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

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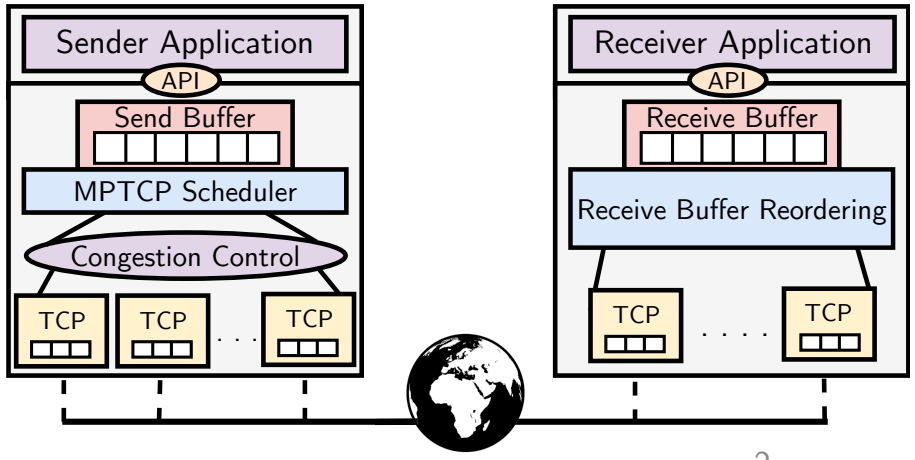
Multipath TCP (MPTCP)

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



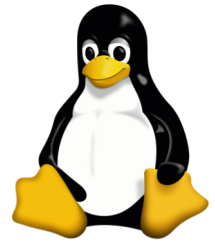
MPTCP in the Internet

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



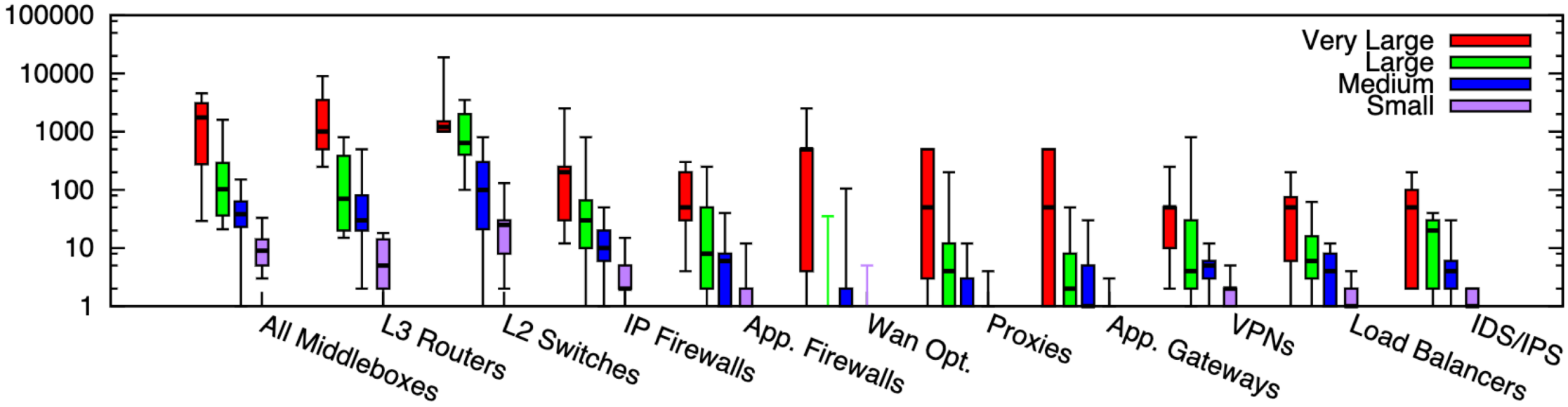
Yet there is no recent Internet-wide study analyzing MPTCP adoption!

MPTCP in the Internet

Understanding MPTCP adoption is important:

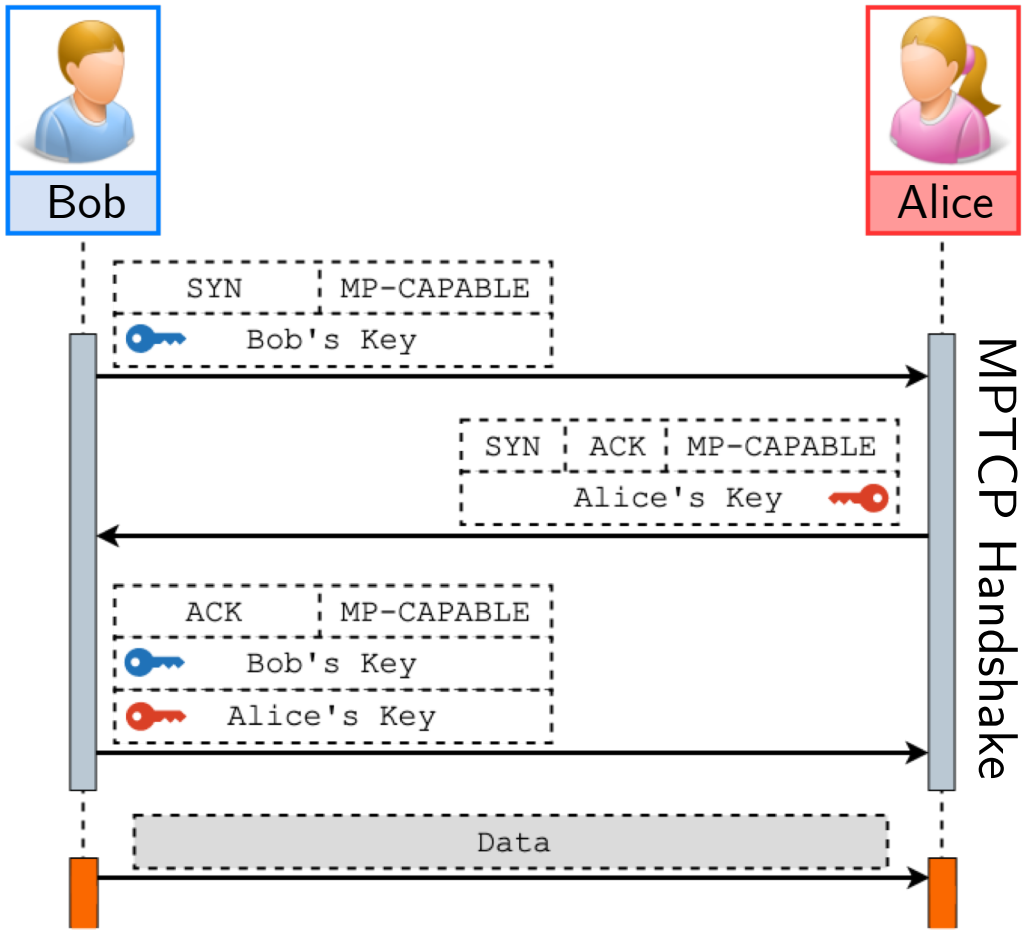
1. Clients can only use MPTCP if **servers also** support it

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



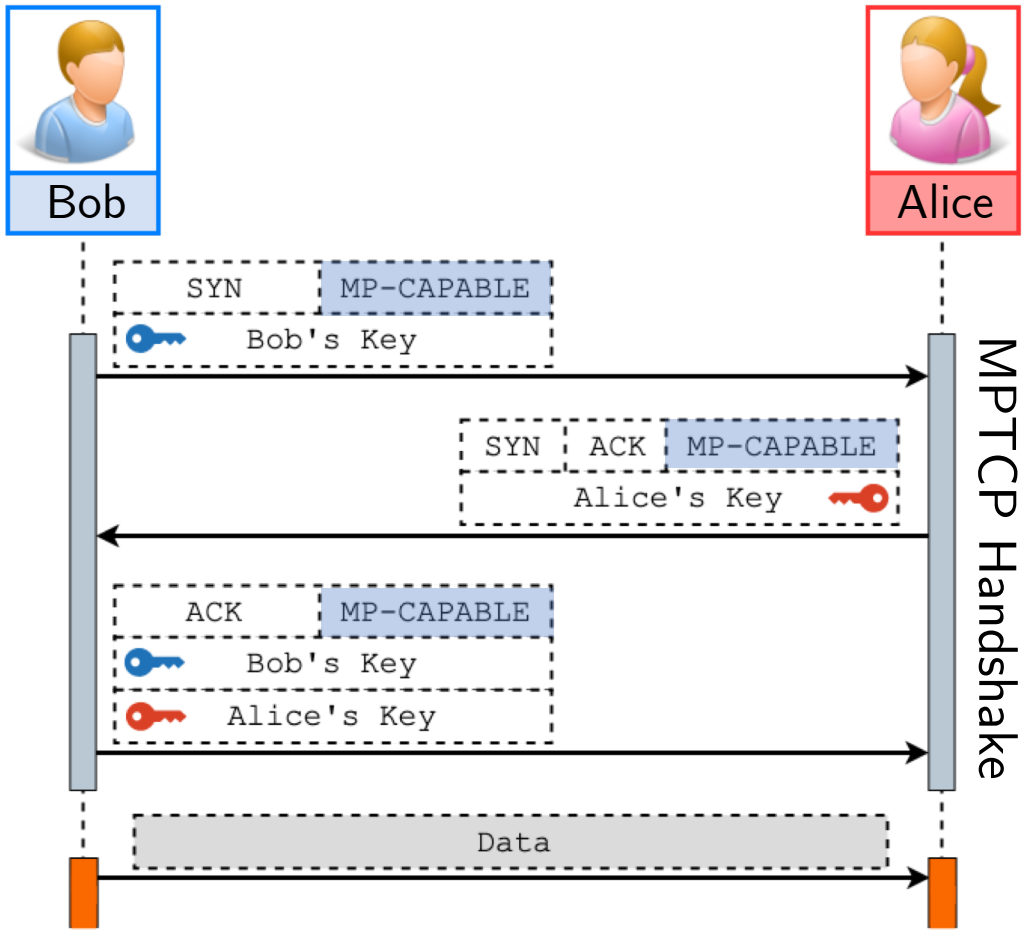
Sherry, Justine, et al. "Making middleboxes someone else's problem: Network processing as a cloud service." ACM SIGCOMM Computer Communication Review 2012

