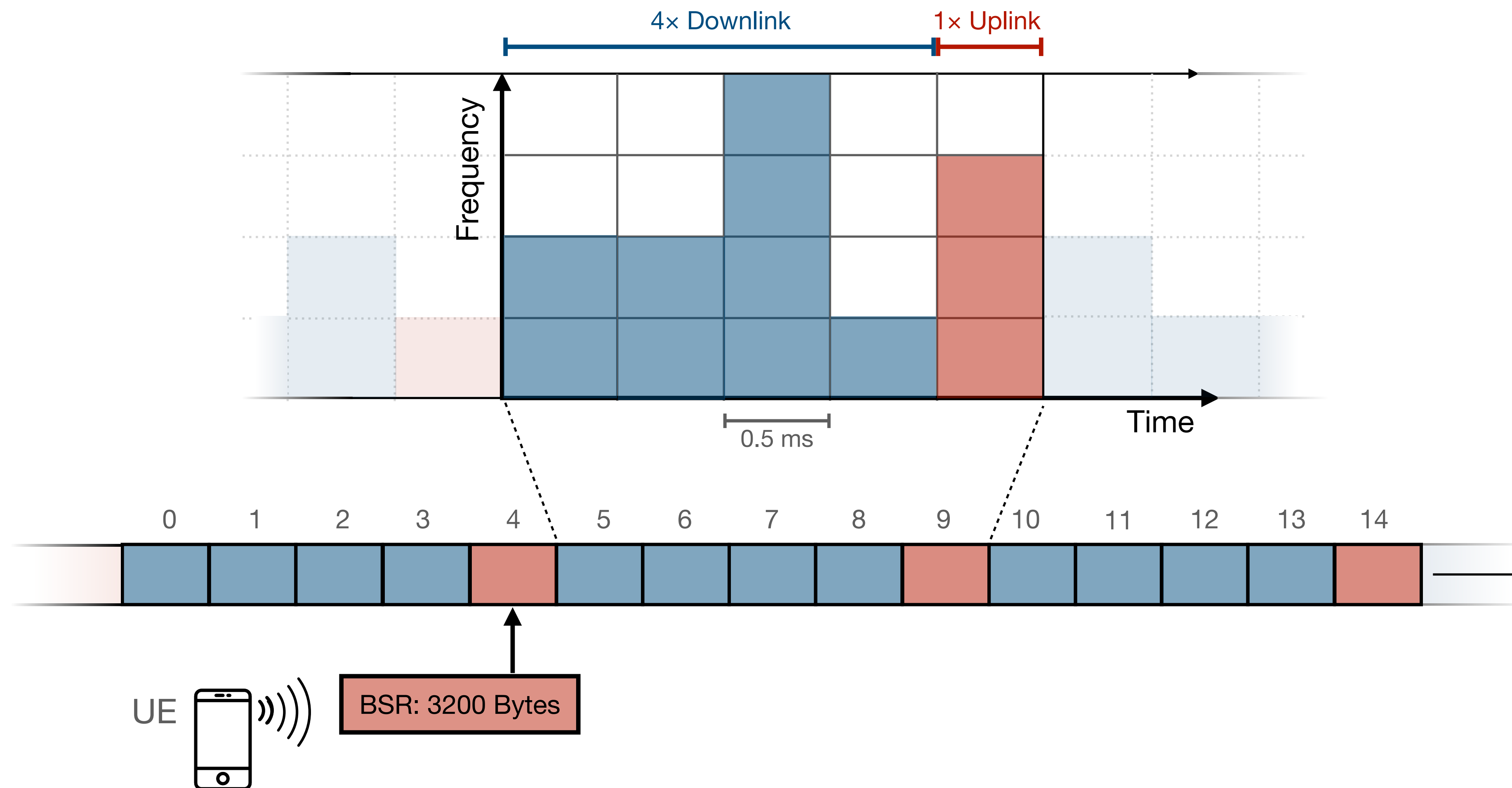
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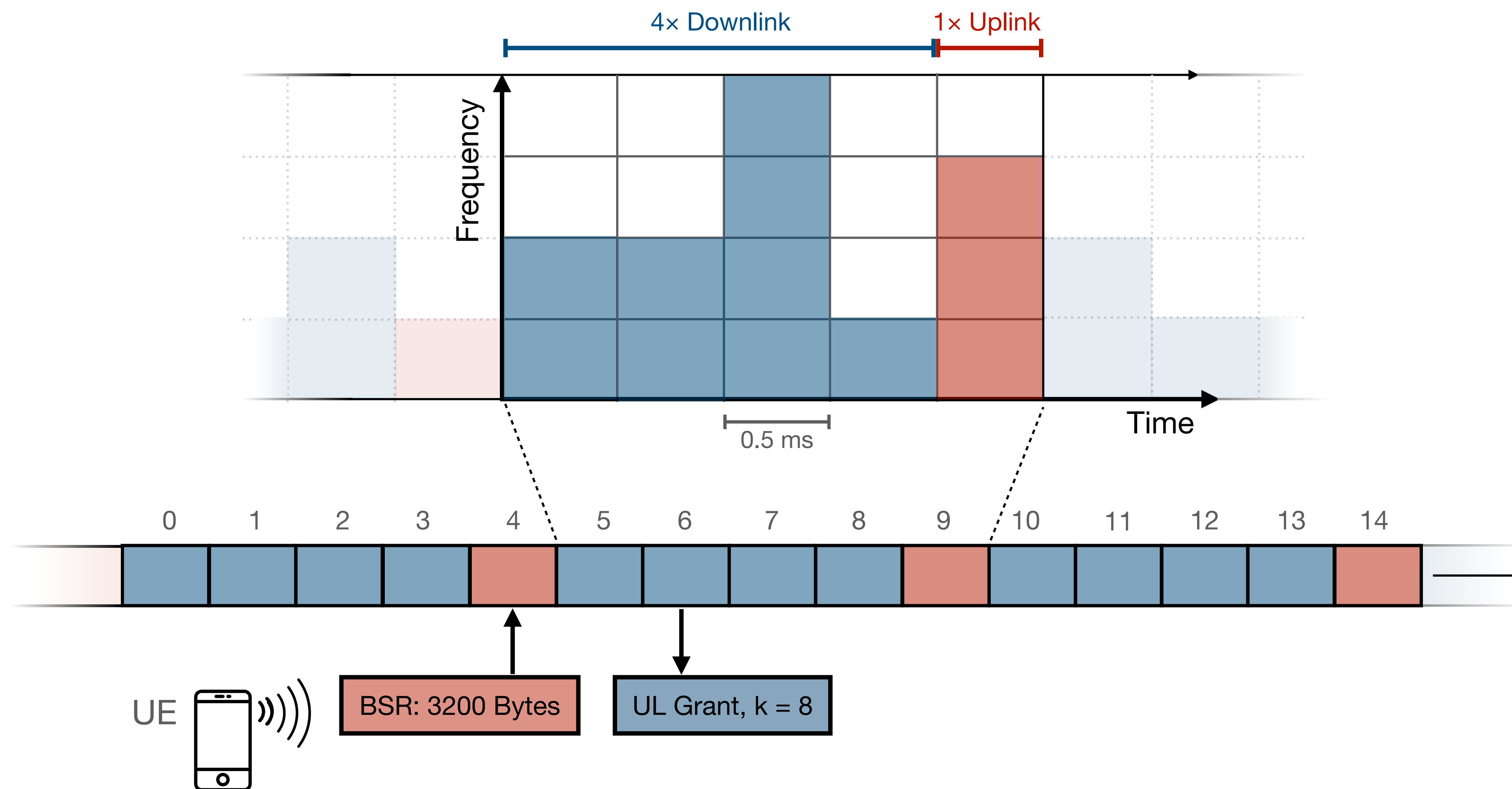
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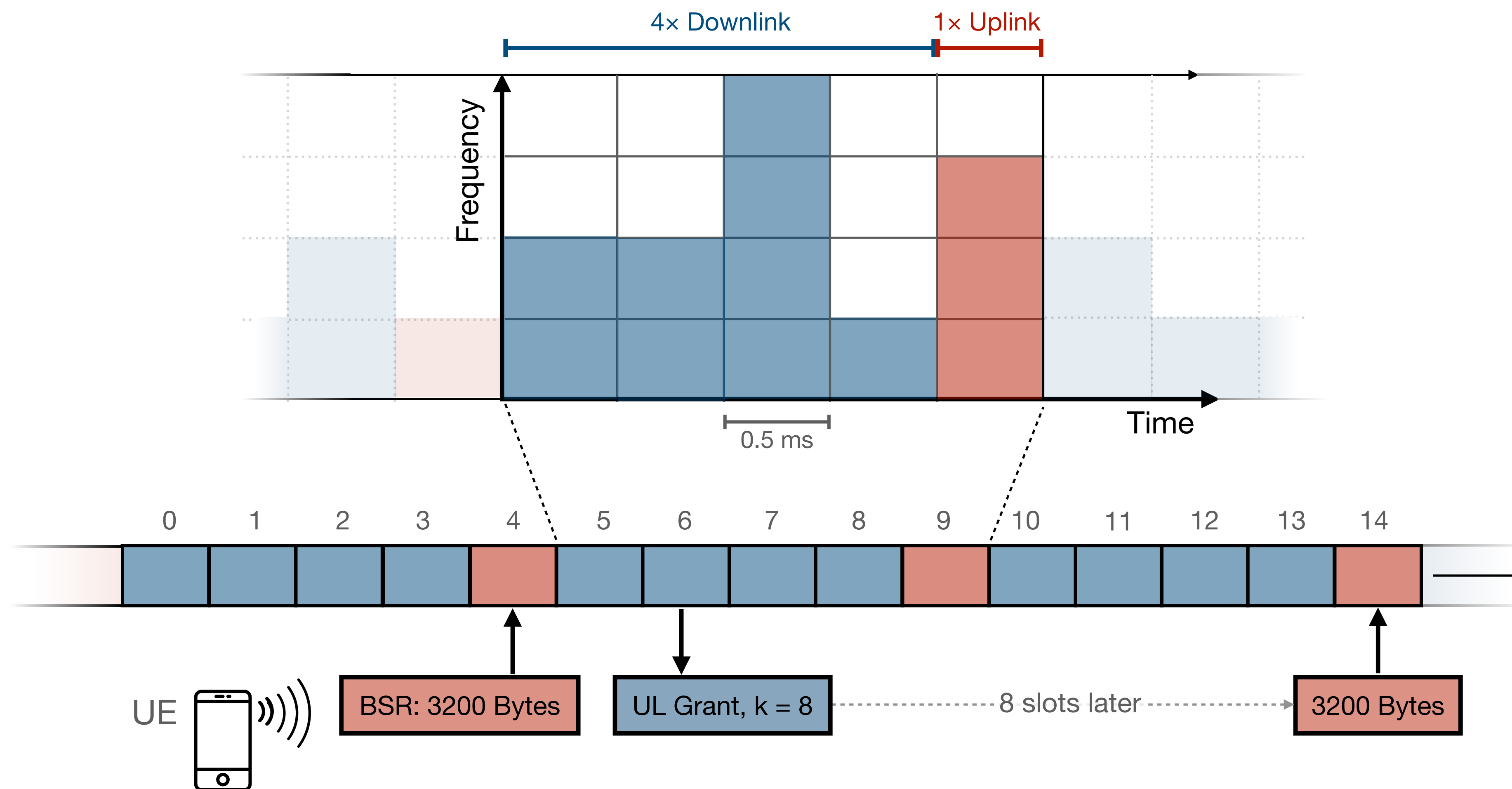
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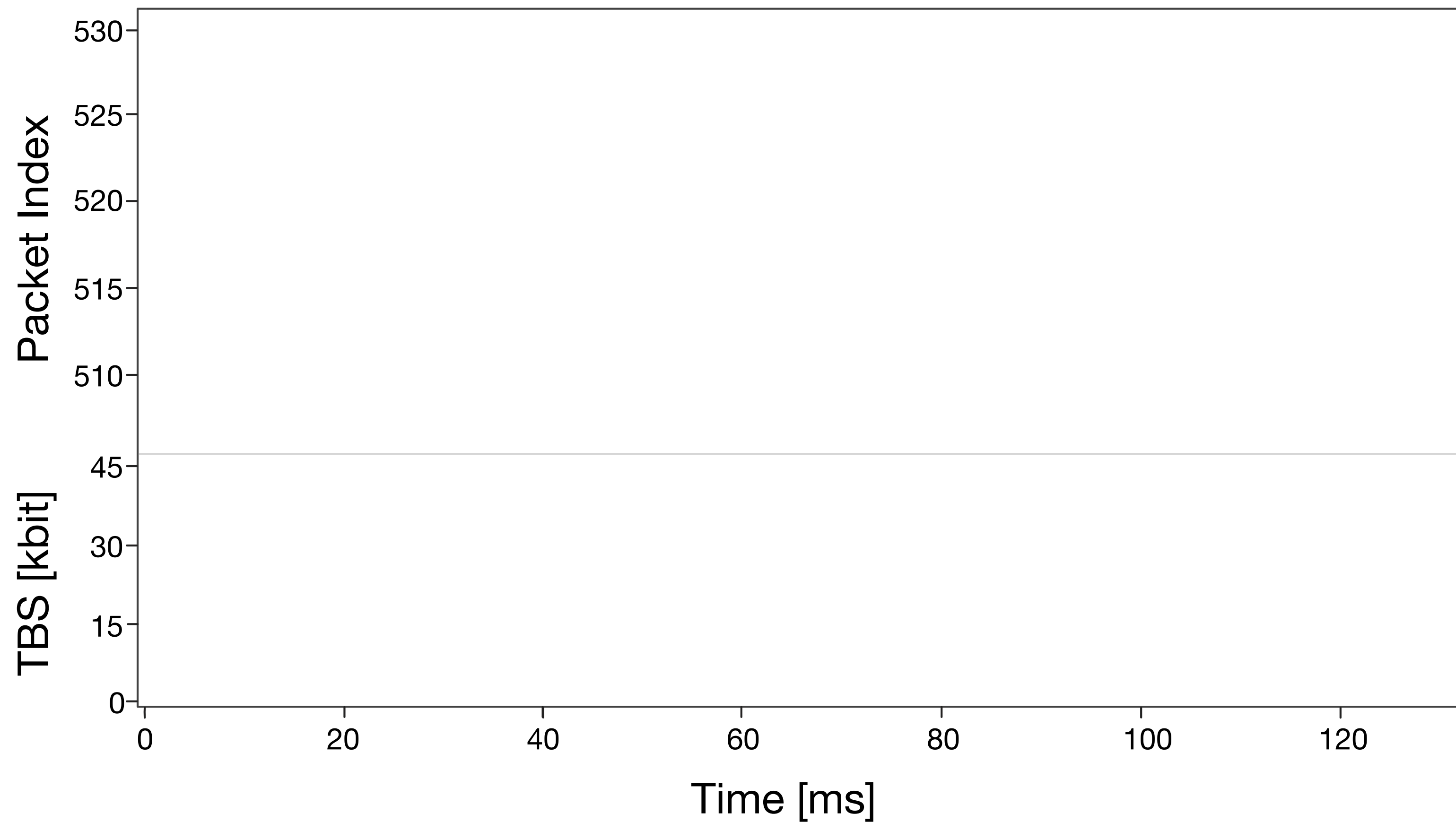


