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From Single Lane to Highways: Analyzing the Adoption of Multipath TCP in the Internet

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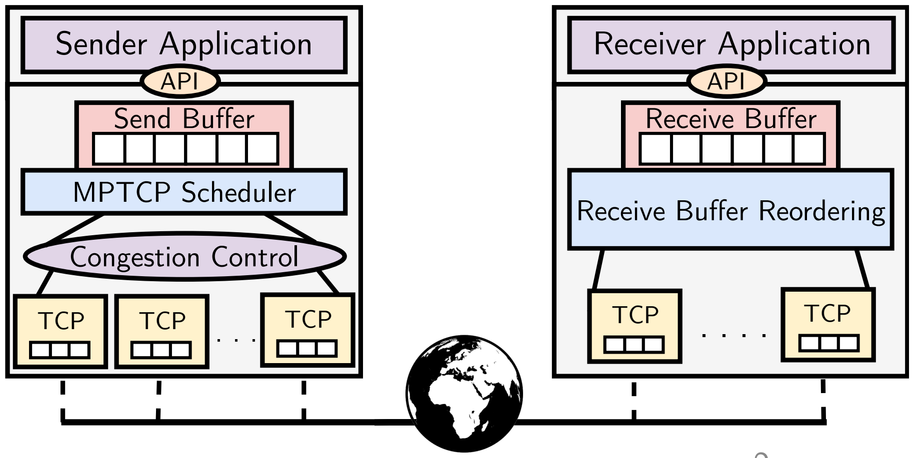
Multipath TCP (MPTCP)

MPTCP is a *multipath* extension to TCP

- Allows *n-to-m* TCP connections between end-hosts

- Originally proposed in 2013 (RFC 6824) and standardized in March 2020 (RFC 8684)

- Benefits over TCP
  - Improve aggregated **throughput**
  - Improve **resilience** to losses
  - Provides **seamless** mobility



MPTCP in the Internet

Large organizations have been been using MPTCP for several years

- Apple uses MPTCP in iOS, Siri, Music, WiFi-Assist...
- Korea Telecom uses MPTCP to achieve Gigabit speeds over LTE+WiFi
- MPTCPv1 is available (and enabled) in Linux kernel v5.6 or newer

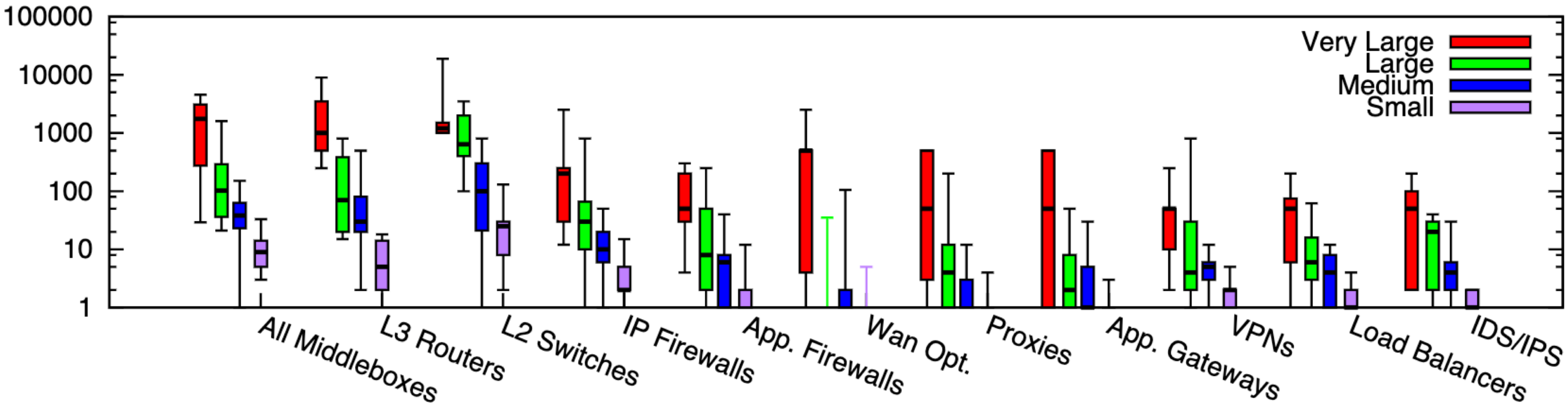
Yet there is no Internet-wide study analyzing MPTCP adoption and usage!

MPTCP in the Internet

Understanding MPTCP adoption is important:

1. Clients can only use MPTCP if **servers also** support it

2. MPTCP relies on TCP header extensions which are known to be blocked by middleboxes



Sherry, Justine, et al. "Making middleboxes someone else's problem: Network processing as a cloud service." ACM SIGCOMM Computer Communication Review 2012

In this work, we analyze...

1. True support for MPTCPv0 in the Internet
   - Regular ZMap scans over IPv4 and IPv6 over six months (July – Dec 2020)
   - Support on port 80 (HTTP) and port 443 (HTTPS)
   - Identify middleboxes affecting MPTCP transfer using Tracebox

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2. Impact of middleboxes on MPTCP data transfers
   - Identify end-hosts affected by middleboxes that interact with MPTCP header options
   - Triggered parallel HTTP(S) GET requests from MPTCP and TCP clients
   - Analyzed whether middleboxes treat MPTCP traffic any different from regular TCP

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   - On Tier 1 ISP backbone link in North America (released by CAIDA) from 2015 – 2019
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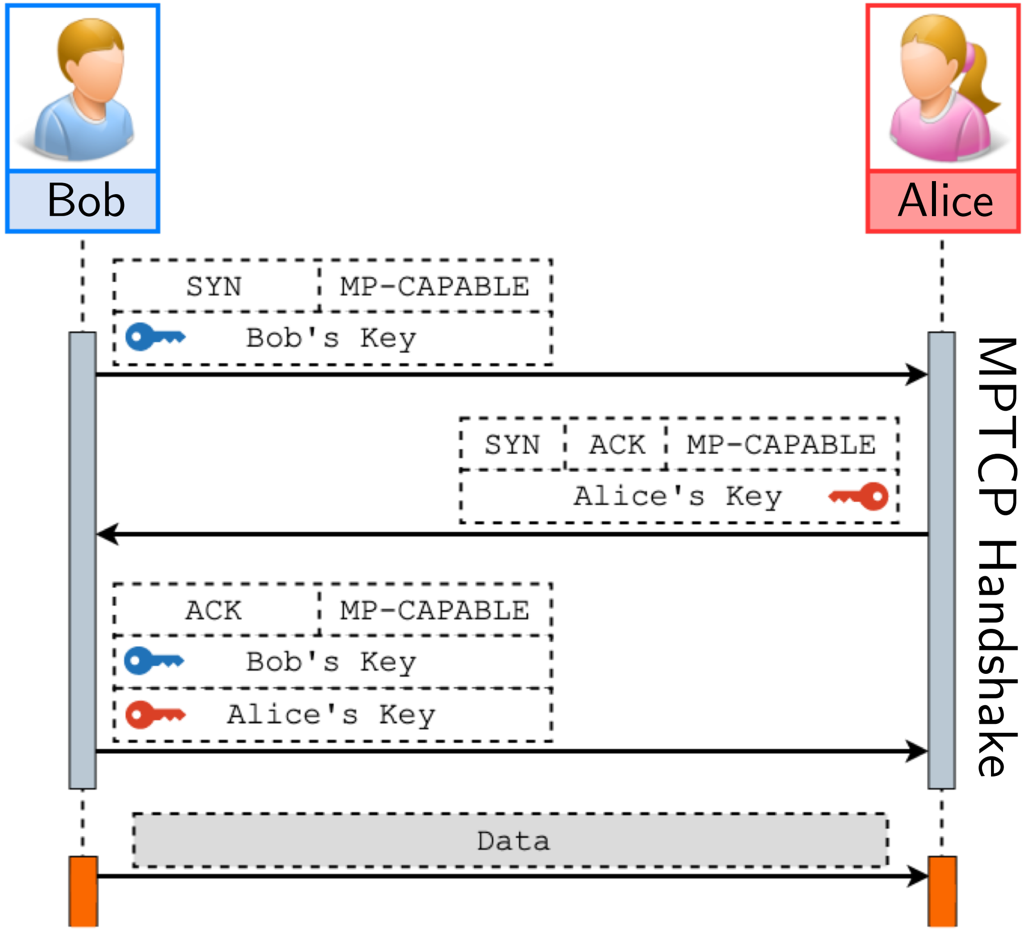
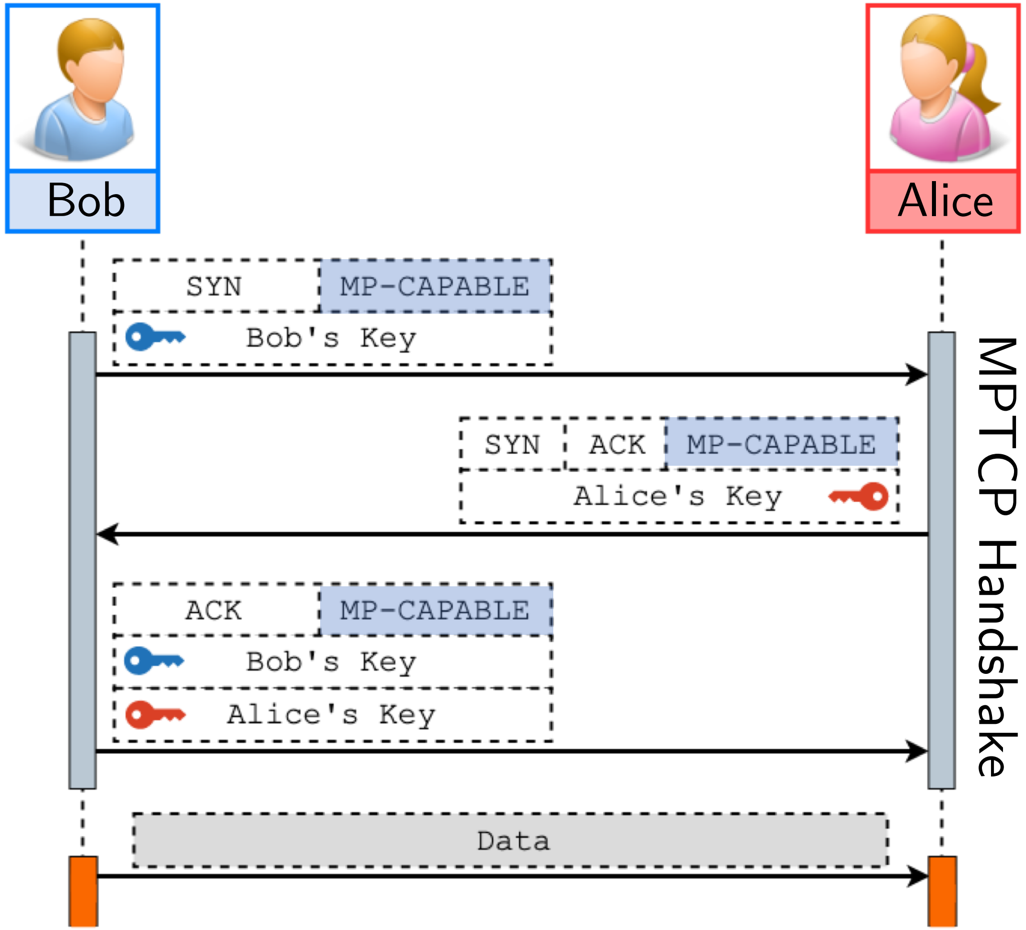
Support for MPTCPv0 in the Internet