Scanning for MPTCPv0 Support



MPTCPv0 connection establishment leverages TCP's three-way handshake

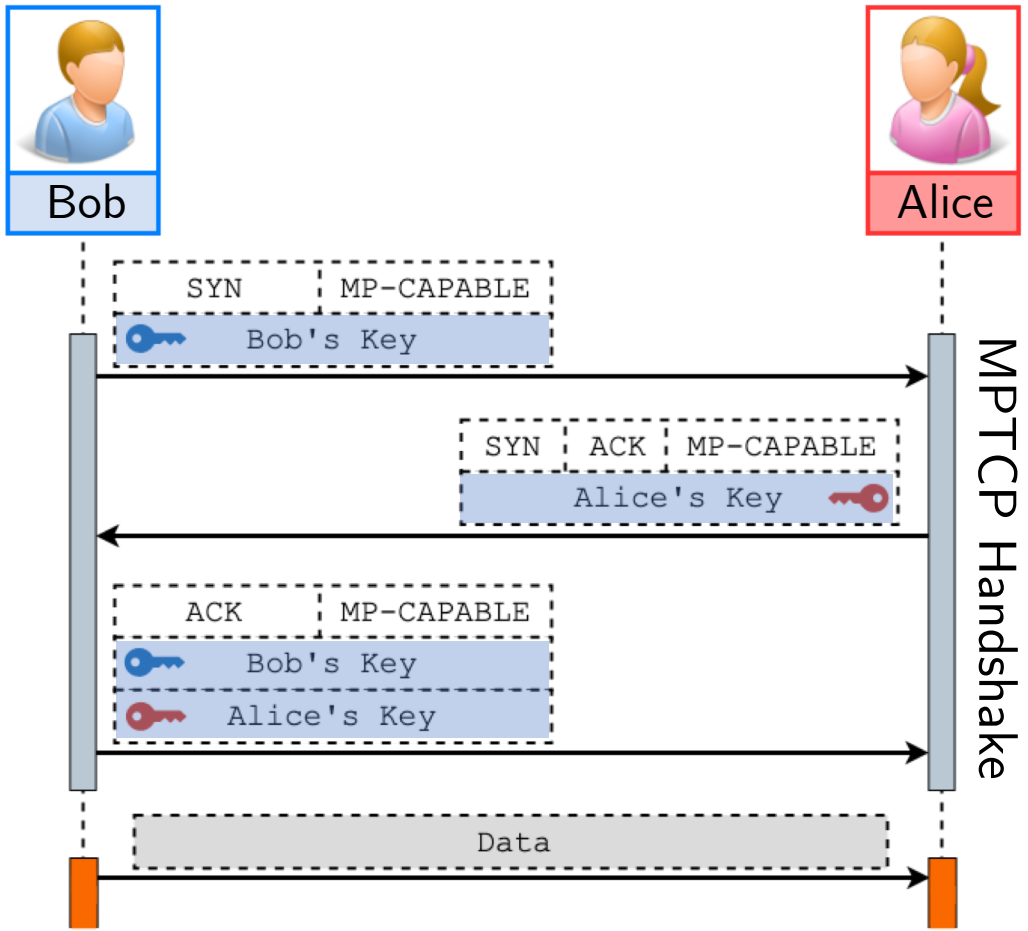
Scanning for MPTCP Support



MPTCPv0 connection establishment leverages TCP's three-way handshake

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

Scanning for MPTCP Support

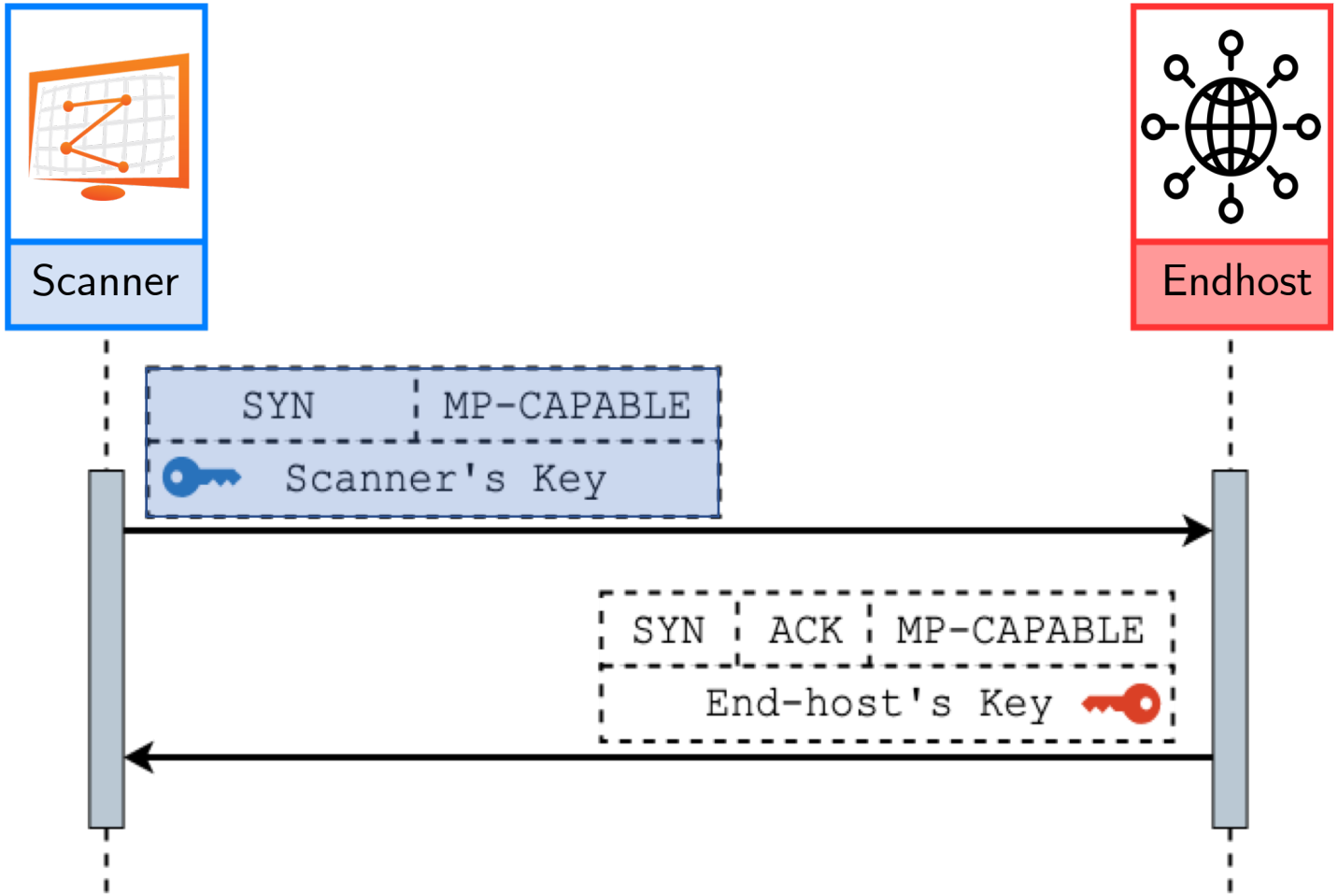


MPTCPv0 connection establishment leverages TCP's three-way handshake

- 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



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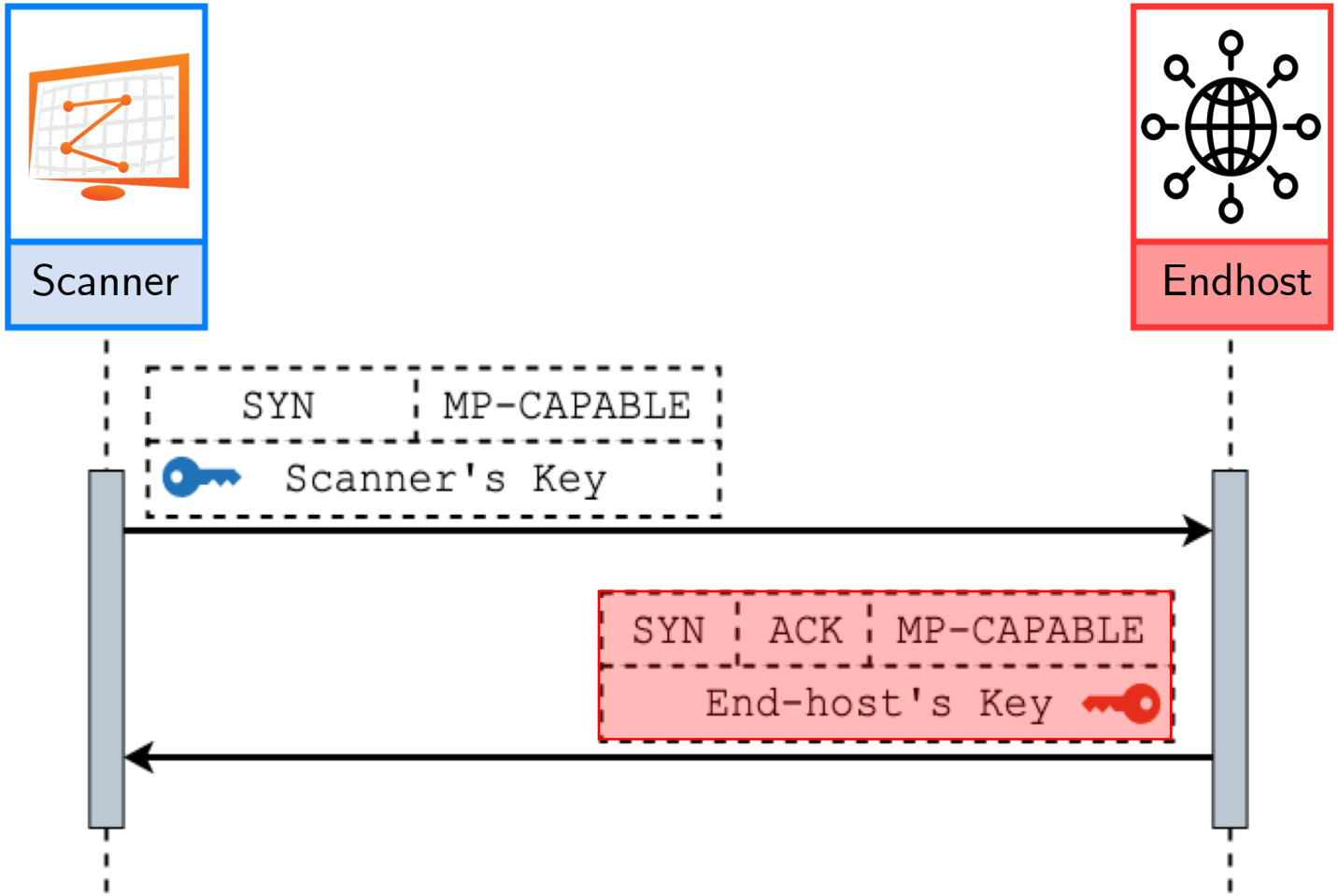