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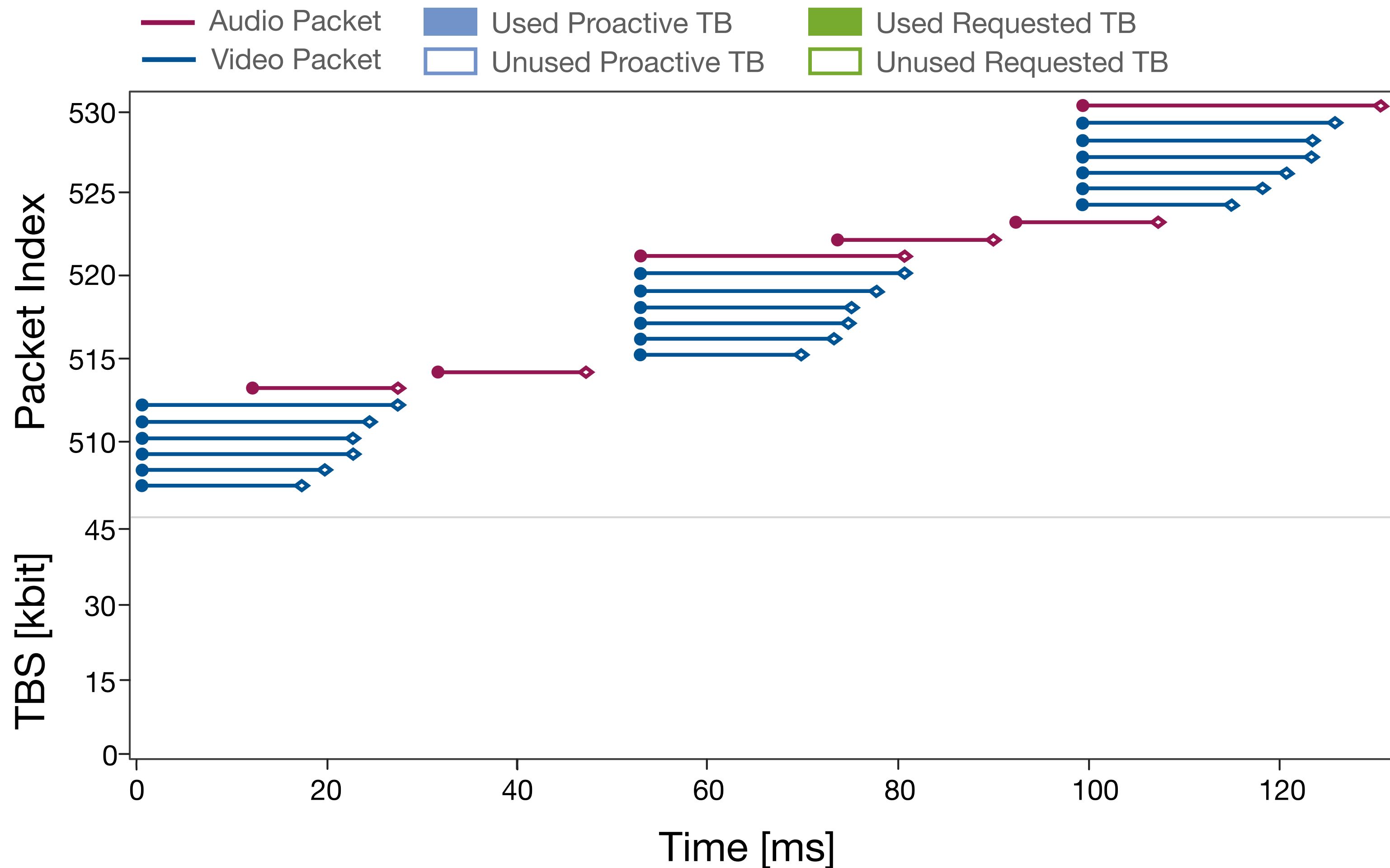
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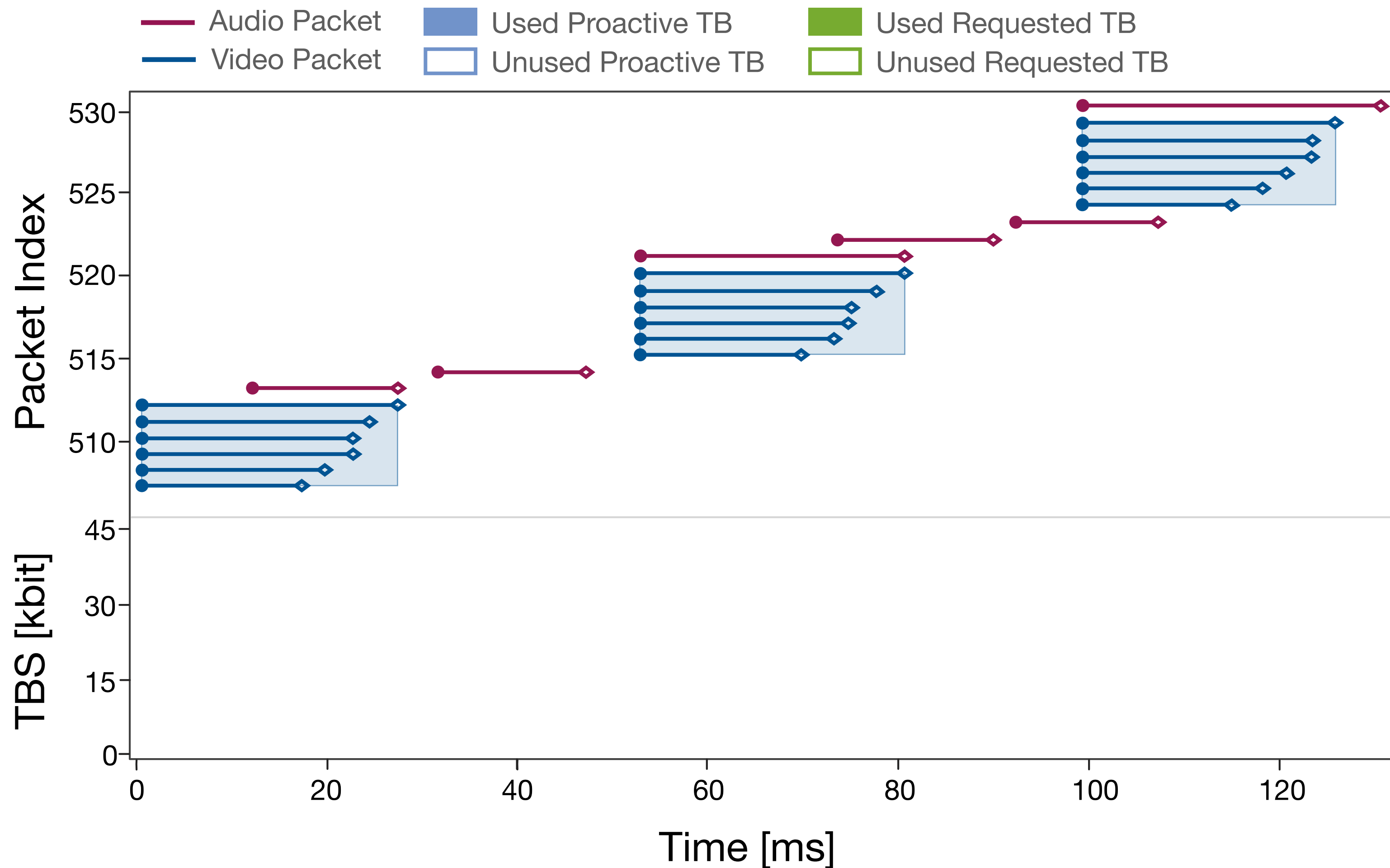
5G Uplink Scheduling Causes Jitter



