PATHspider II: The Tutorial

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Active Measurement of Path Transparency

- Methodology:
  1. Throw packets at the Internet
  2. See what happens
- Ideal: two-ended A/B testing
- Scalable: one-ended A/B testing
- Multiple sources: **isolate** on-path from near-target impairment

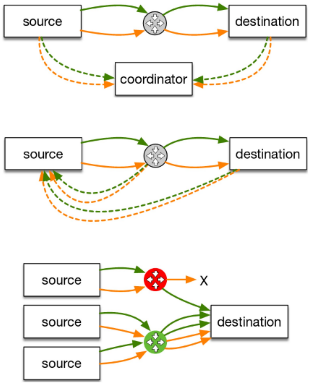


Figure: One-Ended vs. Two-Ended Testing

History

ecnspider

- The original implementation supported by mPlane/RITE
- Three distinct components:
  - DNS List Resolver
  - QoF Flow Meter
  - Active Traffic Generator
- Used hardcoded `sysctl(1)` and `iptables(1)` commands to cause packets to be emitted with various ECN-related flags
- Source code: https://github.com/britram/ecnspider

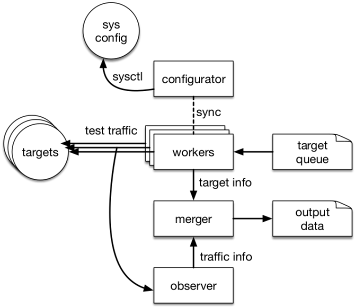
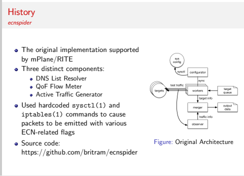


Figure: Original Architecture



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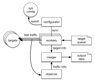


Figure: Original Architecture

QoF is an IPFIX Metering and Exporting process derived from the YAF flowmeter, designed for passive measurement of per-flow performance characteristics.

While it was fast, it was only able to export flow properties it already knew about, and could not be easily extended.

If you are interested in network measurement, you may still like to read about Internet Protocol Flow Information Export (IPFIX) [3]. It was created based on the need for a common, universal standard of export for Internet Protocol flow information from routers, probes and other devices that are used by mediation systems, accounting/billing systems and network management systems to facilitate services such as measurement, accounting and billing.

History

ecnspider Results

- ECN negotiation was found to be successful for 56.17% of hosts connecting for IPv4, 65.41% for IPv6, from the Alexa top 1 million list [8]
- This continues a trend ETH started observing with *ecnspider* in 2013 [6]

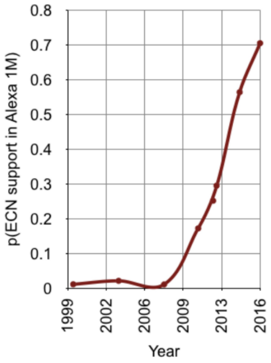


Figure: ECN Support in the Alexa Top 1 Million

PATHspider 1.0

https://github.com/mami-project/pathspider/tree/1.0.1

- Architecture based closely on the original ecnspider
- Generalised to support more than just ECN
    - Added TCP Fast Open and DiffServ Codepoints
- Still performing A/B testing, but with more A/B tests
- Replaced QoF with a Python flowmeter implementation using python-libtrace
- Began to develop a generalised measurement methodology for path transparency testing
- Published at 2016 Applied Networking Research Workshop [7]

Plugin Architecture

- The plugin architecture was not as generalised as it could have been
- Plugin methods:
  - `config_zero`
  - `config_one`
  - `connect`
  - `post_connect`
  - `create_observer`
  - `merge`

Built-In Flowmeter

- PATHspider's built in flow meter is extensible via the plugin architecture
- Using python-libtrace to dissect packets, any flow property imaginable can be reported back based on the raw packets:
  - ECN negotiation (IP/TCP headers)
  - Bleaching of bits, dropping of options
  - Checksum recalculations

PATHspider 1.0 Results

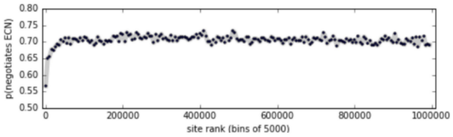
We presented some initial findings along with the publication of PATHspider 1.0 [7]:

Explicit Congestion Notification (ECN)

State of ECN server-side deployment, as measured from a Digital Ocean vantage point in Amsterdam on 13th June 2016:

	IPv4	IPv6	all
No ECN connectivity issues	99.5%	99.9%	99.5%
ECN successfully negotiated	70.0%	82.8%	70.5%

ECN negotiation by Alexa rank bin:

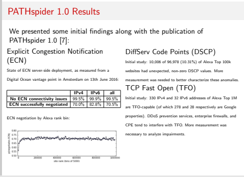


DiffServ Code Points (DSCP)

Initial study: 10,006 of 96,978 (10.31%) of Alexa Top 100k websites had unexpected, non-zero DSCP values. More measurement was needed to better characterize these anomalies.

