

Enabling Passive Measurement of Zoom Performance in Production Networks

Oliver Michel

NANOG 87, Atlanta, GA, February 15th, 2023.

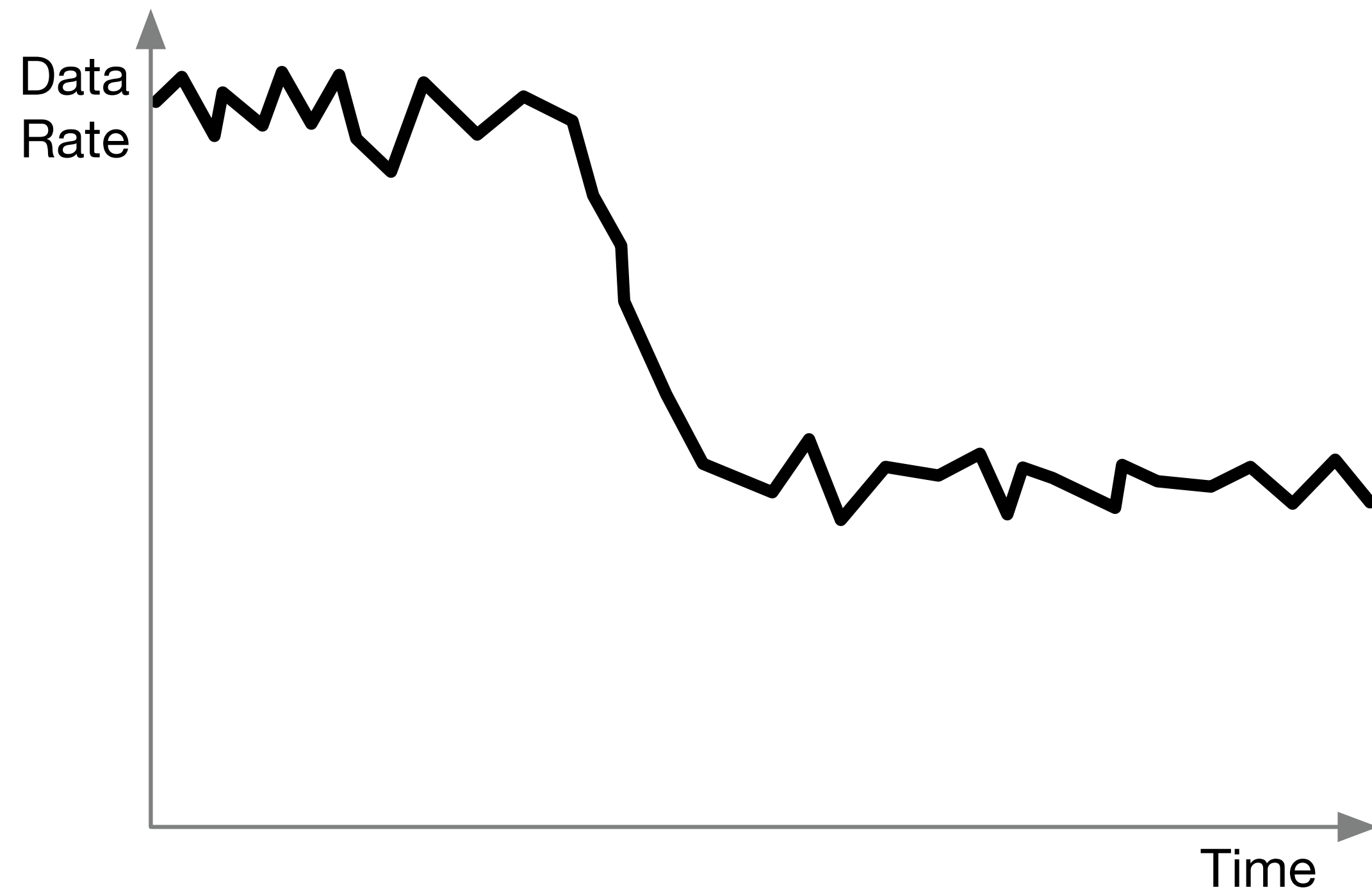


Video Conferencing

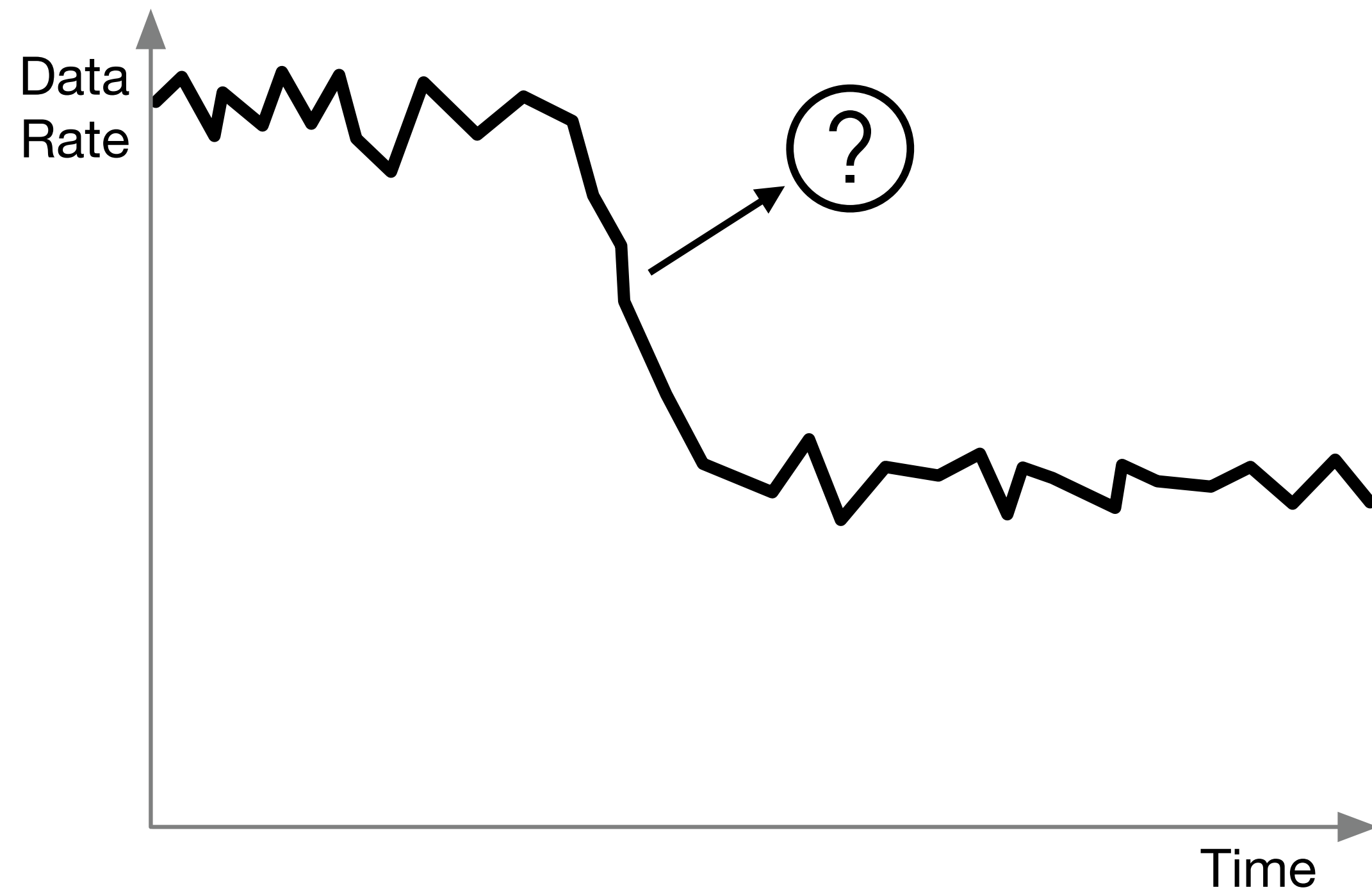
- Essential application across most industries
- Relevant to research community
- Relevant to network operators



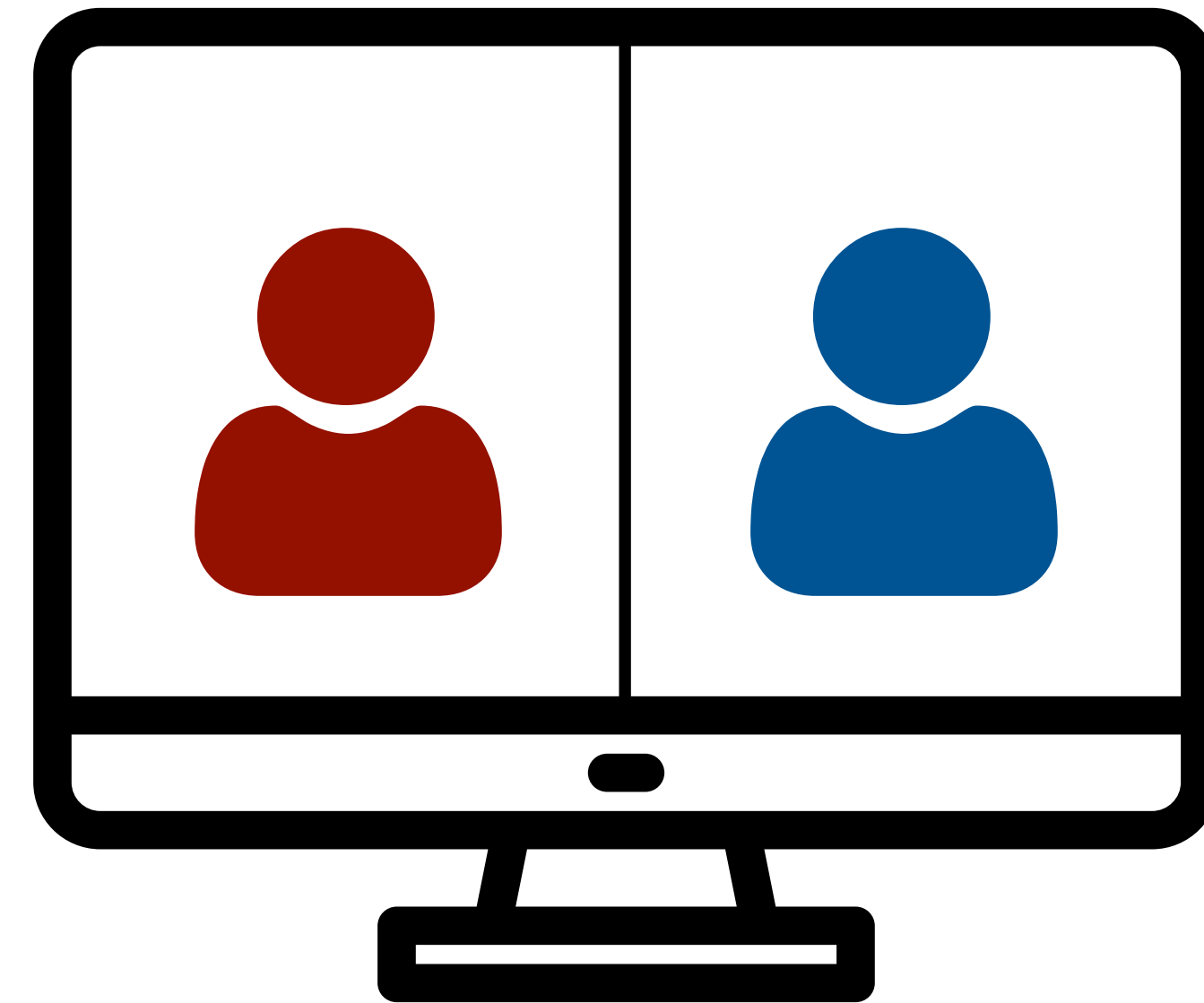
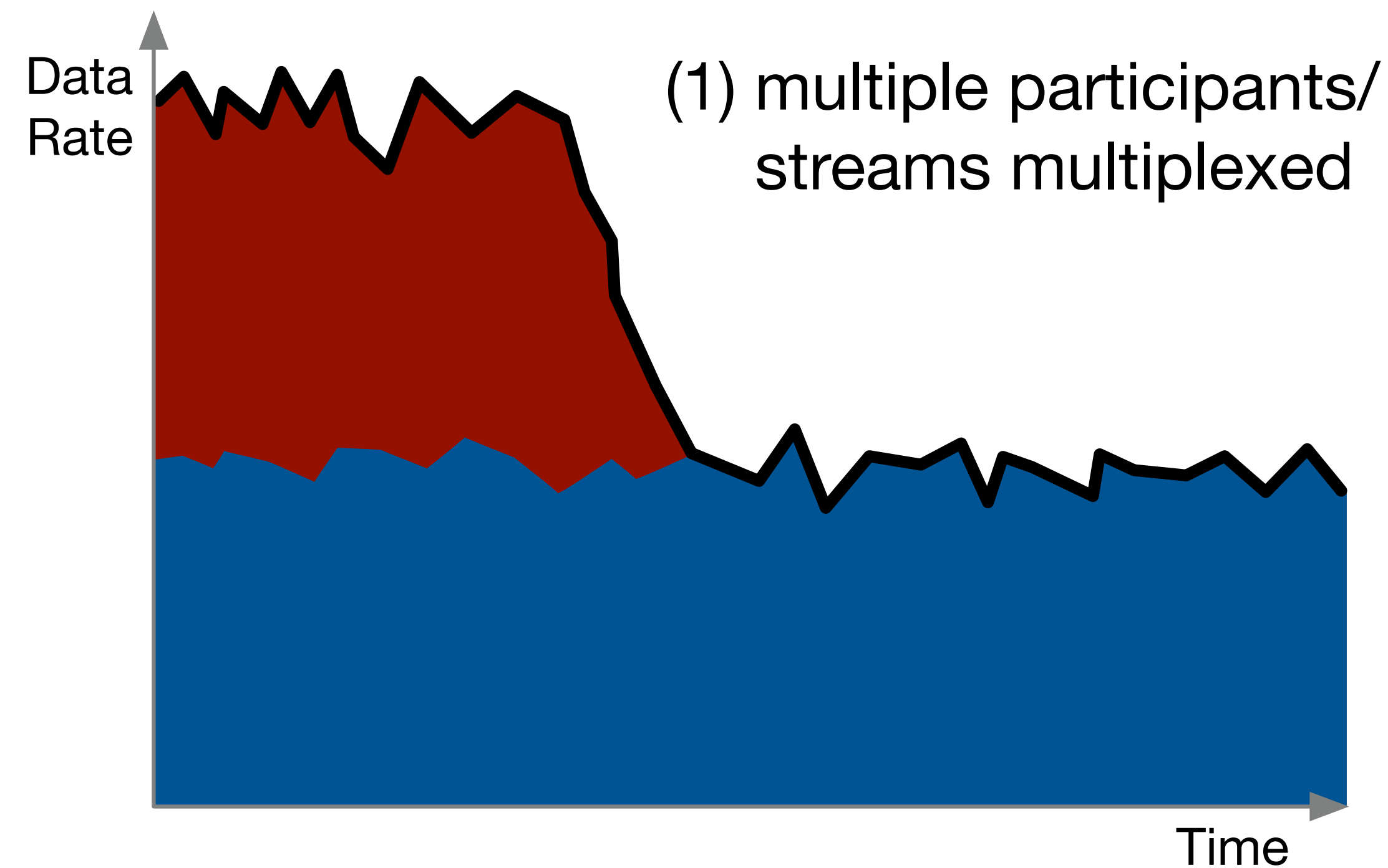
Measuring Video-Conferencing Applications is Hard



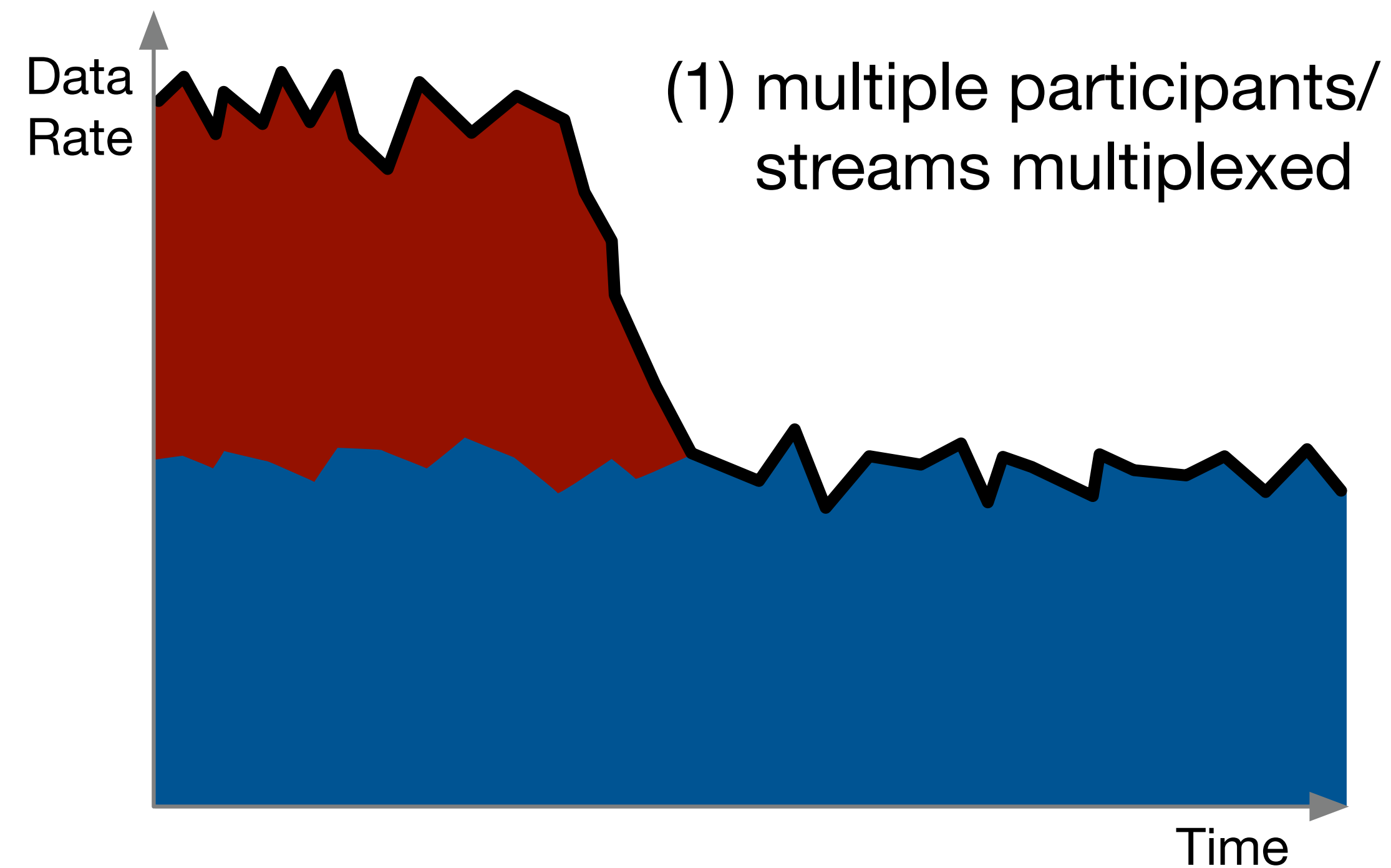
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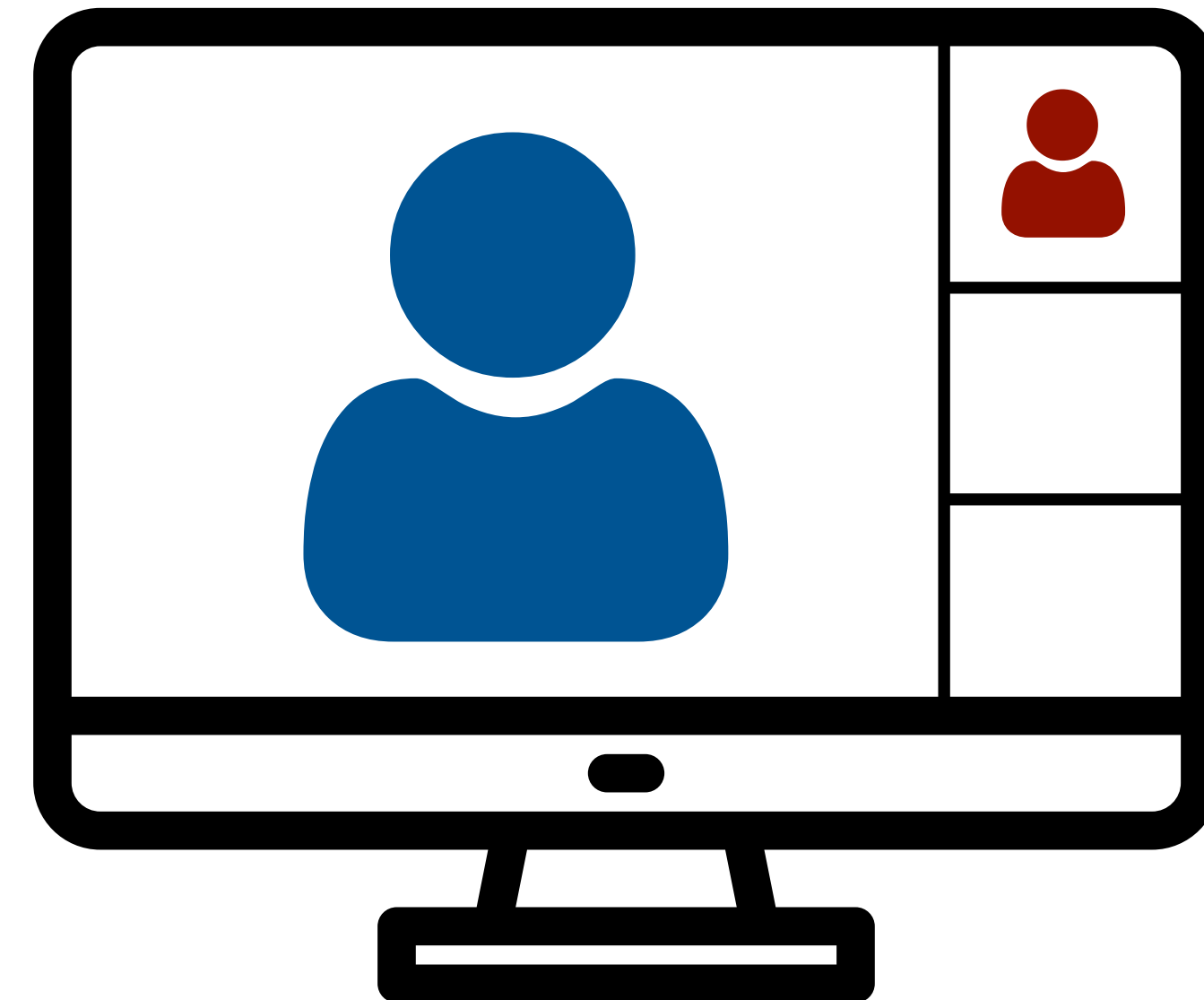
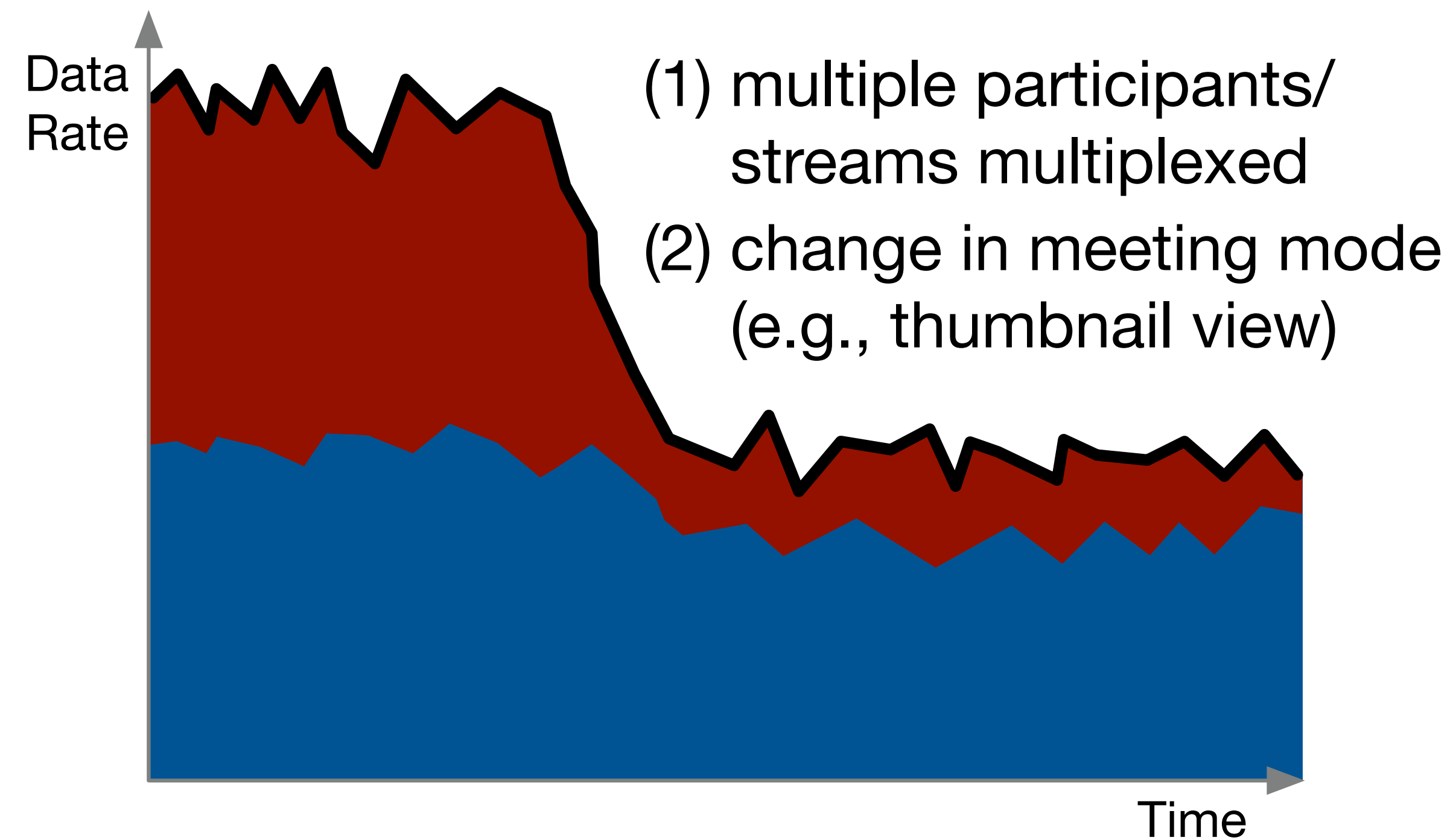
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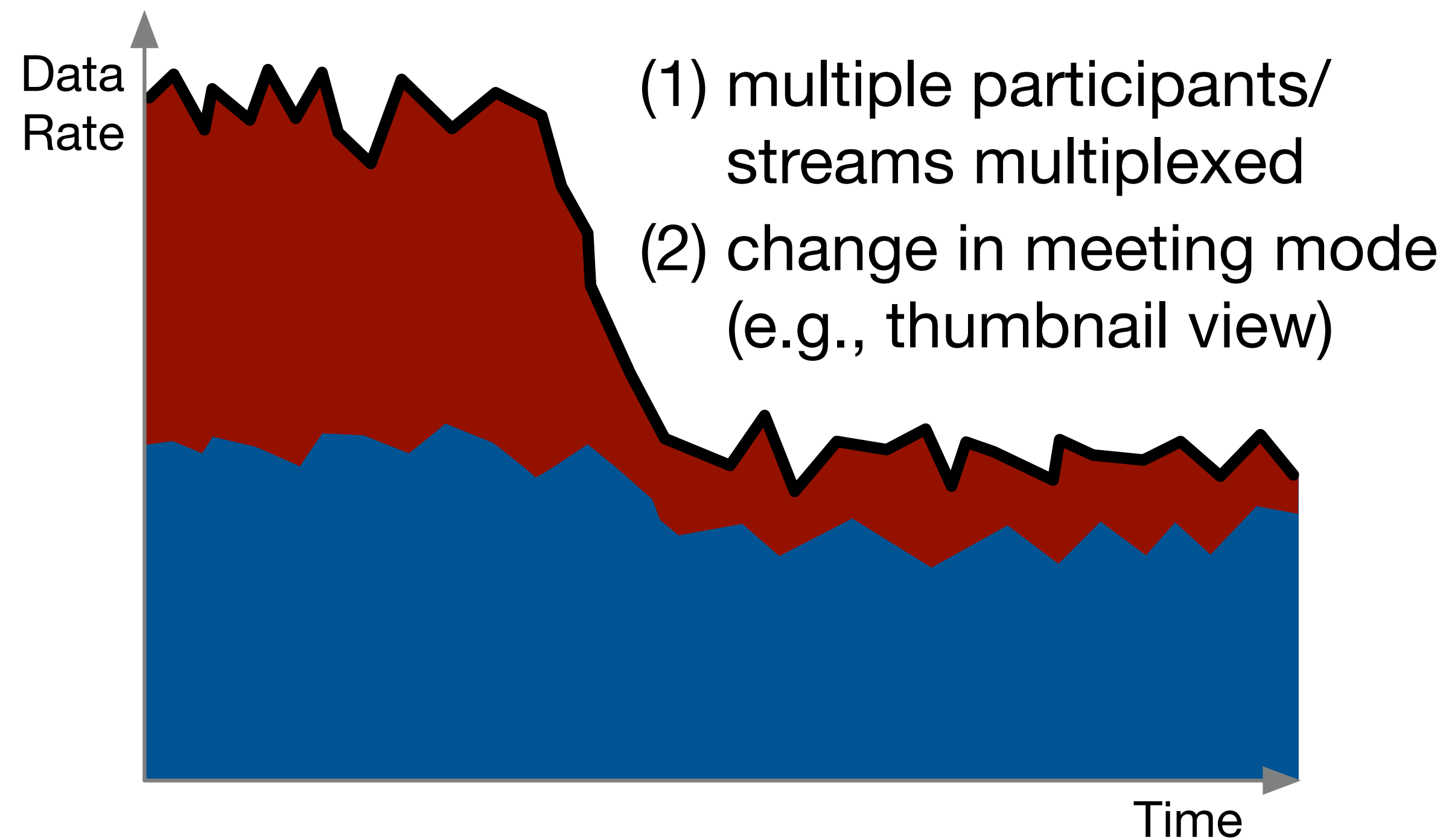
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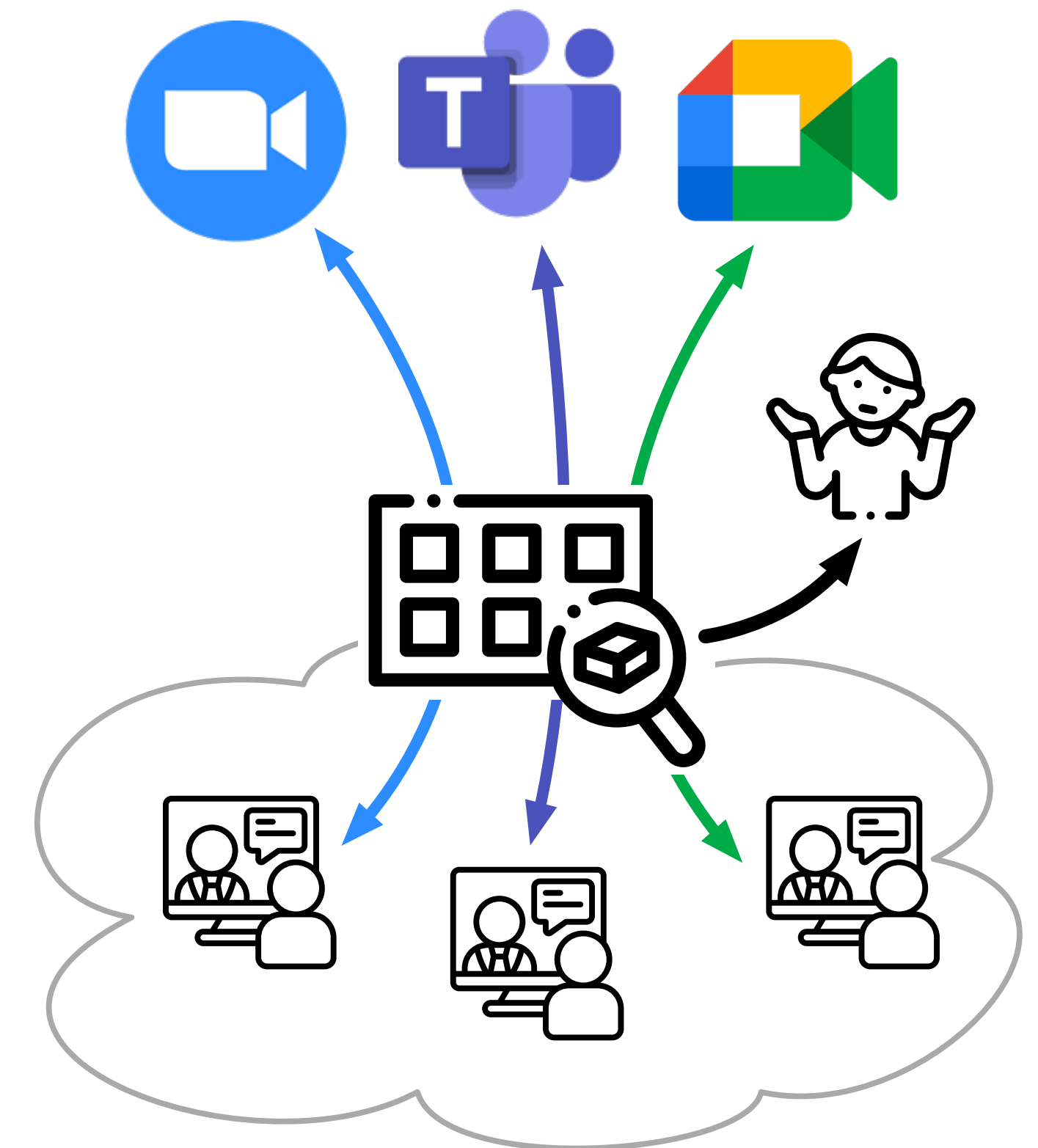


Need to dig deeper to extract
meaningful metrics

Latency
Jitter
Loss & Retransmissions
Out-of-order packets
Frame rate & size
Media bit rate
Meeting composition

Measuring Video-Conferencing Applications is Hard

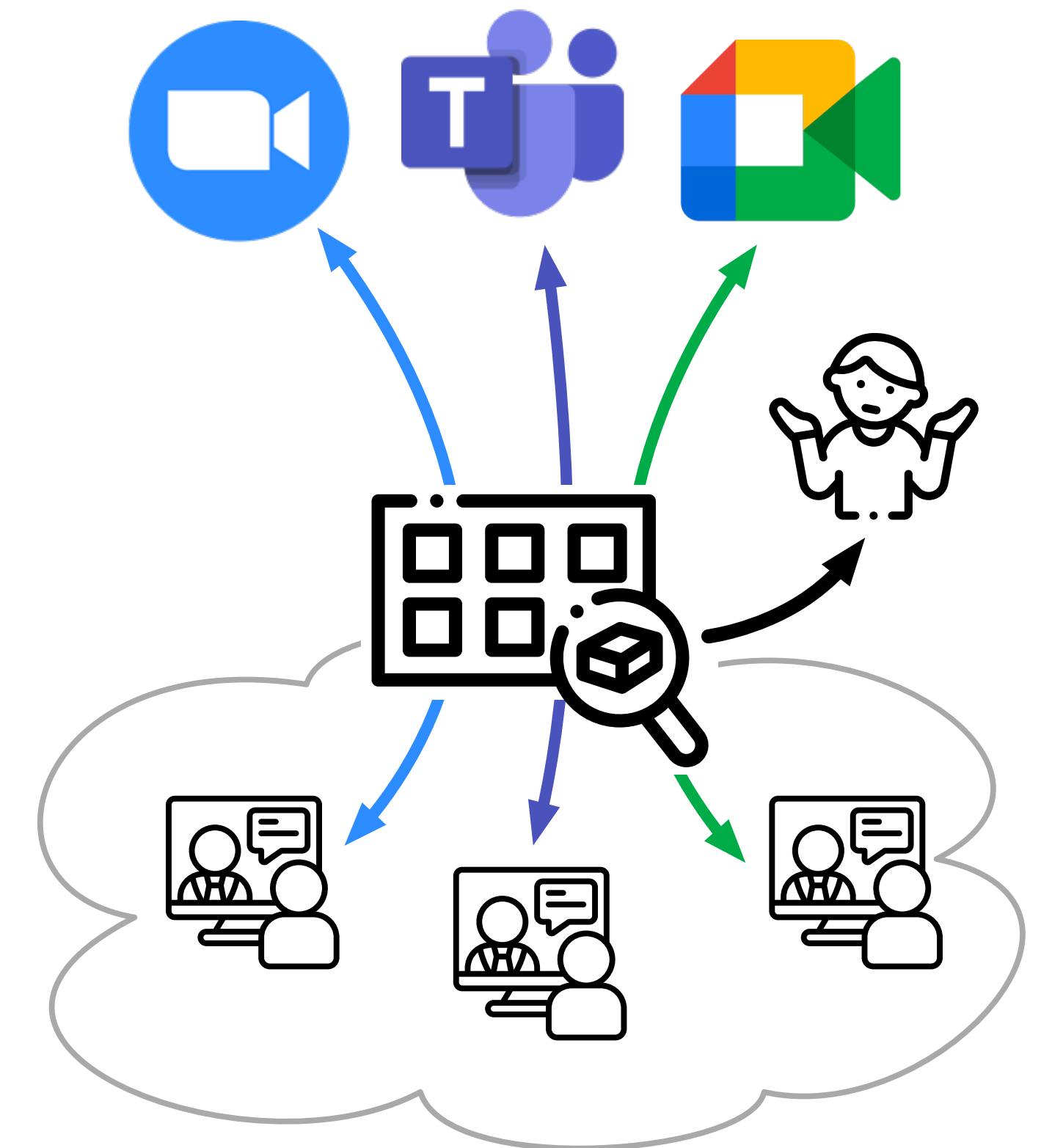
Problem: **Hard for researchers and operators to extract useful metrics from traffic**