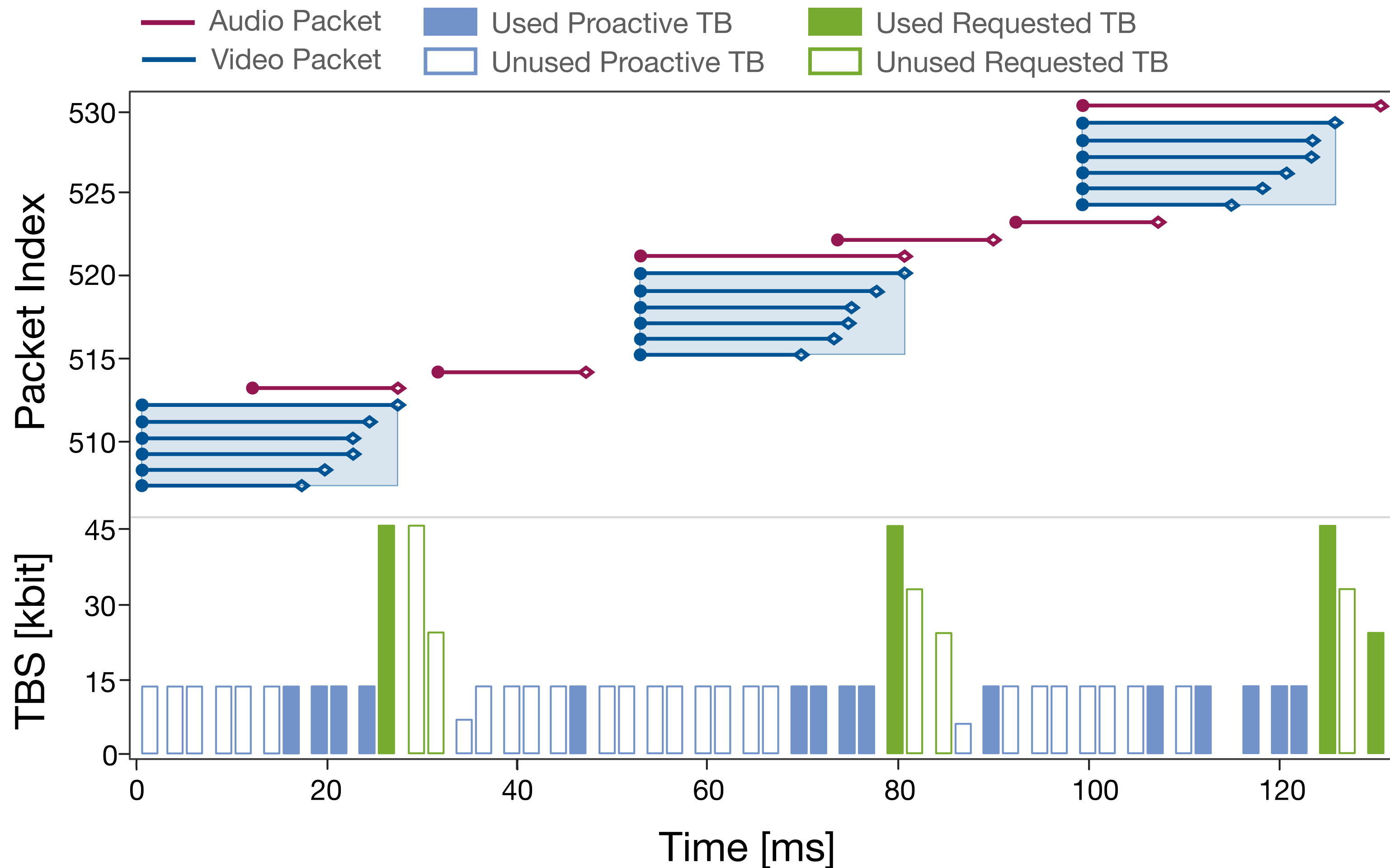
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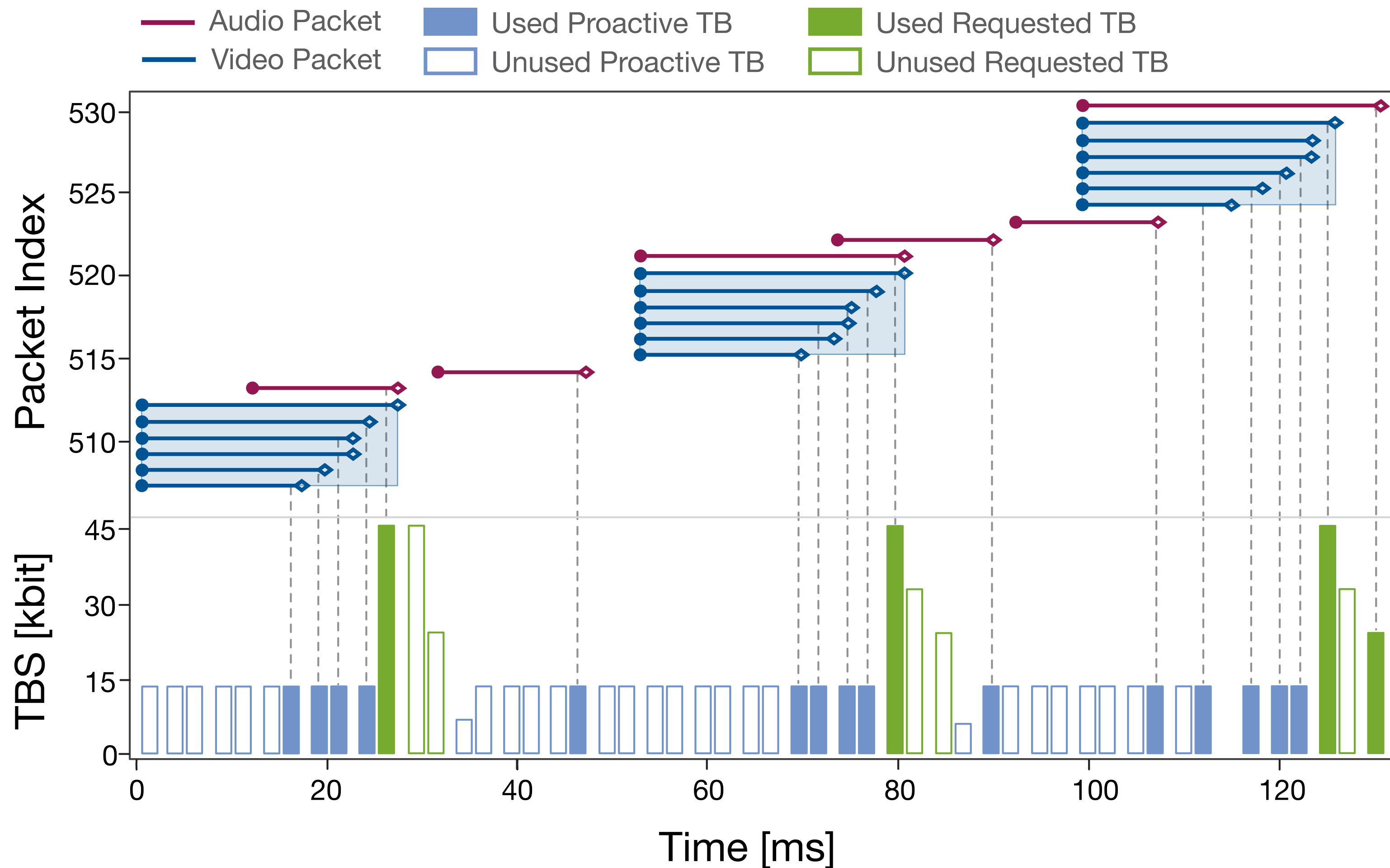
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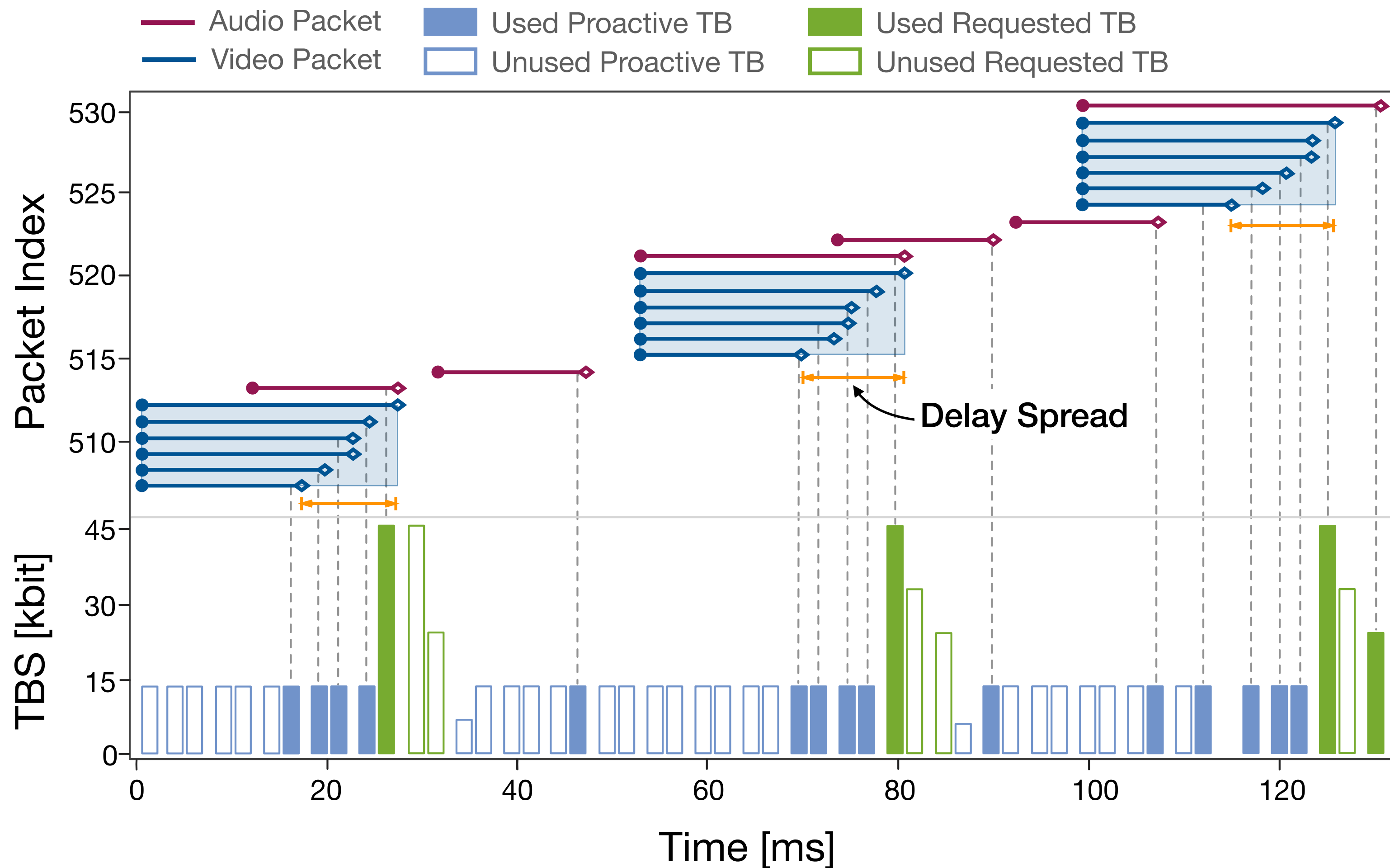
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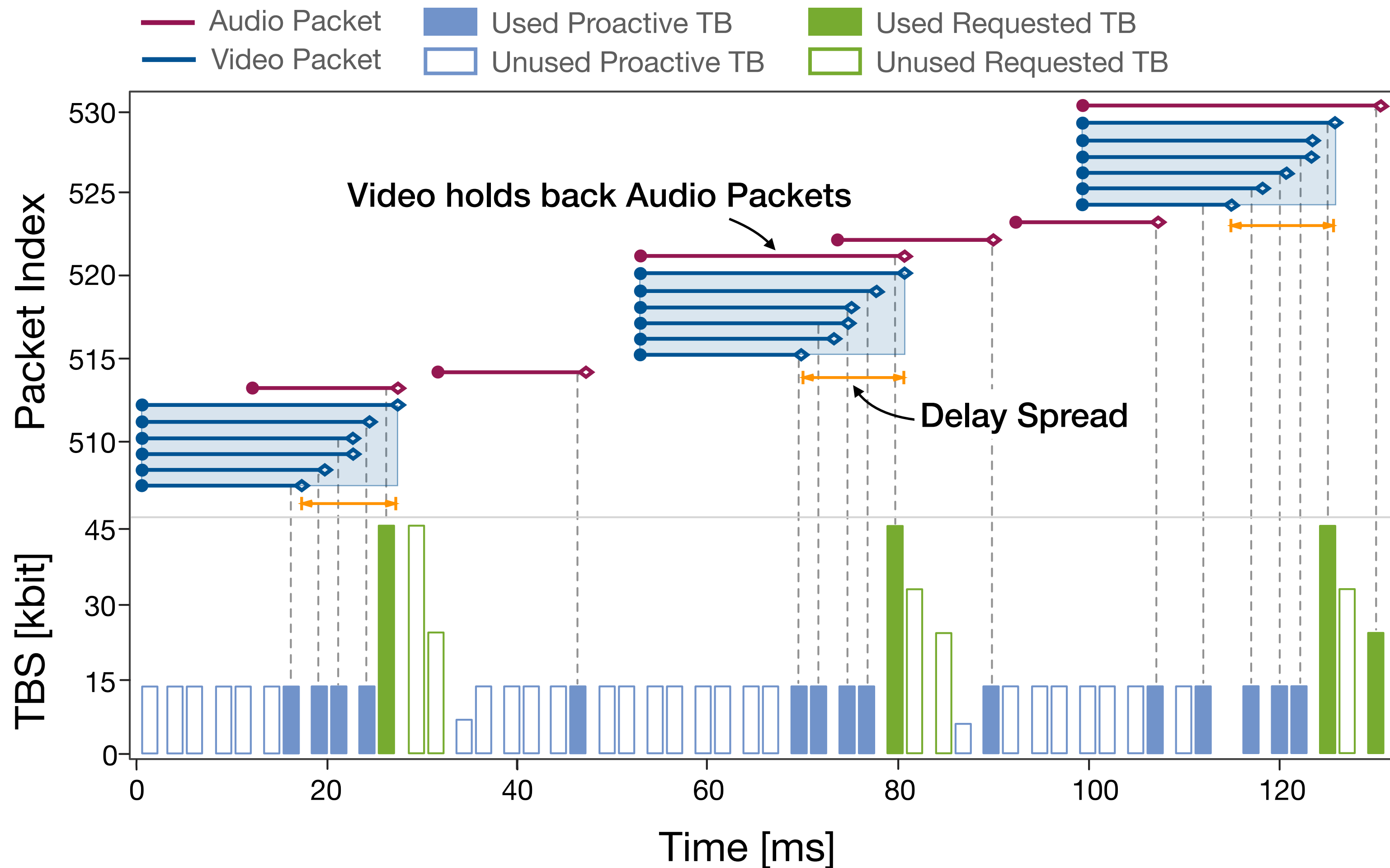


5G Uplink Scheduling Causes Jitter



→ Proactive grants cause delay spread at receiver side resulting in jitter

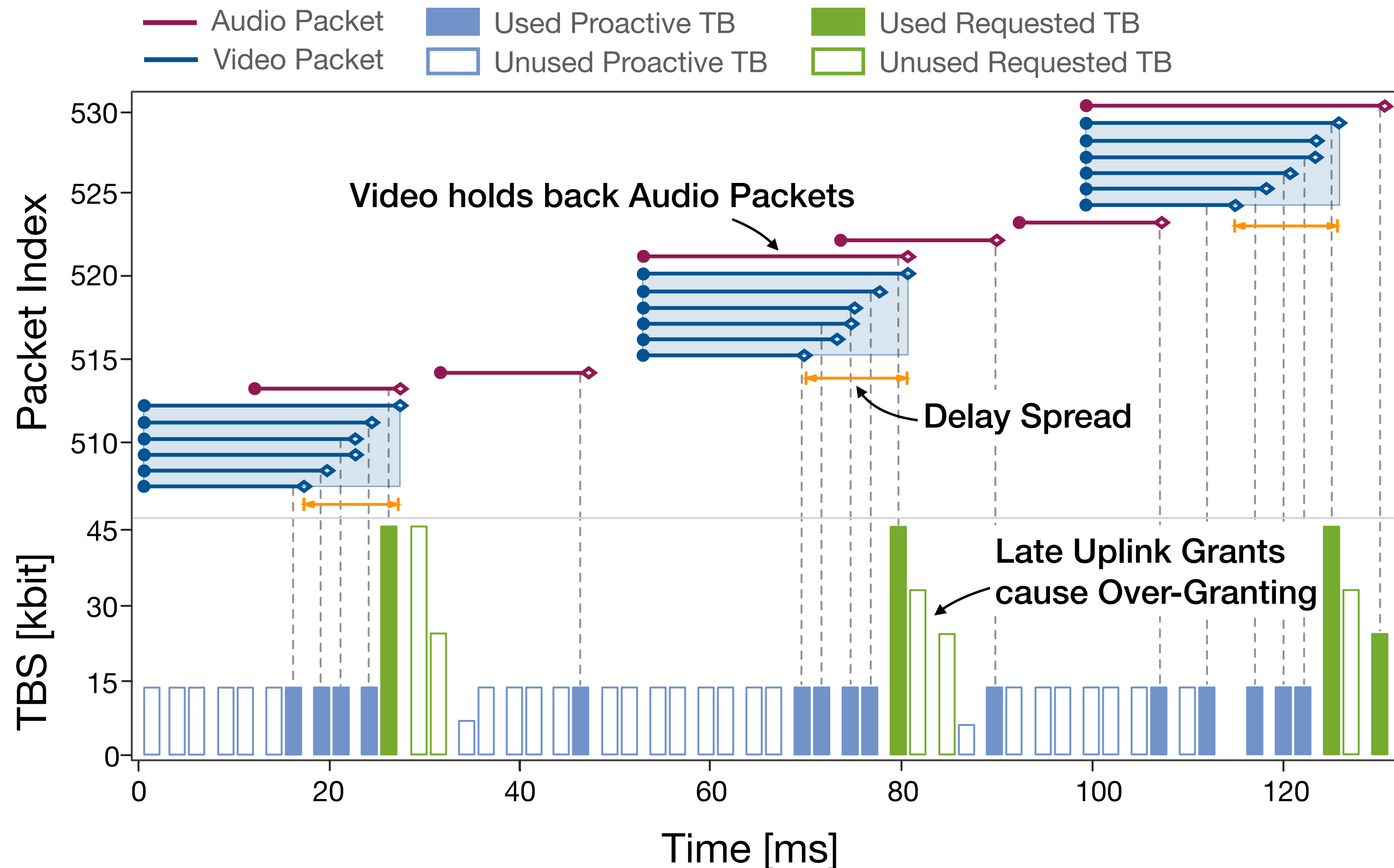
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→ Audio packets sent alongside video frames are delayed by video

