Faculté des Sciences Appliquées

Tracking Middleboxes with Tracebox

IETF93: HOPS

Korian Edeline, Benoit Donnet
University of Liège

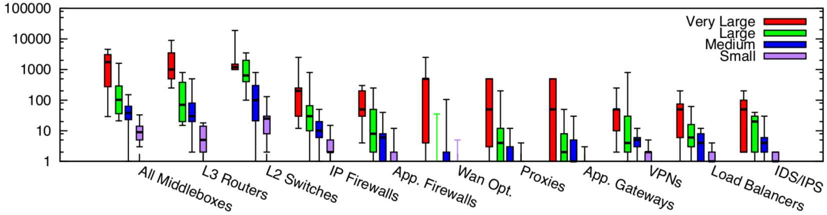
mPlane

Introduction

1. Middleboxes
2. How to detect them ?
3. Tracebox
4. Implementations

Plan

Deployment



Box plot of middlebox deployments for small (fewer than 1k hosts), medium (1k-10k hosts), large (10k-100k hosts), and very large (more than 100k hosts) enterprise networks. Y-axis is in log scale. [1]

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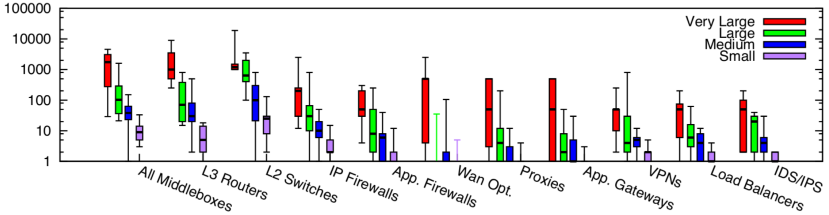

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- The market for security-oriented middleboxes is estimated to exceed \$10B by 2016[2]

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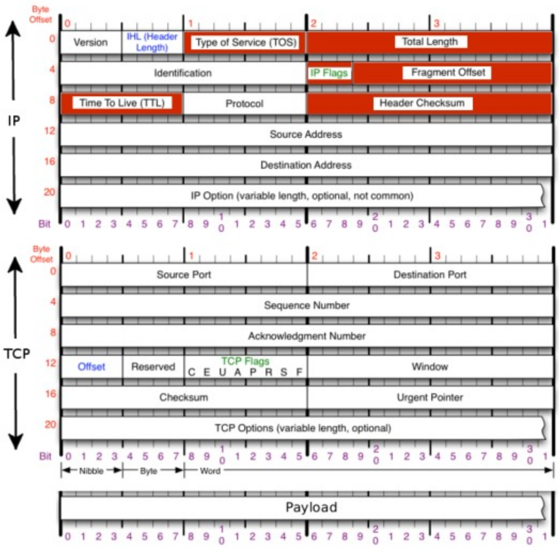
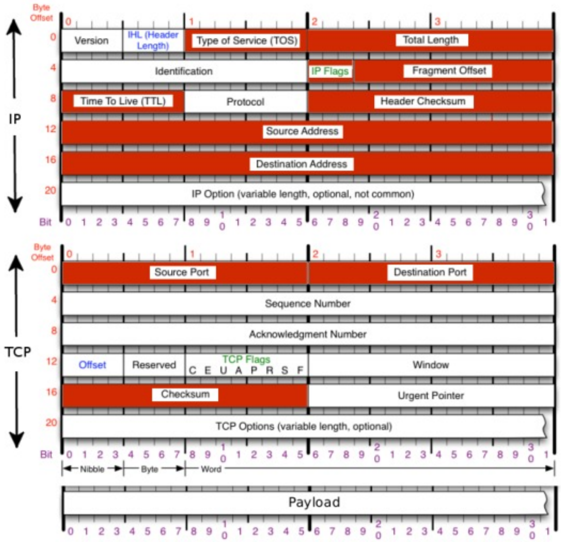
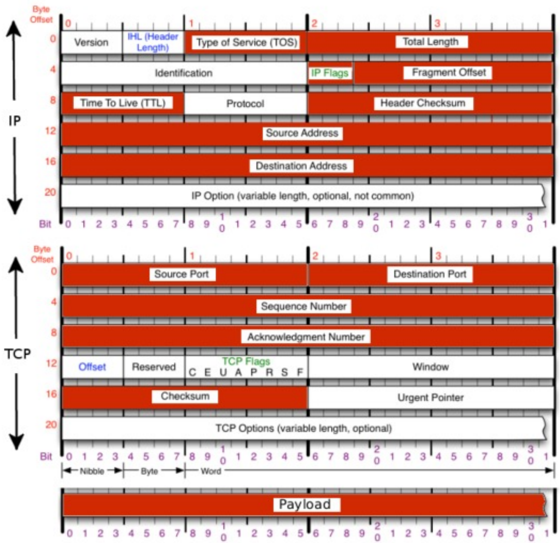
Router processing



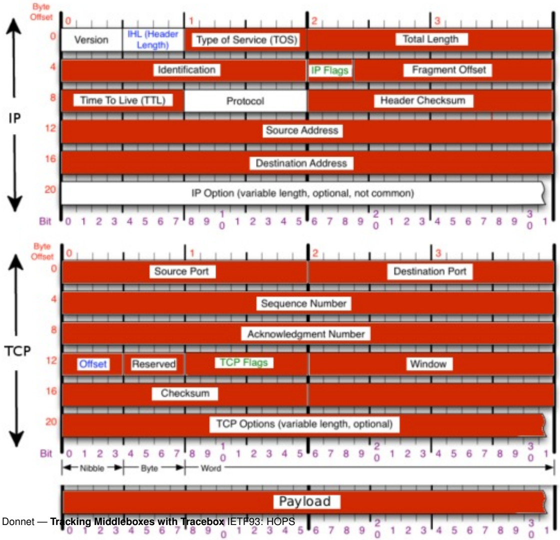
NAT processing



ALG processing



Potential processing over the whole Internet



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TBIT

- `tbit`[3]

[3] Alberto Medina, Mark Allman, and Sally Floyd. “Measuring interactions between transport protocols and middleboxes”. In: *Proceedings of the 4th ACM SIGCOMM conference on Internet measurement*. ACM. 2004, pp. 336–341.

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- Purpose
  - detect whether ECN, IP options, and TCP options can be safely used

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- Effect
  - Detect last modification, errors
  - Differentiate inbound & outbound modifications

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TCP HICCUPS

- TCP HICCUPS[5]
- Lightweight TCP extension that exposes in flight packet header modification to end points
- Basic question behind TCP HICCUPS
  - did my packet arrive at the destination with the same headers as sent?

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TCP HICCUPS

- HICCUPS overloads 3 header fields in the TCP 3-way handshake
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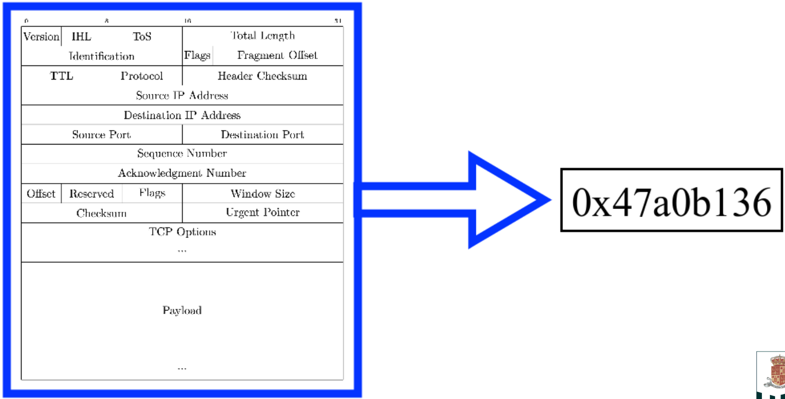
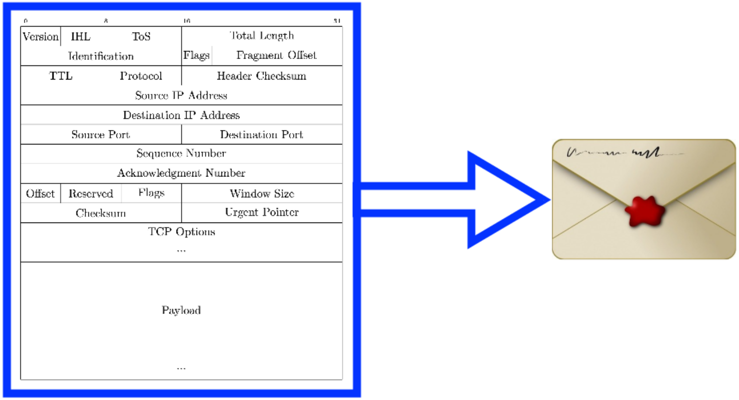
- HICCUPS overloads 3 header fields in the TCP 3-way handshake
  - ISN, IPID, RWIN
- ... with a function of the packet header



