DNS Cache-Poisoning: New Vulnerabilities and Implications, or: DNSSEC, the time has come!

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About us

Bar Ilan University
NetSec group

Haya Shulman:

Fresh Graduate
PhD Thesis:
DNS Security
(and more...)

Amir Herzberg:

NetSec/Crypto
Researcher
Attacks: DNS,
TCP/IP, DoS, …

2013… DNSSEC, IPSEC:15yrs old
Yet: < 6% of traffic encrypted,…
→ Insecure against MitM attacker

WHY???

False hope: attackers are `off-path`

Can send spoofed packets but not intercept

Reality: MitM attackers are common

Open WiFi, **route hijacking**, mal-devices, **DNS poisoning**

False belief: DNS, TCP immune to off-path attacks

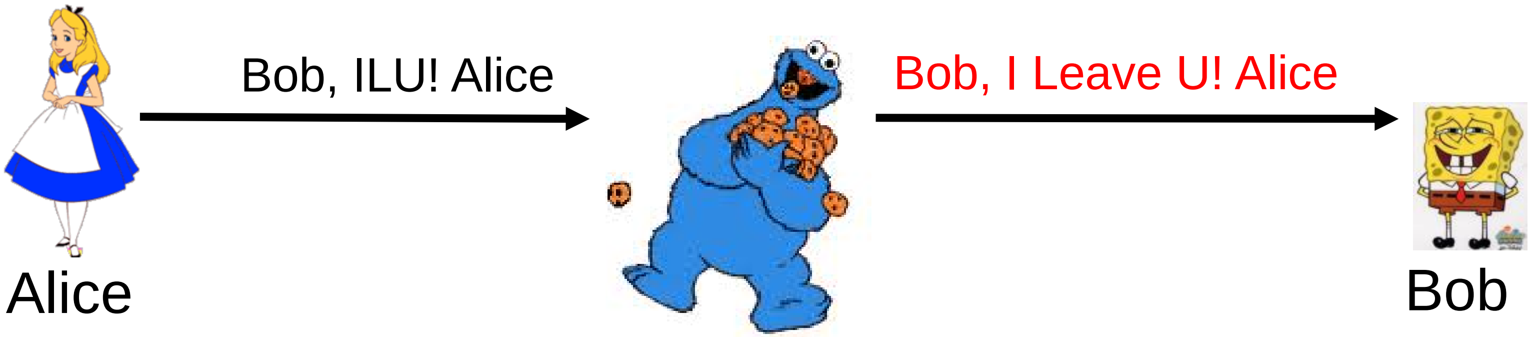
Reality: TCP hijacking, **DNS poisoning**

Outline

- **Attack model: MitM vs. Off-path**
- DNS poisoning: Background
- **Source-port de-randomization** attacks
  - Resolver-behind-NAT, proxy-using-upstream
- **1st-fragment piggybacking** attacks
- Implications and defenses
  - Patches: to resolvers, name-servers, registrars
  - Deploy DNSSEC – correctly… [and fix it, too??]

Attacker Model: MitM or Off-Path?

- **Man-in-the-Middle** attacker
  - On path
    - Harder but possible: wifi, route hijack, vulnerable router, …
    - Or: give wrong address – **DNS poisoning**
  - Prevent with **crypto**: overhead, complexity, PKI …
    - Why bother?