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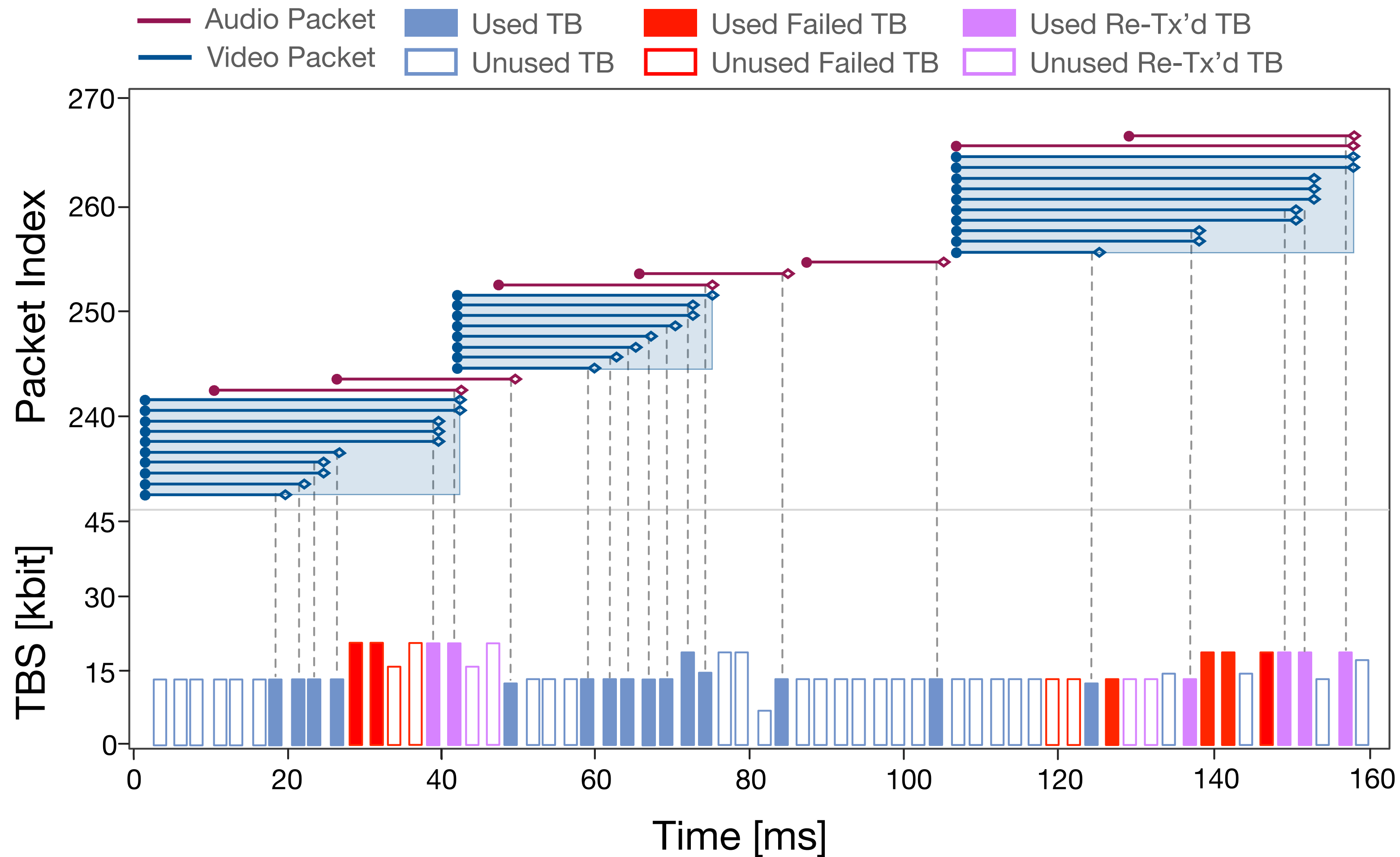


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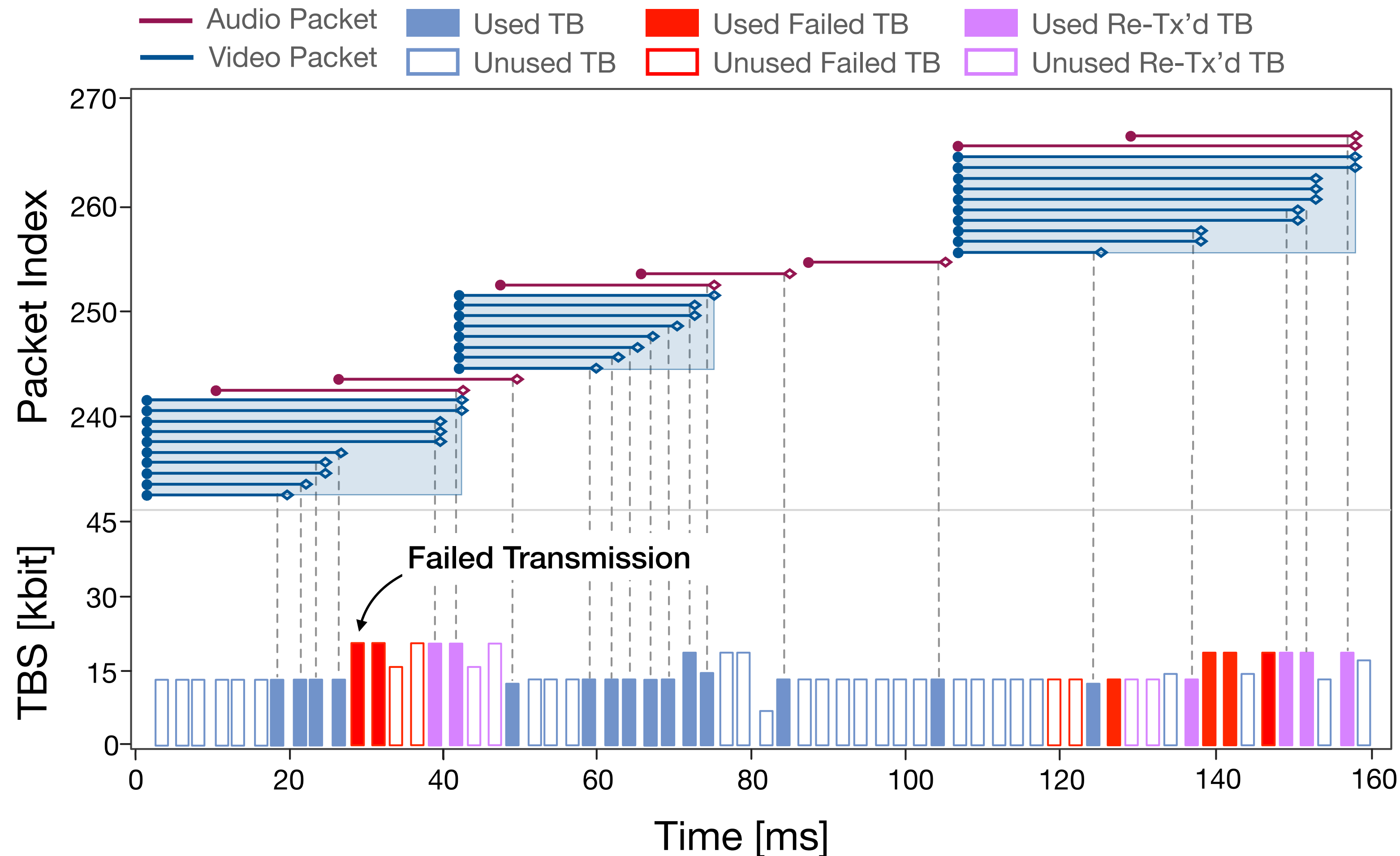
→ Audio packets sent alongside video frames are delayed by video

→ Late BSR-triggered uplink grants waste capacity

5G Retransmissions Causes Jitter

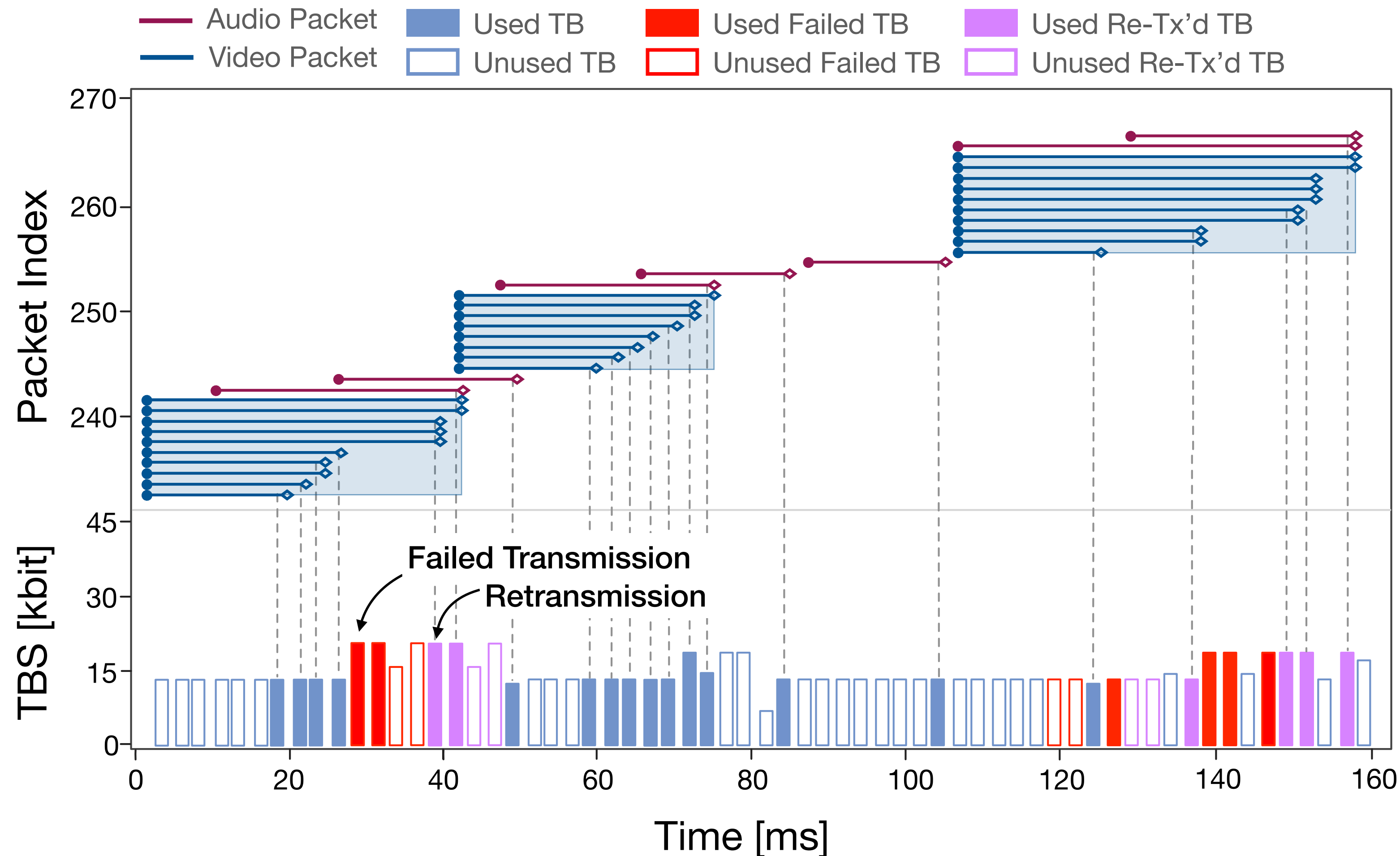


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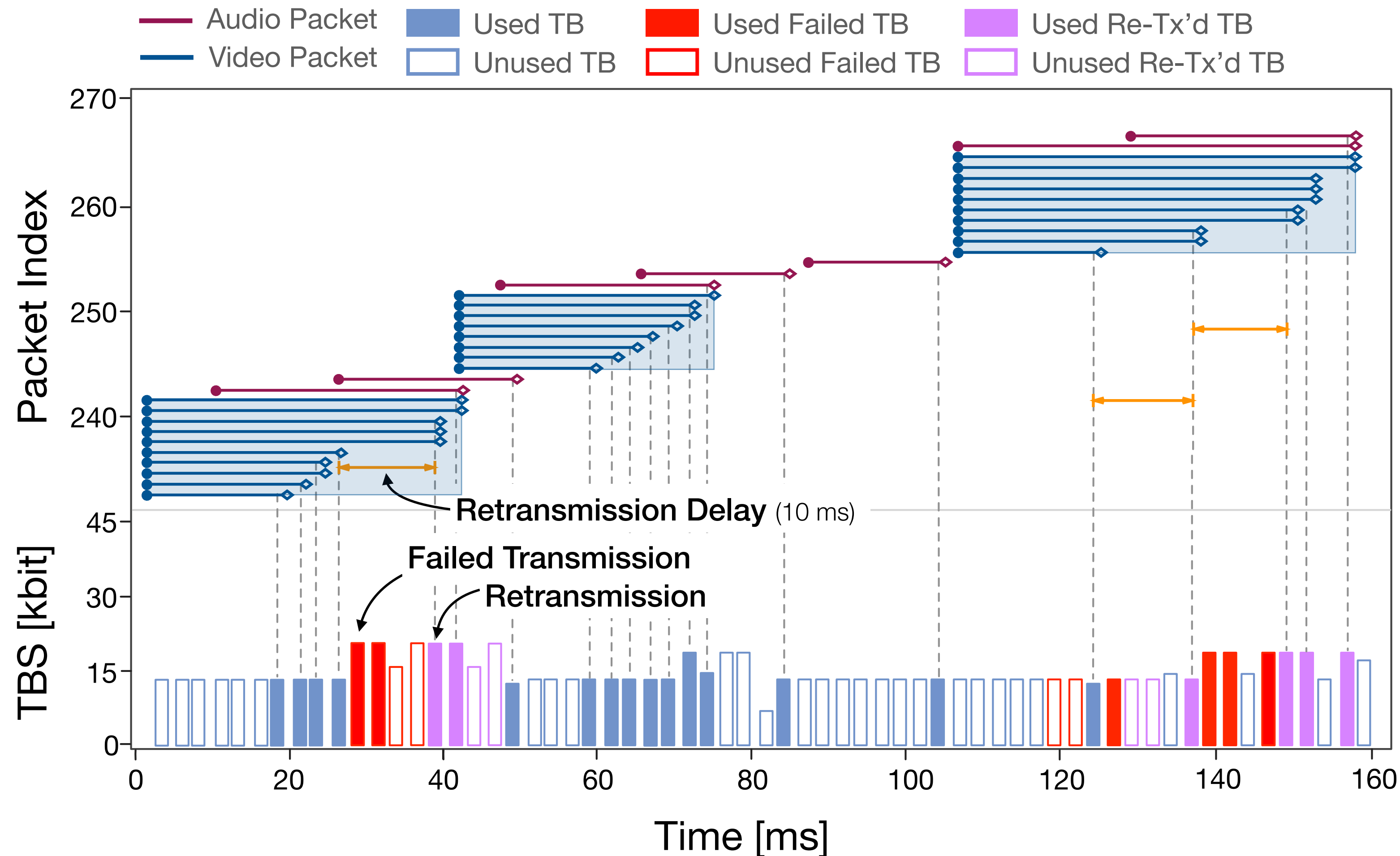
→ Athena can explain per-packet latency: link-layer retransmissions further inflate delay by 10 ms

