DNS privacy in theory and practice

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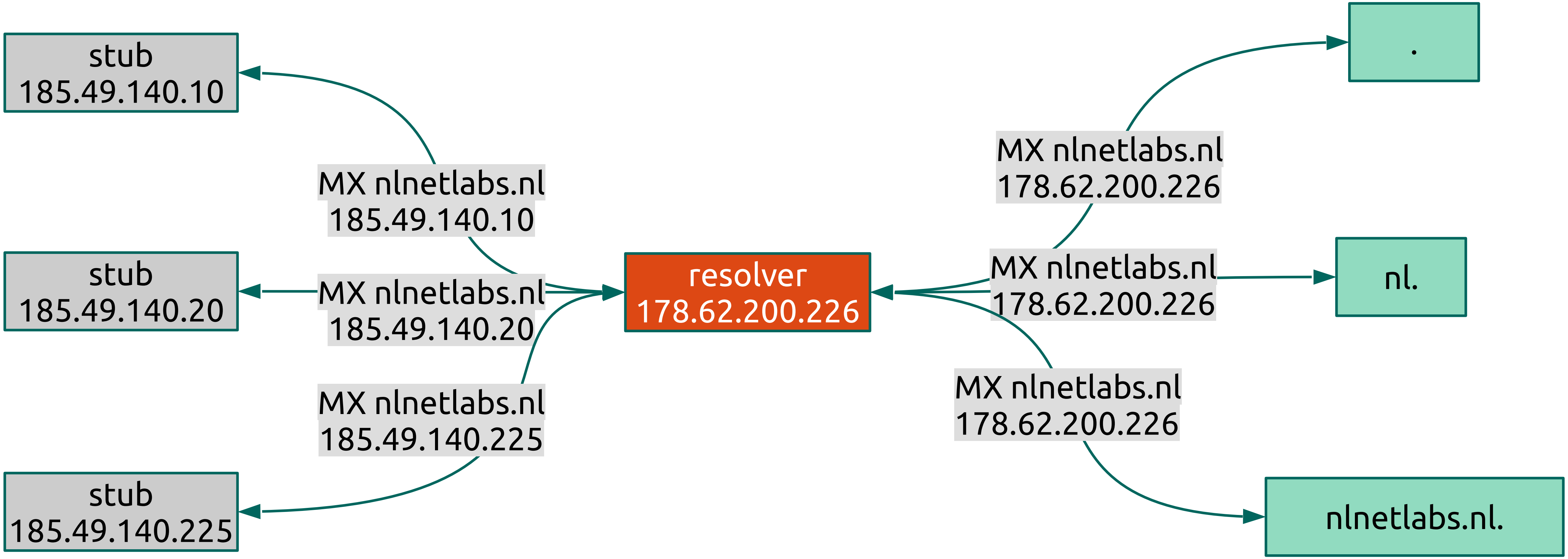
Goal of this talk

- Become familiar with the privacy implication in DNS
- Understand how recent developments can reduce these privacy implications
- Learn how to configure DNS software to make use of these recent developments

Privacy in DNS

- DNS data is public
- Until recently no privacy considerations in the DNS protocol
  - 30+ year old protocol
- Transactions should not be public
  - Almost every Internet activity starts with a DNS query

DNS data disclosure



stub
185.49.140.10

stub
185.49.140.20

stub
185.49.140.225

MX nlnetlabs.nl
185.49.140.10

MX nlnetlabs.nl
185.49.140.20

MX nlnetlabs.nl
185.49.140.225

resolver
178.62.200.226

MX nlnetlabs.nl
178.62.200.226

MX nlnetlabs.nl
178.62.200.226

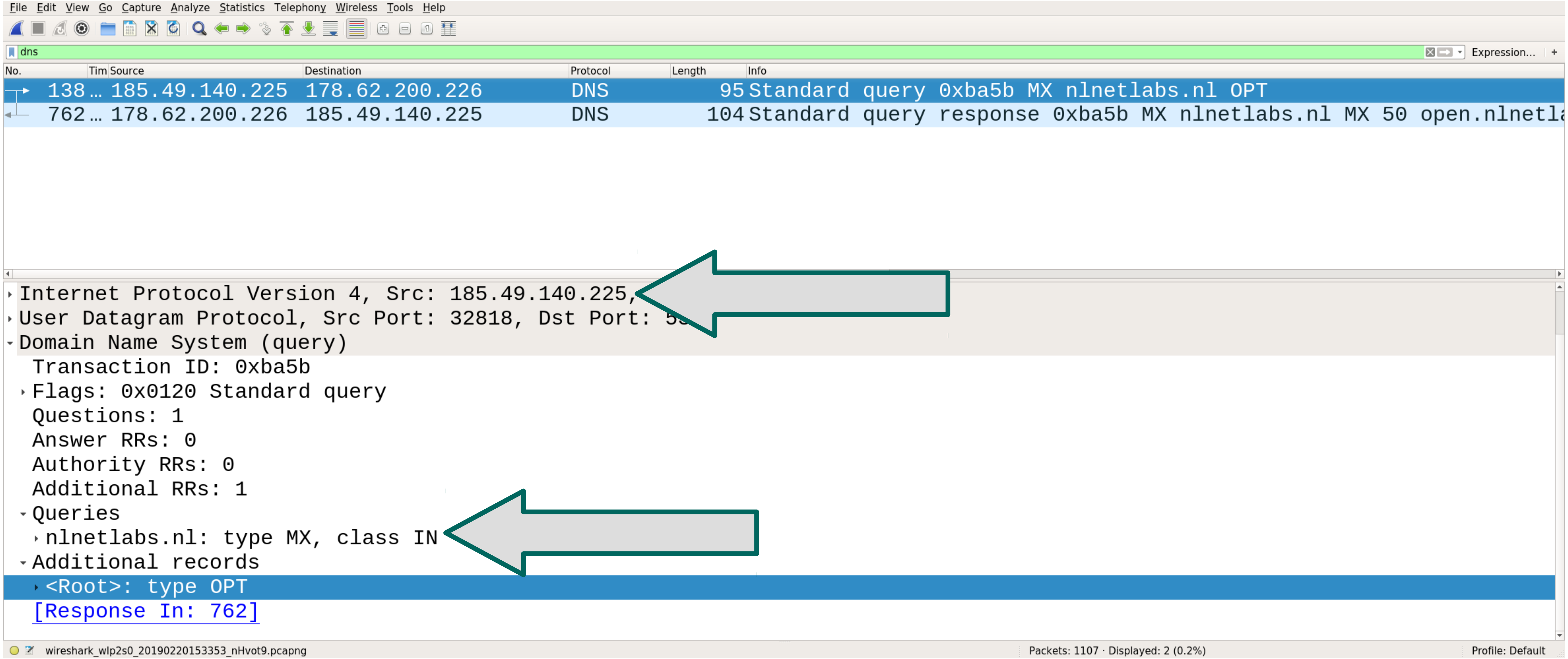
MX nlnetlabs.nl
178.62.200.226

.

nl.

nlnetlabs.nl.

Stub → resolver

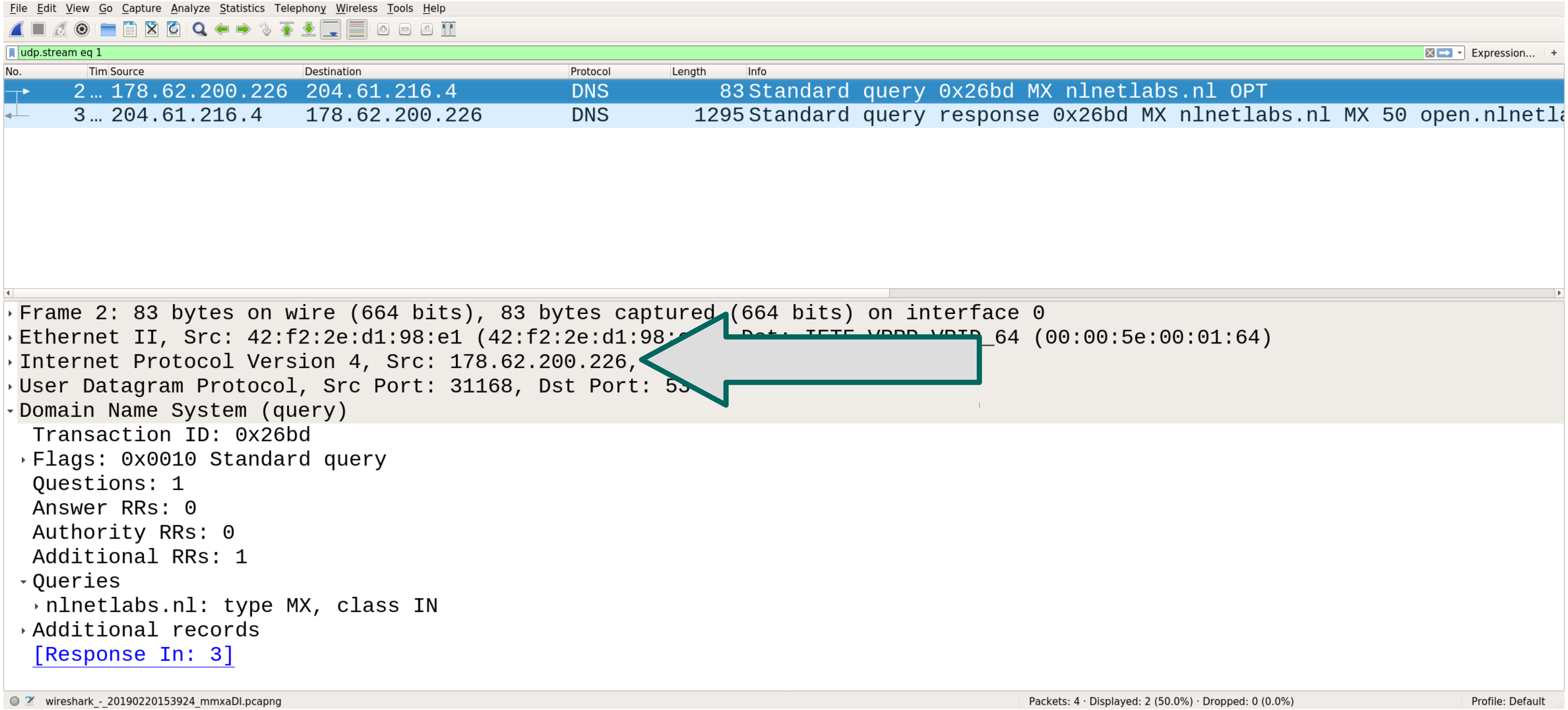

File Edit View Go Capture Analyze Statistics Telephony Wireless Tools Help
Expression…
+

```
dns

No.    Tim Source          Destination     Protocol  Length Info
138 …  185.49.140.225  178.62.200.226  DNS           95 Standard query 0xba5b MX nlnetlabs.nl OPT
762 …  178.62.200.226  185.49.140.225  DNS          104 Standard query response 0xba5b MX nlnetlabs.nl MX 50 open.nlnetla

Internet Protocol Version 4, Src: 185.49.140.225,
User Datagram Protocol, Src Port: 32818, Dst Port: 5
Domain Name System (query)
  Transaction ID: 0xba5b
  Flags: 0x0120 Standard query
  Questions: 1
  Answer RRs: 0
  Authority RRs: 0
  Additional RRs: 1
  Queries
    nlnetlabs.nl: type MX, class IN
  Additional records
    <Root>: type OPT
  [Response In: 762]

wireshark_wlp2s0_20190220153353_nHvot9.pcapng    Packets: 1107 · Displayed: 2 (0.2%)    Profile: Default
```

https://www.nlnetlabs.nl/

NLNETLABS

Resolver → authoritative name server


File Edit View Go Capture Analyze Statistics Telephony Wireless Tools Help
Expression…
+

udp.stream eq 1

```
No.      Tim Source           Destination        Protocol   Length Info
2…   178.62.200.226   204.61.216.4       DNS            83 Standard query 0x26bd MX nlnetlabs.nl OPT
3…   204.61.216.4     178.62.200.226     DNS          1295 Standard query response 0x26bd MX nlnetlabs.nl MX 50 open.nlnetla
```

```
▸ Frame 2: 83 bytes on wire (664 bits), 83 bytes captured (664 bits) on interface 0
▸ Ethernet II, Src: 42:f2:2e:d1:98:e1 (42:f2:2e:d1:98:e     Dst: IETF VRRP VRID_64 (00:00:5e:00:01:64)
▸ Internet Protocol Version 4, Src: 178.62.200.226,
▸ User Datagram Protocol, Src Port: 31168, Dst Port: 53
▾ Domain Name System (query)
    Transaction ID: 0x26bd
  ▸ Flags: 0x0010 Standard query
    Questions: 1
    Answer RRs: 0
    Authority RRs: 0
    Additional RRs: 1
  ▾ Queries
    ▸ nlnetlabs.nl: type MX, class IN
  ▸ Additional records
    [Response In: 3]
```

wireshark_-_20190220153924_mmxaDl.pcapng   Packets: 4 · Displayed: 2 (50.0%) · Dropped: 0 (0.0%)   Profile: Default

https://www.nlnetlabs.nl/

NLNETLABS

unbound

- We will use the Unbound resolver in our examples
  - https://nlnetlabs.nl/unbound/
- Can be installed from distribution package:
  - apt install unbound
  - brew install unbound
  - Windows installer available

Unbound: minimal installation - 1/2

- Configure DNSSEC root key (if not already done by distribution package)
  - Get key:

```
$ unbound-anchor -a /usr/local/etc/unbound/root.key
```

  - Add key to Unbound config:

```
auto-trust-anchor-file: /usr/local/etc/unbound/root.key
```

Unbound: minimal installation - 2/2

- Set access control list:

```
access-control:127.0.0.0/8 allow
access-contol: ::1 allow
```

getdns / Stubby

- We will use the Stubby DNS privacy stub resolver in our examples
    - getdns proxy daemon
- Installation:
    - brew install stubby
    - Install using windows installer
    - Compile from source for Linux

Stubby as minimal proxy

- Listen on local address and send queries to upstream resolver

```
listen_addresses:
  - 127.0.0.1
  - 0::1
upstream_recursive_servers:
  - address_data: 178.62.200.226
```

- Configure OS to send all queries to stubby
  - Set DNS server to stubby listen address in Network settings
  - /etc/resolv.conf

Privacy and the IETF

- July 2013: RFC6973 - Privacy Considerations for Internet Protocols
- May 2014: RFC7258 - Pervasive Monitoring Is an Attack
  - Pervasive monitoring is a technical attack that should be mitigated in the design of IETF protocols, where possible.

Privacy Threat Mitigation

- Privacy Considerations for Internet Protocols, RFC6973
  - 6.1 Data Minimization
    - “Reducing the amount of data exchanged reduces the amount of data that can be misused or leaked.”
  - 6.3 Security
    - “Confidentiality: Keeping data secret from unintended listeners.”