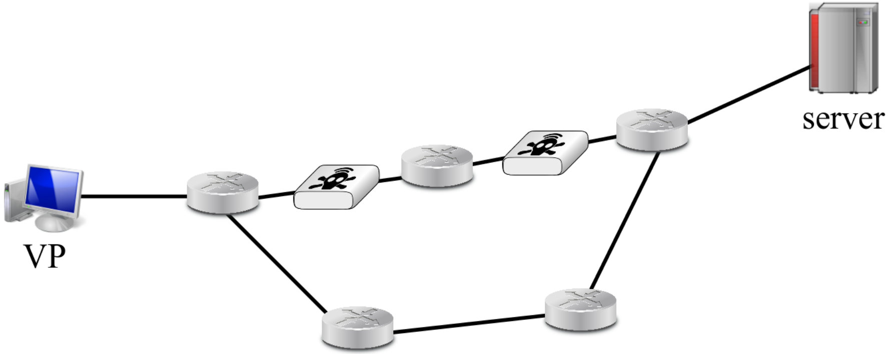
TCP HICCUPS

- All in all, it creates an end-to-end tamper-evident seal over the packet headers
- Different than a checksum
  - if some mods occur, the packet is still accepted



Controlling both ends

- Controlling both ends allows to detect middleboxes on one path



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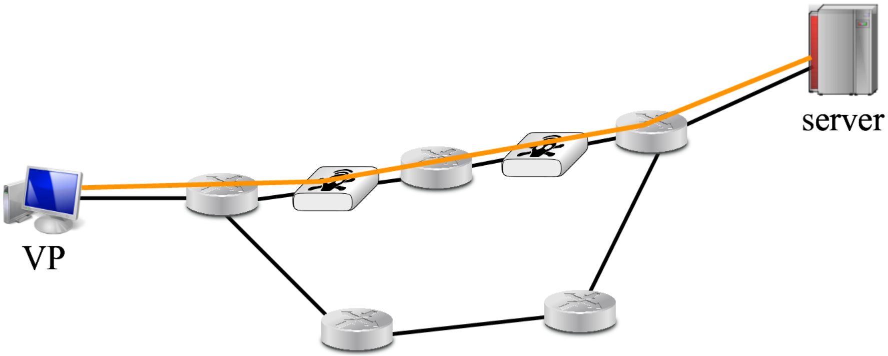
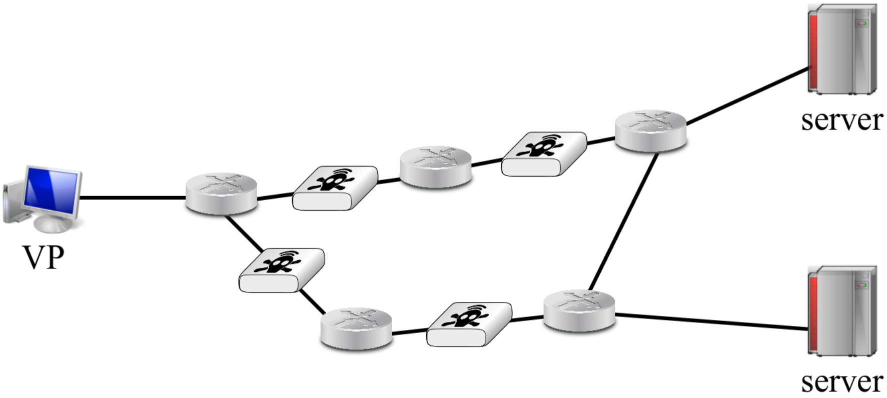


Controlling both ends

- What happens with uncontrolled server(s)?
  - potentially miss a lot of middleboxes



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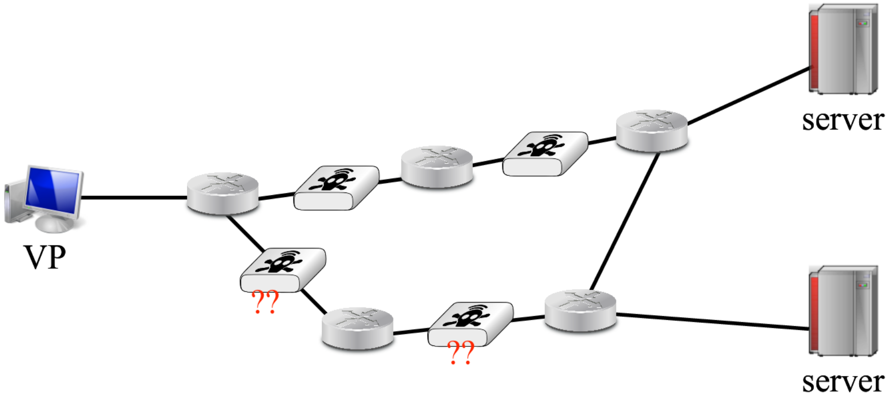

Tracebox

- Tracebox[6]
- Extension to traceroute
  - send TTL limited TCP probes
  - inspect incoming ICMP time-exceeded packets
  - compare the TCP probe quoted and the TCP probe sent
  - in case of difference(s), a middlebox is found along the path

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- Purpose
  - Middlebox detection
  - Middlebox location

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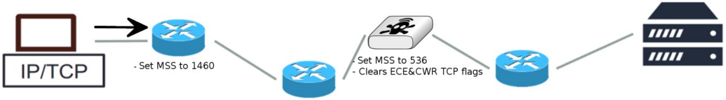
Plan

Tracebox


IP/TCP
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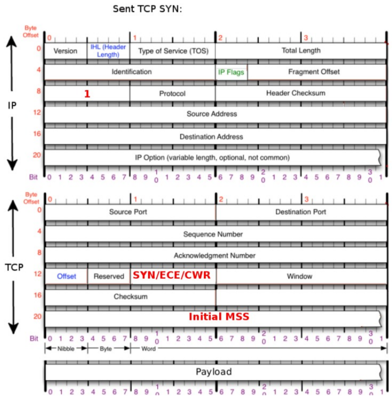
- Set MSS to 536
- Clears ECE&CWR TCP flags


Sent TCP SYN:
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Version
IHL (Header Length)
Type of Service (TOS)
Total Length
Identification
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Fragment Offset
1
Protocol
Header Checksum
Source Address
Destination Address
IP Option (variable length, optional, not common)
TCP
Source Port
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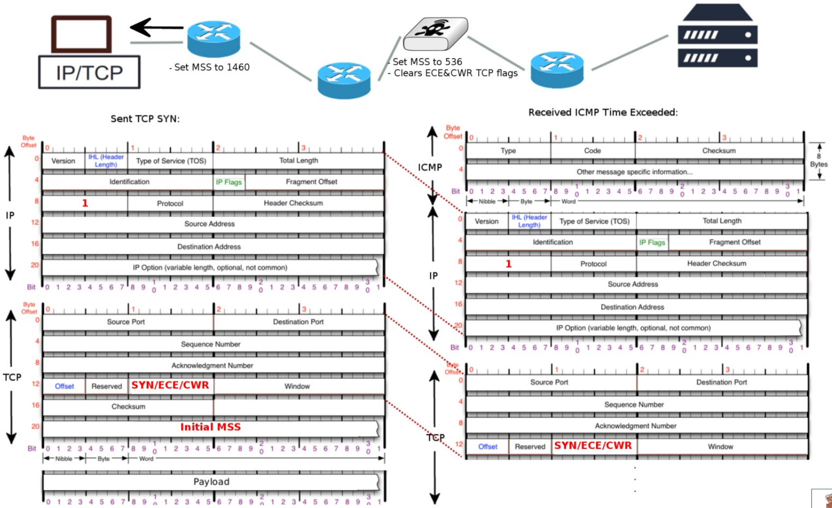
Word
Payload

Tracebox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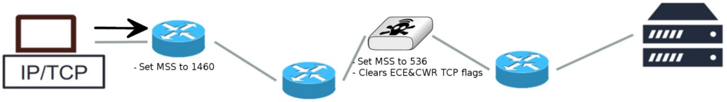

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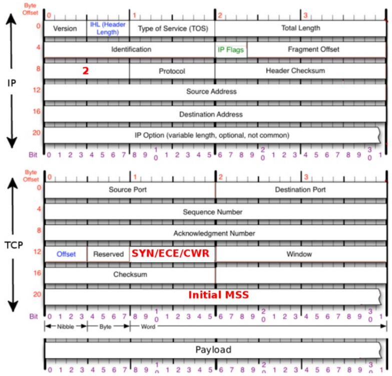

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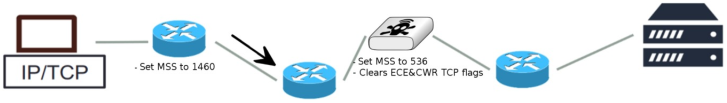

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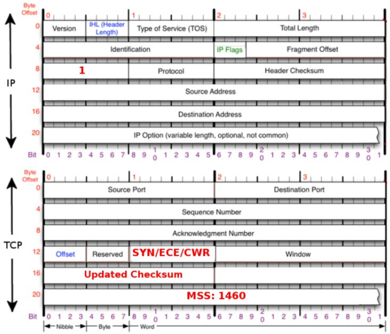

