Protocol Compliance Study in Popular RTC Applications

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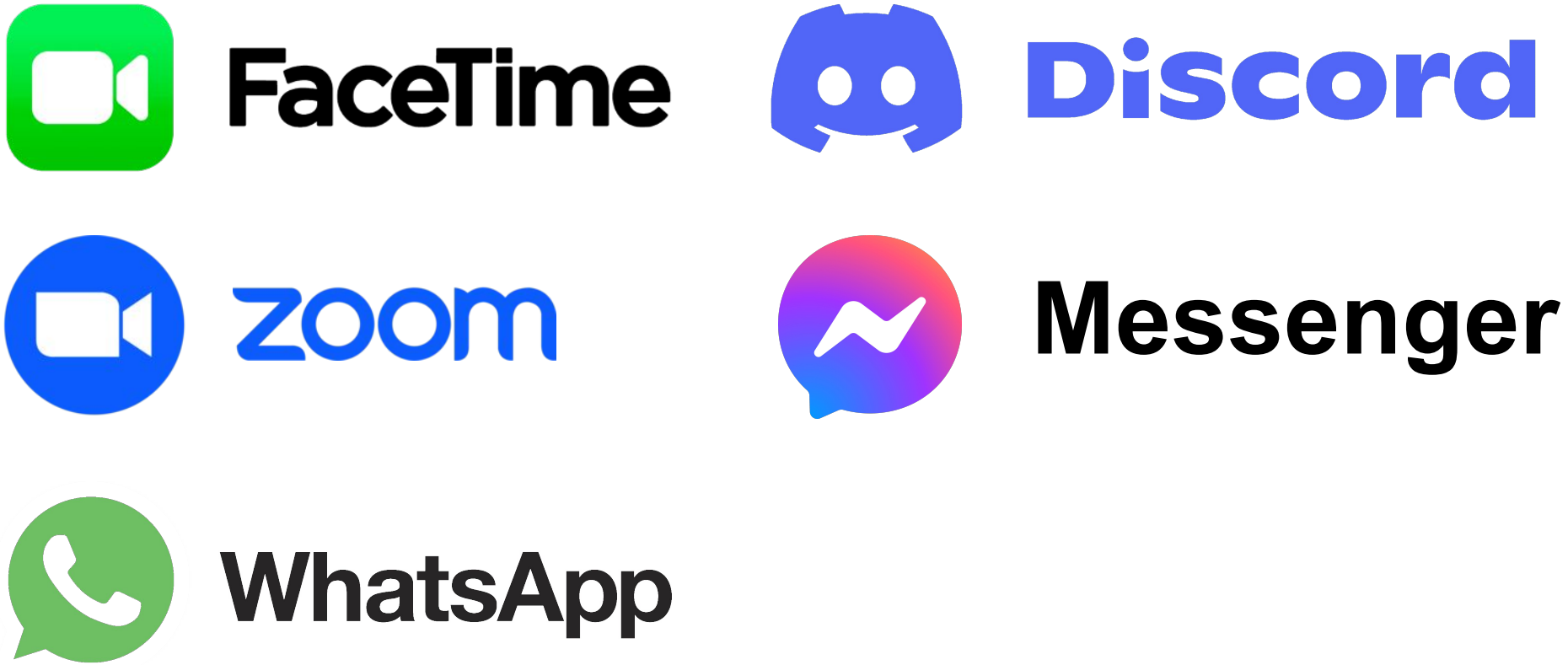
RTC Apps are Wild

- Do NOT fully comply with RFCs.
- We will measure and discuss:
  - To what extent do RTC apps comply?
  - Why do RTC apps modify, or augment the standards?

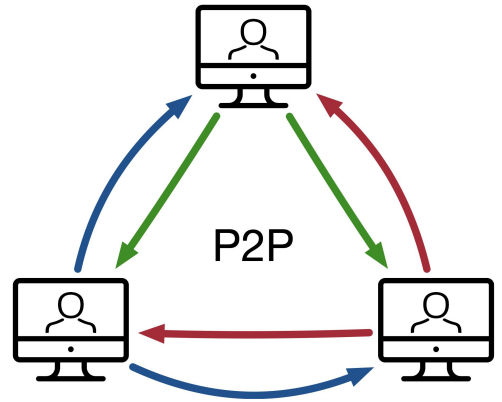
	FaceTime	Zoom	Discord	Messenger	WhatsApp
Extension of standard features				✅	✅
Proprietary implementation of standard features	✅	✅	✅		✅
Invention of non-standard features	✅	✅	✅		✅