Measuring Video-Conferencing Applications is Hard

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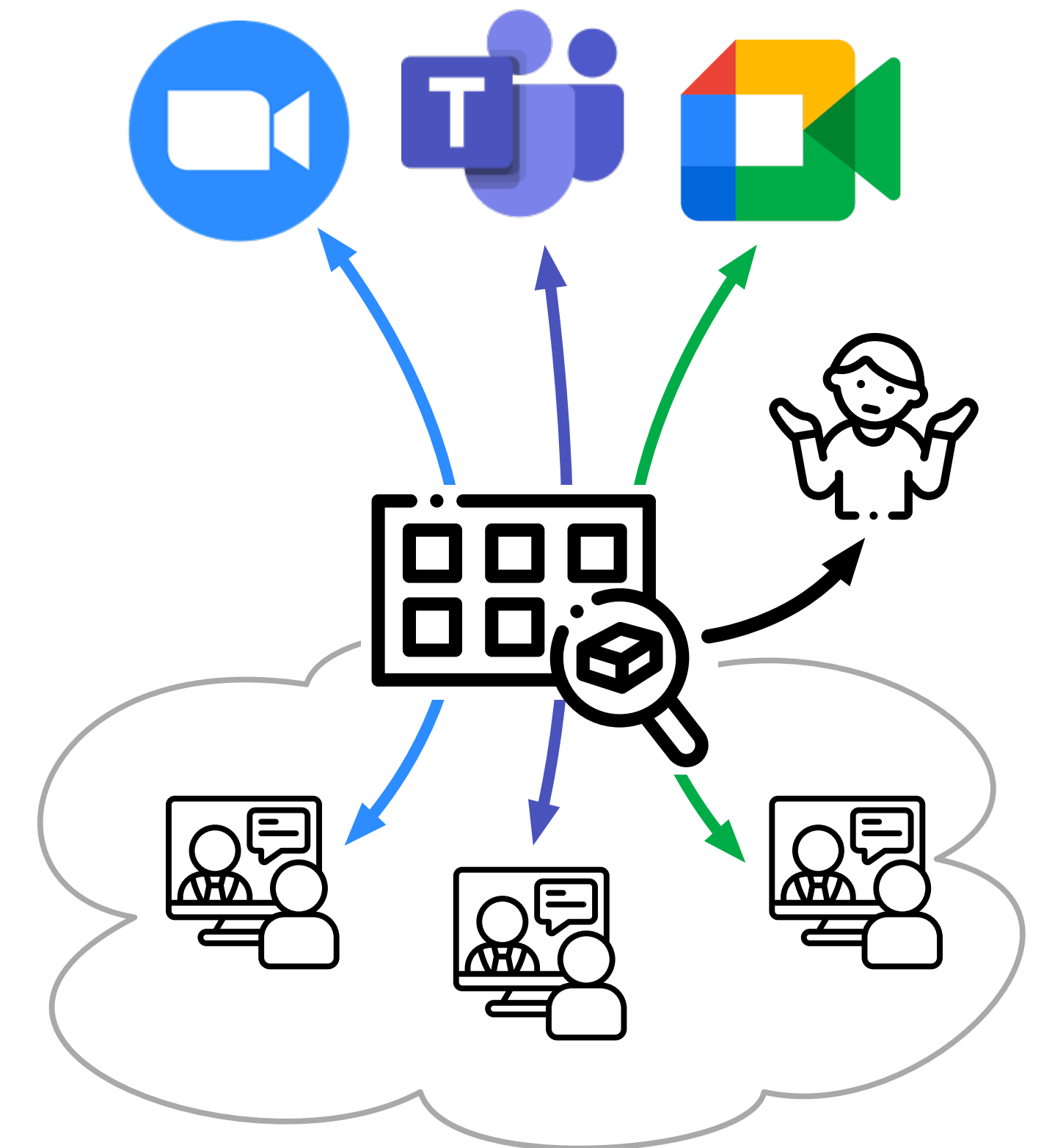
- Quality/performance metrics not directly observable from traffic
- Application-provided metrics only useful for small-scale, controlled experiment



Measuring Video-Conferencing Applications is Hard

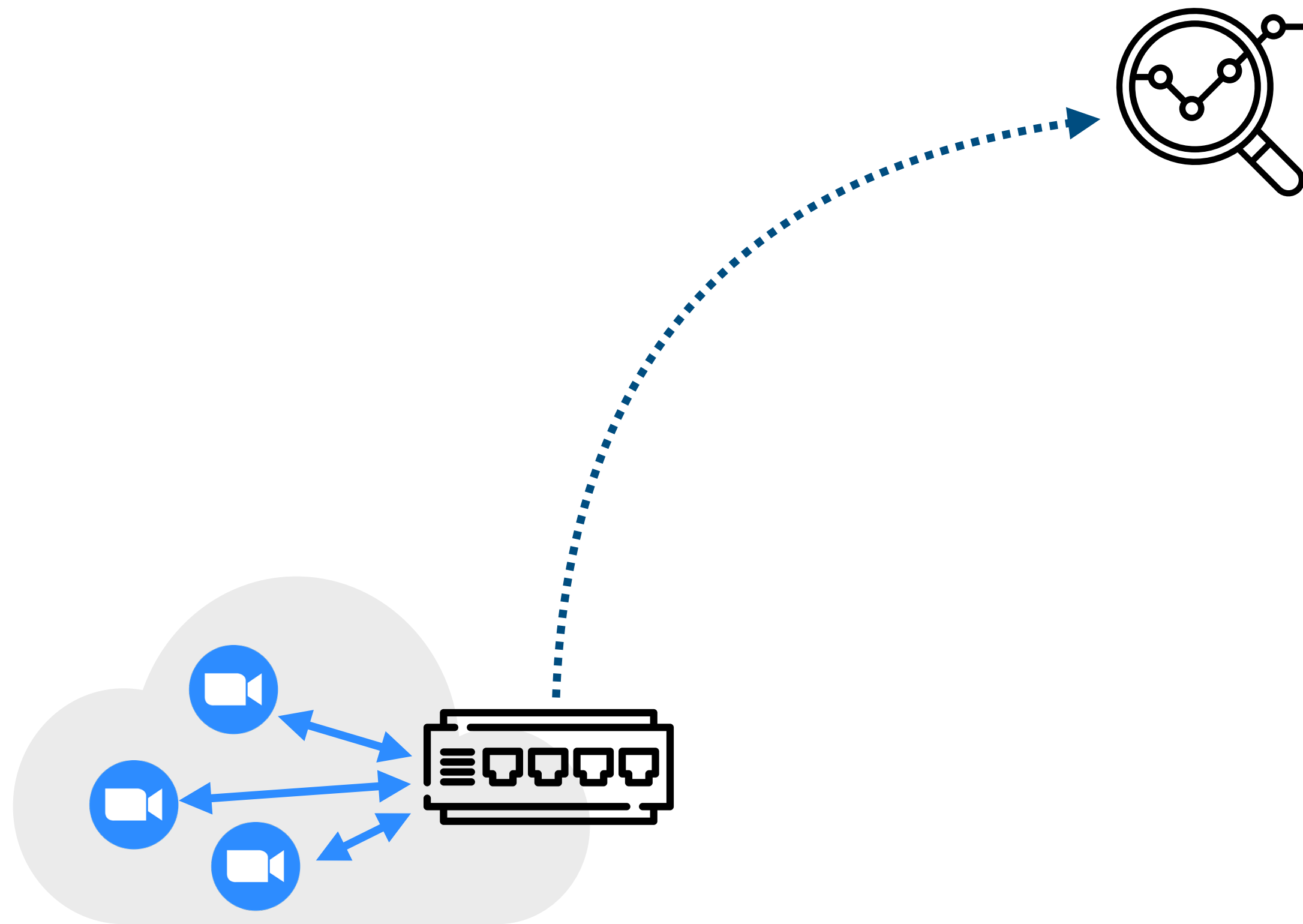
Problem: **Hard for researchers and operators to extract useful metrics from traffic**

- Quality/performance metrics not directly observable from traffic
- Application-provided metrics only useful for small-scale, controlled experiment



→ Operator's vantage point and capabilities less well explored

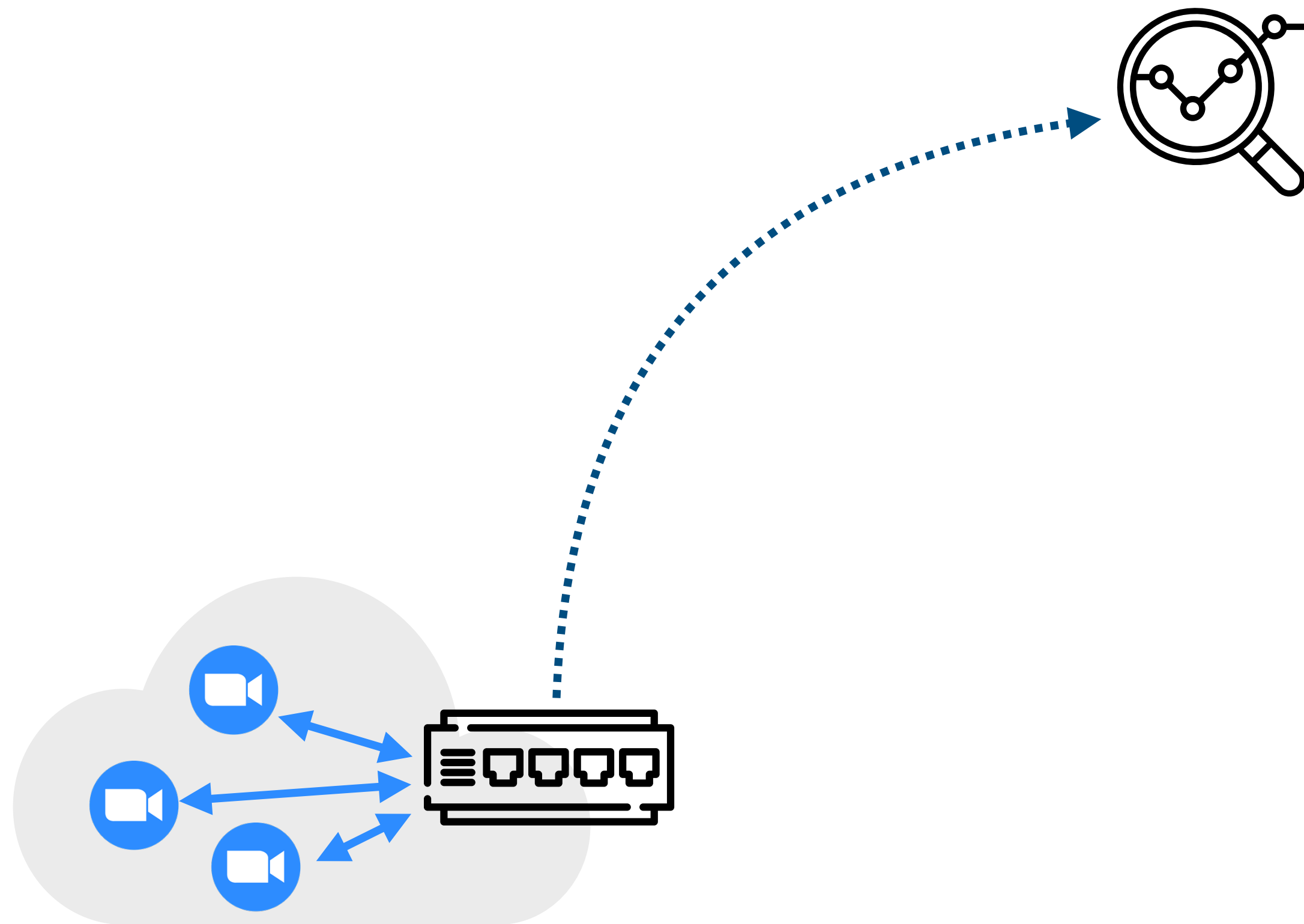
Enabling Passive Measurement



Goal:

**Measure & analyze performance
of video-conferencing sessions
*in the wild***

Enabling Passive Measurement

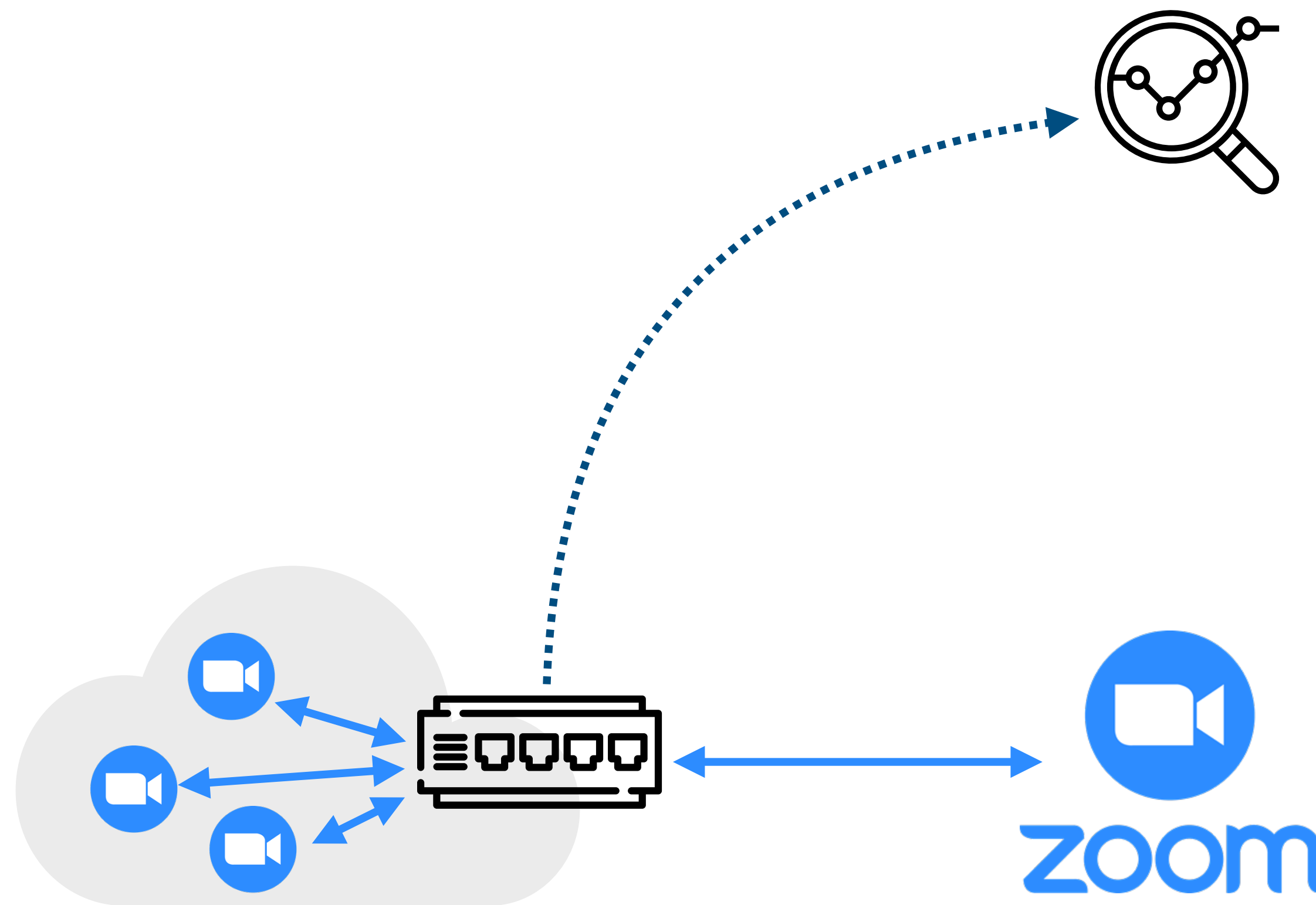


Goal:

Measure & analyze performance of video-conferencing sessions *in the wild*

- passively collected packets
- without end-host control
- in large-scale networks

Enabling Passive Measurement



Goal:

Measure & analyze performance of video-conferencing sessions *in the wild*

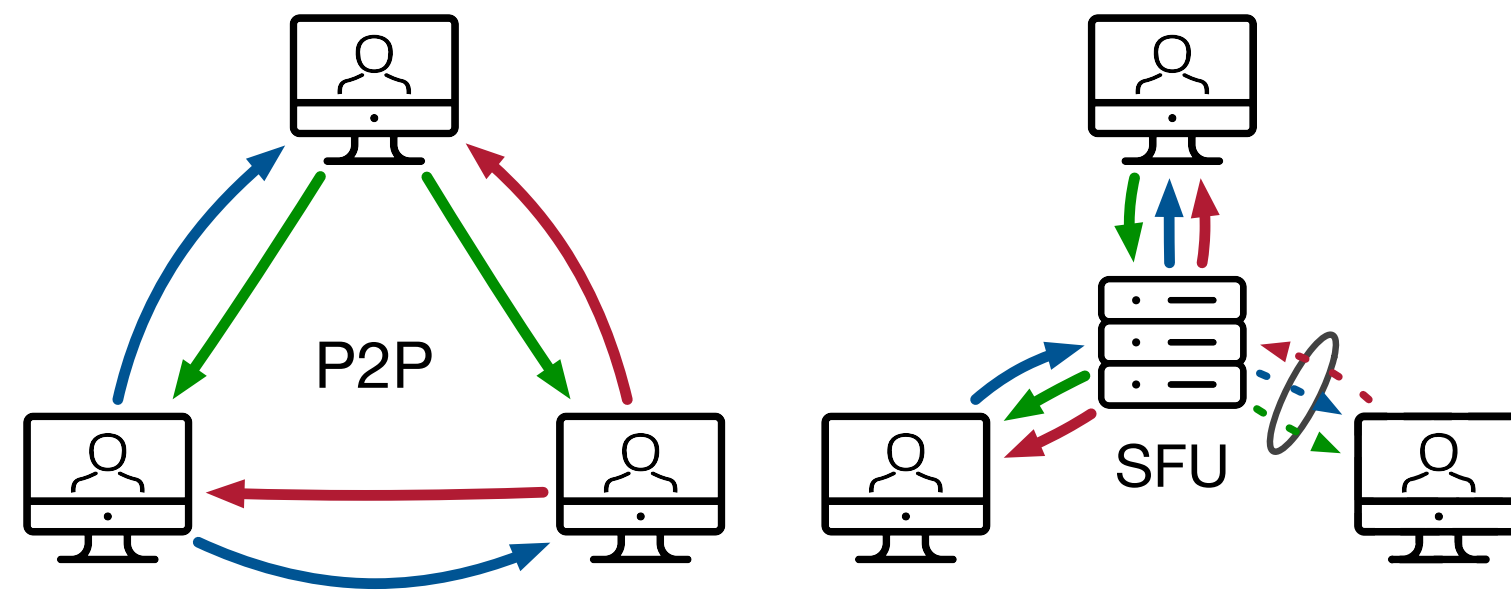
- passively collected packets
- without end-host control
- in large-scale networks
- widely used in general and at Princeton
- particularly challenging: proprietary packet format

Challenges

Video conferencing is complex.

Challenges

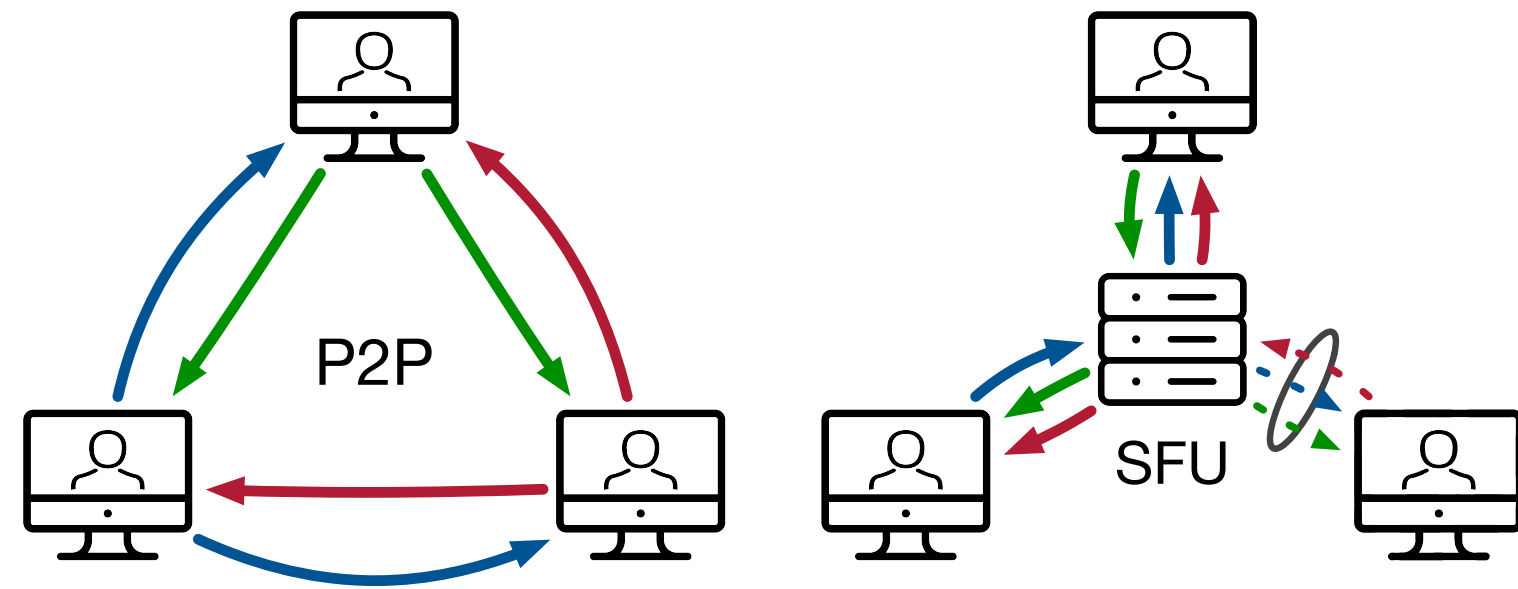
Video conferencing is complex.



Use of different conferencing architectures

Challenges

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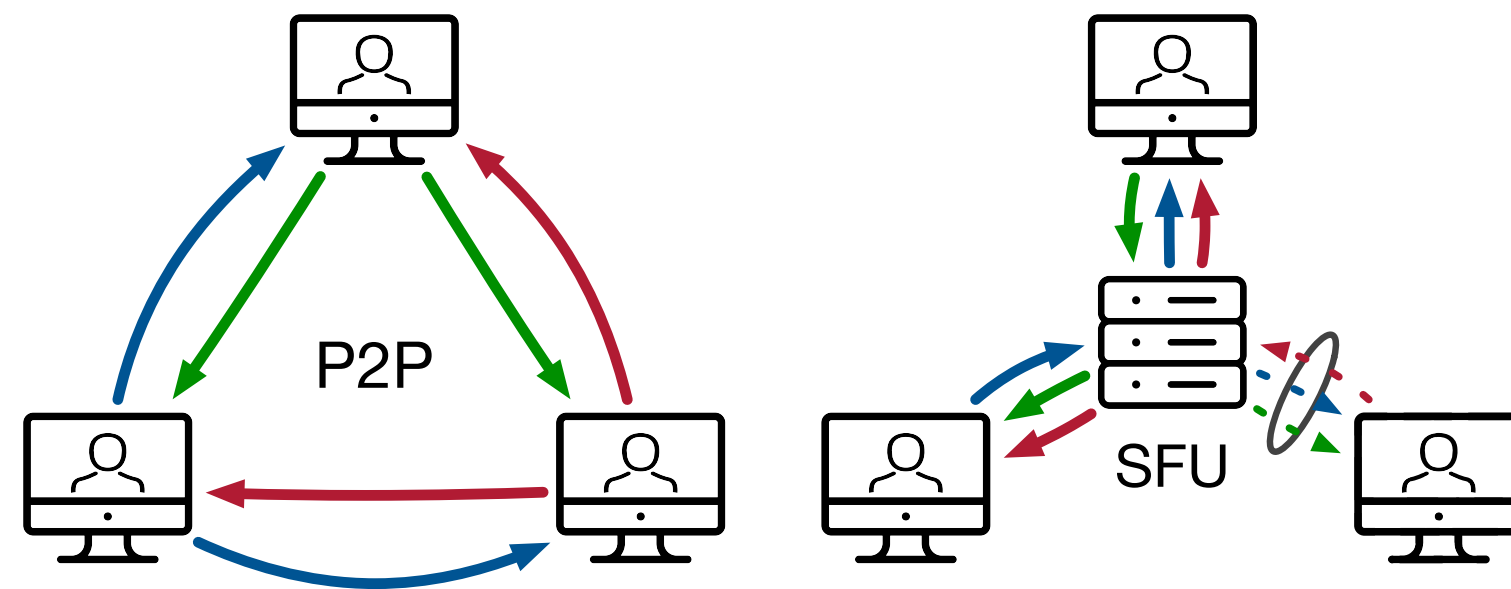
Use of different conferencing architectures



Encrypted control traffic and media

Challenges

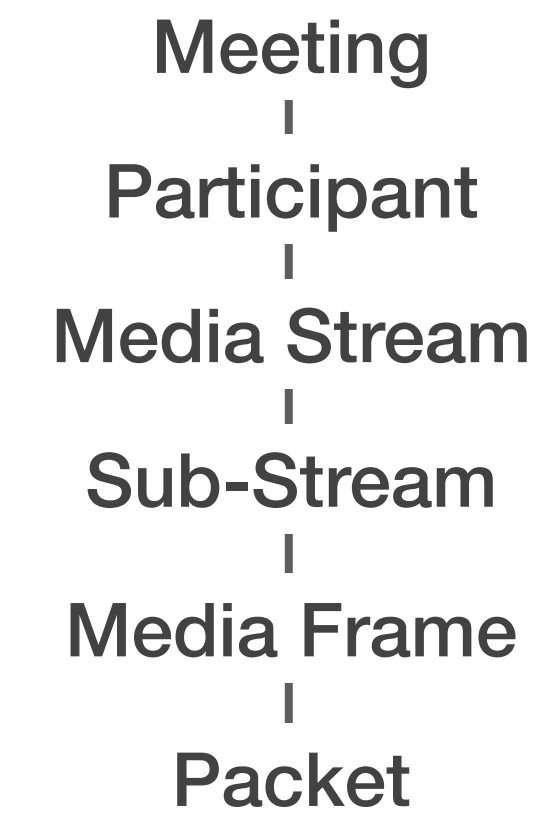
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Use of different conferencing architectures



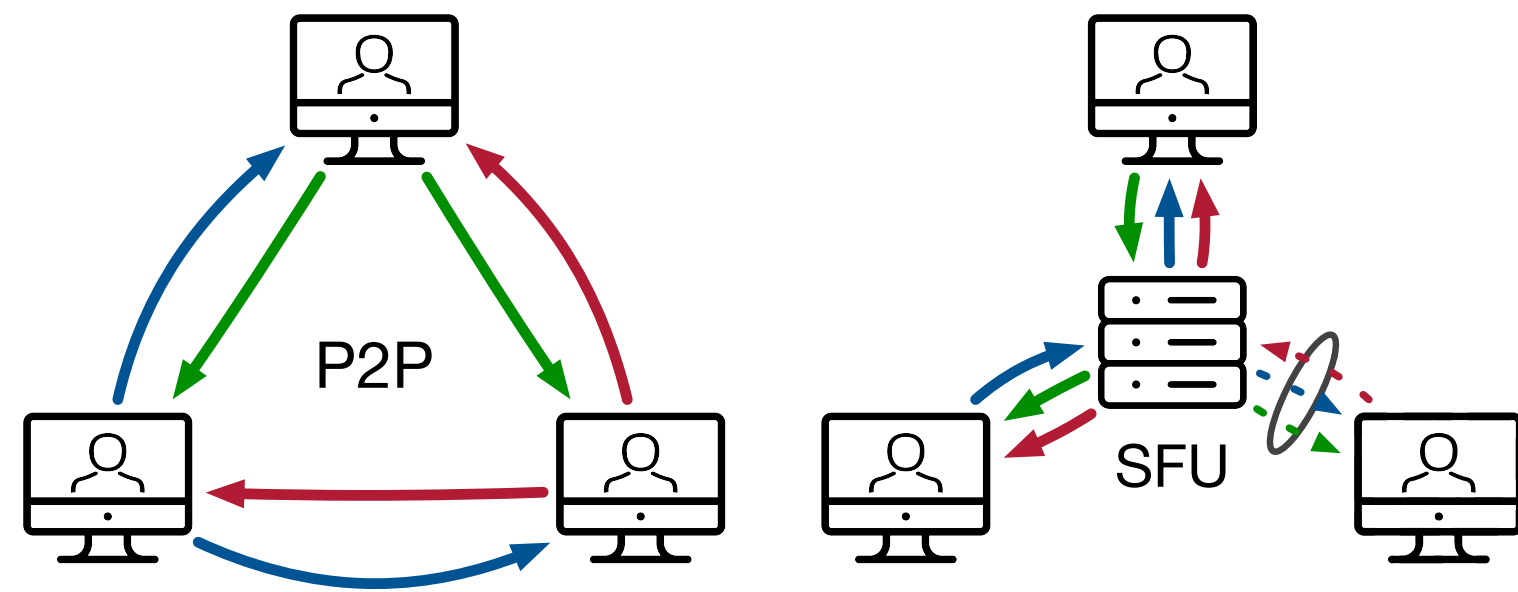
Encrypted control traffic and media



Complex hierarchy within network protocols

Challenges

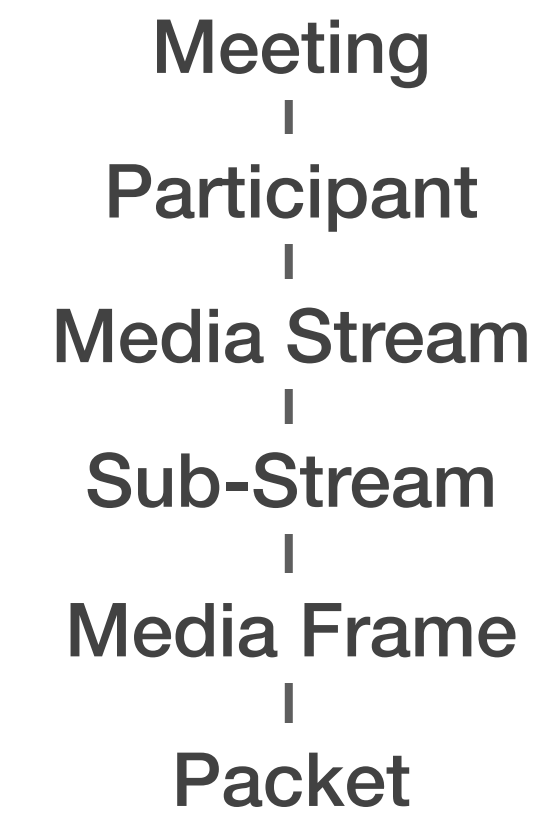
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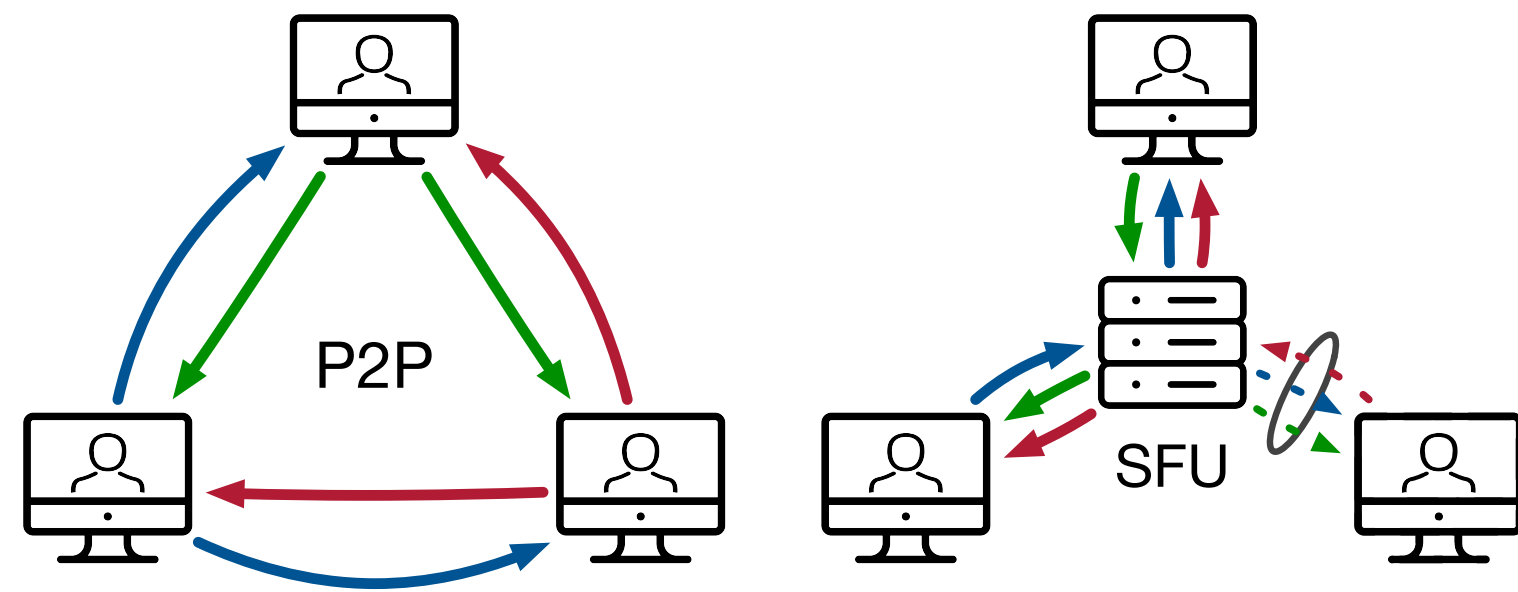
Complex hierarchy within network protocols

1

How do we reliably detect all Zoom traffic?

Challenges

Video conferencing is complex.



Use of different conferencing architectures

1

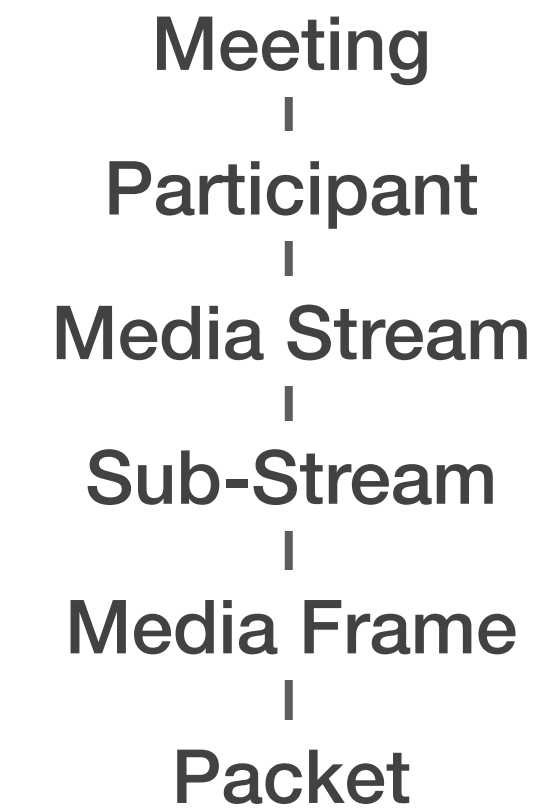
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Encrypted control traffic and media

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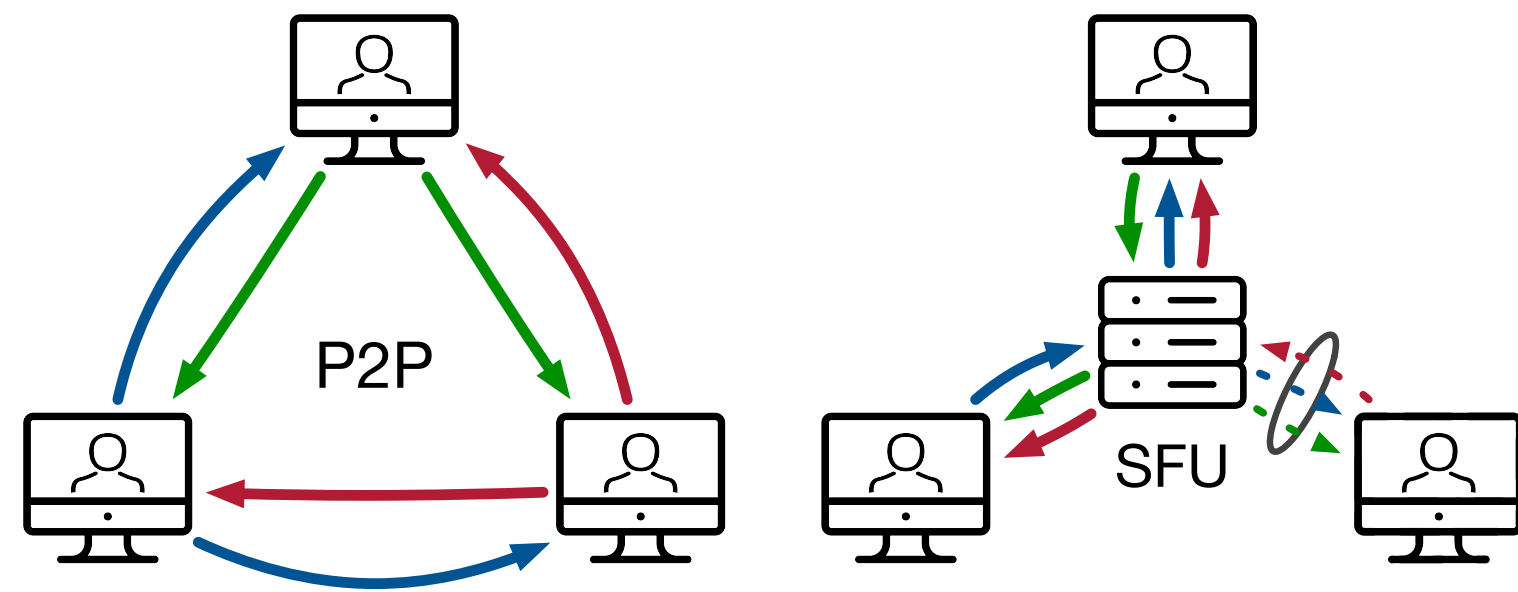
What is Zoom's packet format and what information can be extracted from packets?



Complex hierarchy within network protocols

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Use of different conferencing architectures

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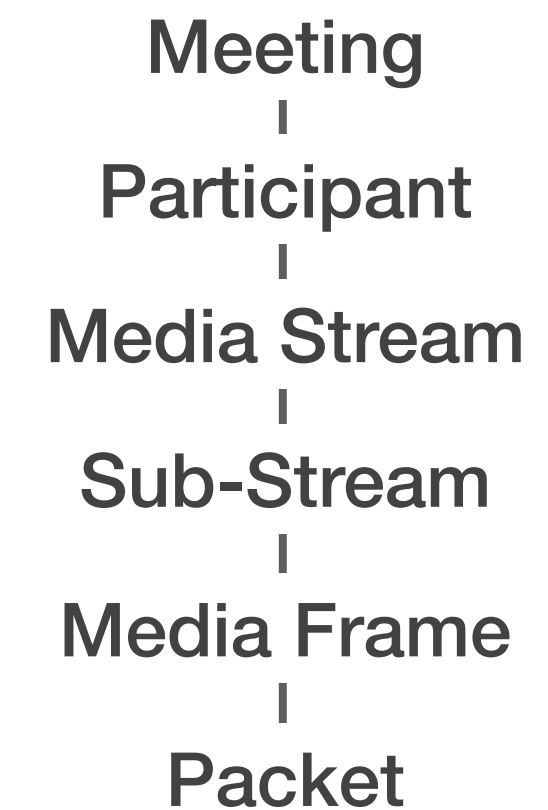
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Encrypted control traffic and media

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What is Zoom's packet format and what information can be extracted from packets?