Bob, ILU! Alice

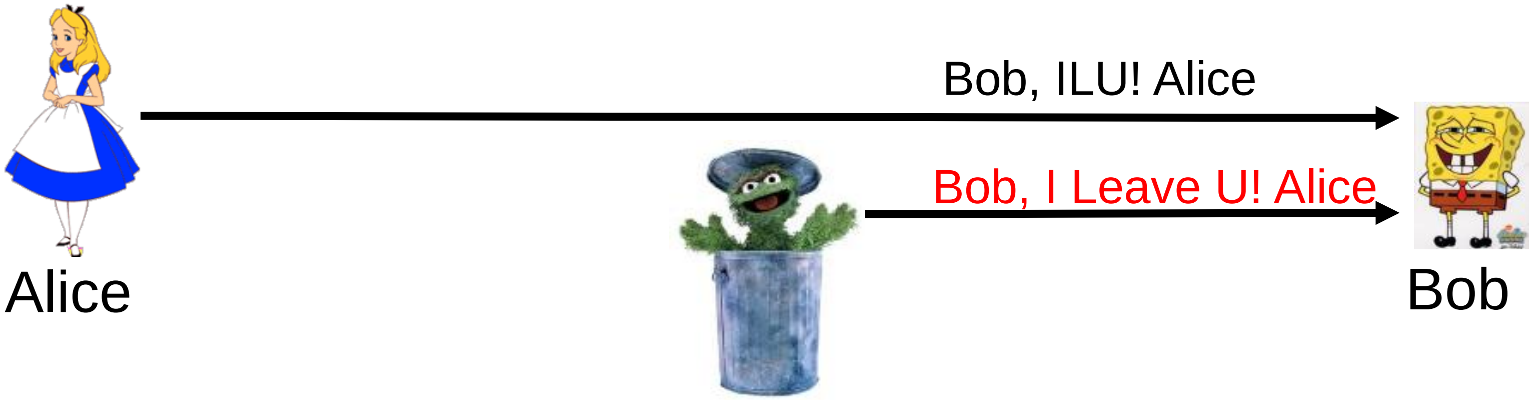
Bob, I Leave U! Alice

Alice

Bob

Attacker Model: MitM or Off-Path?

- Folklore: most attackers are weak, off-path
- `Security' is often against **Off-Path Oscar**
  - Do not control devices en-route
    - Cannot intercept/modify/block traffic
  - **Prevent: with challenge-response (`cookie`)**



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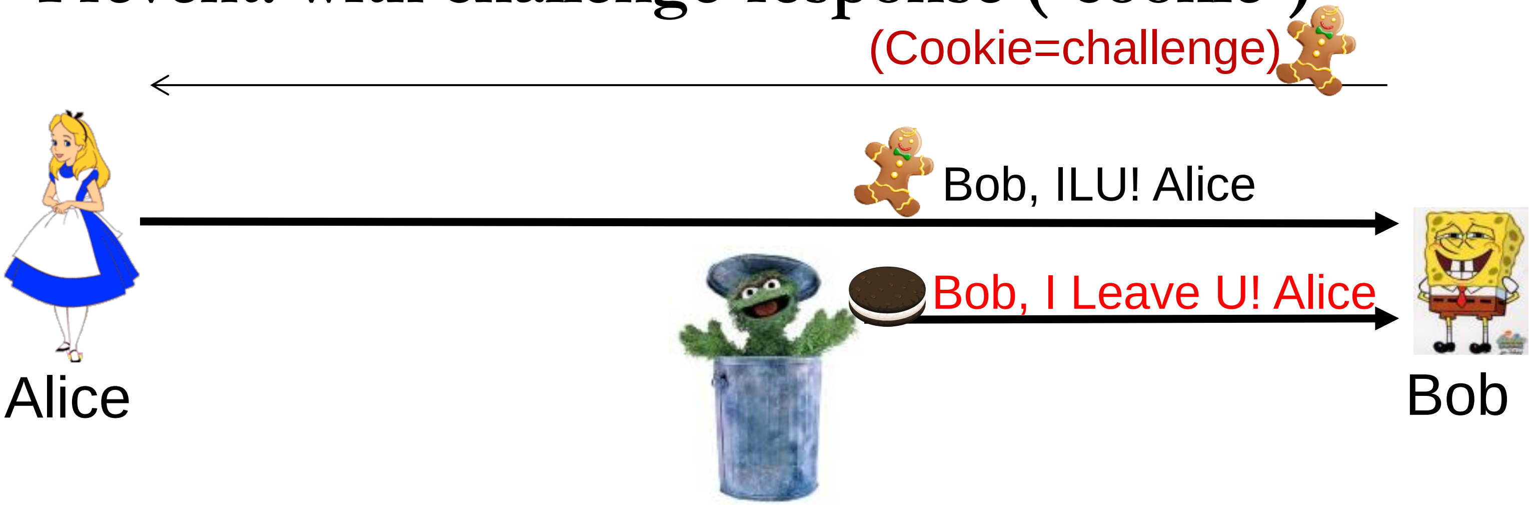

Challenge-Response: **What Can Go Wrong?**

- Attacker **has** MitM capabilities
- **Insufficient entropy**: too short or non-uniform
  - TCP [Zalewski01, Watson04]
  - DNS [Klein03, Kaminsky08]
- Side-channel: reused field (source port)
  - DNS [HS12, HS13], TCP [GH12, GH13, QM(X)12]
- Cut-&-paste: use real cookie in spoofed packet
  - DNS [HS13]

