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

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mptcp.io
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 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
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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   - Identify middleboxes affecting MPTCP transfer using Tracebox

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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3. MPTCP traffic share in the Internet
   • 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
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- Both hosts must send MP_CAPABLE flag to denote MPTCP capability
Scanning for MPTCP Support

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

Scanner

Endhost

Potentially MPTCP-capable!
# MPTCP Support in-the-wild

## IPv4 ZMap

<table>
<thead>
<tr>
<th>Potential MPTCP</th>
<th>July</th>
<th>August</th>
<th>September</th>
<th>October</th>
<th>November</th>
<th>December</th>
</tr>
</thead>
<tbody>
<tr>
<td>Port 80</td>
<td>179.5K</td>
<td>201.6K</td>
<td>197.1K</td>
<td>196.1K</td>
<td>205.4K</td>
<td>206.3K</td>
</tr>
<tr>
<td>Port 443</td>
<td>211.1K</td>
<td>198.1K</td>
<td>-</td>
<td>232.7K</td>
<td>239.5K</td>
<td>233.8K</td>
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## IPv6 ZMap

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</tr>
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<tbody>
<tr>
<td>Port 80</td>
<td>-</td>
<td>43</td>
<td>43</td>
<td>43</td>
<td>43</td>
<td>44</td>
</tr>
<tr>
<td>Port 443</td>
<td>-</td>
<td>165</td>
<td>166</td>
<td>165</td>
<td>167</td>
<td>168</td>
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MPTCP Support in-the-wild

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But do all these hosts *truly* support MPTCP?

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MPTCP over Middleboxes
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Rule 1: Drop
MPTCP over Middleboxes

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Rule 2: Mirror
MPTCP over Middleboxes

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Rule 3: Proxy
MPTCP over Middleboxes

Rule 1: Drop
Scanner → Middlebox → Endhost
SYN, MP-CAPABLE, Scanner's Key

Rule 2: Mirror
Scanner → Middlebox → Endhost
SYN, MP-CAPABLE, Scanner's Key

Rule 3: Proxy
Scanner → Middlebox → Endhost
SYN, ACK, MP-CAPABLE, Modified Key

Rule 4: Pass-through
Scanner → Middlebox → Endhost
SYN, ACK, MP-CAPABLE, End-host's Key
Impact of Middleboxes on Scans

- Left graph: Occurrences vs. Hamming weight for IPv4 TCP/443, with a normal distribution $\mathcal{N}(32, 16)$.
- Right graph: Occurrences vs. Hamming weight for IPv6 TCP/443, with a normal distribution $\mathcal{N}(32, 16)$. 
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

Rule 3: Proxy
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

<table>
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<td>Port 80:</td>
</tr>
<tr>
<td>≈5.5k</td>
<td>31</td>
</tr>
<tr>
<td>Port 443:</td>
<td>Port 443:</td>
</tr>
<tr>
<td>≈4.5k</td>
<td>27</td>
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MPTCP Traffic Share in the Internet
Traffic Characteristics

- 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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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...

HTTPS is dominant application with 99% of MPTCP traffic!
MPTCP Adoption in a Nutshell

True support for MPTCPv0

[Bar chart showing Unique IP Addresses for each month from July to December, with categories for Truly-MP, Middlebox, Port 80, and Port 443.]
MPTCP Adoption in a Nutshell

True support for MPTCPv0

- Truly-MP
- Middlebox
- Port 80
- Port 443

Impact of middleboxes on MPTCP data transfers

- MPTCP is faster
- MPTCP is slower

Unique IP Addresses

July: 1200
August: 2400
September: 3600
October: 4800
November: 4800
December: 4800
MPTCP Adoption in a Nutshell

True support for MPTCPv0

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