Scanning for MPTCP Support



MPTCP connection establishment leverages TCP's three-way handshake

Scanning for MPTCP Support



MPTCP connection establishment leverages TCP's three-way handshake

- Both hosts must send `MP_CAPABLE` flag to denote MPTCP capability

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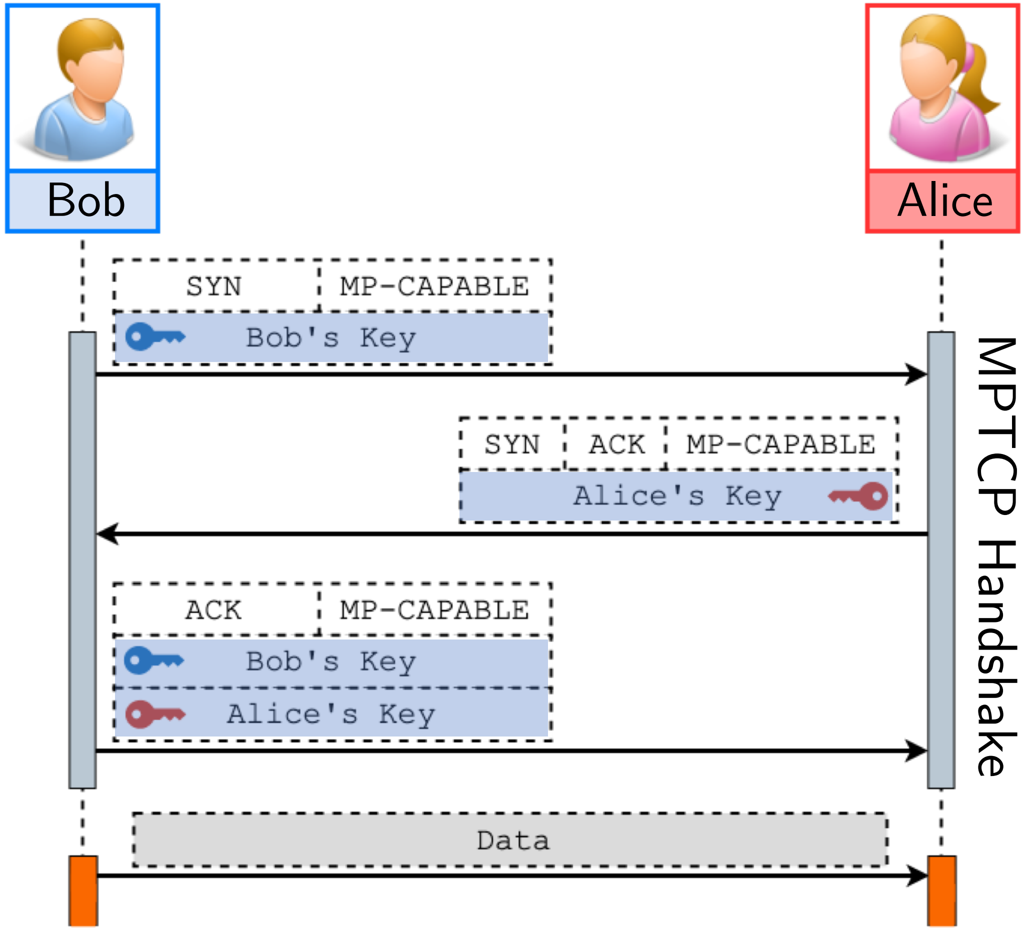
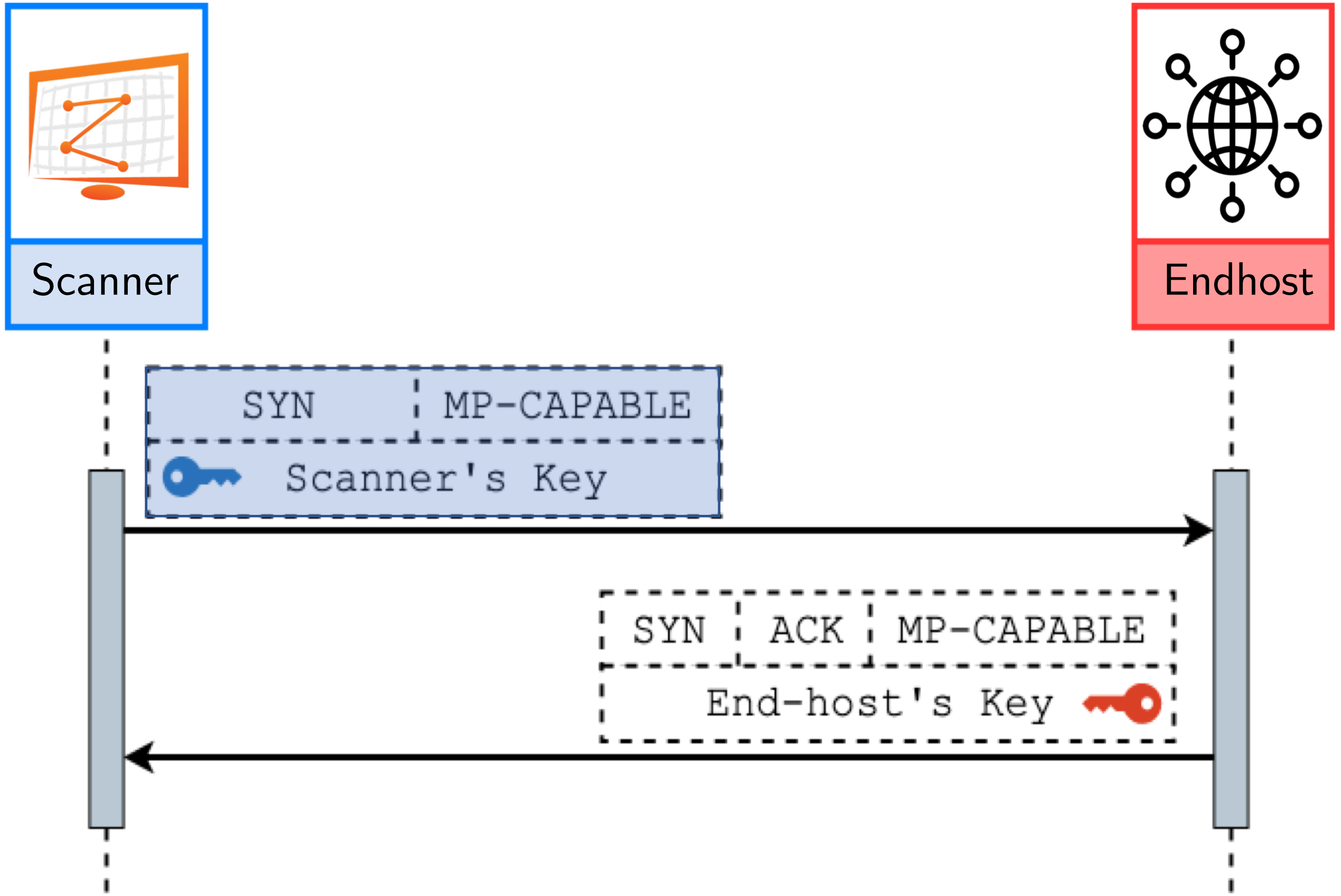


MPTCP connection establishment leverages TCP's three-way handshake

- Both hosts must send `MP_CAPABLE` flag to denote MPTCP capability
- `MPTCP Key` is a random 64-bit sequence