Privacy Threat Mitigation

- Data minimisation
  - → Limit the number of DNS queries
  - Minimise the data disclosed in DNS transactions
- Security
  - Hide transaction by using encryption
  - Limit data disclosure to authenticated parties

Limit the number of DNS queries

- At stub: not much that can be done
- At recursive resolver: multiple (non-exclusive) options
  - Local root
  - Aggressive NSEC

RFC7706 – root zone in resolver

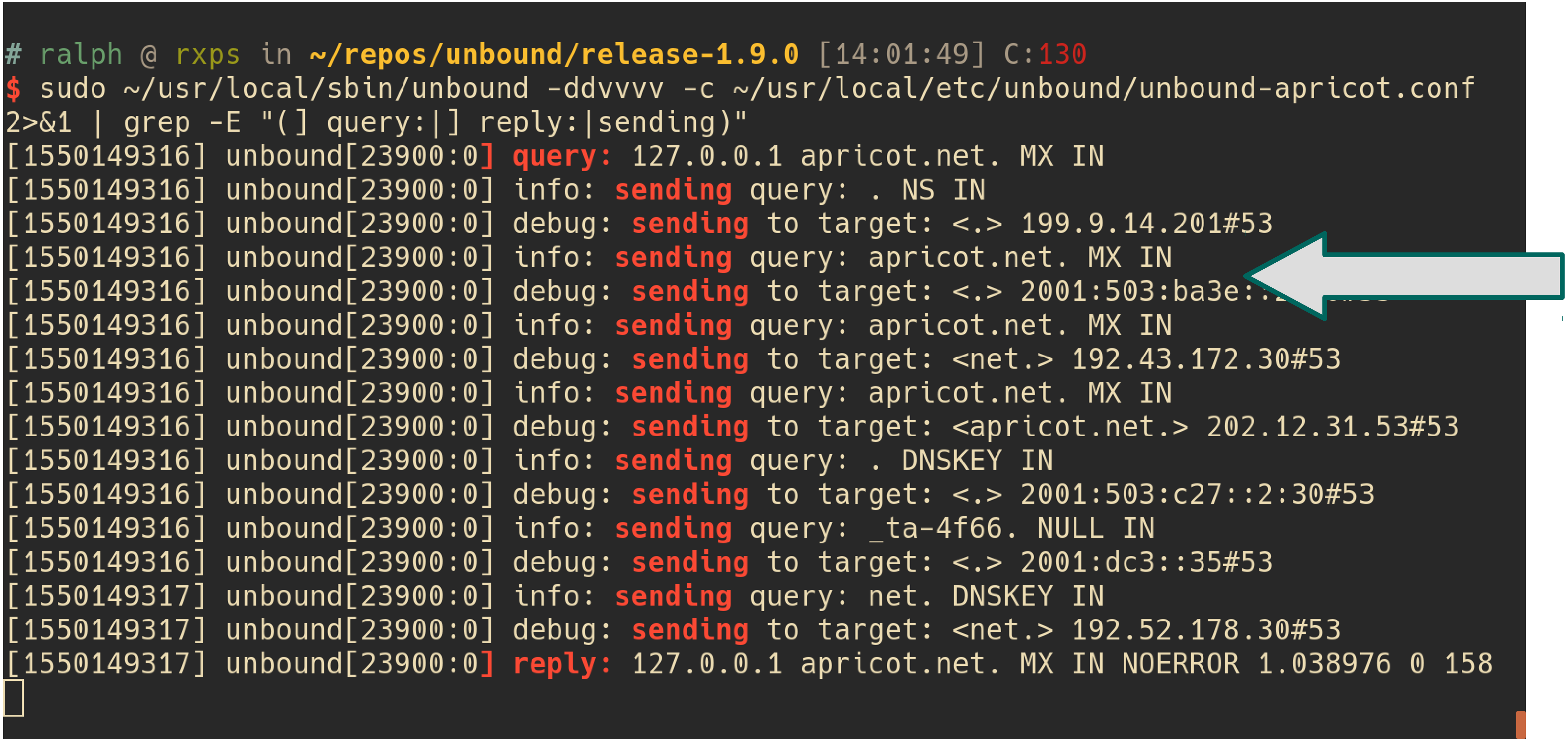
- Get complete root zone locally
- No need to expose privacy sensitive data to the root anymore

Unbound: root zone in resolver

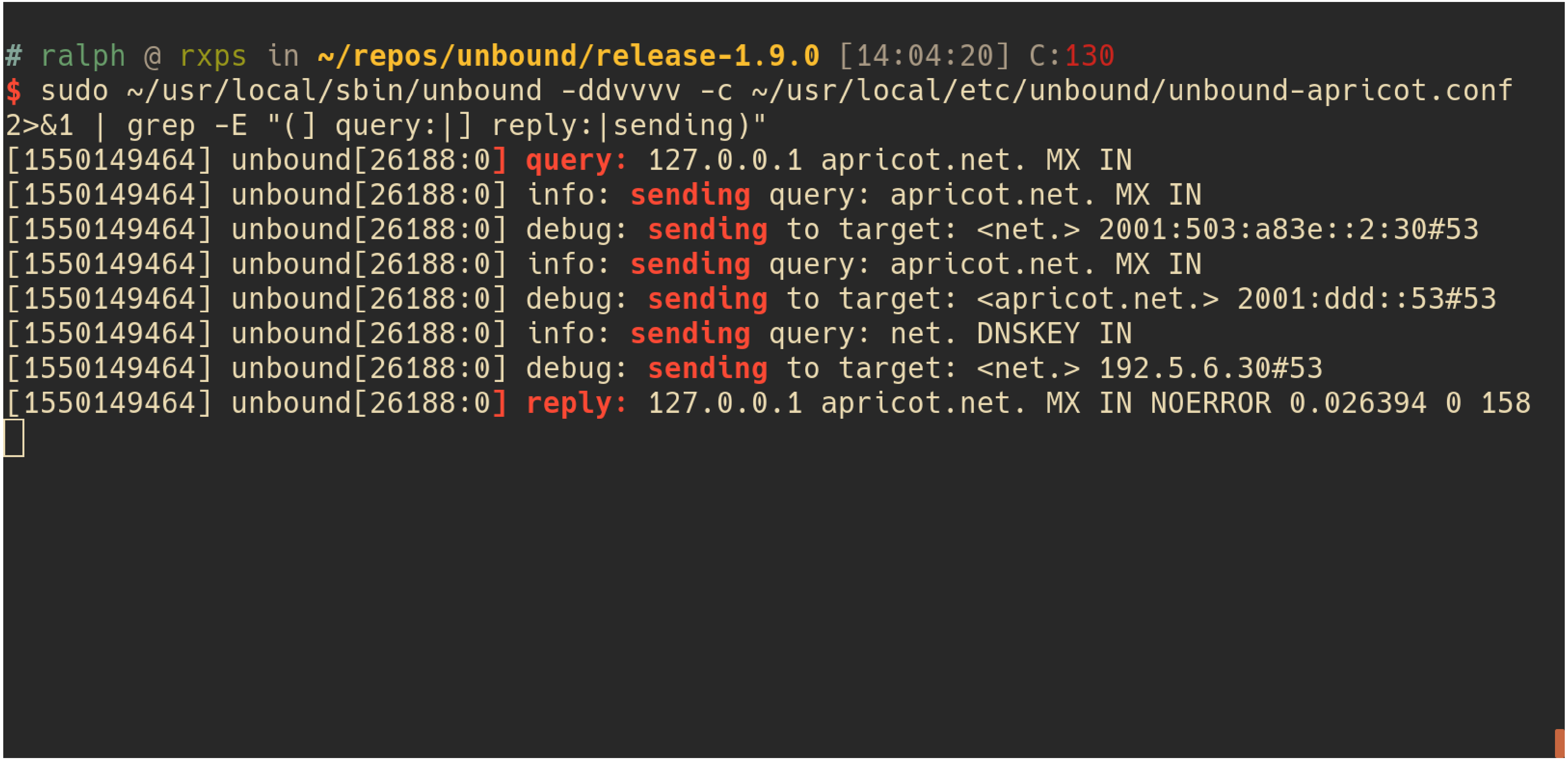
- Auth-zone functionality in Unbound since version 1.7.0
- AXFR/IXFR and HTTP zone transfer
  - NOTIFY support
- Reading from and writing to file

Unbound: root zone in resolver

```
auth-zone:
        name: "."
        master: 199.9.14.201               # b.root-servers.net
        master: 192.33.4.12                # c.root-servers.net
        master: 199.7.91.13                # d.root-servers.net
        master: 192.5.5.241                # f.root-servers.net
        master: 192.112.36.4               # g.root-servers.net
        master: 193.0.14.129               # k.root-servers.net
        master: 192.0.47.132               # xfr.cjr.dns.icann.org
        master: 192.0.32.132               # xfr.lax.dns.icann.org
        master: 2001:500:200::b            # b.root-servers.net
        master: 2001:500:2::c              # c.root-servers.net
        master: 2001:500:2d::d             # d.root-servers.net
        master: 2001:500:2f::f             # f.root-servers.net
        master: 2001:500:12::d0d           # g.root-servers.net
        master: 2001:7fd::1                # k.root-servers.net
        master: 2620:0:2830:202::132       # xfr.cjr.dns.icann.org
        master: 2620:0:2d0:202::132        # xfr.lax.dns.icann.org
        fallback-enabled: yes
        for-downstream: no
        for-upstream: yes
```



```
# ralph @ rxps in ~/repos/unbound/release-1.9.0 [14:01:49] C:130
$ sudo ~/usr/local/sbin/unbound -ddvvvv -c ~/usr/local/etc/unbound/unbound-apricot.conf
2>&1 | grep -E "(] query:|] reply:|sending)"
[1550149316] unbound[23900:0] query: 127.0.0.1 apricot.net. MX IN
[1550149316] unbound[23900:0] info: sending query: . NS IN
[1550149316] unbound[23900:0] debug: sending to target: <.> 199.9.14.201#53
[1550149316] unbound[23900:0] info: sending query: apricot.net. MX IN
[1550149316] unbound[23900:0] debug: sending to target: <.> 2001:503:ba3e::2:30#53
[1550149316] unbound[23900:0] info: sending query: apricot.net. MX IN
[1550149316] unbound[23900:0] debug: sending to target: <net.> 192.43.172.30#53
[1550149316] unbound[23900:0] info: sending query: apricot.net. MX IN
[1550149316] unbound[23900:0] debug: sending to target: <apricot.net.> 202.12.31.53#53
[1550149316] unbound[23900:0] info: sending query: . DNSKEY IN
[1550149316] unbound[23900:0] debug: sending to target: <.> 2001:503:c27::2:30#53
[1550149316] unbound[23900:0] info: sending query: _ta-4f66. NULL IN
[1550149316] unbound[23900:0] debug: sending to target: <.> 2001:dc3::35#53
[1550149317] unbound[23900:0] info: sending query: net. DNSKEY IN
[1550149317] unbound[23900:0] debug: sending to target: <net.> 192.52.178.30#53
[1550149317] unbound[23900:0] reply: 127.0.0.1 apricot.net. MX IN NOERROR 1.038976 0 158
```



```
# ralph @ rxps in ~/repos/unbound/release-1.9.0 [14:04:20] C:130
$ sudo ~/usr/local/sbin/unbound -ddvvvv -c ~/usr/local/etc/unbound/unbound-apricot.conf
2>&1 | grep -E "(] query:|] reply:|sending)"
[1550149464] unbound[26188:0] query: 127.0.0.1 apricot.net. MX IN
[1550149464] unbound[26188:0] info: sending query: apricot.net. MX IN
[1550149464] unbound[26188:0] debug: sending to target: <net.> 2001:503:a83e::2:30#53
[1550149464] unbound[26188:0] info: sending query: apricot.net. MX IN
[1550149464] unbound[26188:0] debug: sending to target: <apricot.net.> 2001:ddd::53#53
[1550149464] unbound[26188:0] info: sending query: net. DNSKEY IN
[1550149464] unbound[26188:0] debug: sending to target: <net.> 192.5.6.30#53
[1550149464] unbound[26188:0] reply: 127.0.0.1 apricot.net. MX IN NOERROR 0.026394 0 158
```

Unbound: local TLD

- Not limited to the root zone

```
auth-zone:
        name: "se"
        fallback-enabled: yes
        for-downstream: no
        master: zonedata.iis.se
        zonefile: “se.zone”
```

RFC8198 - Aggressive NSEC

- Use cached NSEC and NSEC3 records to synthesise answers
  - Negative answers (NODATA and NXDOMAIN)
  - Wildcard answers
- Does not work for NSEC3 opt-out

NSEC

Unsigned zone:

```
apricot-demo.nlnetlabs.nl.              SOA [..]
                                        NS albatross
albatross.apricot-demo.nlnetlabs.nl.        A 185.49.140.60
zebra.apricot-demo.nlnetlabs.nl.        A 185.49.140.70
```

NSEC records generated after zone signing:

```
apricot-demo.nlnetlabs.nl.              NSEC albatross.apricot-demo.nlnetlabs.nl. [..]
albatross.apricot-demo.nlnetlabs.nl.        NSEC zebra.apricot-demo.nlnetlabs.nl. [..]
zebra.apricot-demo.nlnetlabs.nl.        NSEC apricot-demo.nlnetlabs.nl. [..]
```

NSEC proof of non existence

```
$ dig tiger.apricot-demo.nlnetlabs.nl +dnssec

; <<>> DiG 9.11.3-1ubuntu1.3-Ubuntu <<>> tiger.apricot-demo.nlnetlabs.nl +dnssec
;; global options: +cmd
;; Got answer:
;; ->>HEADER<<- opcode: QUERY, status: NXDOMAIN, id: 58617
;; flags: qr rd ra ad; QUERY: 1, ANSWER: 0, AUTHORITY: 6, ADDITIONAL: 1

;; OPT PSEUDOSECTION:
; EDNS: version: 0, flags: do; udp: 4096
;; QUESTION SECTION:
;tiger.apricot-demo.nlnetlabs.nl. IN   A

;; AUTHORITY SECTION:
albatross.apricot-demo.nlnetlabs.nl. 3600 IN NSEC zebra.apricot-demo.nlnetlabs.nl. A RRSIG NSEC
albatross.apricot-demo.nlnetlabs.nl. 3600 IN RRSIG NSEC [..]
apricot-demo.nlnetlabs.nl. 3600   IN   NSEC     albatross.apricot-demo.nlnetlabs.nl. NS SOA RRSIG NSEC DNSKEY
apricot-demo.nlnetlabs.nl. 3600   IN   RRSIG    NSEC [..]
apricot-demo.nlnetlabs.nl. 3600   IN   SOA ns.nlnetlabs.nl. ralph.nlnetlabs.nl. 1550139530 14400 3600 604800 3600
apricot-demo.nlnetlabs.nl. 3600   IN   RRSIG    SOA [..]
```

NSEC proof of non existence

```
$ dig elephant.apricot-demo.nlnetlabs.nl +dnssec

; <<>> DiG 9.11.3-1ubuntu1.3-Ubuntu <<>> elephant.apricot-demo.nlnetlabs.nl +dnssec
;; global options: +cmd
;; Got answer:
;; ->>HEADER<<- opcode: QUERY, status: NXDOMAIN, id: 13618
;; flags: qr rd ra ad; QUERY: 1, ANSWER: 0, AUTHORITY: 6, ADDITIONAL: 1

;; OPT PSEUDOSECTION:
; EDNS: version: 0, flags: do; udp: 4096
;; QUESTION SECTION:
;elephant.apricot-demo.nlnetlabs.nl. IN    A

;; AUTHORITY SECTION:
albatross.apricot-demo.nlnetlabs.nl. 3600 IN NSEC zebra.apricot-demo.nlnetlabs.nl. A RRSIG NSEC
albatross.apricot-demo.nlnetlabs.nl. 3600 IN RRSIG NSEC [..]
apricot-demo.nlnetlabs.nl. 3600   IN    NSEC     albatross.apricot-demo.nlnetlabs.nl. NS SOA RRSIG NSEC DNSKEY
apricot-demo.nlnetlabs.nl. 3600   IN    RRSIG    NSEC [..]
apricot-demo.nlnetlabs.nl. 3600   IN    SOA ns.nlnetlabs.nl. ralph.nlnetlabs.nl. 1550139530 14400 3600 604800 3600
apricot-demo.nlnetlabs.nl. 3600   IN    RRSIG    SOA [..]
```

Using cached NSEC records

- NSEC records in cache after *tiger.apricot-demo.nlnetlabs.nl* query:

```
albatross.apricot-demo.nlnetlabs.nl. 3600 IN NSEC zebra.apricot-demo.nlnetlabs.nl. A RRSIG NSEC
apricot-demo.nlnetlabs.nl. 3600 IN    NSEC    albatross.apricot-demo.nlnetlabs.nl. NS SOA RRSIG NSEC DNSKEY
```