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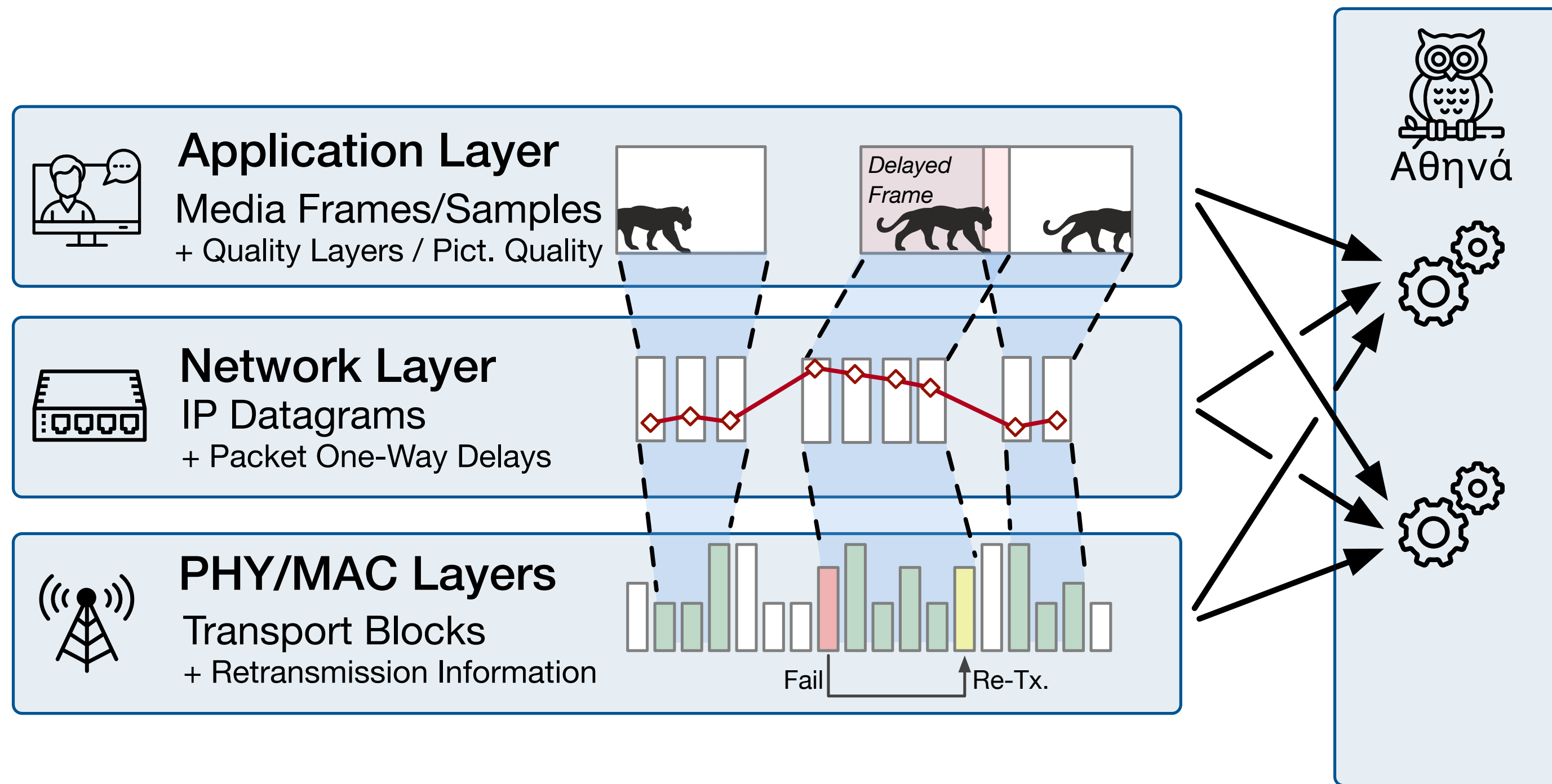
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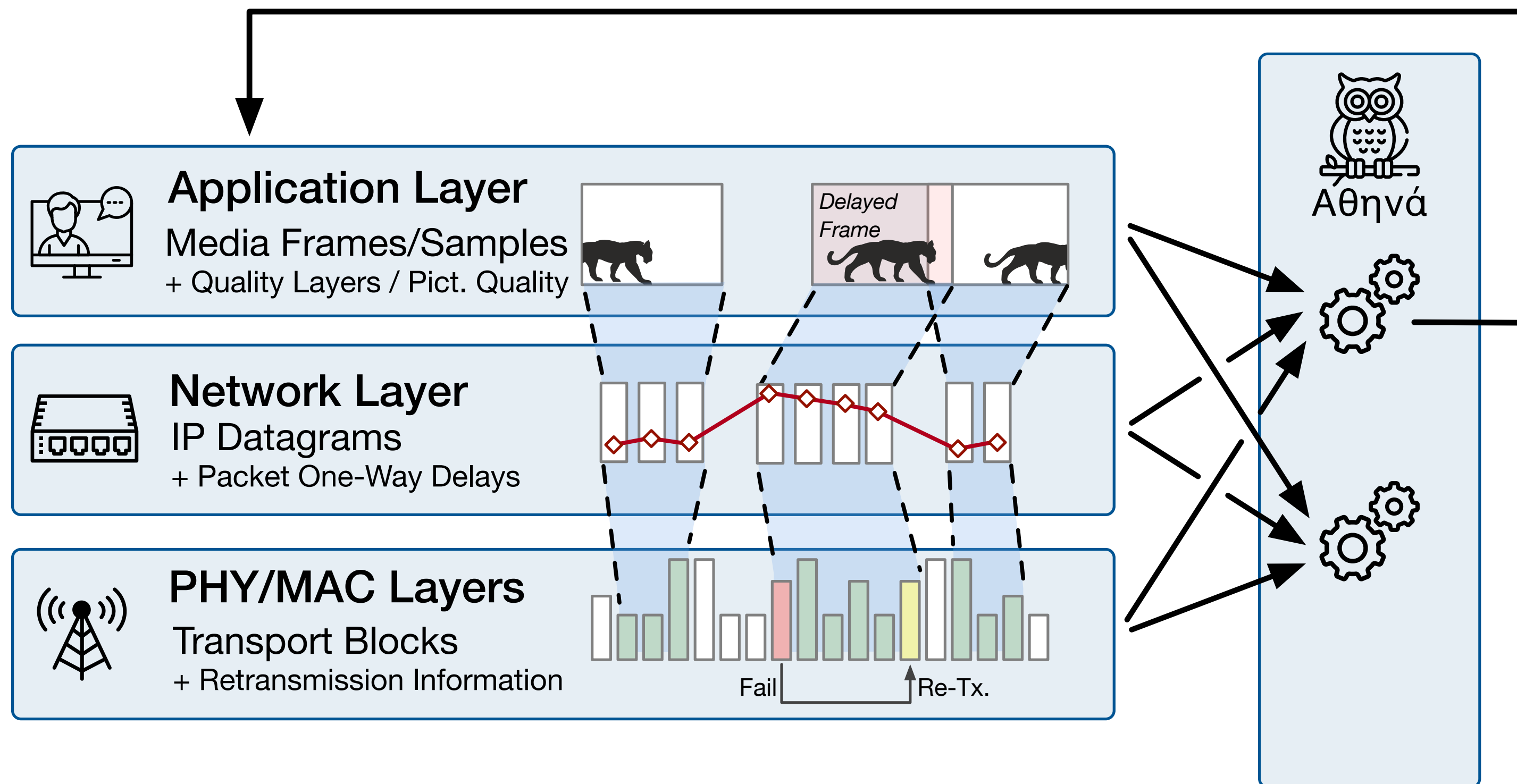


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Athena Cross-Layer Optimization Opportunities



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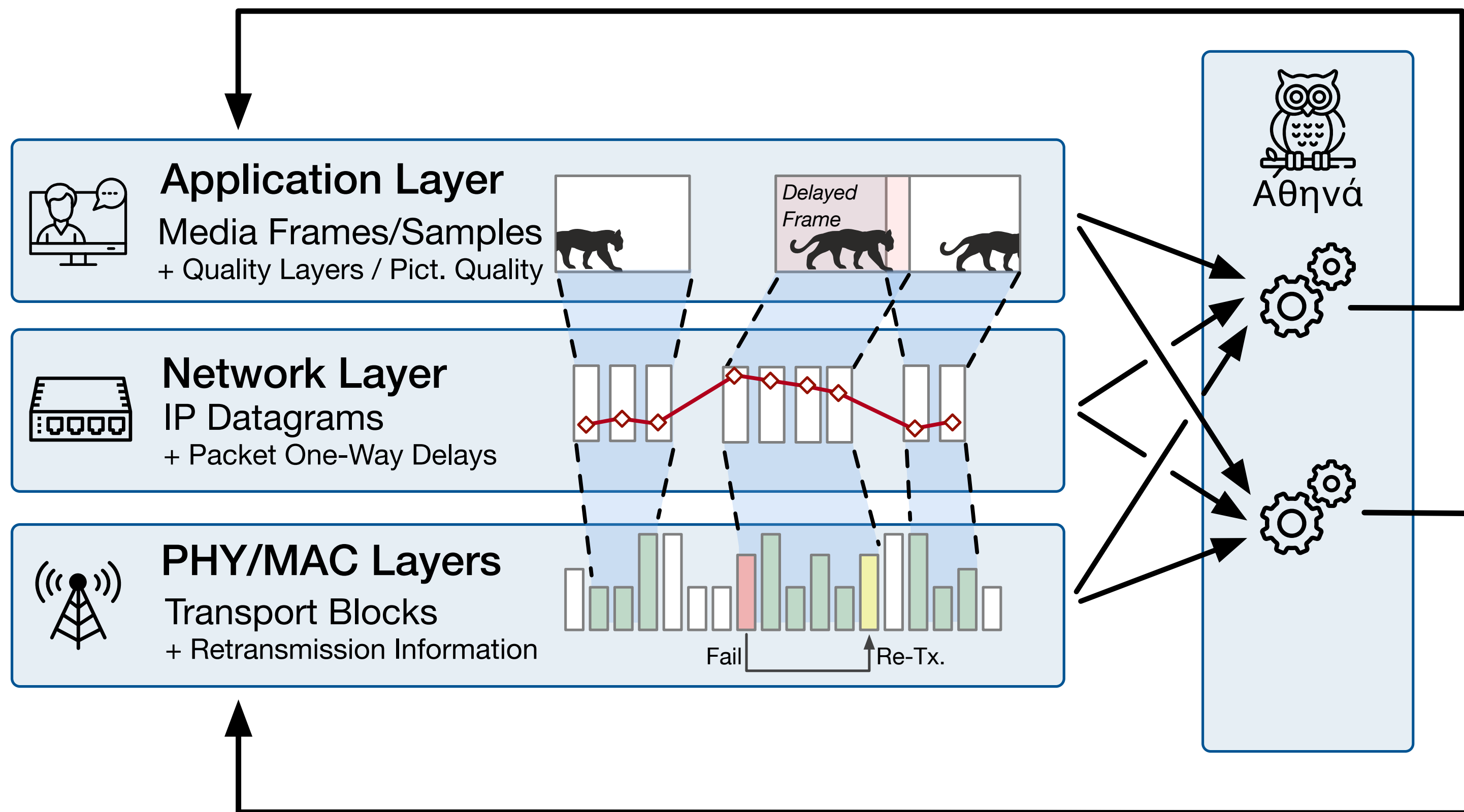