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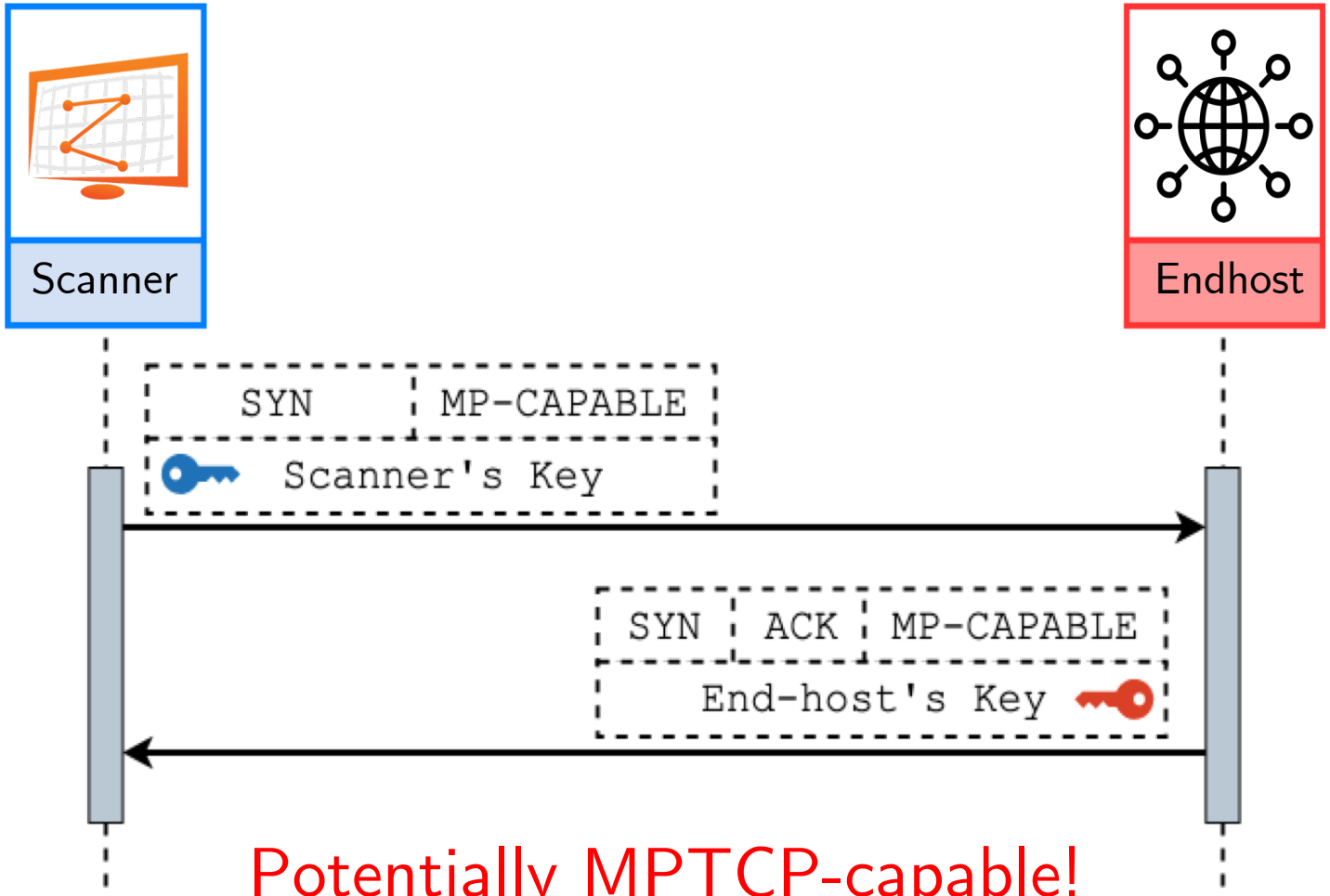

Potentially MPTCP-capable!

MPTCPv0 Support in-the-wild

Over six months in 2020

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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But do all these hosts ***truly*** support MPTCP?

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MPTCP over Middleboxes

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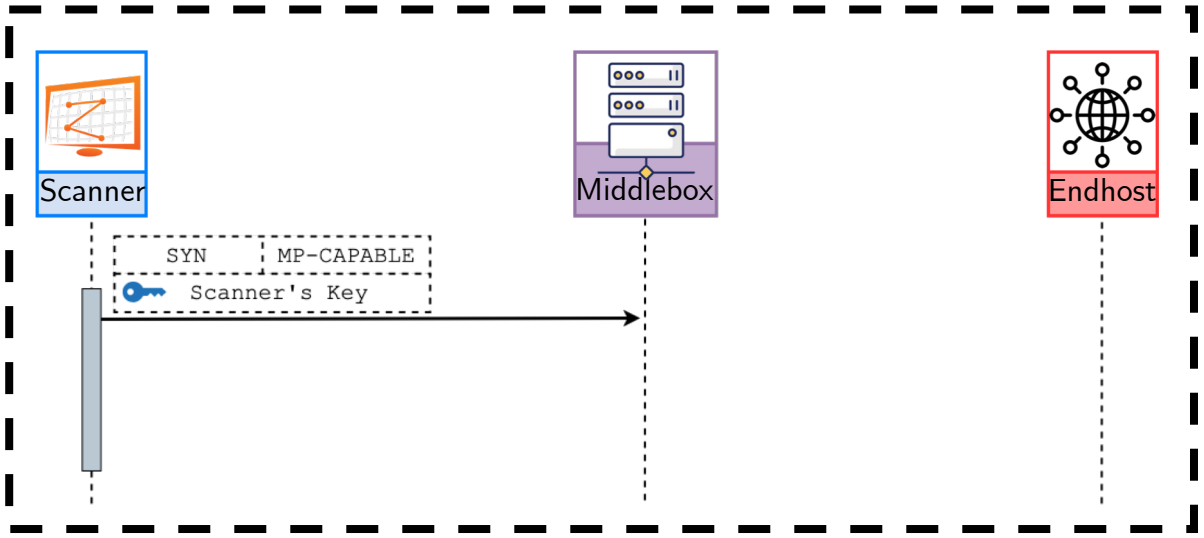

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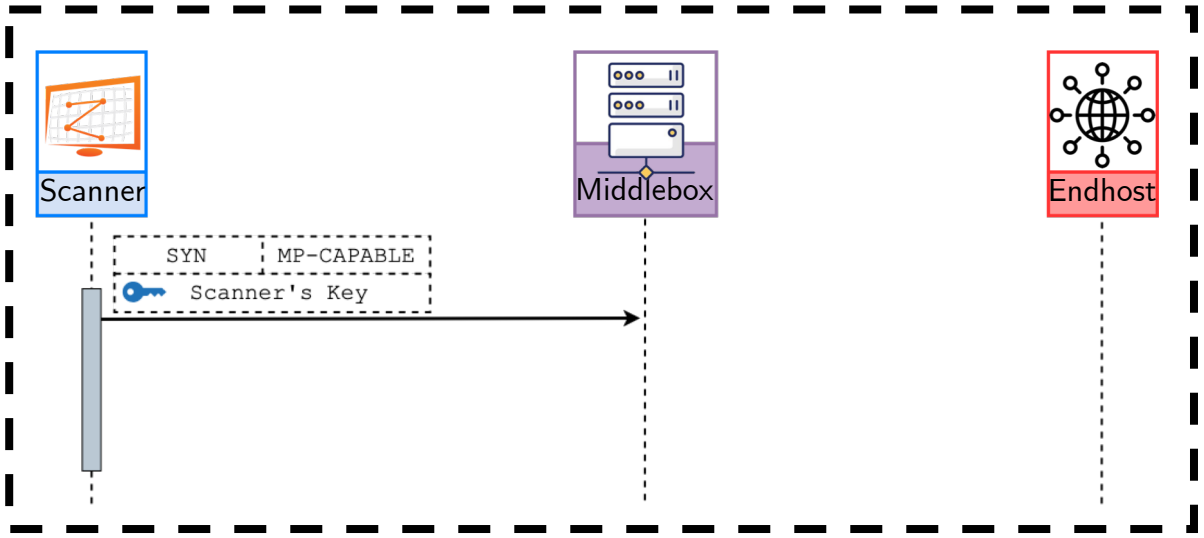