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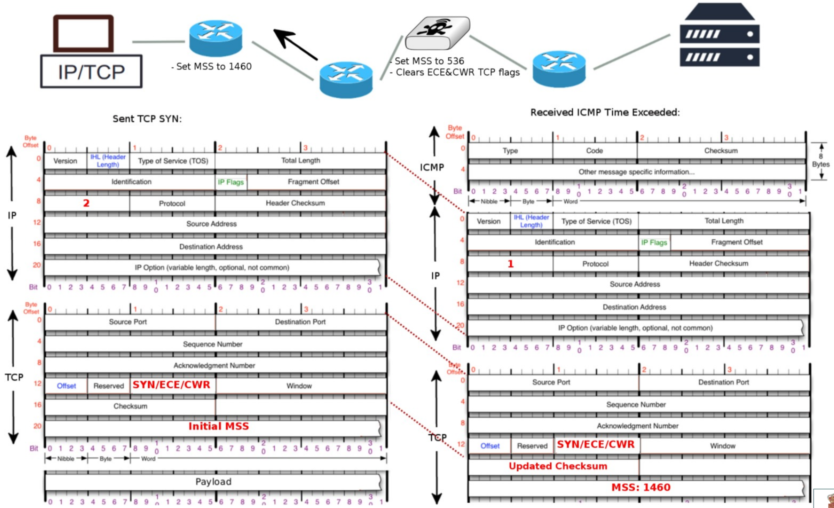
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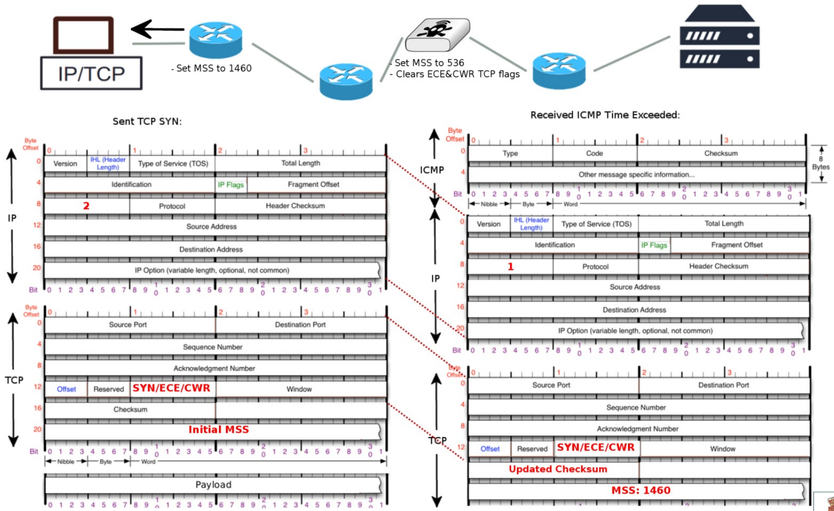
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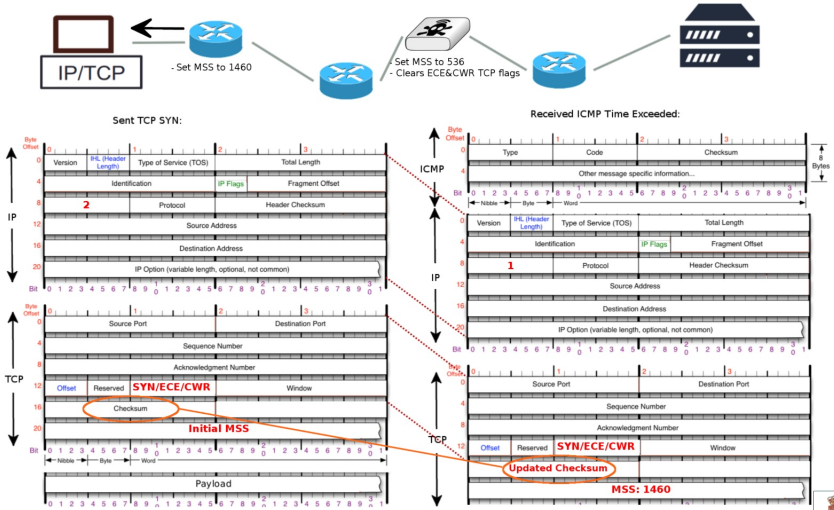
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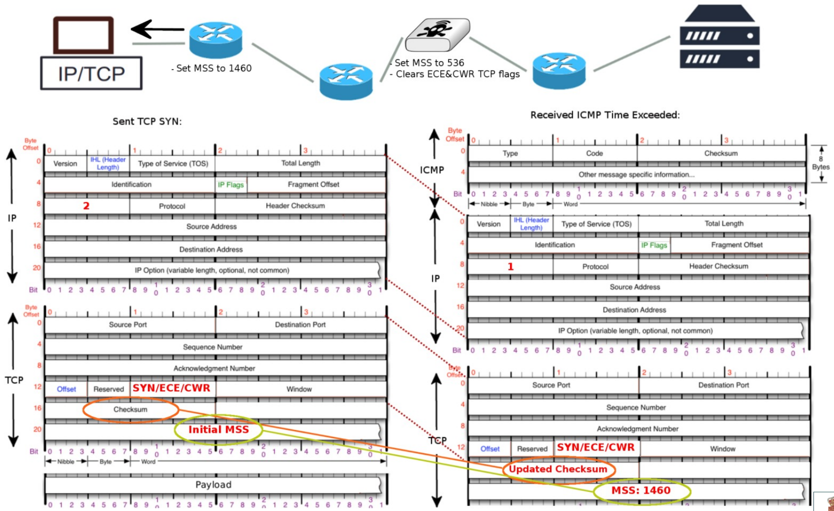
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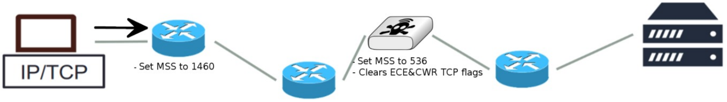

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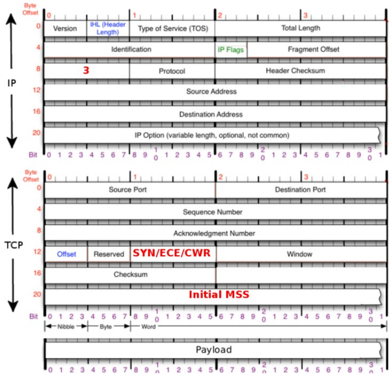

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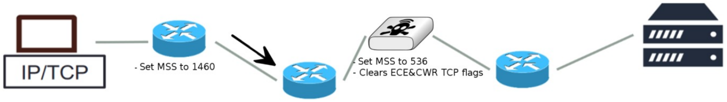

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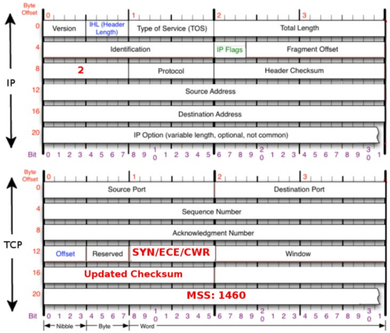

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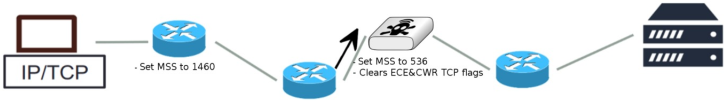

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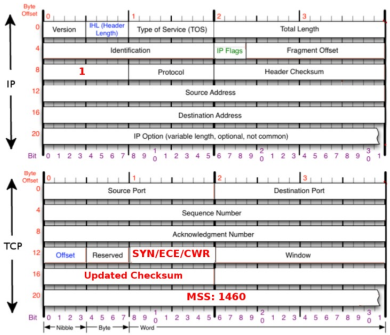