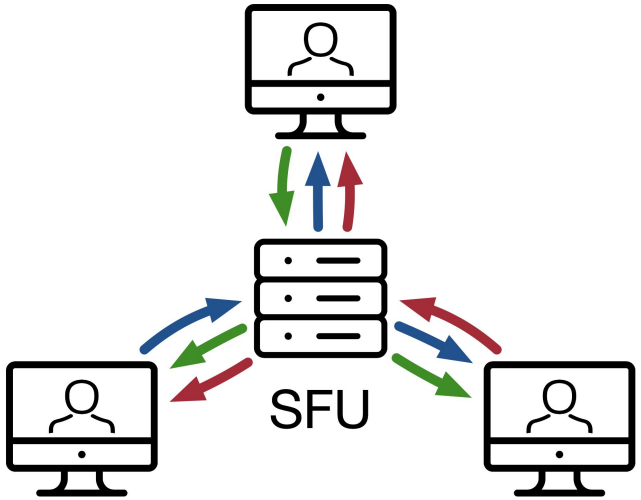
Real-Time Communication (RTC) Apps



RFCs for RTC

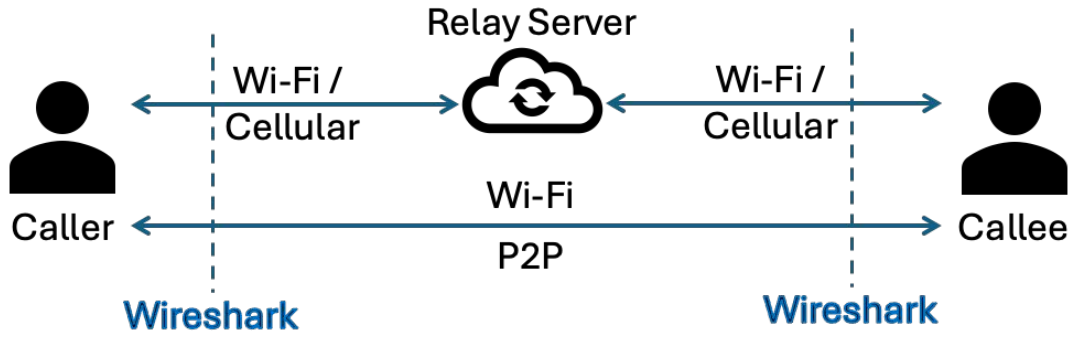
- Session Establishment
  - Session Traversal Utilities for NAT (STUN)
  - Traversal Using Relays around NAT (TURN)
  - Interactive Connectivity Establishment (ICE)
- Transport Protocols
  - UDP/TCP/QUIC
- Media Transport Protocols
  - Real-Time Transport Protocol (RTP)
  - RTP Control Protocol (RTCP)





Data Collection & Preprocessing

- One-to-One Call Setup
  - 5 Apps: FaceTime, Zoom, Discord, Messenger, WhatsApp
  - Device/Tools: Two iOS client devices + Wireshark on Mac for capturing packets
  - Networks: cellular network + Wi-Fi
- Test Procedure
  - 5s period for each user action:
    - Turn on/off media devices (e.g. video and audio)
    - Switch networks (Wi-Fi vs Cellular)
    - Reconnect the call after temporary exiting
- Preprocessing
  - Remove background traffic
  - Classify call sessions into P2P or relay mode
  - Differentiation between media and non-media data



Highlights

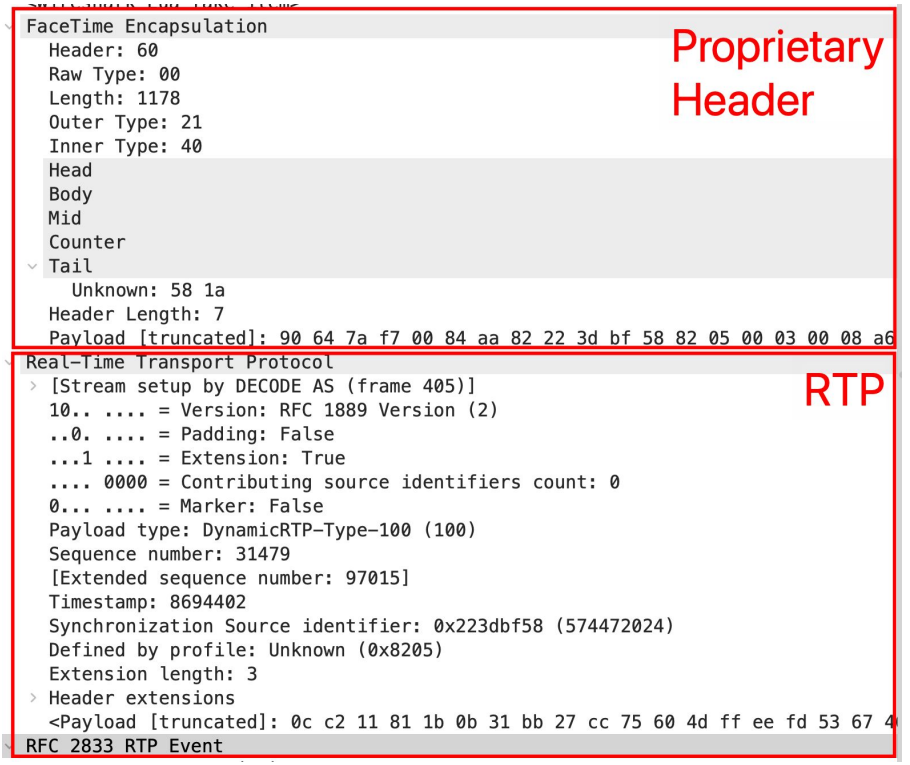
Applications	Features
FaceTime	● Co-existence of QUIC and non-QUIC in one UDP session. ● Proprietary RTP Encapsulation. ● various types of ping-pong messages
Zoom	● 1000-byte filler packets. ● Proprietary RTP Encapsulation. ● Proprietary ping-pong packets with time-based counters.
Discord	● Absence of P2P mode in one-to-one calls. ● Proprietary STUN-like packets for client public IP discovery. ● Proprietary ping-pong packets with a time-based counter.
Messenger	● Proprietary STUN attribute as timestamp. ● Proprietary STUN attribute as client network cost and type. ● Proprietary TURN attribute as client identifier.
WhatsApp	● 5/9 STUN messages are proprietary ● 5/11 STUN attributes are proprietary ● 3/11 STUN attributes are not compliant

FaceTime: multiplexing

- QUIC (.9%)
  - complete QUIC handshake
  - one QUIC session per network interface
  - client to relay server, not caller to callee
- RTP (96.7%)
  - Locate the standard RTP header
- STUN (1%)
- Others (1.4%)