- These records can be used to return an NXDOMAIN answer for *elephant.apricot-demo.nlnetlabs.nl* → Aggressive use of NSEC
  - Less upstream queries

Unbound: Aggressive NSEC

- Disabled by default (for now)
- Limited to NSEC (for now)

```
aggressive-nsec: yes
```

Aggressive NSEC – NODATA

- Cached NSEC records can also be used to synthesise **NODATA** answers

```
albatross.apricot-demo.nlnetlabs.nl. 3600 IN NSEC zebra.apricot-demo.nlnetlabs.nl. A RRSIG NSEC
```

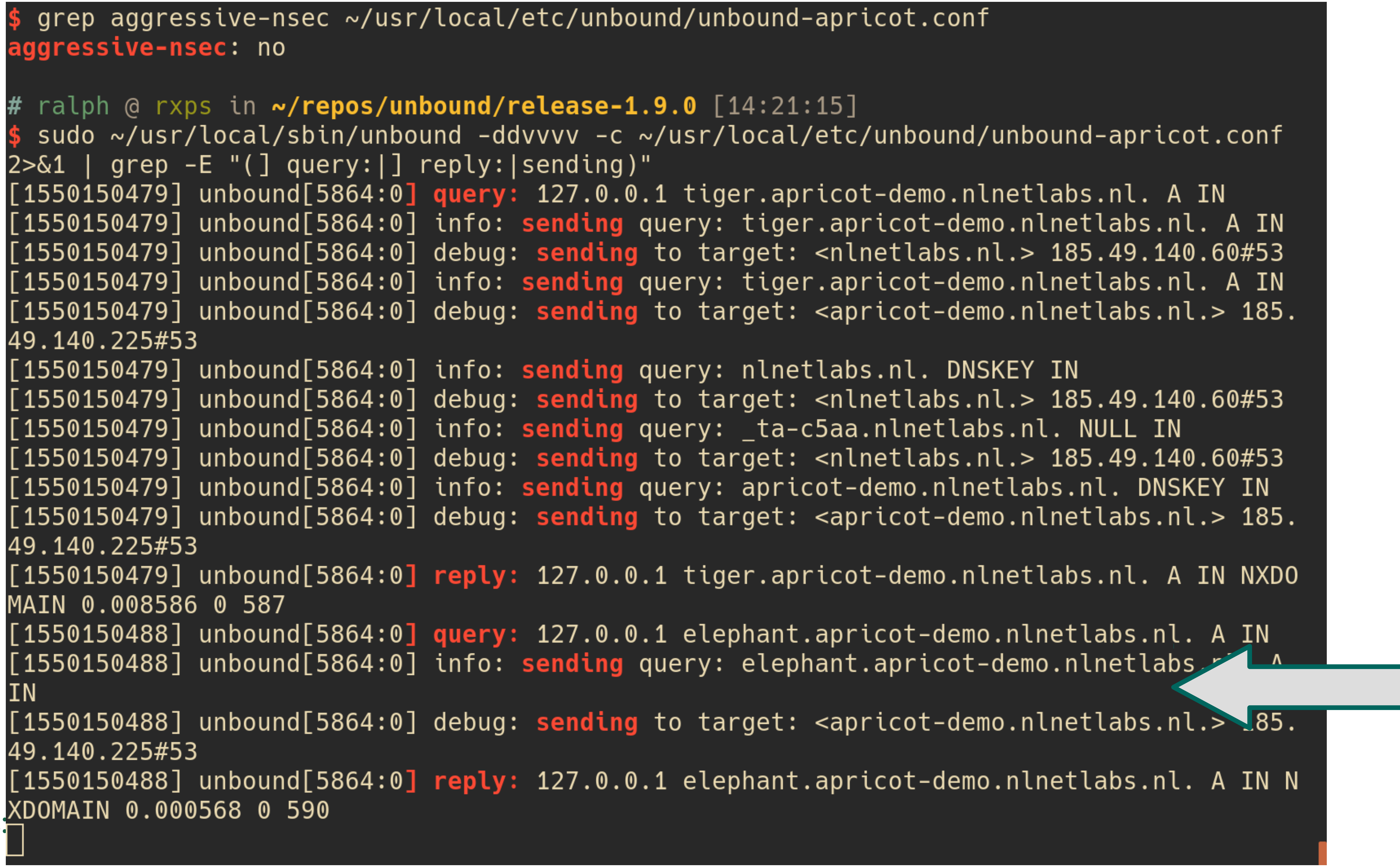
- MX query for *albatross.apricot-demo.nlnetlabs.nl* can be answered without upstream query

Aggressive NSEC – Wildcard records

- Cached wildcard + NSEC records can also be used to synthesise **wildcard** answers

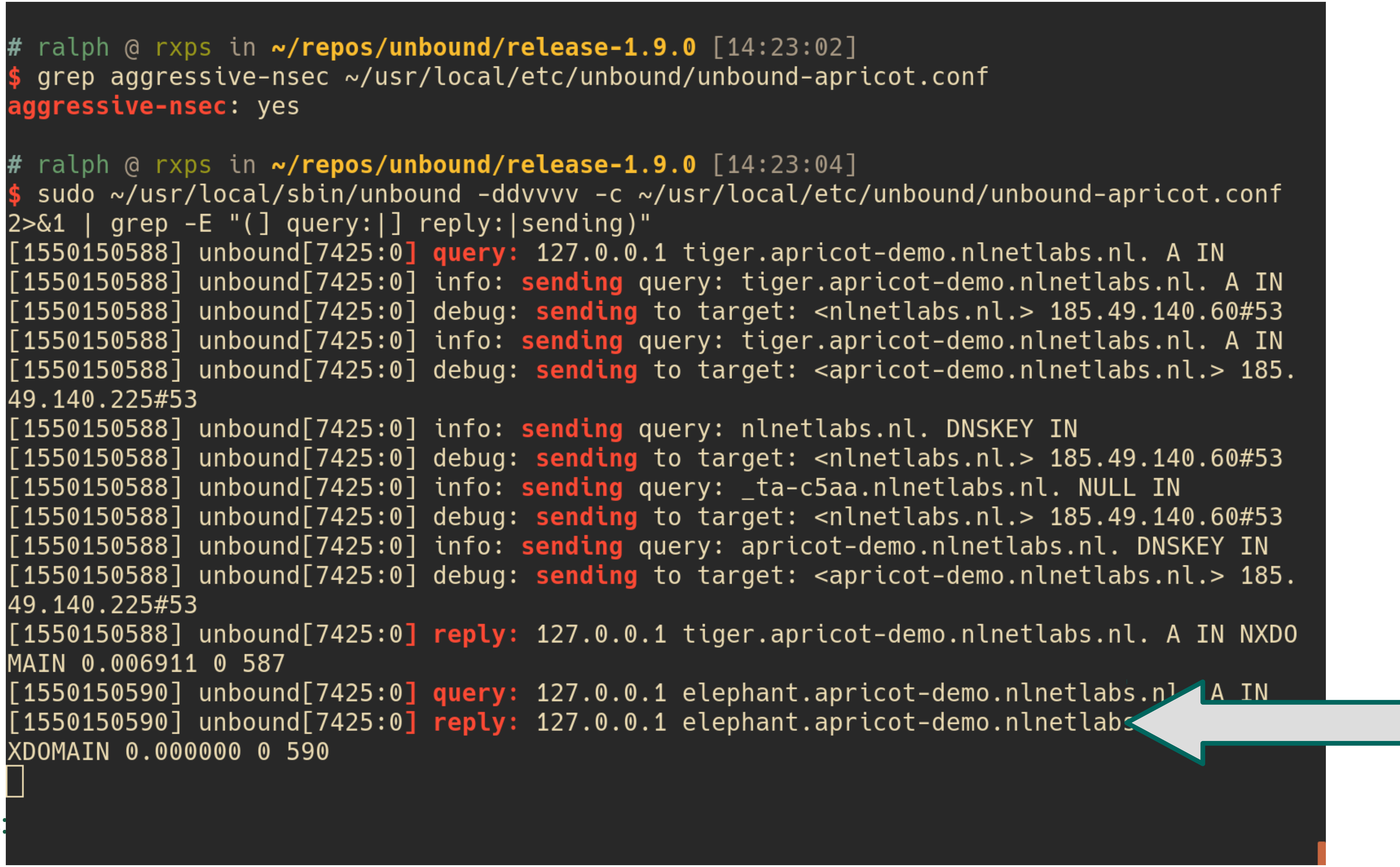
```
albatross.apricot-demo.nlnetlabs.nl. 3600 IN NSEC zebra.apricot-demo.nlnetlabs.nl. A RRSIG NSEC
*.apricot-demo.nlnetlabs.nl. 3600 IN TXT “wildcard record”
```

- TXT query for *camel.apricot-demo.nlnetlabs.nl* can be answered without upstream query
  - camel.apricot-demo.nlnetlabs.nl provably non existent
  - TXT record in cache → camel.apricot-demo.nlnetlabs.nl TXT “wildcard record”



```
$ grep aggressive-nsec ~/usr/local/etc/unbound/unbound-apricot.conf
aggressive-nsec: no

# ralph @ rxps in ~/repos/unbound/release-1.9.0 [14:21:15]
$ sudo ~/usr/local/sbin/unbound -ddvvvv -c ~/usr/local/etc/unbound/unbound-apricot.conf
2>&1 | grep -E "(] query:|] reply:|sending)"
[1550150479] unbound[5864:0] query: 127.0.0.1 tiger.apricot-demo.nlnetlabs.nl. A IN
[1550150479] unbound[5864:0] info: sending query: tiger.apricot-demo.nlnetlabs.nl. A IN
[1550150479] unbound[5864:0] debug: sending to target: <nlnetlabs.nl.> 185.49.140.60#53
[1550150479] unbound[5864:0] info: sending query: tiger.apricot-demo.nlnetlabs.nl. A IN
[1550150479] unbound[5864:0] debug: sending to target: <apricot-demo.nlnetlabs.nl.> 185.
49.140.225#53
[1550150479] unbound[5864:0] info: sending query: nlnetlabs.nl. DNSKEY IN
[1550150479] unbound[5864:0] debug: sending to target: <nlnetlabs.nl.> 185.49.140.60#53
[1550150479] unbound[5864:0] info: sending query: _ta-c5aa.nlnetlabs.nl. NULL IN
[1550150479] unbound[5864:0] debug: sending to target: <nlnetlabs.nl.> 185.49.140.60#53
[1550150479] unbound[5864:0] info: sending query: apricot-demo.nlnetlabs.nl. DNSKEY IN
[1550150479] unbound[5864:0] debug: sending to target: <apricot-demo.nlnetlabs.nl.> 185.
49.140.225#53
[1550150479] unbound[5864:0] reply: 127.0.0.1 tiger.apricot-demo.nlnetlabs.nl. A IN NXDO
MAIN 0.008586 0 587
[1550150488] unbound[5864:0] query: 127.0.0.1 elephant.apricot-demo.nlnetlabs.nl. A IN
[1550150488] unbound[5864:0] info: sending query: elephant.apricot-demo.nlnetlabs.nl. A
IN
[1550150488] unbound[5864:0] debug: sending to target: <apricot-demo.nlnetlabs.nl.> 185.
49.140.225#53
[1550150488] unbound[5864:0] reply: 127.0.0.1 elephant.apricot-demo.nlnetlabs.nl. A IN N
XDOMAIN 0.000568 0 590
```

https:



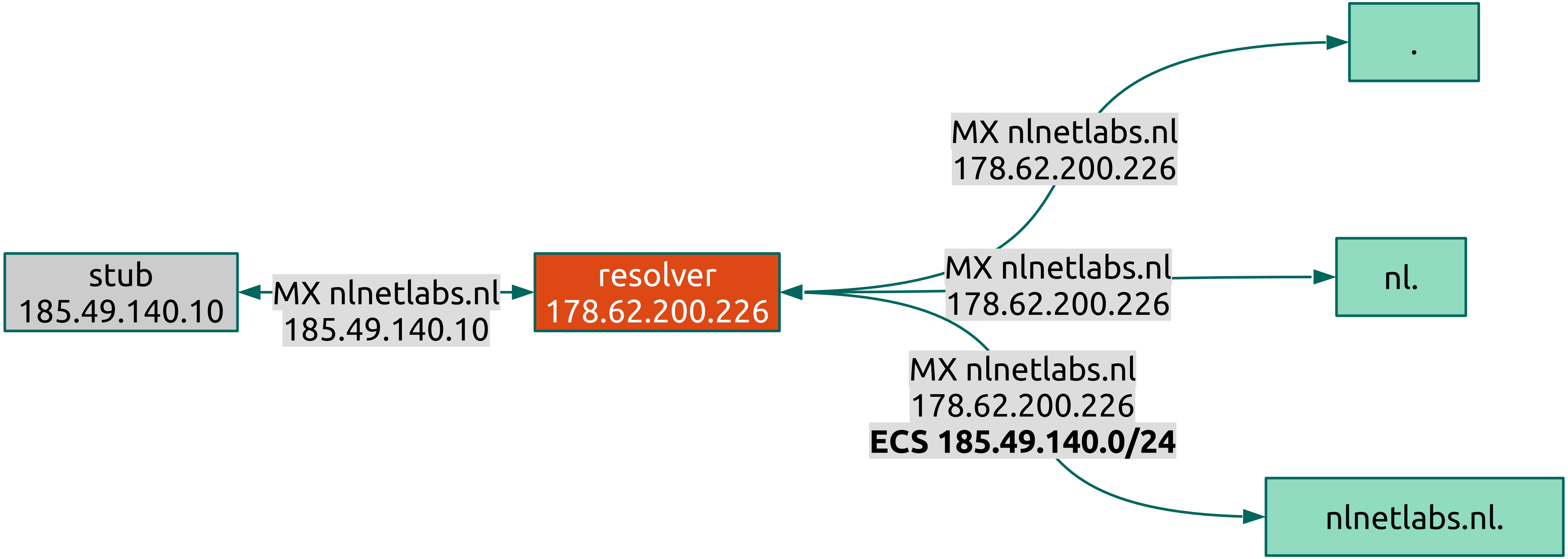
```
# ralph @ rxps in ~/repos/unbound/release-1.9.0 [14:23:02]
$ grep aggressive-nsec ~/usr/local/etc/unbound/unbound-apricot.conf
aggressive-nsec: yes

# ralph @ rxps in ~/repos/unbound/release-1.9.0 [14:23:04]
$ sudo ~/usr/local/sbin/unbound -ddvvvv -c ~/usr/local/etc/unbound/unbound-apricot.conf
2>&1 | grep -E "(] query:|] reply:|sending)"
[1550150588] unbound[7425:0] query: 127.0.0.1 tiger.apricot-demo.nlnetlabs.nl. A IN
[1550150588] unbound[7425:0] info: sending query: tiger.apricot-demo.nlnetlabs.nl. A IN
[1550150588] unbound[7425:0] debug: sending to target: <nlnetlabs.nl.> 185.49.140.60#53
[1550150588] unbound[7425:0] info: sending query: tiger.apricot-demo.nlnetlabs.nl. A IN
[1550150588] unbound[7425:0] debug: sending to target: <apricot-demo.nlnetlabs.nl.> 185.
49.140.225#53
[1550150588] unbound[7425:0] info: sending query: nlnetlabs.nl. DNSKEY IN
[1550150588] unbound[7425:0] debug: sending to target: <nlnetlabs.nl.> 185.49.140.60#53
[1550150588] unbound[7425:0] info: sending query: _ta-c5aa.nlnetlabs.nl. NULL IN
[1550150588] unbound[7425:0] debug: sending to target: <nlnetlabs.nl.> 185.49.140.60#53
[1550150588] unbound[7425:0] info: sending query: apricot-demo.nlnetlabs.nl. DNSKEY IN
[1550150588] unbound[7425:0] debug: sending to target: <apricot-demo.nlnetlabs.nl.> 185.
49.140.225#53
[1550150588] unbound[7425:0] reply: 127.0.0.1 tiger.apricot-demo.nlnetlabs.nl. A IN NXDO
MAIN 0.006911 0 587
[1550150590] unbound[7425:0] query: 127.0.0.1 elephant.apricot-demo.nlnetlabs.nl  A IN
[1550150590] unbound[7425:0] reply: 127.0.0.1 elephant.apricot-demo.nlnetlabs
XDOMAIN 0.000000 0 590
```

https:

Privacy Threat Mitigation

- Data minimisation
  - Limit the number of DNS queries
  - → Minimise the data disclosed in DNS transactions
- Security
  - Hide transaction by using encryption
  - Limit data disclosure to authenticated parties

DNS data disclosure with ECS



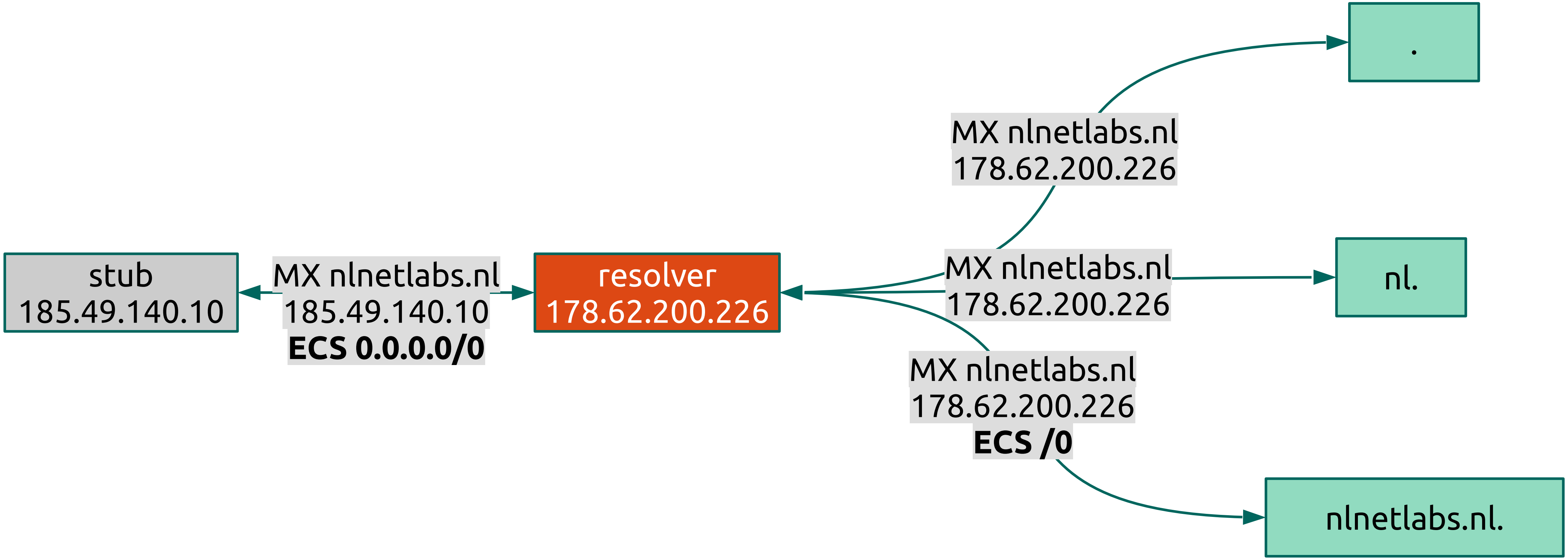
ECS - 0 source prefix length

- RFC7871, section 7.1.2:
  - “A SOURCE PREFIX-LENGTH value of 0 means that the Recursive Resolver MUST NOT add the client's address information to its queries.”
- Not honored by OpenDNS :(

EDNS Client Subnet

- From stub
    - Set EDNS Client Subnet prefix to /0
- From resolver
    - Do not use EDNS Client Subnet
    - (set ECS prefix to /0 when forwarding)

DNS data disclosure with ECS (/0 source prefix)



Unbound: EDNS Client Subnet

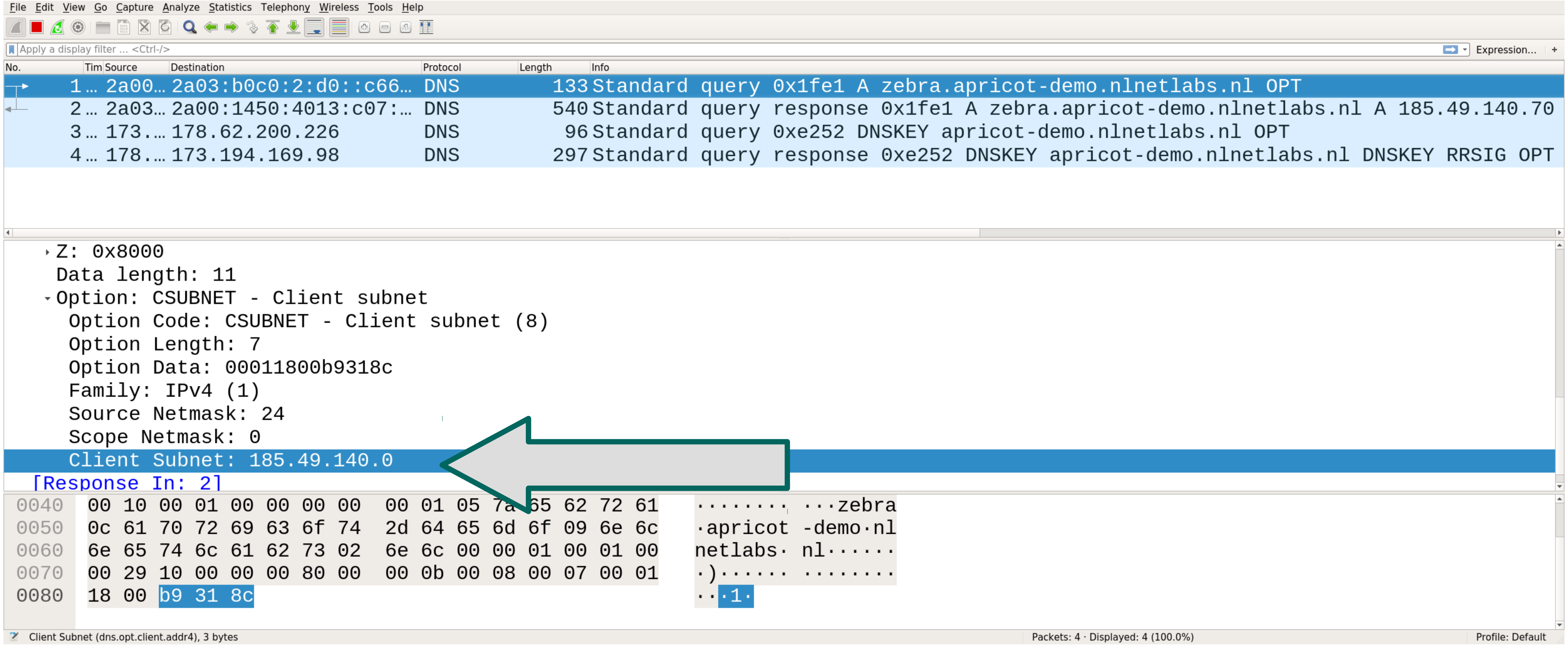
- Default off, no need to change for privacy aware resolver
- Forwarding /0 not implemented yet

Stubby: ECS /0

- Always send ECS 0 source prefix option:

```
edns_client_subnet_private : 1
```

dig zebra.apricot-demo.nlnetlabs.nl @8.8.8.8


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

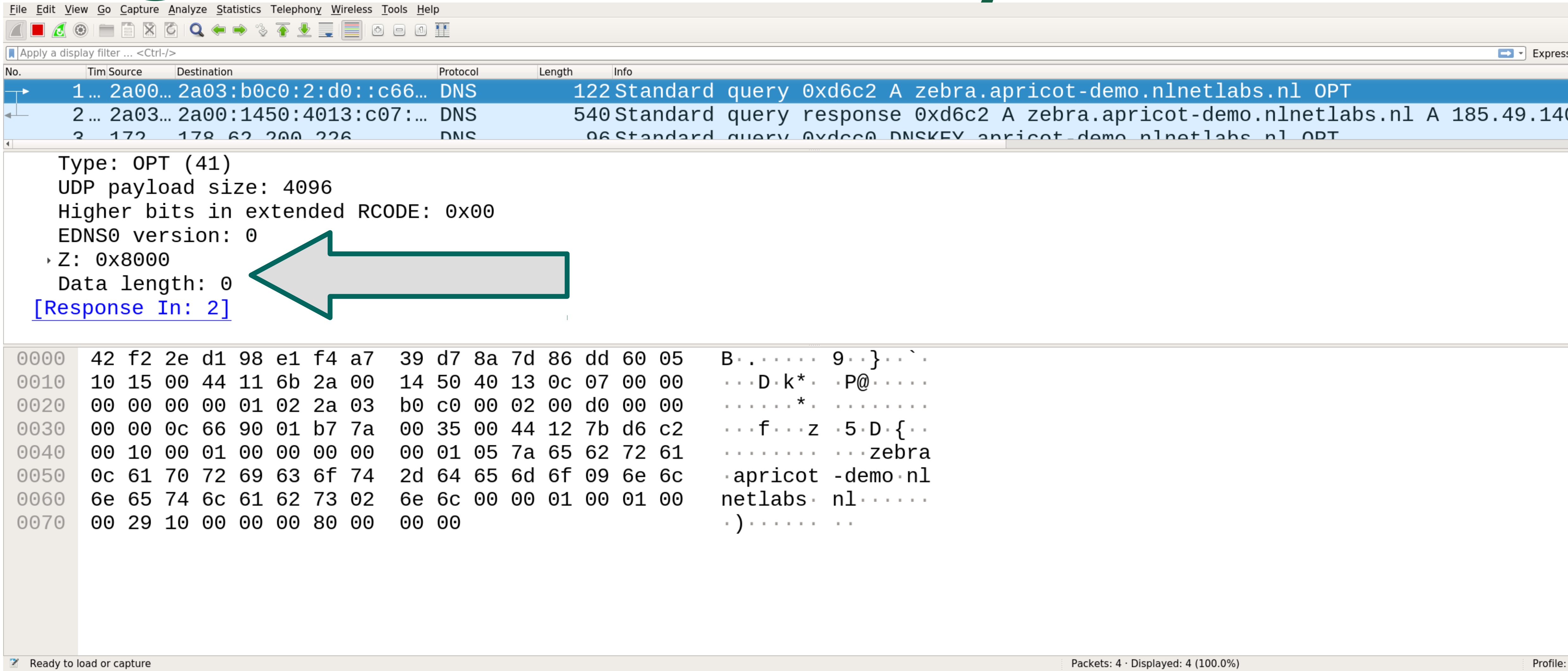
```
No.   Tim Source  Destination           Protocol  Length Info
  1 … 2a00…  2a03:b0c0:2:d0::c66…  DNS          133 Standard query 0x1fe1 A zebra.apricot-demo.nlnetlabs.nl OPT
  2 … 2a03…  2a00:1450:4013:c07:…  DNS          540 Standard query response 0x1fe1 A zebra.apricot-demo.nlnetlabs.nl A 185.49.140.70
  3 … 173.…  178.62.200.226        DNS           96 Standard query 0xe252 DNSKEY apricot-demo.nlnetlabs.nl OPT
  4 … 178.…  173.194.169.98        DNS          297 Standard query response 0xe252 DNSKEY apricot-demo.nlnetlabs.nl DNSKEY RRSIG OPT
```

```
  › Z: 0x8000
    Data length: 11
  ˅ Option: CSUBNET - Client subnet
      Option Code: CSUBNET - Client subnet (8)
      Option Length: 7
      Option Data: 00011800b9318c
      Family: IPv4 (1)
      Source Netmask: 24
      Scope Netmask: 0
      Client Subnet: 185.49.140.0
 [Response In: 2]
```

```
0040  00 10 00 01 00 00 00 00  00 01 05 7a 65 62 72 61   ········ ···zebra
0050  0c 61 70 72 69 63 6f 74  2d 64 65 6d 6f 09 6e 6c   ·apricot -demo·nl
0060  6e 65 74 6c 61 62 73 02  6e 6c 00 00 01 00 01 00   netlabs· nl······
0070  00 29 10 00 00 00 80 00  00 0b 00 08 00 07 00 01   ·)······ ········
0080  18 00 b9 31 8c                                     ···1·
```

Client Subnet (dns.opt.client.addr4), 3 bytes   Packets: 4 · Displayed: 4 (100.0%)   Profile: Default

dig zebra.apricot-demo.nlnetlabs.nl @8.8.8.8 +subnet=0.0.0.0/0



```
No.    Tim Source   Destination              Protocol     Length Info
  1 …  2a00…  2a03:b0c0:2:d0::c66…  DNS     122 Standard query 0xd6c2 A zebra.apricot-demo.nlnetlabs.nl OPT
  2 …  2a03…  2a00:1450:4013:c07:…  DNS     540 Standard query response 0xd6c2 A zebra.apricot-demo.nlnetlabs.nl A 185.49.140
  3 …  172…   178.62.200.226        DNS      96 Standard query 0xdcc0 DNSKEY apricot-demo.nlnetlabs.nl OPT
```