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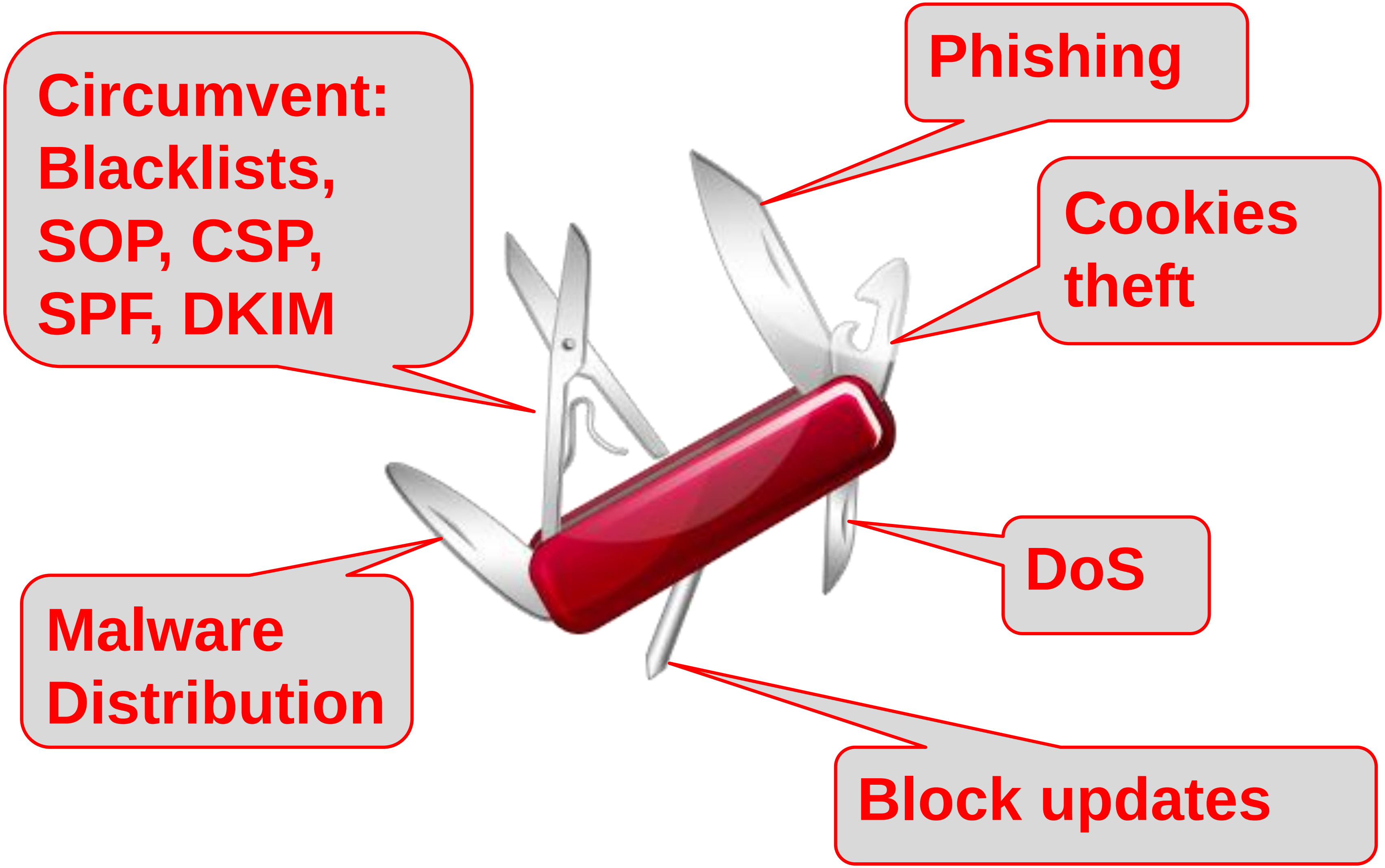
DNS Poisoning: the Hacker's Knife