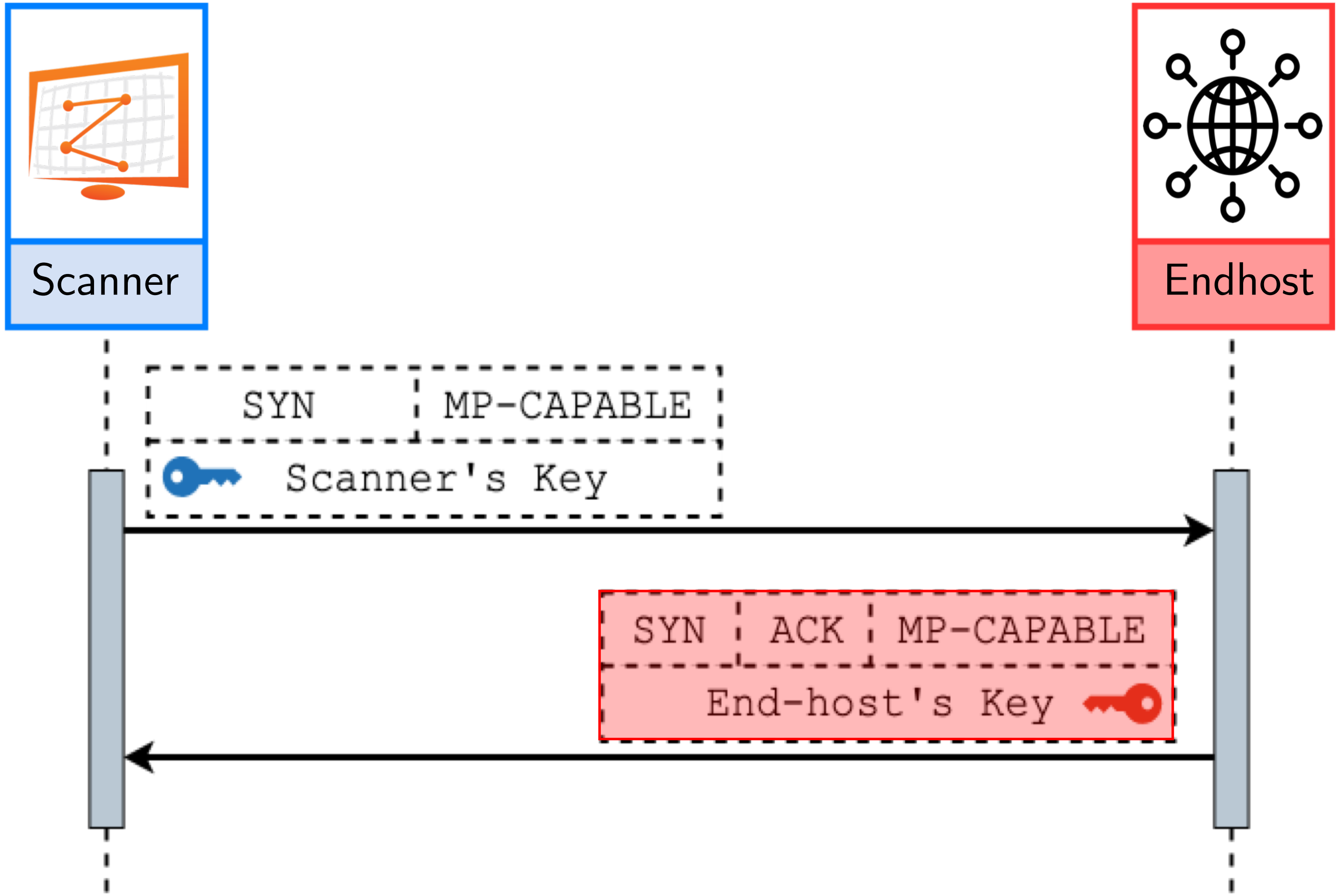
Scanning for MPTCP Support

ZMap Scanning Approach



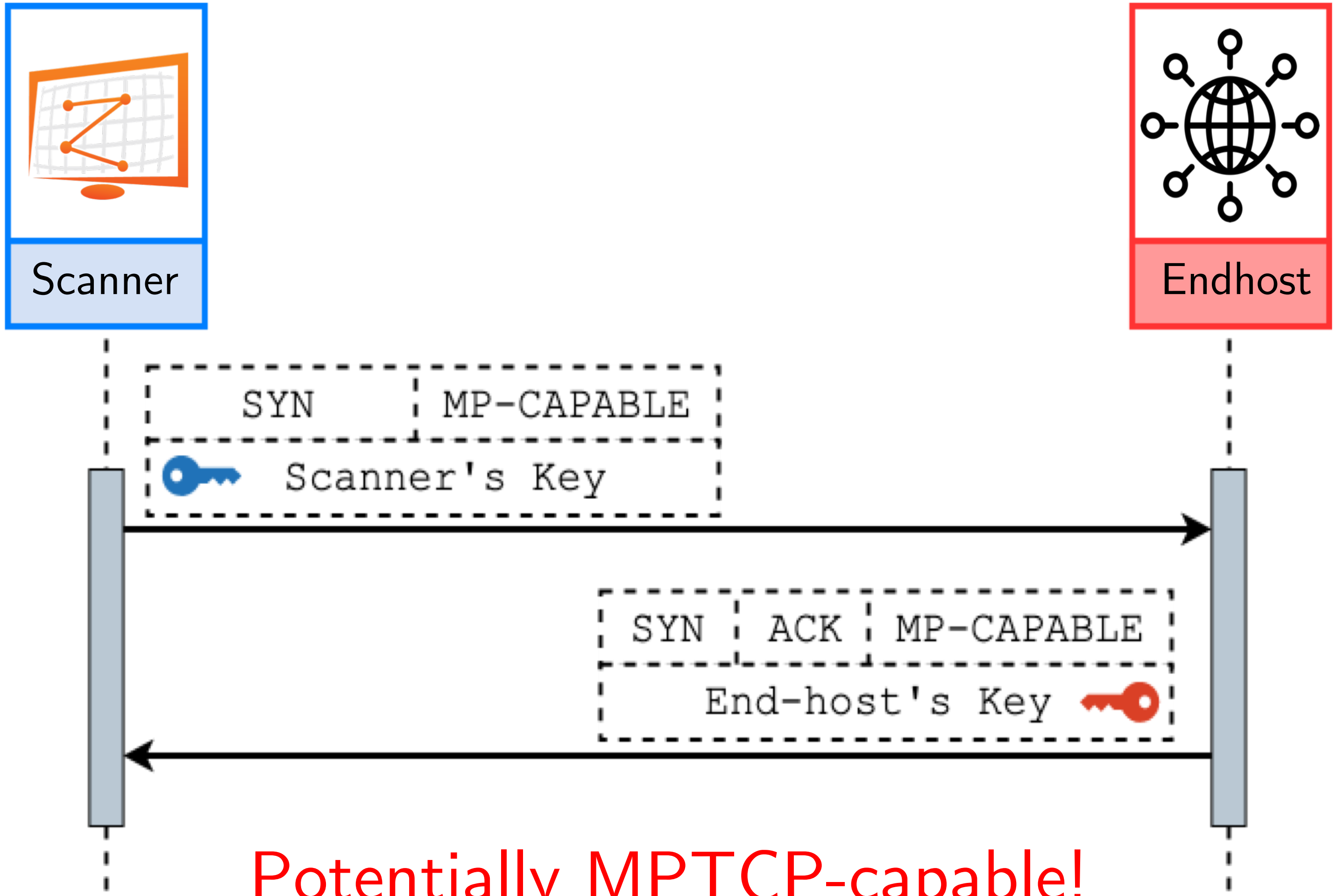
Scanning for MPTCP Support

ZMap Scanning Approach



Scanning for MPTCP Support

ZMap Scanning Approach



Potentially MPTCP-capable!

MPTCP Support in-the-wild

IPv4 ZMap		July	August	September	October	November	December
Potential MPTCP	Port 80	179.5K	201.6K	197.1K	196.1K	205.4K	206.3K
	Port 443	211.1K	198.1K	-	232.7K	239.5K	233.8K

IPv6 ZMap		July	August	September	October	November	December
Potential MPTCP	Port 80	-	43	43	43	43	44
	Port 443	-	165	166	165	167	168

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IPv4 ZMap		July	August	September	October	November	December
Potential MPTCP	Port 80	179.5K	201.6K	197.1K	196.1K	205.4K	206.3K
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But do all these hosts ***truly*** support MPTCP?

IPv6 ZMap		July	August	September	October	November	December
Potential MPTCP	Port 80	-	43	43	43	43	44
	Port 443	-	165	166	165	167	168

MPTCP over Middleboxes

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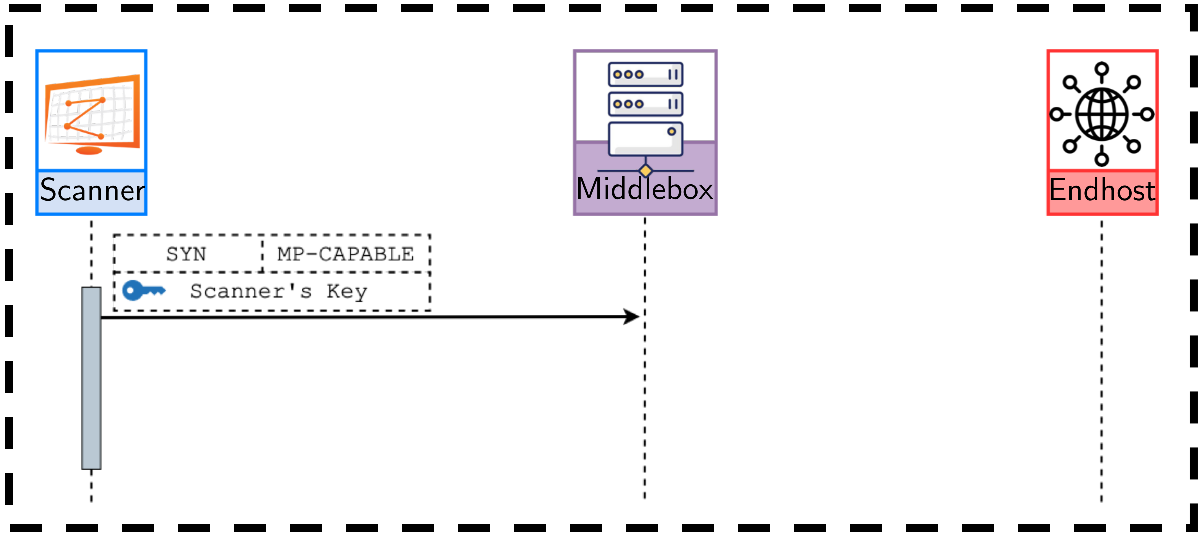

MPTCP over Middleboxes

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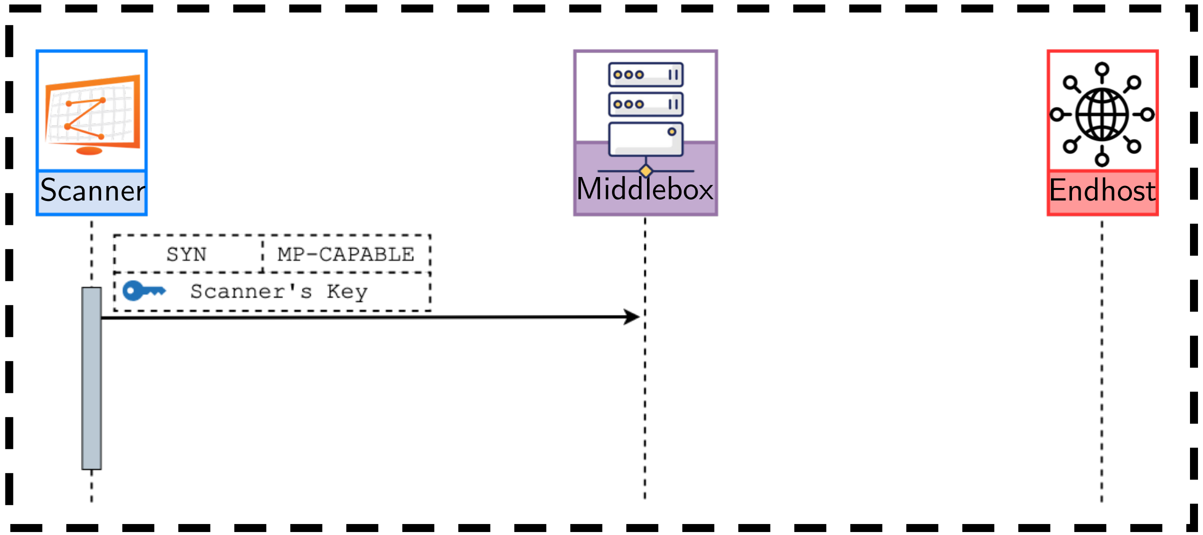
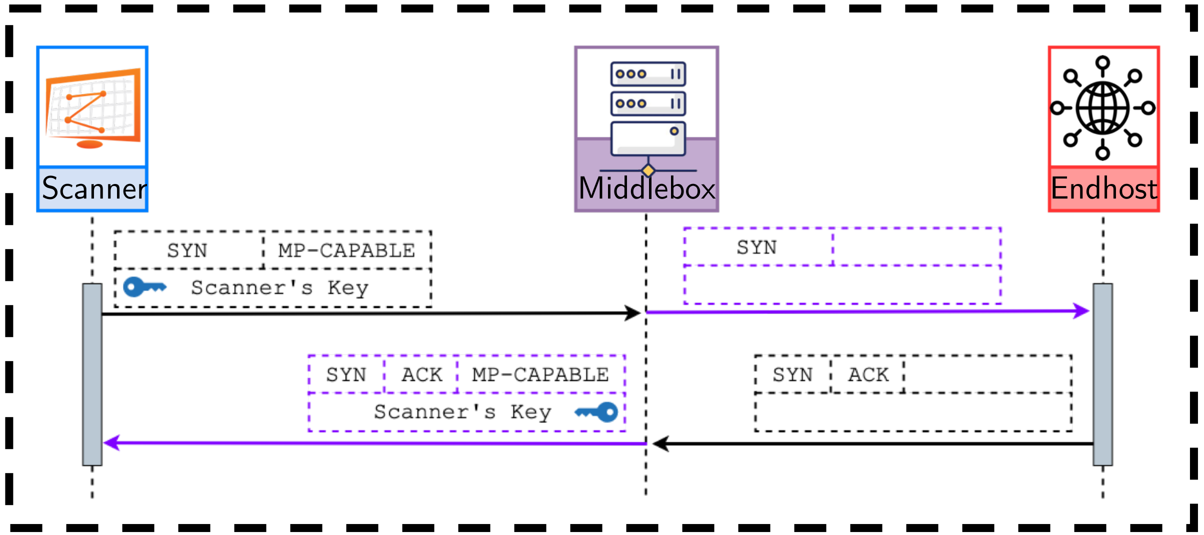