TCP Fast Open (TFO)

Initial study: 330 IPv4 and 32 IPv6 addresses of Alexa Top 1M are TFO-capable (of which 278 and 28 respectively are Google properties). DDoS prevention services, enterprise firewalls, and CPE tend to interfere with TFO. More measurement was necessary to analyze impairments.



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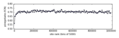

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Higher ranked servers tended to disable (or not support to begin with) ECN. This is likely due to the specialised nature of services that have to handle such large volumes of traffic. They may be using entirely custom codebases, or are otherwise tuned and optimised.

For a more comprehensive measurement study on the use and impairments to use of DiffServ Codepoints in the Internet, see [4].

PATHspider 2.0

- Architecture changed to add a flow combiner
- Generalised to support more than just A/B testing
  - Any permutation of any number of tests
- Replaced PATHspider's HTTP code with cURL
- Added framework for packet forging based plugins using Scapy
- Completely rewritten (in Go) target list resolver
- Observer modules usable for standalone passive observation or analysis
- Source code: https://github.com/mami-project/pathspider/tree/2.0.0/

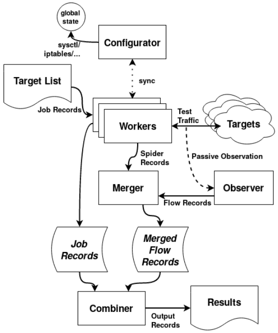
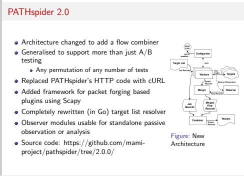


Figure: New Architecture



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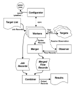
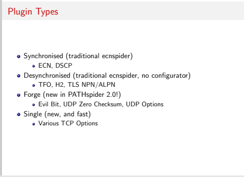


Figure: New Architecture

The combiner thread holds a table of merged flows and waits for $|flows| = |jobs|$. Conditions are generated based on the combined flows.

Plugin Types

- Synchronised (traditional ecnspider)
  - ECN, DSCP
- Desynchronised (traditional ecnspider, no configurator)
  - TFO, H2, TLS NPN/ALPN
- Forge (new in PATHspider 2.0!)
  - Evil Bit, UDP Zero Checksum, UDP Options
- Single (new, and fast)
  - Various TCP Options



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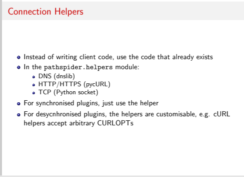
The desynchronized plugins will run more quickly than synchronized plugins while still using the real network stack. Forge plugins will run slower as there is overhead in the Scapy packet generation that doesn't exist in optimised kernel stacks.

Connection Helpers

- Instead of writing client code, use the code that already exists
- In the `pathspider.helpers` module:
  - DNS (dnslib)
  - HTTP/HTTPS (pycURL)
  - TCP (Python socket)
- For synchronised plugins, just use the helper
- For desycnhronised plugins, the helpers are customisable, e.g. cURL helpers accept arbitrary CURLOPTs



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You can find the pyCURL documentation at `http://pycurl.io/docs/latest/`. This contains information on all the CURLOPTs that are currently available.

During development of PATHspider plugins, we have found that some options that exist in the C library are not included in the Python bindings, but we have been able to produce patches and upstream these relatively easily. For example: `https://github.com/pycurl/pycurl/pull/456`.