Circumvent: Blacklists, SOP, CSP, SPF, DKIM

Phishing

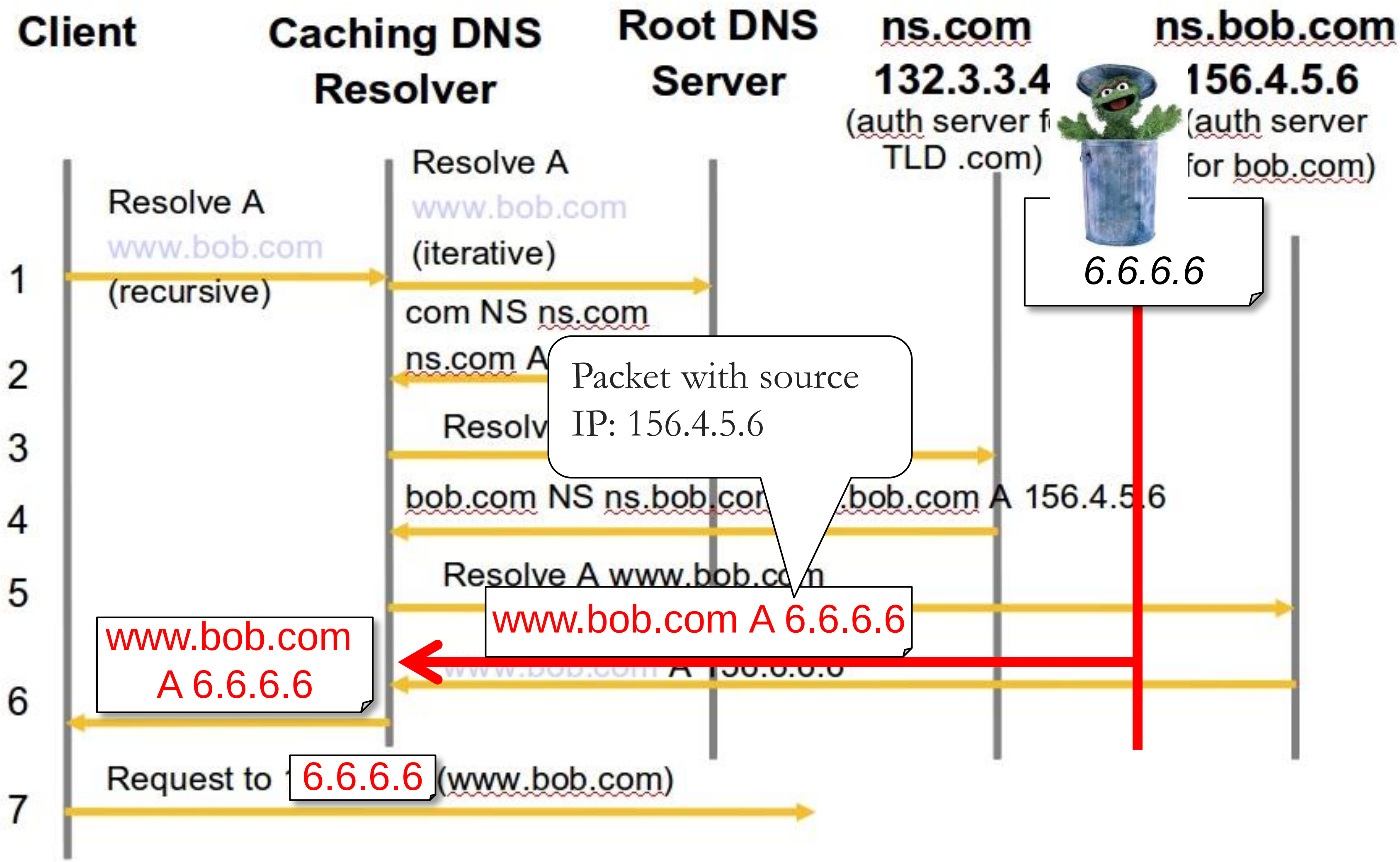
Cookies theft

DoS

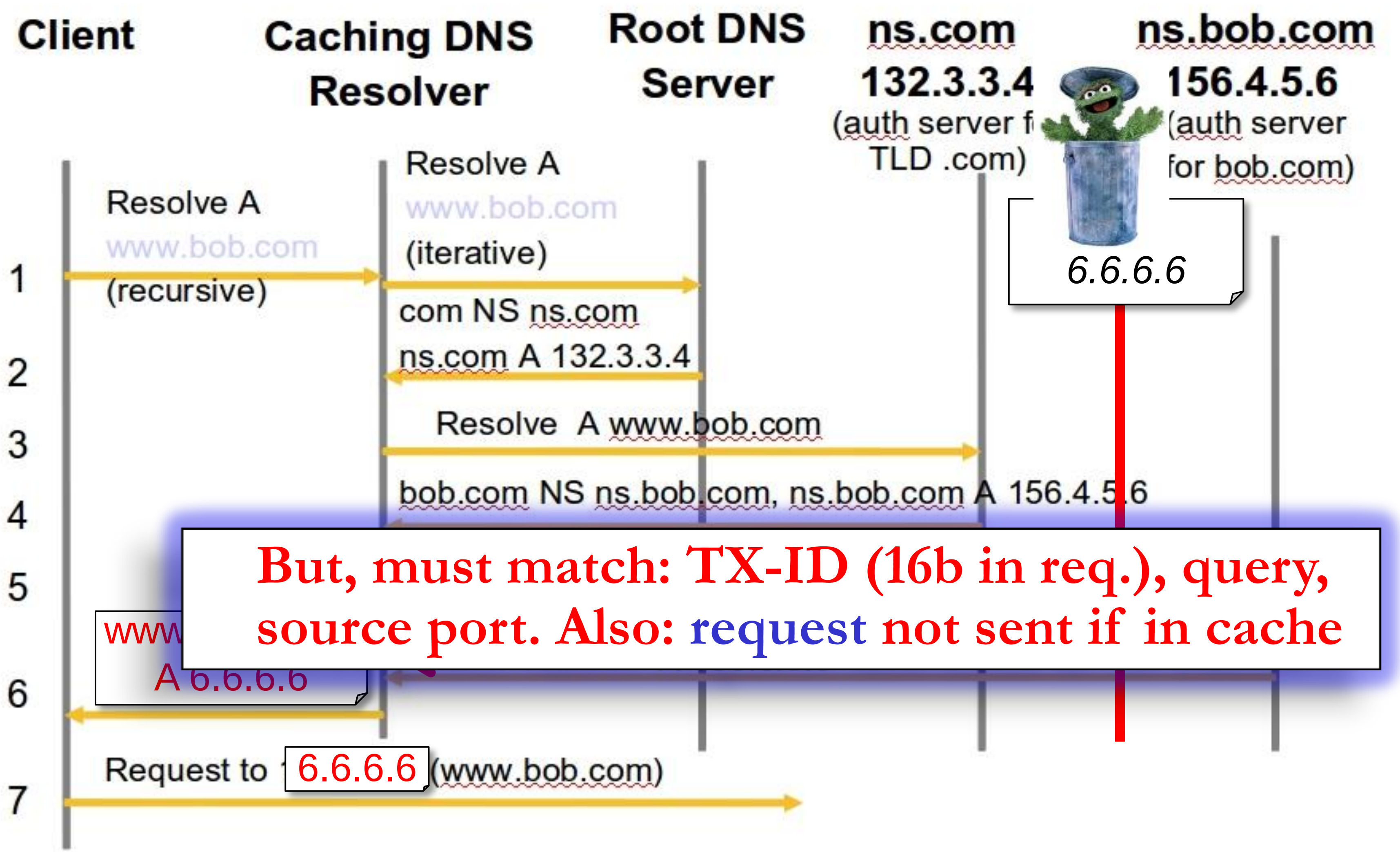
Malware Distribution

Block updates

DNS Cache Poisoning



DNS Cache Poisoning



Client

Caching DNS Resolver

Root DNS Server

ns.com 132.3.3.4 (auth server f TLD .com)

ns.bob.com 156.4.5.6 (auth server for bob.com)

6.6.6.6

1 Resolve A www.bob.com (recursive)

Resolve A www.bob.com (iterative)

2 com NS ns.com ns.com A 132.3.3.4

3 Resolve A www.bob.com

4 bob.com NS ns.bob.com, ns.bob.com A 156.4.5.6

5

6 www A 6.6.6.6

7 Request to 6.6.6.6 (www.bob.com)