Network to Application

Telemetry about network, e.g.,

- Available capacity
- Cause of delay increase

Athena Cross-Layer Optimization Opportunities



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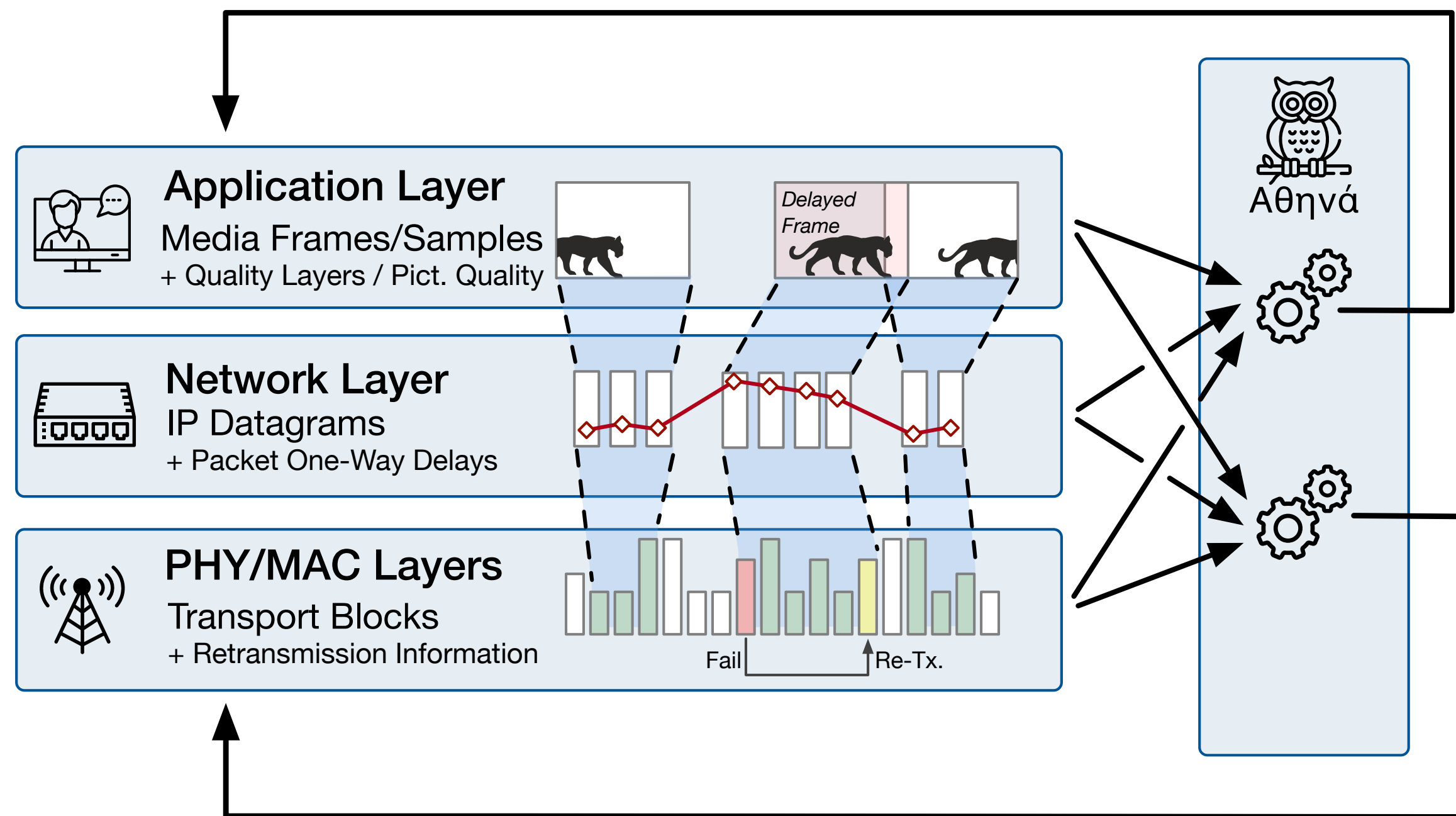
- Available capacity
- Cause of delay increase

Application to Network

Use application semantics in network, e.g.,

- Intelligent dropping of frames
- Application-aware scheduling

Conclusion / Call for Research



- Synchronizes fine-grained measurements of video conferencing across all layers of the stack
- Reveals new performance insights for application and transport protocol designers to improve end-to-end algorithms
- Starting point for long arc of research uncovering the intricacies of cutting-edge access networks

Q&A

omichel@princeton.edu

<https://olivermichel.github.io>

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 Conference on emerging Networking EXperiments and Technologies (CoNEXT '24)

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Fan Yi
Princeton University
fanyi@princeton.edu

Jennifer Rexford
Princeton University
jrex@princeton.edu

Haoran Wan
Princeton University
haoran.w@princeton.edu

Yaxiong Xie
University at Buffalo
yaxiongx@buffalo.edu

Kyle Jamieson
Princeton University
kylej@princeton.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:

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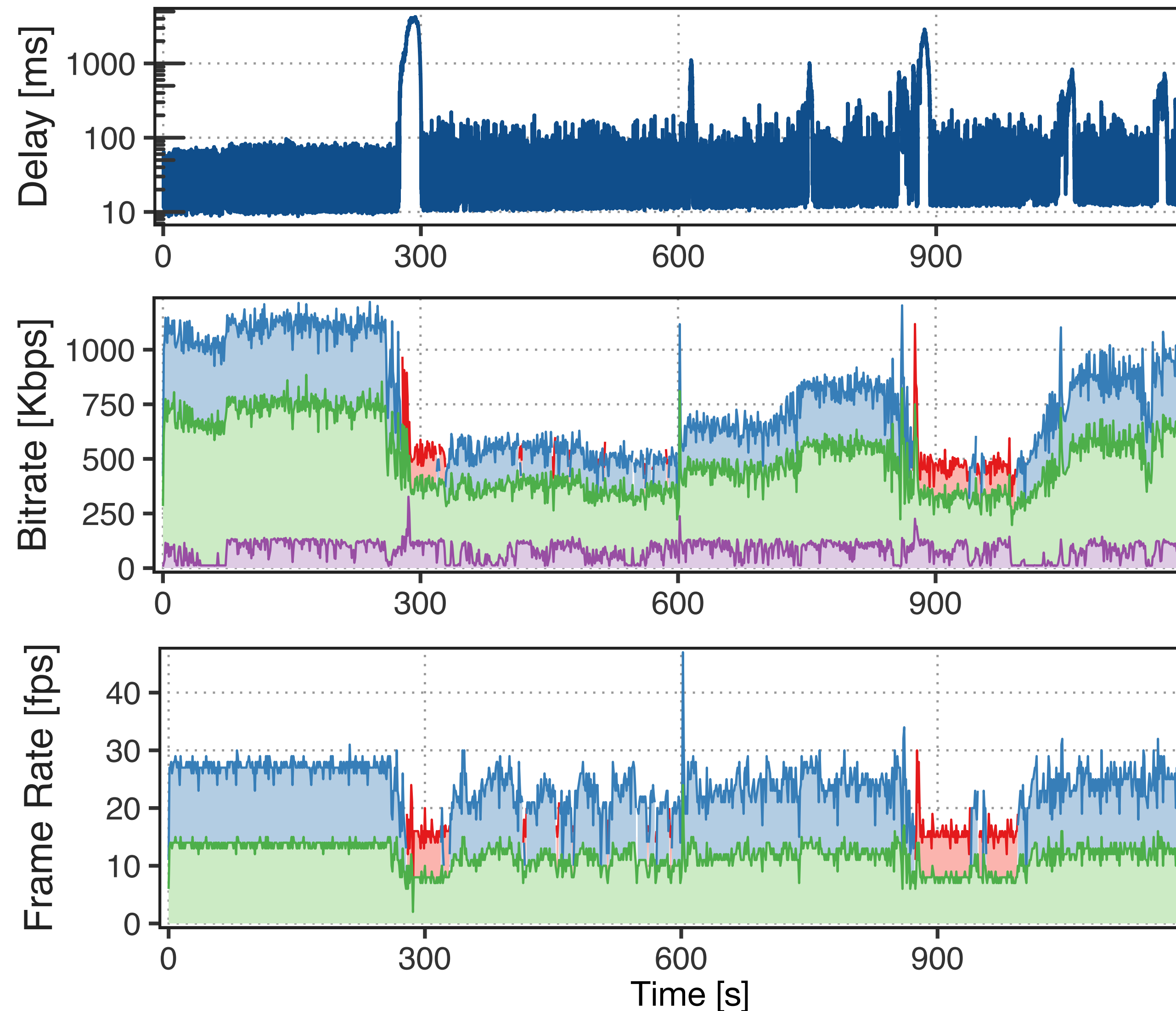
1 INTRODUCTION

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

Athena Application and Network Layer Measurements



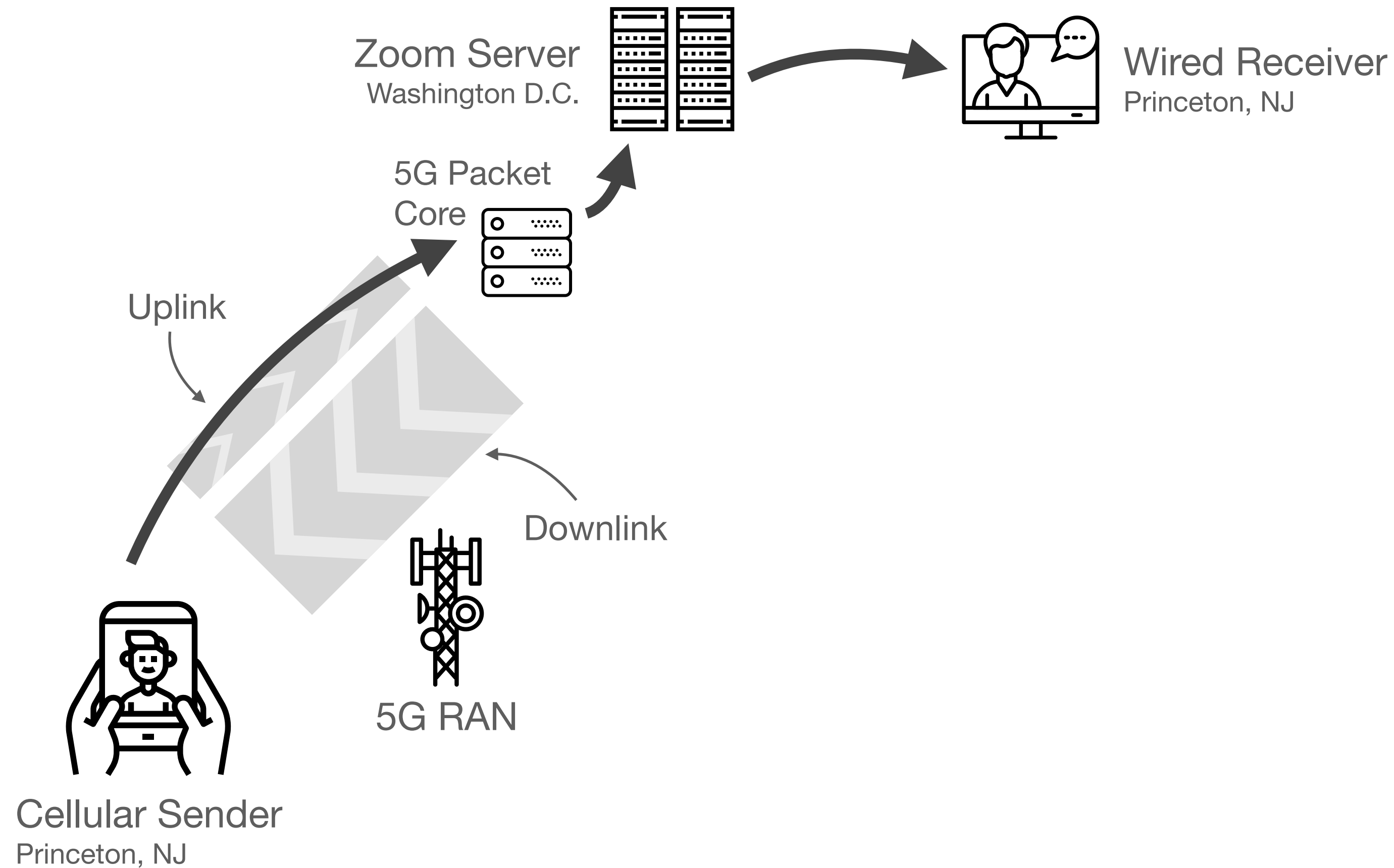
Athena measures:

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

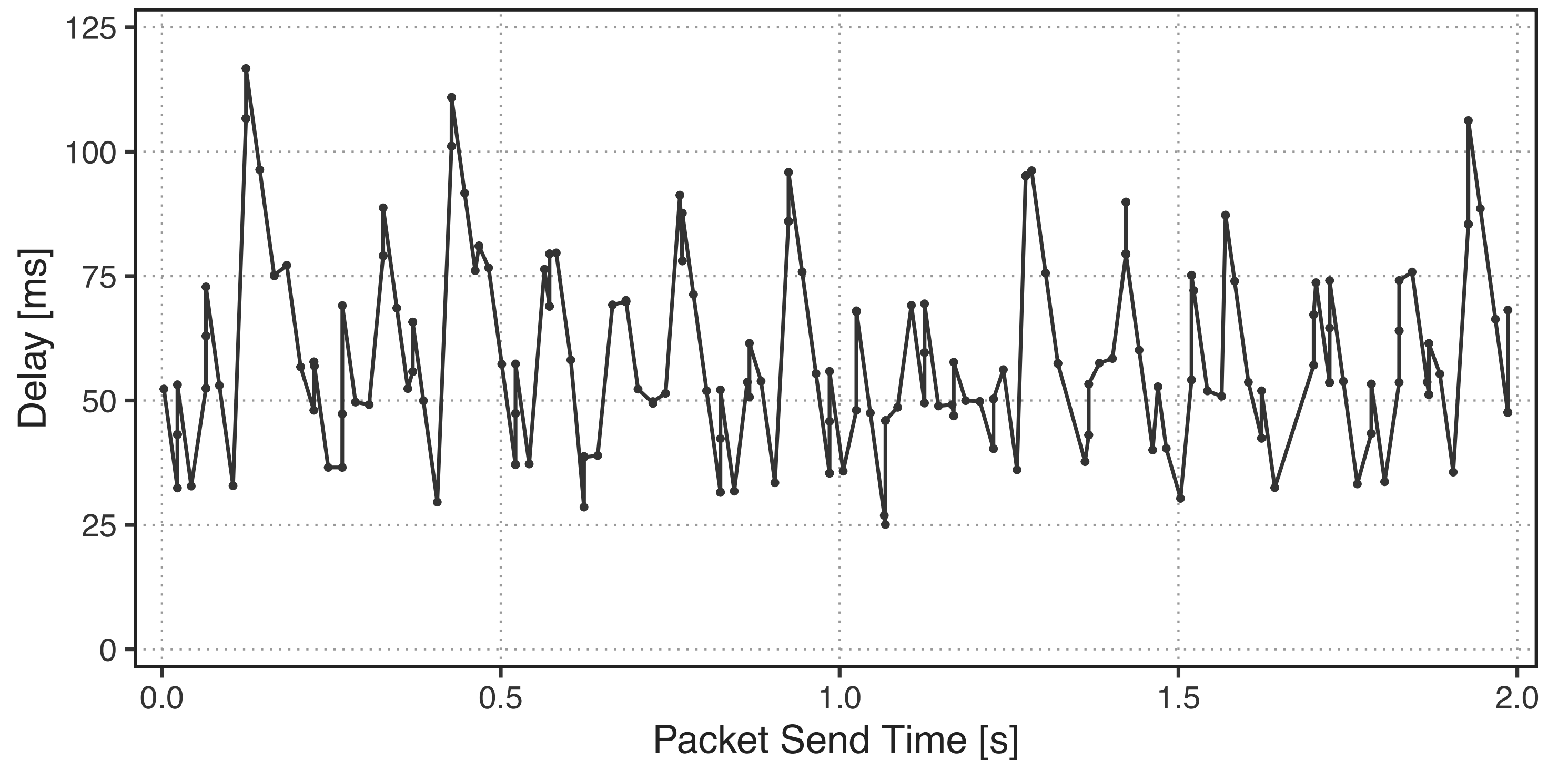
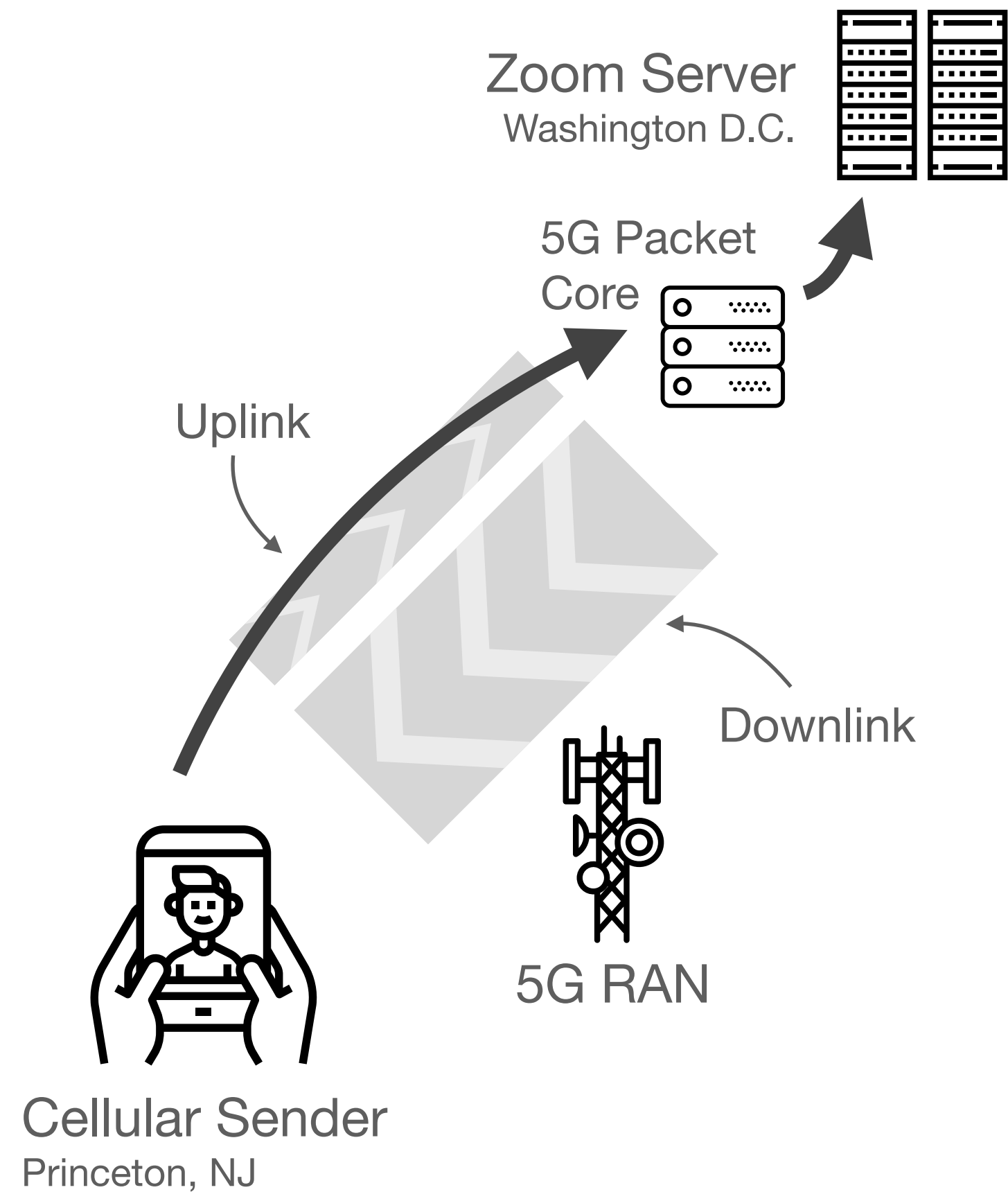
- Zoom reacts to high latency primarily by reducing frame rate
- Jitter causes unstable frame rate



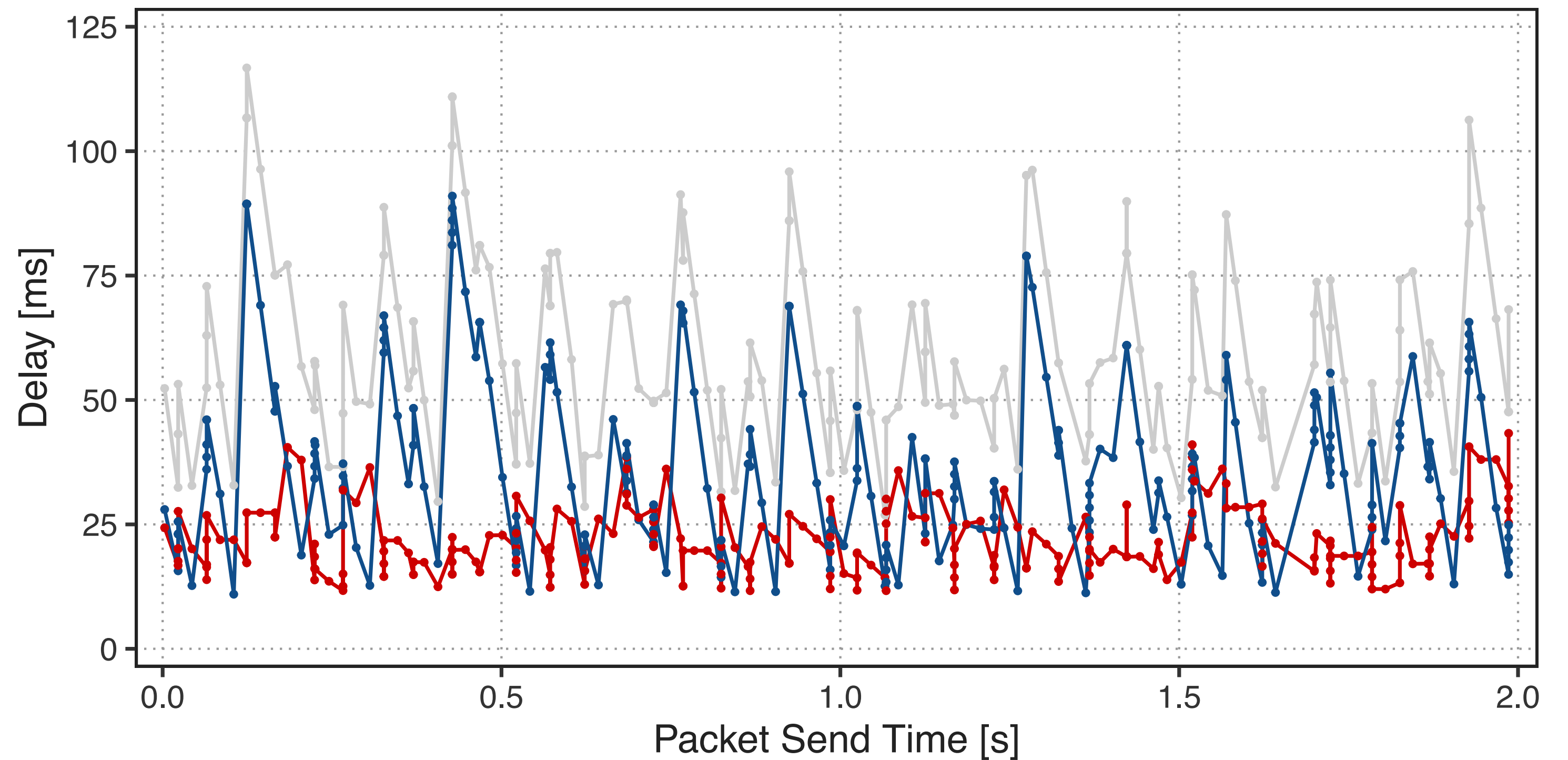
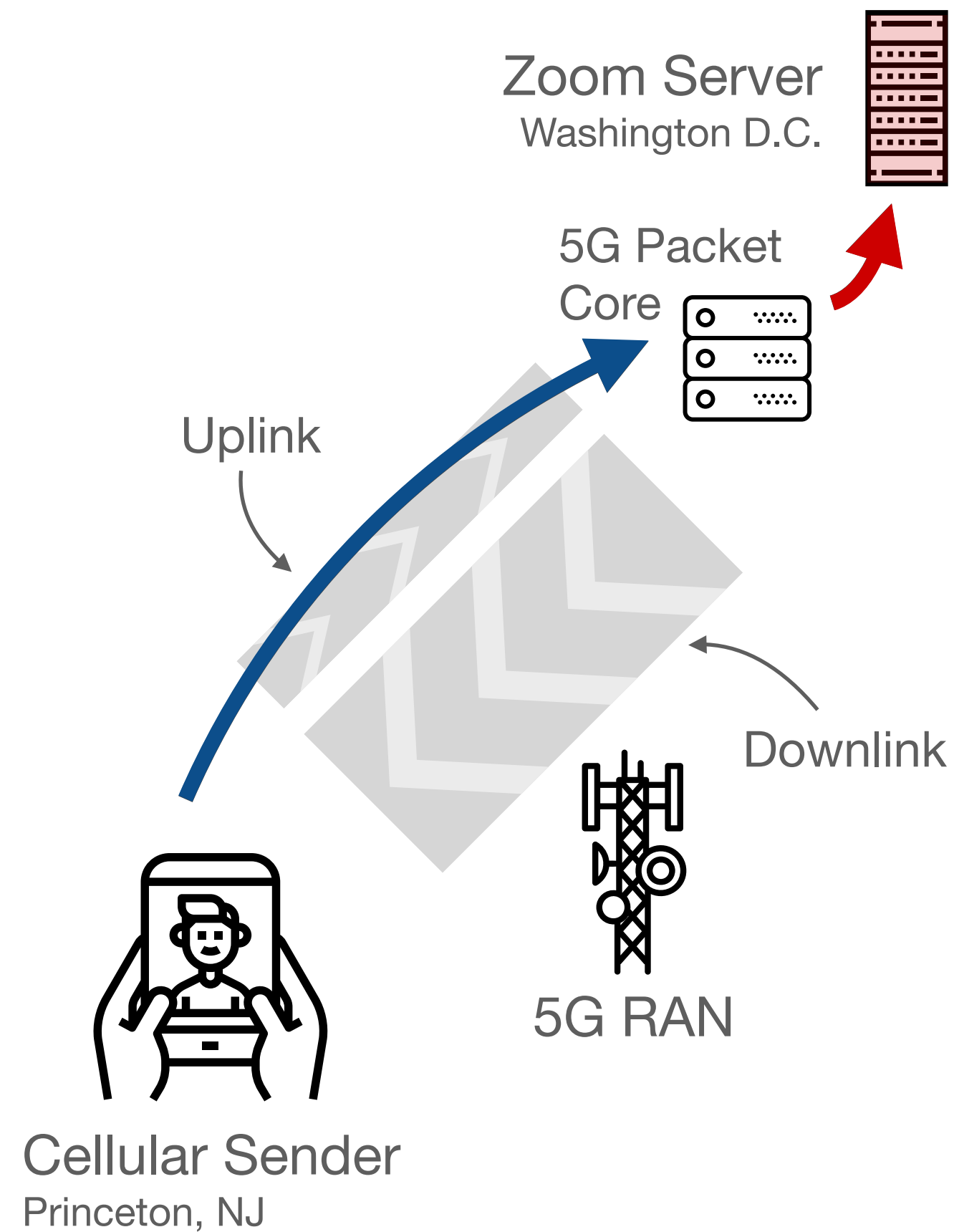
5G Uplink causes high Latency and Jitter