Rule 2: Mirror



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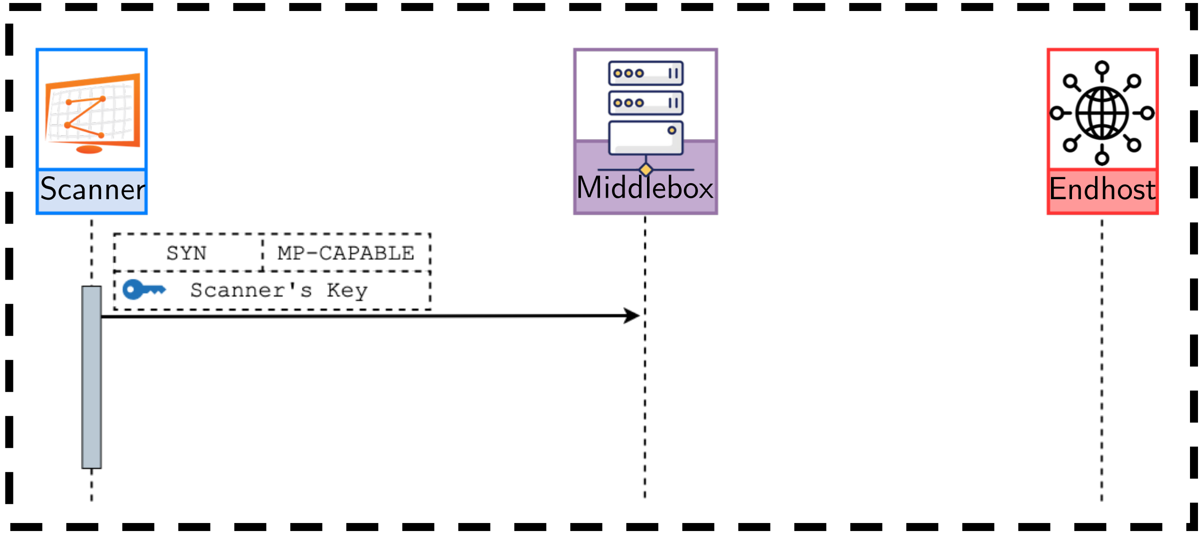

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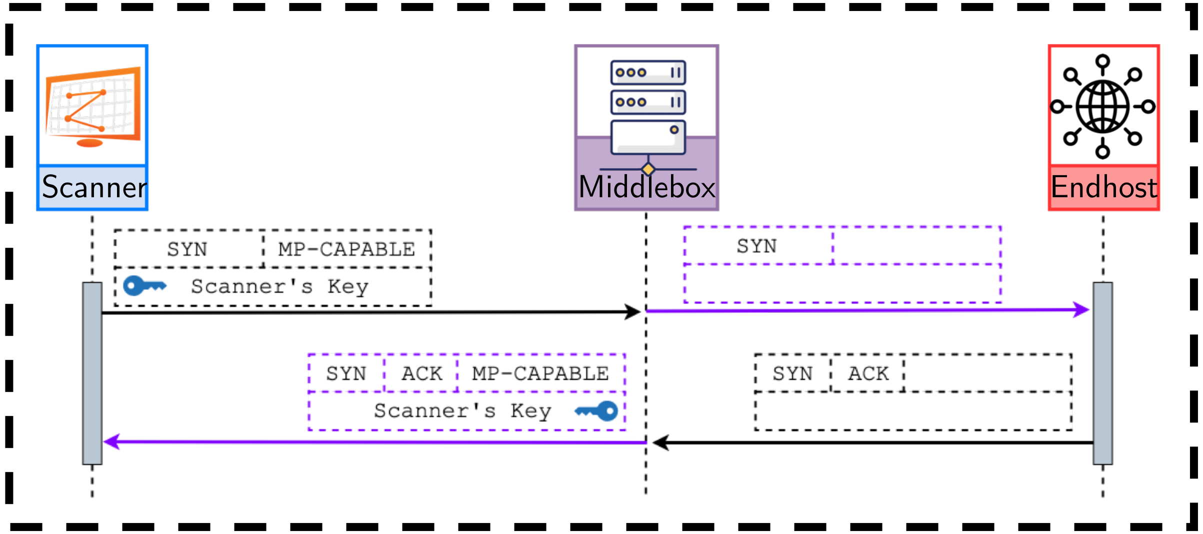
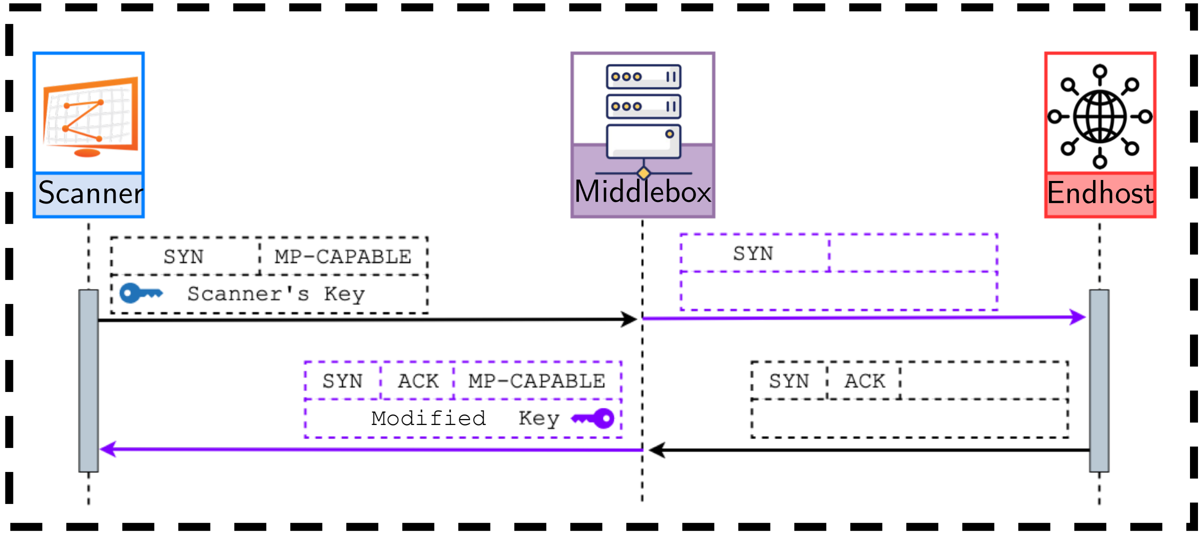


Rule 3: Proxy



MPTCP over Middleboxes

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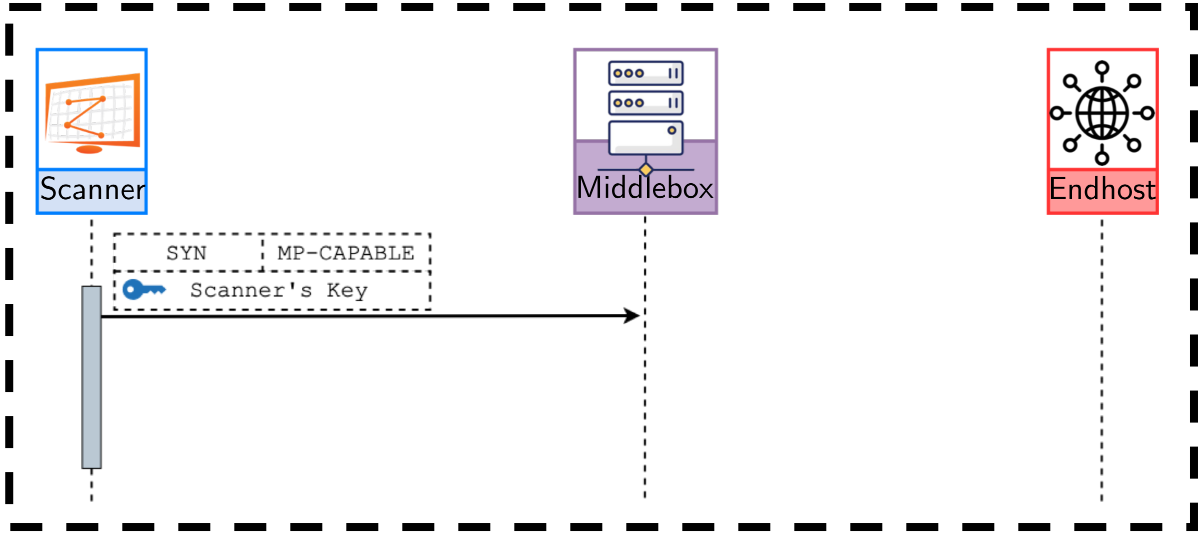

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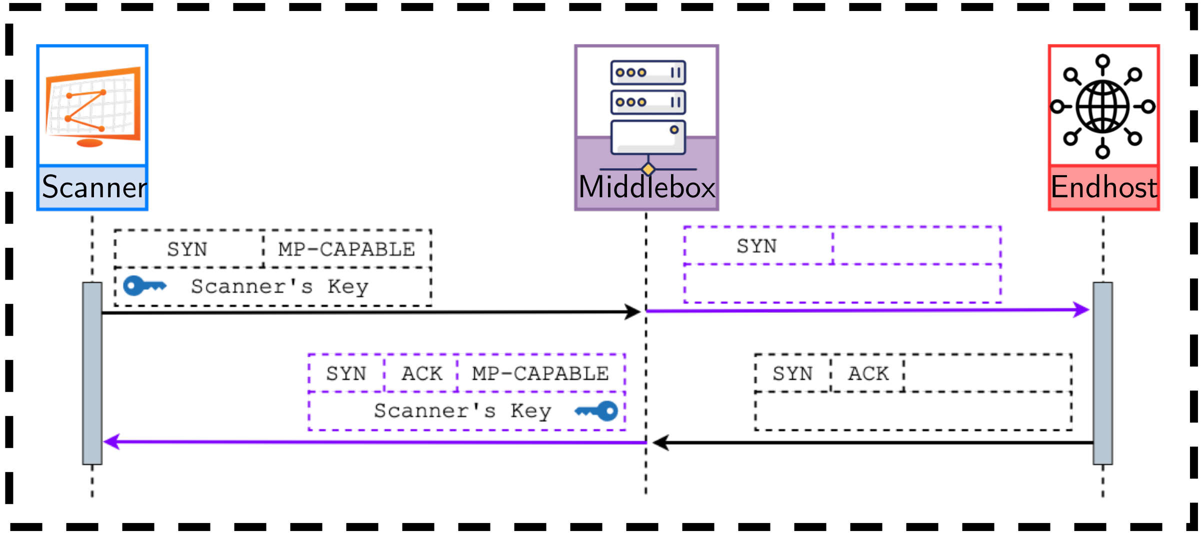