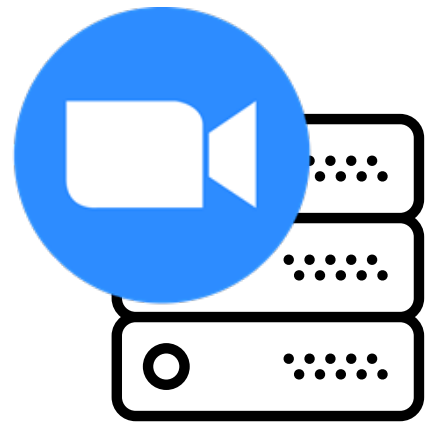
Complex hierarchy within network protocols

3

How do we group packets belonging to the same meeting together?

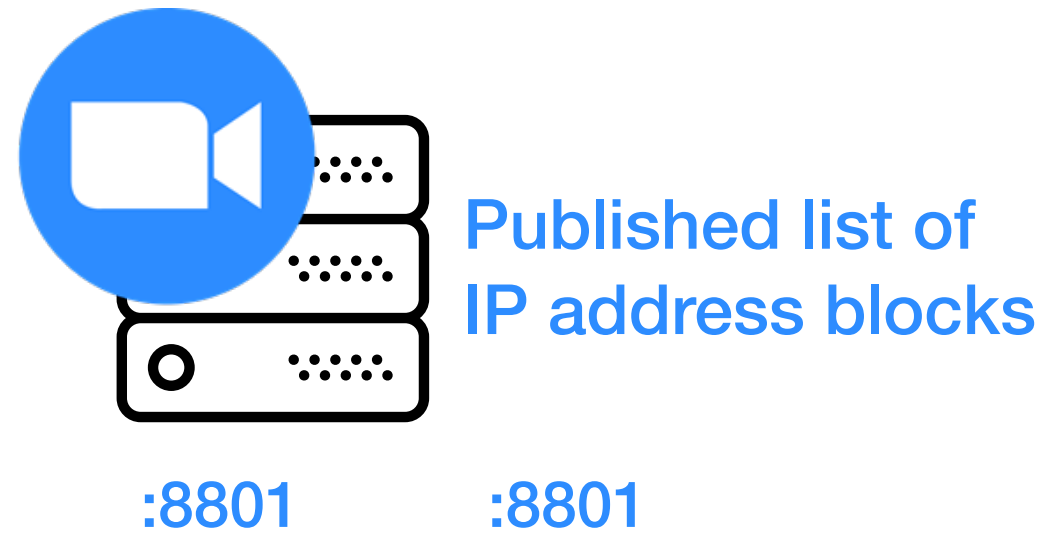
Demystifying Zoom

1 Detecting Zoom Traffic



Demystifying Zoom

1 Detecting Zoom Traffic



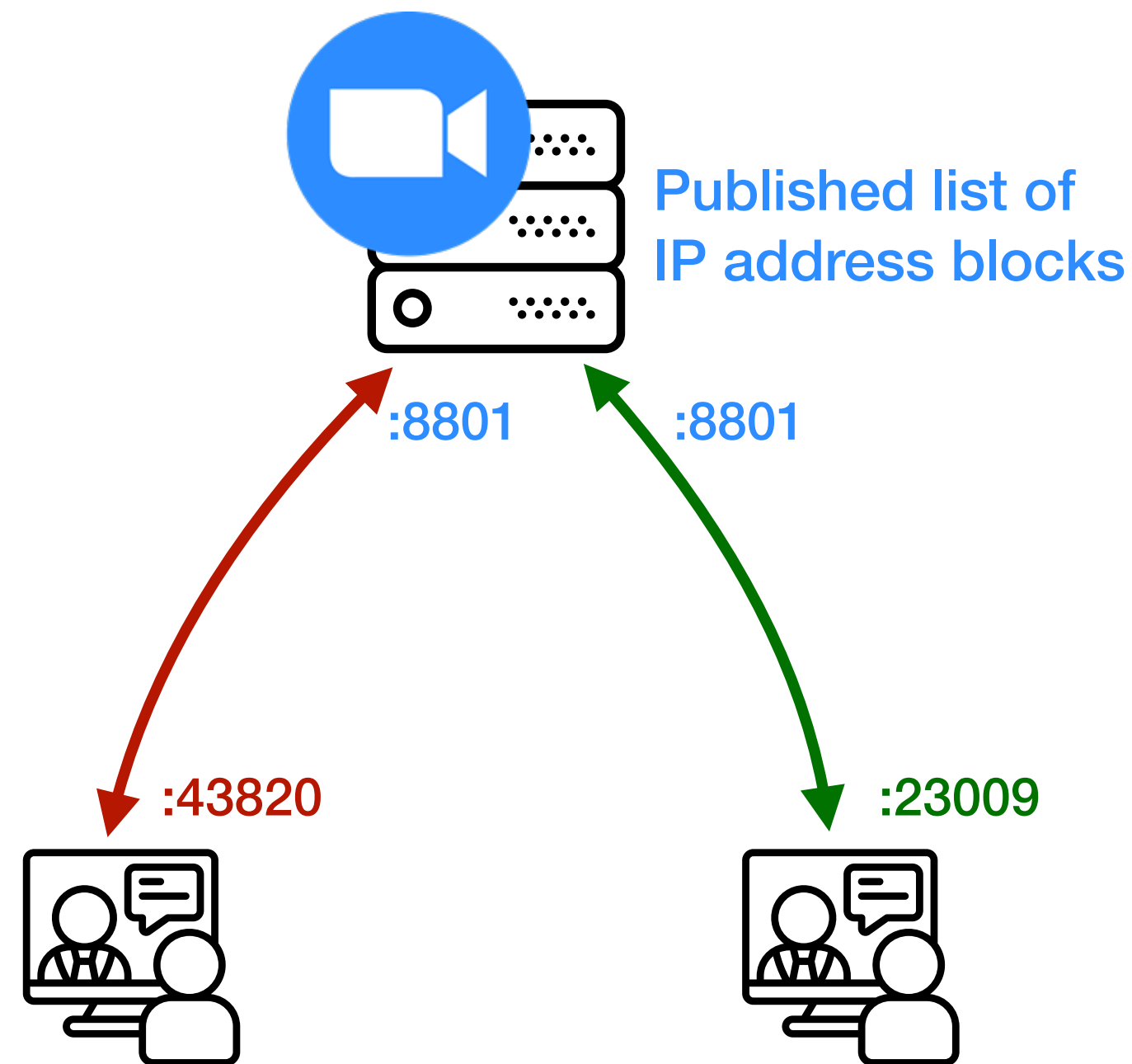
Server-Based Meetings

- Published list of IP addresses and port numbers on server side



Demystifying Zoom

1 Detecting Zoom Traffic

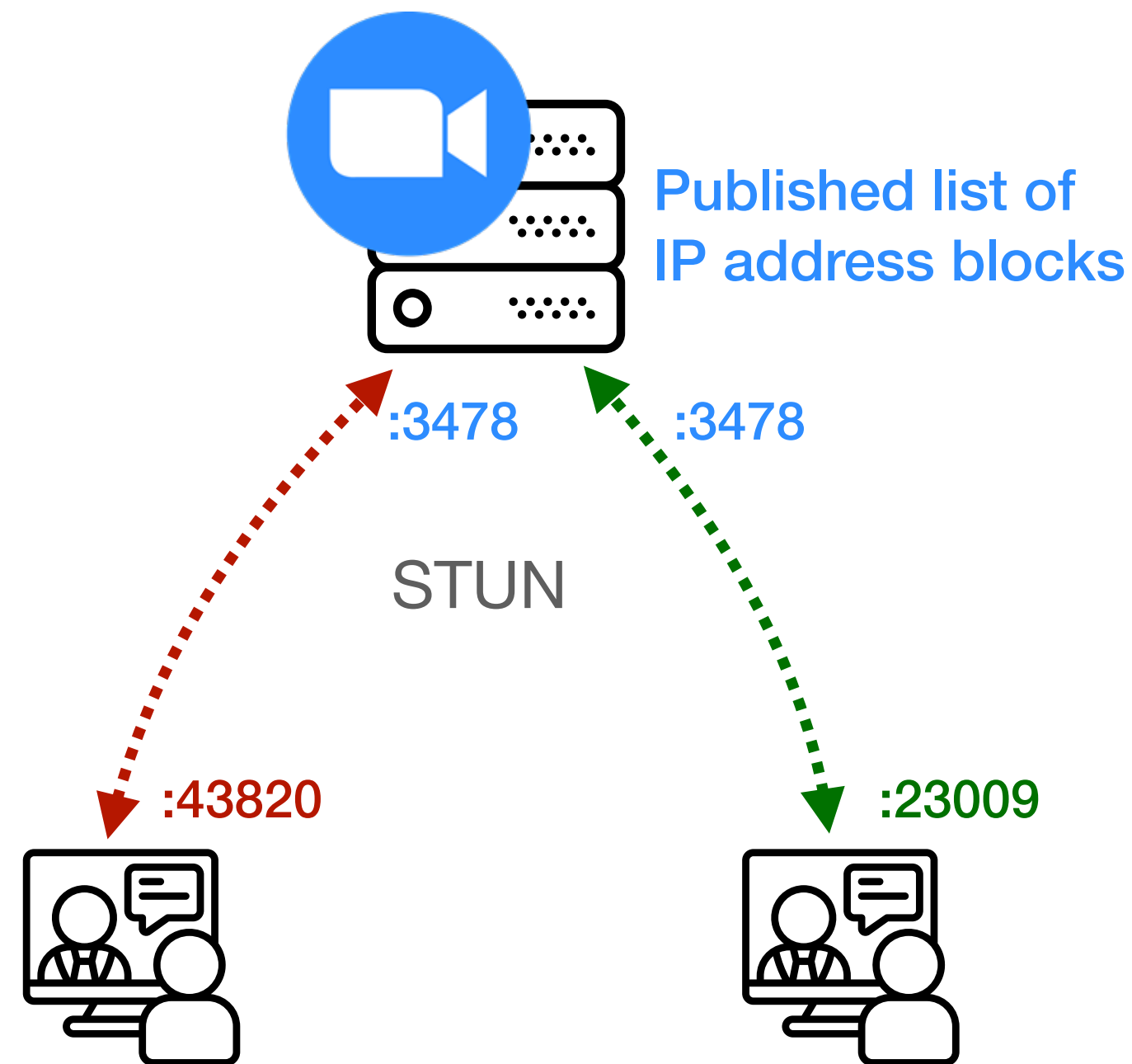


Server-Based Meetings

- Published list of IP addresses and port numbers on server side
- Ephemeral ports on client side

Demystifying Zoom

1 Detecting Zoom Traffic



Server-Based Meetings

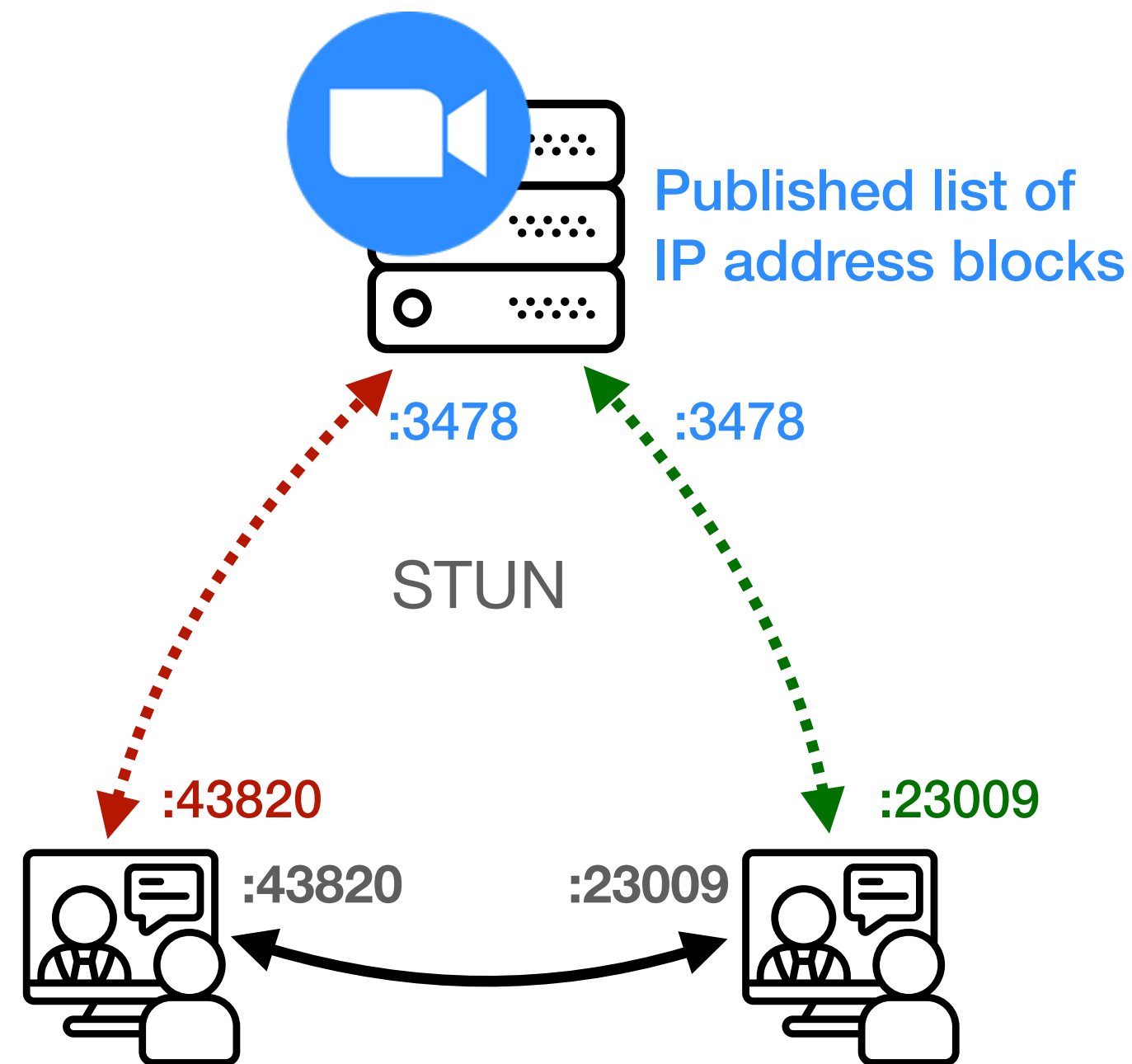
- Published list of IP addresses and port numbers on server side
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P2P Meetings

- STUN exchange before P2P establishment

Demystifying Zoom

1 Detecting Zoom Traffic



Server-Based Meetings

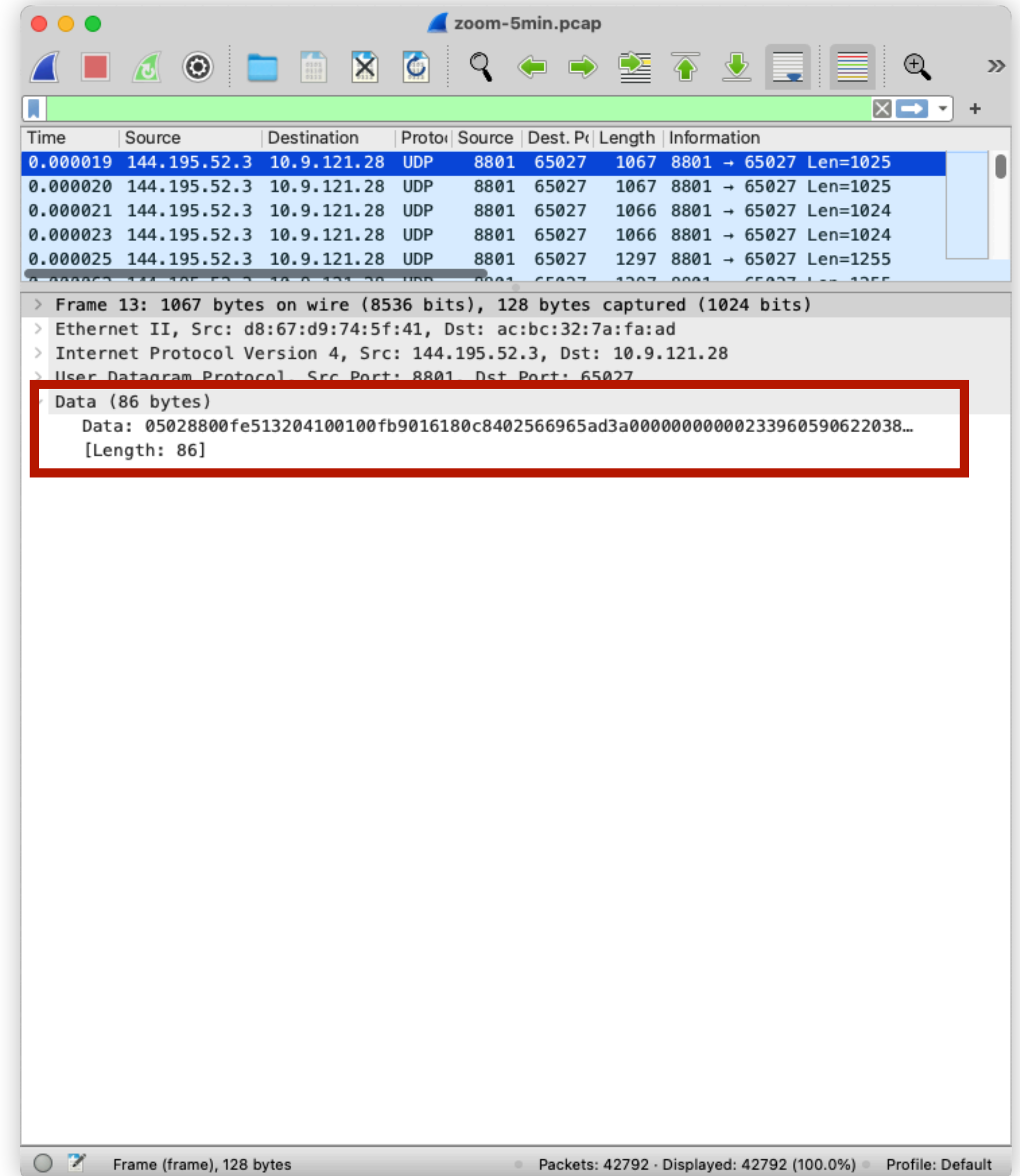
- Published list of IP addresses and port numbers on server side
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P2P Meetings

- STUN exchange before P2P establishment
- Use of client-side ports from STUN for P2P connection

Demystifying Zoom

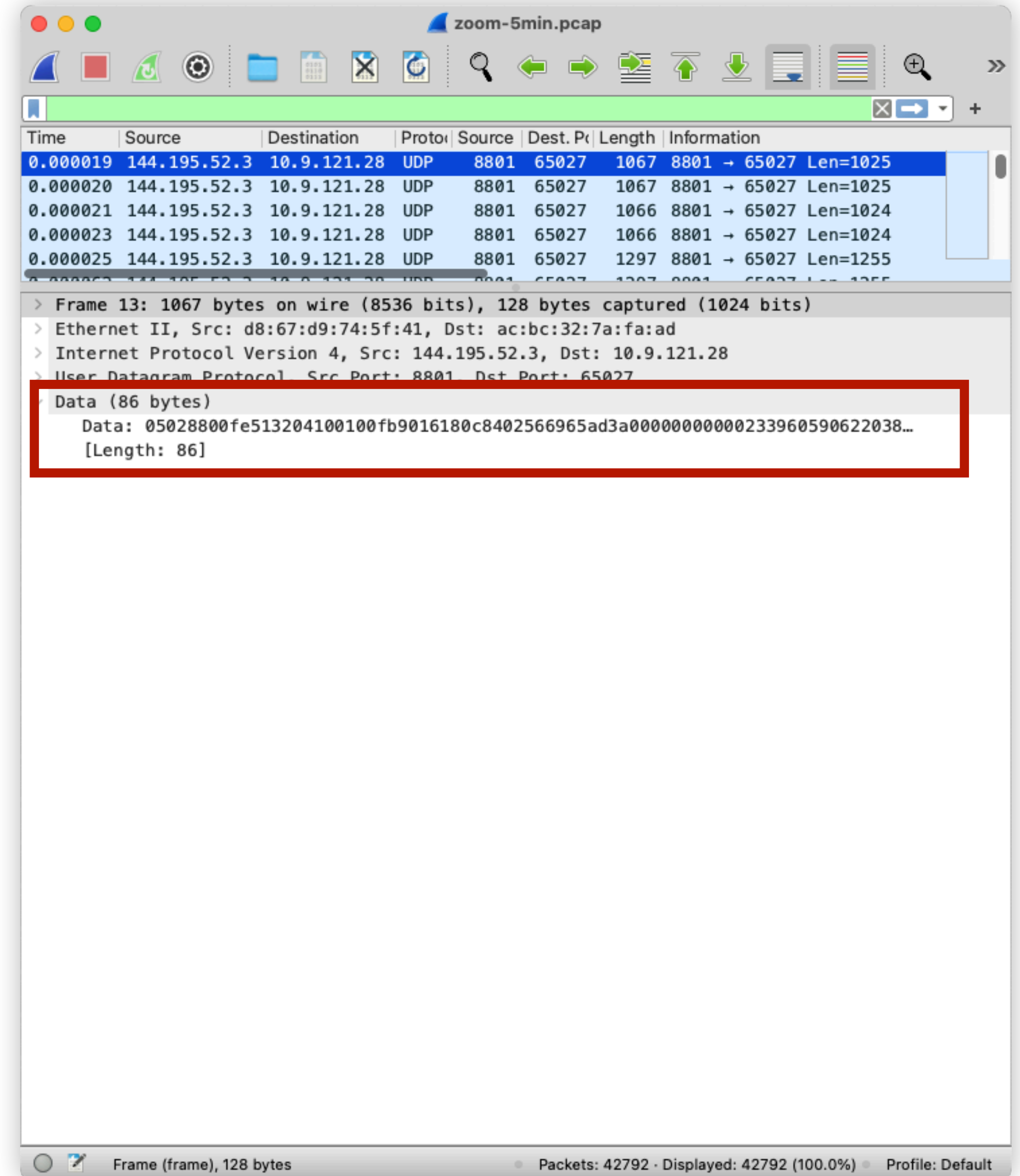
2 Inferring Header Formats via Entropy Analysis



Demystifying Zoom

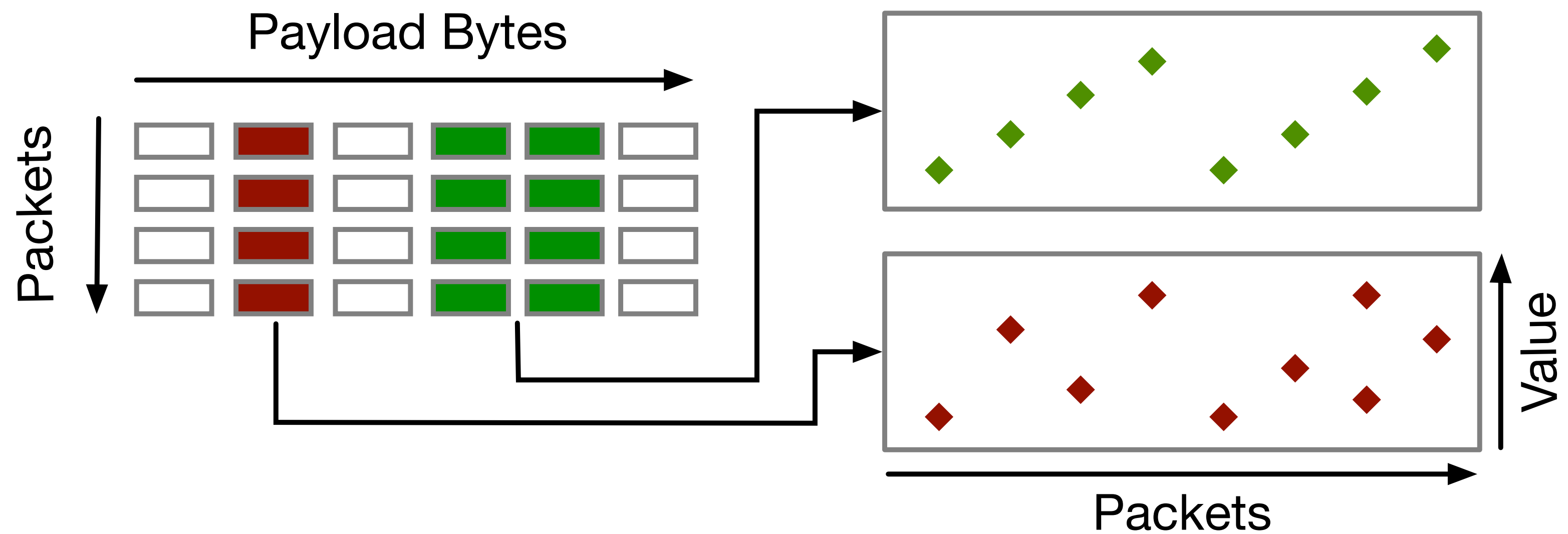
2 Inferring Header Formats via Entropy Analysis

- (1) Are there unencrypted parts in Zoom's media packets?
- (2) If so, are there patterns that could map to header fields?



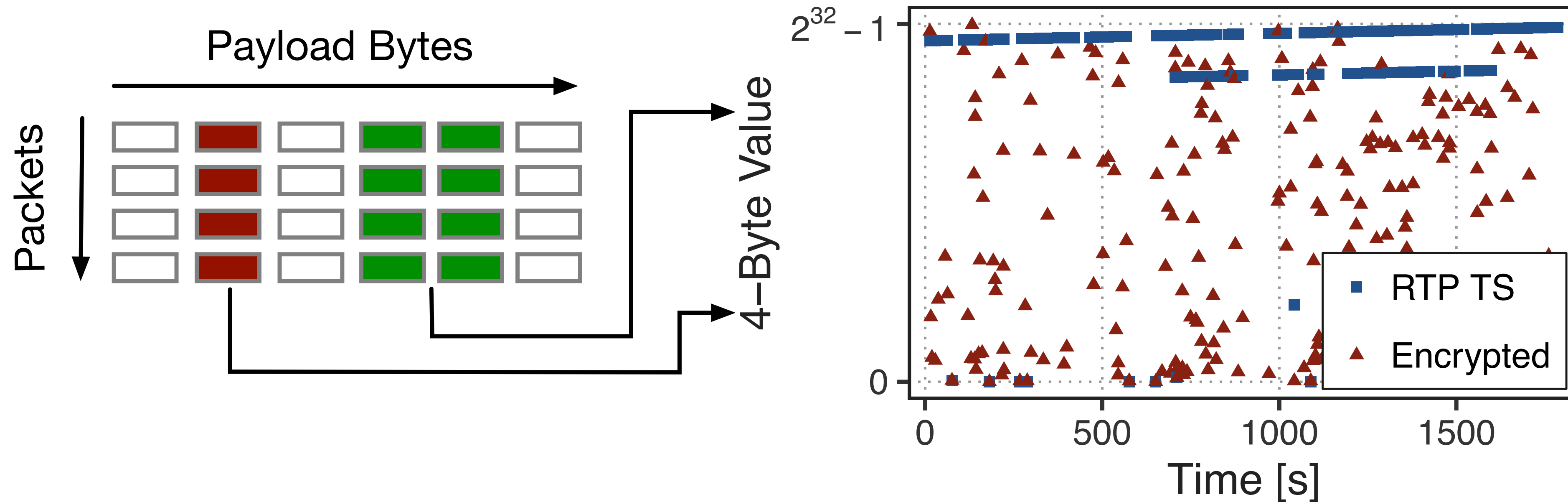
Demystifying Zoom

2 Inferring Header Formats via Entropy Analysis



Demystifying Zoom

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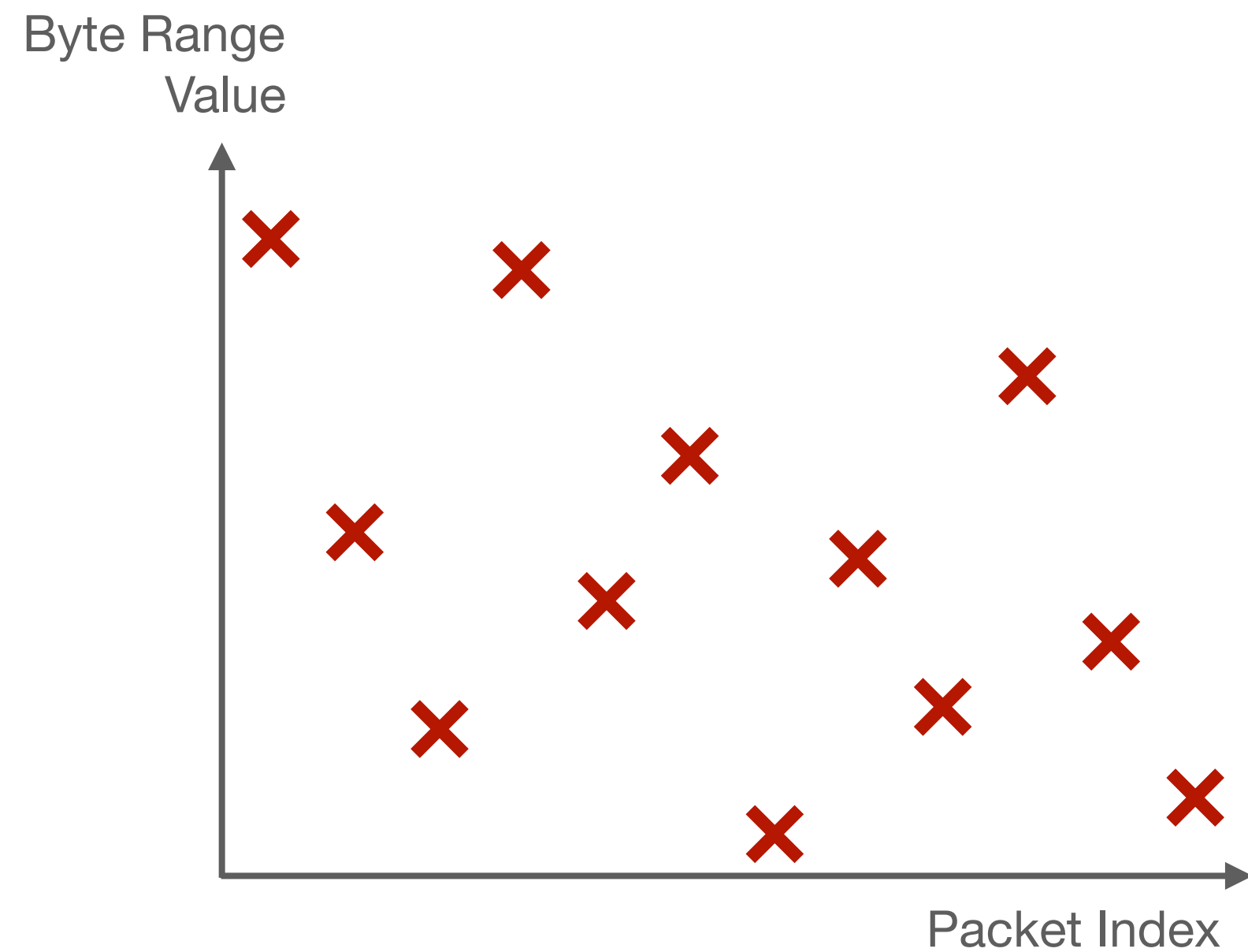


Demystifying Zoom

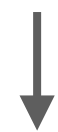
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Demystifying Zoom

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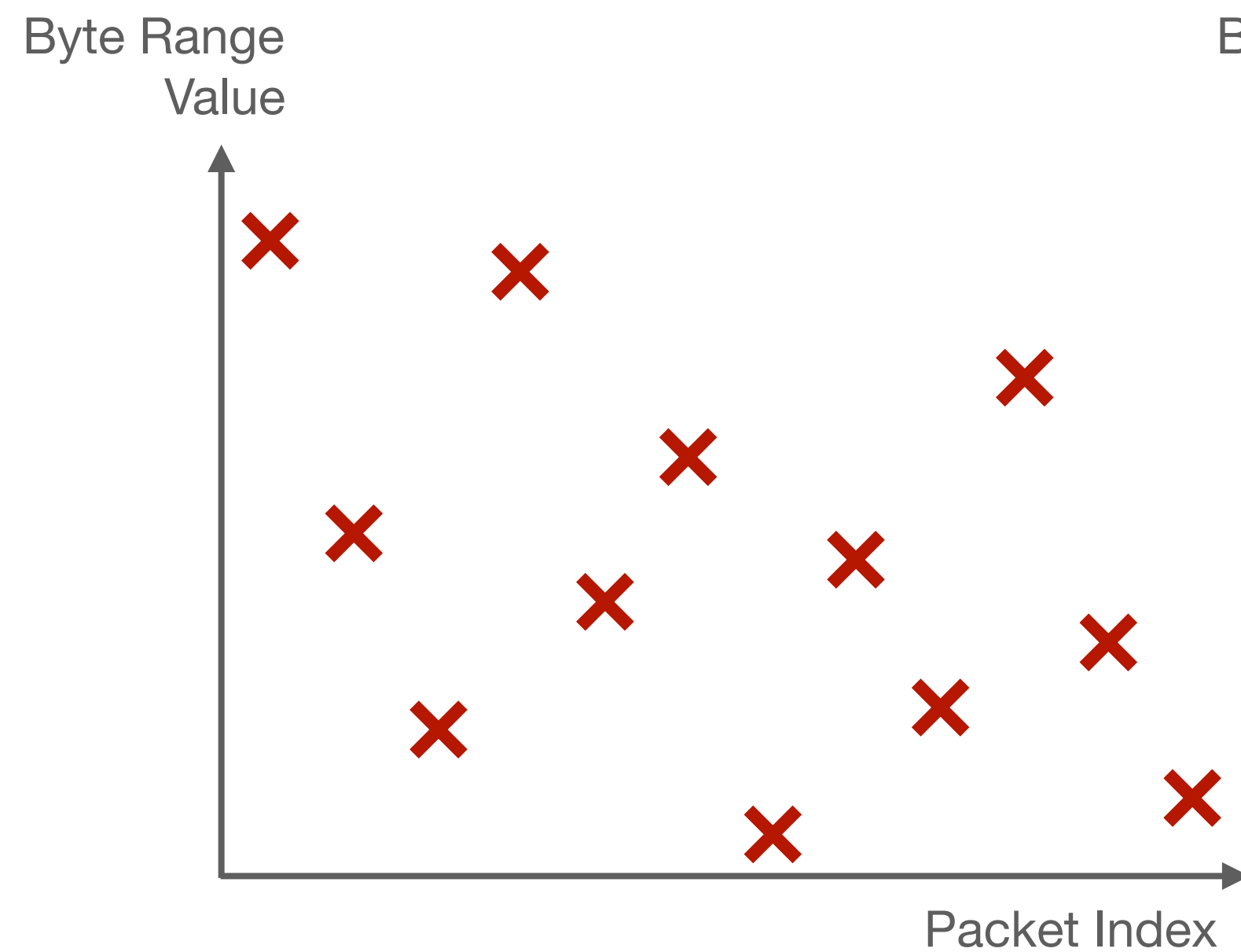
(1) random / max. entropy



encrypted

Demystifying Zoom

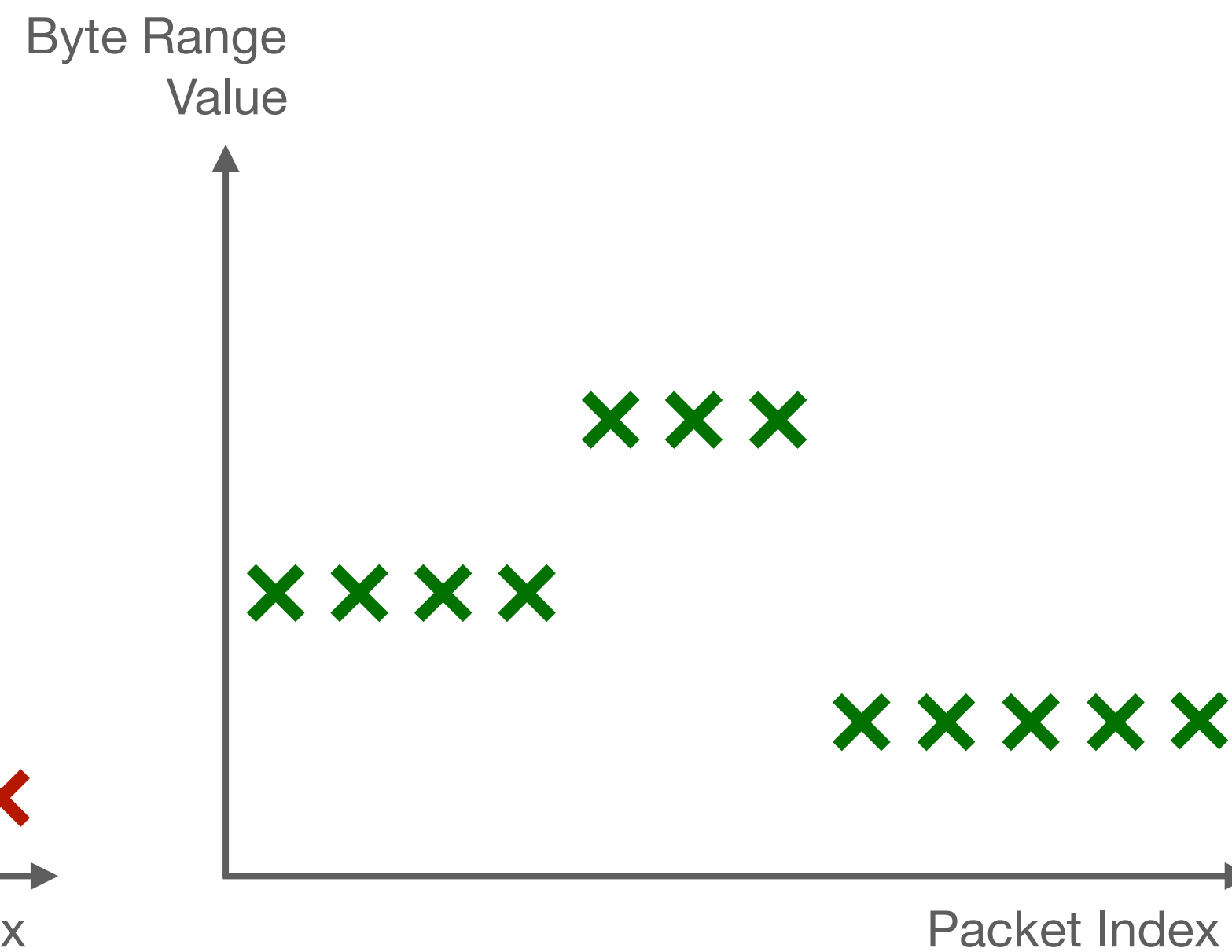
2 Inferring Header Formats via Entropy Analysis