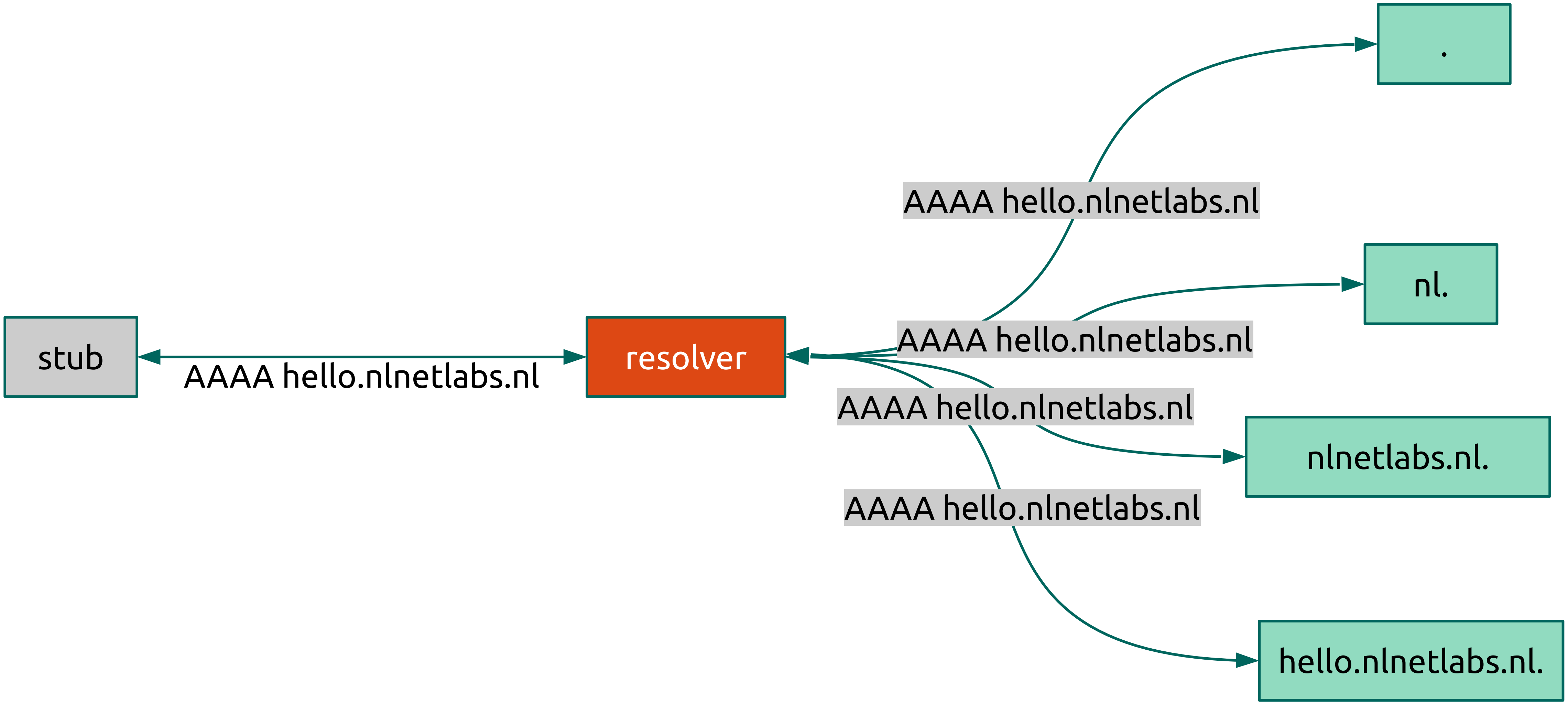
```
    Type: OPT (41)
    UDP payload size: 4096
    Higher bits in extended RCODE: 0x00
    EDNS0 version: 0
  ▸ Z: 0x8000
    Data length: 0
  [Response In: 2]
```

```
0000  42 f2 2e d1 98 e1 f4 a7  39 d7 8a 7d 86 dd 60 05   B·.·····9··}··`·
0010  10 15 00 44 11 6b 2a 00  14 50 40 13 0c 07 00 00   ···D·k*··P@·····
0020  00 00 00 00 01 02 2a 03  b0 c0 00 02 00 d0 00 00   ······*·········
0030  00 00 0c 66 90 01 b7 7a  00 35 00 44 12 7b d6 c2   ···f···z·5·D·{··
0040  00 10 00 01 00 00 00 00  00 01 05 7a 65 62 72 61   ···········zebra
0050  0c 61 70 72 69 63 6f 74  2d 64 65 6d 6f 09 6e 6c   ·apricot-demo·nl
0060  6e 65 74 6c 61 62 73 02  6e 6c 00 00 01 00 01 00   netlabs·nl······
0070  00 29 10 00 00 00 80 00  00 00                     ·)········
```

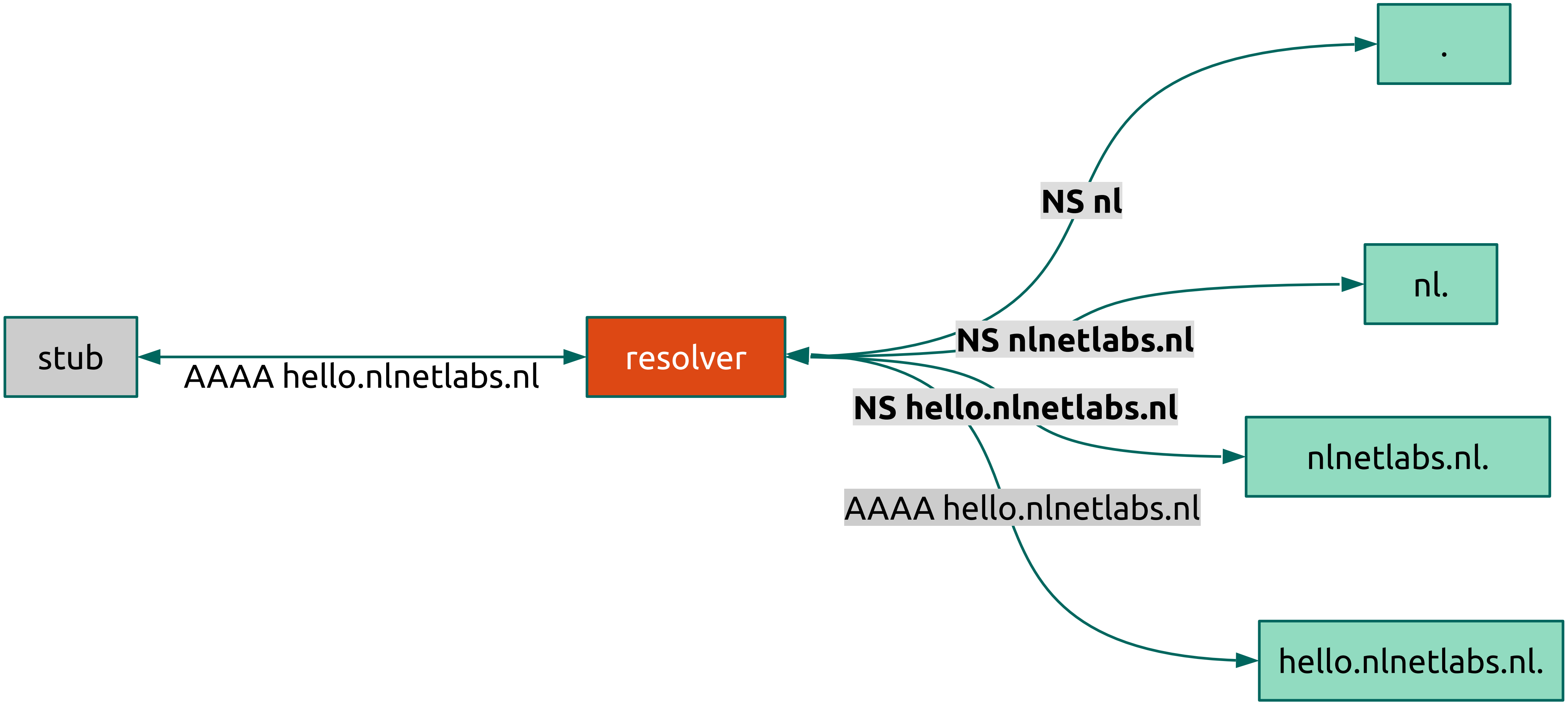
QNAME minimisation

- DNS Query Name Minimisation to Improve Privacy, RFC7816:
    - “The request is done with:
        - the QTYPE NS,
        - the QNAME which is the original QNAME, stripped to just one label more than the zone for which the server is authoritative.”

Without QNAME minimisation



With QNAME minimisation

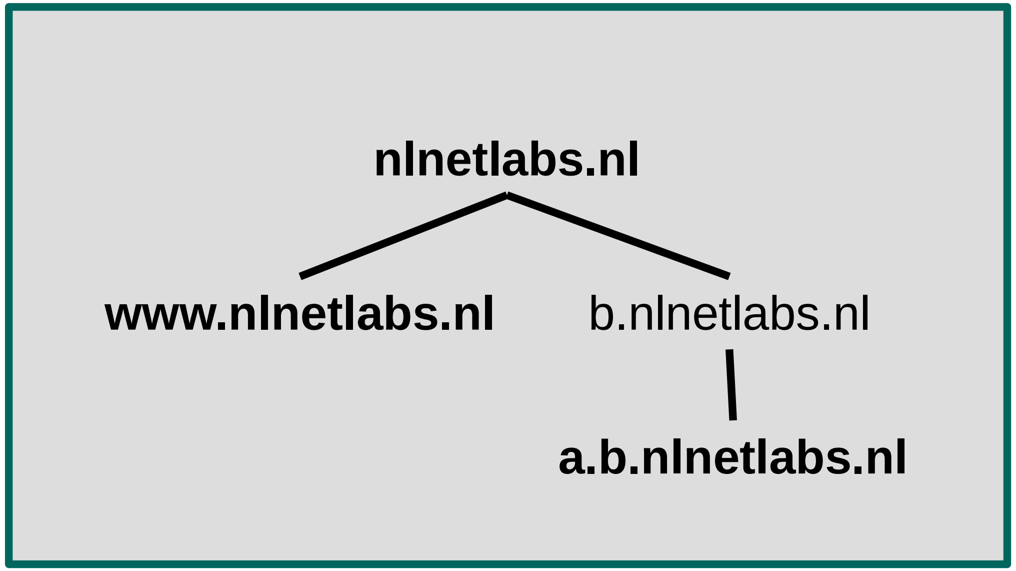


QNAME minimisation issues

- Lot of queries for some domains, e.g. 0.1.0.0.0.0.0.0.0.0.0.0.1.0.0.0.0.0.0.0.0.0.0.0.0.0.0.9.b.4.0.a.2.ip6.arpa.
- Queries for NS QTYPE not always (correctly) answered
- Unclear when to stop resolving
    - RFC8020- NXDOMAIN: There Really Is Nothing Underneath

Empty-non-terminals

- Existing name without records
- Example zone with records for **nlnetlabs.nl**, **www.nlnetlabs.nl** and **a.b.nlnetlabs.nl**
- b.nlnetlabs.nl is an empty-non-terminal



QNAME minimisation in Unbound

- Do QNAME minimisation with QTYPE=A
- Limit number of queries
  - Limit QNAME minimisation iterations to 10
  - Always append one label for the first 4 queries
- Continue without minimisation when RCODE != NOERROR
  - Exception for DNSSEC signed domains
  - Not in strict mode

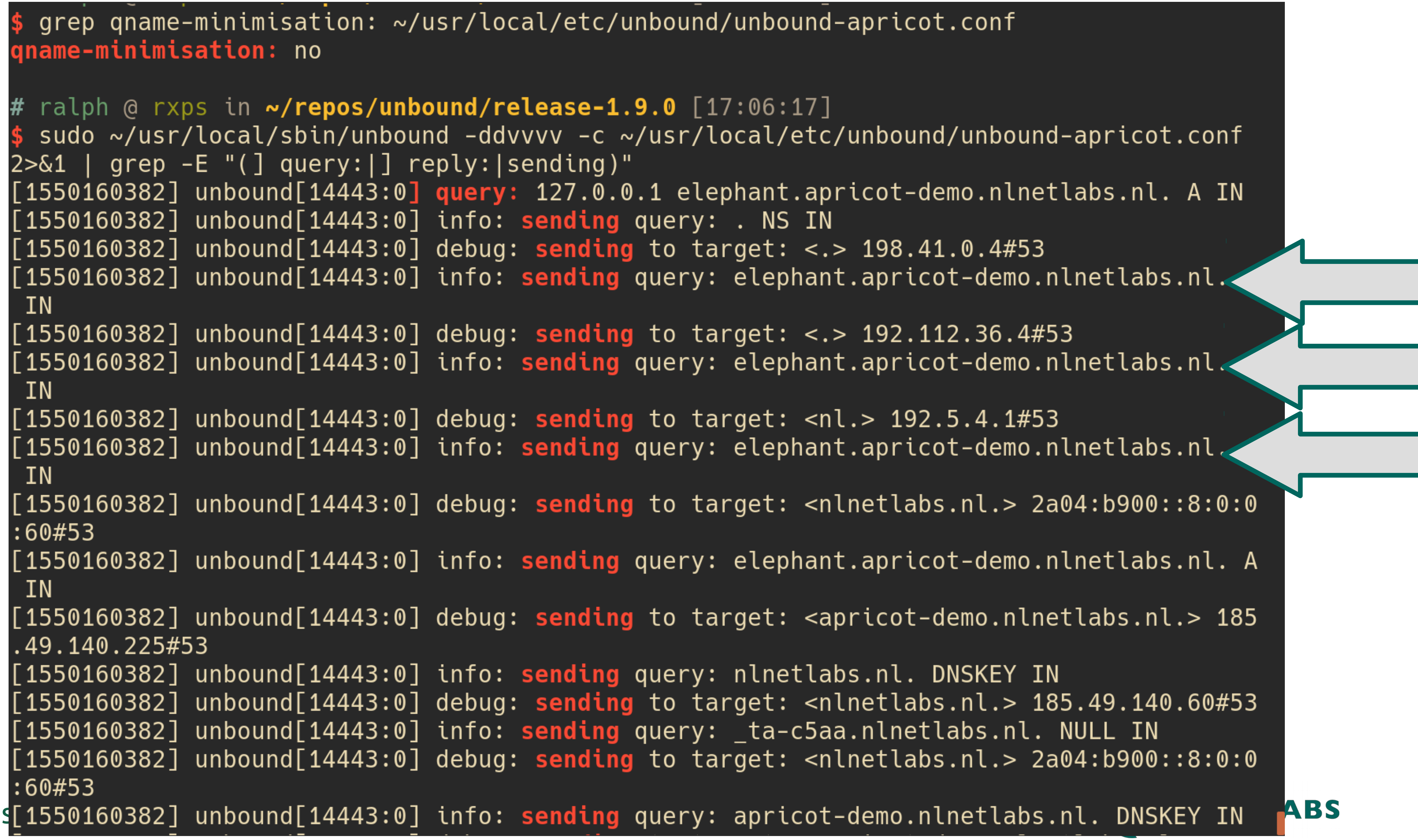
QNAME minimisation in Unbound

- Enable QNAME minimisation (default):