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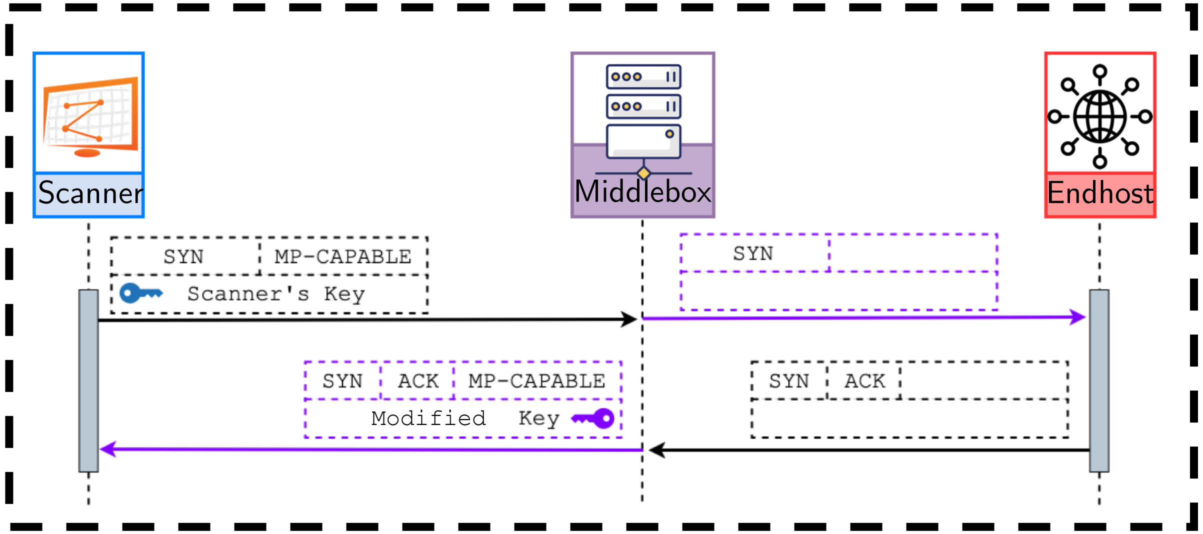
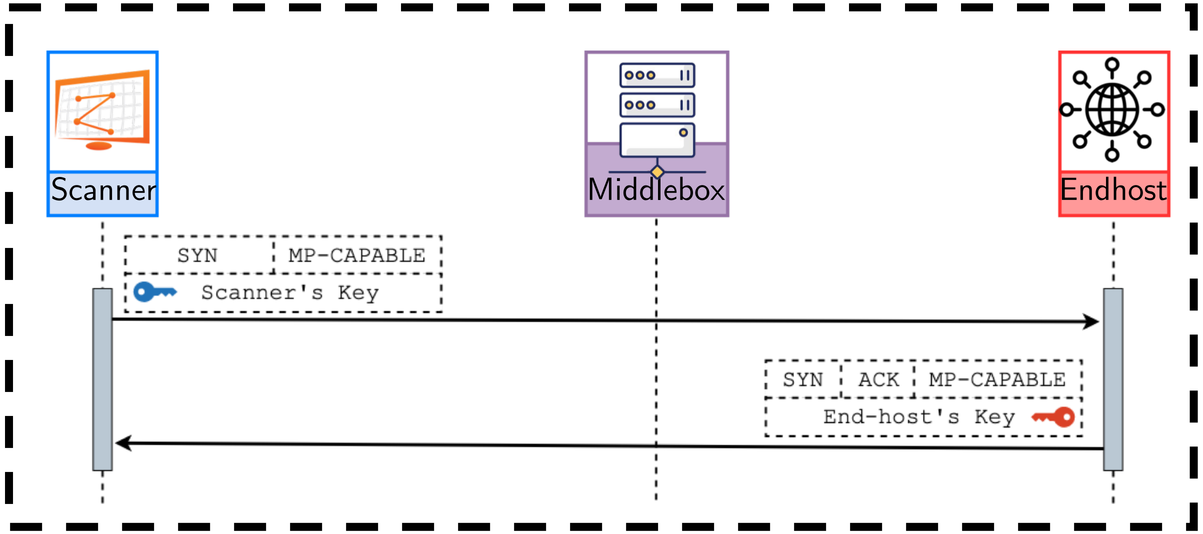
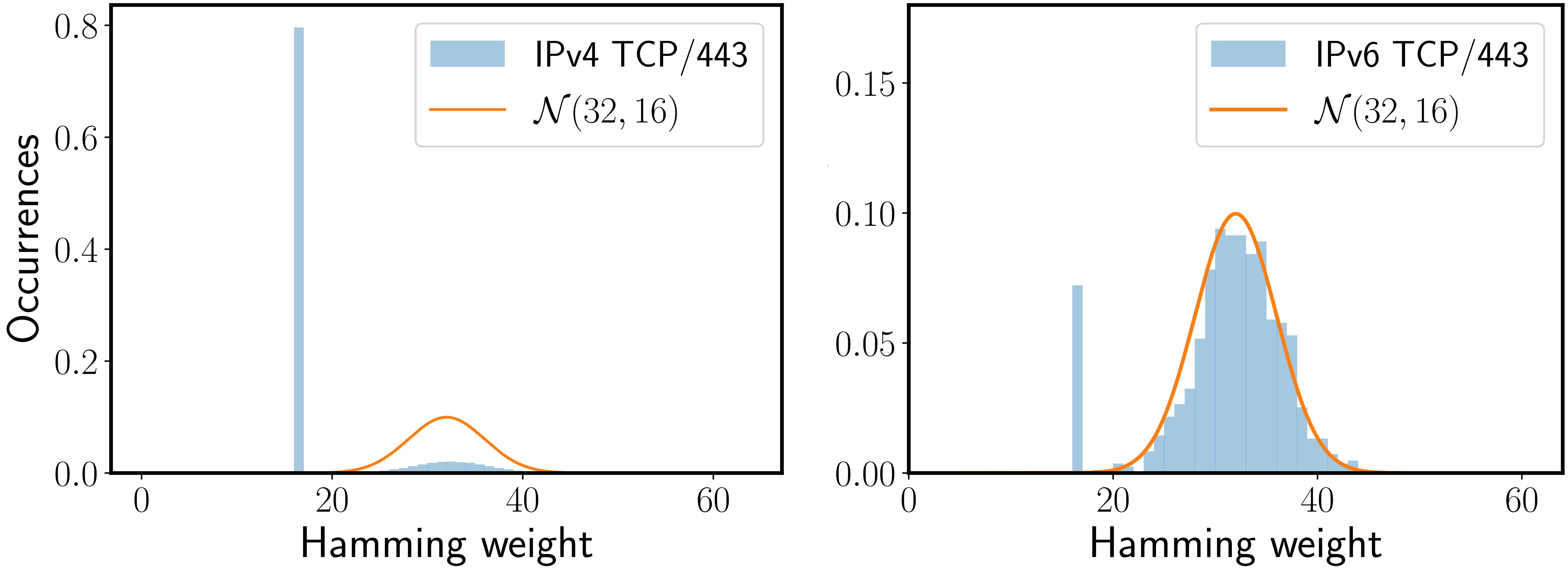


Rule 4: Pass-through



Impact of Middleboxes on Scans



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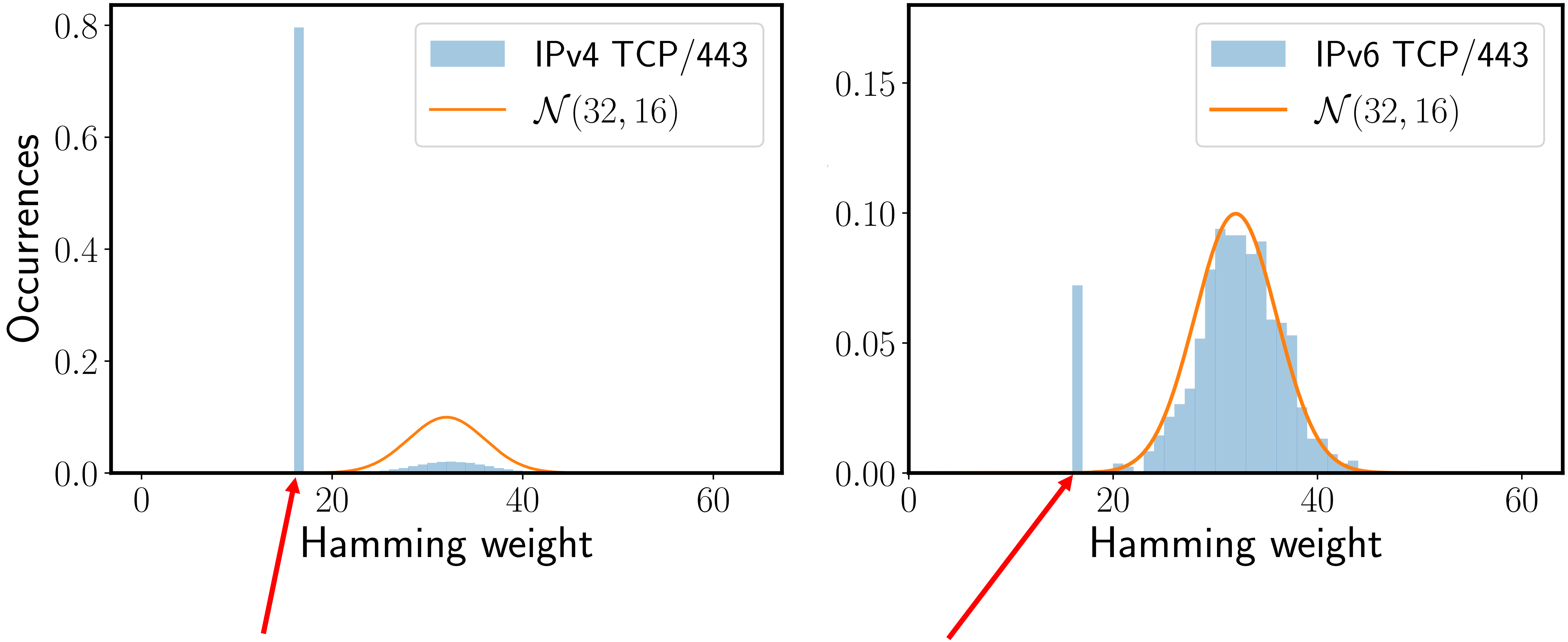

ZMap-based MPTCP identification is severely affected by middleboxes

Impact of Middleboxes on Scans

Judging presence of middleboxes from mirrored sender's key value is not completely effective

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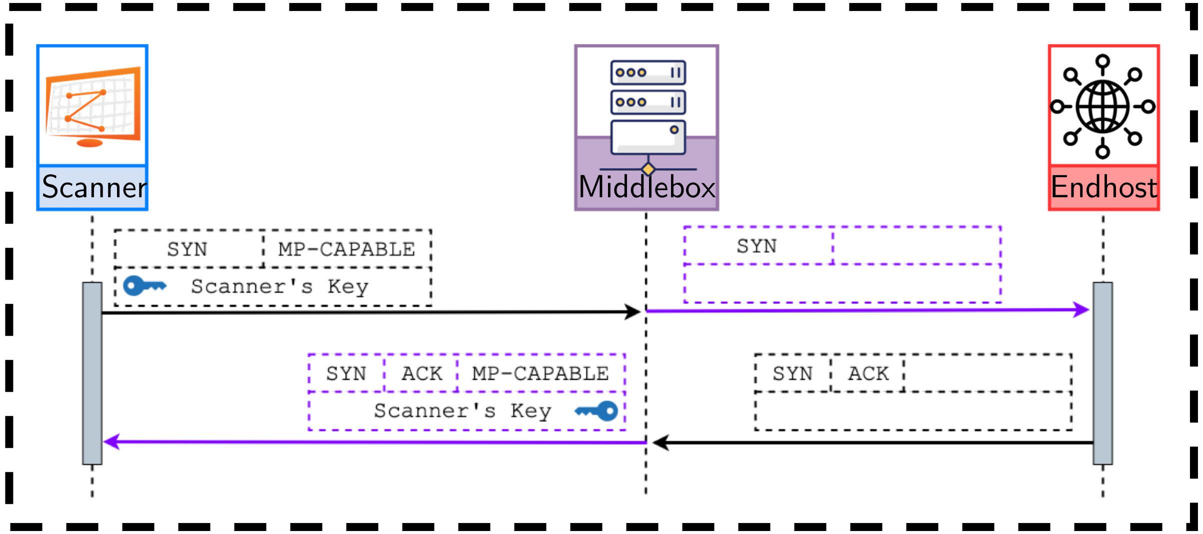