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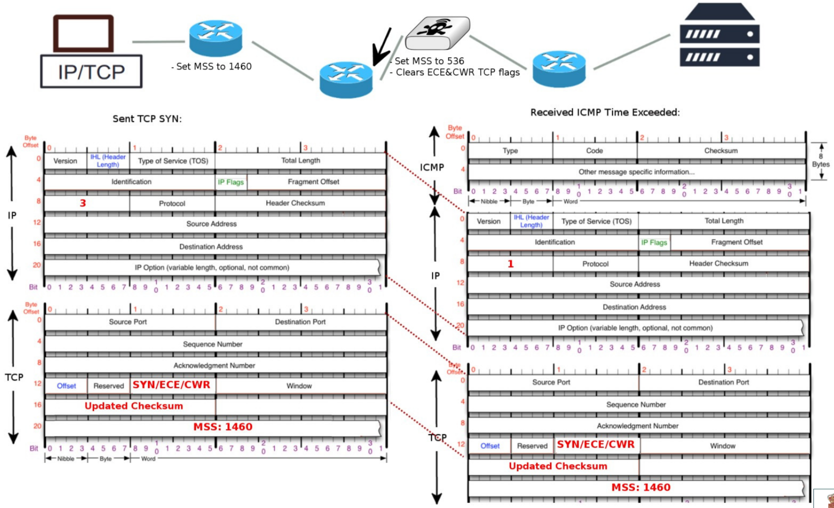
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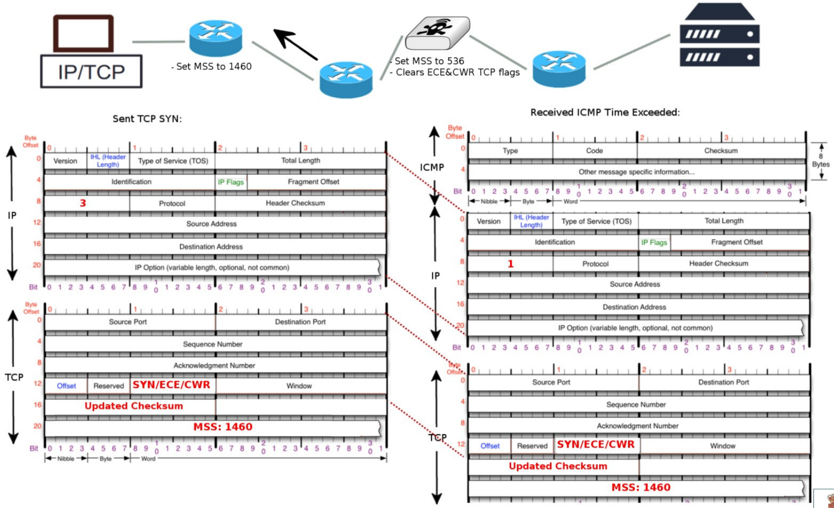
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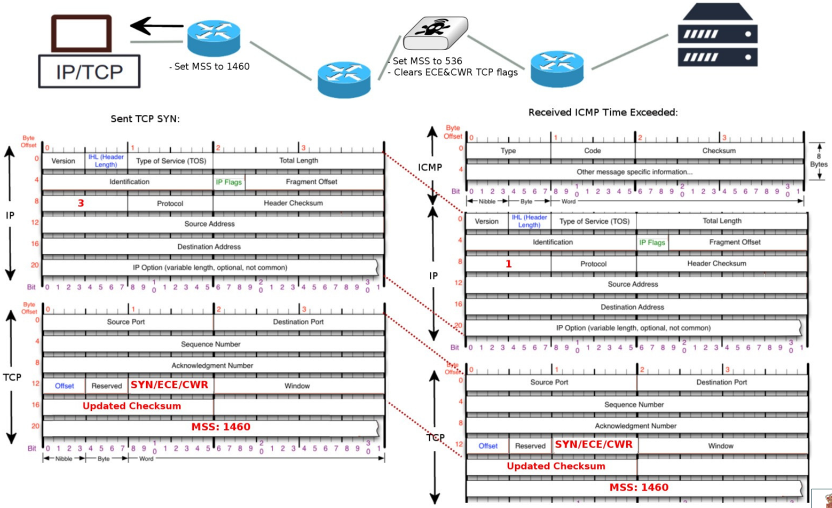
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Source Port
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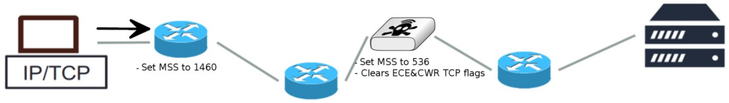
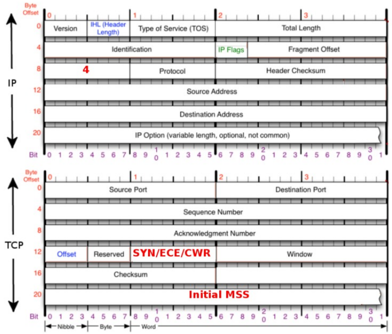
Sequence Number
Acknowledgment Number
Offset
Reserved
Window
Type
Code
Checksum
Other message specific information...
8 Bytes
Byte Offset
Bit
Nibble
Byte
Word

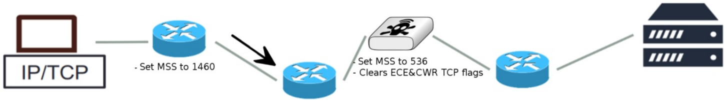
Tracebox



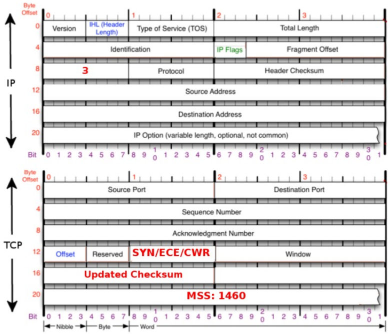
Sent TCP SYN:



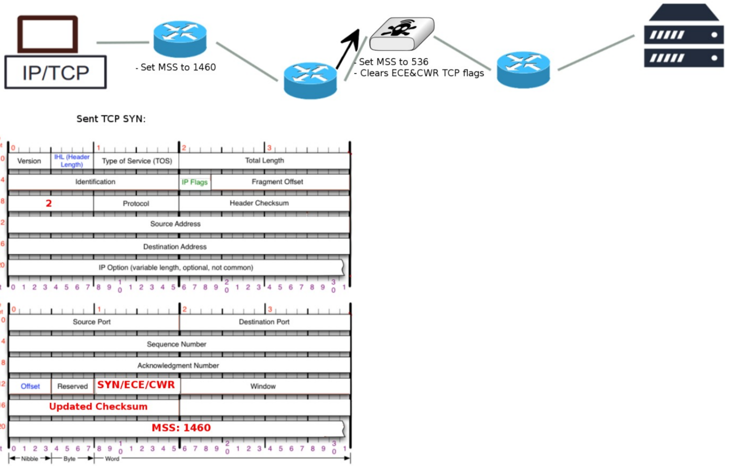
Tracebox



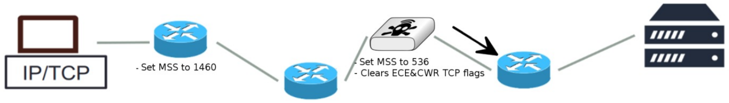
Sent TCP SYN:



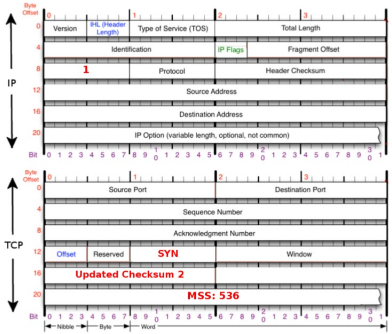
Tracebox


IP/TCP
- Set MSS to 1460
- Set MSS to 536
- Clears ECE&CWR TCP flags
Sent TCP SYN:
IP
TCP
Version
IHL (Header Length)
Type of Service (TOS)
Total Length
Identification
IP Flags
Fragment Offset
2
Protocol
Header Checksum
Source Address
Destination Address
IP Option (variable length, optional, not common)
Source Port
Destination Port
Sequence Number
Acknowledgment Number
Offset
Reserved
SYN/ECE/CWR
Window
Updated Checksum
MSS: 1460
Byte Offset
Bit
Nibble
Byte
Word

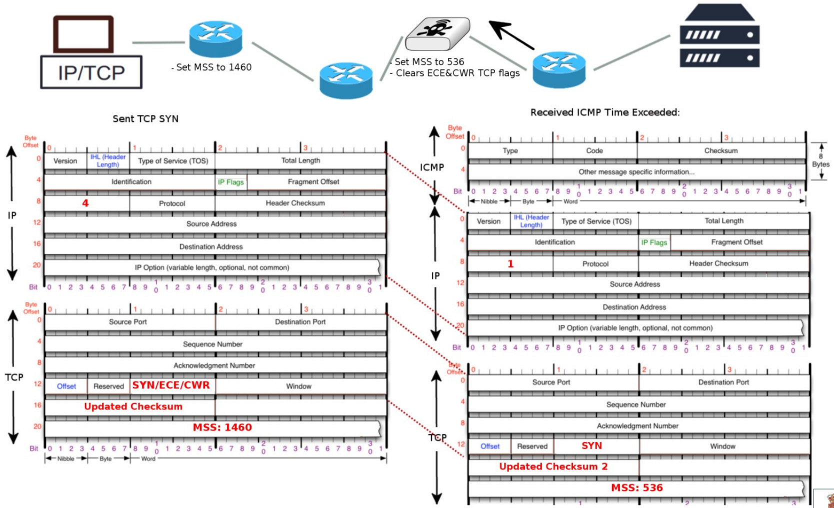
Tracebox



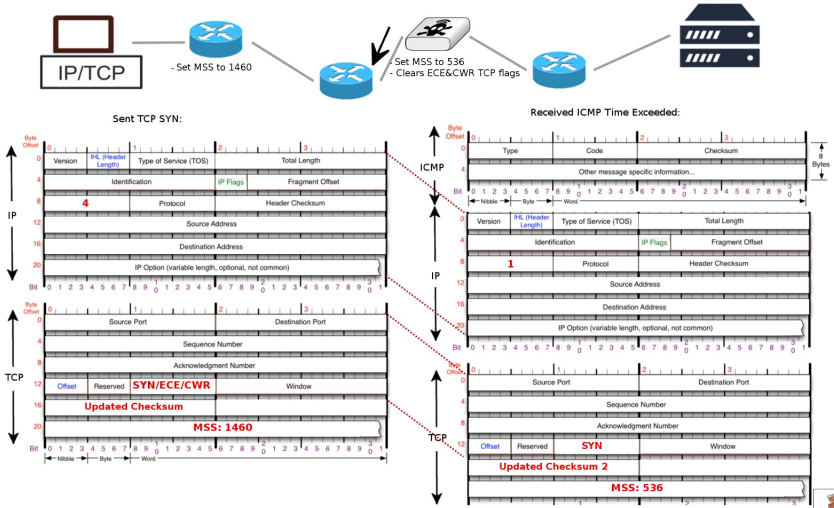
Sent TCP SYN:



Tracebox


IP/TCP
- Set MSS to 1460
- Set MSS to 536
- Clears ECE&CWR TCP flags
Sent TCP SYN
Received ICMP Time Exceeded:
IP
TCP
ICMP
Version
IHL (Header Length)
Type of Service (TOS)
Total Length
Identification
IP Flags
Fragment Offset
4
1
Protocol
Header Checksum
Source Address
Destination Address
IP Option (variable length, optional, not common)
Source Port
Destination Port
Sequence Number
Acknowledgment Number
Offset
Reserved
SYN/ECE/CWR
SYN
Window
Updated Checksum
Updated Checksum 2
MSS: 1460
MSS: 536
Type
Code
Checksum
Other message specific information...
8 Bytes
Byte Offset
Bit
Nibble
Byte
Word

Tracebox


IP/TCP
- Set MSS to 1460
- Set MSS to 536
- Clears ECE&CWR TCP flags
Sent TCP SYN:
Received ICMP Time Exceeded:
IP
TCP
ICMP
4
1
SYN/ECE/CWR
Updated Checksum
MSS: 1460
SYN
Updated Checksum 2
MSS: 536
Version
IHL (Header Length)
Type of Service (TOS)
Total Length
Identification
IP Flags
Fragment Offset
Protocol
Header Checksum
Source Address
Destination Address
IP Option (variable length, optional, not common)
Source Port
Destination Port
Sequence Number
Acknowledgment Number
Offset
Reserved
Window
Type
Code
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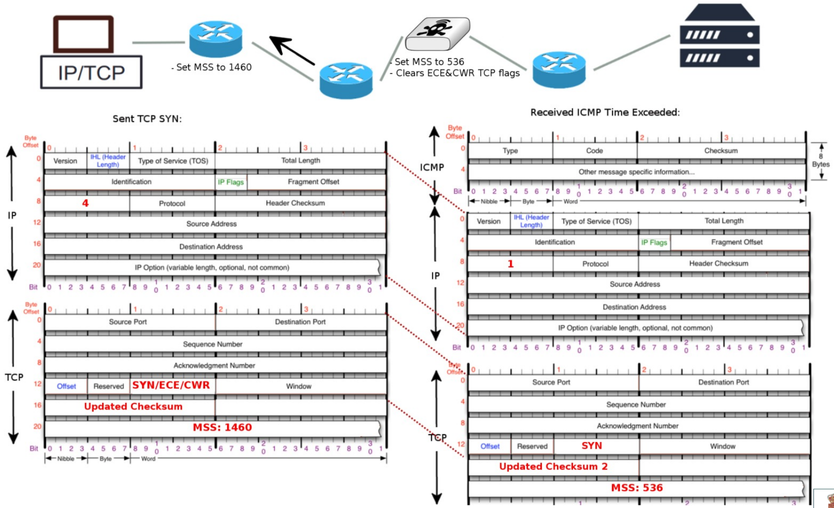
Other message specific information...
8 Bytes
Byte Offset
Bit
Nibble
Byte
Word

Tracebox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Total Length
Identification
IP Flags
Fragment Offset
4
1
Protocol
Header Checksum
Source Address
Destination Address
IP Option (variable length, optional, not common)
Source Port
Destination Port
Sequence Number
Acknowledgment Number
Offset
Reserved
SYN/ECE/CWR
SYN
Window
Updated Checksum
Updated Checksum 2
MSS: 1460
MSS: 536
Type
Code
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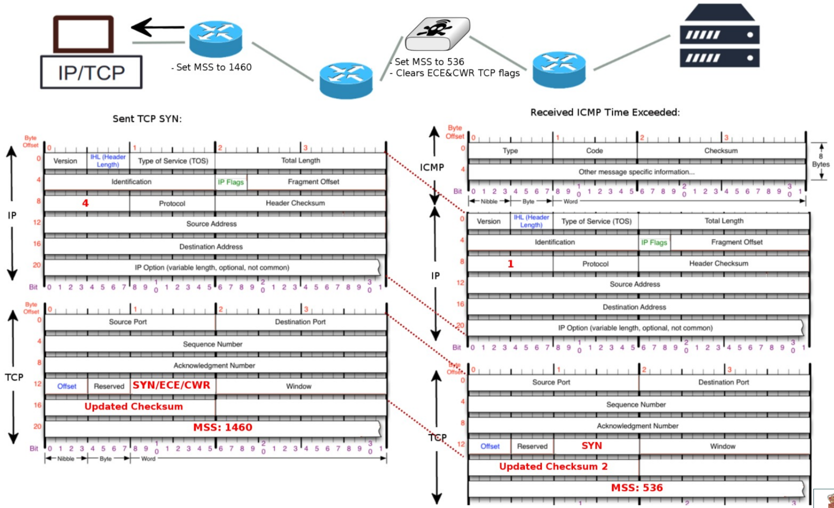
Other message specific information...
8 Bytes
Byte Offset
Bit
Nibble
Byte
Word

Tracebox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Received ICMP Time Exceeded:
IP
TCP
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Identification
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4
1
Protocol
Header Checksum
Source Address
Destination Address
IP Option (variable length, optional, not common)
Source Port
Destination Port
Sequence Number
Acknowledgment Number
Offset
Reserved
SYN/ECE/CWR
SYN
Window
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MSS: 1460
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Byte Offset
Bit
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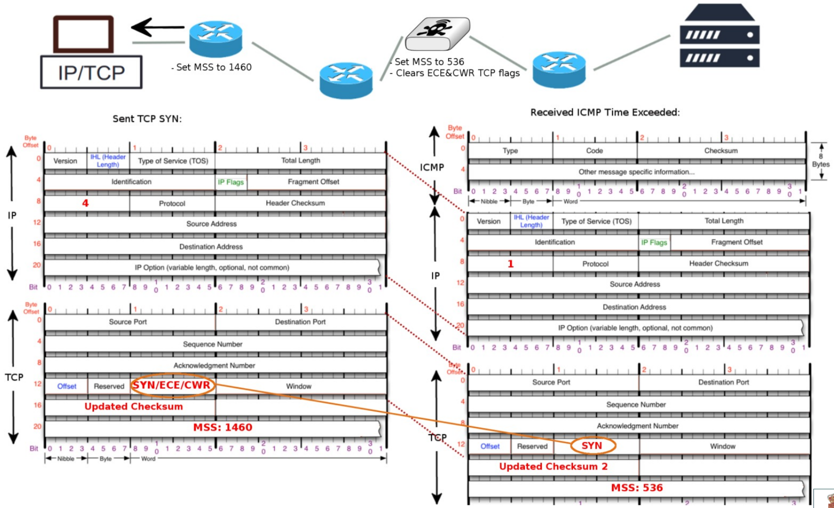
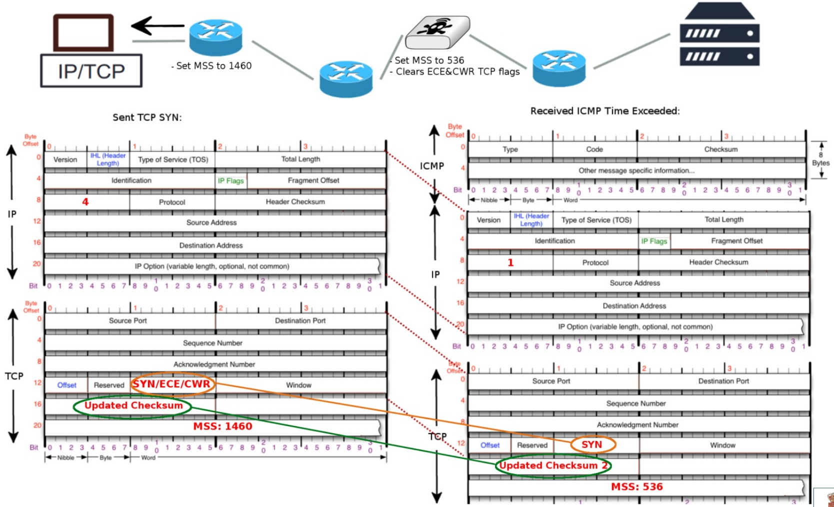
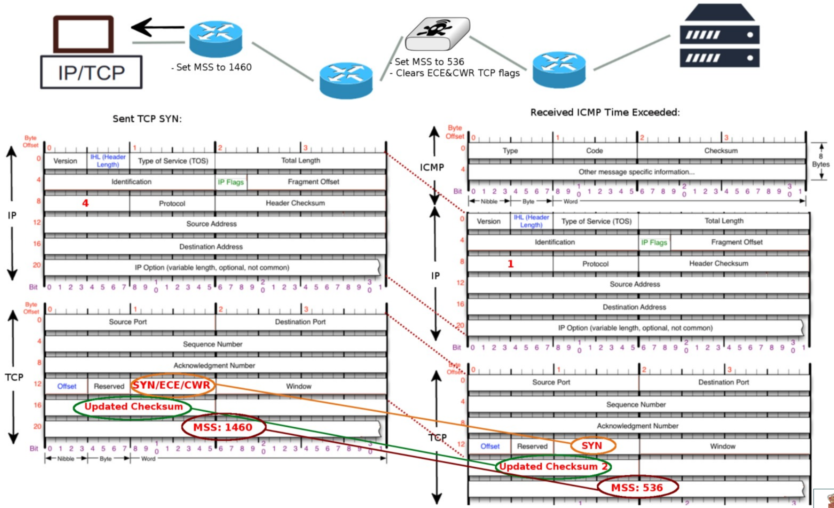
Tracebox