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encrypted



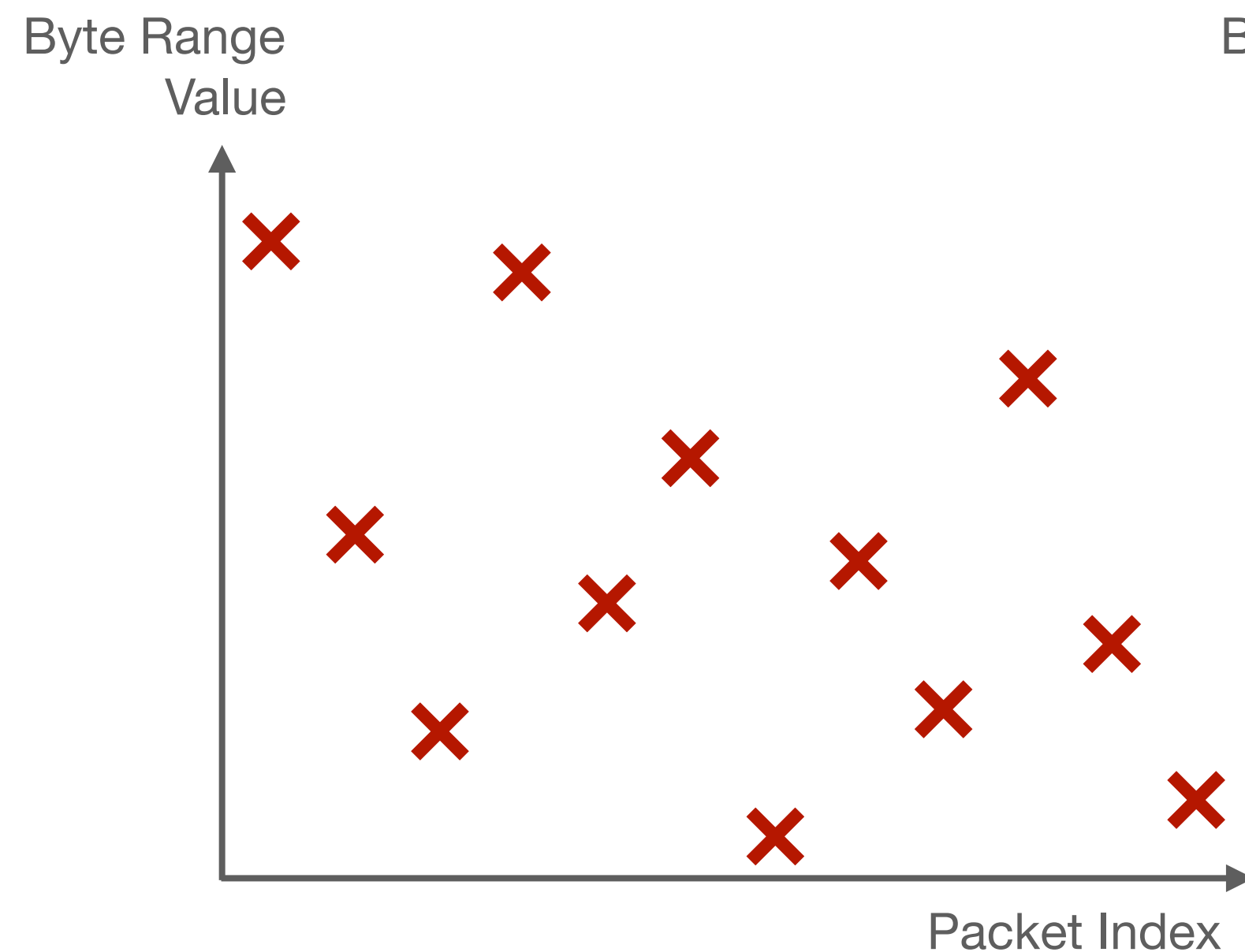
(2) horizontal lines



identifiers, bitfields

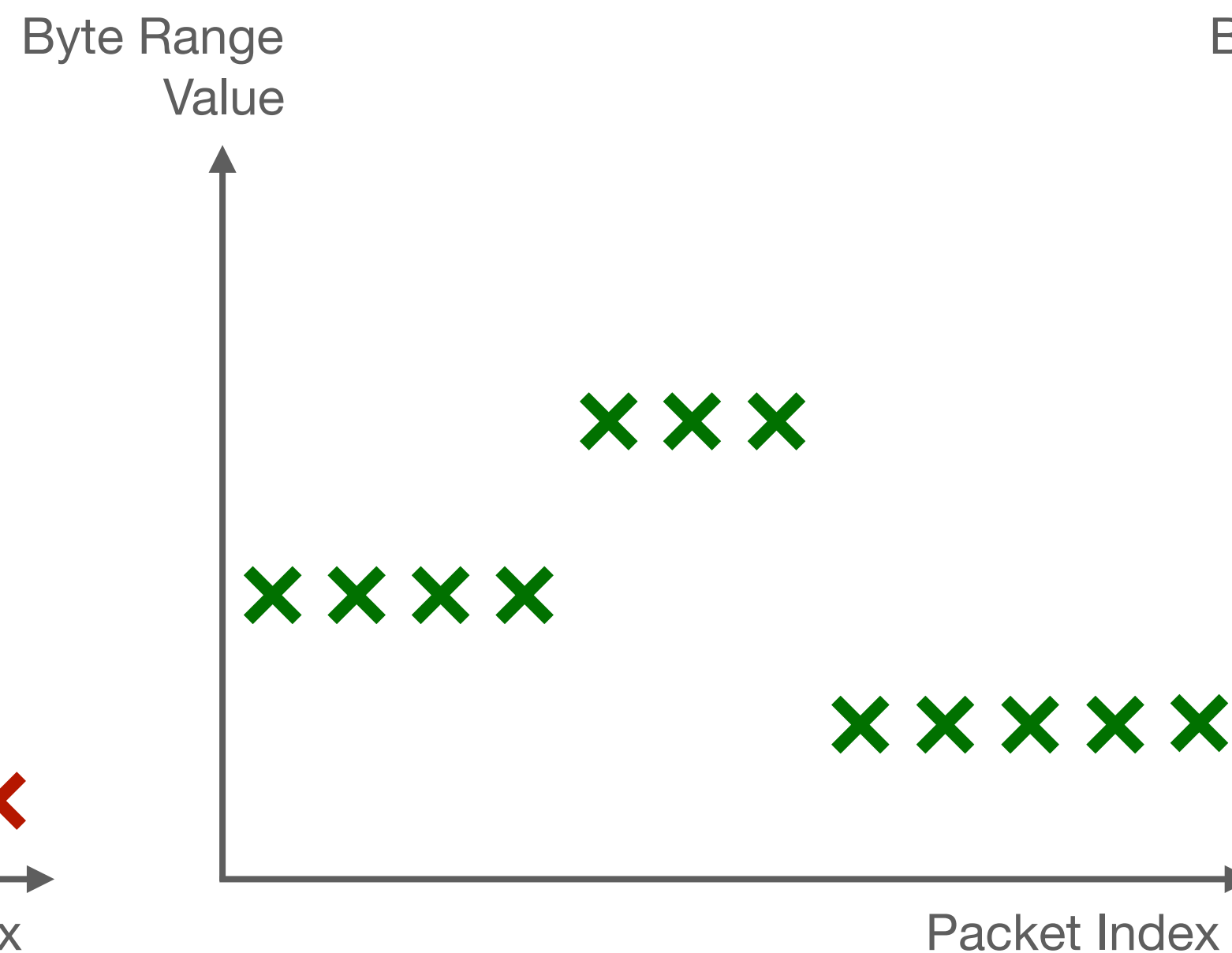
Demystifying Zoom

2 Inferring Header Formats via Entropy Analysis



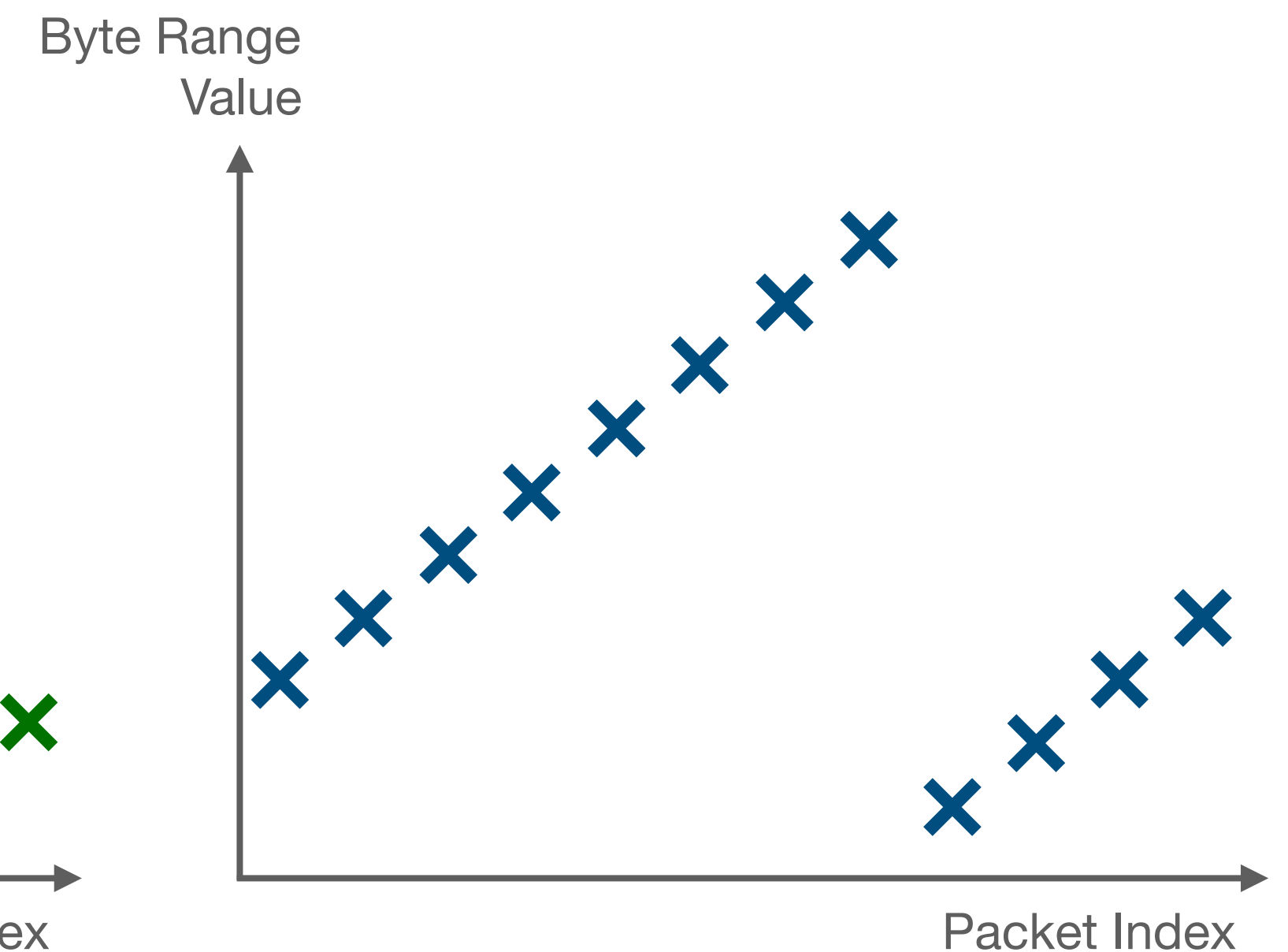
(1) random / max. entropy

↓
encrypted



(2) horizontal lines

↓
identifiers, bitfields

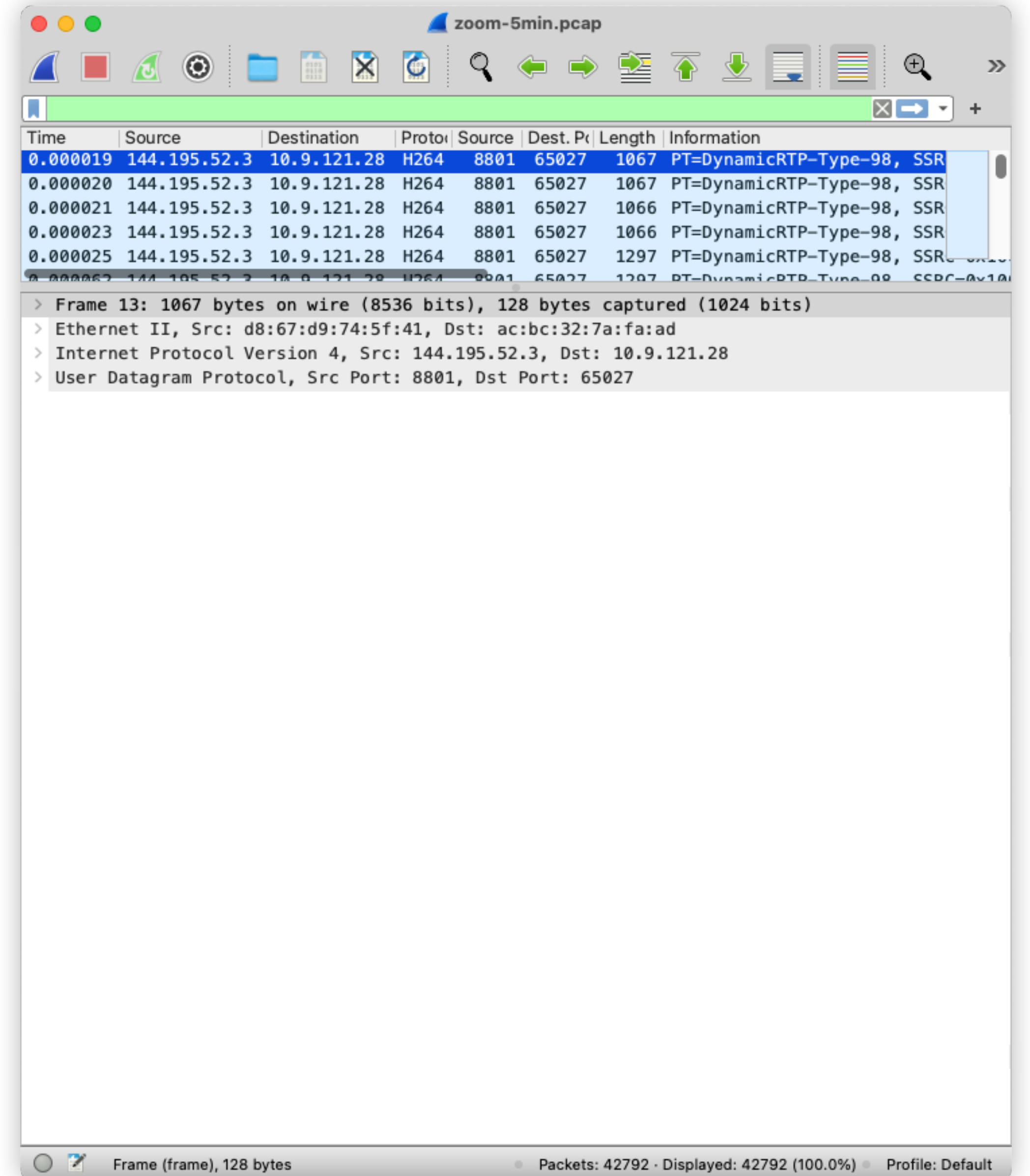


(3) diagonal lines

↓
seq. numbers, timestamps

Demystifying Zoom

2 Inferring Header Formats via Entropy Analysis

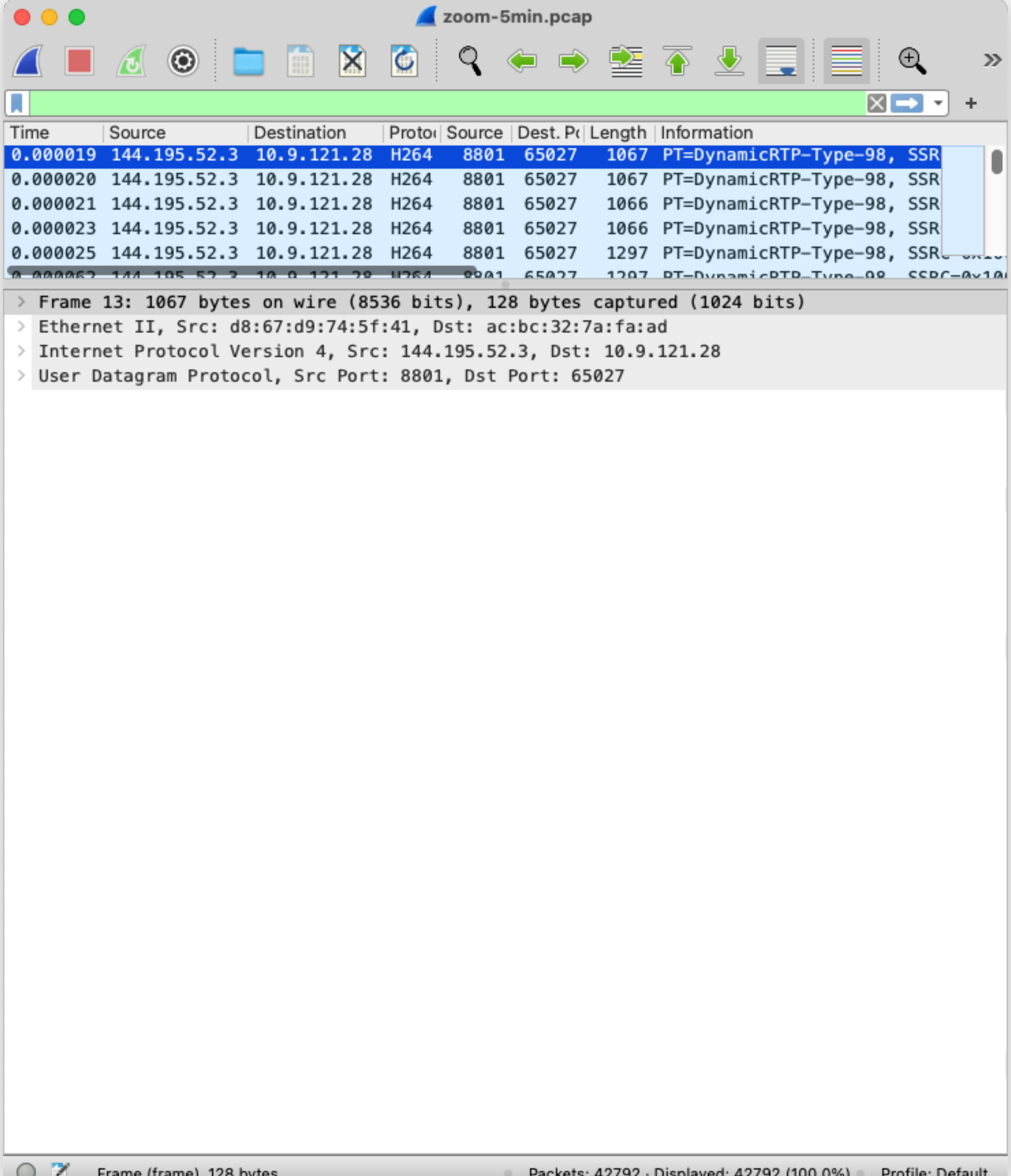


Demystifying Zoom

2 Inferring Header Formats via Entropy Analysis

...

UDP



The screenshot shows a Wireshark interface for a file named 'zoom-5min.pcap'. The main pane displays a list of network packets. The selected packet (Frame 13) is expanded to show its protocol layers: Ethernet II, Internet Protocol Version 4, and User Datagram Protocol (UDP). The UDP layer shows source port 8801 and destination port 65027.

Time	Source	Destination	Protocol	Source	Dest. Port	Length	Information
0.000019	144.195.52.3	10.9.121.28	H264	8801	65027	1067	PT=DynamicRTP-Type-98, SSR
0.000020	144.195.52.3	10.9.121.28	H264	8801	65027	1067	PT=DynamicRTP-Type-98, SSR
0.000021	144.195.52.3	10.9.121.28	H264	8801	65027	1066	PT=DynamicRTP-Type-98, SSR
0.000023	144.195.52.3	10.9.121.28	H264	8801	65027	1066	PT=DynamicRTP-Type-98, SSR
0.000025	144.195.52.3	10.9.121.28	H264	8801	65027	1297	PT=DynamicRTP-Type-98, SSR

> Frame 13: 1067 bytes on wire (8536 bits), 128 bytes captured (1024 bits)
> Ethernet II, Src: d8:67:d9:74:5f:41, Dst: ac:bc:32:7a:fa:ad
> Internet Protocol Version 4, Src: 144.195.52.3, Dst: 10.9.121.28
> User Datagram Protocol, Src Port: 8801, Dst Port: 65027

Demystifying Zoom

2 Inferring Header Formats via Entropy Analysis

...

UDP

Server/SFU Encapsulation

The screenshot shows a Wireshark interface for a file named 'zoom-5min.pcap'. The packet list pane shows several H264 packets from source 144.195.52.3 to destination 10.9.121.28. Packet 13 is selected, and the packet details pane shows the following structure:

- Frame 13: 1067 bytes on wire (8536 bits), 128 bytes captured (1024 bits)
- Ethernet II, Src: d8:67:d9:74:5f:41, Dst: ac:bc:32:7a:fa:ad
- Internet Protocol Version 4, Src: 144.195.52.3, Dst: 10.9.121.28
- User Datagram Protocol, Src Port: 8801, Dst Port: 65027
- Zoom SFU Encapsulation**
 - Type: 5
 - Sequence number: 648
 - Direction: 4 (from Zoom)

The 'Zoom SFU Encapsulation' section is highlighted with a red border. The status bar at the bottom indicates 'Frame (frame), 128 bytes', 'Packets: 42792 · Displayed: 42792 (100.0%)', and 'Profile: Default'.

Demystifying Zoom

2 Inferring Header Formats via Entropy Analysis

...

UDP

Server/SFU Encapsulation

Media Encapsulation

The screenshot shows a Wireshark interface with a packet capture named 'zoom-5min.pcap'. The packet list pane shows several packets of type H264. The packet details pane for packet 13 is expanded, showing the following structure:

- Frame 13: 1067 bytes on wire (8536 bits), 128 bytes captured (1024 bits)
- Ethernet II, Src: d8:67:d9:74:5f:41, Dst: ac:bc:32:7a:fa:ad
- Internet Protocol Version 4, Src: 144.195.52.3, Dst: 10.9.121.28
- User Datagram Protocol, Src Port: 8801, Dst Port: 65027
- Zoom SFU Encapsulation
 - Type: 5
 - Sequence number: 648
 - Direction: 4 (from Zoom)
- Zoom Media Encapsulation (highlighted with a red box)
 - Type: 16 (Video)
 - Sequence number: 598
 - Timestamp: 1768271162
 - Frame number: 13206
 - Packets in frame: 5

The status bar at the bottom indicates: Frame (frame), 128 bytes | Packets: 42792 · Displayed: 42792 (100.0%) · Profile: Default

Demystifying Zoom

2 Inferring Header Formats via Entropy Analysis

...

UDP

Server/SFU Encapsulation

Media Encapsulation

RTP/RTCP

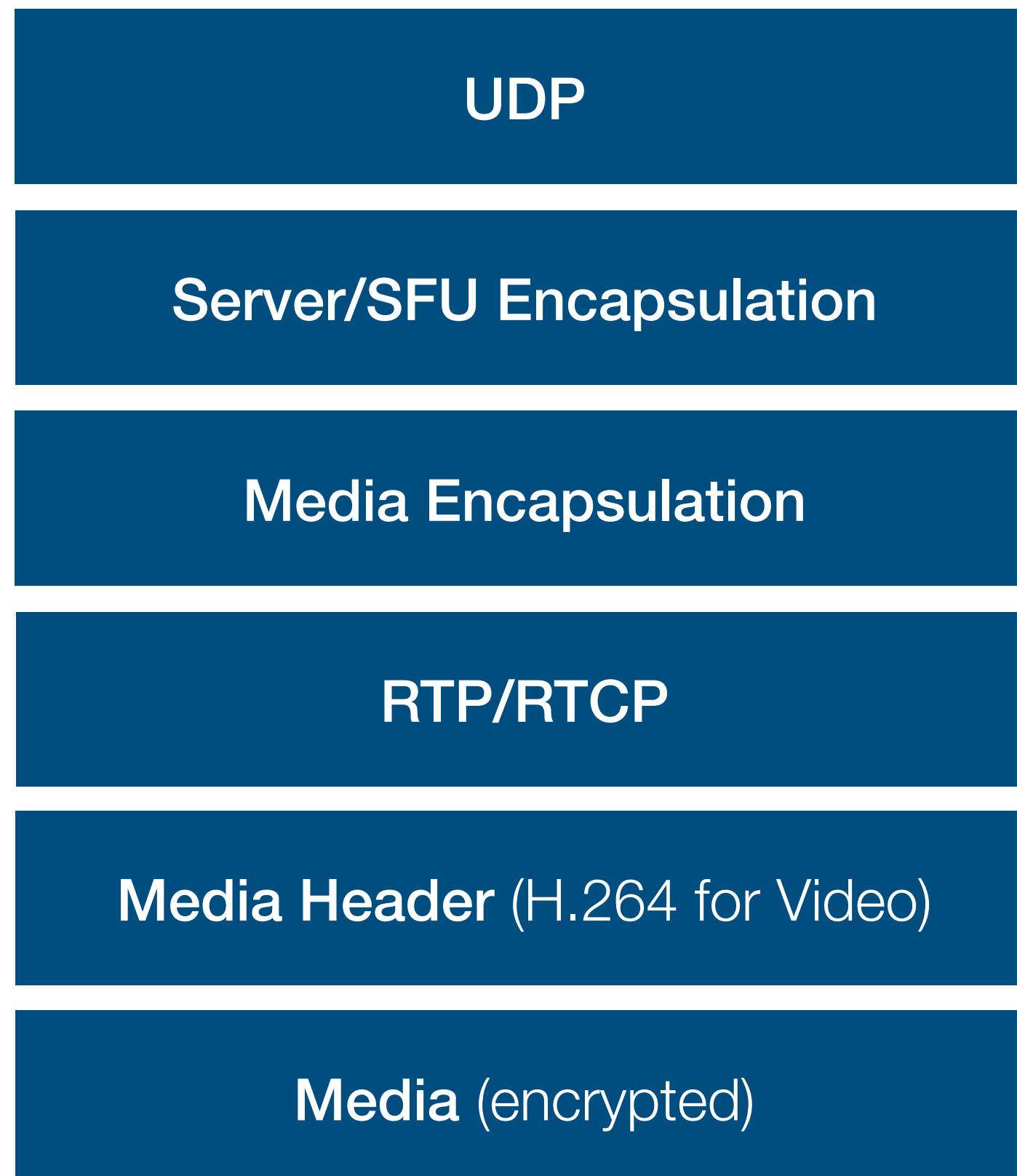
The screenshot shows a Wireshark interface with a packet list table at the top and a detailed view of a selected packet below. The packet list table has columns for Time, Source, Destination, Protocol, Source Port, Destination Port, Length, and Information. The selected packet is at time 0.000019, source 144.195.52.3, destination 10.9.121.28, protocol H264, source port 8801, destination port 65027, and length 1067. The detailed view shows the following structure:

- Frame 13: 1067 bytes on wire (8536 bits), 128 bytes captured (1024 bits)
- Ethernet II, Src: d8:67:d9:74:5f:41, Dst: ac:bc:32:7a:fa:ad
- Internet Protocol Version 4, Src: 144.195.52.3, Dst: 10.9.121.28
- User Datagram Protocol, Src Port: 8801, Dst Port: 65027
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 - Type: 5
 - Sequence number: 648
 - Direction: 4 (from Zoom)
- Zoom Media Encapsulation
 - Type: 16 (Video)
 - Sequence number: 598
 - Timestamp: 1768271162
 - Frame number: 13206
 - Packets in frame: 5
- Real-Time Transport Protocol
 - 10.. = Version: RFC 1889 Version (2)
 - ..0. = Padding: False
 - ...1 = Extension: True
 - 0000 = Contributing source identifiers count: 0
 - 0... = Marker: False
 - Payload type: DynamicRTP-Type-98 (98)
 - Sequence number: 8248
 - Timestamp: 4092686930
 - Synchronization Source identifier: 0x01000801 (16779265)
 - Defined by profile: Unknown (0xbede)
 - Extension length: 4
 - Header extensions
 - > RFC 5285 Header Extension (One-Byte Header)
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Demystifying Zoom

2 Inferring Header Formats via Entropy Analysis

...



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0.000020	144.195.52.3	10.9.121.28	H264	8801	65027	1067	PT=DynamicRTP-Type-98, SSR
0.000021	144.195.52.3	10.9.121.28	H264	8801	65027	1066	PT=DynamicRTP-Type-98, SSR
0.000023	144.195.52.3	10.9.121.28	H264	8801	65027	1066	PT=DynamicRTP-Type-98, SSR
0.000025	144.195.52.3	10.9.121.28	H264	8801	65027	1297	PT=DynamicRTP-Type-98, SSR

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> Ethernet II, Src: d8:67:d9:74:5f:41, Dst: ac:bc:32:7a:fa:ad

> Internet Protocol Version 4, Src: 144.195.52.3, Dst: 10.9.121.28

> User Datagram Protocol, Src Port: 8801, Dst Port: 65027

Zoom SFU Encapsulation

- Type: 5
- Sequence number: 648
- Direction: 4 (from Zoom)

Zoom Media Encapsulation

- Type: 16 (Video)
- Sequence number: 598
- Timestamp: 1768271162
- Frame number: 13206
- Packets in frame: 5

Real-Time Transport Protocol

- 10.. = Version: RFC 1889 Version (2)
- ..0. = Padding: False
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Header extensions

- > RFC 5285 Header Extension (One-Byte Header)
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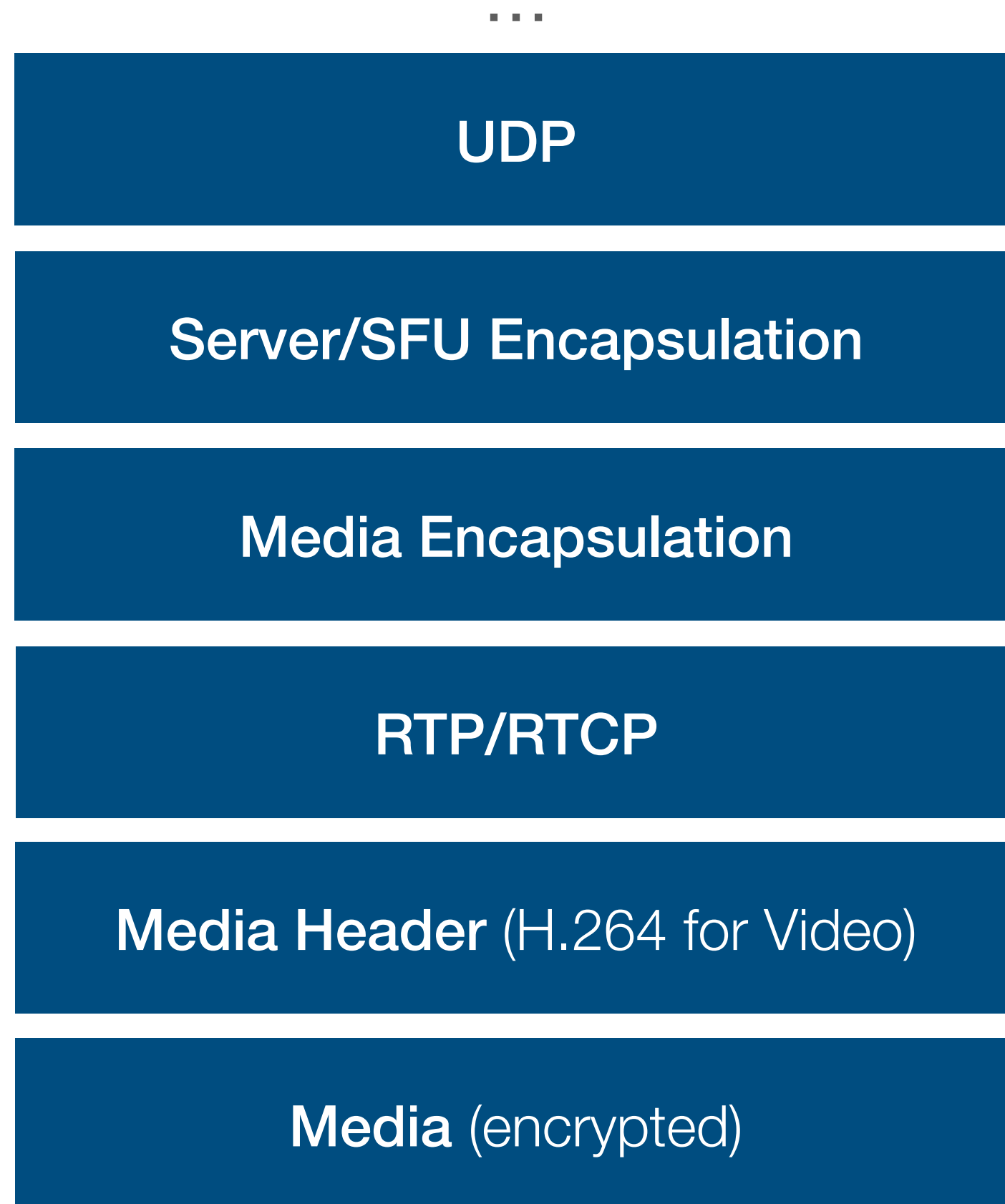
H.264

- > FU identifier
- > FU Header
- H264 NAL Unit Payload

Frame (frame), 128 bytes Packets: 42792 - Displayed: 42792 (100.0%) Profile: Default

Demystifying Zoom

2 Inferring Header Formats via Entropy Analysis



Wireshark Plugin for Zoom
(part of paper artifacts)



zoom-5min.pcap

Time	Source	Destination	Proto	Source	Dest. P	Length	Information
0.000019	144.195.52.3	10.9.121.28	H264	8801	65027	1067	PT=DynamicRTP-Type-98, SSR
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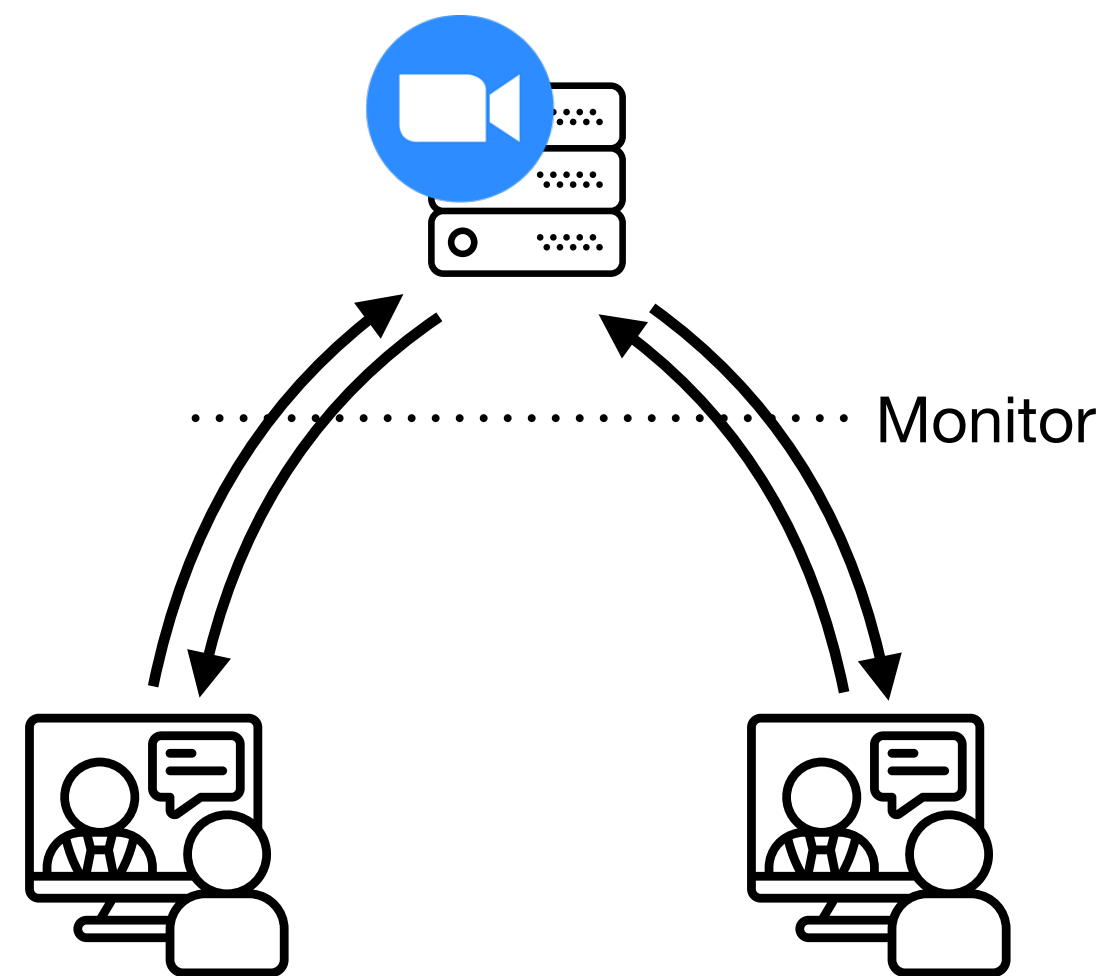
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 - 0000 = Contributing source identifiers count: 0
 - 0... = Marker: False
 - Payload type: DynamicRTP-Type-98 (98)
 - Sequence number: 8248
 - Timestamp: 4092686930
 - Synchronization Source identifier: 0x01000801 (16779265)
 - Defined by profile: Unknown (0xbede)
 - Extension length: 4
 - Header extensions
 - > RFC 5285 Header Extension (One-Byte Header)
 - > RFC 5285 Header Extension (One-Byte Header)
 - > RFC 5285 Header Extension (One-Byte Header)
 - > RFC 5285 Header Extension (One-Byte Header)
- H.264
 - > FU identifier
 - > FU Header
 - H264 NAL Unit Payload

Frame (frame), 128 bytes Packets: 42792 - Displayed: 42792 (100.0%) Profile: Default