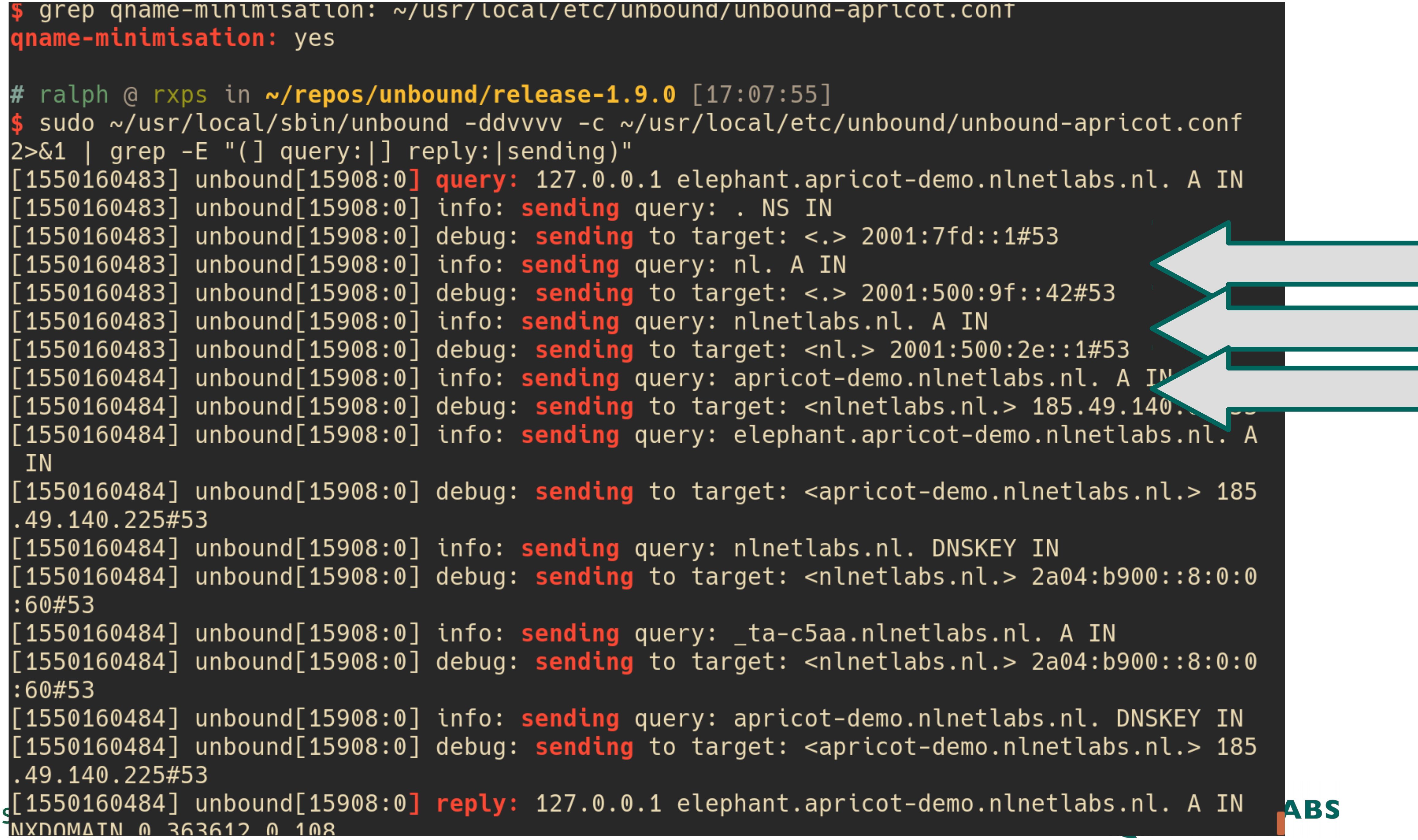
```
qname-minimisation: yes
```

- QNAME minimisation in strict mode (not recommended):

```
qname-minimisation-strict: yes
```



```
$ grep qname-minimisation: ~/usr/local/etc/unbound/unbound-apricot.conf
qname-minimisation: no

# ralph @ rxps in ~/repos/unbound/release-1.9.0 [17:06:17]
$ sudo ~/usr/local/sbin/unbound -ddvvvv -c ~/usr/local/etc/unbound/unbound-apricot.conf
2>&1 | grep -E "(] query:|] reply:|sending)"
[1550160382] unbound[14443:0] query: 127.0.0.1 elephant.apricot-demo.nlnetlabs.nl. A IN
[1550160382] unbound[14443:0] info: sending query: . NS IN
[1550160382] unbound[14443:0] debug: sending to target: <.> 198.41.0.4#53
[1550160382] unbound[14443:0] info: sending query: elephant.apricot-demo.nlnetlabs.nl.
 IN
[1550160382] unbound[14443:0] debug: sending to target: <.> 192.112.36.4#53
[1550160382] unbound[14443:0] info: sending query: elephant.apricot-demo.nlnetlabs.nl.
 IN
[1550160382] unbound[14443:0] debug: sending to target: <nl.> 192.5.4.1#53
[1550160382] unbound[14443:0] info: sending query: elephant.apricot-demo.nlnetlabs.nl.
 IN
[1550160382] unbound[14443:0] debug: sending to target: <nlnetlabs.nl.> 2a04:b900::8:0:0
:60#53
[1550160382] unbound[14443:0] info: sending query: elephant.apricot-demo.nlnetlabs.nl. A
 IN
[1550160382] unbound[14443:0] debug: sending to target: <apricot-demo.nlnetlabs.nl.> 185
.49.140.225#53
[1550160382] unbound[14443:0] info: sending query: nlnetlabs.nl. DNSKEY IN
[1550160382] unbound[14443:0] debug: sending to target: <nlnetlabs.nl.> 185.49.140.60#53
[1550160382] unbound[14443:0] info: sending query: _ta-c5aa.nlnetlabs.nl. NULL IN
[1550160382] unbound[14443:0] debug: sending to target: <nlnetlabs.nl.> 2a04:b900::8:0:0
:60#53
[1550160382] unbound[14443:0] info: sending query: apricot-demo.nlnetlabs.nl. DNSKEY IN
```



```
$ grep qname-minimisation: ~/usr/local/etc/unbound/unbound-apricot.conf
qname-minimisation: yes

# ralph @ rxps in ~/repos/unbound/release-1.9.0 [17:07:55]
$ sudo ~/usr/local/sbin/unbound -ddvvvv -c ~/usr/local/etc/unbound/unbound-apricot.conf
2>&1 | grep -E "(] query:|] reply:|sending)"
[1550160483] unbound[15908:0] query: 127.0.0.1 elephant.apricot-demo.nlnetlabs.nl. A IN
[1550160483] unbound[15908:0] info: sending query: . NS IN
[1550160483] unbound[15908:0] debug: sending to target: <.> 2001:7fd::1#53
[1550160483] unbound[15908:0] info: sending query: nl. A IN
[1550160483] unbound[15908:0] debug: sending to target: <.> 2001:500:9f::42#53
[1550160483] unbound[15908:0] info: sending query: nlnetlabs.nl. A IN
[1550160483] unbound[15908:0] debug: sending to target: <nl.> 2001:500:2e::1#53
[1550160484] unbound[15908:0] info: sending query: apricot-demo.nlnetlabs.nl. A IN
[1550160484] unbound[15908:0] debug: sending to target: <nlnetlabs.nl.> 185.49.140.
[1550160484] unbound[15908:0] info: sending query: elephant.apricot-demo.nlnetlabs.nl. A
 IN
[1550160484] unbound[15908:0] debug: sending to target: <apricot-demo.nlnetlabs.nl.> 185
.49.140.225#53
[1550160484] unbound[15908:0] info: sending query: nlnetlabs.nl. DNSKEY IN
[1550160484] unbound[15908:0] debug: sending to target: <nlnetlabs.nl.> 2a04:b900::8:0:0
:60#53
[1550160484] unbound[15908:0] info: sending query: _ta-c5aa.nlnetlabs.nl. A IN
[1550160484] unbound[15908:0] debug: sending to target: <nlnetlabs.nl.> 2a04:b900::8:0:0
:60#53
[1550160484] unbound[15908:0] info: sending query: apricot-demo.nlnetlabs.nl. DNSKEY IN
[1550160484] unbound[15908:0] debug: sending to target: <apricot-demo.nlnetlabs.nl.> 185
.49.140.225#53
[1550160484] unbound[15908:0] reply: 127.0.0.1 elephant.apricot-demo.nlnetlabs.nl. A IN
NXDOMAIN 0.363612 0 108
```

Privacy Threat Mitigation

- Data minimisation
  - Limit the number of DNS queries
  - Minimise the data disclosed in DNS transactions
- Security
  - → Hide transaction by using encryption
  - → Limit data disclosure to authenticated parties

DPRIVE

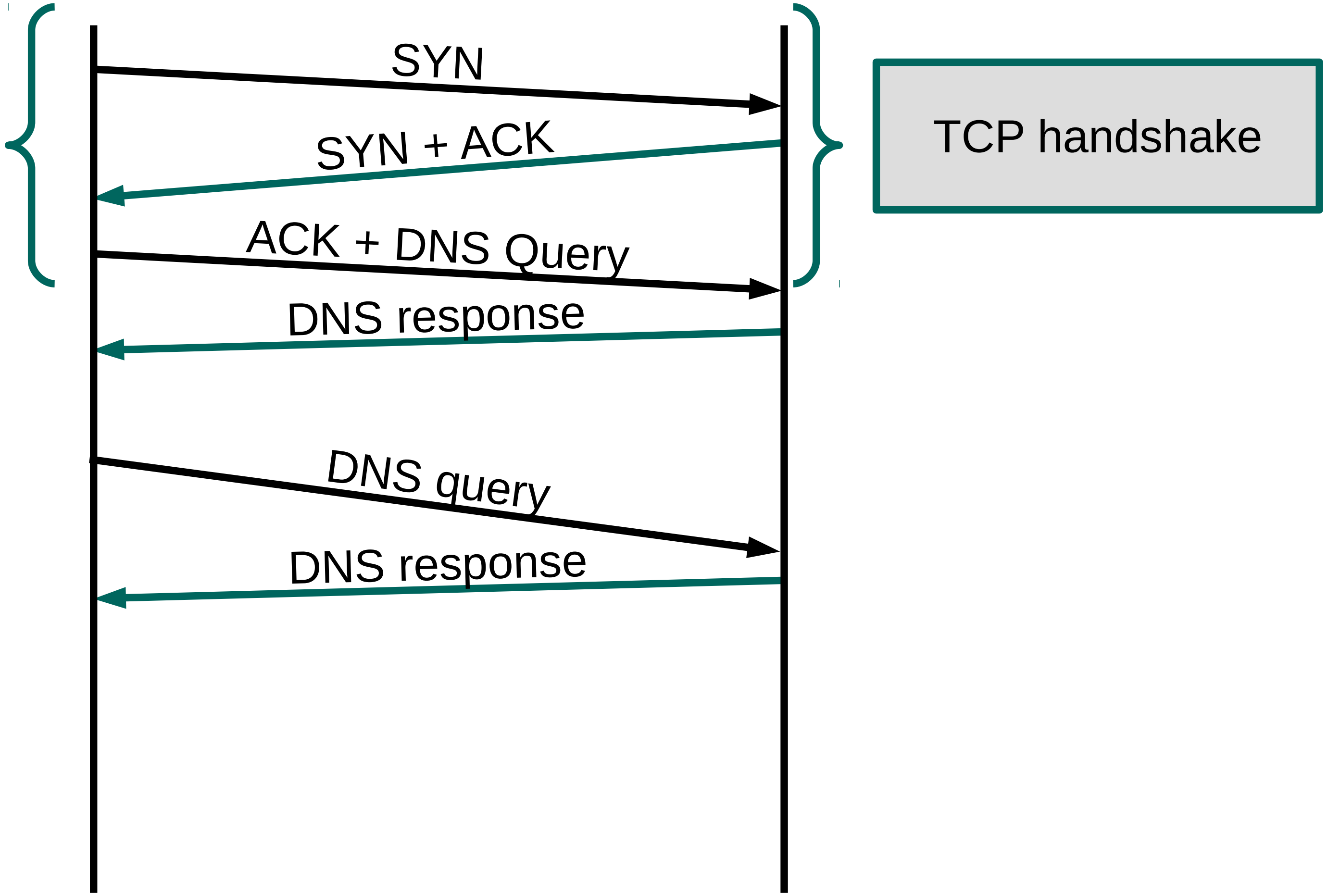
- DNS Privacy Considerations (RFC7626)
- Initial focus on stub –> resolver
- DNS-over-TLS
  - Needs TCP
  - Own port (853)

DNS over TCP

- Most DNS traffic currently UDP
- Changes are needed in DNS software to better handle the increased TCP load
- RFC7766
  - Query pipelining / out of order processing
  - Connection reuse
  - TCP fast open