Synchronized Plugin

- SynchronizedSpider plugins use **built-in connection methods** along with **global system configuration** to change the behaviour of the connections
- Configuration functions are at the heart of a SynchronizedSpider plugin
- Configuration functions may make calls to sysctl or iptables to make changes to the way that traffic is generated.
- One function should be written for each of the configurations and PATHspider will ensure that the configurations are set before the corresponding traffic is generated. It is the responsibility of plugin authors to ensure that any configuration is reset by the next configuration function if that is required

Synchronized Plugin

```python
class ECN(SynchronizedSpider, PluggableSpider):
    def config_no_ecn(self): # pylint: disable=no-self-use
        """
        Disables ECN negotiation via sysctl.
        """

        logger = logging.getLogger('ecn')
        subprocess.check_call(
            ['/sbin/sysctl', '-w', 'net.ipv4.tcp_ecn=2'],
            stdout=subprocess.DEVNULL,
            stderr=subprocess.DEVNULL)
        logger.debug("Configurator disabled ECN")

    def config_ecn(self): # pylint: disable=no-self-use
        """
        Enables ECN negotiation via sysctl.
        """

        logger = logging.getLogger('ecn')
        subprocess.check_call(
            ['/sbin/sysctl', '-w', 'net.ipv4.tcp_ecn=1'],
            stdout=subprocess.DEVNULL,
            stderr=subprocess.DEVNULL)
        logger.debug("Configurator enabled ECN")

    configurations = [config_no_ecn, config_ecn]
```

Listing 1: Configuration Functions for the ECN Plugin

Desynchronized Plugin

- DesynchronizedSpider plugins modify the connection logic in order to change the behaviour of the connections. There is no global state synchronisation and so a DesynchronizedSpider can be more efficient than a SynchronizedSpider
- Connection functions are at the heart of a DesynchronizedSpider plugin
- These use a connection helper (or custom connection logic) to generate traffic towards with a target to get a reply from the target
- One function should be written for each connection to be made, usually with at least two functions to provide a baseline followed by an experimental connection

Desynchronized Plugin

```
class H2(DesynchronizedSpider, PluggableSpider):
    def conn_no_h2(self, job, config): # pylint: disable=unused-argument
        curlopts = {}
        curlinfos = [pycurl.INFO_HTTP_VERSION]
        if self.args.connect == "http":
            return connect_http(self.source, job, self.args.timeout, curlopts, curlinfos)
        if self.args.connect == "https":
            return connect_https(self.source, job, self.args.timeout, curlopts, curlinfos
    )
        else:
            raise RuntimeError("Unknown connection mode specified")

    def conn_h2(self, job, config): # pylint: disable=unused-argument
        curlopts = {pycurl.HTTP_VERSION: pycurl.CURL_HTTP_VERSION_2_0}
        curlinfos = [pycurl.INFO_HTTP_VERSION]
        if self.args.connect == "http":
            return connect_http(self.source, job, self.args.timeout, curlopts, curlinfos)
        if self.args.connect == "https":
            return connect_https(self.source, job, self.args.timeout, curlopts, curlinfos
    )
        else:
            raise RuntimeError("Unknown connection mode specified")

    connections = [conn_no_h2, conn_h2]
```

Listing 2: Connection Functions for the H2 Plugin

Forge Plugin

- ForgeSpider plugins use Scapy to send forged packets to targets
- The heart of a ForgeSpider is the `forge()` function
- This function takes two arguments, the job containing the target information and the sequence number
- This function will be called the number of times set in the packets metadata variable and seq will be set to the number of times the function has been called for this job

Single Plugin

- SingleSpider uses the built-in connection helpers to make a single connection to the target which is optionally observed by Observer chains
- This is the simplest model and only requires a `combine_flows()` function to generate conditions from the connection helper output and flow record output from the Observer

Observer Modules

- While these used to be part of plugins in PATHspider 1.0, they are now independent and so can be reused across multiple plugins:
  - BasicChain, DNSChain, DSCPChain, ECNChain, EvilChain, ICMPChain, TCPChain, TFOChain
- These can also be used together, limiting each chain to just a single layer and letting the combiner produce conditions
- Chains can produce information to be consumed by other chains later in the list
- These can be used independently of a PATHspider measurement:

```
irl@z~$ pspdr observe tcp ecn
```

Listing 3: Running the PATHspider Observer independently

Target List Resolution

- Hellfire is a parallelised DNS resolver. It is written in Go and for the purpose of generating input lists to PATHspider, though may be useful for other applications
- Can use many sources for inputs:
  - Alexa Top 1 Million Global Sites
  - Cisco Umbrella 1 Million
  - Citizen Lab Test Lists
  - OpenDNS Public Domain Lists
  - Comma-Seperated Values Files
  - Plain Text Domain Lists
- More on this later