Demystifying Zoom

3 Grouping Packets by Meeting

Knowledge about individual streams not sufficient, e.g. for latency measurement

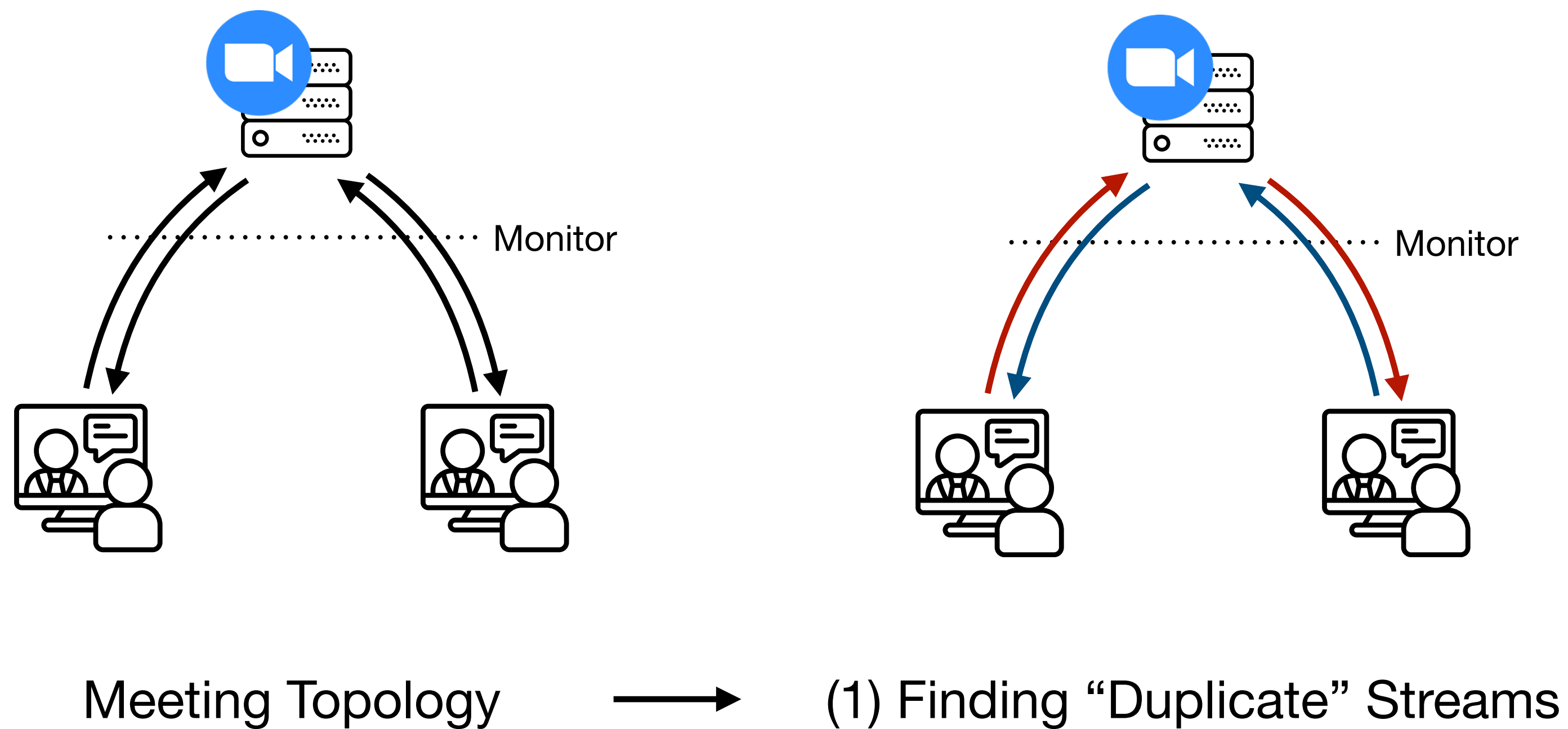


Meeting Topology

Demystifying Zoom

3 Grouping Packets by Meeting

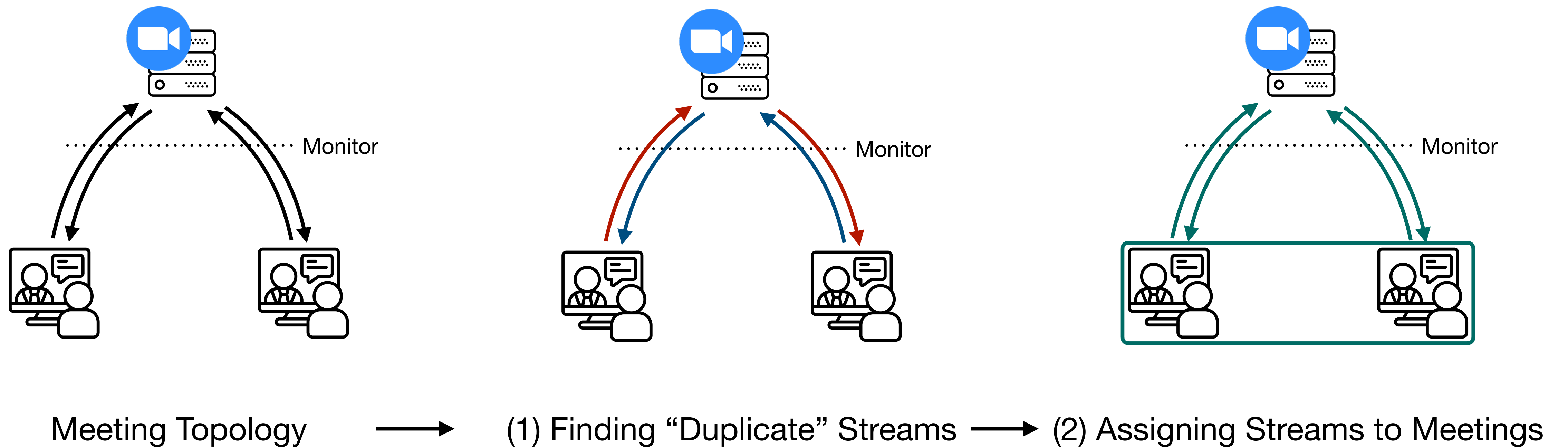
Knowledge about individual streams not sufficient, e.g. for latency measurement



Demystifying Zoom

3 Grouping Packets by Meeting

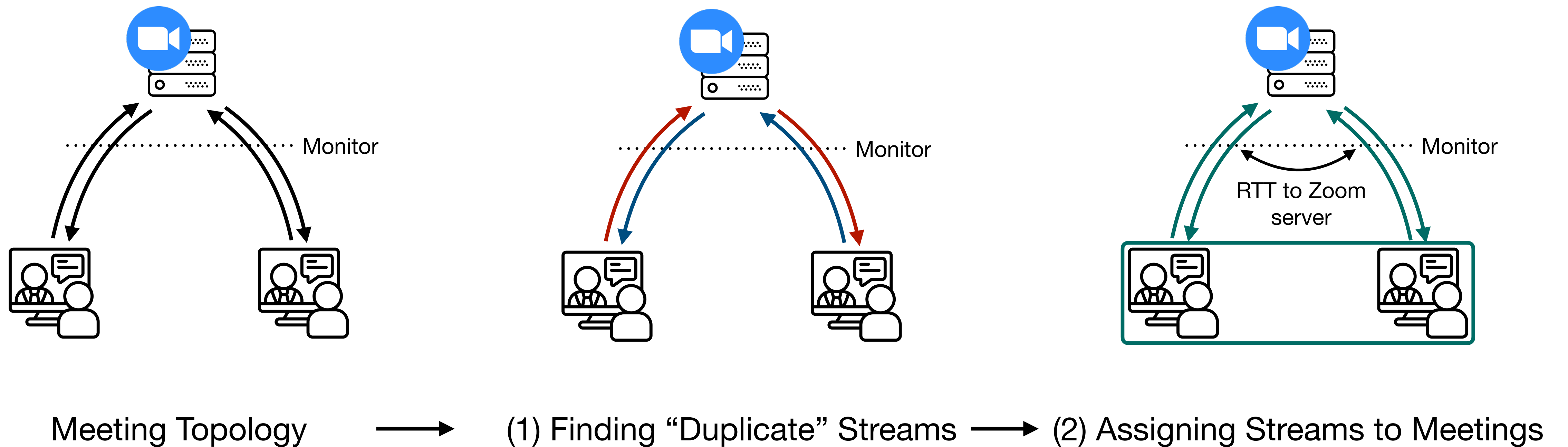
Knowledge about individual streams not sufficient, e.g. for latency measurement



Demystifying Zoom

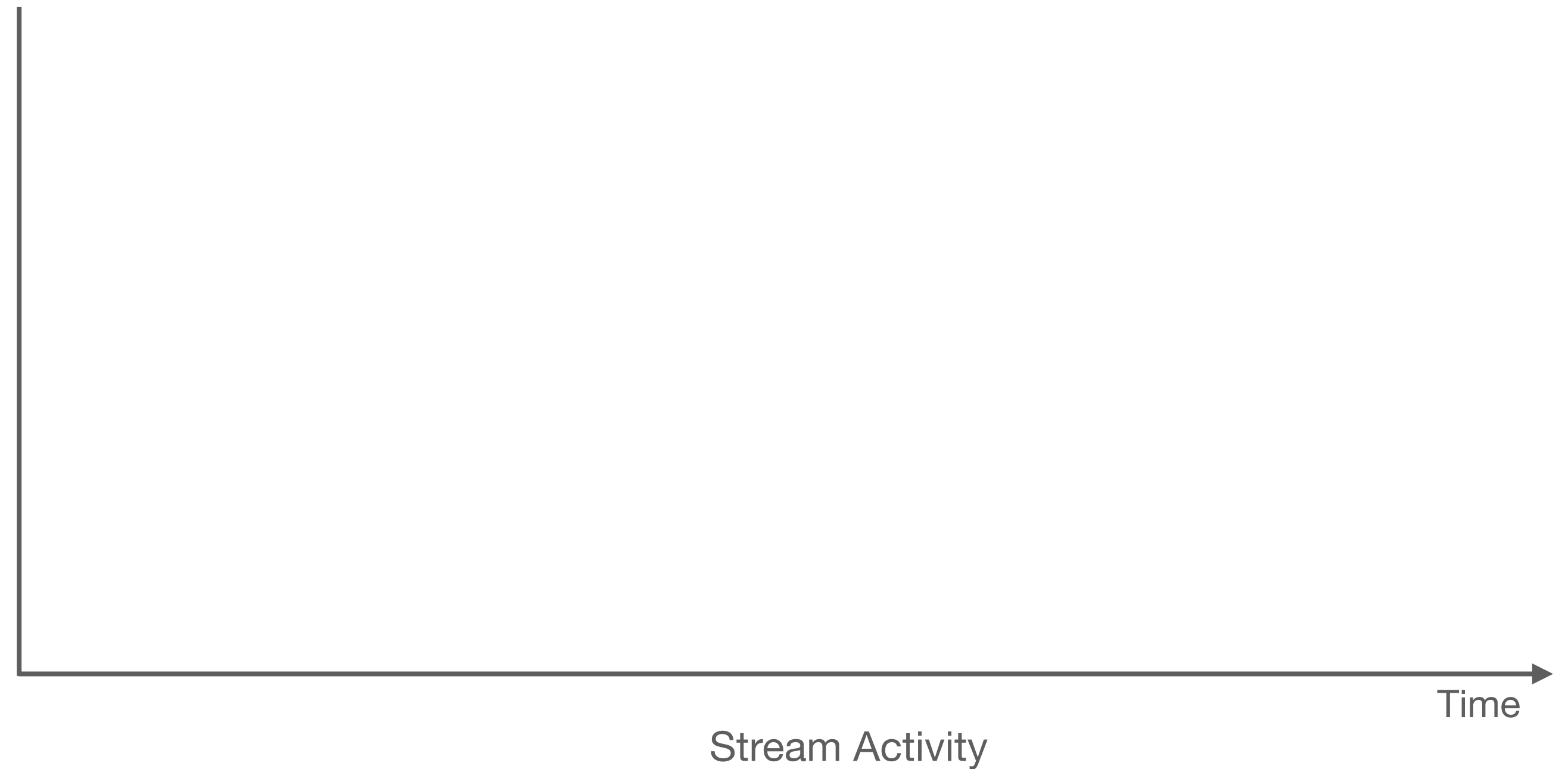
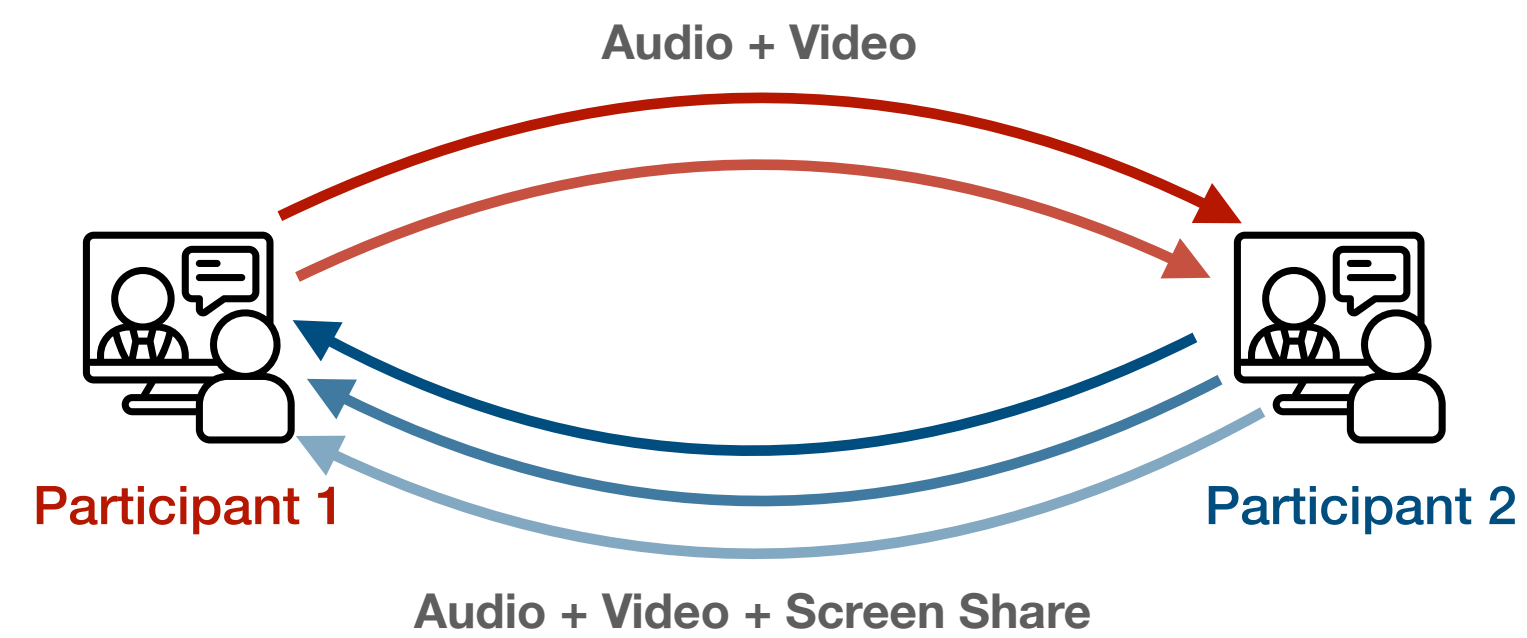
3 Grouping Packets by Meeting

Knowledge about individual streams not sufficient, e.g. for latency measurement



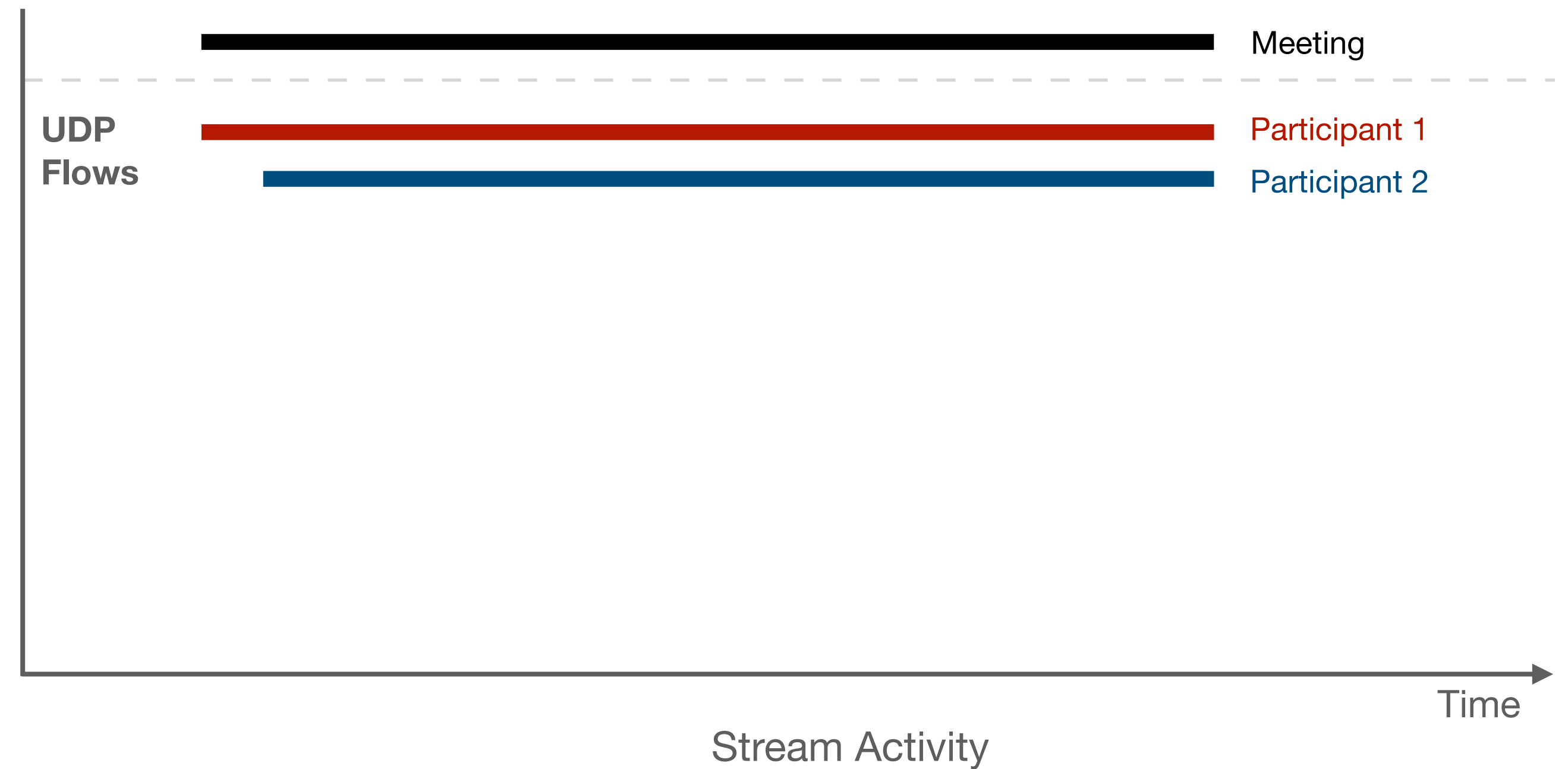
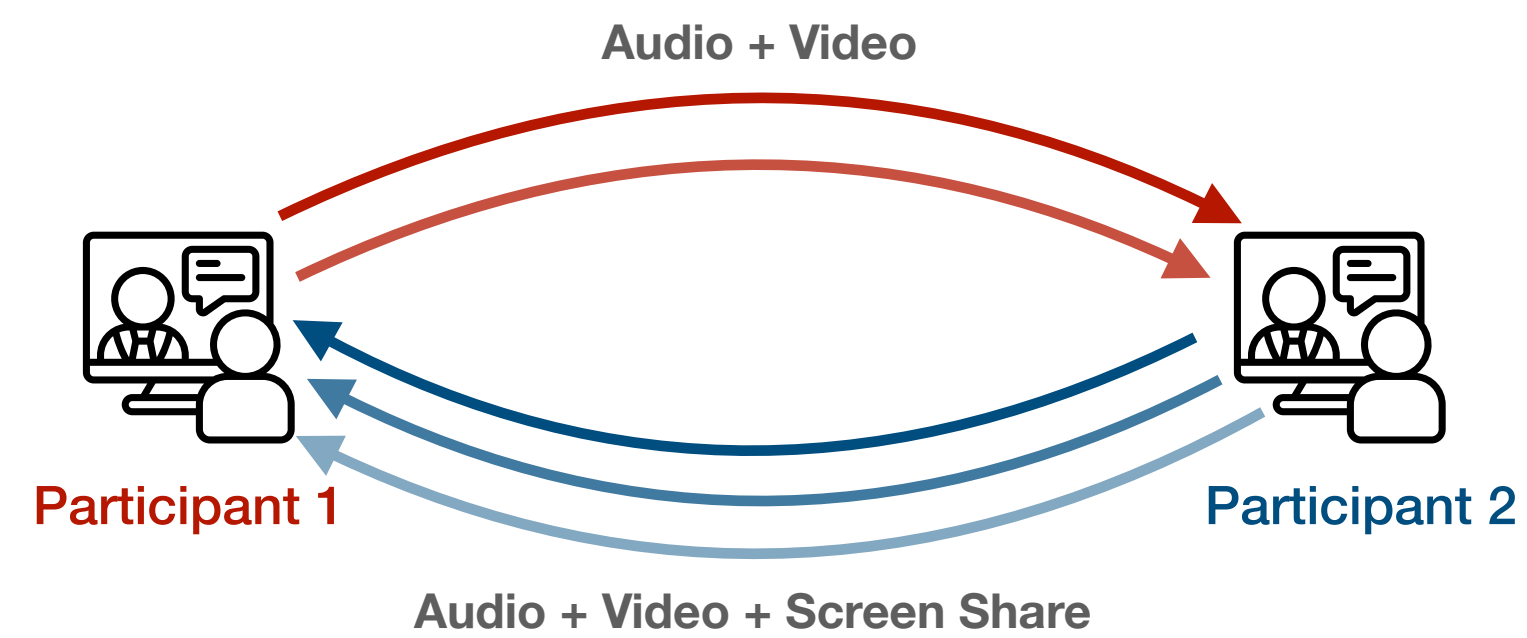
Demystifying Zoom

3 Grouping Packets by Meeting



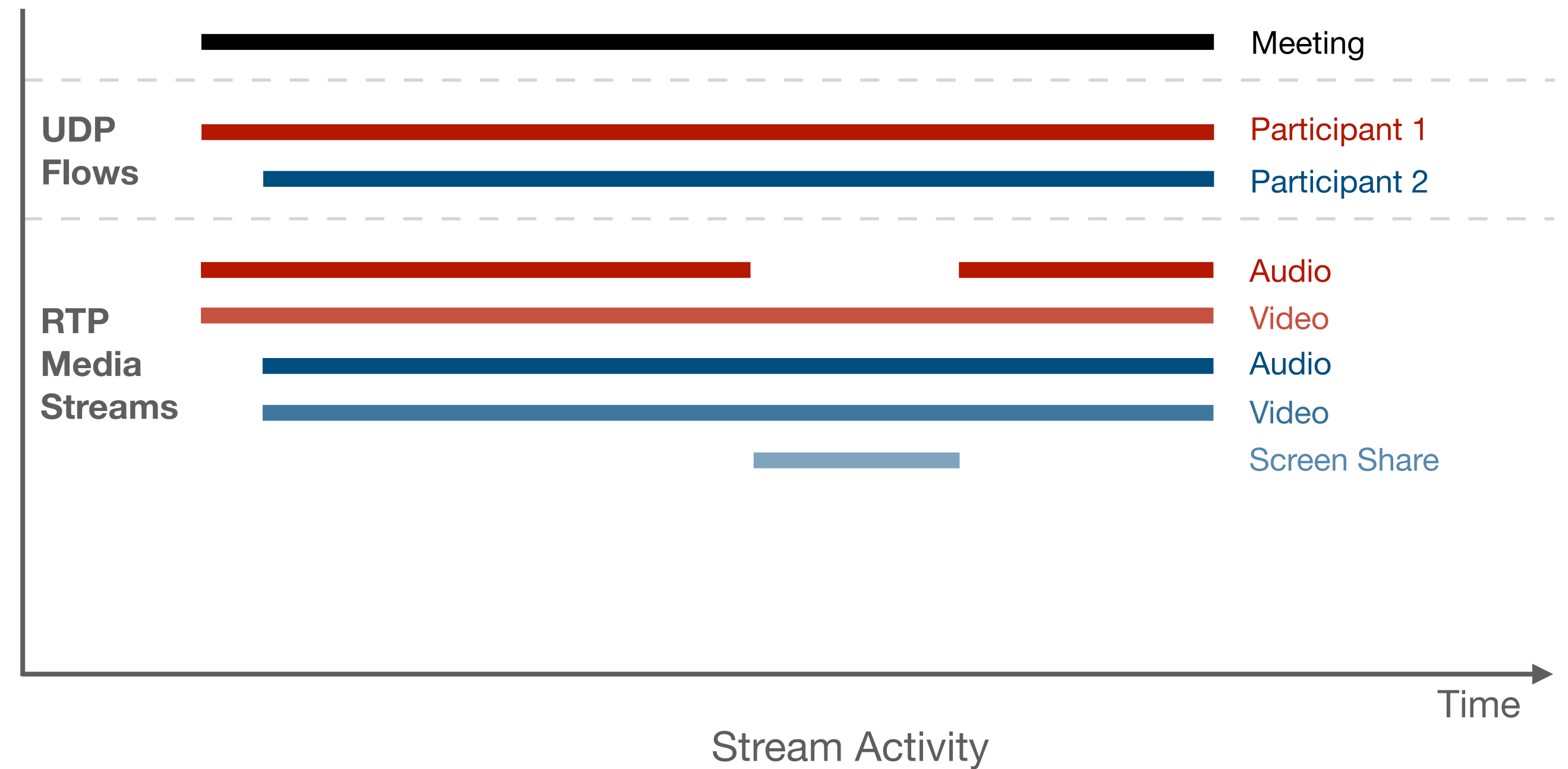
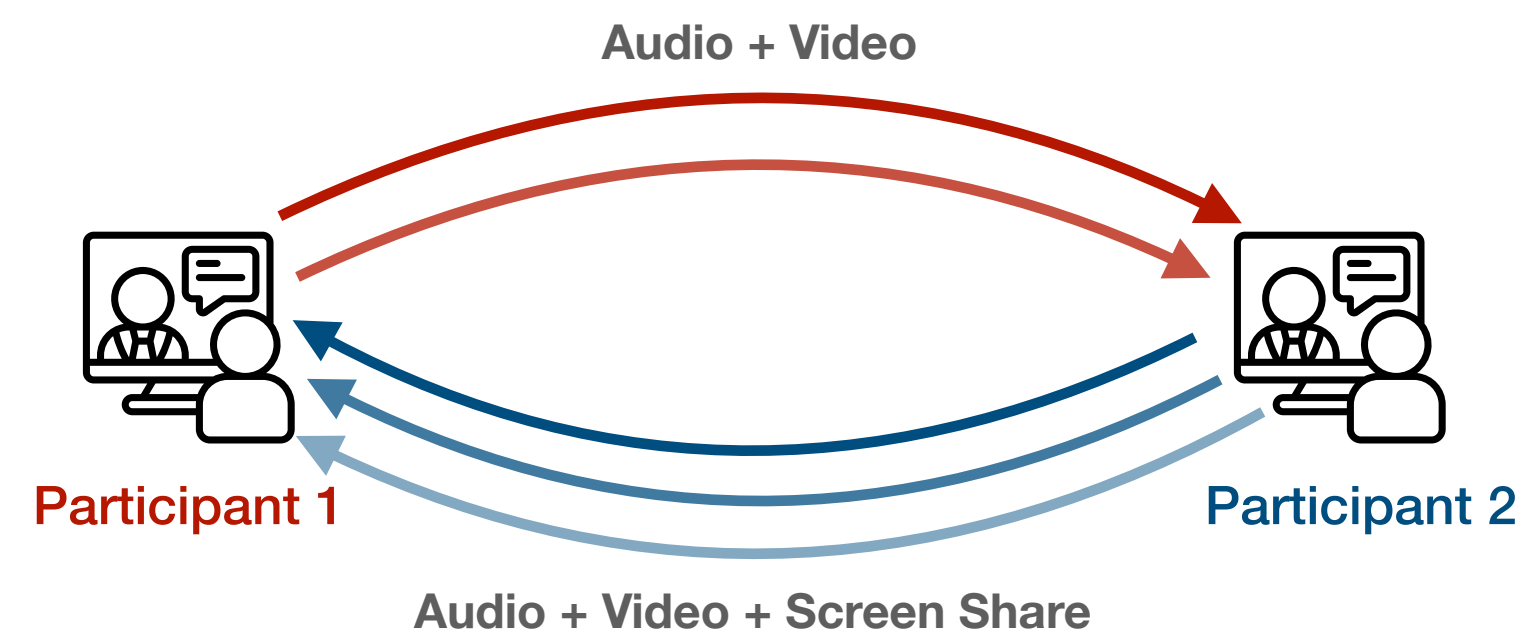
Demystifying Zoom

3 Grouping Packets by Meeting



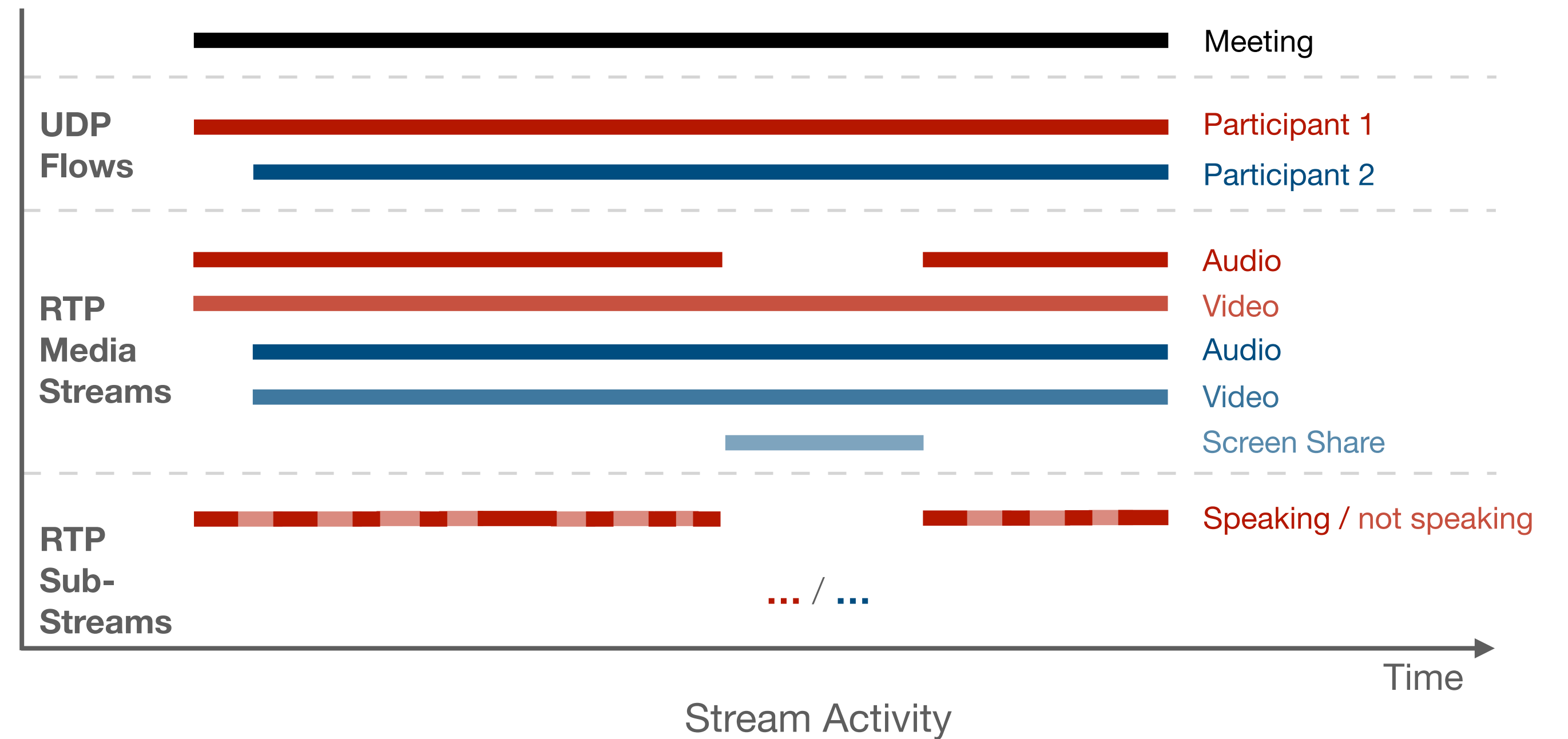
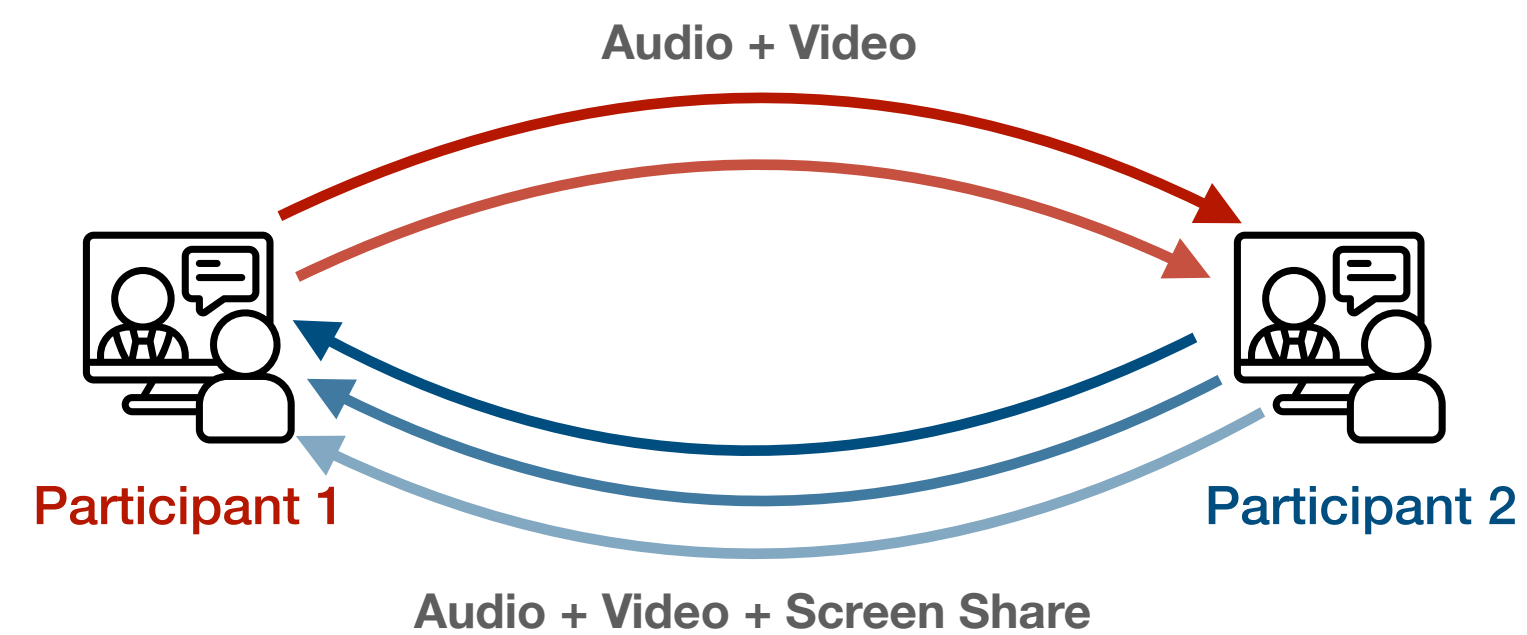
Demystifying Zoom

3 Grouping Packets by Meeting



Demystifying Zoom

3 Grouping Packets by Meeting



Measuring Zoom Performance

Packet Format → Metrics

The screenshot shows the Wireshark interface for a packet capture named 'zoom-5min.pcap'. The main pane displays a list of packets with columns for No., Time, Source, Destination, Protocol, Source Port, Dest. Port, Length, and Information. Packet 80 is highlighted. The bottom pane shows the expanded details for packet 80, including Zoom SFU Encapsulation, Zoom Media Encapsulation, and Real-Time Transport Protocol fields.