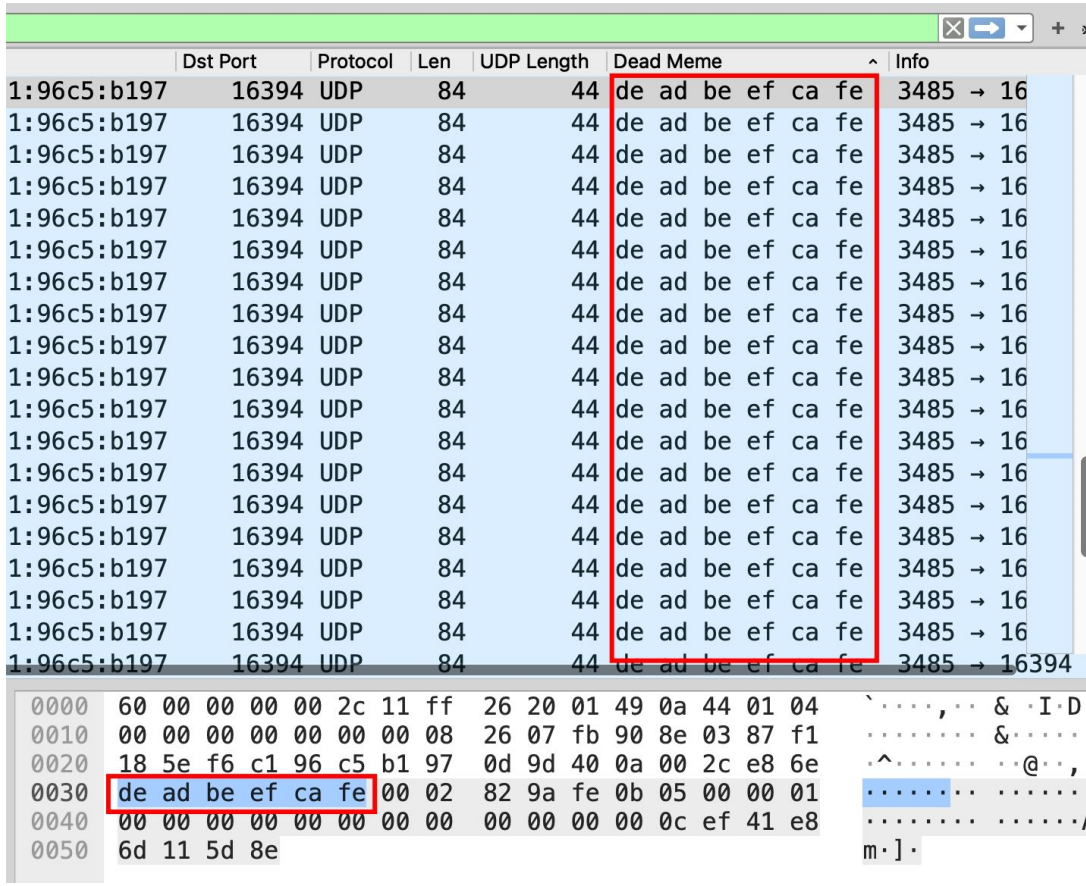
FaceTime: Proprietary RTP Encapsulation

- RTP with a proprietary header (96.7%)
  - Locate the standard RTP header
  - This proprietary header varies from 5 to 43 bytes.



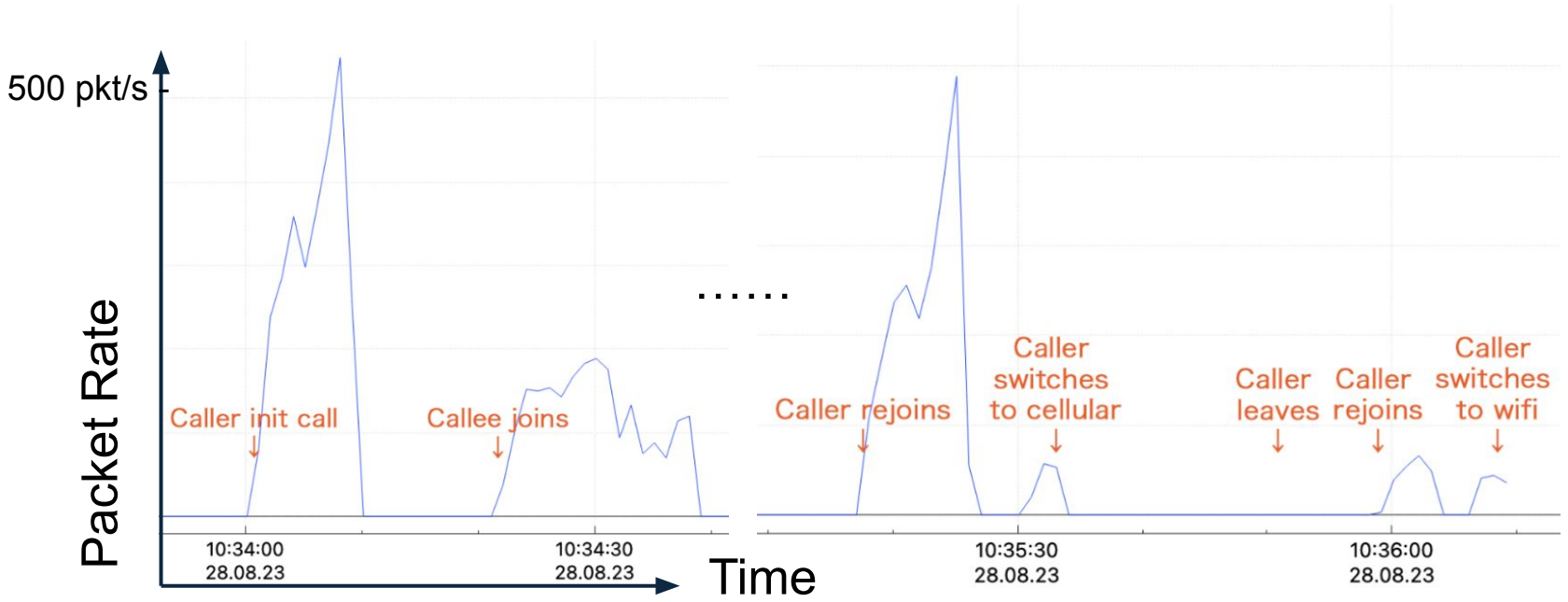
FaceTime: Ping-Pong at various protocols