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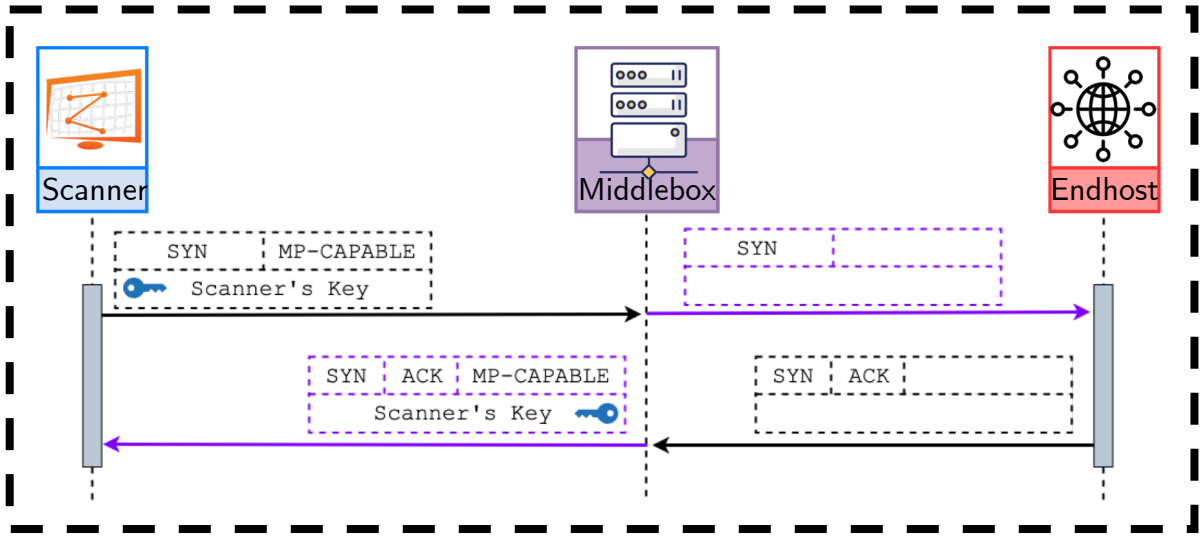

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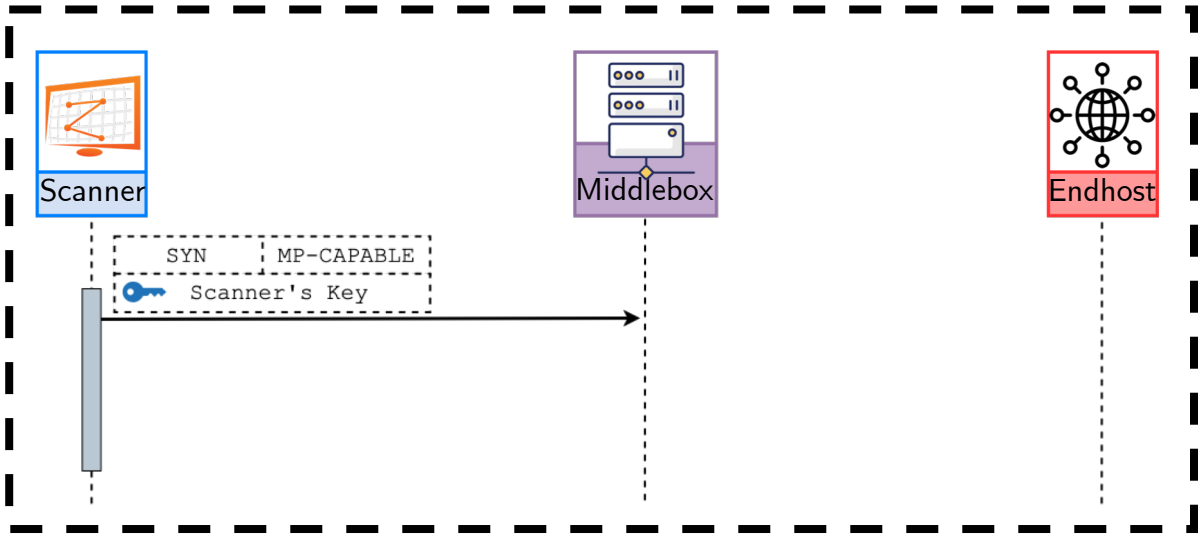

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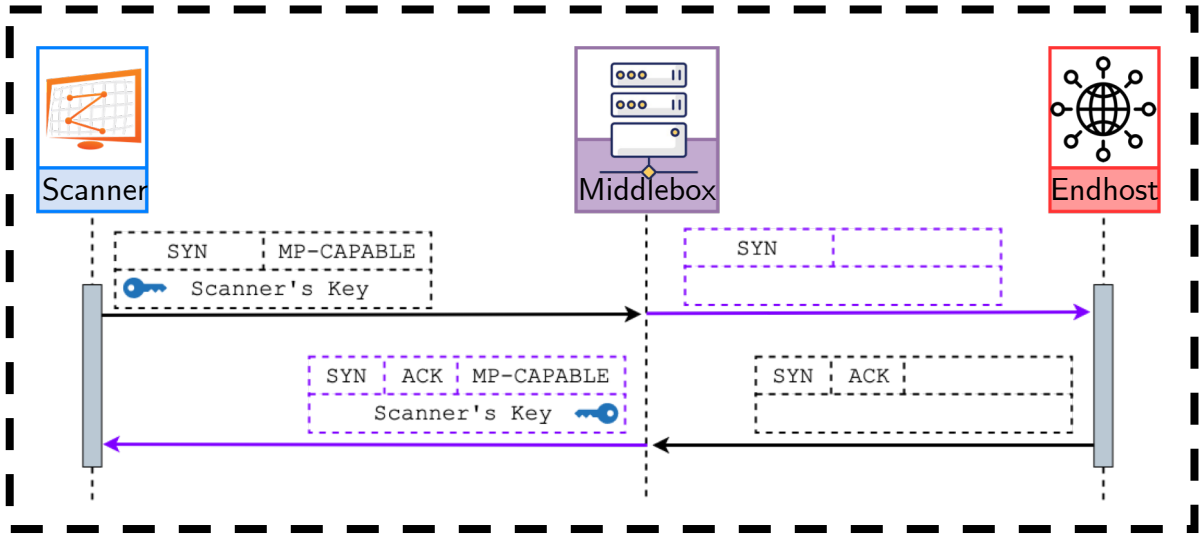

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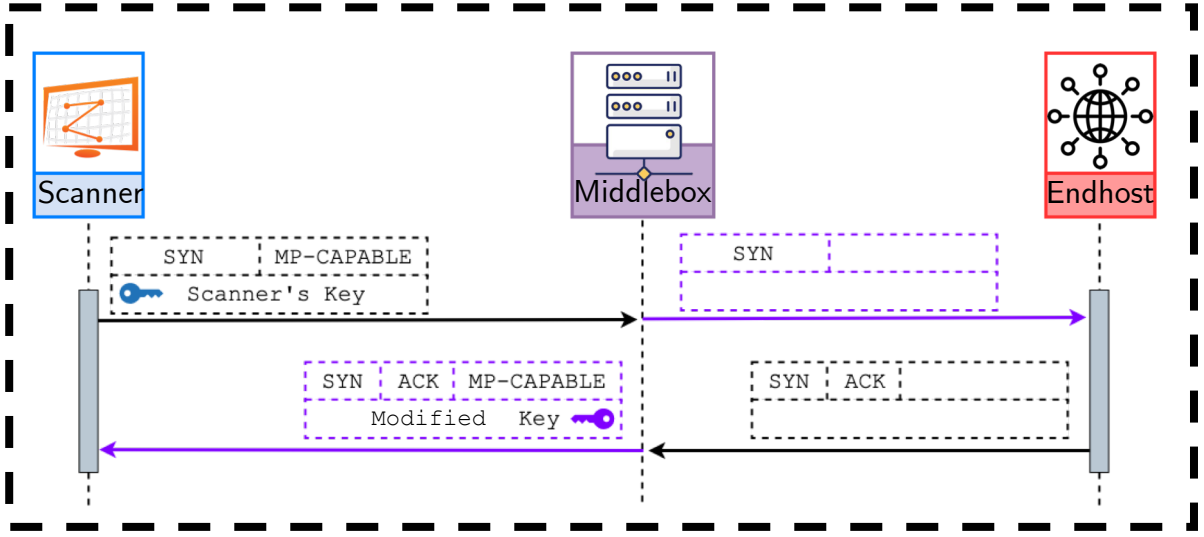

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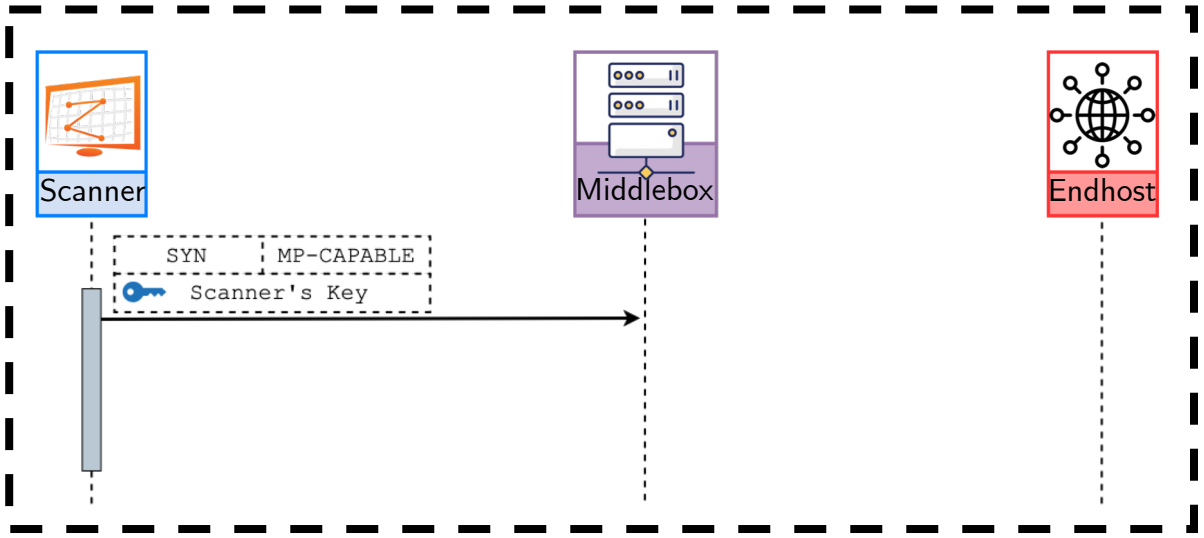