But, must match: TX-ID (16b in req.), query, source port. Also: request not sent if in cache

Defenses against DNS Poisoning

- **Currently**, mostly Challenge-response defenses:
  - Unilateral (in resolver): `challenges' using existing request fields echoed in responses
  - TX-ID (16b), Source port (16b), Query [0x20]
- Cryptographic defenses (**DNSSEC**): limited use
  - Root and many TLDs signed
  - Many resolvers request signatures, but few **validate**
  - **Why?** Myths (rare MitM, weak Oscar)

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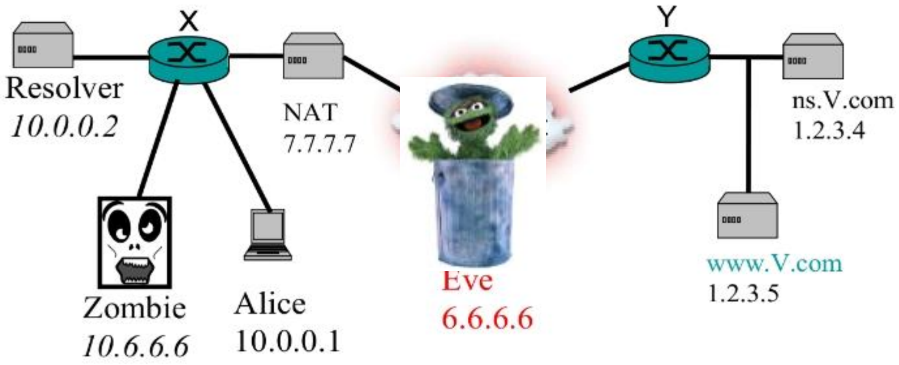
Source Port De-Randomisation Attacks