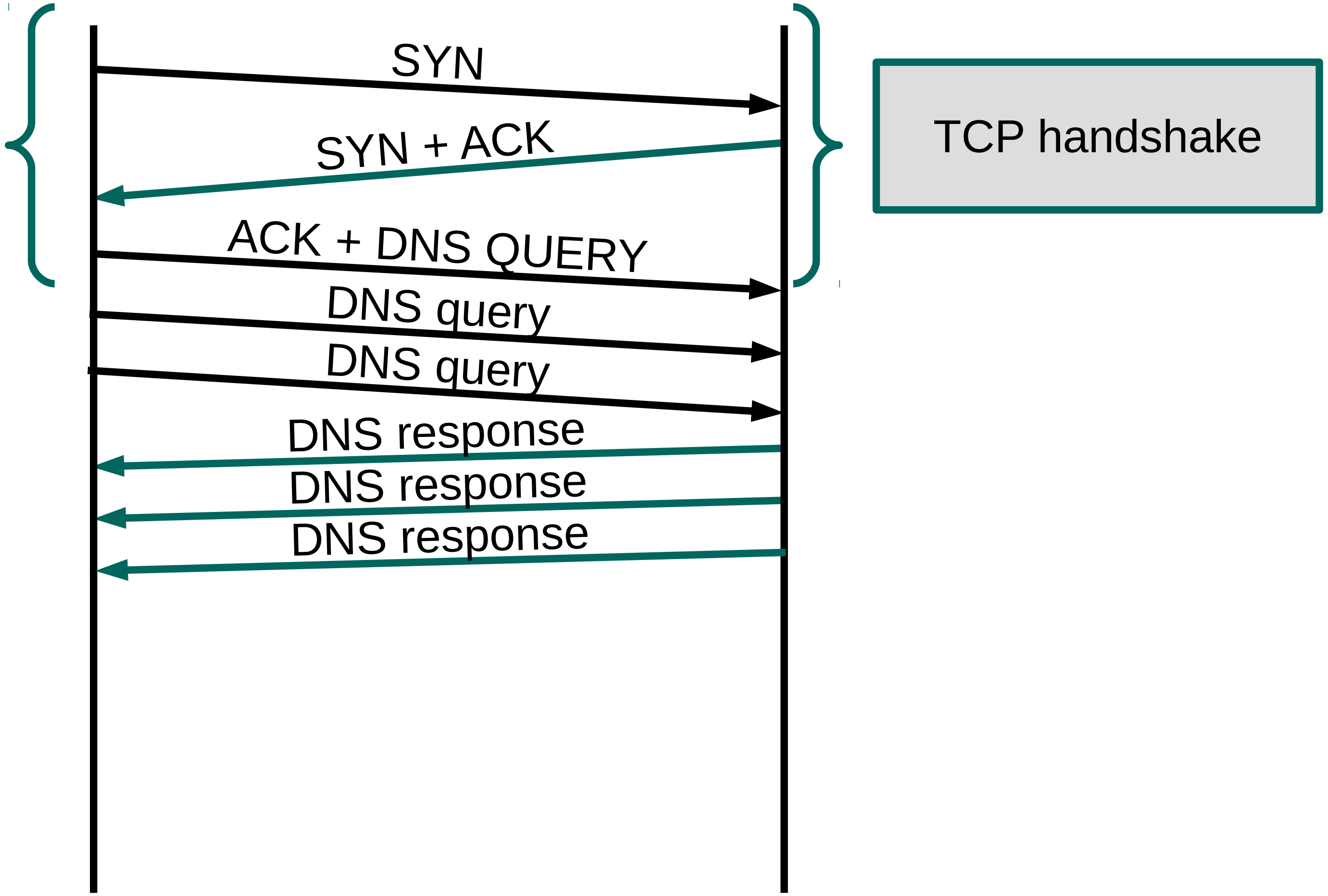
Connection reuse

- Limit the TCP connection setup latency

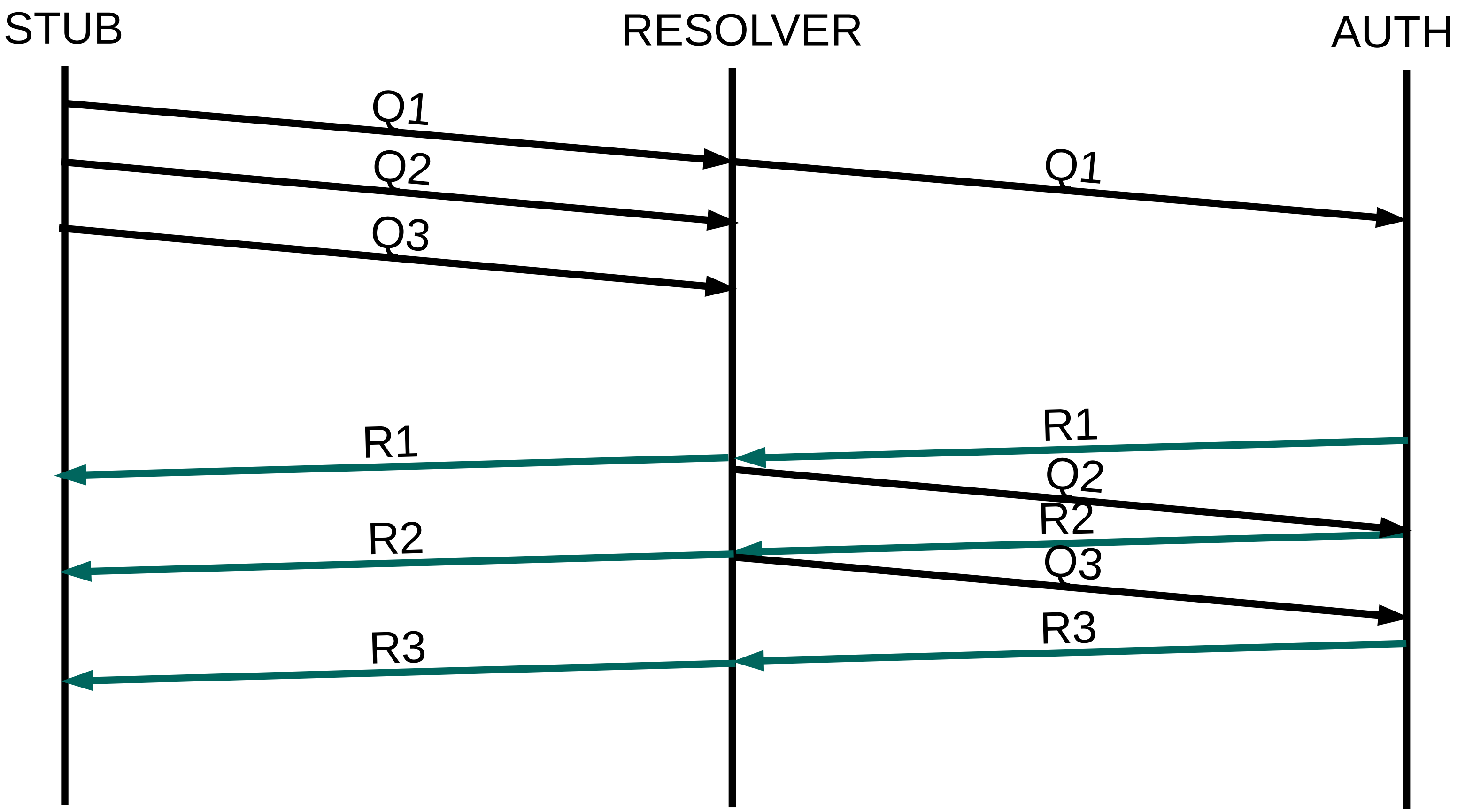


Query pipelining

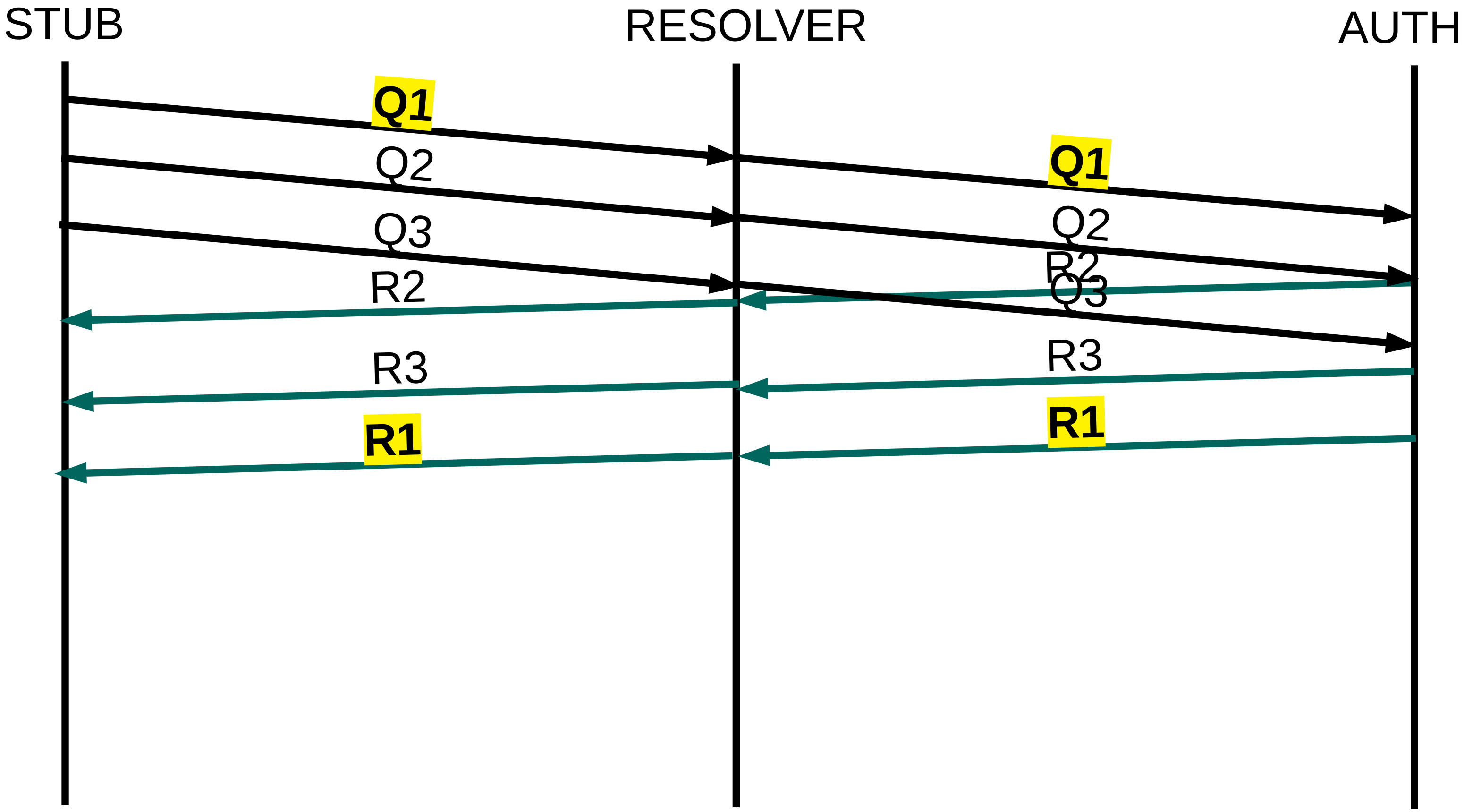
- Do not wait for a reply before sending the next query



In order processing



Out of order processing



Stubby: Connection reuse

- Connection reuse and query pipelining by default
- Keep idle TCP connections open:

```
idle_timeout: 10000
```

Unbound: Query pipelining / OOOP

- Downstream persistent connections in Unbound for many years
- Downstream out of order processing since Unbound 1.9.0
  - No configuration change needed
- Upstream connection reuse not **yet** in Unbound

Unbound – handling persistent client connections

- Number of incoming tcp connections:

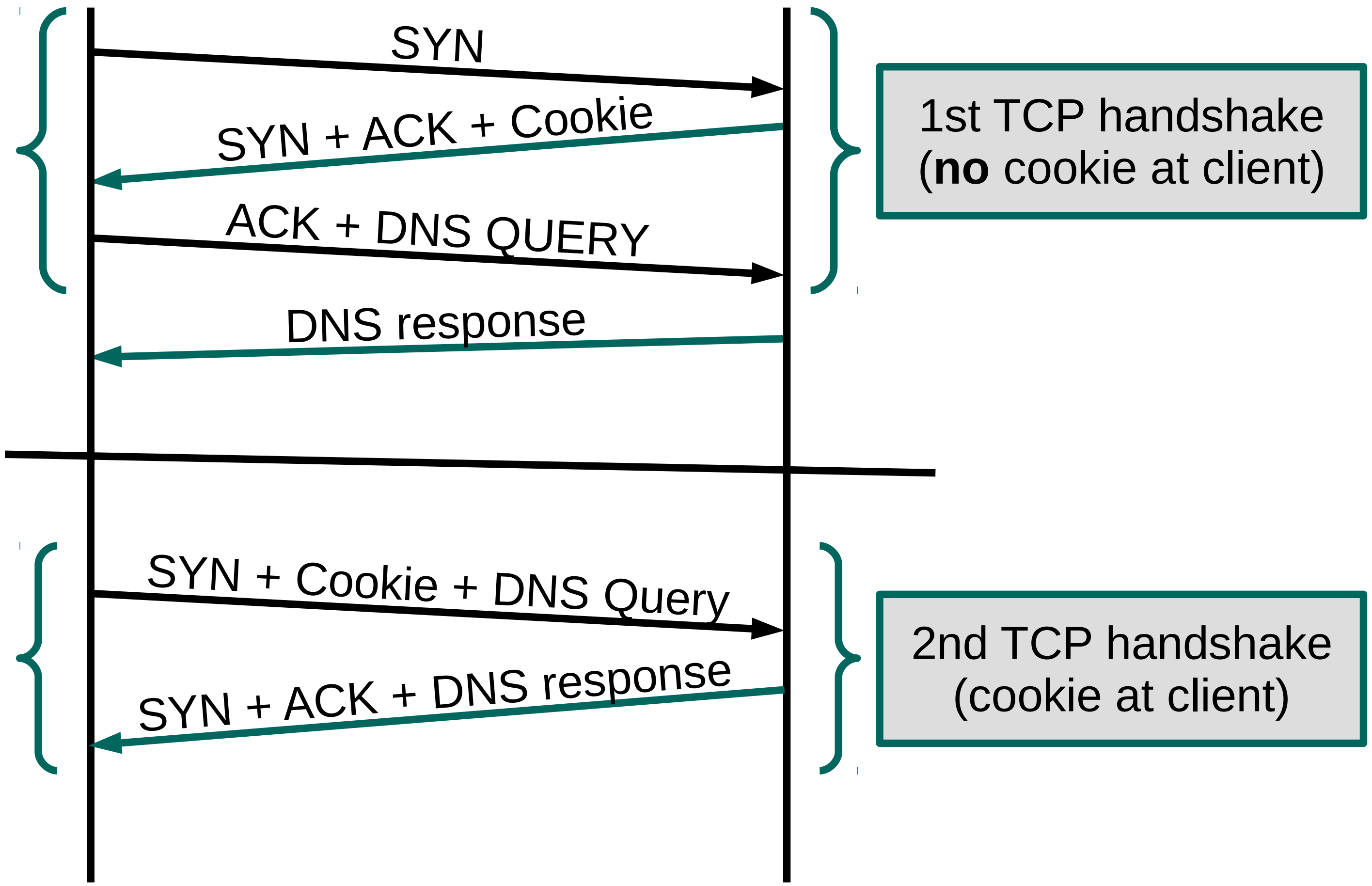
```
incoming-num-tcp: 128
```

- TCP idle timeout (in msec):

```
tcp-idle-timeout: 30000
```

TCP fast open

- Save one RTT by putting application data in SYN and SYN-ACK packets
  - Server-side generated security cookie to authenticate client



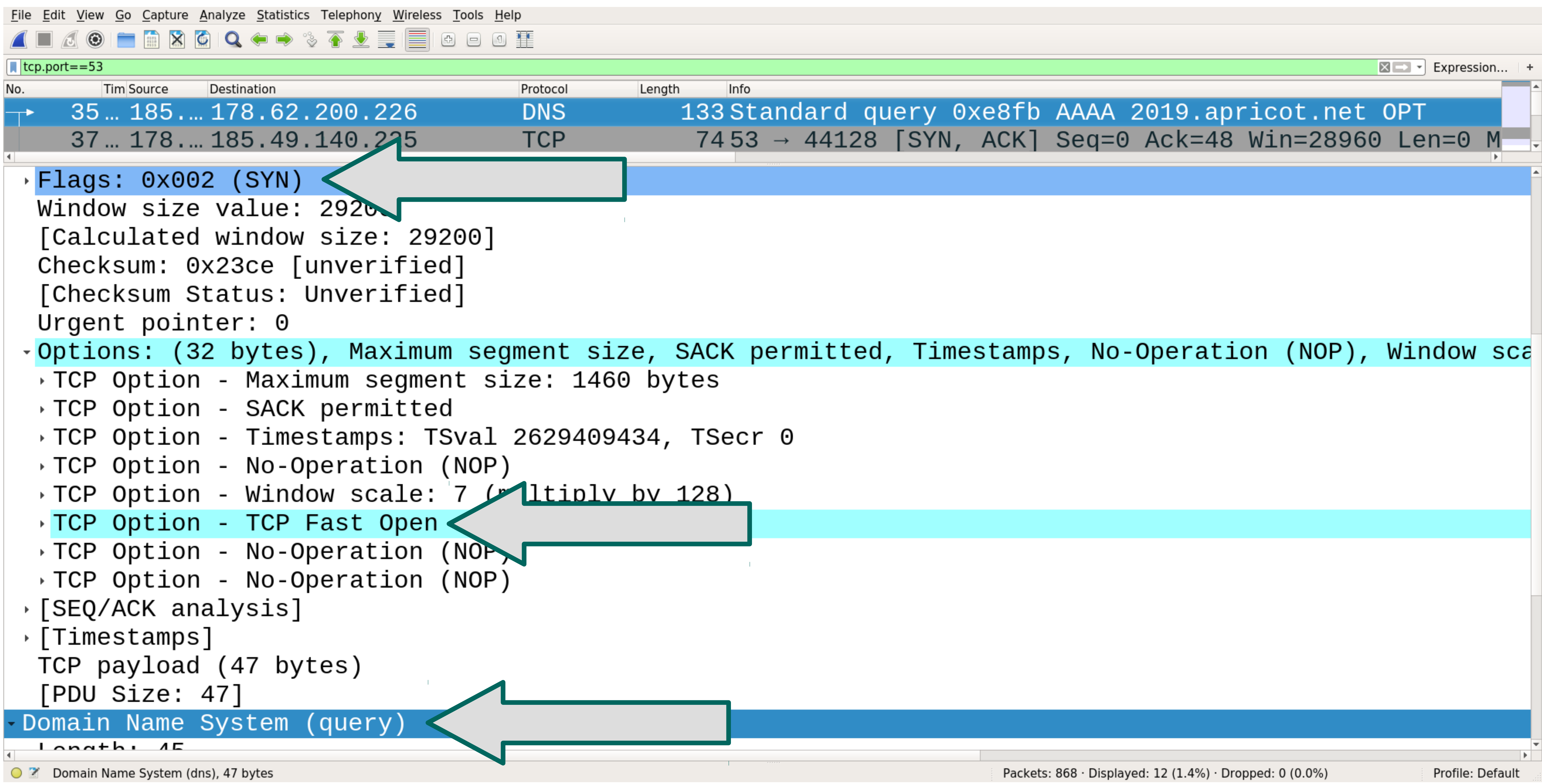
TCP fast open on OS

- Linux: net.ipv4.tcp_fastopen=N*
- OSX: net.inet.tcp.fastopen=N*
- FreeBSD: net.inet.tcp.fastopen.server_enabled=1

- * 1 = client, 2 = server, 3 = client+server

Unbound/getdns: TCP fast open

- Unbound
  - --enable-tfo-client
  - --enable-tfo-server
- getdns
  - Enabled by default if available


File Edit View Go Capture Analyze Statistics Telephony Wireless Tools Help
Expression…

```
tcp.port==53
```

```
No.   Tim Source  Destination       Protocol  Length  Info
35 …  185.…  178.62.200.226    DNS       133     Standard query 0xe8fb AAAA 2019.apricot.net OPT
37 …  178.…  185.49.140.225    TCP       74      53 → 44128 [SYN, ACK] Seq=0 Ack=48 Win=28960 Len=0 M
```

```
 ▸ Flags: 0x002 (SYN)
   Window size value: 29200
   [Calculated window size: 29200]
   Checksum: 0x23ce [unverified]
   [Checksum Status: Unverified]
   Urgent pointer: 0
 ▾ Options: (32 bytes), Maximum segment size, SACK permitted, Timestamps, No-Operation (NOP), Window sca
    ▸ TCP Option - Maximum segment size: 1460 bytes
    ▸ TCP Option - SACK permitted
    ▸ TCP Option - Timestamps: TSval 2629409434, TSecr 0
    ▸ TCP Option - No-Operation (NOP)
    ▸ TCP Option - Window scale: 7 (multiply by 128)
    ▸ TCP Option - TCP Fast Open
    ▸ TCP Option - No-Operation (NOP)
    ▸ TCP Option - No-Operation (NOP)
 ▸ [SEQ/ACK analysis]
 ▸ [Timestamps]
   TCP payload (47 bytes)
   [PDU Size: 47]
▾ Domain Name System (query)
   Length: 45
```