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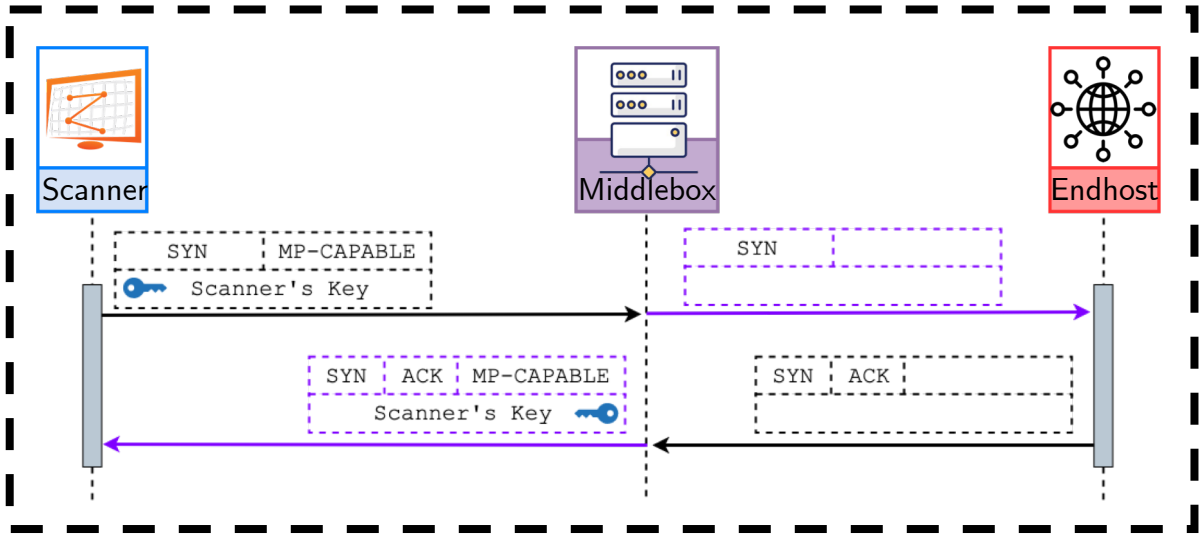

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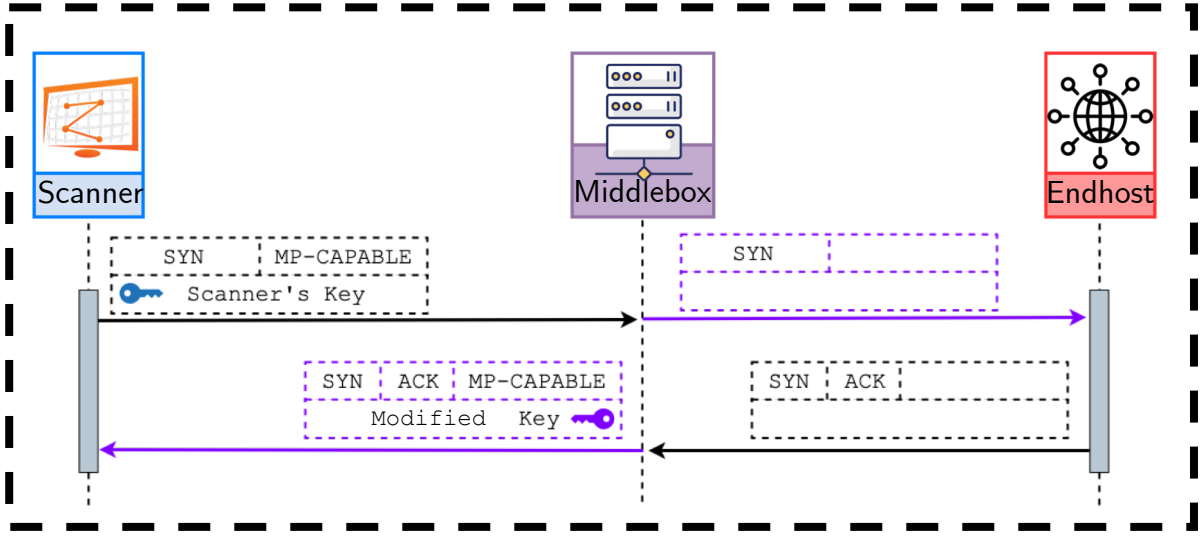
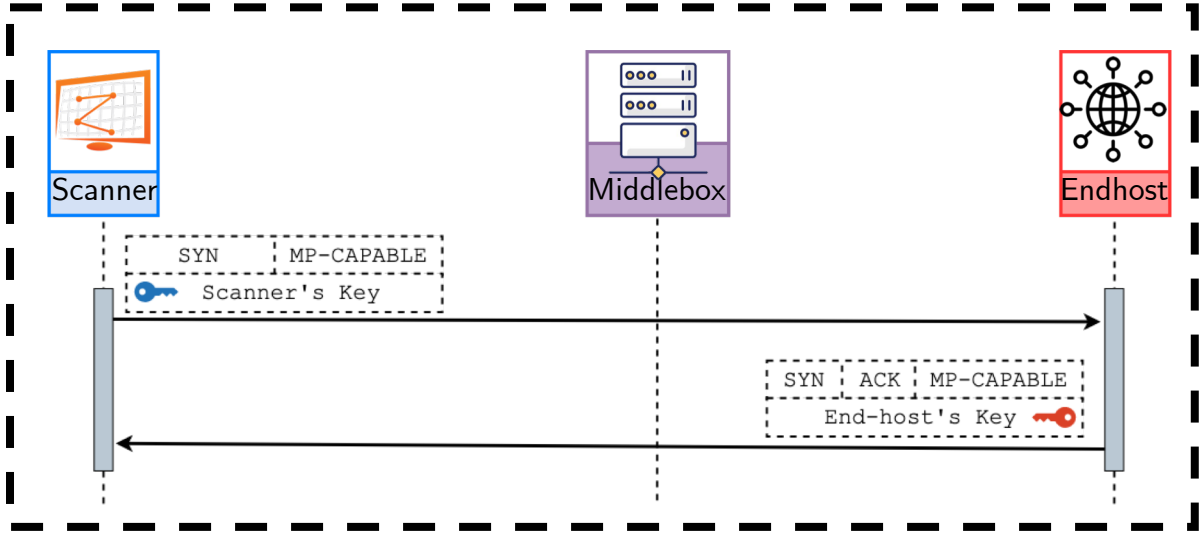
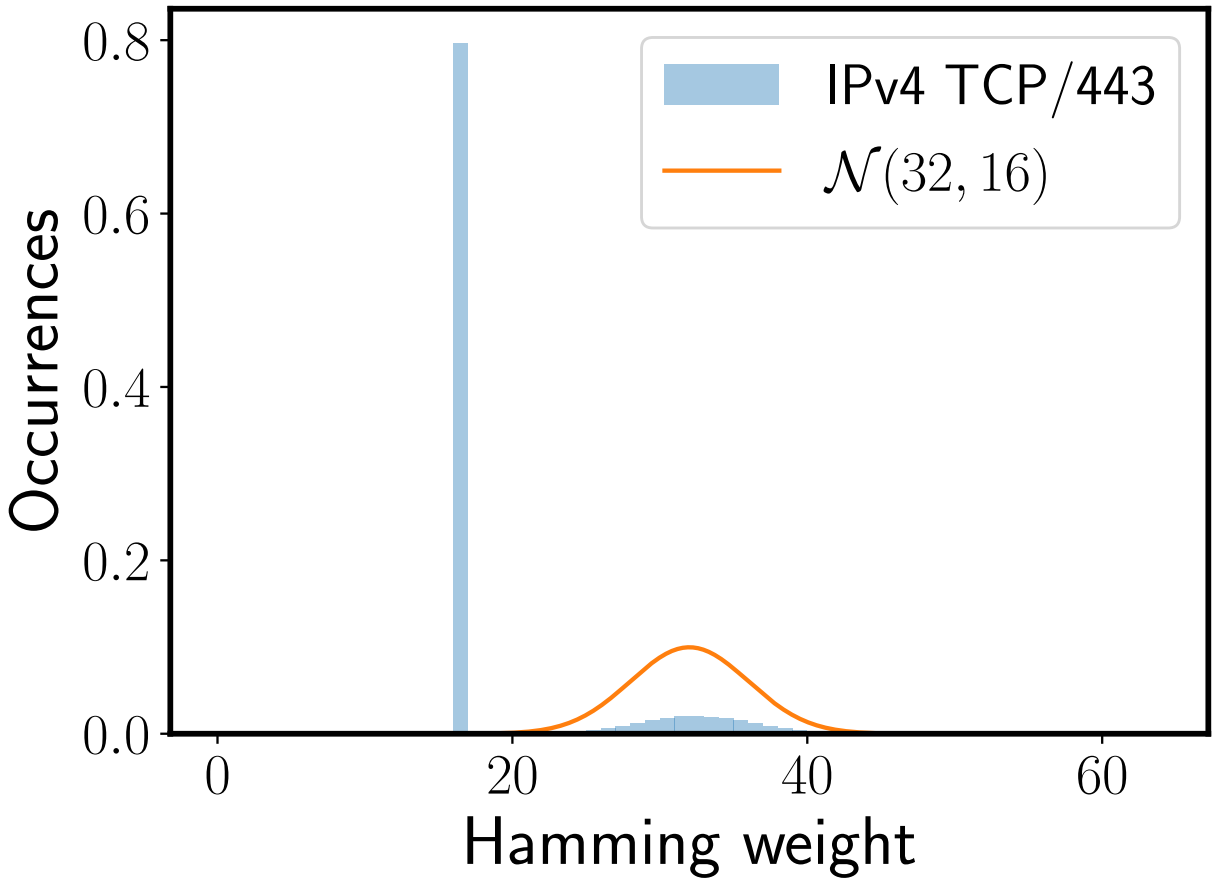
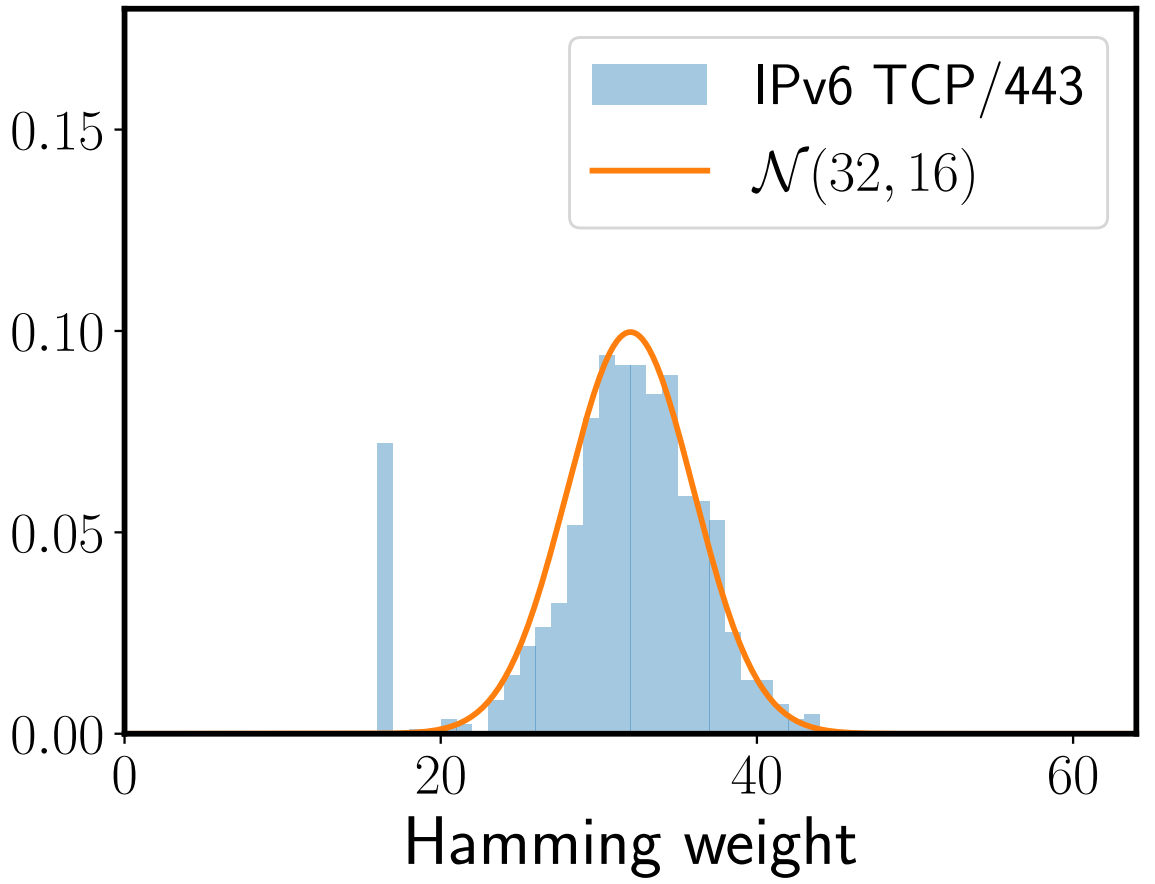