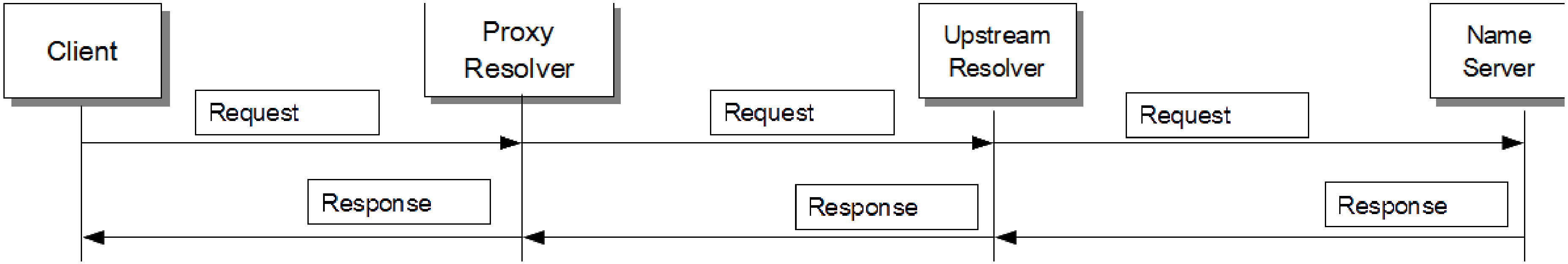
- **Learn source-port via side channel**
- Attacks on two common configurations:
  - Resolver-behind-NAT [Esorics'12]
    - Attacks for most types of NATs (only one was secure)
  - Upstream resolver (e.g., OpenDNS) [Esorics'13]
    - Learn resolver's IP address, too [often enough for DoS !]

Resolver-behind-NAT: Attack

- Example: attack on **per-dest incrementing** (e.g., Linux)
- Initial port is random; can attacker predict/trap port?
- Attack phases:
  - Hole-punch the NAT
  - Exploit assigned mapping to guess port
- Variations apply to different NAT devices

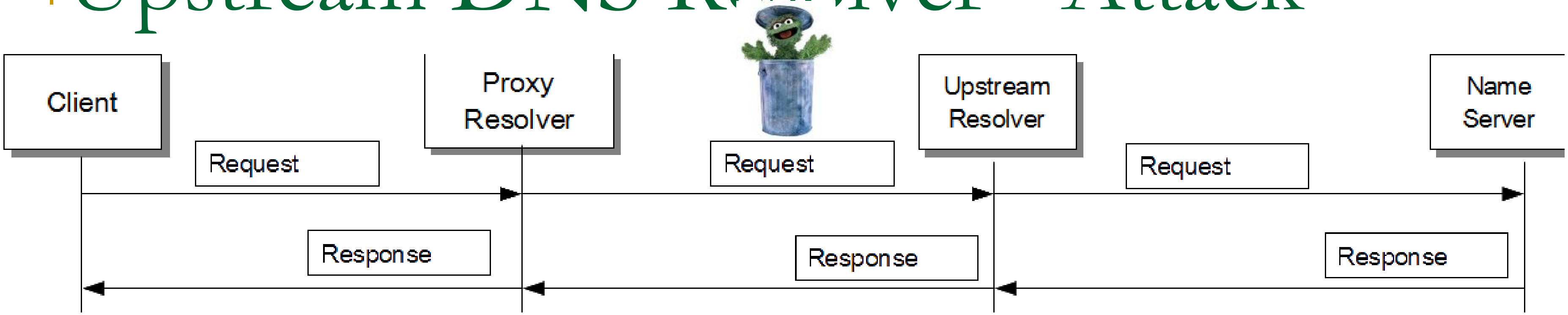


Upstream DNS Resolver



- Upstream DNS resolvers:
- Popular: Google's public-DNS, OpenDNS, many others
- Recommended by experts, vendors
  - E.g., Akamai: 'Customer's primary DNS are not directly exposed to end users, so the risk of cache poisoning and DoS attacks is mitigated'…
- Proxy resolvers often has lower bandwidth, weaker security
  - We found (CAIDA): 54% incrementing ports, 30% fixed port
  - And… both types are vulnerable!