IP/TCP
- Set MSS to 1460
- Set MSS to 536
- Clears ECE&CWR TCP flags
Sent TCP SYN:
Received ICMP Time Exceeded:
IP
TCP
ICMP
4
1
SYN/ECE/CWR
Updated Checksum
MSS: 1460
SYN
Updated Checksum 2
MSS: 536

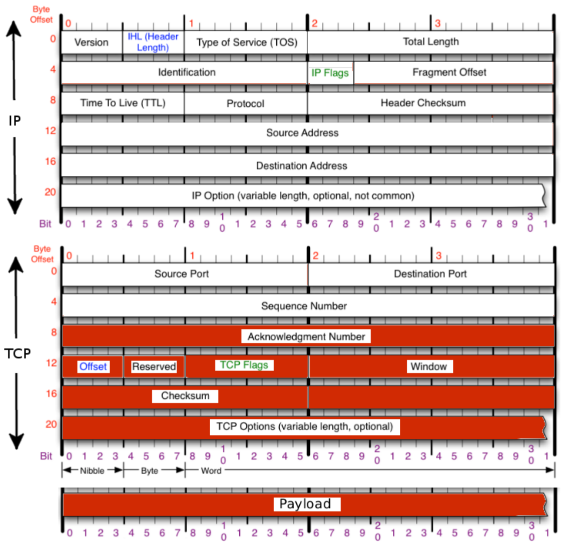
Tracebox


IP/TCP
- Set MSS to 1460
- Set MSS to 536
- Clears ECE&CWR TCP flags
Sent TCP SYN:
Received ICMP Time Exceeded:
IP
TCP
ICMP
4
1
SYN/ECE/CWR
SYN
Updated Checksum
Updated Checksum 2
MSS: 1460
MSS: 536
8 Bytes

Tracebox


IP/TCP
- Set MSS to 1460
- Set MSS to 536
- Clears ECE&CWR TCP flags
Sent TCP SYN:
Received ICMP Time Exceeded:
IP
TCP
ICMP
4
1
SYN/ECE/CWR
Updated Checksum
MSS: 1460
SYN
Updated Checksum 2
MSS: 536

Cannot detect all changes



ICMP Payload size

- ICMP only includes the network header plus the first 8 bytes of he transport header.
    - RFC792 (ICMPv4):
      "Internet Header + 64 bits of Data Datagram"
    - RFC1812 (ICMPv4):
      "the ICMP datagram SHOULD contain as much of the original datagram as possible without the length of the ICMP datagram exceeding 576 bytes."
    - RFC4443 (ICMPv6):
      "As much of invoking packet as possible without the ICMPv6 packet exceeding the minimum IPv6 MTU"

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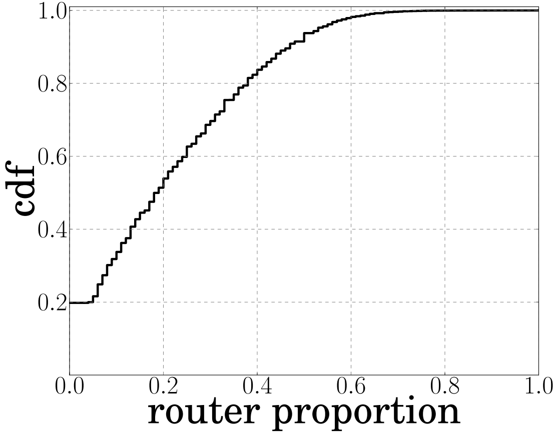
  - RFC4443 (ICMPv6):
    "As much of invoking packet as possible without the ICMPv6 packet exceeding the minimum IPv6 MTU"
- Maximal quoting by default on Linux, Cisco IOX, HP routers, Alcatel routers, PaloAlto Fiewall, etc.

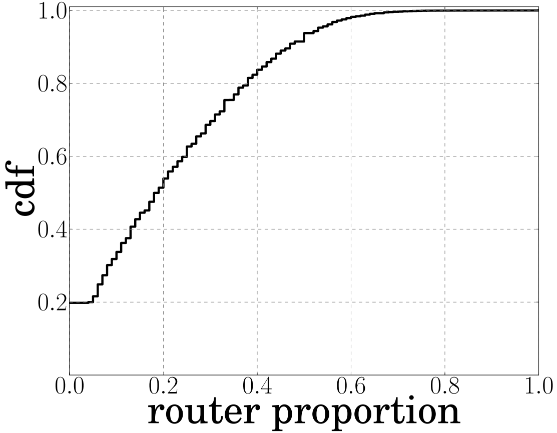
ICMPv4 Payload size

- RFC1812-compliant routers (2013, 72 PL VPs to Alexa 5000)



ICMPv4 Payload size

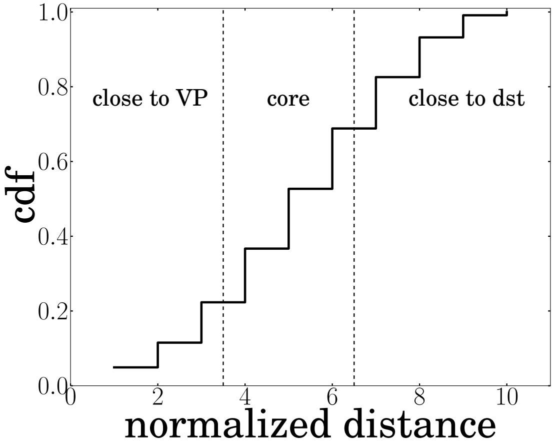
- RFC1812-compliant routers (2013, 72 PL VPs to Alexa 5000)



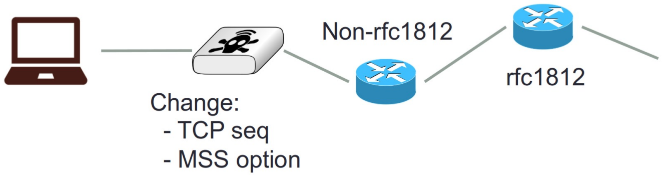
- 80 % of Internet paths contains at least on RFC1812-capable router

ICMPv4 Payload size

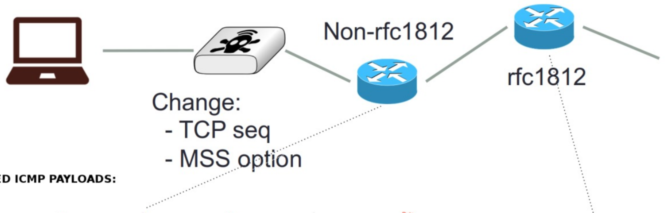
- RFC1812-compliant routers location (2013, 72 PL VPs to Alexa 5000)



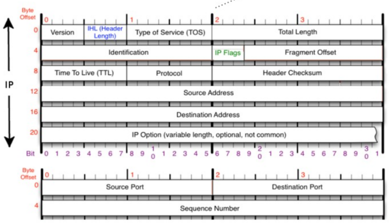
ICMP detection limitation

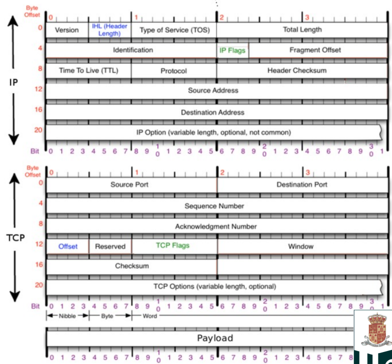


ICMP detection limitation

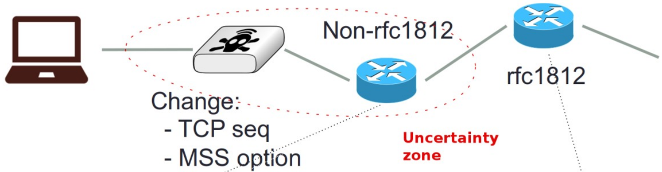


RECEIVED ICMP PAYLOADS:

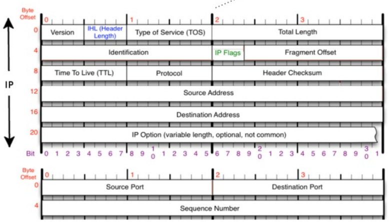


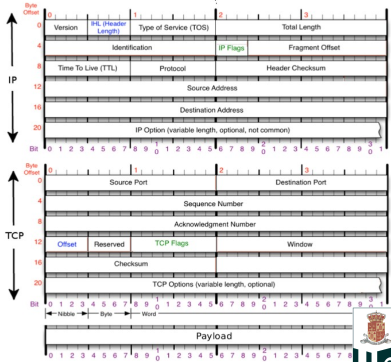


ICMP detection limitation



RECEIVED ICMP PAYLOADS:





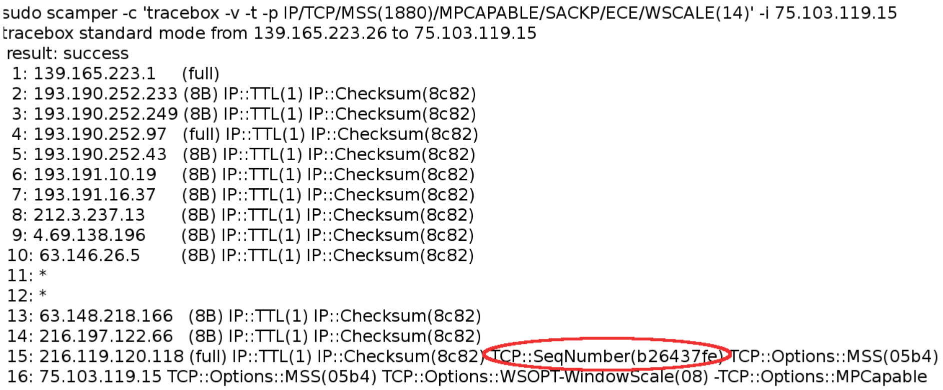
Use cases

- Testing new protocols deployability
  - MPTCP, TCP FO, TCP EDO, ...
- Testing new hardware/configurations
  - CGN deployment, ...
- Locating an issue
- Network management/debugging

Output Example

```
sudo scamper -c 'tracebox -v -t -p IP/TCP/MSS(1880)/MPCAPABLE/SACKP/ECE/WSCALE(14)' -i 75.103.119.15
tracebox standard mode from 139.165.223.26 to 75.103.119.15
 result: success
  1: 139.165.223.1    (full)
  2: 193.190.252.233 (8B) IP::TTL(1) IP::Checksum(8c82)
  3: 193.190.252.249 (8B) IP::TTL(1) IP::Checksum(8c82)
  4: 193.190.252.97   (full) IP::TTL(1) IP::Checksum(8c82)
  5: 193.190.252.43   (8B) IP::TTL(1) IP::Checksum(8c82)
  6: 193.191.10.19    (8B) IP::TTL(1) IP::Checksum(8c82)
  7: 193.191.16.37    (8B) IP::TTL(1) IP::Checksum(8c82)
  8: 212.3.237.13     (8B) IP::TTL(1) IP::Checksum(8c82)
  9: 4.69.138.196     (8B) IP::TTL(1) IP::Checksum(8c82)
 10: 63.146.26.5      (8B) IP::TTL(1) IP::Checksum(8c82)
 11: *
 12: *
 13: 63.148.218.166  (8B) IP::TTL(1) IP::Checksum(8c82)
 14: 216.197.122.66  (8B) IP::TTL(1) IP::Checksum(8c82)
 15: 216.119.120.118 (full) IP::TTL(1) IP::Checksum(8c82) TCP::SeqNumber(b26437fe) TCP::Options::MSS(05b4)
 16: 75.103.119.15 TCP::Options::MSS(05b4) TCP::Options::WSOPT-WindowScale(08) -TCP::Options::MPCapable
```

Output Example



```
sudo scamper -c 'tracebox -v -t -p IP/TCP/MSS(1880)/MPCAPABLE/SACKP/ECE/WSCALE(14)' -i 75.103.119.15
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  6: 193.191.10.19     (8B) IP::TTL(1) IP::Checksum(8c82)
  7: 193.191.16.37     (8B) IP::TTL(1) IP::Checksum(8c82)
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 14: 216.197.122.66  (8B) IP::TTL(1) IP::Checksum(8c82)
 15: 216.119.120.118 (full) IP::TTL(1) IP::Checksum(8c82) TCP::SeqNumber(b26437fe) TCP::Options::MSS(05b4)
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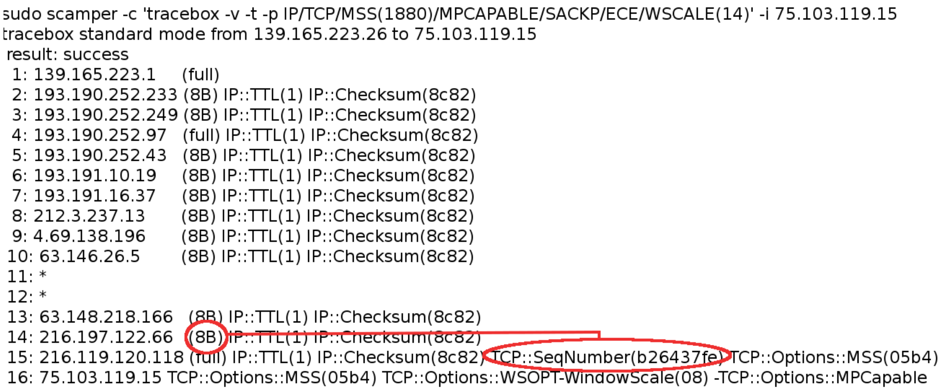
Output Example



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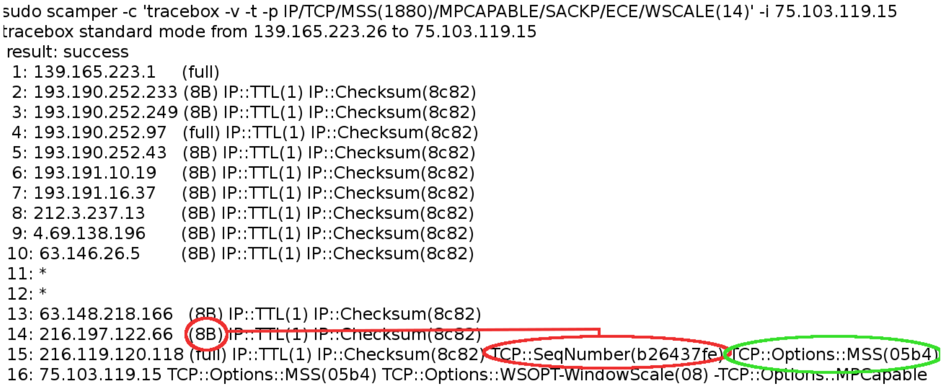
Output Example



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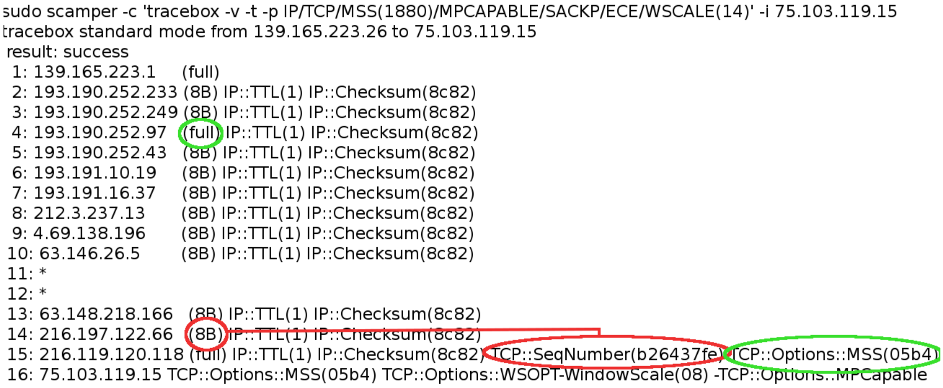

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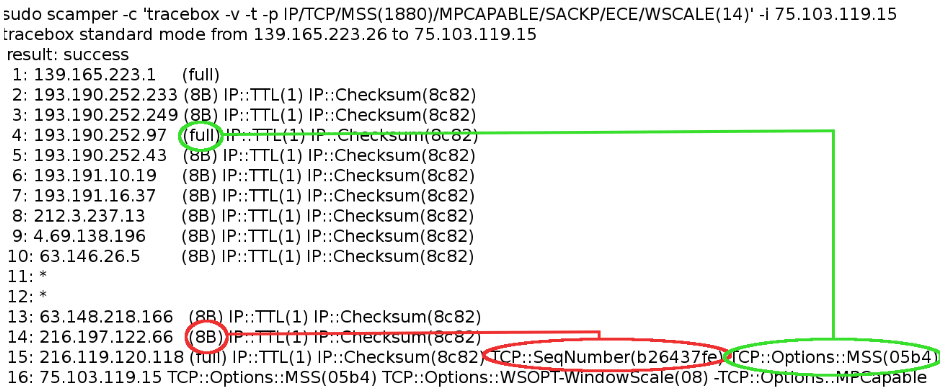
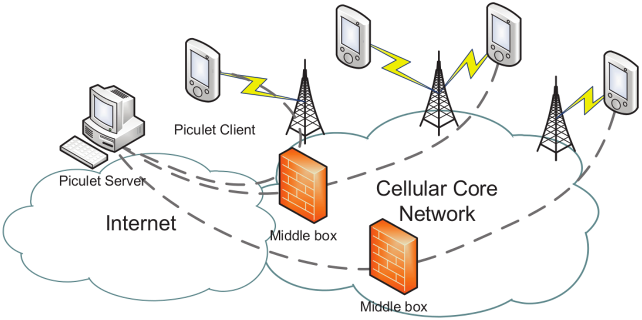