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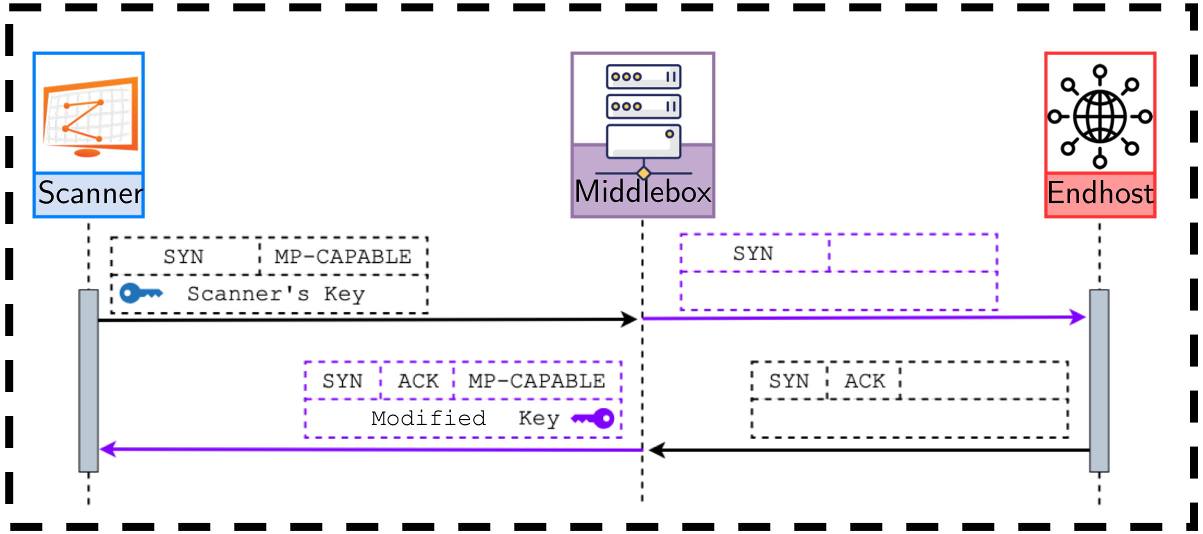


Analyzing True Support of MPTCP

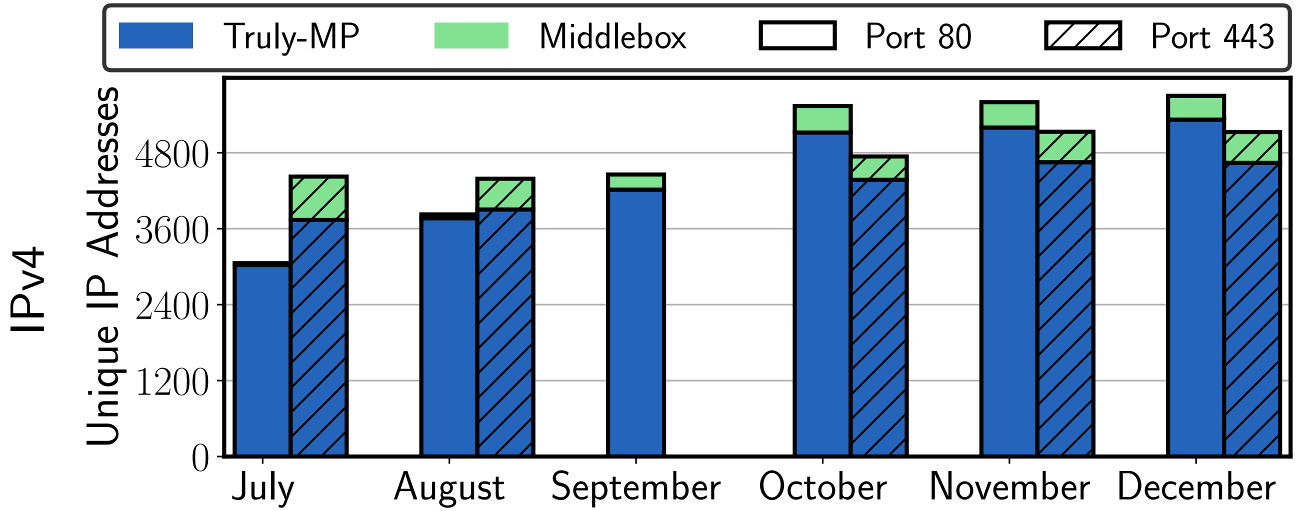
Triggered Tracebox towards all potentially MPTCP hosts from ZMap

- Allows us to detect middleboxes that modified TCP options between end-hosts

Three broad categories:

1. Target host modified MPTCP options → True MPTCP
2. Intermediate hop modified MPTCP option → Middlebox-affected
3. Target did not respond → Unresponsive

True MPTCP Support in the Internet



- Large number of MPTCP hosts in IPv4 are transient
- Only 6 middlebox-affected hosts in IPv4 *truly* support MPTCP
- MPTCP support is increasing in IPv4 but is almost constant in IPv6

IPv4

Port 80: ≈5.5k Port 443: ≈4.5k

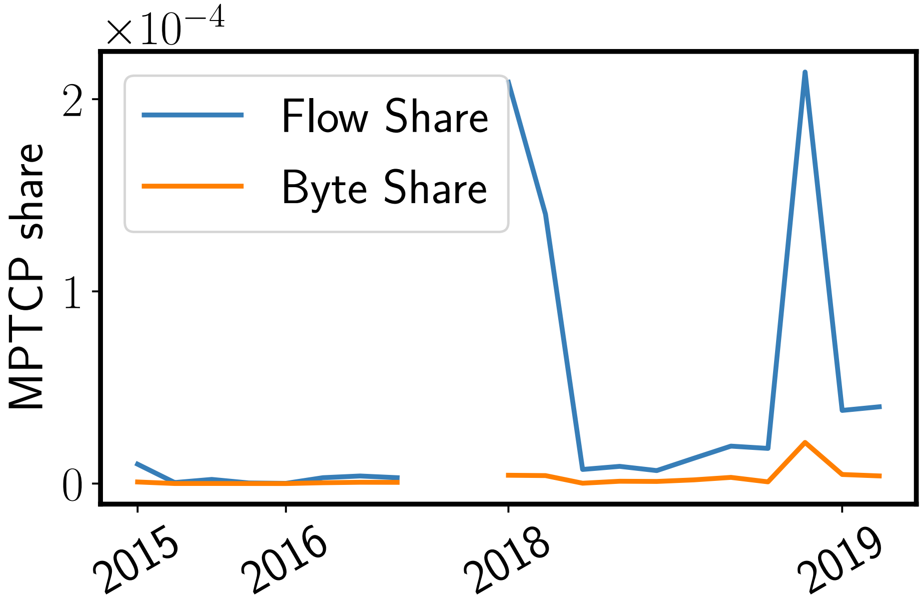
IPv6

Port 80: 31 Port 443: 27

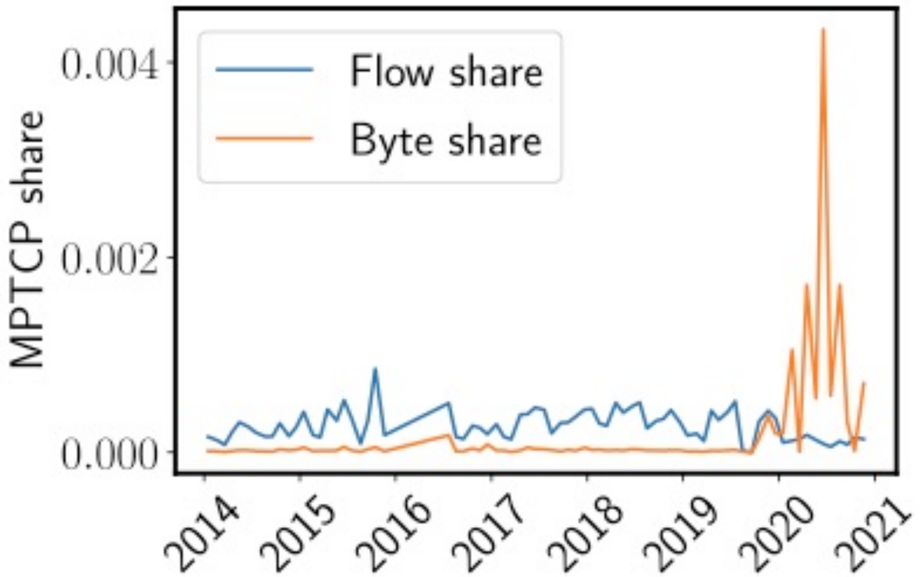
MPTCP Traffic Share in the Internet

Traffic Characteristics

CAIDA



MAWI



- ➢ MPTCP flow share shows gradual ↑ in CAIDA post 2018
- ➢ Significant ↑ in MPTCP flow/byte share in MAWI after 2019
- ➢ Flow distribution indicates usage of MPTCP to carry actual data
- ➢ Popular applications that use MPTCP in Internet: HTTPS, HTTP, Siri, RDP…

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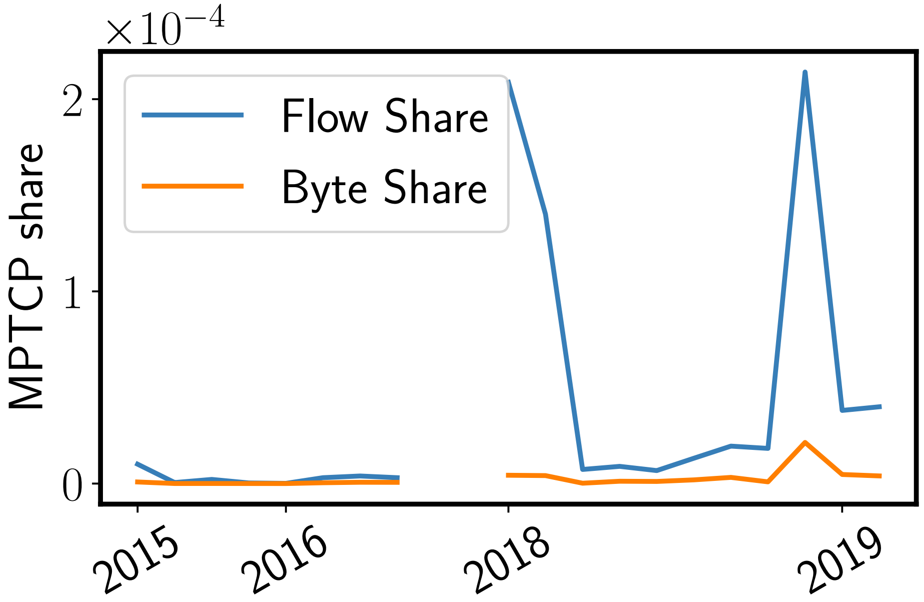