Upstream DNS Resolver - Attack



- Poisoning attack in three phases
- Phase 1: find proxy’s IP address
  - Many requests with fragmented response… `kill` with spoofed frag
  - Suffices for DoS attack on proxy!
- Phase 2: find fixed/current port #
  - By a more complex frag attack, or by `port overloading’
- Phase 3: `regular’ (`Kaminsky’) poisoning

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1st-**fragment piggybacking** attacks

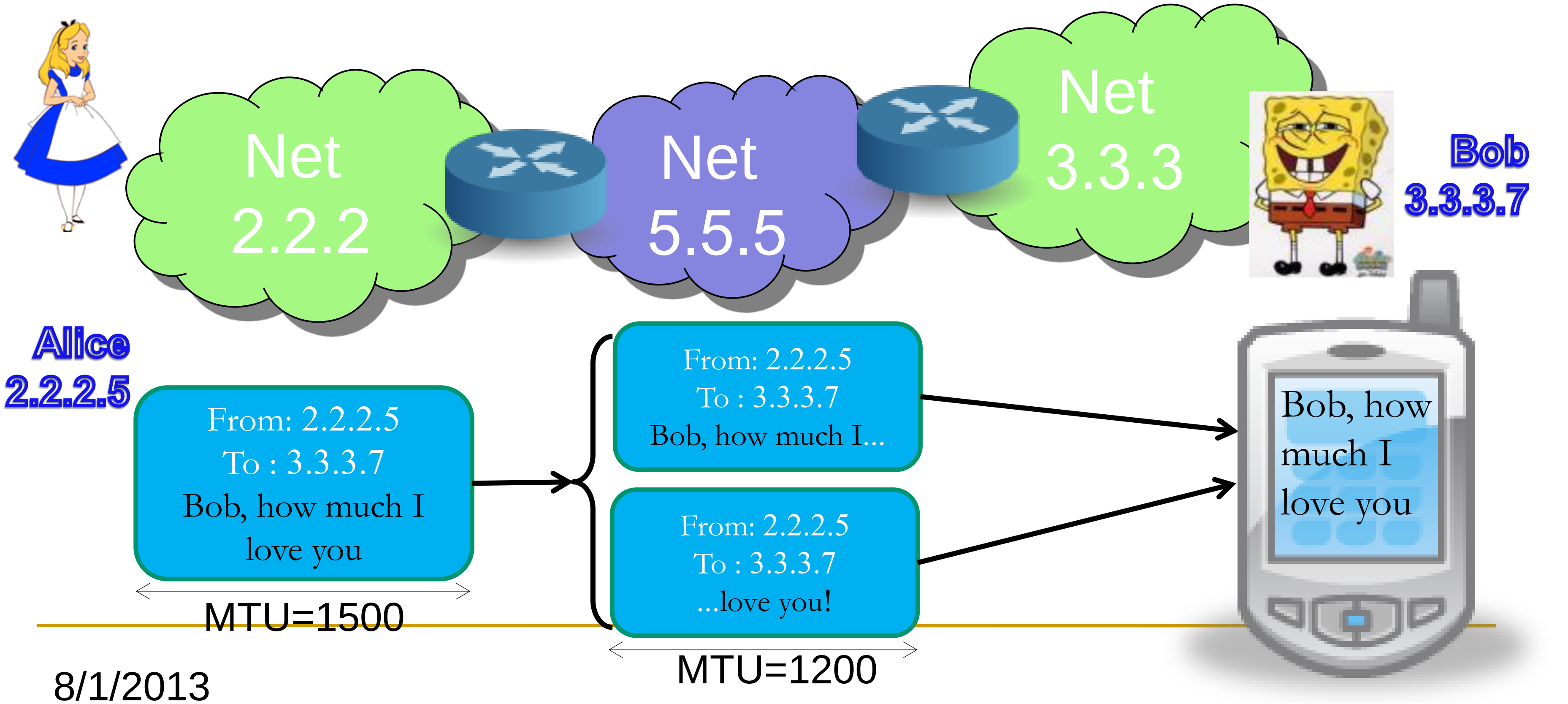
- Cut'n'Paste attack:
- Poison a long, **fragmented** DNS response
  - Source fragmentation will do [works even for IPv6]
- **All `challenges' are in the first fragment!**
  - **TXID, "src" port, even query [e.g., 0x20 defense]**
- Replace 2nd fragment with a fake one!
- Few details and quick recap on IP fragmentation

IP Fragmentation

Nets have a limit on maximal packet size

If the packet is larger than the limit: fragmentation

Reassemble at the receiver



From: 2.2.2.5
To : 3.3.3.7
Bob, how much I
love you

From: 2.2.2.5
To : 3.3.3.7
Bob, how much I…

From: 2.2.2.5
To : 3.3.3.7
…love you!