Rule 4: Pass-through



Impact of Middleboxes on Scans





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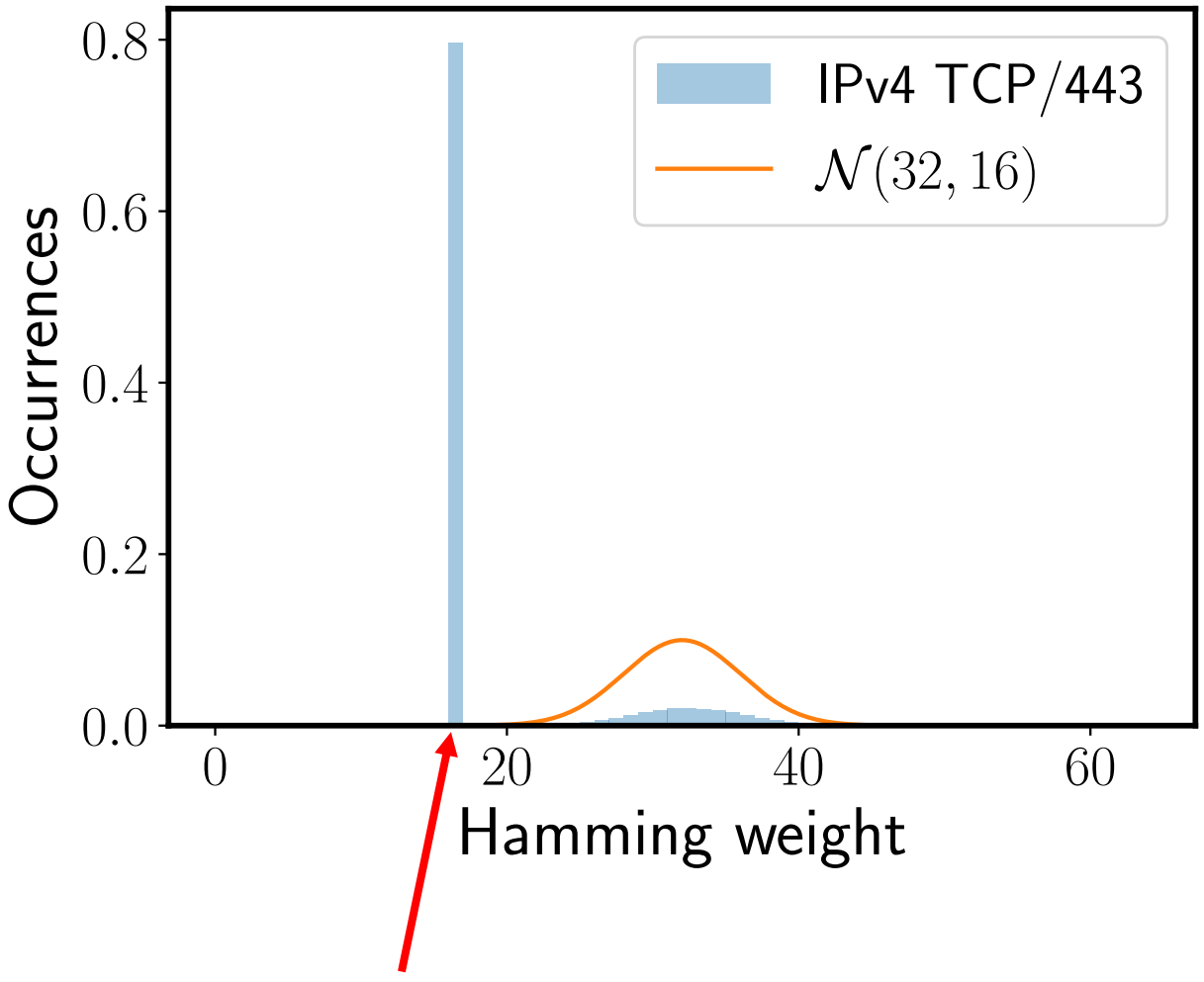
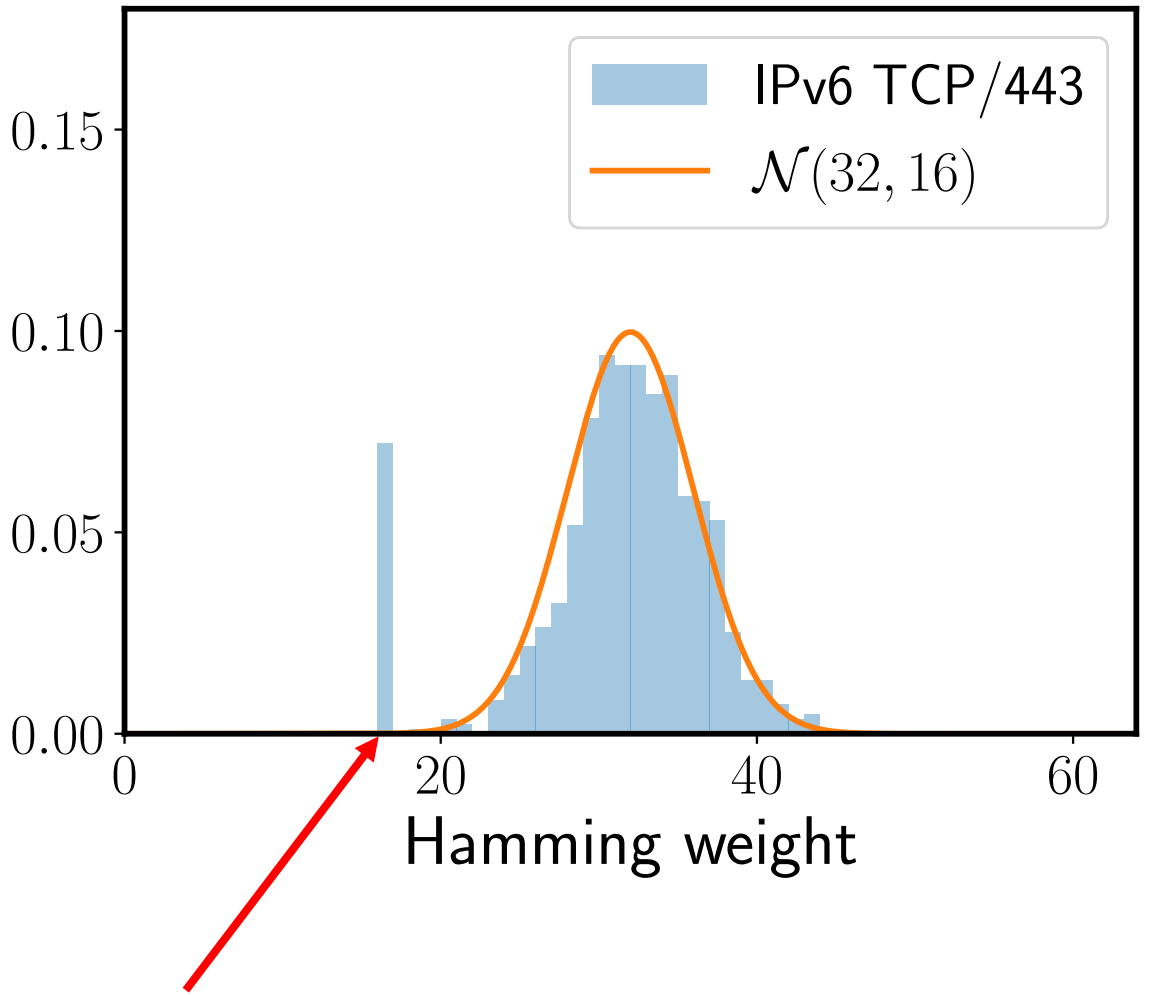