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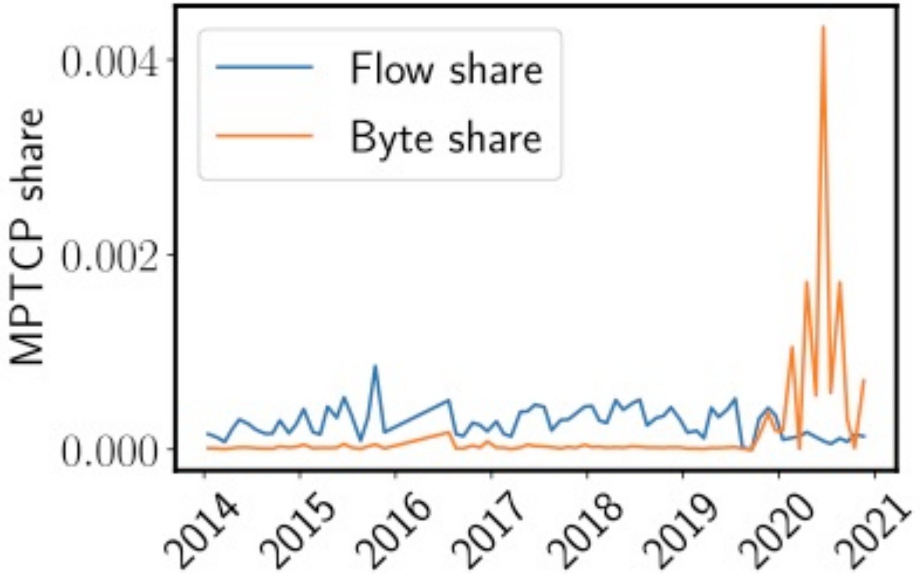

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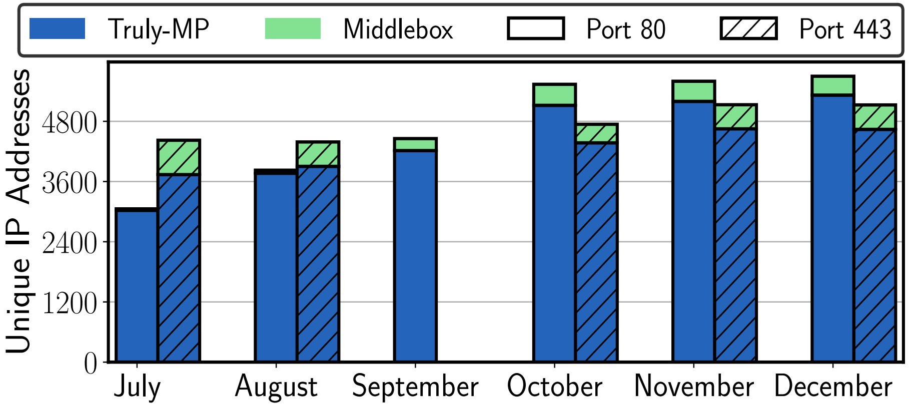
HTTPS is dominant application with 99% of MPTCP traffic!

MPTCP Adoption in a Nutshell

True support for MPTCPv0



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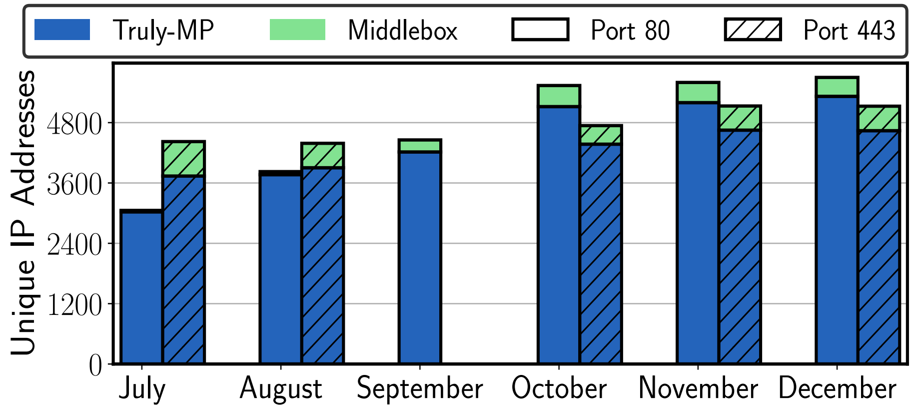
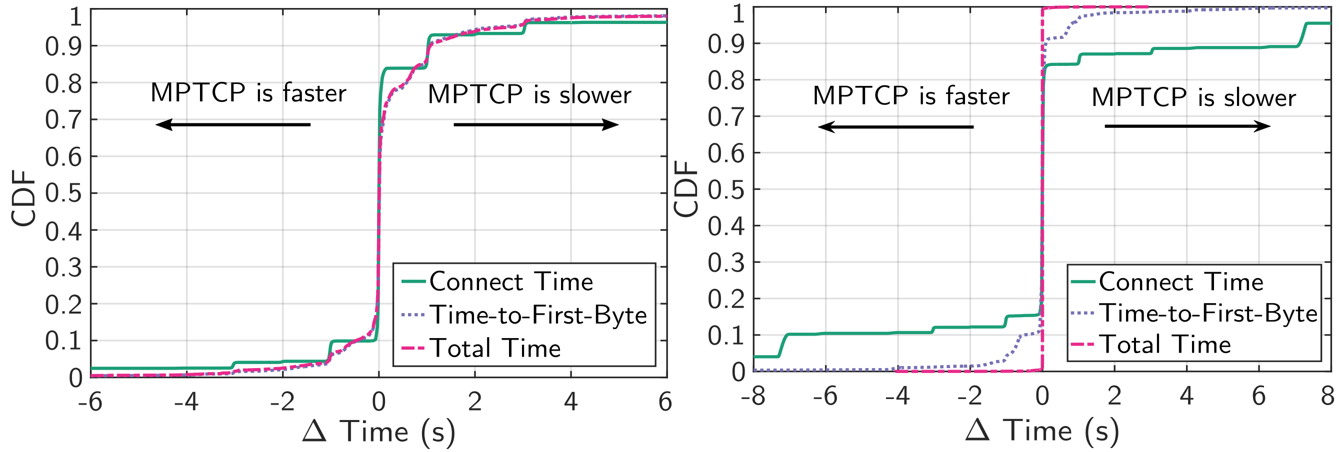


Impact of middleboxes on MPTCP data transfers



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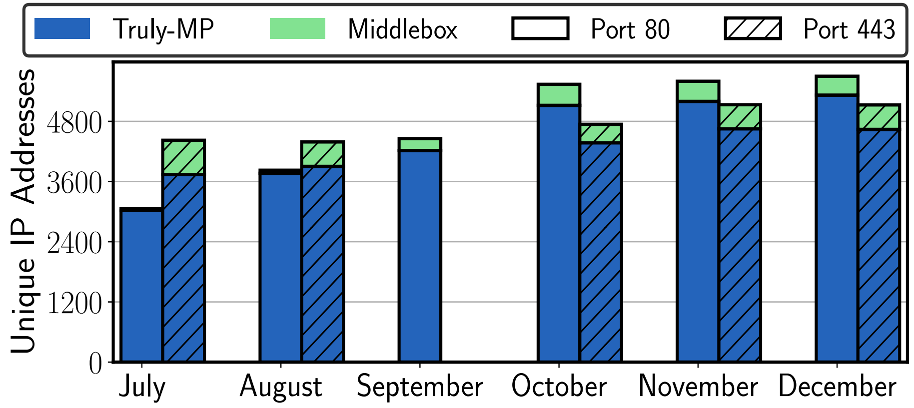

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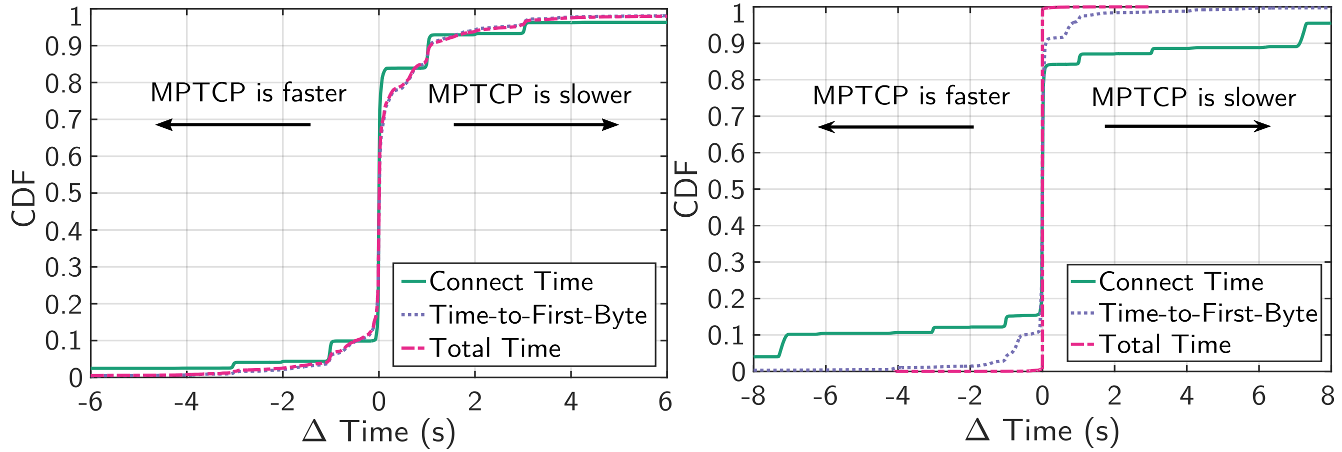
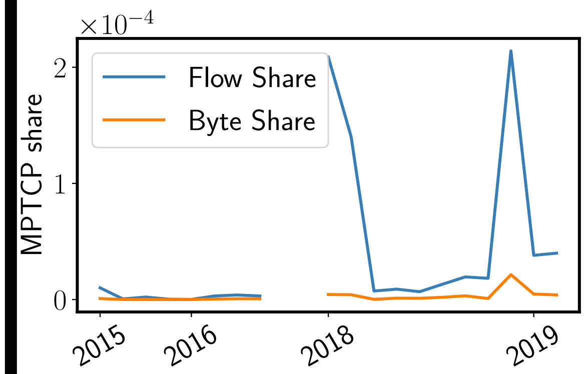
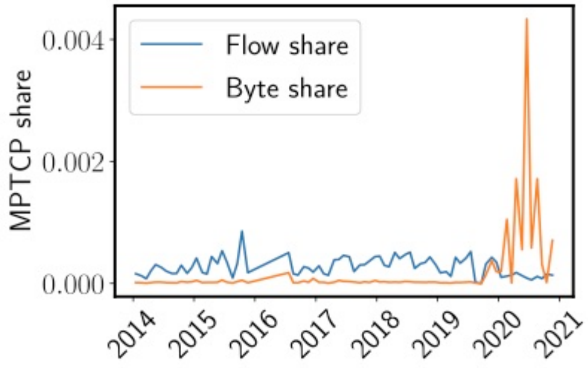


MPTCP traffic share in the Internet





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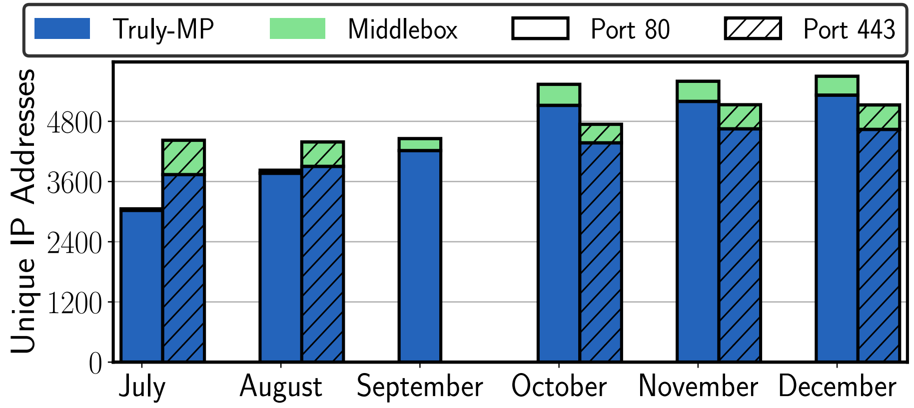