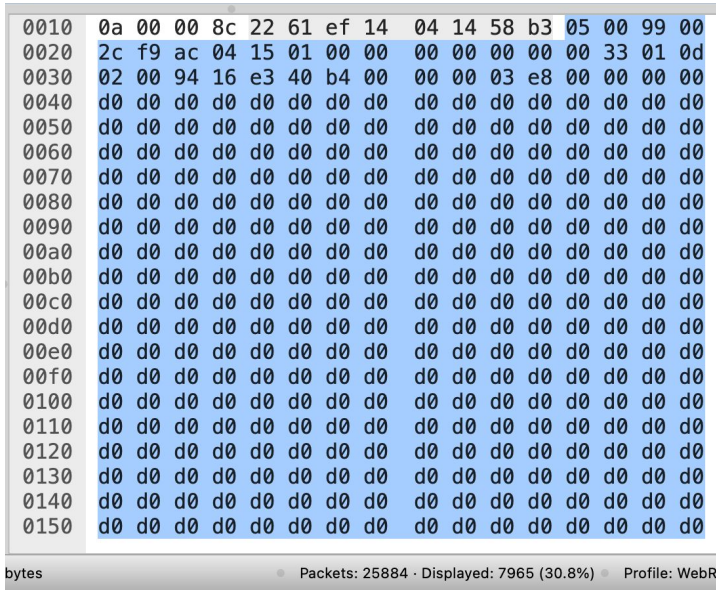
- QUIC
  - 5-8 QUIC packets every 15s
- Proprietary protocol
  - Cellular only and server to client only
  - datagrams of 44 bytes @ 17 pkt/s
  - starts with “0xdeadbeefcafe”
- STUN binding requests
  - last for exact 60s, at a constant pps



Zoom: 1000-Byte Filler Packets

- Payload bytes are identical (“0xda”)
  - it lasts 10~20s, after network changes
  - pps ramps up to ~500 pkt/s
- Speculation: Proprietary protocol for bandwidth probing

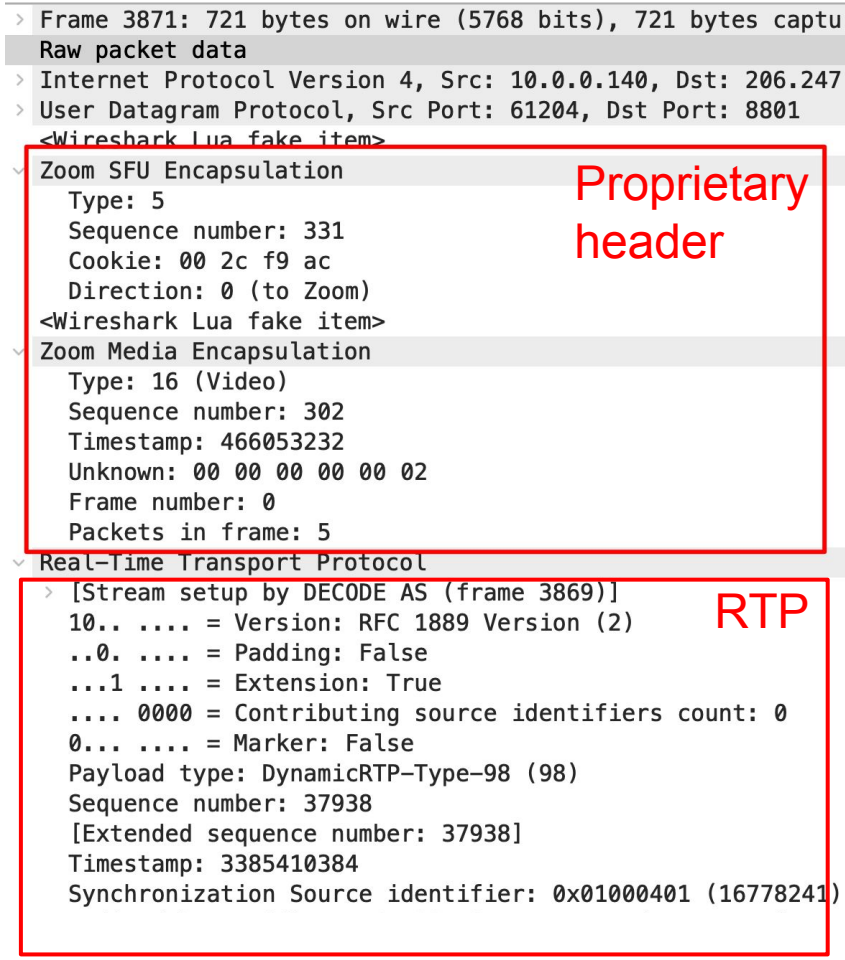




Zoom: Proprietary Encapsulation

- Proprietary header before and RTP*
  - 27~33 bytes
  - 1-byte indicator for packet direction
  - 1-byte indicator for media type

- Speculation: Additional media info layer.

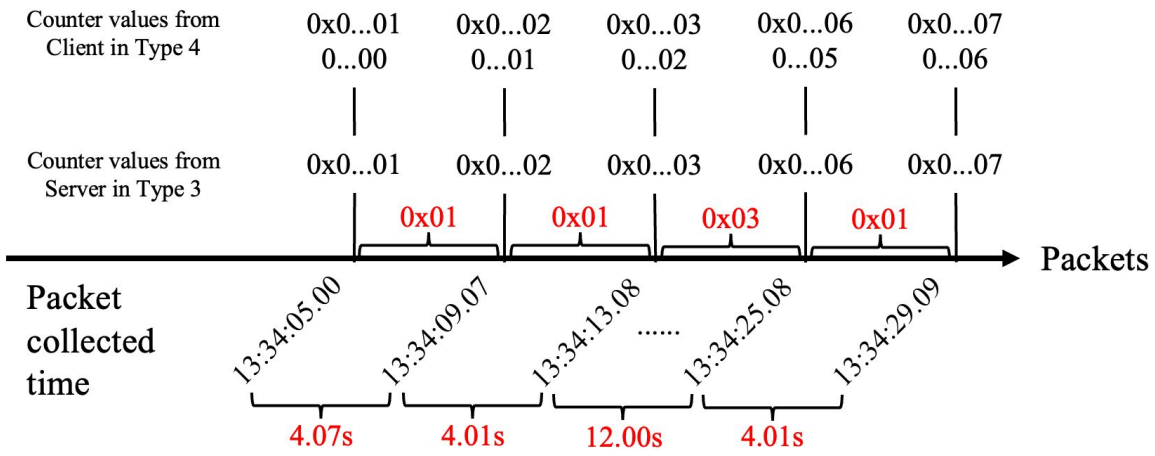


* Michel, Oliver, et al. "Enabling Passive Measurement of Zoom Performance in Production Networks." Proceedings of the 22nd ACM Internet Measurement Conference (IMC '22), 2022