No.	Time	Source	Destination	Protocol	Source Port	Dest. Port	Length	Information
77	0.641066	10.9.121.28	144.195.52.3	H264	65027	8801	1237	PT=DynamicRTP-Type-98, SSRC=0x1000401, Seq=26403, T
78	0.652066	10.9.121.28	144.195.52.3	H264	65027	8801	1237	PT=DynamicRTP-Type-98, SSRC=0x1000401, Seq=26404, T
79	0.655209	10.9.121.28	144.195.52.3	RTP	55189	8801	152	PT=DynamicRTP-Type-112, SSRC=0x1000402, Seq=61714, T
80	0.662657	10.9.121.28	144.195.52.3	H264	65027	8801	1236	PT=DynamicRTP-Type-98, SSRC=0x1000401, Seq=26405, T
81	0.672504	10.9.121.28	144.195.52.3	RTP	55189	8801	154	PT=DynamicRTP-Type-112, SSRC=0x1000402, Seq=61715, T
82	0.681196	10.9.121.28	144.195.52.3	H264	65027	8801	1236	PT=DynamicRTP-Type-98, SSRC=0x1000401, Seq=26406, T
83	0.691718	10.9.121.28	144.195.52.3	H264	65027	8801	1236	PT=DynamicRTP-Type-98, SSRC=0x1000401, Seq=26407, T
84	0.693202	10.9.121.28	144.195.52.3	RTP	55189	8801	156	PT=DynamicRTP-Type-112, SSRC=0x1000402, Seq=61716, T
85	0.703773	10.9.121.28	144.195.52.3	H264	65027	8801	1236	PT=DynamicRTP-Type-98, SSRC=0x1000401, Seq=26408, T
86	0.712934	10.9.121.28	144.195.52.3	RTP	55189	8801	161	PT=DynamicRTP-Type-112, SSRC=0x1000402, Seq=61717, T
87	0.712934	10.9.121.28	144.195.52.3	H264	65027	8801	1236	PT=DynamicRTP-Type-98, SSRC=0x1000401, Seq=26409, T
88	0.729705	10.9.121.28	144.195.52.3	RTP	65027	8801	1268	PT=DynamicRTP-Type-110, SSRC=0x1000401, Seq=46666, T
89	0.734788	10.9.121.28	144.195.52.3	RTP	55189	8801	171	PT=DynamicRTP-Type-112, SSRC=0x1000402, Seq=61718, T
90	0.741473	10.9.121.28	144.195.52.3	H264	65027	8801	1199	PT=DynamicRTP-Type-98, SSRC=0x1000401, Seq=26410, T
91	0.744316	10.9.121.28	144.195.52.3	RTCP	65027	8801	94	Sender Report

Zoom SFU Encapsulation
Type: 5
Sequence number: 81
Direction: 0 (to Zoom)

Zoom Media Encapsulation
Type: 16 (Video)
Sequence number: 2
Timestamp: 91412103
Frame number: 23685
Packets in frame: 7

Real-Time Transport Protocol
10.. = Version: RFC 1889 Version (2)
..0. = Padding: False
...1 = Extension: True
... 0000 = Contributing source identifiers count: 0
0... = Marker: False
Payload type: DynamicRTP-Type-98 (98)
Sequence number: 26405
Timestamp: 4215635418
Synchronization Source identifier: 0x01000401 (16778241)
Defined by profile: Unknown (0xbede)
Extension length: 4

Measuring Zoom Performance

Packet Format → Metrics

No.	Time	Source	Destination	Protocol	Source Port	Dest. Port	Length	Information
77	0.641066	10.9.121.28	144.195.52.3	H264	65027	8801	1237	PT=DynamicRTP-Type-98, SSRC=0x1000401, Seq=26403, T
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81	0.672504	10.9.121.28	144.195.52.3	RTP	55189	8801	154	PT=DynamicRTP-Type-112, SSRC=0x1000402, Seq=61715, T
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83	0.691718	10.9.121.28	144.195.52.3	H264	65027	8801	1236	PT=DynamicRTP-Type-98, SSRC=0x1000401, Seq=26407, T
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87	0.712934	10.9.121.28	144.195.52.3	H264	65027	8801	1236	PT=DynamicRTP-Type-98, SSRC=0x1000401, Seq=26409, T
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Zoom SFU Encapsulation
Type: 5
Sequence number: 81
Direction: 0 (to Zoom)

Zoom Media Encapsulation
Type: 16 (Video)
Sequence number: 2
Timestamp: 91412103
Frame number: 23685
Packets in frame: 7

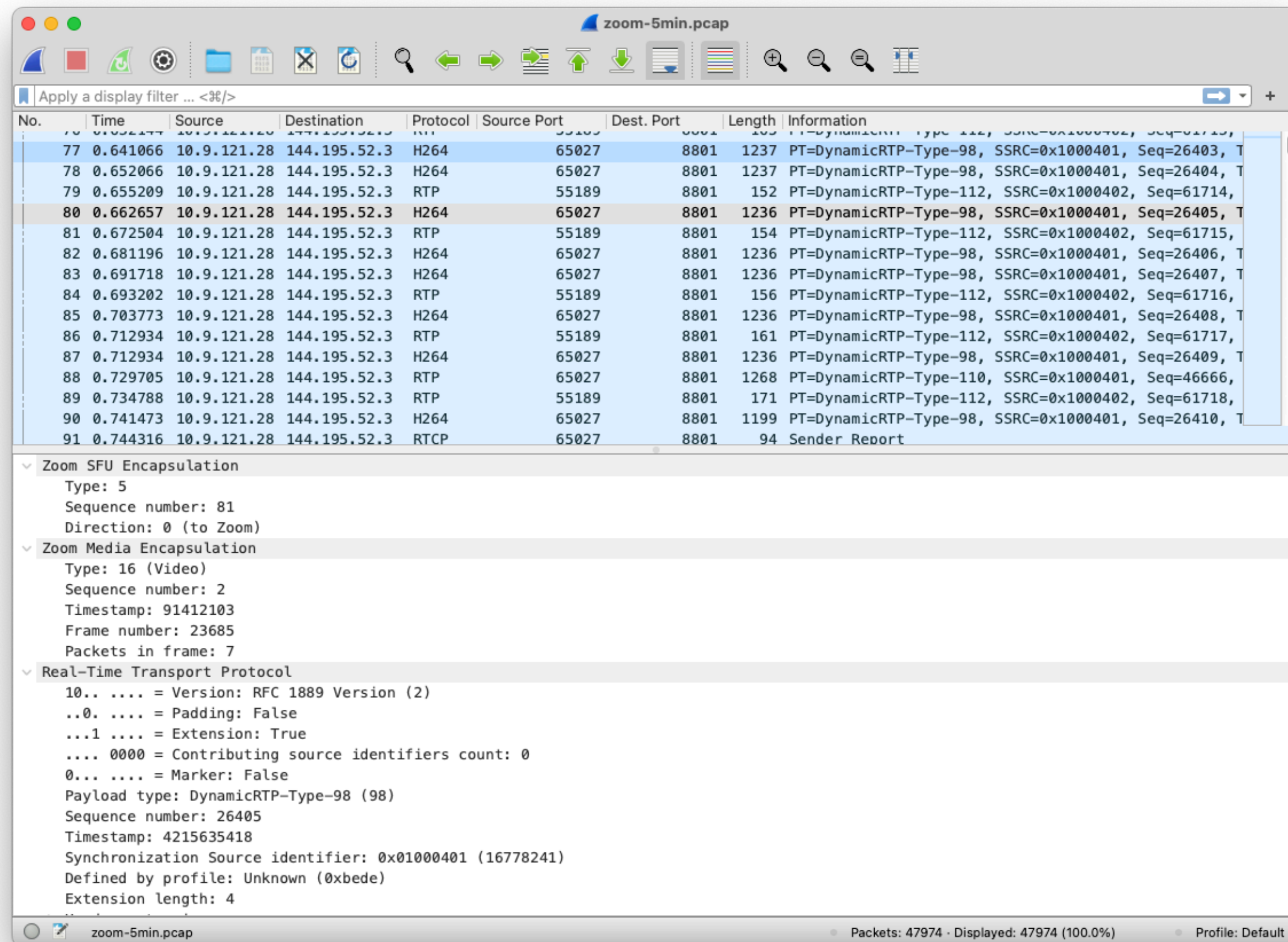
Real-Time Transport Protocol
10.. = Version: RFC 1889 Version (2)
..0. = Padding: False
...1 = Extension: True
... 0000 = Contributing source identifiers count: 0
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Payload type: DynamicRTP-Type-98 (98)
Sequence number: 26405
Timestamp: 4215635418
Synchronization Source identifier: 0x01000401 (16778241)
Defined by profile: Unknown (0xbede)
Extension length: 4



- Metric
- Media Bit Rate
- Frame Rate
- Frame Size
- Latency
- Jitter
- Loss, RTX, out-of-order

Measuring Zoom Performance

Packet Format → Metrics



Metric	Requires Headers
Media Bit Rate	●
Frame Rate	●
Frame Size	●
Latency	●
Jitter	●
Loss, RTX, out-of-order	●

Measuring Zoom Performance

Packet Format → Metrics

The screenshot shows a Wireshark interface with a packet capture named 'zoom-5min.pcap'. The main pane displays a list of packets, and the bottom pane shows the detailed view of a Real-Time Transport Protocol (RTP) packet. The detailed view includes fields such as Version, Padding, Extension, and Payload type.

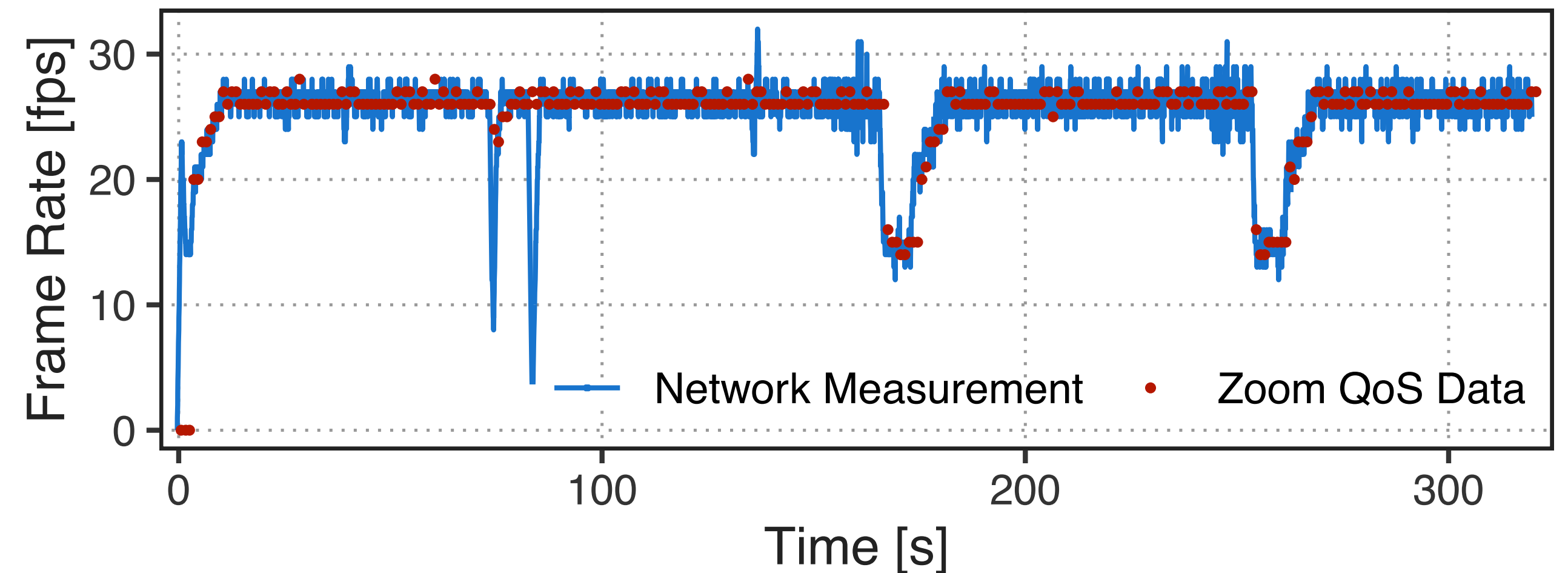


Metric	Requires Headers	Available in Zoom SDK	Validated
Media Bit Rate	●		
Frame Rate	●	●	●
Frame Size	●		
Latency	●	●	●
Jitter	●	●	●
Loss, RTX, out-of-order	●		

Measuring Zoom Performance

Frame Rate Validation

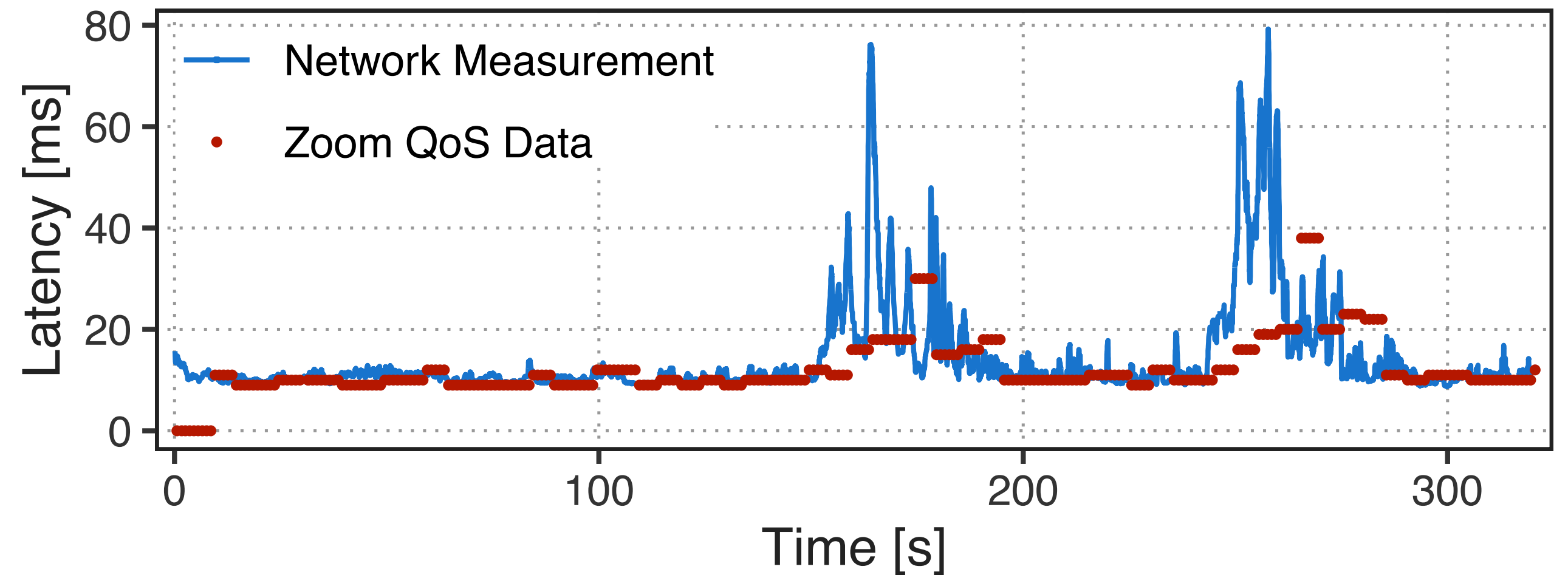
- Controlled experiments with instrumented Zoom Client using Zoom SDK
- Frame rate measurement matches Zoom QoS data exactly
- Finer-grained data, detect short-term variations ($< 1s$)
(1 per frame vs. 1 per sec. \rightarrow up to 30/sec.)



Measuring Zoom Performance

Latency + Frame-level Jitter Validation

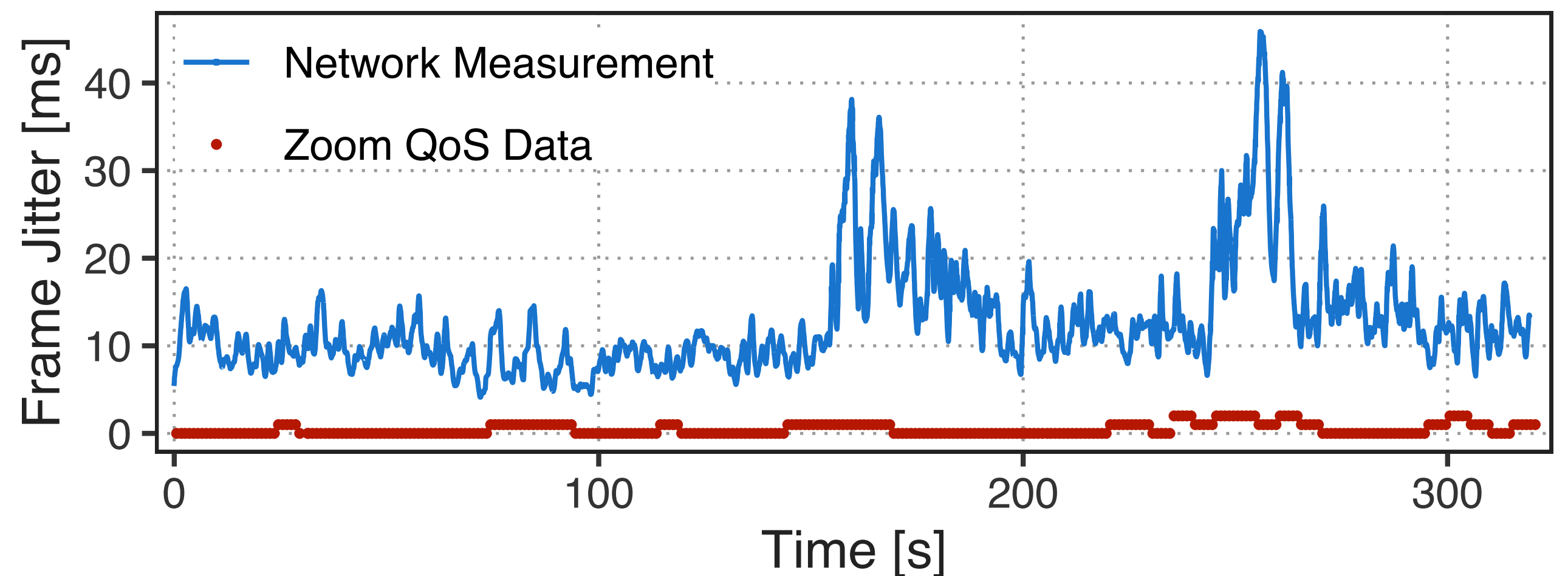
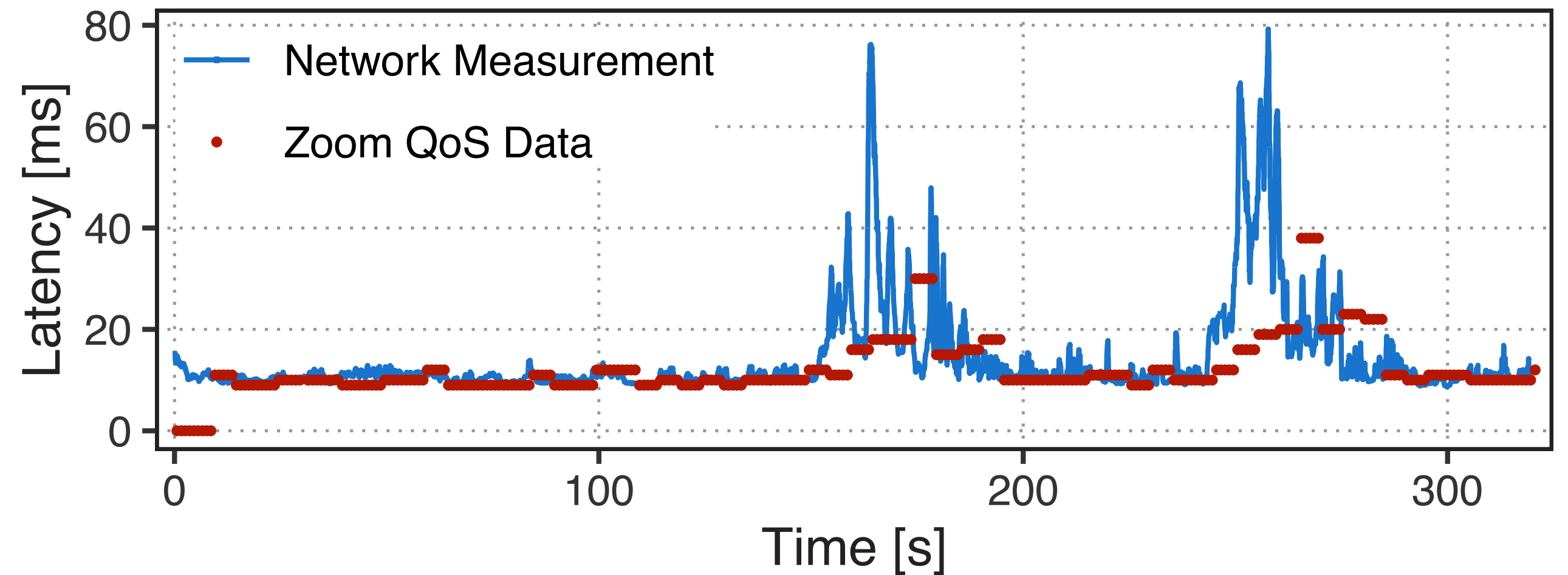
- Latency to Zoom SFU measured by matching RTP sequence numbers
- Latency measurements match despite long smoothing
- Finer-grained measurement (1 per 5 sec. vs. 1 per packet → 100s per sec.)



Measuring Zoom Performance

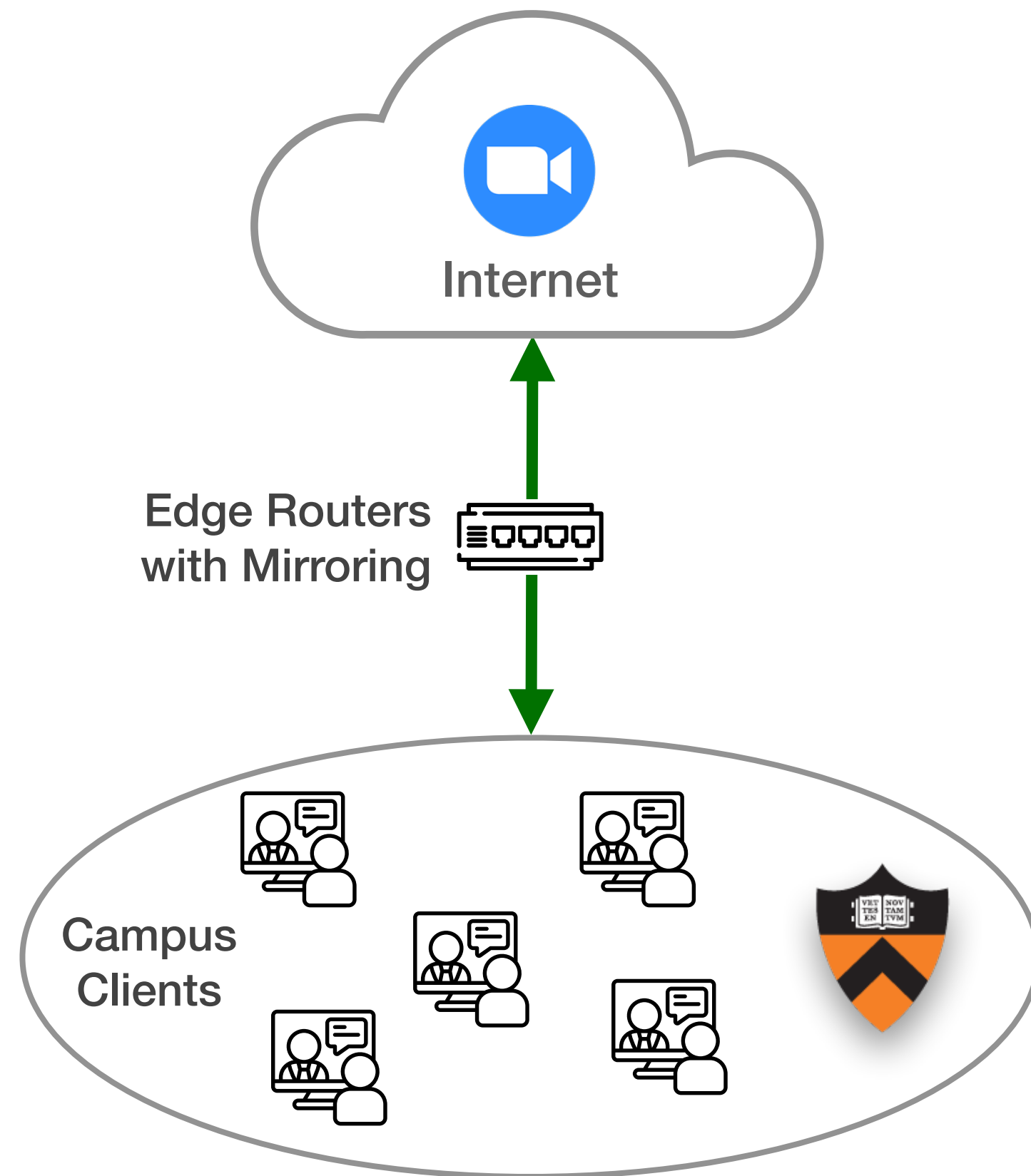
Latency + Frame-level Jitter Validation

- Latency to Zoom SFU measured by matching RTP sequence numbers
- Latency measurements match despite long smoothing
- Finer-grained measurement (1 per 5 sec. vs. 1 per packet → 100s per sec.)
- Discrepancy in jitter



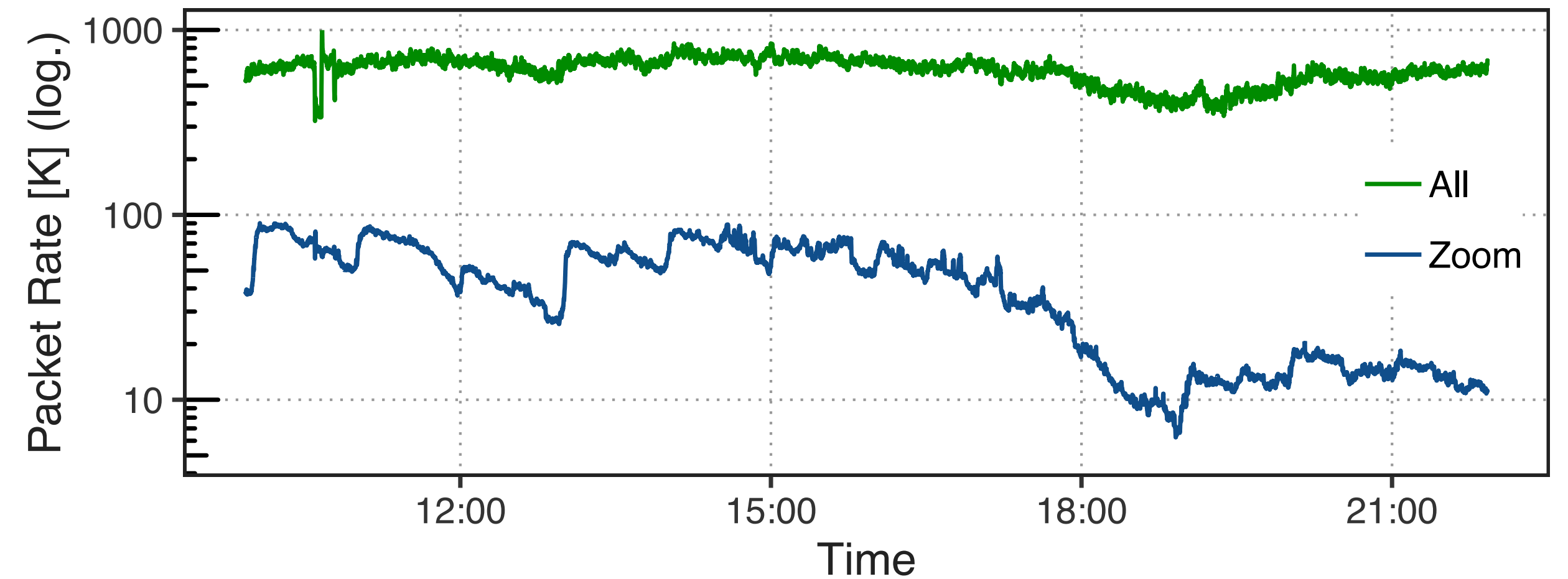
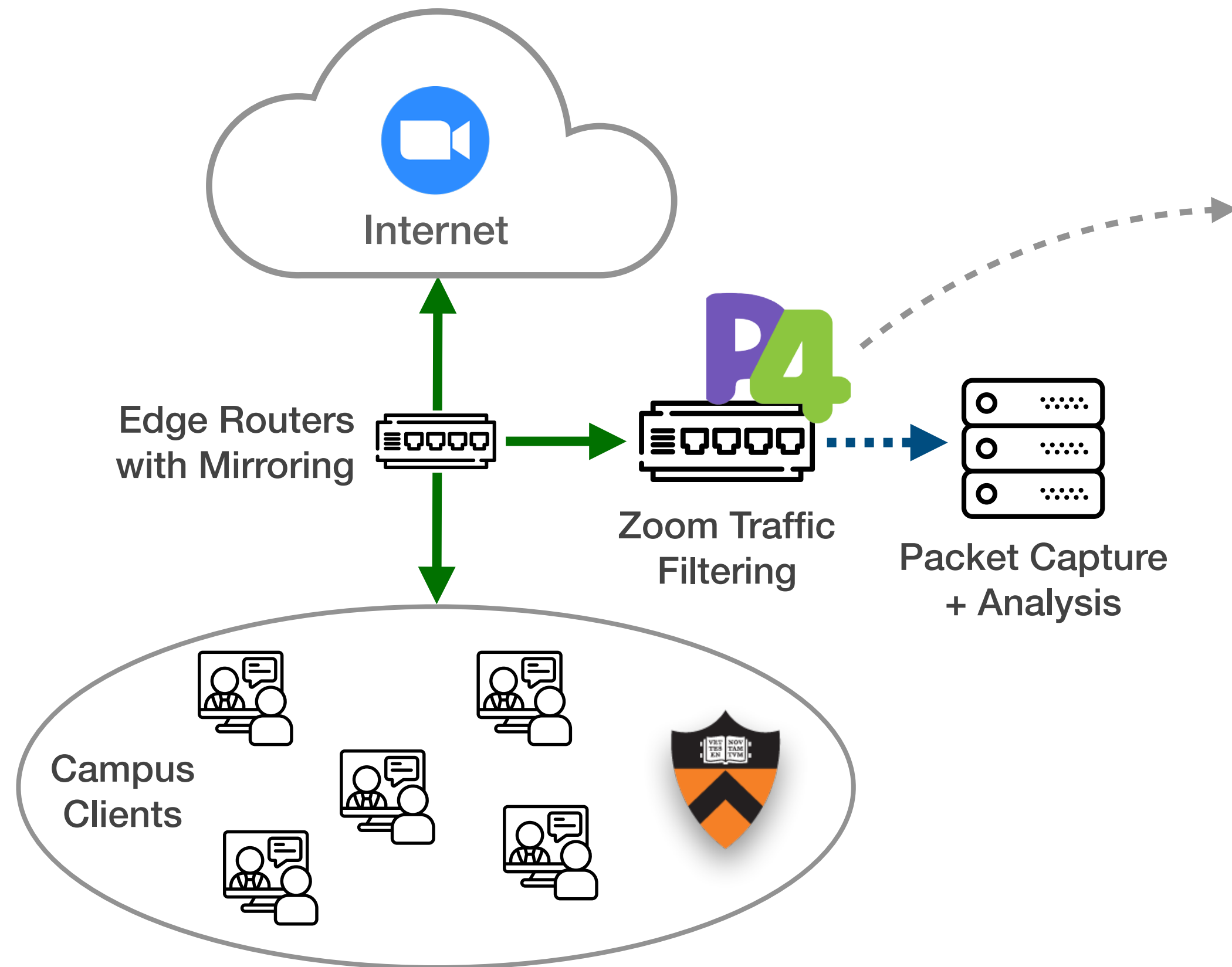
Analyzing Zoom Campus Traffic

Traffic Capture



Analyzing Zoom Campus Traffic

Traffic Capture



Analyzing Zoom Campus Traffic

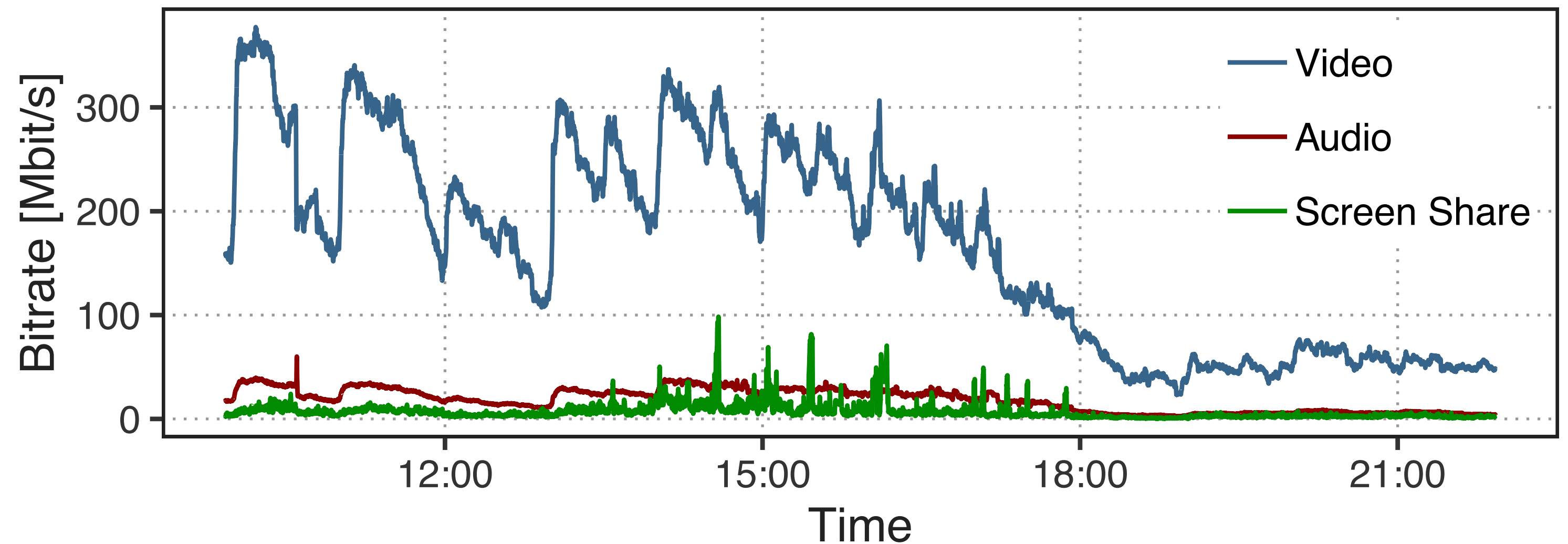
Data Rate per Media Type

Capture Duration	12 hours
Zoom Packets	1,846 M (~43K/s)
Zoom Data Rate	222.9 Mbit/s avg.
Zoom RTP Media Streams	59,020

Analyzing Zoom Campus Traffic

Data Rate per Media Type

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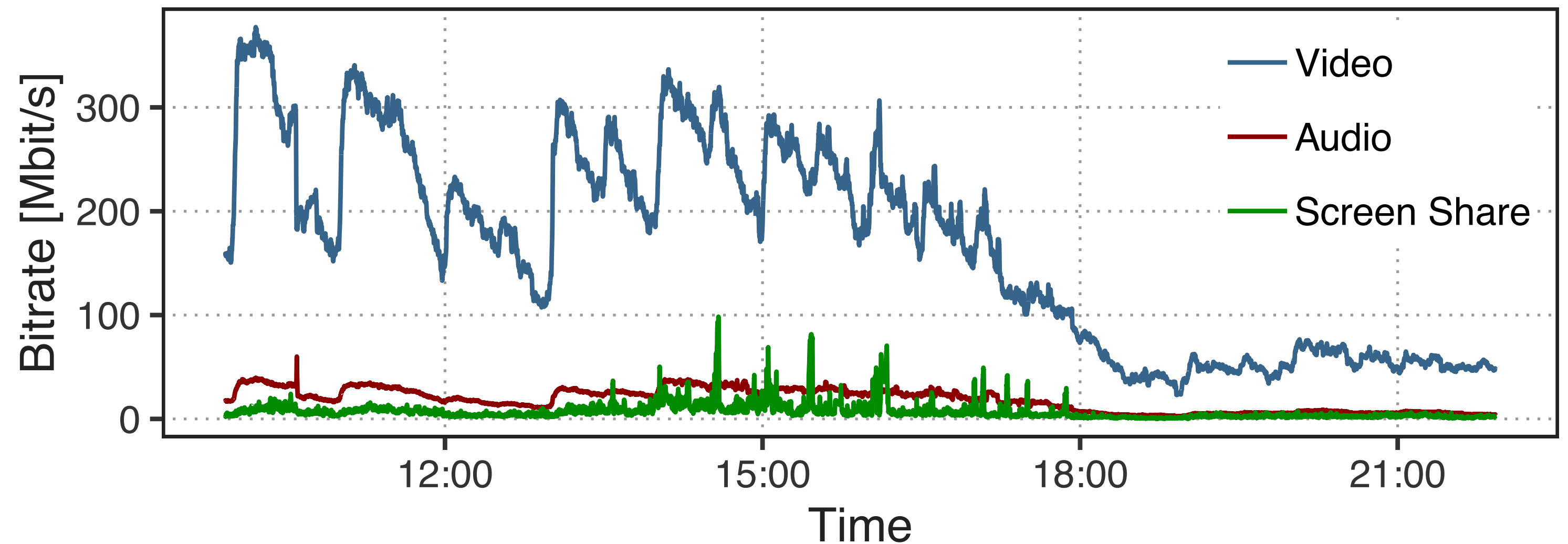


Data Rate of Zoom Media Streams by Media Type

Analyzing Zoom Campus Traffic

Data Rate per Media Type

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Zoom RTP Media Streams	59,020



Data Rate of Zoom Media Streams by Media Type

1. Number of participants per meeting

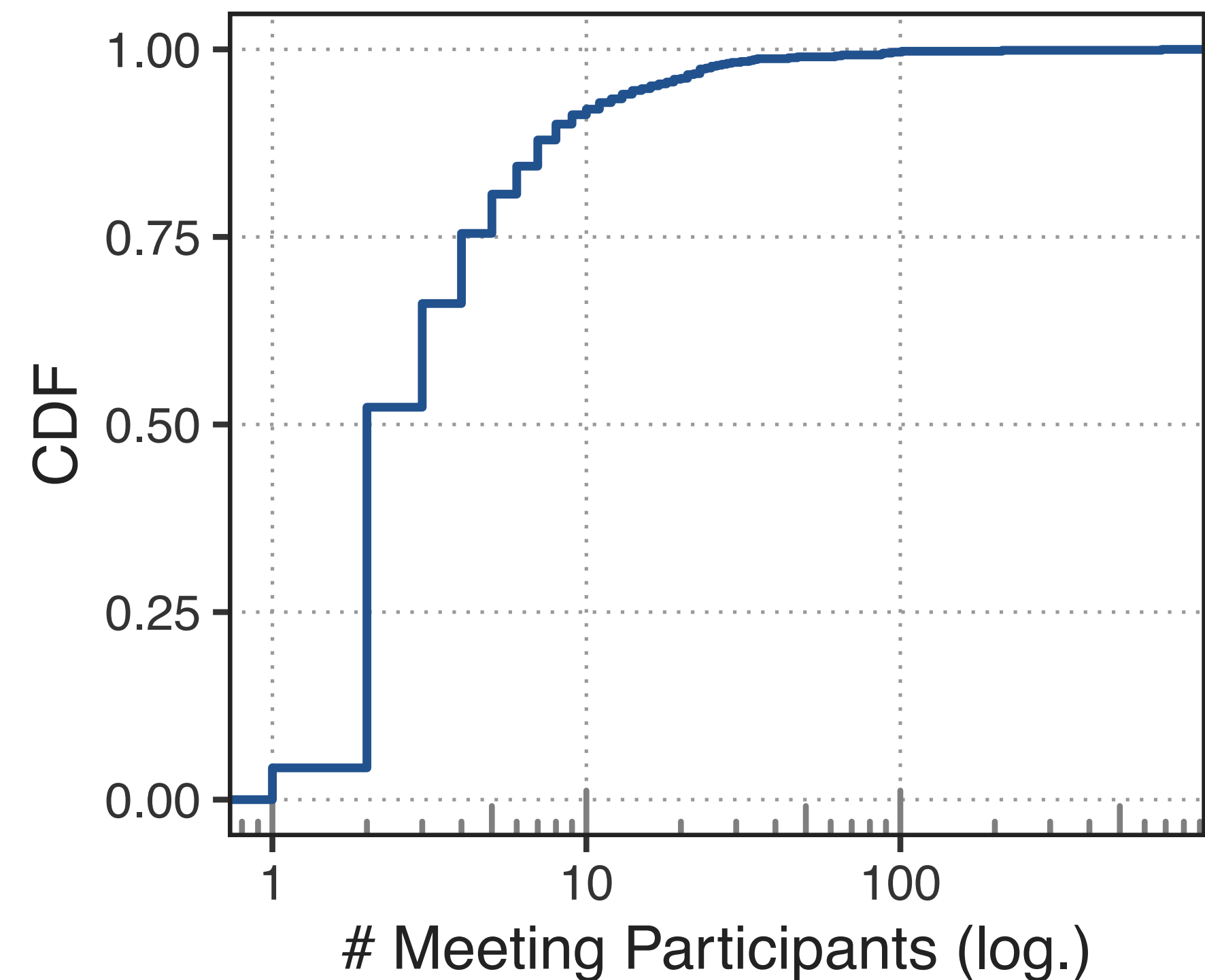
2. RTT to Zoom Server

3. Video Frame Rate

Analyzing Zoom Campus Traffic

Number of Participants per Meeting

- Grouping heuristic to arrange media streams by meeting
- 803 distinct meetings identified

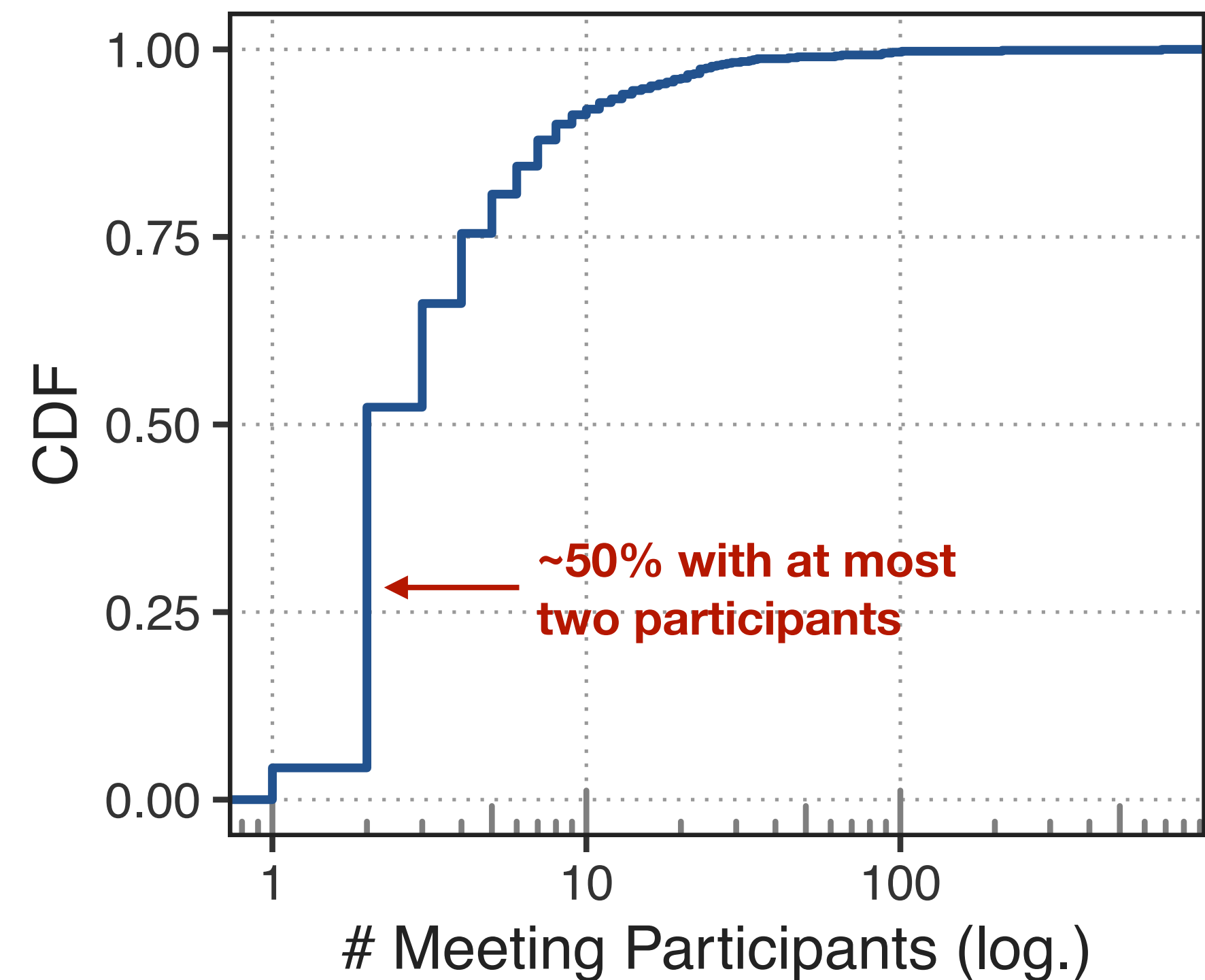


Max. Number of Participants per Meeting
in 12-hour Campus Trace.