Packet Forging

- PATHspider uses the Scapy library for Python for packet forging
- This is the most flexible method of creating new measurement plugins for PATHspider

Make a Packet

- Scapy packets are constructed layer by layer
- While you can specify raw bytes, Scapy provides a number of useful classes for common protocols, which makes things a lot easier

Make a Packet

- Scapy must be launched with `sudo` as we will need to use “raw” sockets to emit forged packets.
- Note also the command is `scapy3`, to ensure we are running the Python 3 version.

```
irl@z:~$ sudo scapy3

                     aSPY//YASa
             apyyyyCY//////////YCa       |
            sY//////YSpcs  scpCY//Pp     | Welcome to Scapy
 ayp ayyyyyyySCP//Pp           syY//C    | Version 2.4.0
 AYAsAYYYYYYYY///Ps              cY//S   |
         pCCCCY//p          cSSps y//Y   | https://github.com/secdev/scapy
         SPPPP///a          pP///AC//Y   |
              A//A            cyP////C   | Have fun!
              p///Ac            sC///a   |
              P////YCpc           A//A   | We are in France, we say Skappee.
       scccccp///pSP///p          p//Y   | OK? Merci.
      sY/////////y  caa           S//P   |             -- Sebastien Chabal
       cayCyayP//Ya              pY/Ya   |
        sY/PsY////YCc          aC//Yp
         sc  sccaCY//PCypaapyCP//YSs
                  spCPY//////YPSps
                       ccaacs
                                       using IPython 5.5.0
>>>
```

Listing 4: Launching Scapy

Make a Packet

IPv4 Header - Create and Dissect

```
>>> IP()
<IP  |>
>>> i = IP()
>>> i.summary()
'127.0.0.1 > 127.0.0.1 hopopt'
>>> i.display()
###[ IP ]###
  version= 4
  ihl= None
  tos= 0x0
  len= None
  id= 1
  flags=
  frag= 0
  ttl= 64
  proto= hopopt
  chksum= None
  src= 127.0.0.1
  dst= 127.0.0.1
  \options\
```

Listing 5: Creating and Dissecting an IPv4 Header

Make a Packet

IPv4 Header - Customize

```
>>> i = IP(src="192.0.2.1",dst="198.51.100.1", ttl=10)
>>> i
<IP  ttl=10 src=192.0.2.1 dst=198.51.100.1 |>
>>> i.summary()
'192.0.2.1 > 198.51.100.1 hopopt'
>>> i.display()
###[ IP ]###
  version= 4
  ihl= None
  tos= 0x0
  len= None
  id= 1
  flags=
  frag= 0
  ttl= 10
  proto= hopopt
  chksum= None
  src= 192.0.2.1
  dst= 198.51.100.1
  \options\
```

Listing 6: Customizing an IPv4 Header[1]

Make a Packet

TCP Header: Create and Dissect

```
>>> TCP()
<TCP  |>
>>> t = TCP()
>>> t.summary()
'TCP ftp_data > http S'
>>> t.display()
###[ TCP ]###
   sport= ftp_data
   dport= http
   seq= 0
   ack= 0
   dataofs= None
   reserved= 0
   flags= S
   window= 8192
   chksum= None
   urgptr= 0
   options= []
```

Listing 7: Creating and Dissecting a TCP Header

Make a Packet

TCP Header: Customizing

```
>>> t = TCP(dport=443)
>>> t
<TCP  dport=https |>
>>> t.summary()
'TCP ftp_data > https S'
>>> t.display()
###[ TCP ]###
  sport= ftp_data
  dport= https
  seq= 0
  ack= 0
  dataofs= None
  reserved= 0
  flags= S
  window= 8192
  chksum= None
  urgptr= 0
  options= []
```

Listing 8: Customizing a TCP Header

Make a Packet

Sticking the Pieces Together

- The / operator is used to join layers together.
- Scapy will automatically set fields, such as the IP Protocol field, when you do this.
- When dissecting, Scapy will automatically choose the dissector to use based on fields such as the IP Protocol field.

```
>>> p=i/t
>>> p.summary()
'IP / TCP 192.0.2.1:ftp_data > 198.51.100.1:https S'
>>> p.display()
    [... output snipped ...]
```