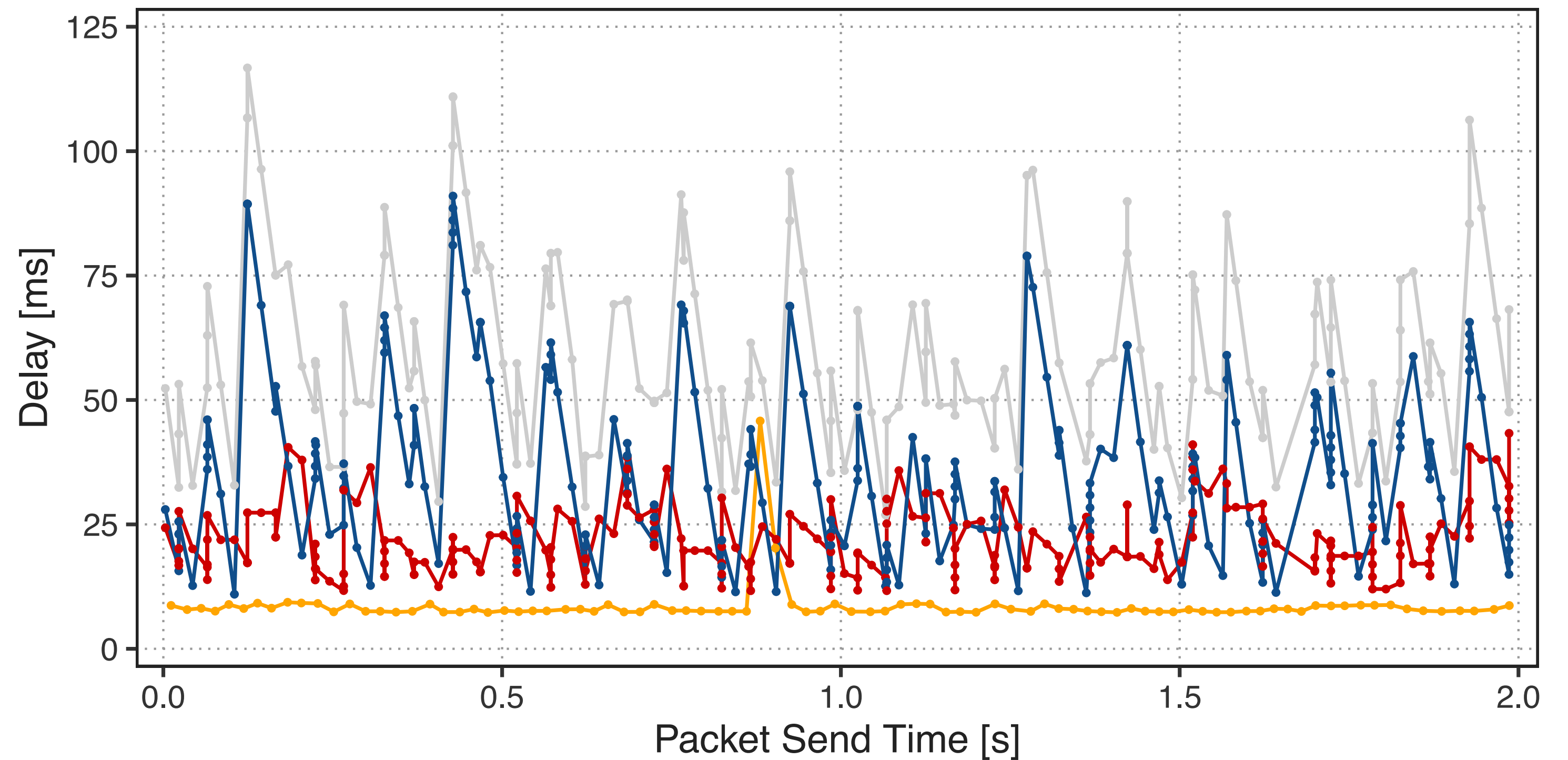
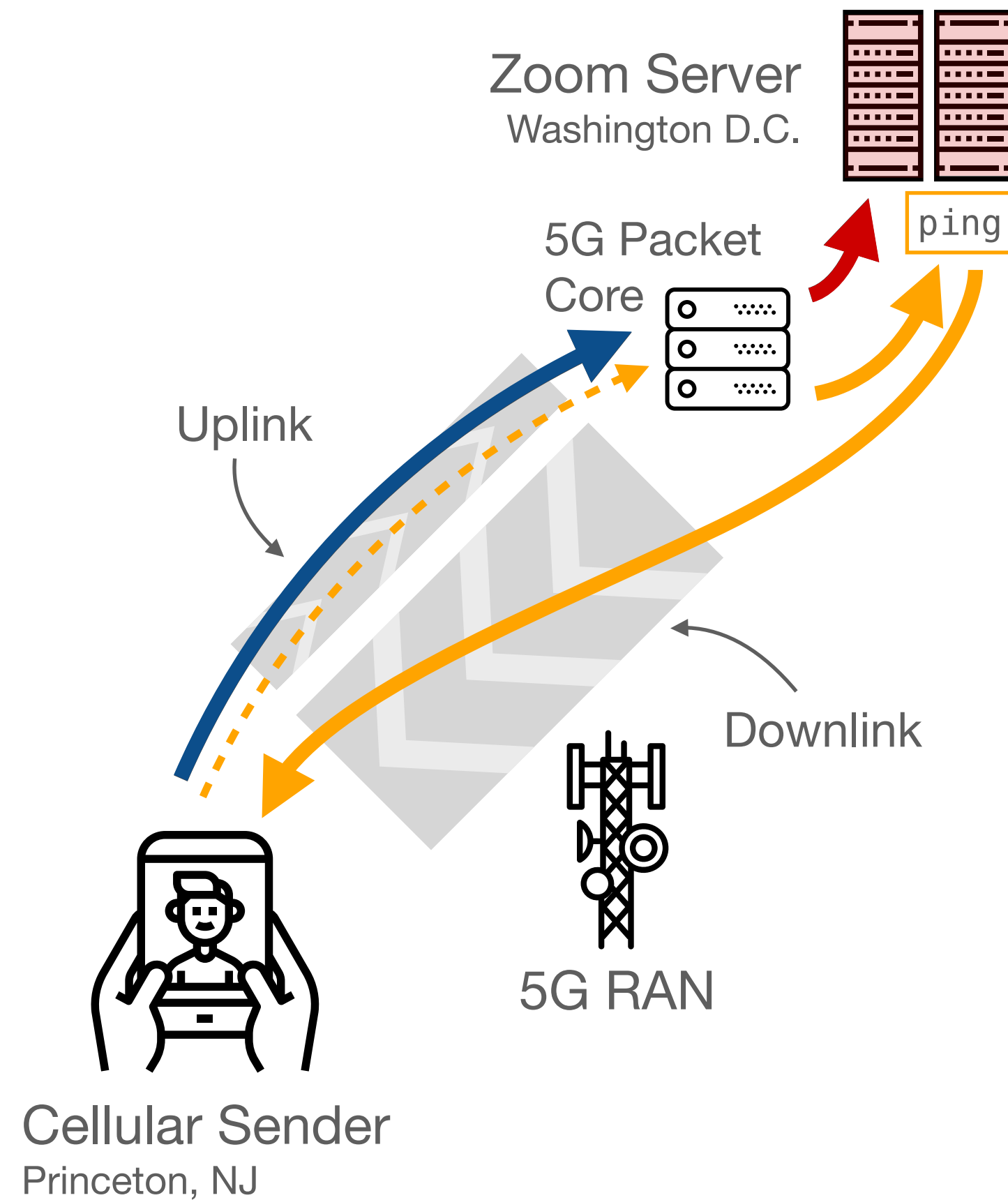
5G Uplink causes high Latency and Jitter



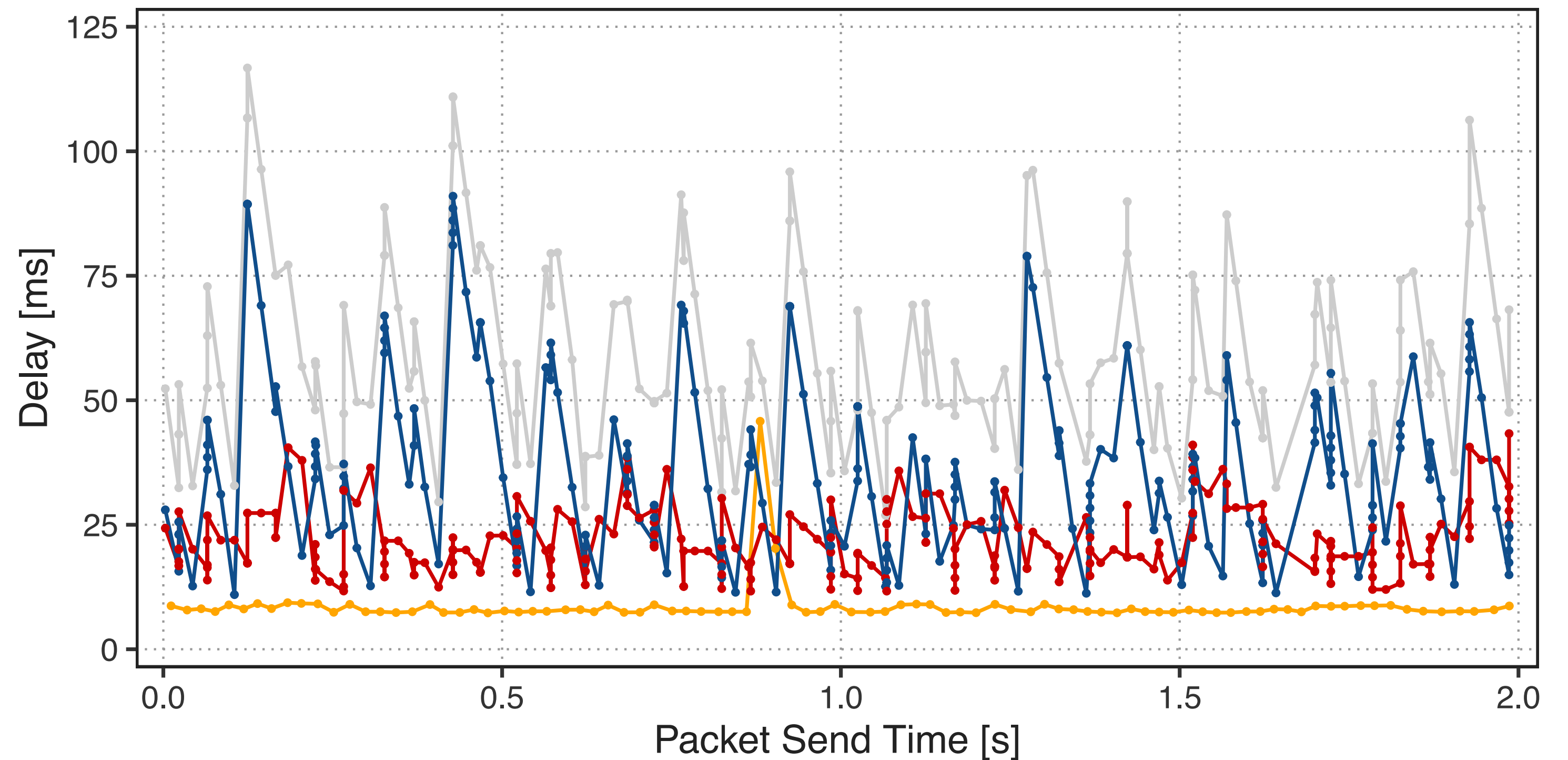
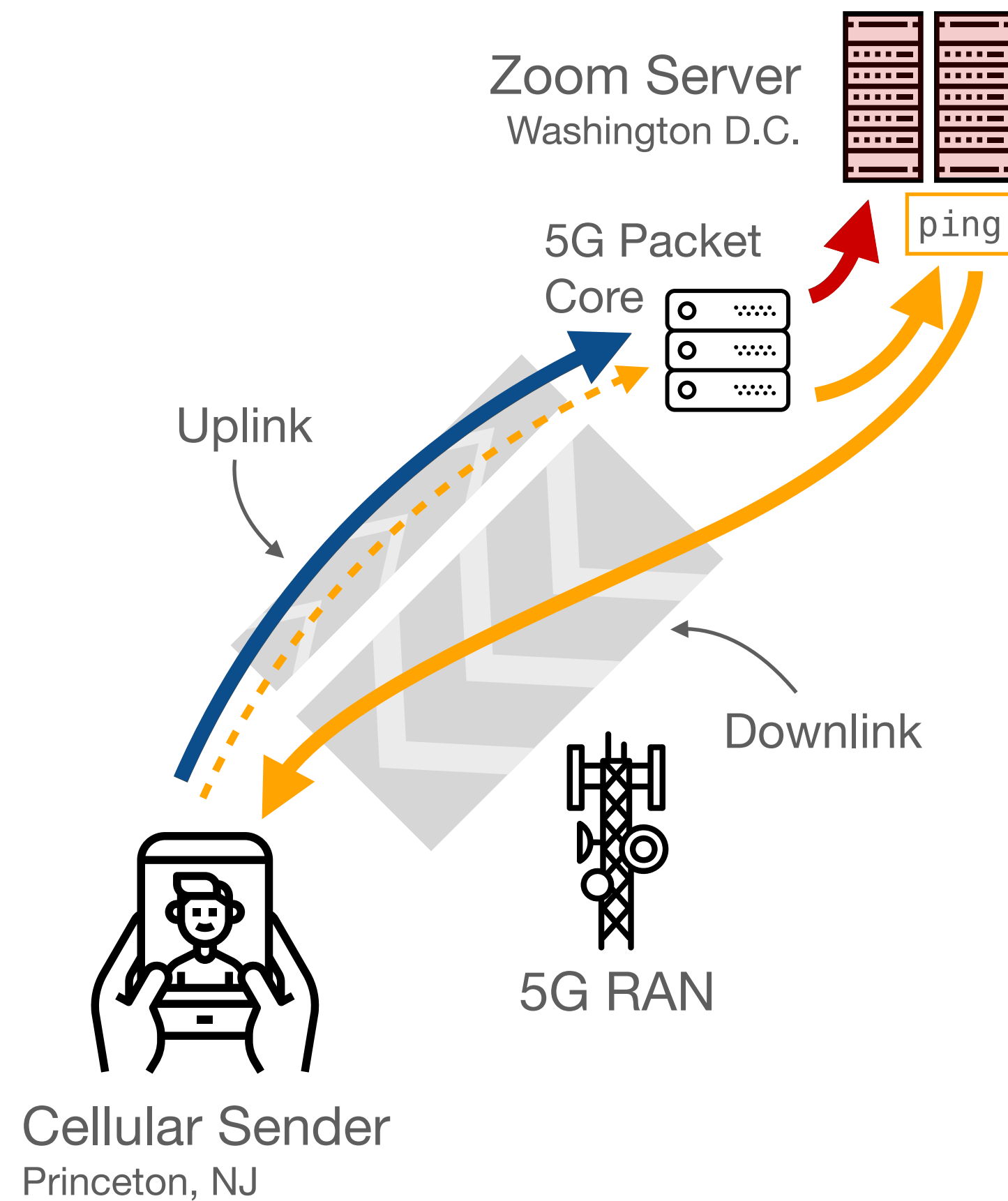
5G Uplink causes high Latency and Jitter



5G Uplink causes high Latency and Jitter



5G Uplink causes high Latency and Jitter



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