Analyzing Zoom Campus Traffic

Number of Participants per Meeting

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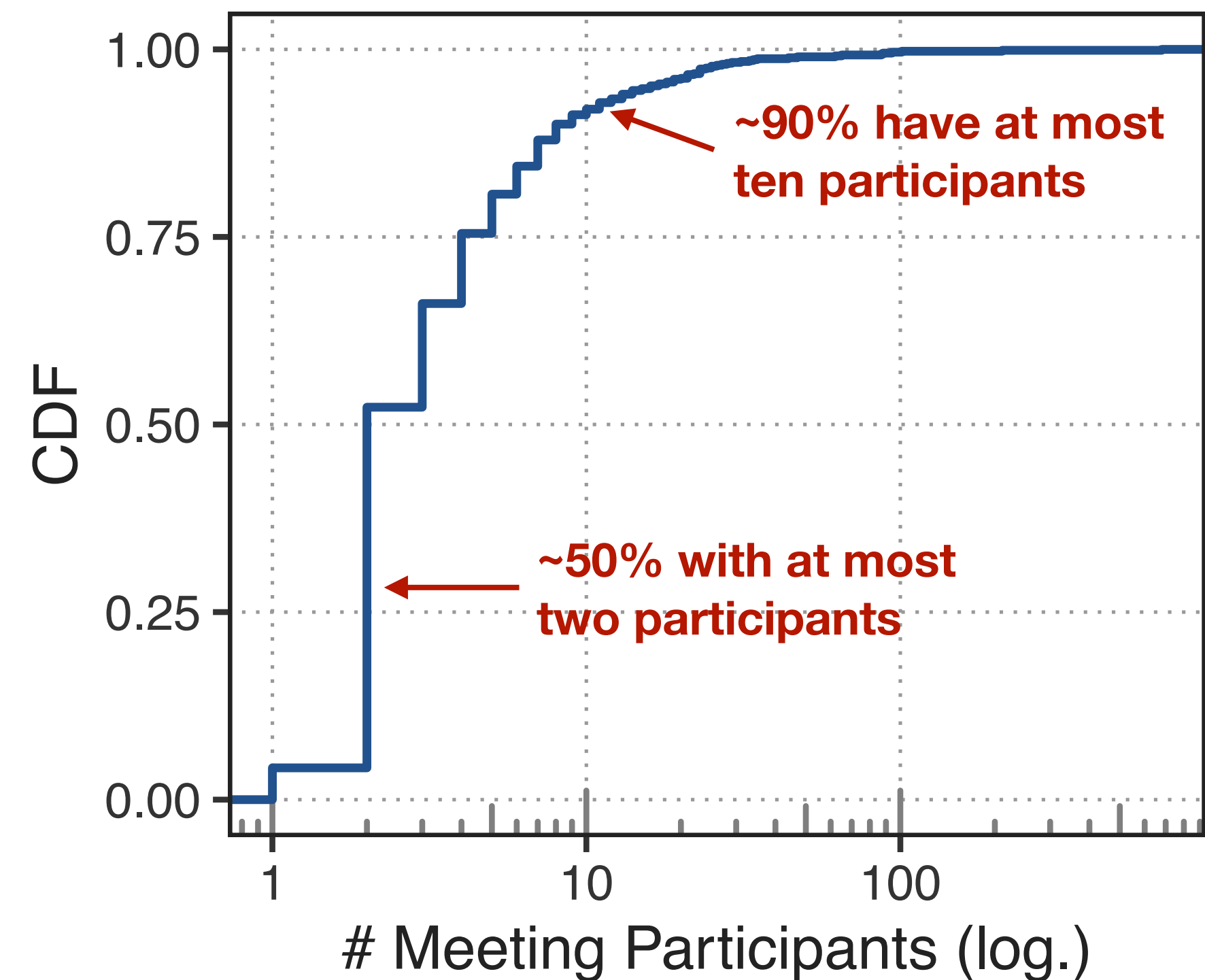


Max. Number of Participants per Meeting
in 12-hour Campus Trace.

Analyzing Zoom Campus Traffic

Number of Participants per Meeting

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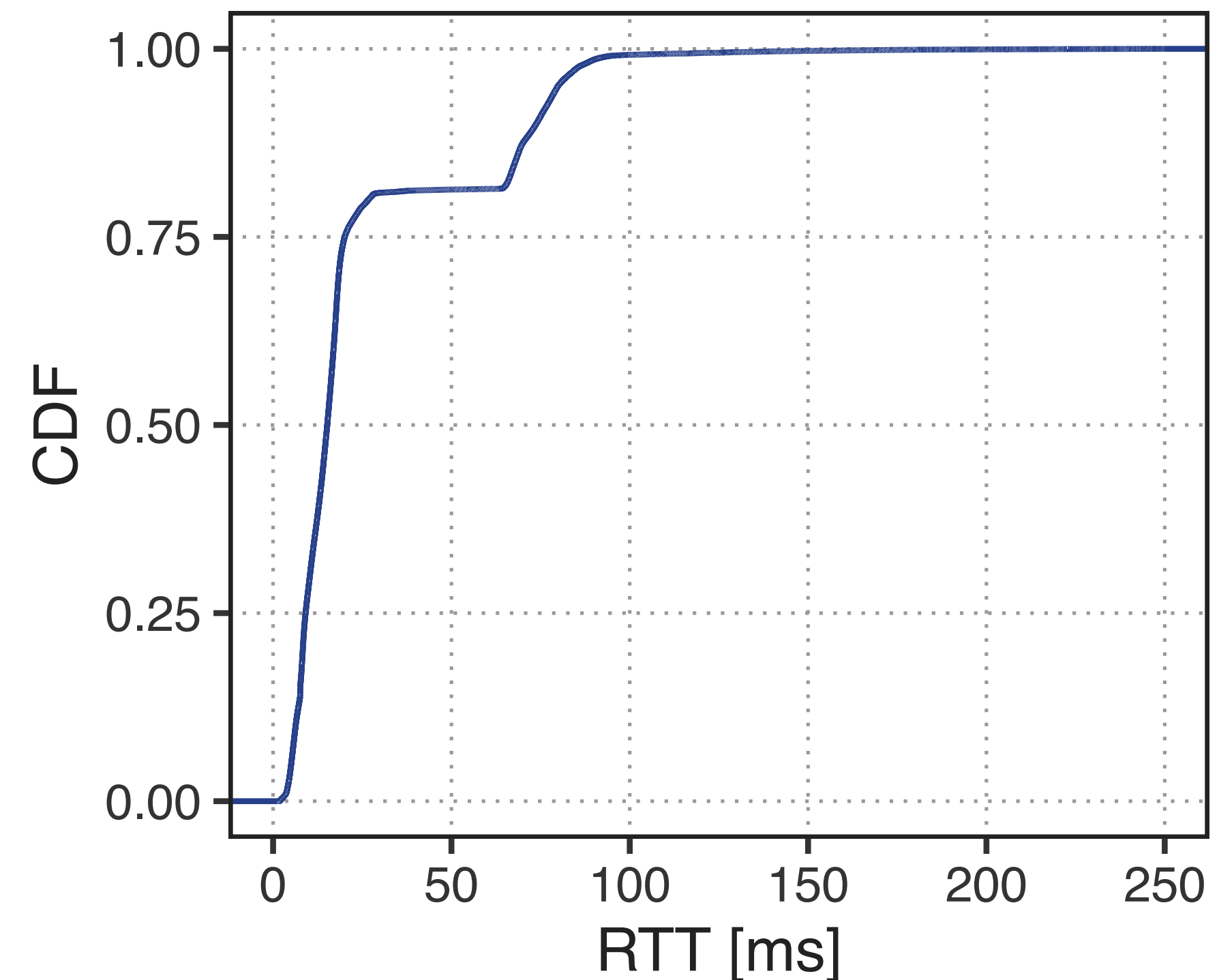


Max. Number of Participants per Meeting
in 12-hour Campus Trace.

Analyzing Zoom Campus Traffic

Latency to Zoom Server

- RTT to server by matching RTP sequence numbers
- 30.1 M latency samples to 521 distinct Zoom IP addresses
- Vast majority of meetings connected to NYC and California data centers

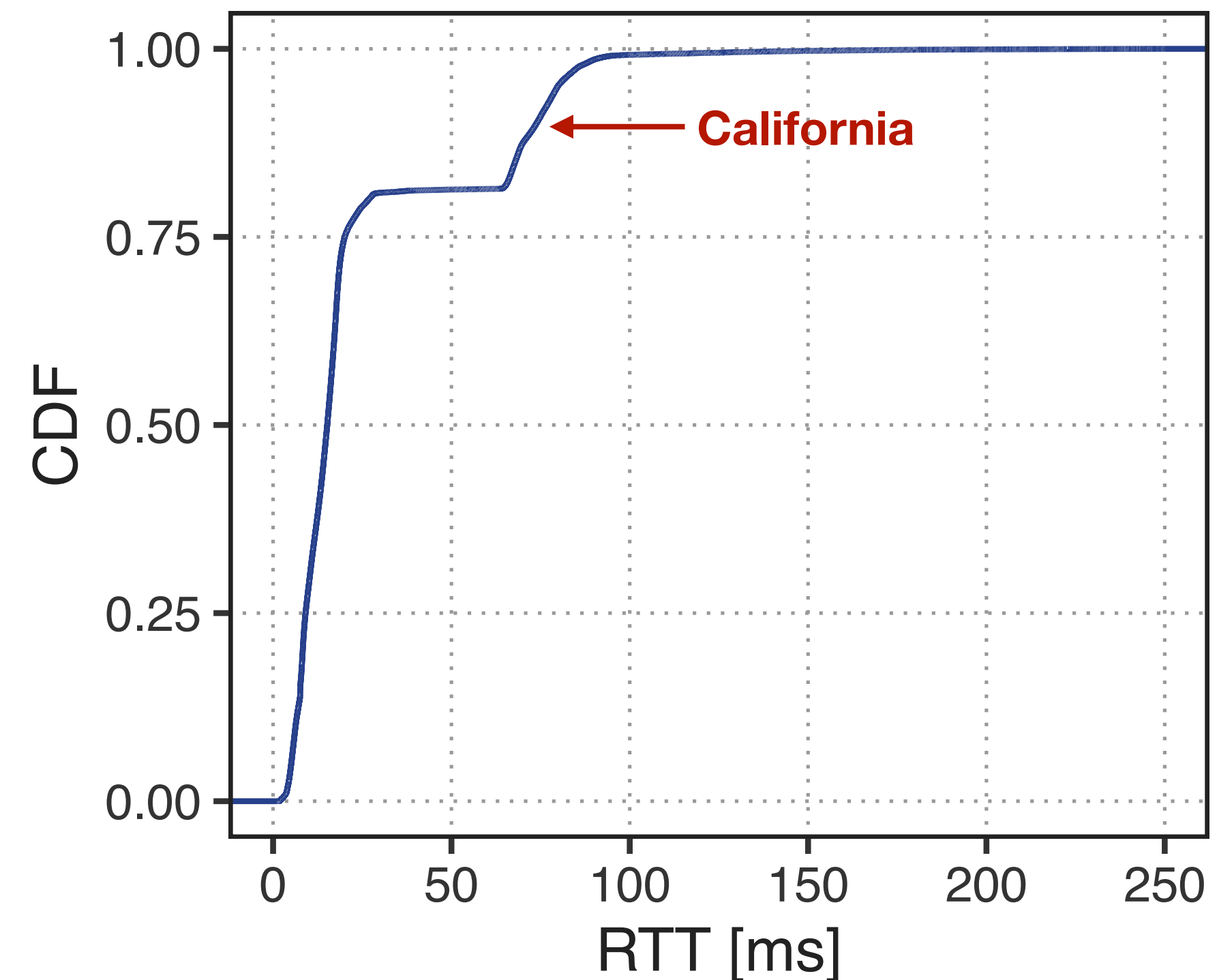


Round-Trip-Times to Zoom Servers
in 12-hour Campus Trace.

Analyzing Zoom Campus Traffic

Latency to Zoom Server

- RTT to server by matching RTP sequence numbers
- 30.1 M latency samples to 521 distinct Zoom IP addresses
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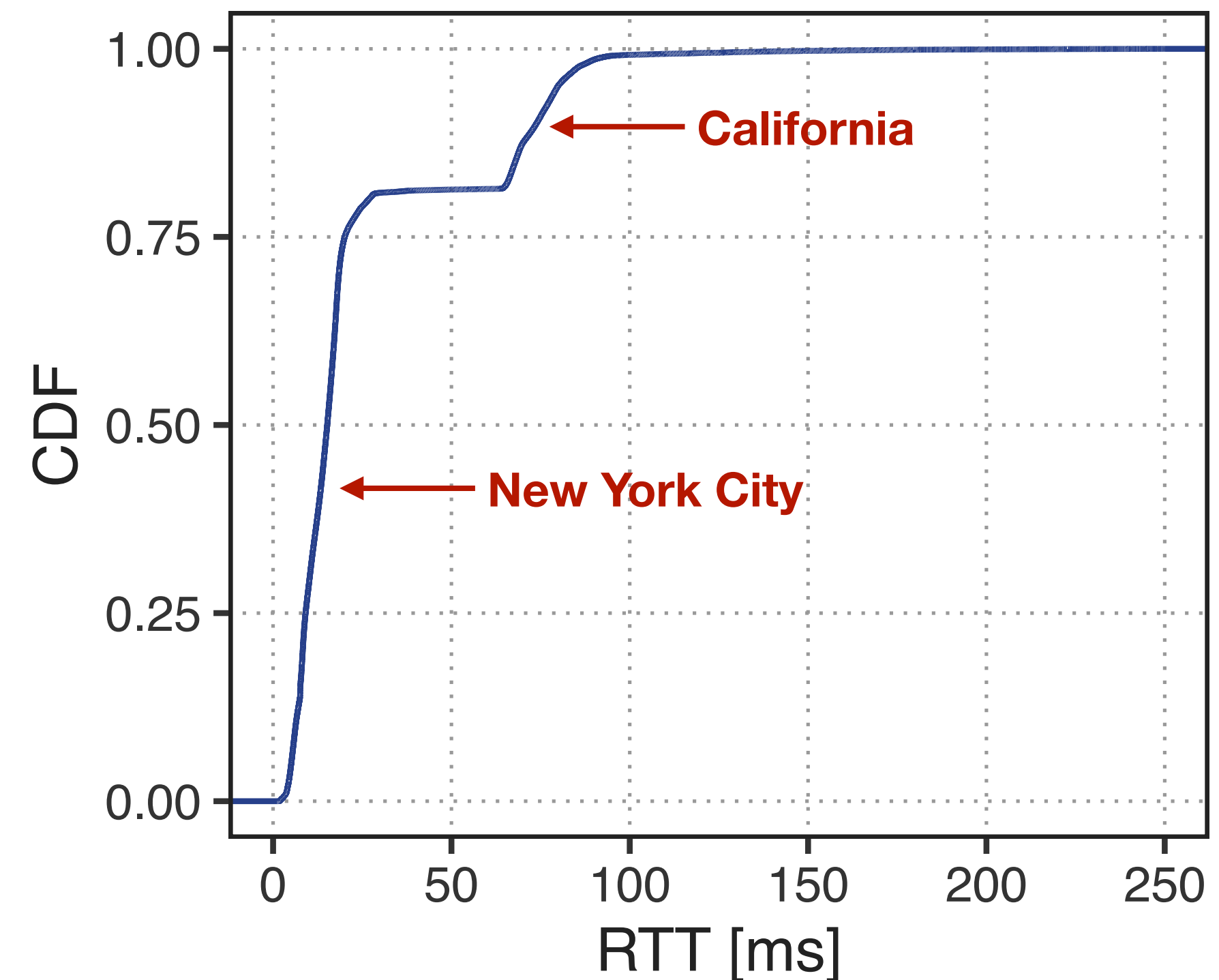


Round-Trip-Times to Zoom Servers
in 12-hour Campus Trace.

Analyzing Zoom Campus Traffic

Latency to Zoom Server

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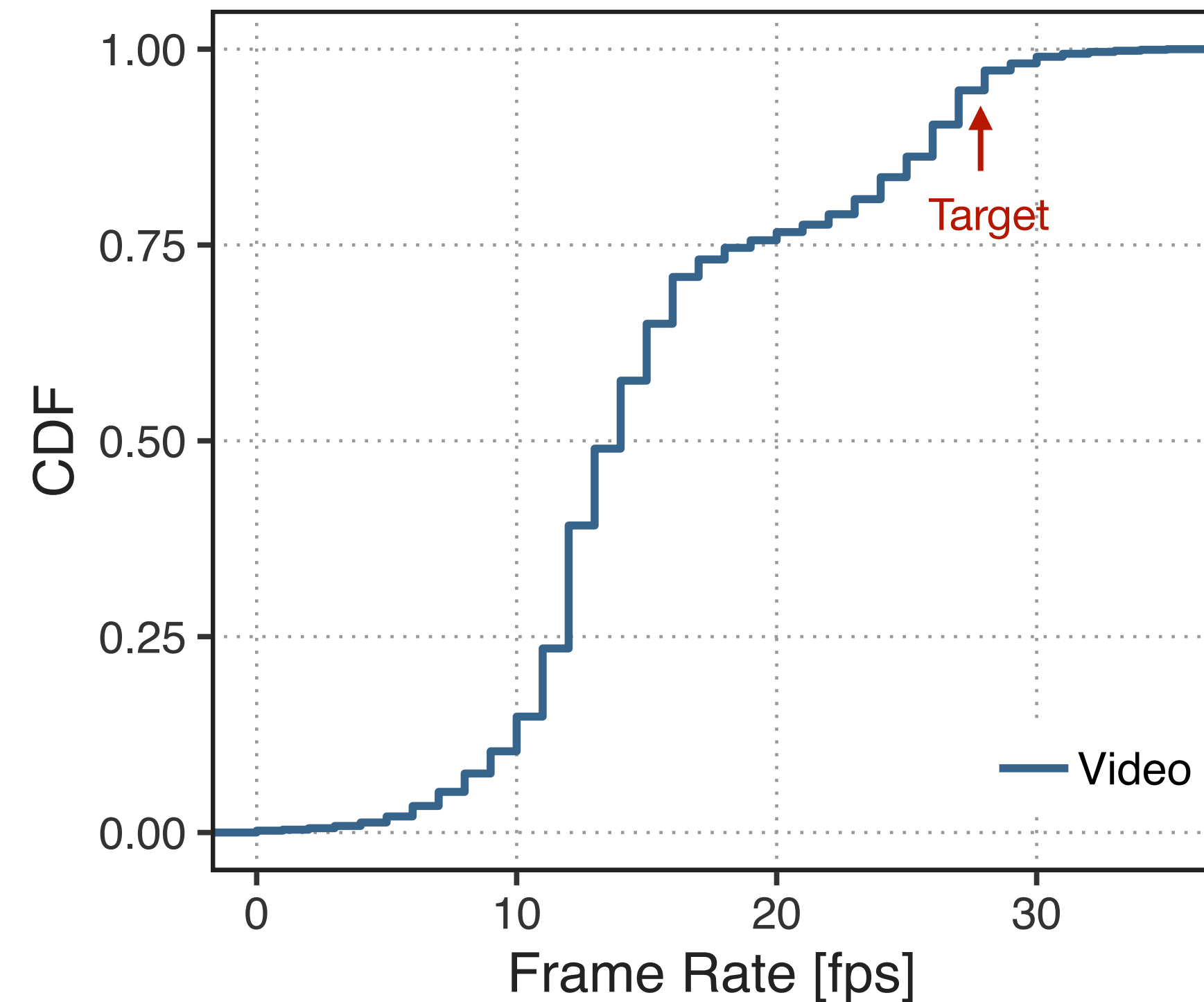


Round-Trip-Times to Zoom Servers
in 12-hour Campus Trace.

Analyzing Zoom Campus Traffic

Frame Rate

- Zoom aims at encoding video at 28 fps
- ~75% of samples show frame rate of less than 20 fps → network problem?

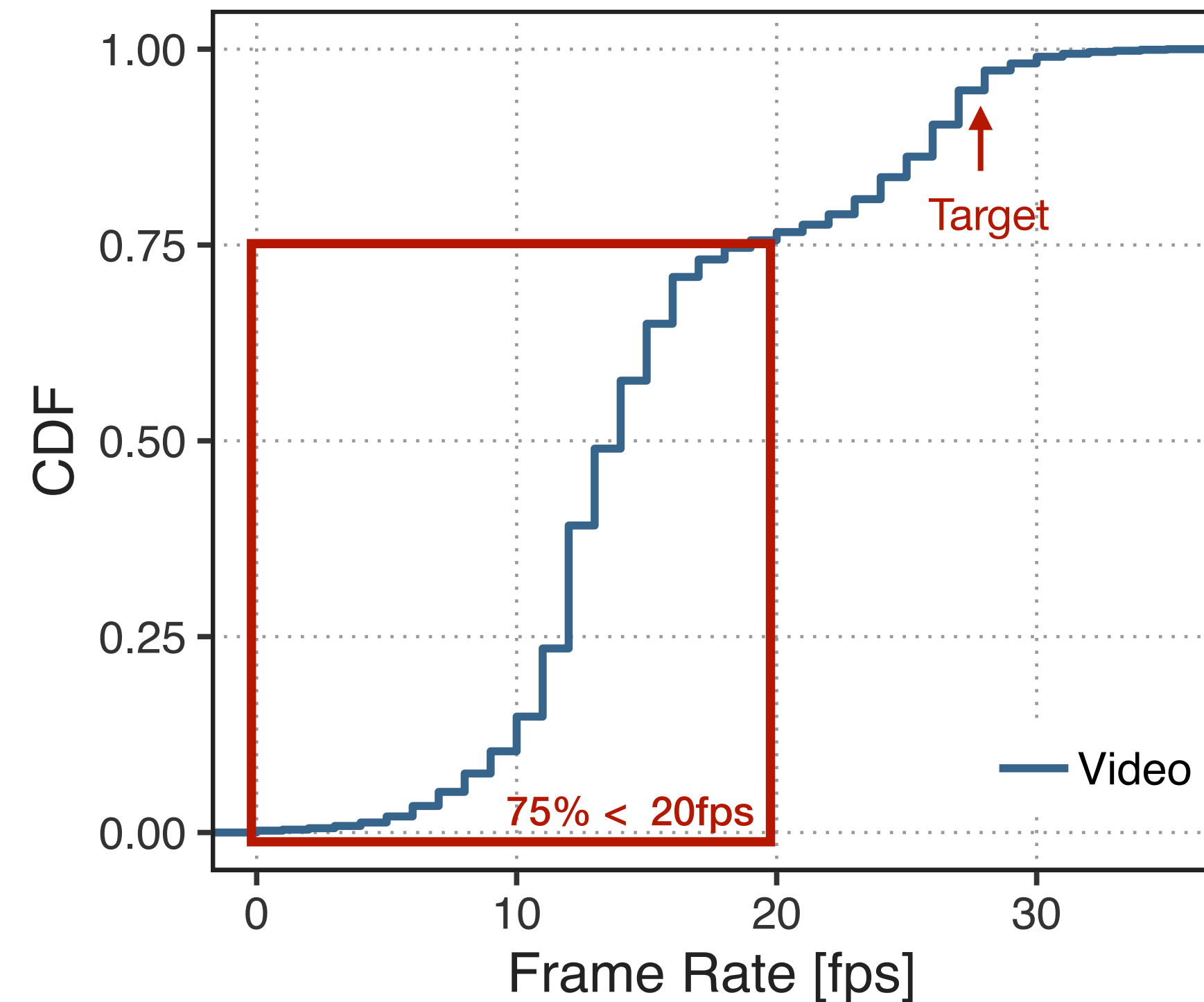


Frame Rates Observed in 12-hour Campus Trace.

Analyzing Zoom Campus Traffic

Frame Rate

- Zoom aims at encoding video at 28 fps
- ~75% of samples show frame rate of less than 20 fps → network problem?

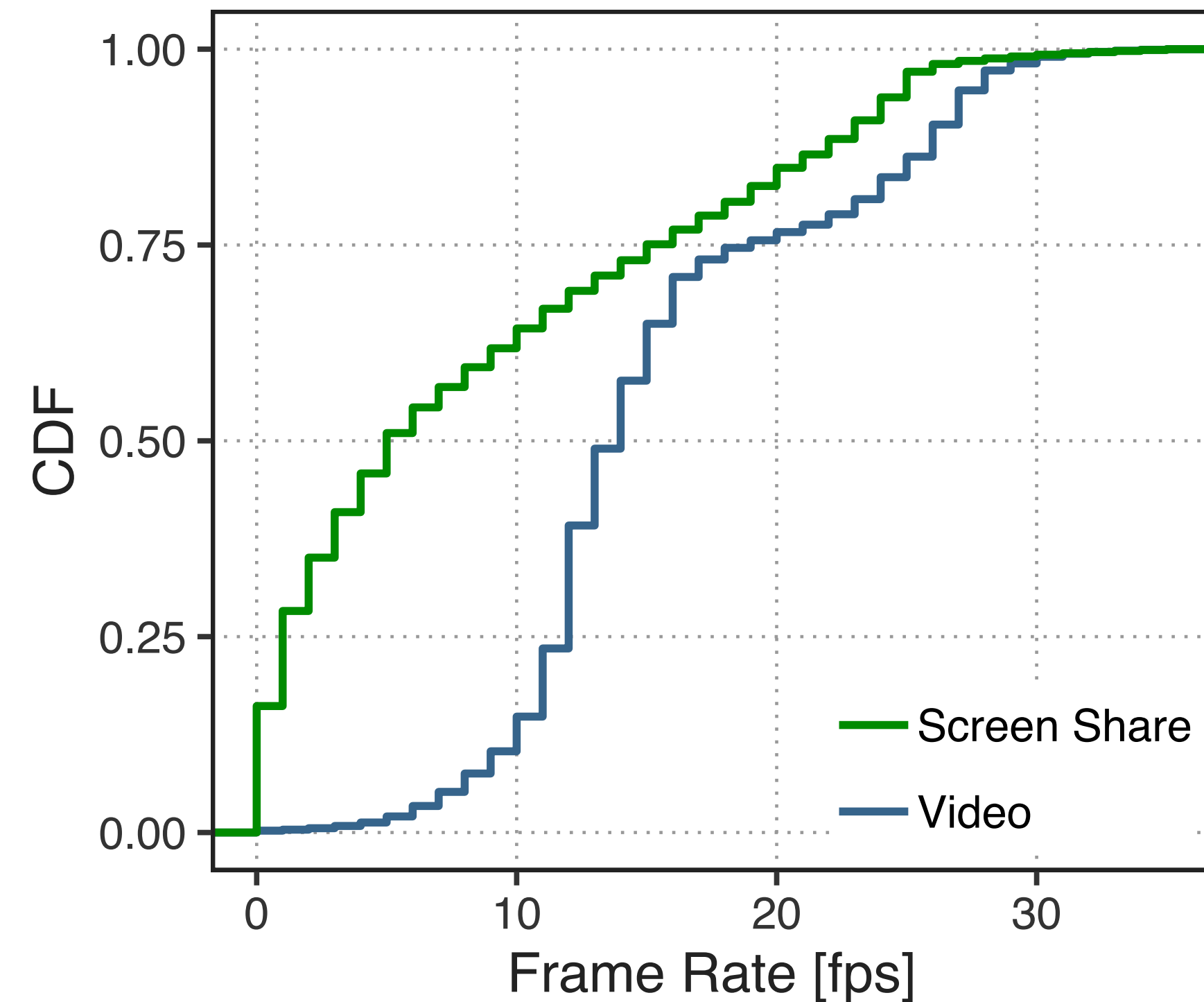


Frame Rates Observed in 12-hour Campus Trace.

Analyzing Zoom Campus Traffic

Frame Rate

- Zoom aims at encoding video at 28 fps
- ~75% of samples show frame rate of less than 20 fps → network problem?
- Content-adaptive encoding of screen sharing content



Frame Rates Observed in 12-hour Campus Trace.

Conclusion

Enable future research and performance measurement on Zoom by

- (1) Demystifying its network protocol and operation
- (2) Showing how to extract useful performance- and quality-related metrics from passive measurements

Conclusion

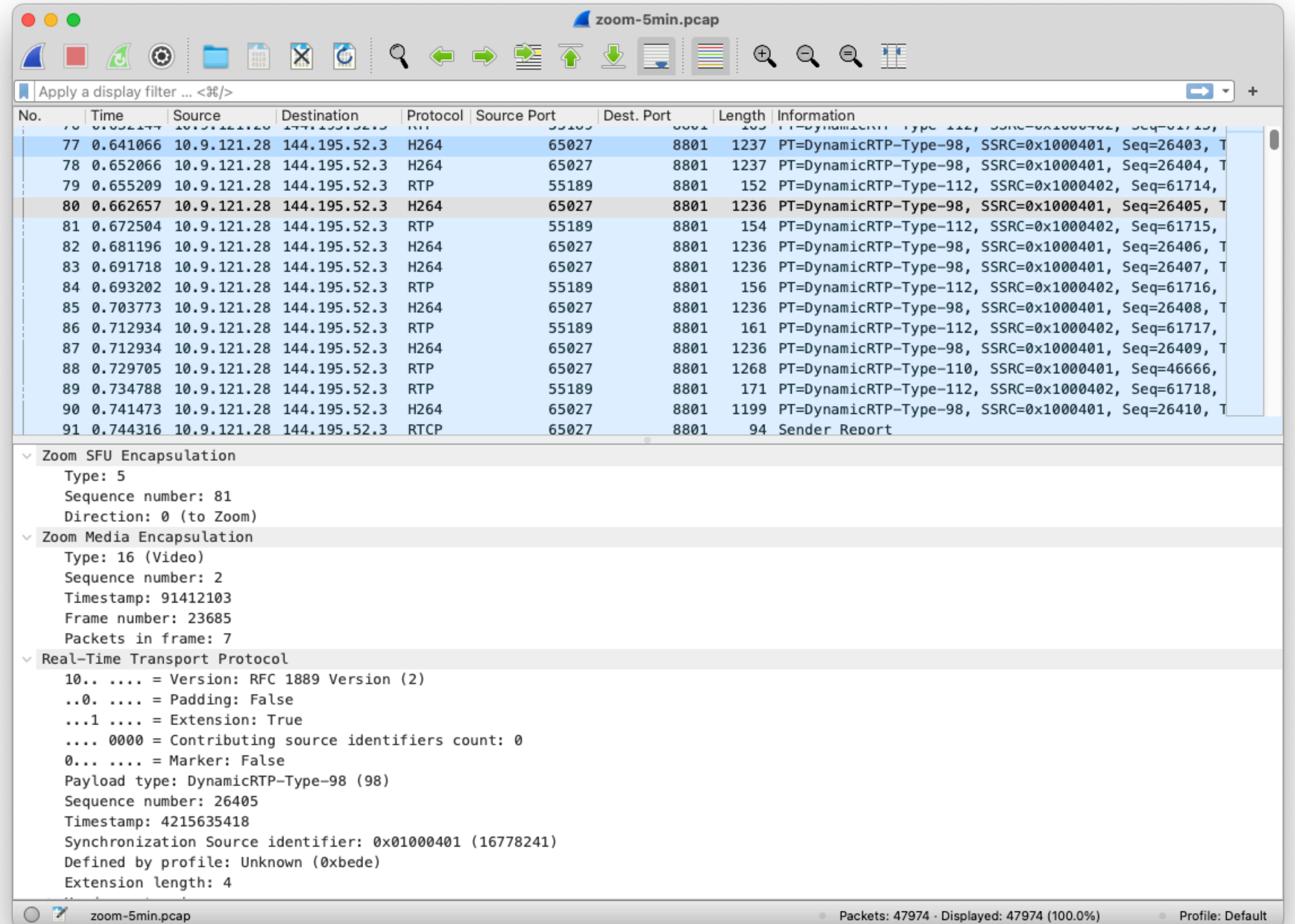
Use Cases & Future Directions

- (1) Better QoE metrics, *e.g.*, estimation of stall likelihood
- (2) Real-time monitoring of video-conferencing performance in programmable switches
- (3) Offloading SFU functionality to programmable switches

Artifacts

- Analysis Tools
- R Notebooks
- Wireshark Plugin
- P4 Capture Program

github.com/princeton-cabernet/zoom-analysis



Q&A

github.com/princeton-cabernet/zoom-analysis

omichel@cs.princeton.edu

Enabling Passive Measurement of Zoom Performance in Production Networks

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ABSTRACT

Video-conferencing applications impose high loads and stringent performance requirements on the network. To better understand and manage these applications, we need effective ways to measure performance in the wild. For example, these measurements would help network operators in capacity planning, troubleshooting, and setting QoS policies. Unfortunately, large-scale measurements of production networks cannot rely on end-host cooperation, and an in-depth analysis of packet traces requires knowledge of the header formats. Zoom is one of the most sophisticated and popular applications, but it uses a proprietary network protocol. In this paper, we demystify how Zoom works at the packet level, and design techniques for analyzing Zoom performance from packet traces. We conduct systematic controlled experiments to discover the relevant unencrypted fields in Zoom packets, as well as how to group streams into meetings and how to identify peer-to-peer meetings. We show how to use the header fields to compute metrics like media bit rates, frame sizes and rates, and latency and jitter, and demonstrate the value of these fine-grained metrics on a 12-hour trace of Zoom traffic on our campus network.

CCS CONCEPTS

• Networks → Application layer protocols; Network measurement; Network architectures.

KEYWORDS

Video Conferencing, Zoom, Measurement, Network Performance, Protocol Analysis, Reverse Engineering

ACM Reference Format:

Oliver Michel, Satadal Sengupta, Hyojoon Kim, Ravi Netravali, and Jennifer Rexford. 2022. Enabling Passive Measurement of Zoom Performance in Production Networks. In *Proceedings of the 22nd ACM Internet Measurement Conference (IMC '22)*, October 25–27, 2022, Nice, France. ACM, New York, NY, USA, 17 pages. <https://doi.org/10.1145/3517745.3561414>

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<https://doi.org/10.1145/3517745.3561414>

1 INTRODUCTION

Video-conferencing applications have seen an unprecedented surge in popularity over the past few years [10, 16]. Zoom has been at the forefront of this phenomenon, with adoption by many organizations to foster teaching, meetings, and presentations during the COVID-19 pandemic [12, 15, 35].

To keep pace with ever-stringent user performance expectations [18, 51] and increasing resource contention, practitioners and researchers need the ability to measure (and improve) Zoom performance in the wild, *without requiring cooperation from end hosts*. For instance, granting this capability to network operators would enable more targeted capacity planning, problem troubleshooting, and traffic-prioritization policies. Realizing this requires the ability to extract metrics such as media bit rates, delay, frame rates, and frame-level jitter solely via analysis of packet captures of Zoom sessions. These insights, in turn, grant a clear understanding of the inner-workings of a Zoom meeting, and the performance and quality experienced by each of its participants. Taken together, we require *fine-grained* measurements and performance insights for Zoom derived from analyzing passively-collected network traffic *in the wild*.

Unfortunately, existing measurement approaches all fall short of at least one of these goals. Some researchers instrument end hosts to run controlled experiments that study Zoom's rate adaptation and performance [7, 10, 25, 27]. However, controlled experiments are labor-intensive, limited in scope, and do not reveal Zoom performance in the wild. Other researchers conduct measurement studies on production networks [12, 35]. Due to Zoom's proprietary network protocol, these studies collect only coarse-grained statistics such as byte and packet rates, which are insufficient for the use cases outlined above. Lastly, while some performance metrics are available to operators through Zoom's API, this data is also coarse-grained (i.e., not packet level) and measured far from the operator's network (i.e., in Zoom's data centers); consequently, this API data is insufficient for rapid adaptation at on-premise network devices.