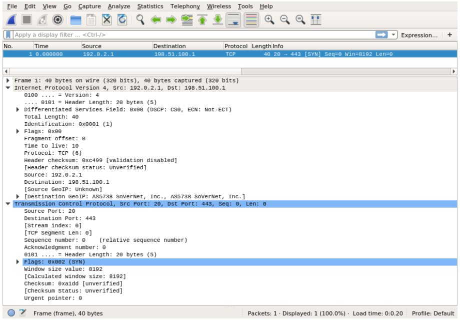
Listing 9: Sticking the IP and TCP Headers Together

Make a Packet

View in Wireshark

```
>>> wrpcap("/tmp/scapy.pcap", [p])
```

Listing 10: Exporting a PCAP File from Scapy


File Edit View Go Capture Analyze Statistics Telephony Wireless Tools Help
Apply a display filter ... <Ctrl-/>
Expression...
+

```
No.  Time      Source      Destination    Protocol Length Info
   1 0.000000  192.0.2.1   198.51.100.1   TCP          40 20 → 443 [SYN] Seq=0 Win=8192 Len=0
```

```
▶ Frame 1: 40 bytes on wire (320 bits), 40 bytes captured (320 bits)
▼ Internet Protocol Version 4, Src: 192.0.2.1, Dst: 198.51.100.1
    0100 .... = Version: 4
    .... 0101 = Header Length: 20 bytes (5)
  ▶ Differentiated Services Field: 0x00 (DSCP: CS0, ECN: Not-ECT)
    Total Length: 40
    Identification: 0x0001 (1)
  ▶ Flags: 0x00
    Fragment offset: 0
    Time to live: 10
    Protocol: TCP (6)
    Header checksum: 0xc499 [validation disabled]
    [Header checksum status: Unverified]
    Source: 192.0.2.1
    Destination: 198.51.100.1
    [Source GeoIP: Unknown]
  ▶ [Destination GeoIP: AS5738 SoVerNet, Inc., AS5738 SoVerNet, Inc.]
▼ Transmission Control Protocol, Src Port: 20, Dst Port: 443, Seq: 0, Len: 0
    Source Port: 20
    Destination Port: 443
    [Stream index: 0]
    [TCP Segment Len: 0]
    Sequence number: 0    (relative sequence number)
    Acknowledgment number: 0
    0101 .... = Header Length: 20 bytes (5)
  ▶ Flags: 0x002 (SYN)
    Window size value: 8192
    [Calculated window size: 8192]
    Checksum: 0xa1dd [unverified]
    [Checksum Status: Unverified]
    Urgent pointer: 0
```

```
Frame (frame), 40 bytes    Packets: 1 · Displayed: 1 (100.0%) · Load time: 0:0.20    Profile: Default
```

Figure: Dissection of the packet created in Scapy, in Wireshark

Send a Packet

- The `sr1()` function sends a single packet, and returns a single packet if a reply is received.
- Start Wireshark capturing before executing the `sr1()` function.

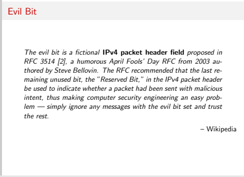
```
>>> p=IP(dst="139.133.210.32")/TCP()
>>> a=sr1(p)
Begin emission:
.Finished sending 1 packets.
*
Received 2 packets, got 1 answers, remaining 0 packets
>>> a
<IP  version=4 ihl=5 tos=0x0 len=44 id=0 flags=DF frag=0 ttl=47 proto=tcp chksum=0xa98d
     src=139.133.210.32 dst=172.22.152.130 options=[] |<TCP  sport=http dport=ftp_data
     seq=3081101820 ack=1 dataofs=6 reserved=0 flags=SA window=29200 chksum=0xe9c7 urgptr
     =0 options=[('MSS', 1452)] |<Padding  load=':v' |>>>
>>> a.summary()
'IP / TCP 139.133.210.32:http > 172.22.152.130:ftp_data SA / Padding'
```

Listing 11: Create and Send an IP/TCP Packet

Evil Bit

The evil bit is a fictional **IPv4 packet header field** *proposed in RFC 3514 [2], a humorous April Fools' Day RFC from 2003 authored by Steve Bellovin. The RFC recommended that the last remaining unused bit, the "Reserved Bit," in the IPv4 packet header be used to indicate whether a packet had been sent with malicious intent, thus making computer security engineering an easy problem — simply ignore any messages with the evil bit set and trust the rest.*

– Wikipedia



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If you enjoy the concept of the evil bit, you may like to also check out [5]: TCP Option to Denote Packet Mood. For example happy packets which are happy because they received their ACK return packet within less than 10ms. Or the Sad Packets which are sad because they faced retransmission rates greater than 20% of all packets sent in a session.