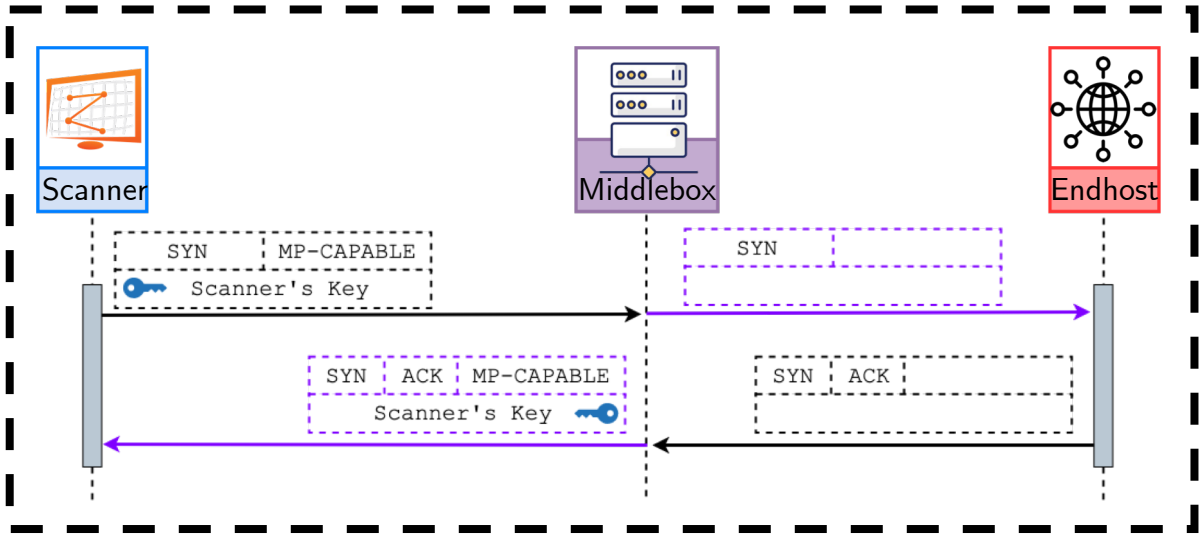


ZMap-based MPTCP identification is severely affected by middleboxes

Impact of Middleboxes on Scans

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

Rule 2: Mirror



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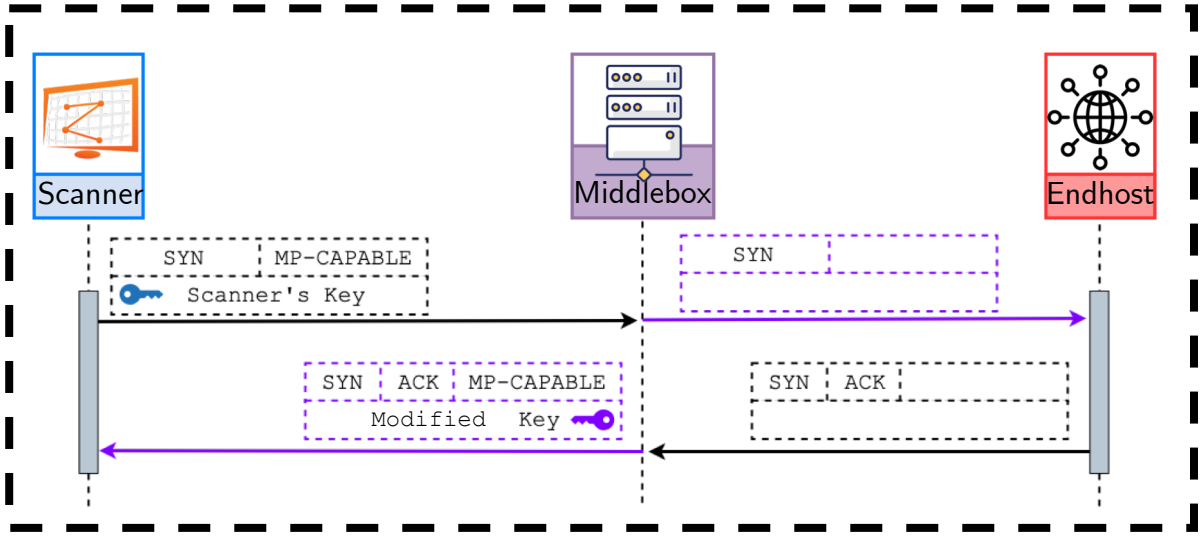


Analyzing True Support of MPTCP

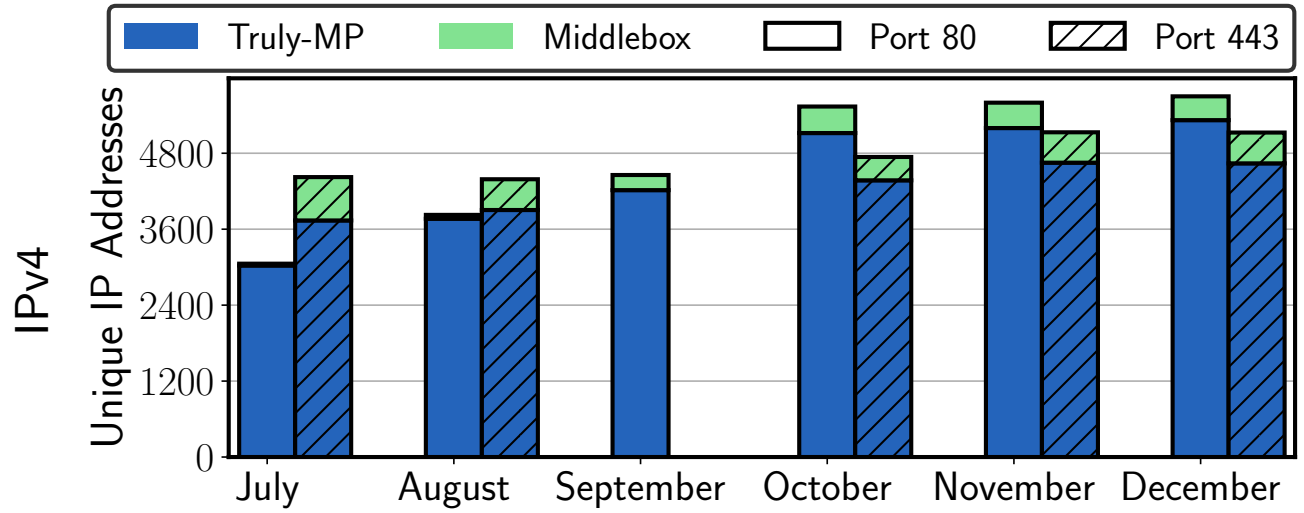
Triggered Tracebox towards all potentially MPTCP hosts from ZMap