Zoom: Proprietary Ping-pong

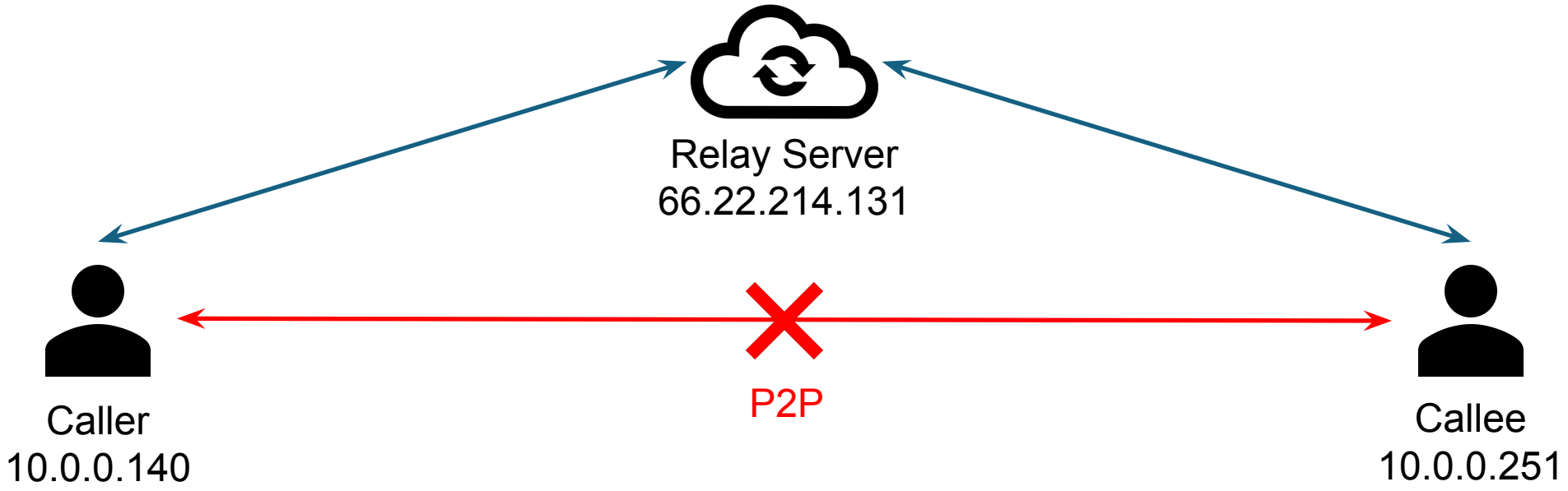
- After call established, 2 ping-pong transactions every 4 seconds,
  - Client ping; Server pong (Same UDP payload size: 81 bytes; No counter)
  - Server ping; Client pong (Different UDP payload size; Both with a time counter)
- If network switches, the counter will be reset.

- Speculation: Proprietary implementation of ICE connectivity check



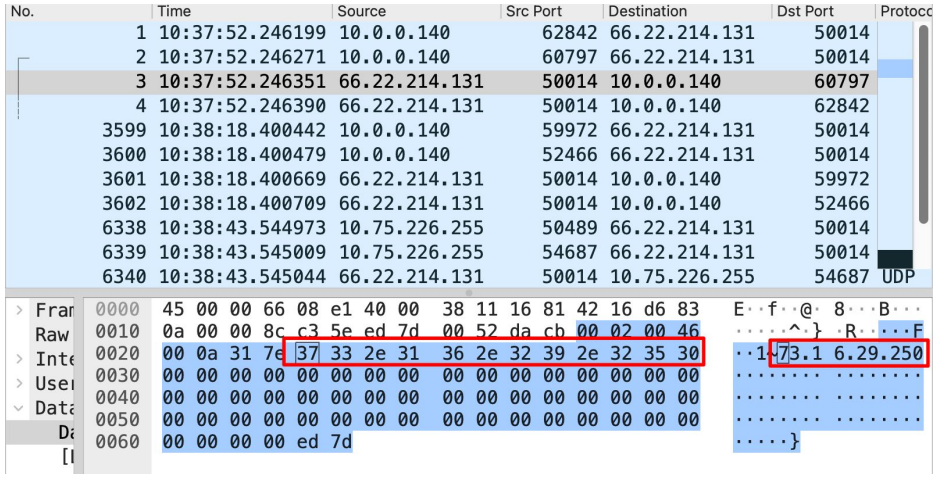
Discord: Absence of P2P Mode in Calls

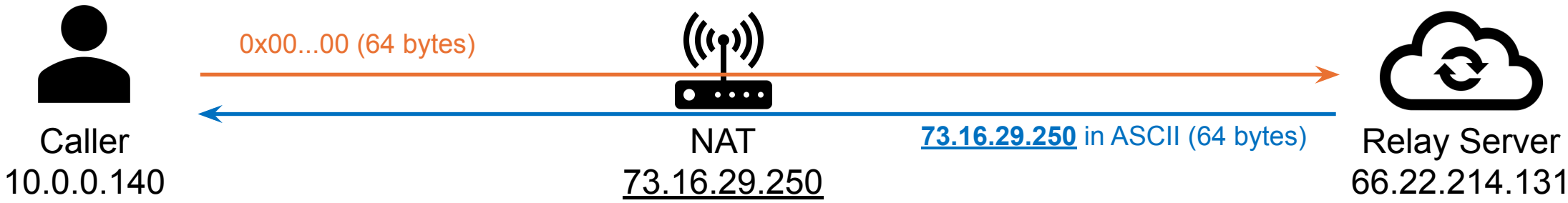
- From our experiments:
  - Discord has no P2P calls
  - Both one-to-one and group calls use relay server.
- Speculation: Support one-to-one call with group call tech stack (relay)