Evil Bit

Setting the Evil Bit with Scapy

- The flags in the IP header are just an attribute you can modify:

```
>>> i = IP()
>>> i.flags = 'evil'
```

Listing 12: Setting the Evil Bit on an IPv4 Header with Scapy

PATHspider Plugins

Download the Evil Bit Demonstration Plugin

```
git clone https://github.com/mami-project/pathspider-evilbit.git
```

Listing 13: Download the Evil Bit Demonstration Plugin

PATHspider Plugins

Directory Layout

- To get started you will need the required directory layout for PATHspider plugins, in this case for the EvilBit plugin:

```
pathspider-evilbit
+-- pathspider
    +-- __init__.py
    +-- plugins
        +-- __init__.py
        +-- evilbit.py
```

- Inside both `__init__.py` files, you will need to add the following (and only the following):

```
from pkgutil import extend_path
__path__ = extend_path(__path__, __name__)
```

- Your plugin will be written in `example.py` and this plugin will be discovered automatically when you run PATHspider

PATHspider Plugins
ForgeSpider

```
class EvilBit(ForgeSpider, PluggableSpider):

    name = "evilbit"
    description = "Evil bit connectivity testing"
    version = '0.0.0'
    chains = [BasicChain, TCPChain, EvilChain]
    connect_supported = ["tcpsyn"]
    packets = 2

    def forge(self, job, seq):
        ...
```

Listing 14: Outline for Evil Bit plugin using ForgeSpider

PATHspider Plugins

Forging the Packets

```python
def forge(self, job, seq):
    sport = 0
    while sport < 1024:
        sport = int(RandShort())
    l4 = (TCP(sport=sport, dport=job['dp']))
    if ':' in job['dip']:
        ip = IPv6(src=self.source[1], dst=job['dip'])
    else:
        ip = IP(src=self.source[0], dst=job['dip'])
    if seq == 1:
        ip.flags = 'evil'
    return ip/l4
```

Listing 15: Creating Packets With and Without the Evil Bit

PATHspider Plugins

Spidering With the Evil Bit

```
./run.sh
```

Listing 16: Running the Evil Bit Plugin

Target Lists

Types of Targets

- Popular - Cisco Umbrella, Alexa Topsites
- Curated Lists - CitizenLab
- Random - massscan

Target Lists

Using *hellfire*

```
irl@z:~$ hellfire
Usage:
  hellfire --topsites [--file=<filename>] [--output=<individual|array|oneeach>] [--type=<
      host|ns|mx>] [--canid=<canid address>]
  hellfire --cisco [--file=<filename>] [--output=<individual|array|oneeach>] [--type=<
      host|ns|mx>] [--canid=<canid address>]
  hellfire --citizenlab [--country=<cc>|--file=<filename>] [--output=<individual|array|
      oneeach>] [--type=<host|ns|mx>] [--canid=<canid address>]
  hellfire --opendns [--list=<name>|--file=<filename>] [--output=<individual|array|
      oneeach>] [--type=<host|ns|mx>] [--canid=<canid address>]
  hellfire --csv --file=<filename> [--output=<individual|array|oneeach>] [--type=<host|ns
      |mx>] [--canid=<canid address>]
  hellfire --txt --file=<filename> [--output=<individual|array|oneeach>] [--type=<host|ns
      |mx>] [--canid=<canid address>]
```

Listing 17: *hellfire*'s Usage Help

```
irl@z~$ hellfire --cisco
```

Listing 18: Start Resolving the Cisco Umbrella List

Explicit Congestion Notification

Using the Built-In Plugin

```
irl@z~$ pspdr measure -i enp0s3 ecn \
        < ~/pathspider-evilbit/targets.ndjson \
        > ~/ecn-results.ndjson
```

Listing 19: Start Resolving the Cisco Umbrella List

Results Analysis

Up next:

Path Transparency Observatory (PTO)

Don't delete your PATHspider results, you'll need them in the next session.

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