In this paper, we address this void, and enable direct (and systematic) measurements of Zoom by (1) demystifying how Zoom works at the packet level and (2) designing tools and techniques for analyzing Zoom performance from packet traces. The key challenges are twofold. First, Zoom uses a proprietary packet format, encrypted control and media traffic, and closed-source client software [12, 25, 29, 35]. As a result, Zoom cannot be analyzed easily

BACKUP SLIDES

Backup Slides

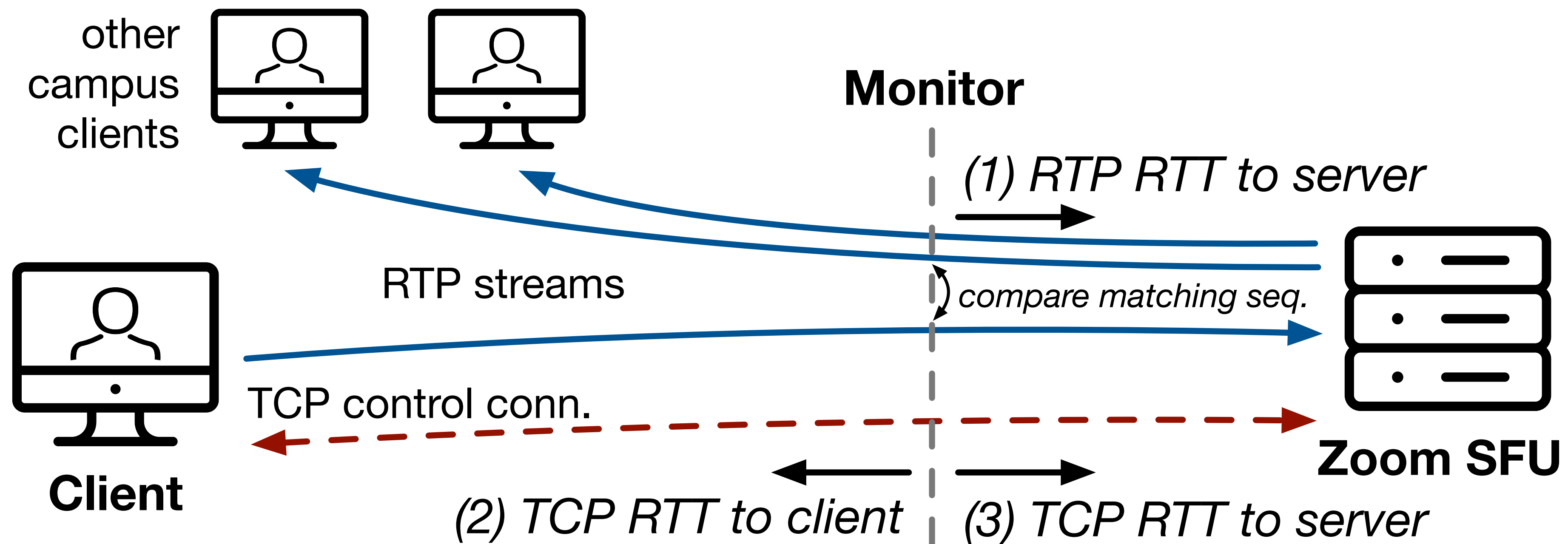
Index

- (23) Possible Reasons for Proprietary Header Format
- (24) Latency Measurement Methods
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- (29) P4 Program
- (30) Relation to ML-based Approaches
- (31) Use of RTP in Video-Conferencing Applications

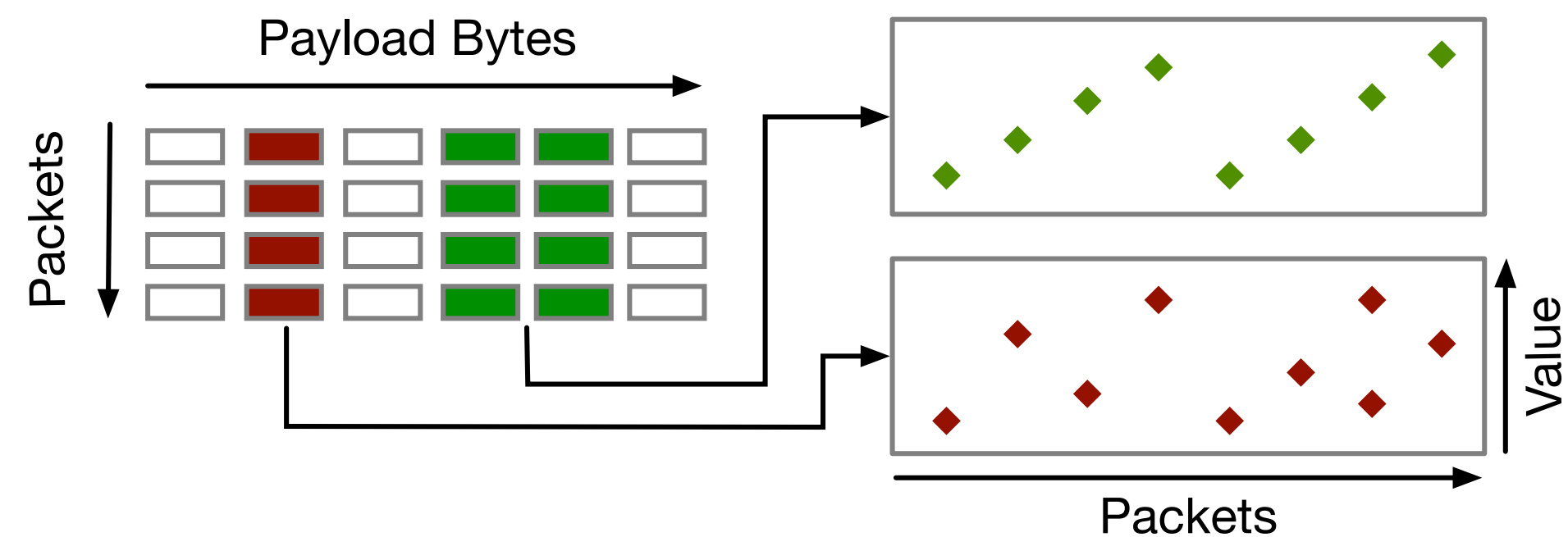
Possible Reasons for Proprietary Header Format

- More advanced/custom congestion control algorithm
- Many customizations that do require additional in-band meta data
- Attempt to hide internals

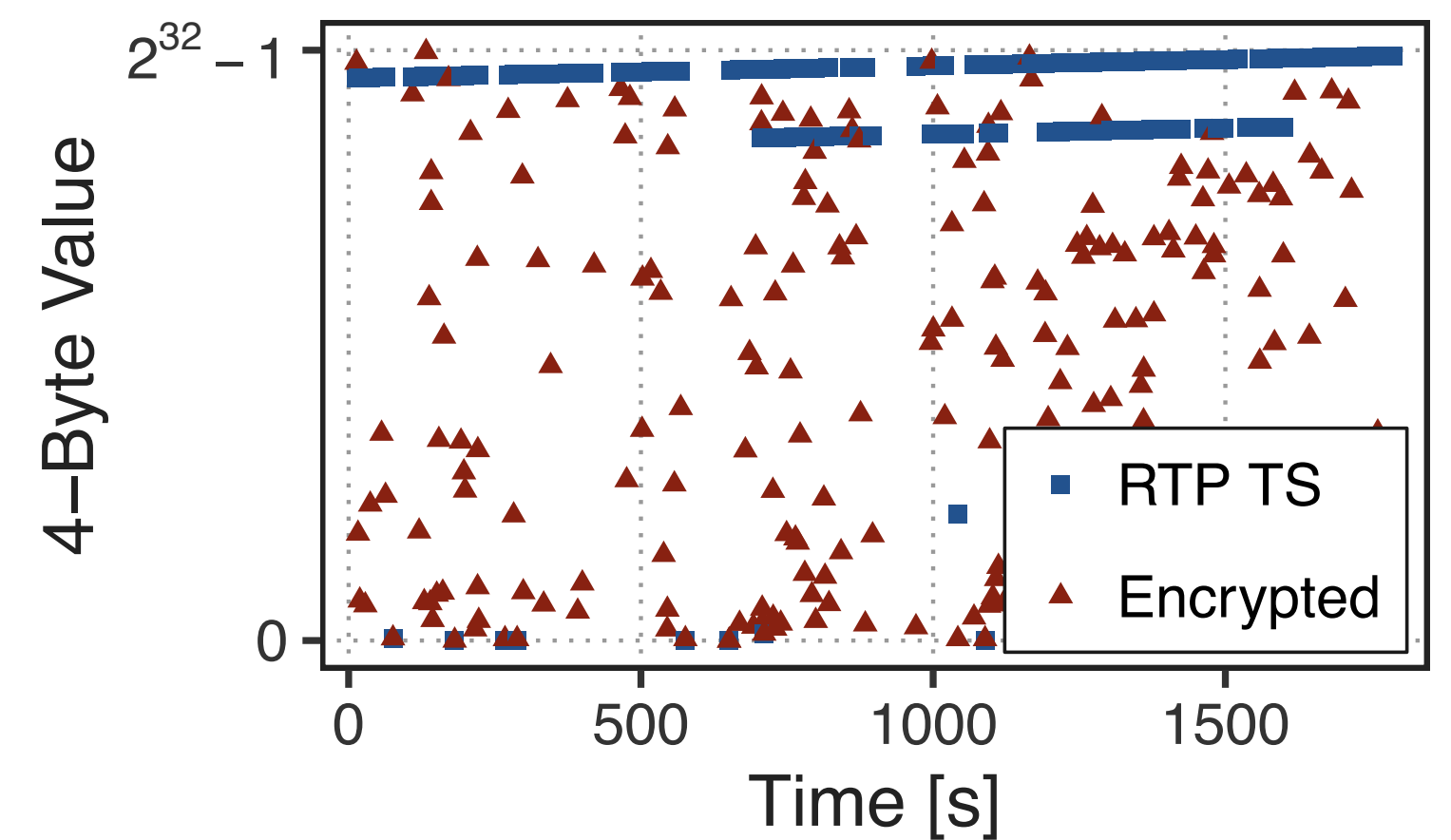
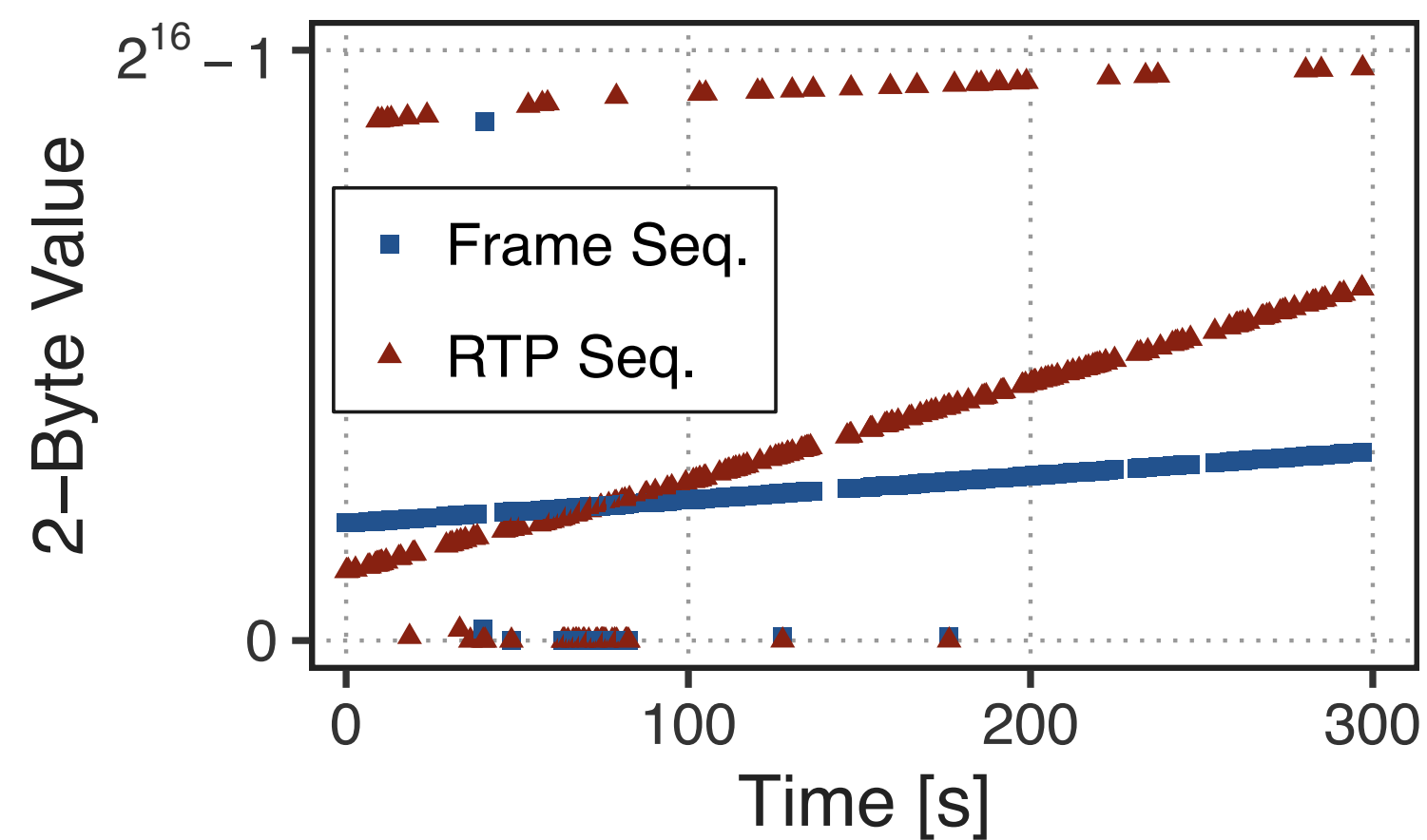
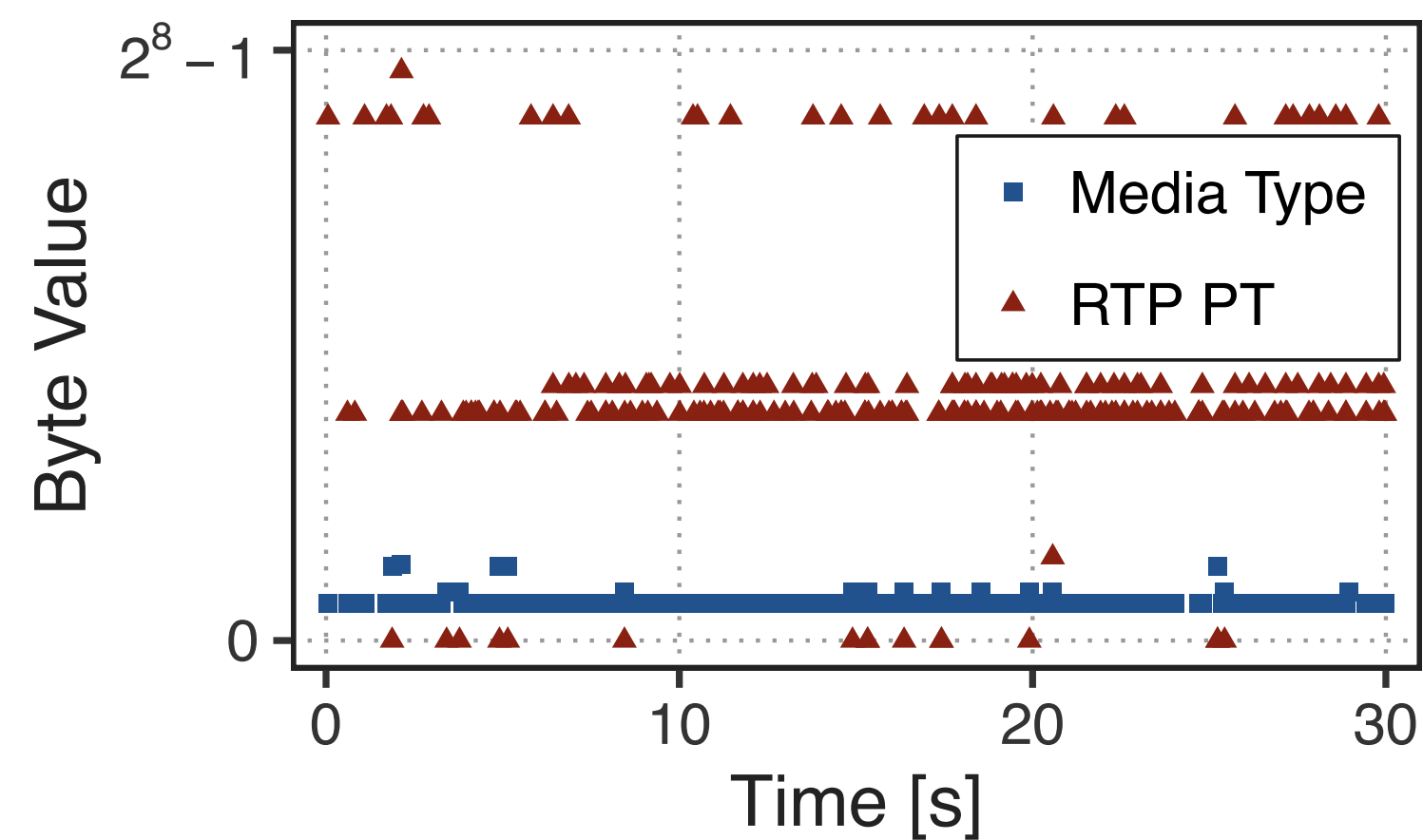
Latency Measurement Methods



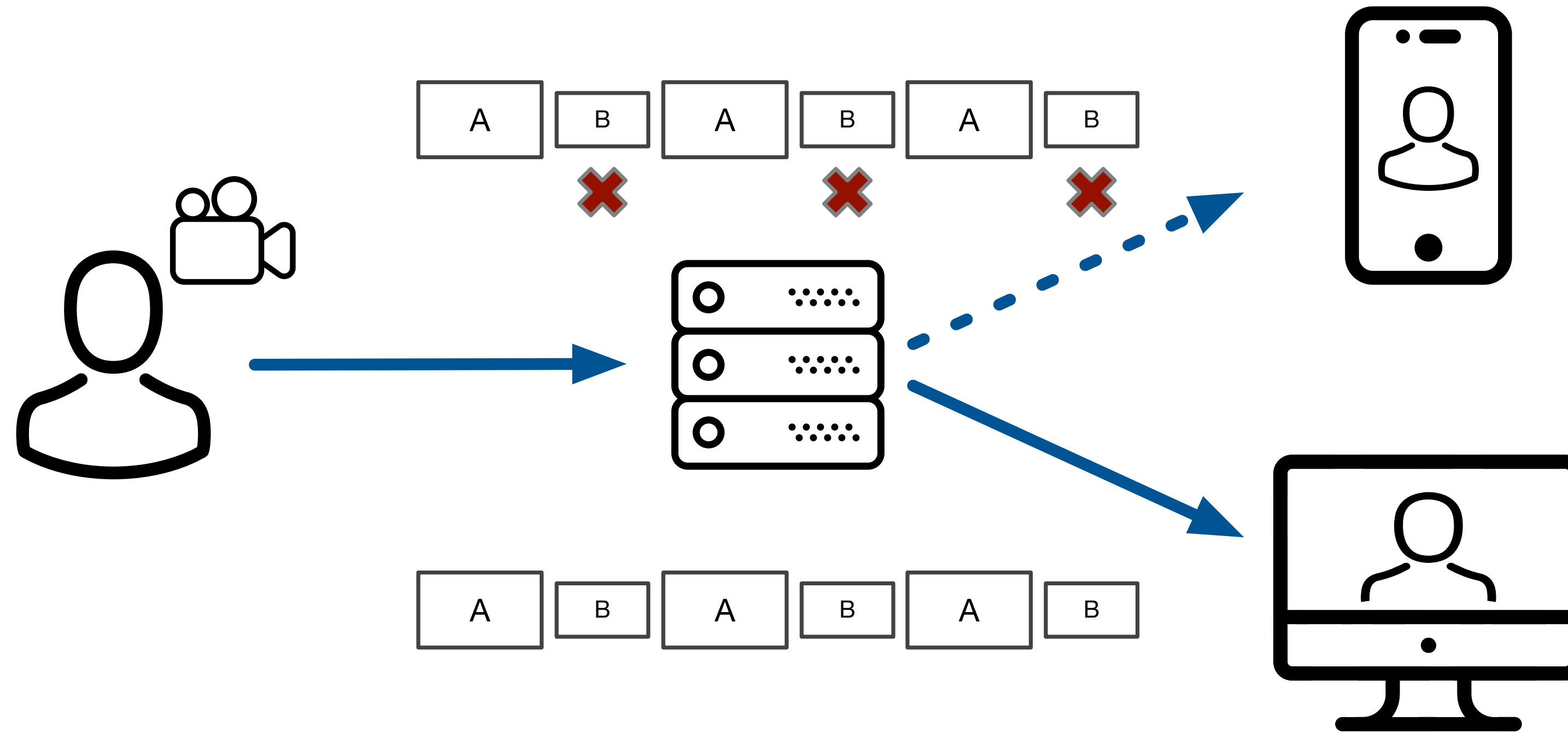
Entropy-based Header Analysis



- Extract 1B, 2B, 4B values from all (1B-aligned) offsets after UDP header
- Plot values over time

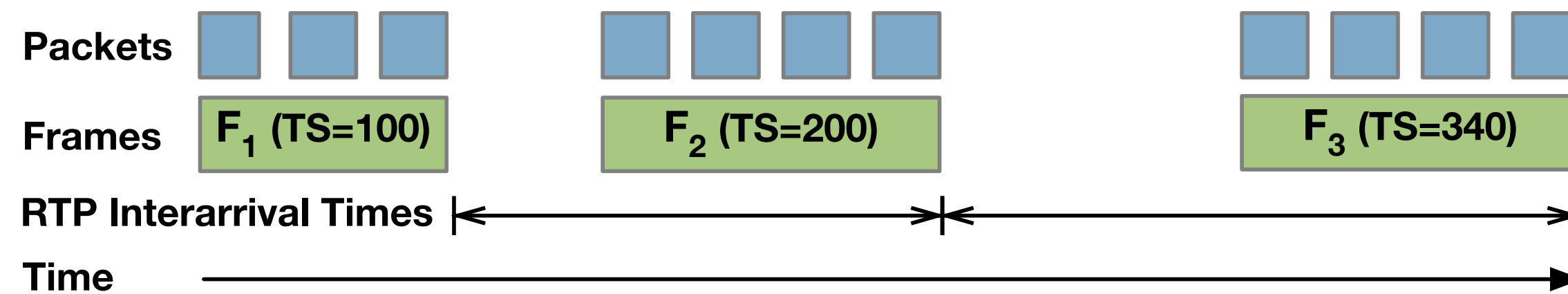


Need for Unencrypted Header Fields/SFU

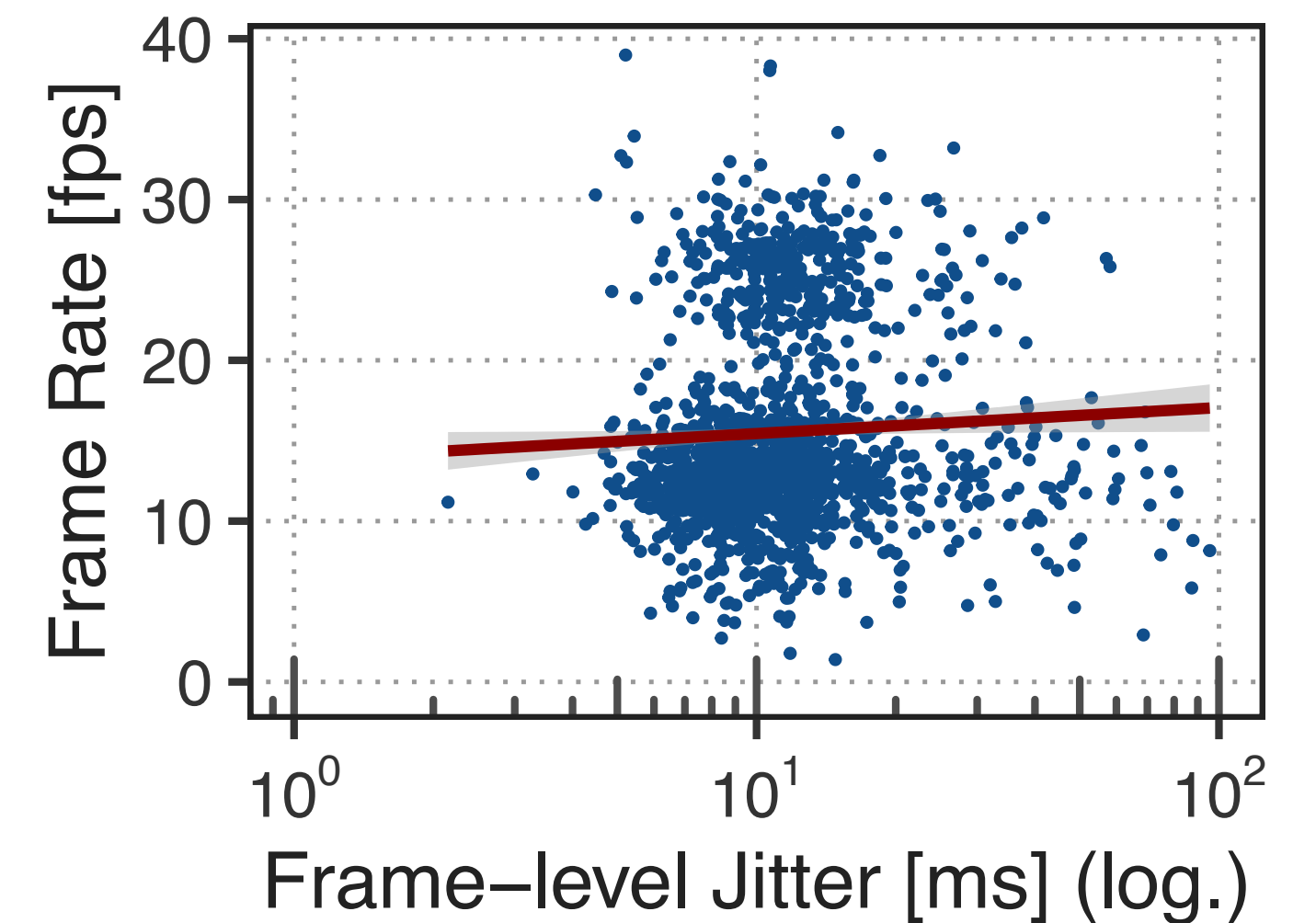
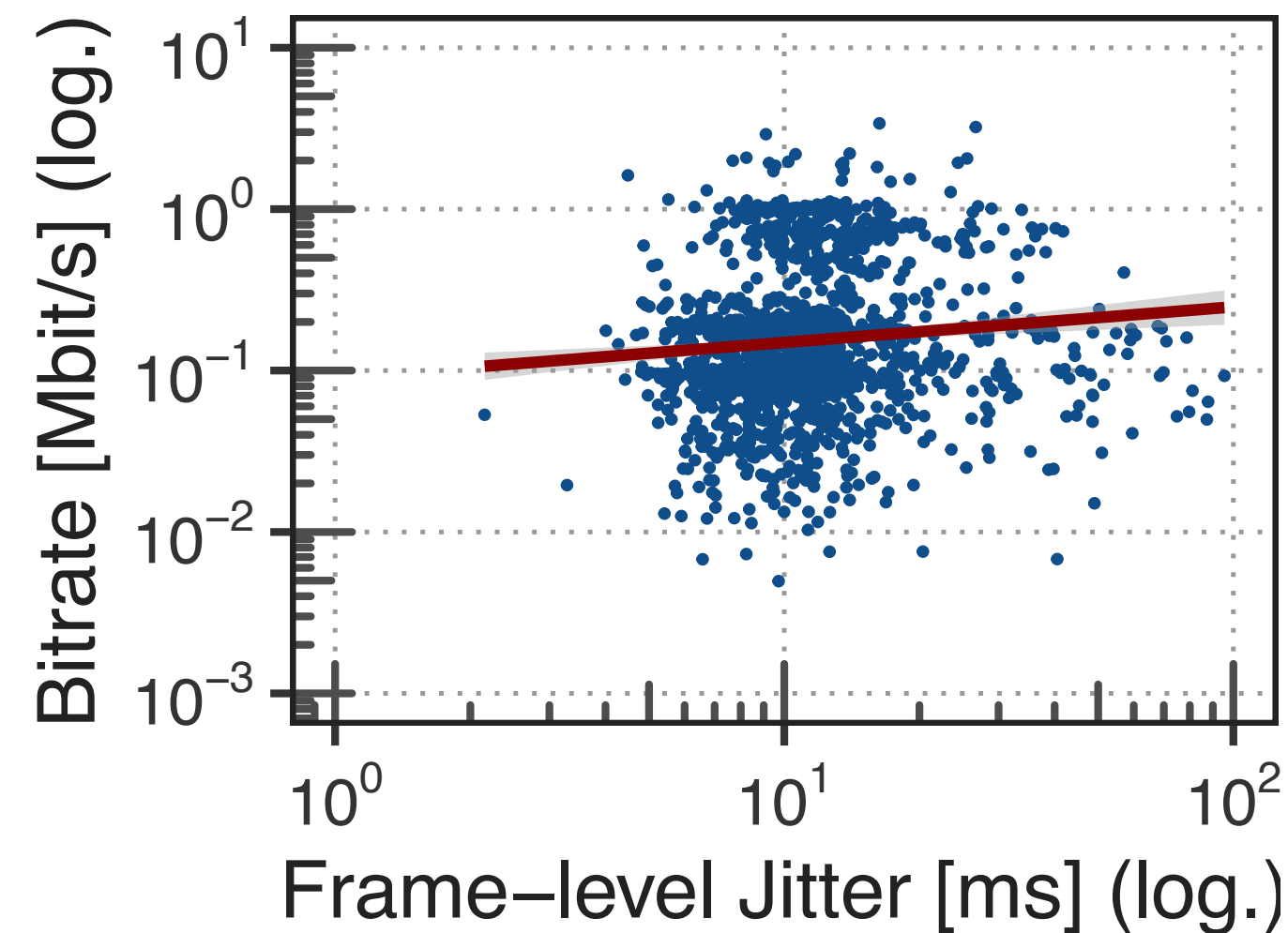
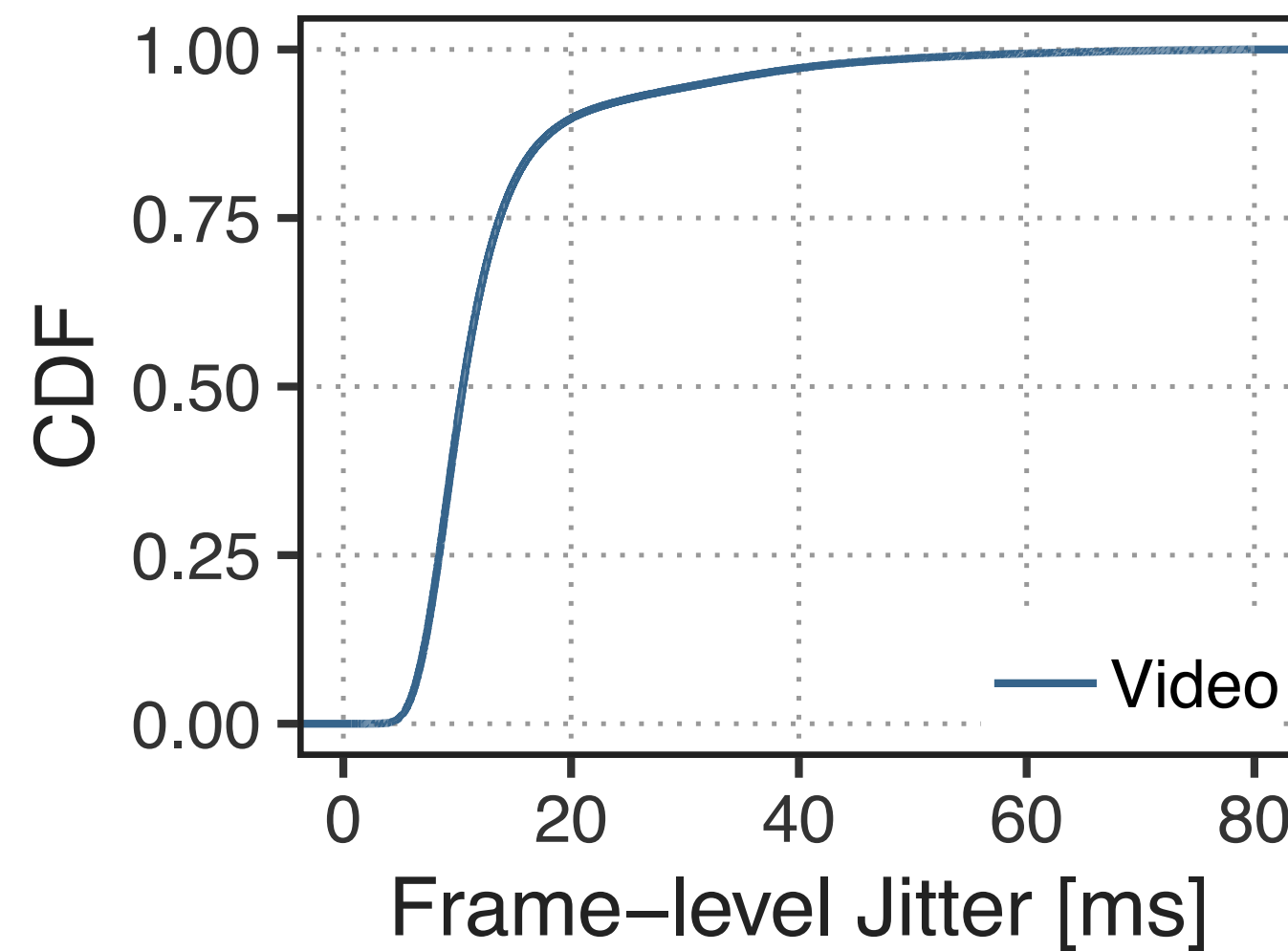


- Selective forwarding based on header meta data
- Encrypted header fields would result in:
 - Decrypt/encrypt for every packet / expensive, not performed by Zoom
 - Not compatible with E2E encryption

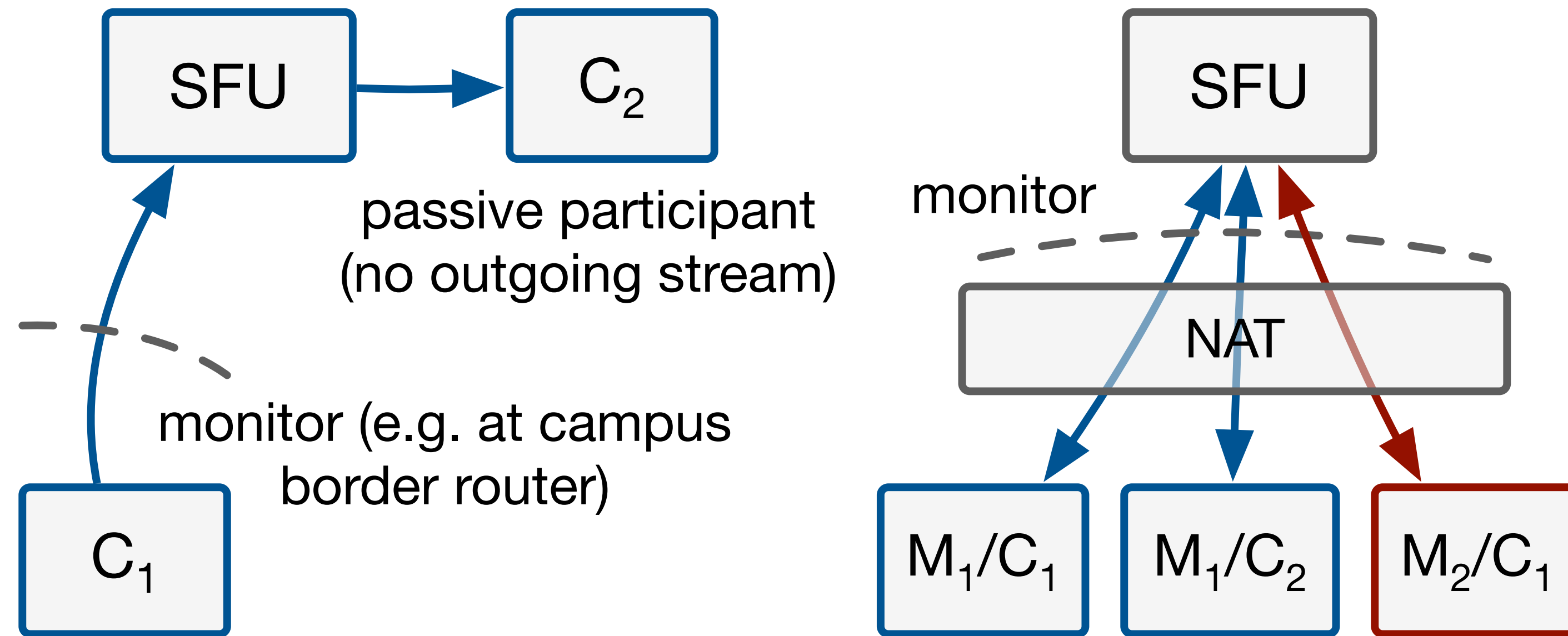
Frame-level Jitter Calculation



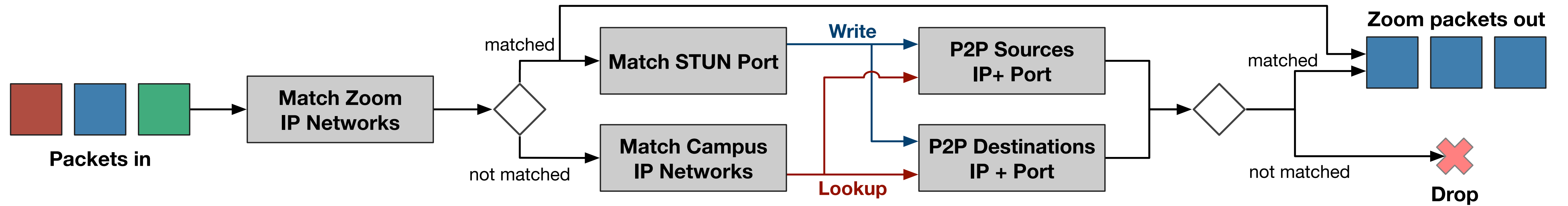
RFC 3550: Appendix A.8
Estimating the Interarrival Jitter



Limitations of Grouping Heuristic



P4 Program



Relation to ML-based Approaches

- Precise measurements / no estimations
- Performance indicators vs. Quality of Experience
 - Measurements can be used to create features
 - Labels from E2E measurements (e.g., SSIM) or MOS
- Create large, feature-rich data sets from production networks

Use of RTP in Video-Conferencing Applications

TABLE II: Comparison of the RTC applications under test. Under *Redundant data*, “F” stands for FEC and “S” for Simulcast. Under *DNS domains*, “B” stands for easy to block, “C” for company-specific and “S” for social networks. Under *Other*, “N” means it uses less than four server-side ports and “T” means that PTs are used in a static fashion.

Application	Protocols				P2P	Operation Redundant Data		Identification		
	RTP	STUN/TURN	DTLS	Other		Other	Own AS	DNS Domains	Other	
Skype	✓	✓		✓	✓	F,S		✓	B	N,T
Google Meet	✓	✓	✓			S	✓	✓	C	N,T
Jitsi Meet	✓	✓	✓		✓				B	
WhatsApp	✓	✓			✓	F		✓	B	N,T
Telegram		✓		✓	✓			✓	B	
Facebook Messenger	✓	✓	✓		✓			✓	S	T
Instagram Messenger	✓	✓						✓	S	N,T
Facetime	✓	✓			✓		✓	✓	C	N,T
HouseParty	✓	✓	✓						B	T
Microsoft Teams	✓	✓		✓	✓	F,S		✓	B	N,T
Webex Teams	✓	✓				F,S	✓	✓	B	N
Zoom	✓			✓	✓	F			B	N,T
GoTo Meeting				✓					B	N

[A. Nisticò, D. Markudova, M. Trevisan, M. Meo and G. Carofiglio, "A comparative study of RTC applications", 2020 IEEE International Symposium on Multimedia (ISM), 2020, pp. 1-8, doi: 10.1109/ISM.2020.00007.]