Discord: Proprietary STUN Protocol

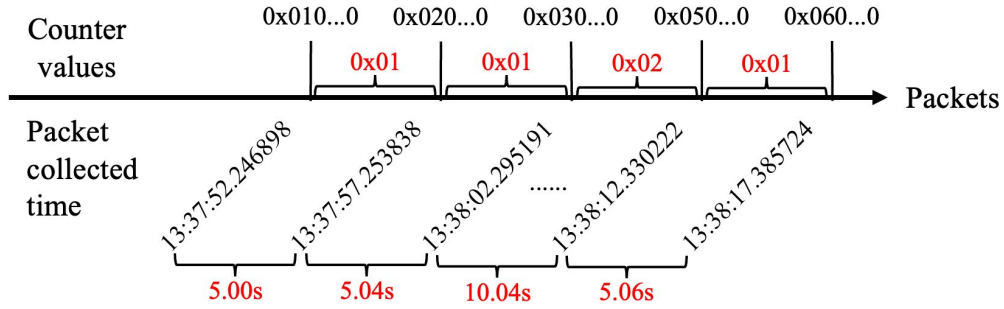
- Once a client starts a call,
  - Client sends a proprietary packet to server.
  - Server's response contains client's public IP address in ASCII.
- Speculation: Proprietary implementation of STUN protocol for client IP discovery





Discord: Proprietary Ping-pong Packets

- After call established, every 5s, 8-byte packets are exchanged between client and server.
- Packet Format:
  - 4-byte constant payload (0x1337cafe)
  - 4-byte counter increasing over time

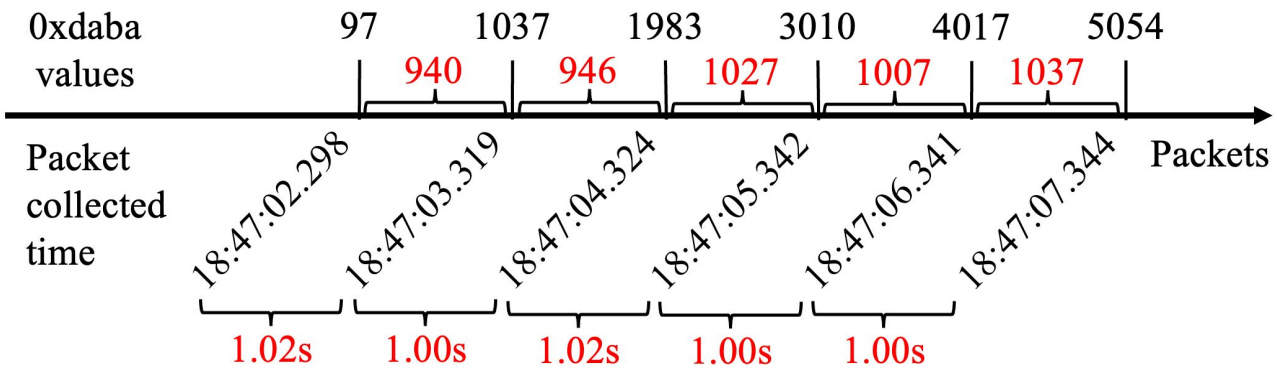


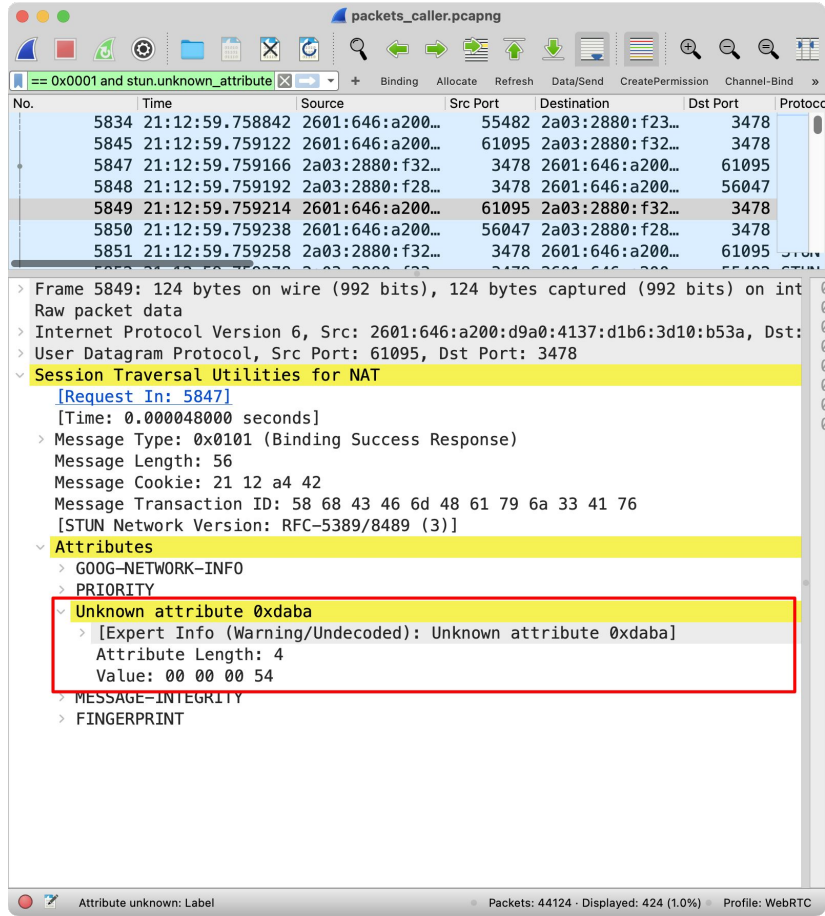
Time	Source	Src Port	Destination	Dst Port	Protocol	Data	Le
10:37:52.246898	10.0.0.140	60797	66.22.214.131	50014	UDP	13 37 ca fe 01 00 00 00	
10:37:52.247160	66.22.214.131	50014	10.0.0.140	60797	UDP	13 37 ca fe 01 00 00 00	
10:37:57.253838	10.0.0.140	60797	66.22.214.131	50014	UDP	13 37 ca fe 02 00 00 00	
10:37:57.253874	66.22.214.131	50014	10.0.0.140	60797	UDP	13 37 ca fe 02 00 00 00	
10:38:02.295191	10.0.0.140	60797	66.22.214.131	50014	UDP	13 37 ca fe 03 00 00 00	
10:38:02.296367	66.22.214.131	50014	10.0.0.140	60797	UDP	13 37 ca fe 03 00 00 00	
10:38:07.330222	10.0.0.140	60797	66.22.214.131	50014	UDP	13 37 ca fe 04 00 00 00	
10:38:07.330539	66.22.214.131	50014	10.0.0.140	60797	UDP	13 37 ca fe 04 00 00 00	
10:38:12.385724	10.0.0.140	60797	66.22.214.131	50014	UDP	13 37 ca fe 05 00 00 00	
10:38:12.386448	66.22.214.131	50014	10.0.0.140	60797	UDP	13 37 ca fe 05 00 00 00	
10:38:19.402415	10.0.0.140	59972	66.22.214.131	50014	UDP	13 37 ca fe 01 00 00 00	