Domain Name System (dns), 47 bytes

Packets: 868 · Displayed: 12 (1.4%) · Dropped: 0 (0.0%)

Profile: Default

https://www.nlnetlabs.nl/

NLNETLABS

TLS recap

- Provides secure application layer communication channel
  - Encryption of data
  - Authentication of server
- Identification using digital certificate
  - Containing public key which is used to generate session key
- Dedicated port or connection upgrade using STARTTLS

DNS-over-TLS

- Uses dedicated port: 853
- Strict privacy vs opportunistic privacy (RFC8310)
  - Mitigate against passive or active attacks
- Authentication
  - Authentication domain name or SPKI pin set needed at client
  - Trusted CA bundle or TLSA record may be needed at client
    - Chicken/egg problem for TLSA: solution DNSSEC chain extension

Setup DNS-over-TLS server

- Generate key and certificate
  - Self signed

    ```
    openssl req -newkey rsa:2048 -nodes -keyout privkey.pem -x509 -days 365 -out certificate.pem
    ```

  - CA (letsencrypt) signed

    ```
    ./certbot-auto certonly --standalone -d albatross.apricot-demo.nlnetlabs.nl
    ```

Unbound: DNS-over-TLS server

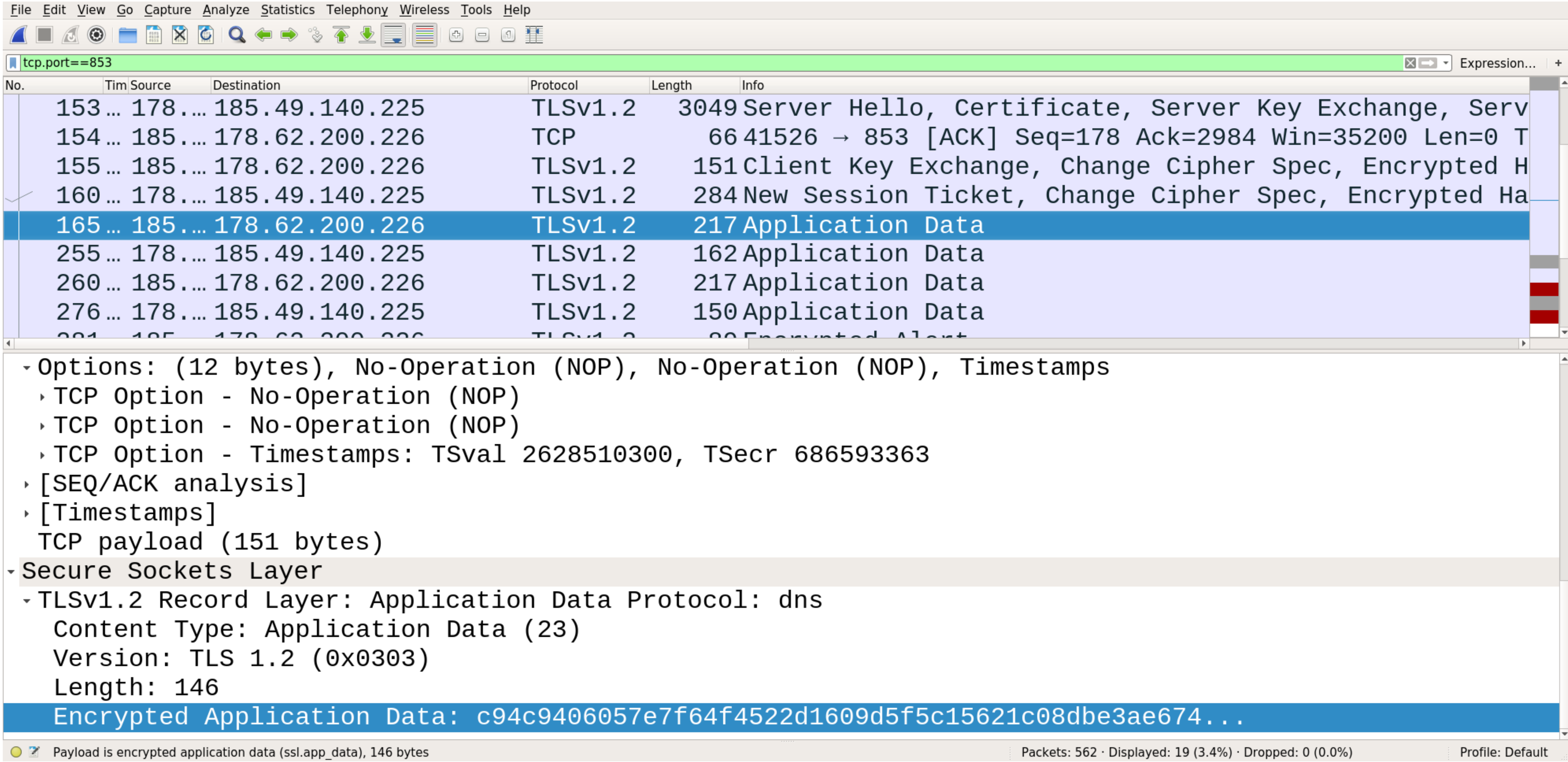
- TLS for client

```
server:
	interface: 0.0.0.0@853
	interface: ::0@853
	tls-service-key: "/etc/letsencrypt/live/albatross.apricot-demo.nlnetlabs.nl/privkey.pem"
	tls-service-pem: "/etc/letsencrypt/live/albatross.apricot-demo.nlnetlabs.nl/fullchain.pem"

	do-udp: no
	udp-upstream-without-downstream: yes
```

getdns_query

- Test our DoT resolver using getdns_query:

```
getdns_query -L -m @178.62.200.226~albatross.apricot-demo.nlnetlabs.nl 2019.apricot.net
```


File Edit View Go Capture Analyze Statistics Telephony Wireless Tools Help
Expression…
+

tcp.port==853

```
No.   Tim Source Destination      Protocol  Length Info
153 … 178.…  185.49.140.225   TLSv1.2   3049 Server Hello, Certificate, Server Key Exchange, Serv
154 … 185.…  178.62.200.226   TCP         66 41526 → 853 [ACK] Seq=178 Ack=2984 Win=35200 Len=0 T
155 … 185.…  178.62.200.226   TLSv1.2    151 Client Key Exchange, Change Cipher Spec, Encrypted H
160 … 178.…  185.49.140.225   TLSv1.2    284 New Session Ticket, Change Cipher Spec, Encrypted Ha
165 … 185.…  178.62.200.226   TLSv1.2    217 Application Data
255 … 178.…  185.49.140.225   TLSv1.2    162 Application Data
260 … 185.…  178.62.200.226   TLSv1.2    217 Application Data
276 … 178.…  185.49.140.225   TLSv1.2    150 Application Data
281 … 185.…  178.62.200.226   TLSv1.2     89 Encrypted Alert
```

```
 ▾ Options: (12 bytes), No-Operation (NOP), No-Operation (NOP), Timestamps
   ▸ TCP Option - No-Operation (NOP)
   ▸ TCP Option - No-Operation (NOP)
   ▸ TCP Option - Timestamps: TSval 2628510300, TSecr 686593363
 ▸ [SEQ/ACK analysis]
 ▸ [Timestamps]
   TCP payload (151 bytes)
▾ Secure Sockets Layer
 ▾ TLSv1.2 Record Layer: Application Data Protocol: dns
    Content Type: Application Data (23)
    Version: TLS 1.2 (0x0303)
    Length: 146
    Encrypted Application Data: c94c9406057e7f64f4522d1609d5f5c15621c08dbe3ae674...
```

Payload is encrypted application data (ssl.app_data), 146 bytes

Packets: 562 · Displayed: 19 (3.4%) · Dropped: 0 (0.0%)

Profile: Default

Stubby DNS-over-TLS

- Opportunistic privacy by default
- Configure strict privacy with CA authentication:

```
dns_transport_list:
  - GETDNS_TRANSPORT_TLS
tls_authentication: GETDNS_AUTHENTICATION_REQUIRED
tls_ca_path: "/etc/ssl/certs/"
upstream_recursive_servers:
  - address_data: 178.62.200.226
    tls_auth_name: "albatross.apricot-demo.nlnetlabs.nl"
```

Get SPKI pin set

- Get SPKI pinset (Base64 encoded sha256 hash of public key fingerprint):

```
openssl s_client -connect 178.62.200.226:853 -servername albatross.apricot-demo.nlnetlabs.nl 1>&/dev/null |
openssl x509 -pubkey -noout | openssl pkey -pubin -outform der | openssl dgst -sha256 -binary |
openssl enc -base64
```

Stubby – SPKI pin set authentication

- No ca_path required for SPKI pin set authentication
- Configure strict SPKI authentication in stubby:

```
dns_transport_list:
  - GETDNS_TRANSPORT_TLS
tls_authentication: GETDNS_AUTHENTICATION_REQUIRED
upstream_recursive_servers:
  - address_data: 178.62.200.226
    tls_auth_name: "albatross.apricot-demo.nlnetlabs.nl"
    tls_pubkey_pinset:
      - digest: "sha256"
        value: aZgr7RhoLDAvug16/FeebD02E2s5+Y5LJKG1jcBVNCA=
```

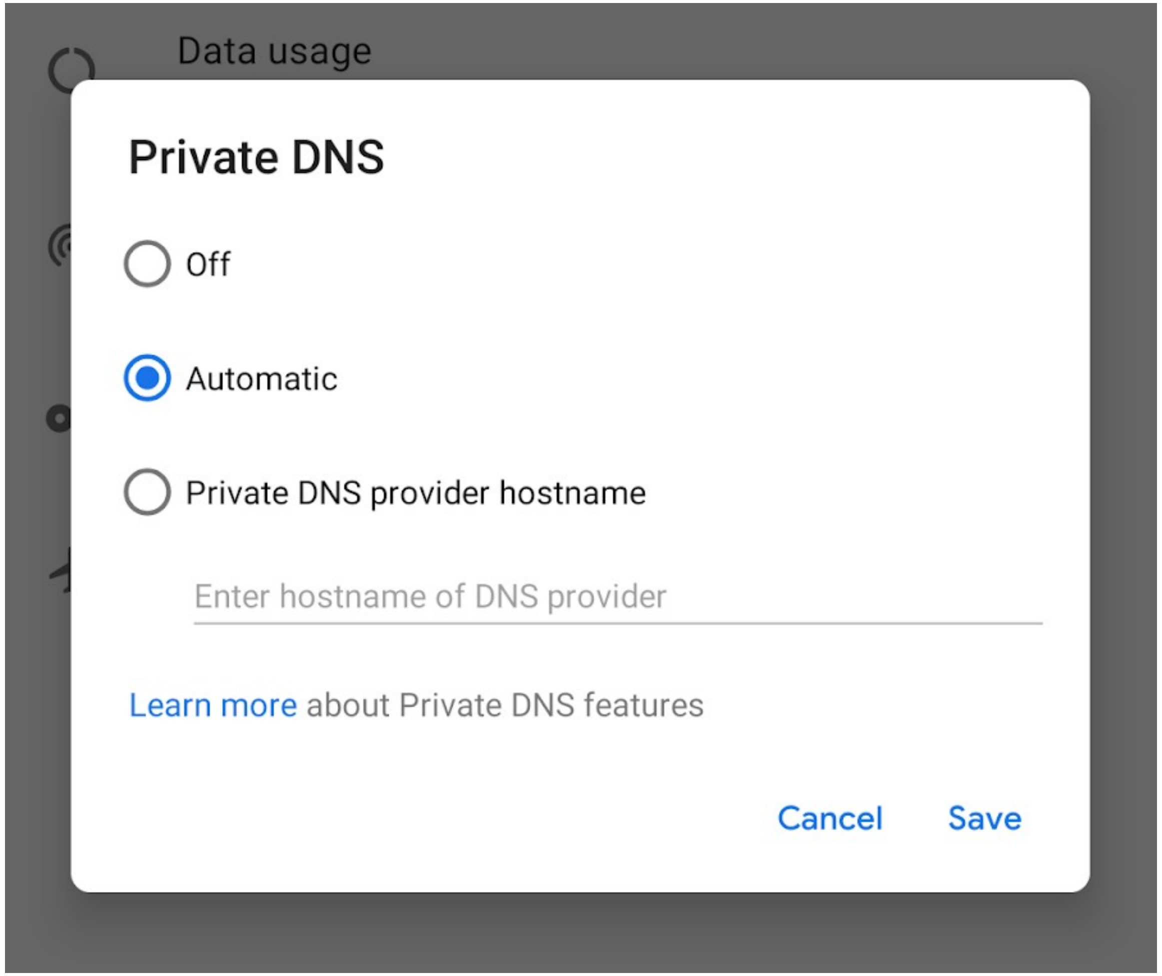
Unbound: DNS-over-TLS client

- Forward all data to DoT resolver using Unbound

```
server:
	tls-cert-bundle: "/etc/ssl/certs/ca-certificates.crt"

forward-zone:
	name: "."
	forward-tls-upstream: yes
	forward-addr: 178.62.200.226@853#albatross.apricot-demo.nlnetlabs.nl
```

Android Pie

- Opportunistic DoT by default
  - Probing queries to port 853 to detect DoT support
- Strict privacy possible after providing authentication domain name
  - Device's CA store used to authenticate the certificate



Data usage

Private DNS

○ Off

● Automatic

○ Private DNS provider hostname

Enter hostname of DNS provider

Learn more about Private DNS features

Image from: android-developers.googleblog.com

DNS-over-TLS server monitoring

- Monitor for certificate expiration!
    - It’s just TLS, existing TLS monitoring tools should work
    - View certificate (including expiration date):

```
openssl s_client -connect 178.62.200.226:853 -servername albatross.apricot-demo.nlnetlabs.nl |
 openssl x509 -noout -text
```

Cert renewal

- You **might** want to reuse the private key (when using public key for authentication), in that case:
  - Generate certificate signing request using existing key

```
openssl req -key privkey.pem -new -out request.csr
```

  - Get self signed certificate using CSR

```
openssl x509 -req -days 365 -in request.csr -signkey privkey.pem -out certificate.pem
```

  - , or get Let’s encrypt certificate using CSR

```
./certbot-auto certonly --standalone -d albatross.apricot-demo.nlnetlabs.nl --csr request.csr
```

DNS-over-HTTPS

- DNS payload wrapped in HTTP transactions
- HTTP 2 with TLS
- Port 443, hides DNS transactions

DoT vs DoH

- DNS-over-HTTP
  - Easier for browser apps
  - Hides DNS traffic in regular HTTP traffic
  - Mature transport ecosystem
- DNS-over-TLS
  - DNS as we know it

Trusted Recursive Resolver

- List of DoH resolvers in browser
- Used instead of configured system resolver
  - Bypass local policies
- Guaranteed to work, no middleboxes hampering lookups
- Privacy impact depends on used resolver

Privacy at the resolver

- Be aware of information logged on your machines
  - Limit privacy sensitive data in your logs
    - Do you really need to store the client addresses?
  - Limit data to personnel who need it for operational purposes
  - Store data for shortest operationally feasible period
  - Consider encrypting and/or anonymising the data

Encryption resolver → auth

- DPRIVE rechartered in May 2018
- Security between resolver and authoritative is next
- Need to authenticate many servers, manual configuration is not going to work here
    - Magic NS names to detect SPKI fingerprint (DNSCurve style)
    - TLSA at _853._tcp.ns.example.net
    - ..?

“best” set-up

- Multiple scenarios possible
  - Local resolver
  - Public resolver
  - Local with forwarding to public
    - Randomise forwards selection, or not?

Questions?

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