- 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

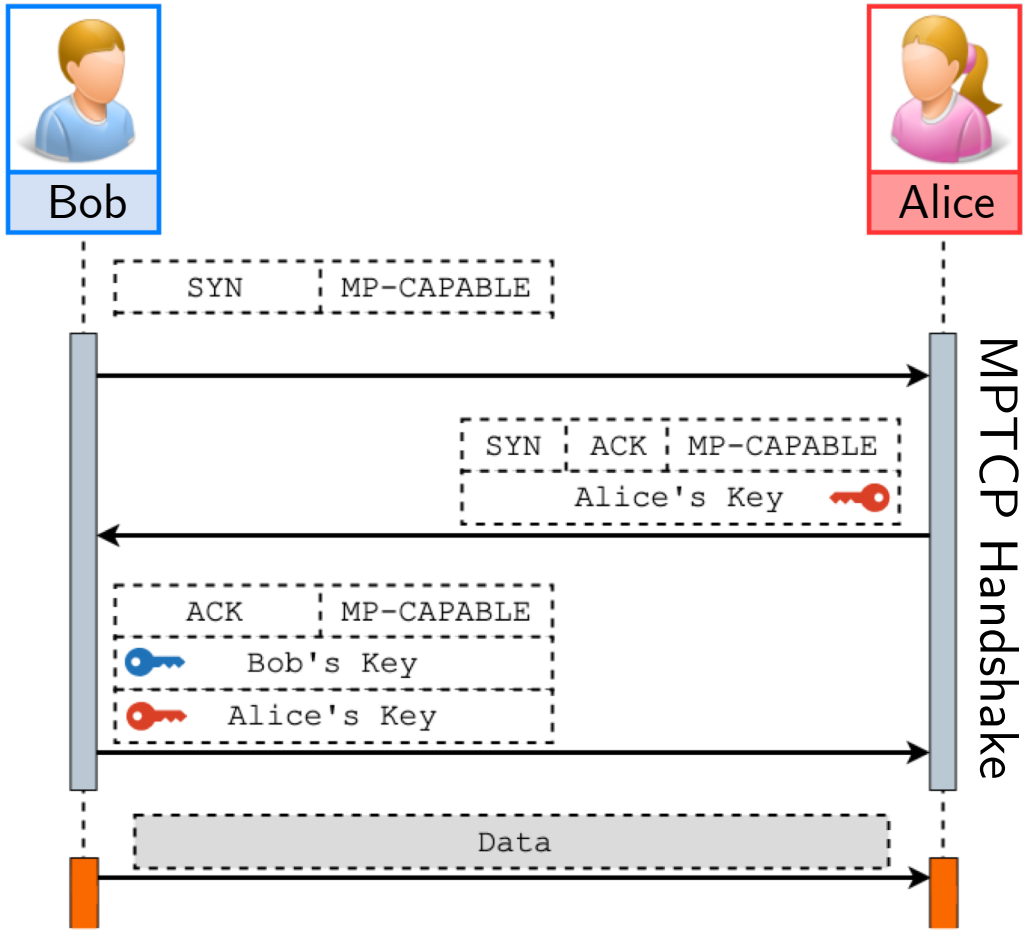
True MPTCPv0 Support in the Internet



- 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

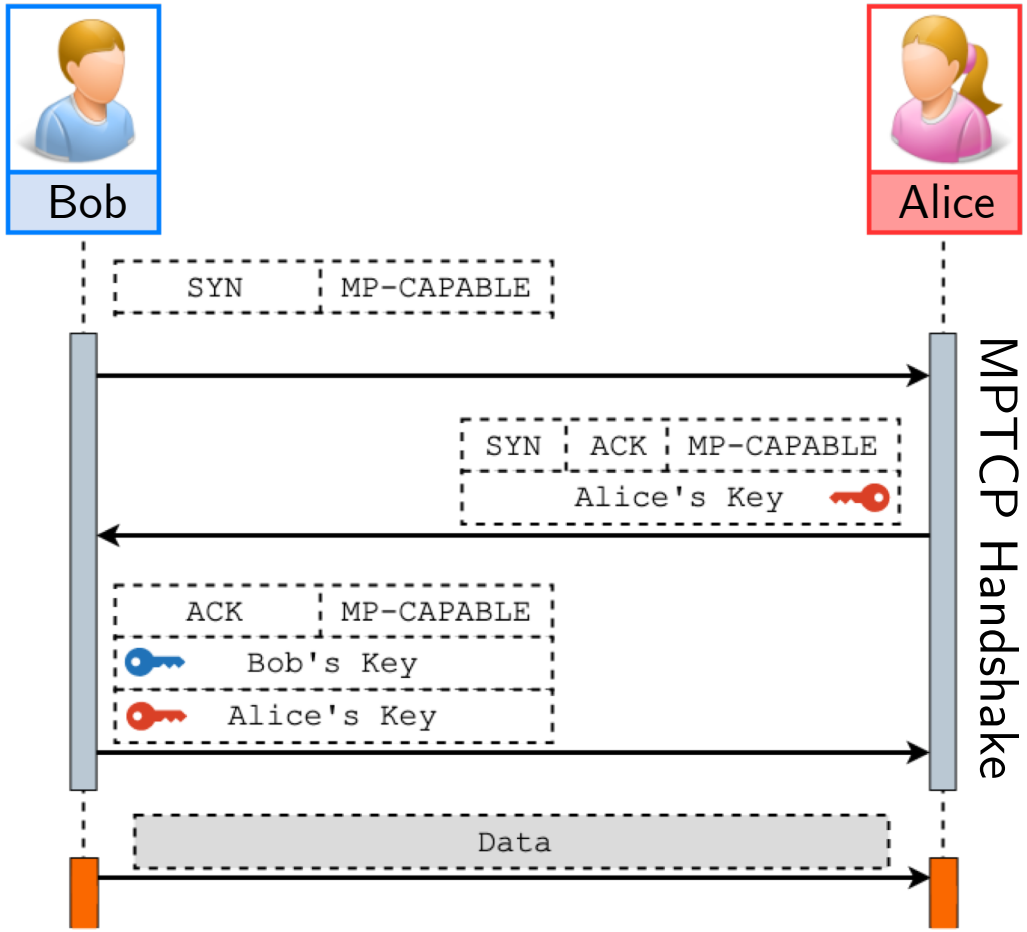
IPv4	IPv6
Port 80: ≈5.5k Port 443: ≈4.5k	Port 80: 31 Port 443: 27

MPTCPv1 Support



MPTCPv1 removes sender's key in SYN

MPTCPv1 Support



MPTCPv1 removes sender's key in SYN

In May 2021

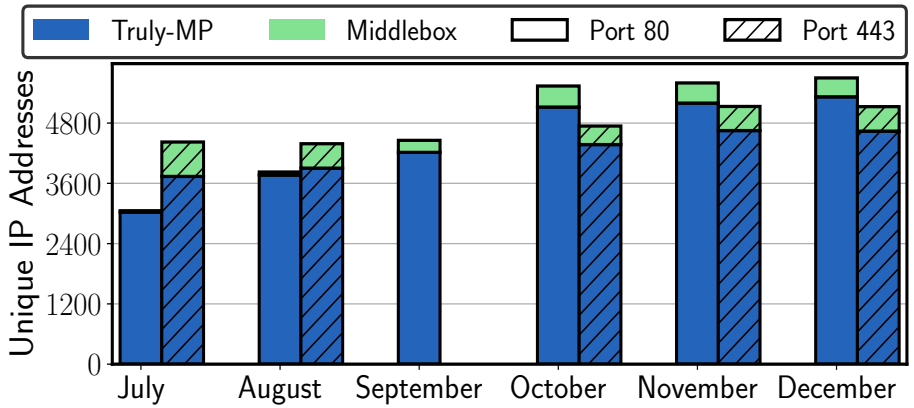
		MP_CAPABLE	MP_CAPABLE + Key
IPv4	Port 80	179194	184
	Port 443	170770	251
IPv6	Port 80	651	3
	Port 443	645	3

- Very high share of middlebox interference
- MPTCPv1 does not have a lot of activity compared to MPTCPv0
- MPTCPv1 while enabled by default, requires application to open MP_PROTO socket

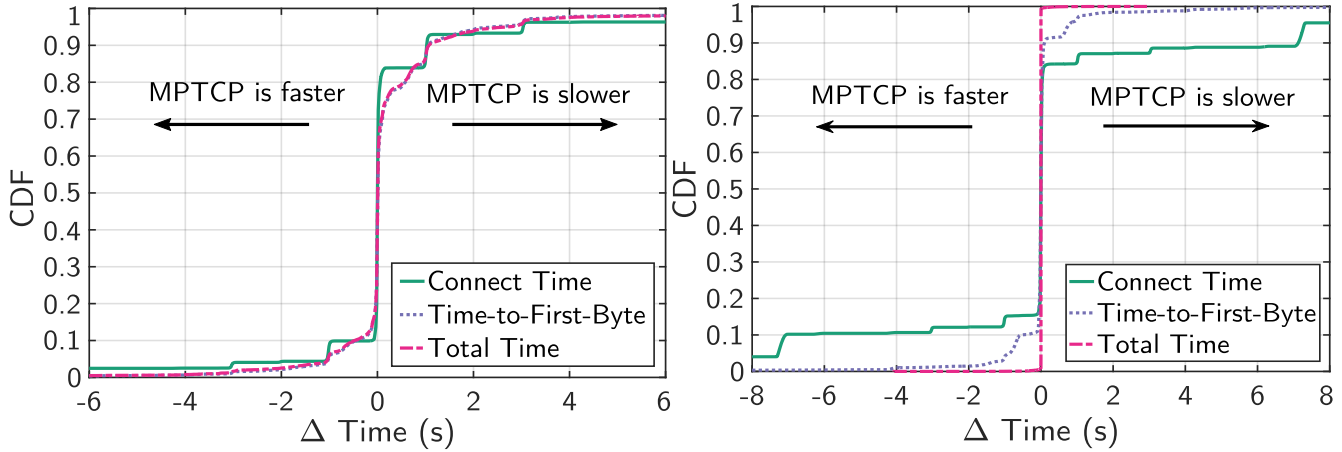
MPTCP Adoption in a Nutshell

Read our IFIP Networking 2021 paper for

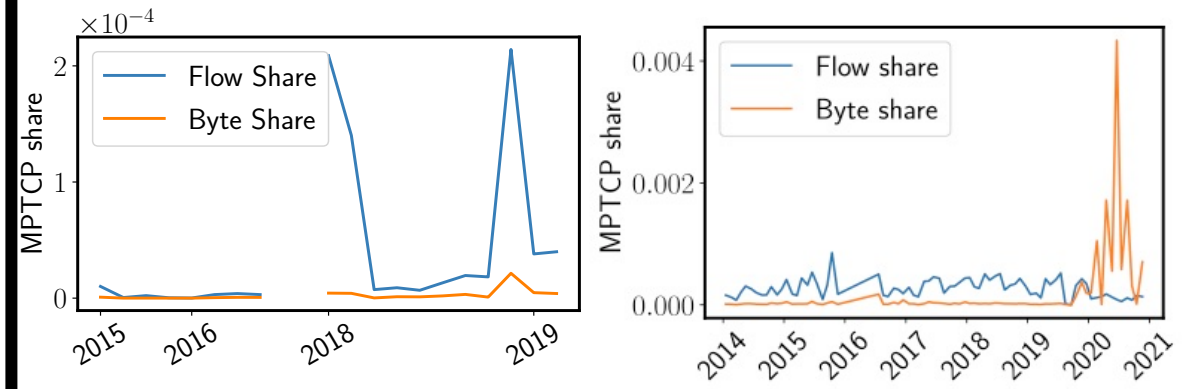
True support for MPTCPv0



Impact of middleboxes on MPTCP data transfers



MPTCP traffic share in the Internet



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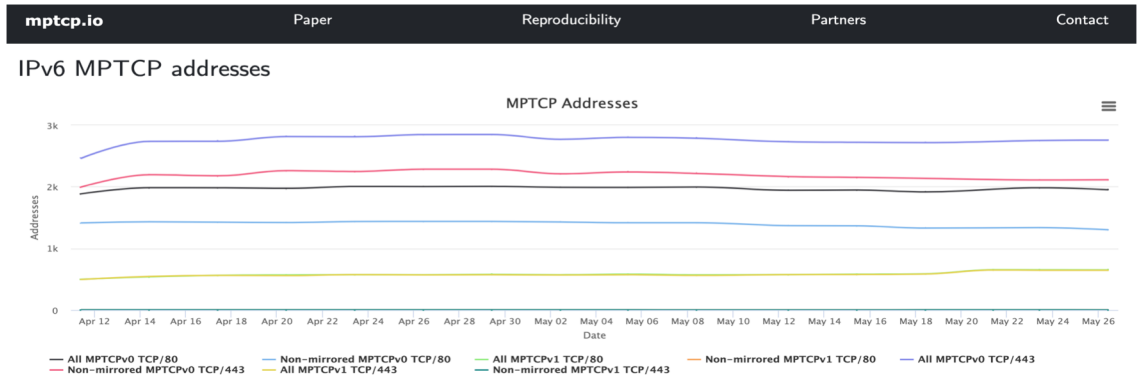

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