```
sudo scamper -c 'tracebox -v -t -p IP/TCP/MSS(1880)/MPCAPABLE/SACKP/ECE/WSCALE(14)' -i 75.103.119.15
tracebox standard mode from 139.165.223.26 to 75.103.119.15
 result: success
  1: 139.165.223.1    (full)
  2: 193.190.252.233 (8B) IP::TTL(1) IP::Checksum(8c82)
  3: 193.190.252.249 (8B) IP::TTL(1) IP::Checksum(8c82)
  4: 193.190.252.97   (full) IP::TTL(1) IP::Checksum(8c82)
  5: 193.190.252.43   (8B) IP::TTL(1) IP::Checksum(8c82)
  6: 193.191.10.19    (8B) IP::TTL(1) IP::Checksum(8c82)
  7: 193.191.16.37    (8B) IP::TTL(1) IP::Checksum(8c82)
  8: 212.3.237.13     (8B) IP::TTL(1) IP::Checksum(8c82)
  9: 4.69.138.196     (8B) IP::TTL(1) IP::Checksum(8c82)
 10: 63.146.26.5      (8B) IP::TTL(1) IP::Checksum(8c82)
 11: *
 12: *
 13: 63.148.218.166  (8B) IP::TTL(1) IP::Checksum(8c82)
 14: 216.197.122.66  (8B) IP::TTL(1) IP::Checksum(8c82)
 15: 216.119.120.118 (full) IP::TTL(1) IP::Checksum(8c82) TCP::SeqNumber(b26437fe) TCP::Options::MSS(05b4)
 16: 75.103.119.15 TCP::Options::MSS(05b4) TCP::Options::WSOPT-WindowScale(08) -TCP::Options::MPCapable
```

What about cellular networks ?

- There are middleboxes too[7]:



[7] Zhaoguang Wang et al. “An untold story of middleboxes in cellular networks”. In: *A SIGCOMM Computer Communication Review* 41.4 (2011), pp. 374–385.

TraceboxAndroid[8]

- On-demand & Background probing

[8] Valentin Thirion, Korian Edeline, and Benoit Donnet. “Tracking Middleboxes in the Mobile World with TraceboxAndroid”. In: *Traffic Monitoring and Analysis*. Springer, 201 pp. 79–91.

TraceboxAndroid[8]

- On-demand & Background probing
- A rooted version
    - Require to root the phone

[8] Valentin Thirion, Korian Edeline, and Benoit Donnet. “Tracking Middleboxes in the Mobile World with TraceboxAndroid”. In: *Traffic Monitoring and Analysis*. Springer, 201 pp. 79–91.

TraceboxAndroid[8]

- On-demand & Background probing
- A rooted version
  - Require to root the phone
- A non-rooted version
  - Non-rooted traceroutes to retreive path-level information
  - Self-controlled server
  - Troubleshooting incentives

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TraceboxAndroid[8]

- On-demand & Background probing
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- A non-rooted version
  - Non-rooted traceroutes to retreive path-level information
  - Self-controlled server
  - Troubleshooting incentives
- Interested ?
  Send me an email at **korian.edeline@ulg.ac.be** to be notified when the new version is released.

[8] Valentin Thirion, Korian Edeline, and Benoit Donnet. “Tracking Middleboxes in the Mobile World with TraceboxAndroid”. In: *Traffic Monitoring and Analysis*. Springer, 201 pp. 79–91.

Plan

Tracebox implementations

- Standalone Tracebox
- Scamper

Standalone Tracebox

- Uses the previous mechanism to detect middleboxes.
- Implemented in C++ with Lua embedded.
- Libcrafter allows for efficiently describe probes as Scapy.
- Open source
- Supports Linux and Mac OSX.
- `http://github.com/tracebox/tracebox`
- `http://www.tracebox.org/`
- More details:[9]

[9] Gregory Detal et al. "Revealing middlebox interference with tracebox". In: *Proceed of the 2013 conference on Internet measurement conference.* ACM. 2013, pp. 1–8.

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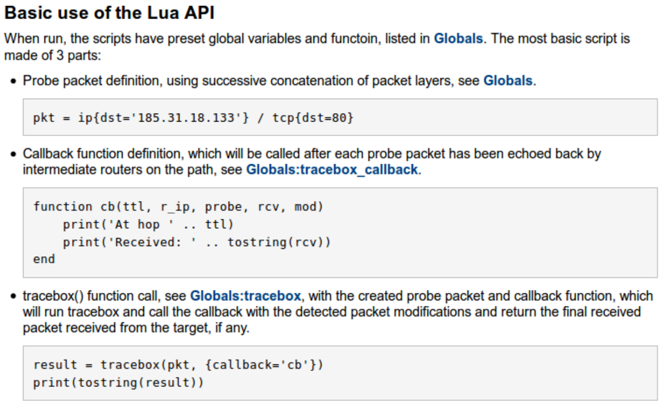

Basic use of the Lua API

When run, the scripts have preset global variables and functoin, listed in Globals. The most basic script is made of 3 parts:

- Probe packet definition, using successive concatenation of packet layers, see Globals.

```
pkt = ip{dst='185.31.18.133'} / tcp{dst=80}
```

- Callback function definition, which will be called after each probe packet has been echoed back by intermediate routers on the path, see Globals:tracebox_callback.

```
function cb(ttl, r_ip, probe, rcv, mod)
    print('At hop ' .. ttl)
    print('Received: ' .. tostring(rcv))
end
```

- tracebox() function call, see Globals:tracebox, with the created probe packet and callback function, which will run tracebox and call the callback with the detected packet modifications and return the final received packet received from the target, if any.

```
result = tracebox(pkt, {callback='cb'})
print(tostring(result))
```

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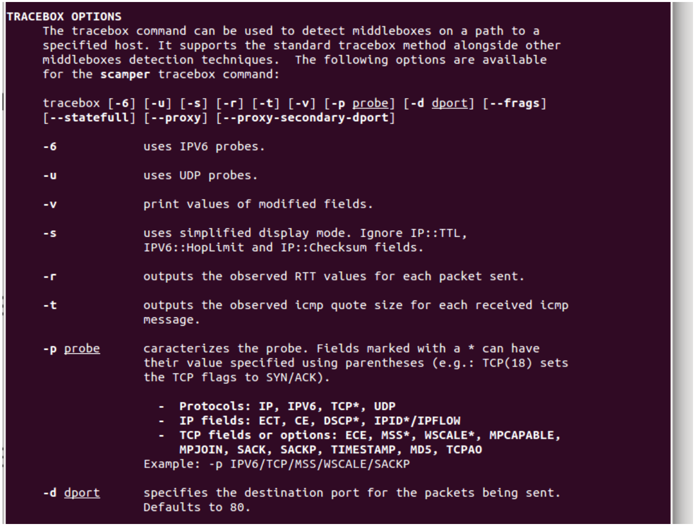
Scamper

- All-around parallelized topology/performance analyzing tool.
- Implements various simple and complex measurement methods (ping, traceroute, dealias, tbit, ...).

Scamper



```
TRACEBOX OPTIONS
     The tracebox command can be used to detect middleboxes on a path to a
     specified host. It supports the standard tracebox method alongside other
     middleboxes detection techniques.  The following options are available
     for the scamper tracebox command:

     tracebox [-6] [-u] [-s] [-r] [-t] [-v] [-p probe] [-d dport] [--frags]
     [--statefull] [--proxy] [--proxy-secondary-dport]

     -6             uses IPV6 probes.

     -u             uses UDP probes.

     -v             print values of modified fields.

     -s             uses simplified display mode. Ignore IP::TTL,
                    IPV6::HopLimit and IP::Checksum fields.

     -r             outputs the observed RTT values for each packet sent.

     -t             outputs the observed icmp quote size for each received icmp
                    message.

     -p probe       caracterizes the probe. Fields marked with a * can have
                    their value specified using parentheses (e.g.: TCP(18) sets
                    the TCP flags to SYN/ACK).

                      -  Protocols: IP, IPV6, TCP*, UDP
                      -  IP fields: ECT, CE, DSCP*, IPID*/IPFLOW
                      -  TCP fields or options: ECE, MSS*, WSCALE*, MPCAPABLE,
                         MPJOIN, SACK, SACKP, TIMESTAMP, MD5, TCPAO
                    Example: -p IPV6/TCP/MSS/WSCALE/SACKP

     -d dport       specifies the destination port for the packets being sent.
                    Defaults to 80.
```

Scamper

- Native output format: warts.
- IPv6 support
- Open source
- Supports FreeBSD, OpenBSD, NetBSD, Linux, MacOS X, Solaris, Windows, and more.
- `http://www.caida.org/tools/measurement/scamper/`
- Debian/Ubuntu packages, FreeBSD ports, ...
- More details:[11]

[11] Matthew Luckie. “Scamper: a scalable and extensible packet prober for active measurement of the internet”. In: *Proceedings of the 10th ACM SIGCOMM conference Internet measurement*. ACM. 2010, pp. 239–245.

Thank you !