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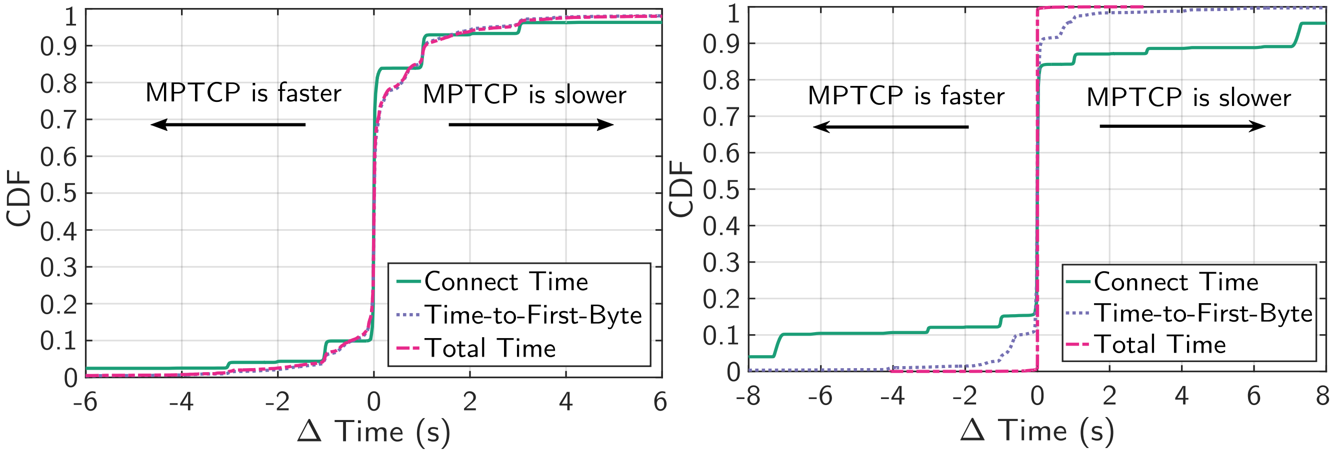

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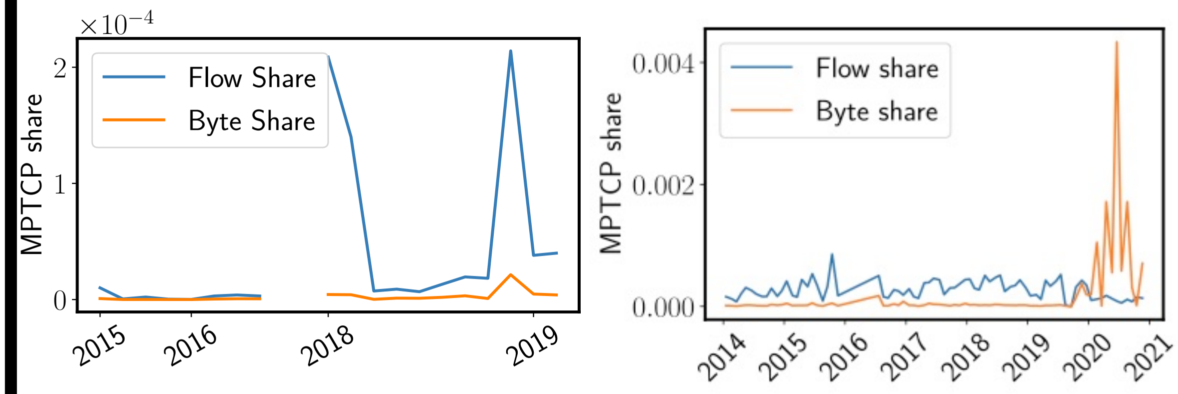

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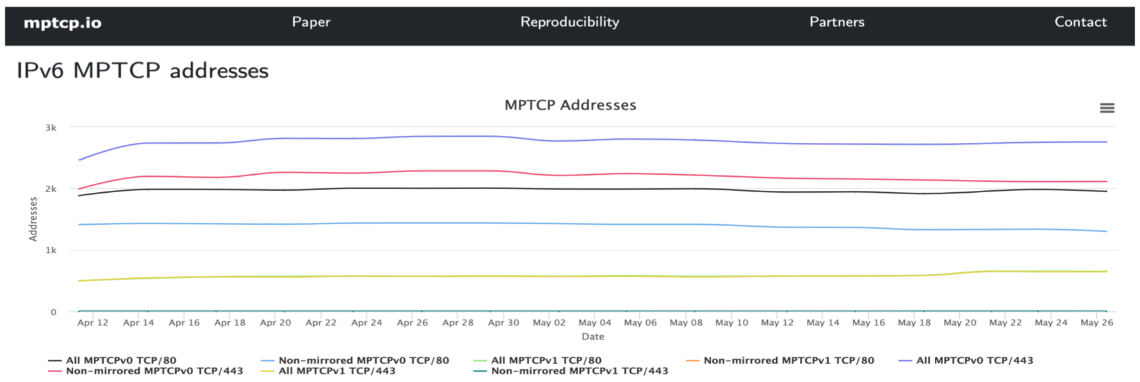

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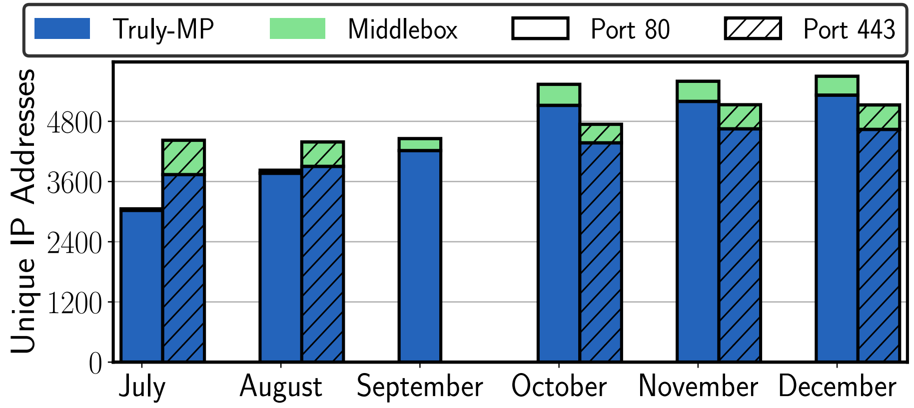

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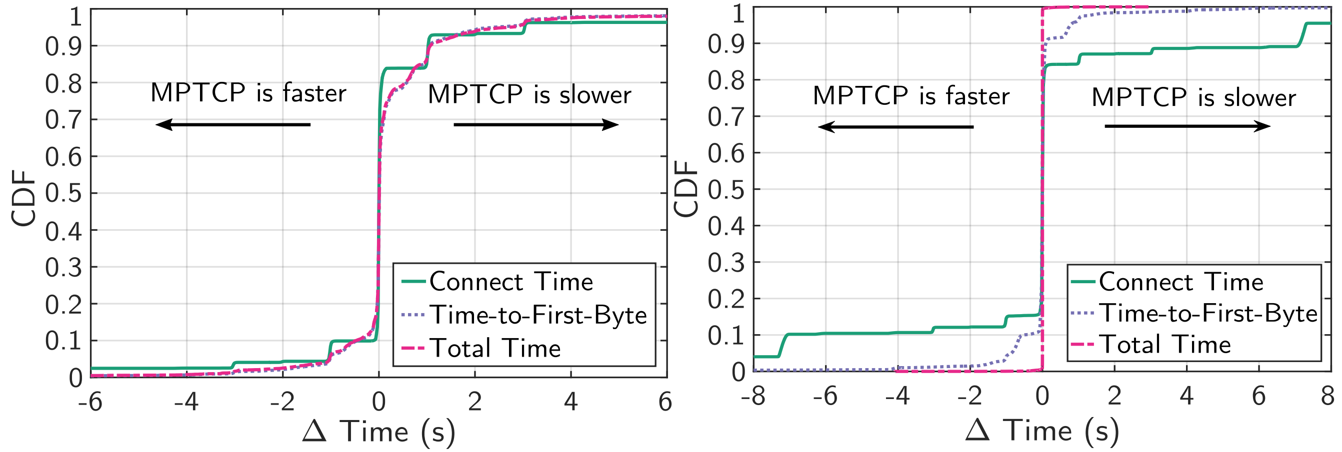

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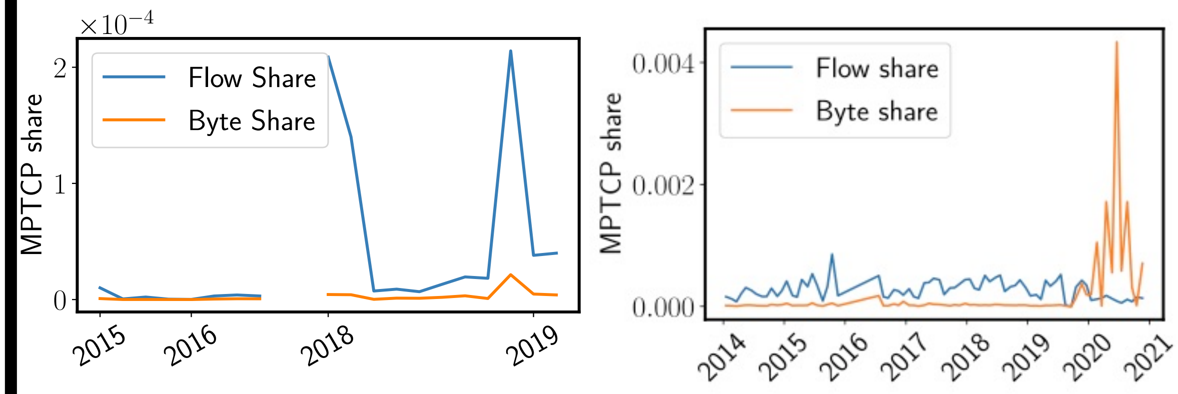

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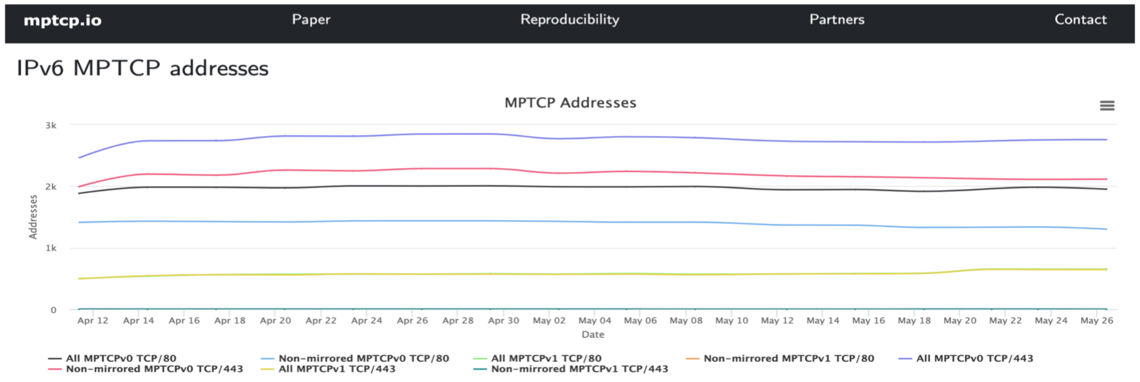

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