- Speculation: Proprietary implementation of ICE connectivity check with additional counter for client status detection

Messenger: Alien STUN Attribute (0xdaba)

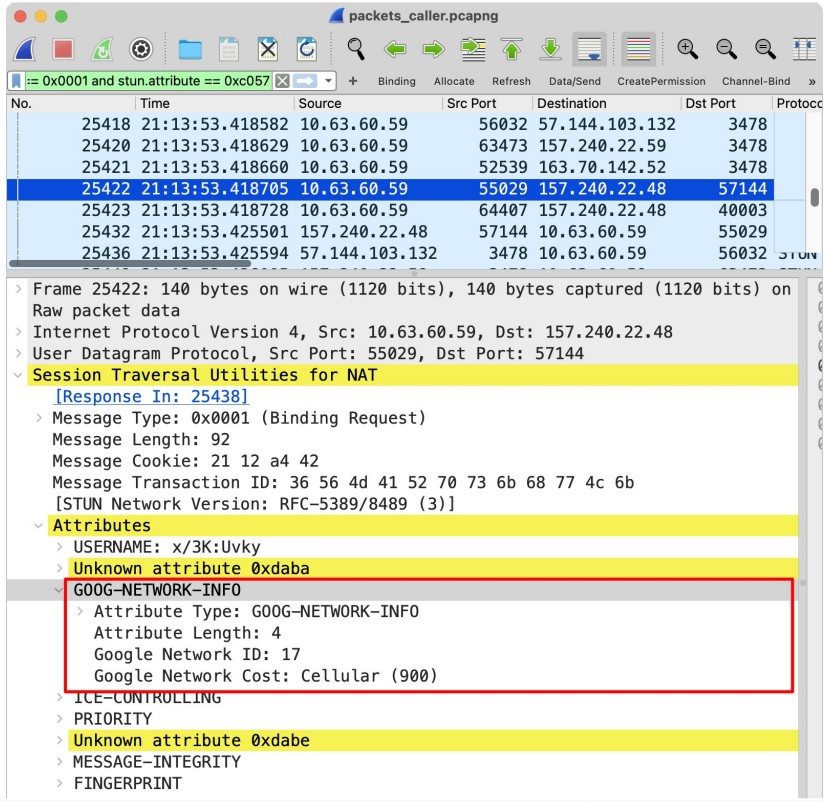
- Exists in 83% of STUN Binding
- Proprietary STUN Attribute (0xdaba)
  - 4-byte counter increasing over time
- Speculation: Latency computation





Messenger: Alien STUN Attribute (0xc057)

- Exist in 41.6% of STUN Binding
- WebRTC STUN attribute (0xc057): *GOOG-NETWORK-INFO*
  - *Google Network ID* (2 bytes)
  - *Google Network Cost* (2 bytes)
- Speculation: Network type indicator

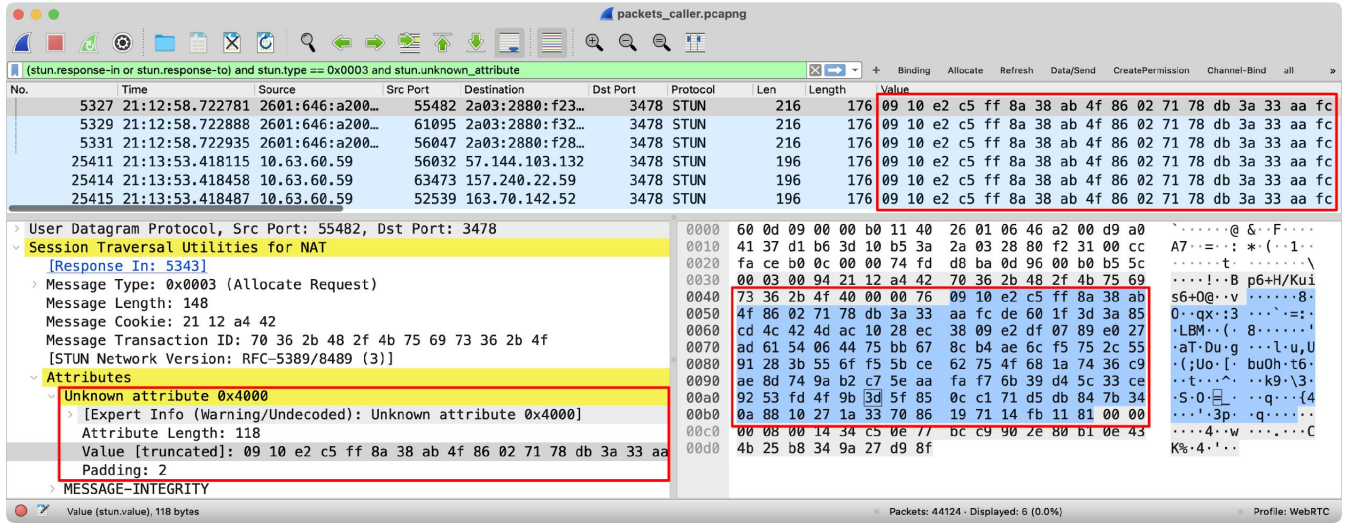


Google Network Cost values in WebRTC source code:

Cost	Max	Cellular2G	Cellular3G	Cellular	Cellular4G	Cellular5G	Unknown	Low	Min
Value	999	980	910	900	500	250	50	10	0

Messenger: Alien TURN Attribute (0x4000)

- Exists in 27.9% of TURN Allocate requests
- Proprietary STUN Attribute (0x4000)
  - 118-byte value: a constant token over the call.
- Speculation: Client connection ID



WhatsApp: 5/9 messages are proprietary

Proprietary STUN Types	Speculations	Observations
0x0800	client closes a session	● only happens at the end of a call ● client sends 5 copies to server, and server never responds ● contains a attribute like call UUID
0x0801 & 0x0802	ping-pong	● 0x0801 (client → server) pairs with a 0x0802 (server → client) ● inter packet gap is ~2ms Before the call is established ● inter packet gap is ~3 second After the call is established
0x0804 & 0x0805	ping-pong	● 0x0804 (client → server) pairs with a 0x0805 (server → client) ● inter packet gap is ~2ms before the call is established ● initiated by server

WhatsApp: 5/11 attributes are proprietary

Proprietary STUN Attributes	Speculations	Observations
0x4000	UUID	● 150 bytes, ● constant throughout the call, unaffected by network switches. ● used in both Allocate and Deallocate
0x4002	A timestamp	8 bytes, the elapsed time since 1/1/1970, in milliseconds.
0x4003	Unknown	1 byte, constant value 0xff
0x4004	Padding bytes	440~452 bytes, with the identical byte (0x00).
0x4007	Unknown	2 bytes, constant value 0x01f4

WhatsApp: 3/11 attributes are not compliant

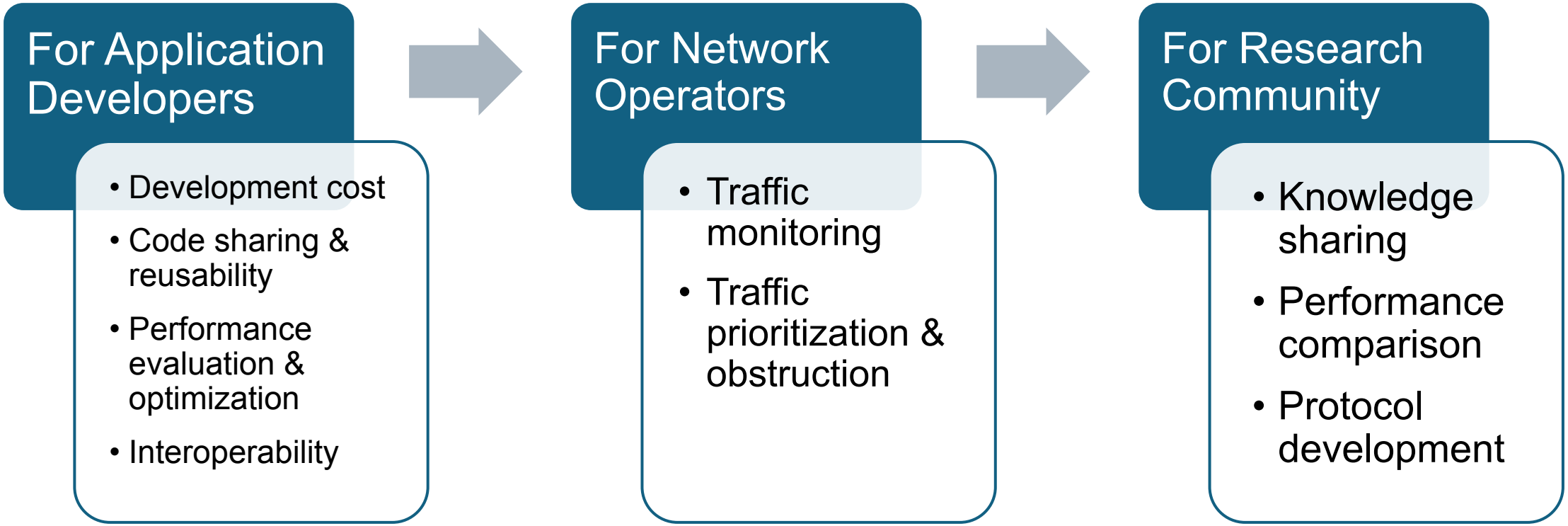
Attribute type	Standards	Observations
0x0022	**RESERVATION-TOKEN** RFC8656: “The server includes this attribute in a success response” RFC8656: “The attribute value is 8 bytes ...”	● It is included in each Allocate request, prior server responses. ● 14 to 16 bytes.
0x802b	**RESPONSE-ORIGIN** RFC5780: “The attribute is inserted by the server and indicates the source IP address and port the response was sent from.”	● sent by the clients at the end of a call. ● 4 bytes, with the constant value 0x02000000.
0x0024	**PRIORITY** RFC8445: “The PRIORITY attribute MUST be included in a Binding request.”	● used in Binding requests and responses. ● 1 byte, with the constant value 0x1.

From Our Experiments & Analysis:

- RTC applications do not fully comply with RFCs
- But, their proprietary implementations share similarity
  - Proprietary RTP encapsulation (Zoom, FaceTime)
  - Call UUID (Messenger, Zoom, FaceTime)
  - Ping-pong with a time counter (Messenger, Discord, Zoom)
  - ...

- Speculation: Existing standards might not be flexible enough to satisfy new demands in today's RTC industry.

Protocol fragmentation



Appendix: Links

- SIGCOMM IMC Paper submission
- Zoom & FaceTime Wireshark plugin
- Datasets

Q & A