Bob, how
much I
love you

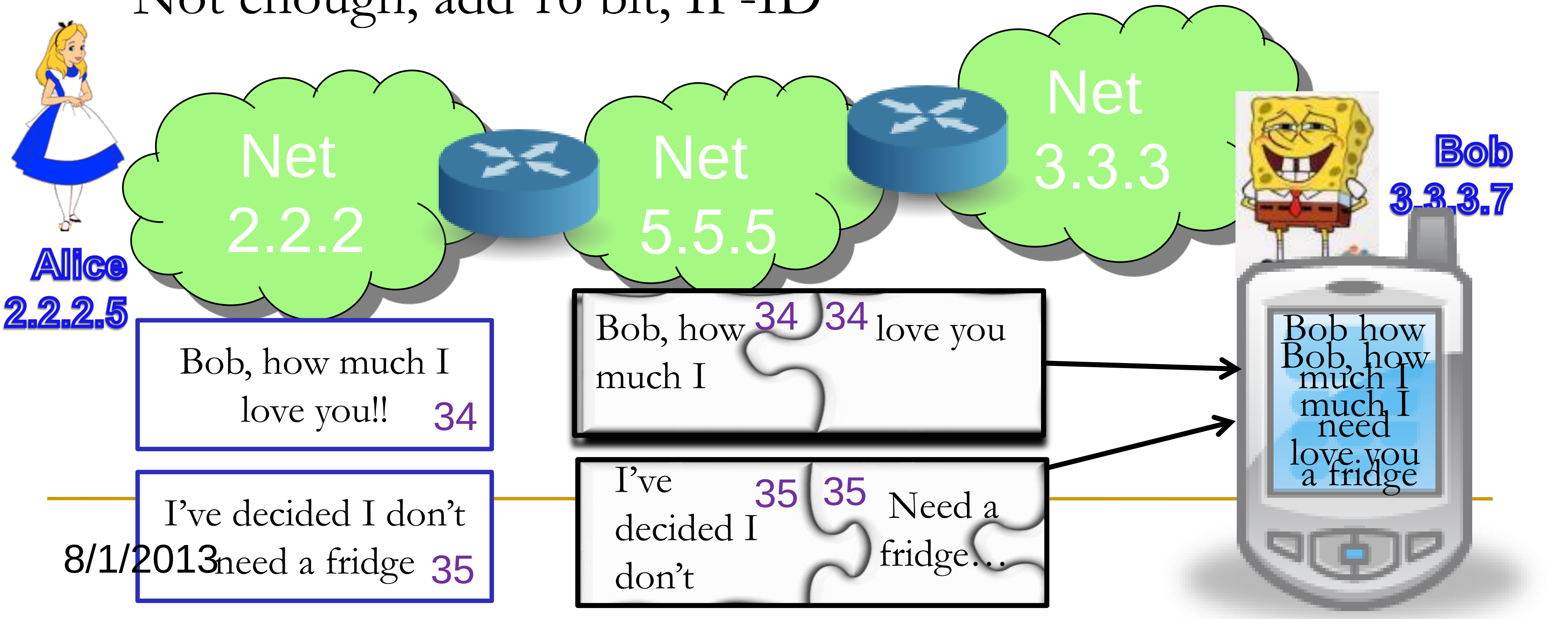
Fragment Reassembly

Bob receives fragments of a packet

How to reassemble without introducing mistakes

Identify fragments of the same packet

- By sender/receiver addresses and protocol (TCP/UDP)
- Not enough, add 16 bit, IP-ID



Bob, how much I love you!! 34

I've decided I don't need a fridge 35

Bob, how much I 34 | 34 love you

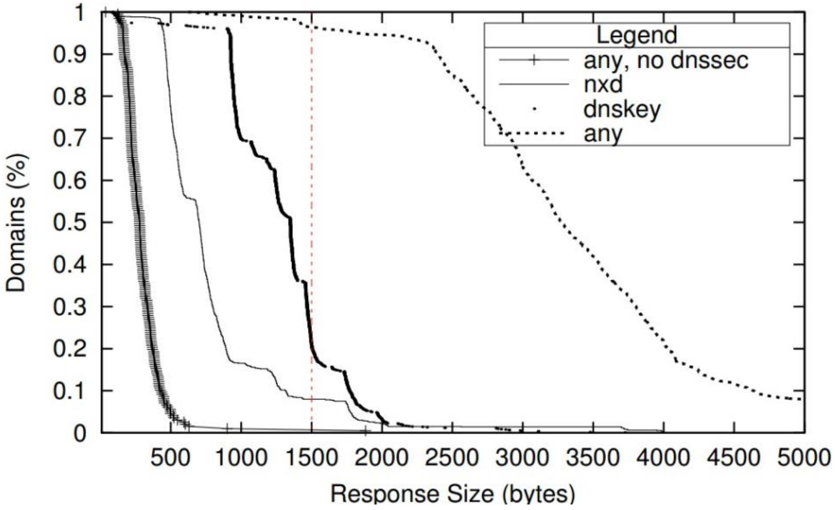
I've decided I don't 35 | 35 Need a fridge…

Bob how
Bob, how
much I
much I
need
love you
a fridge

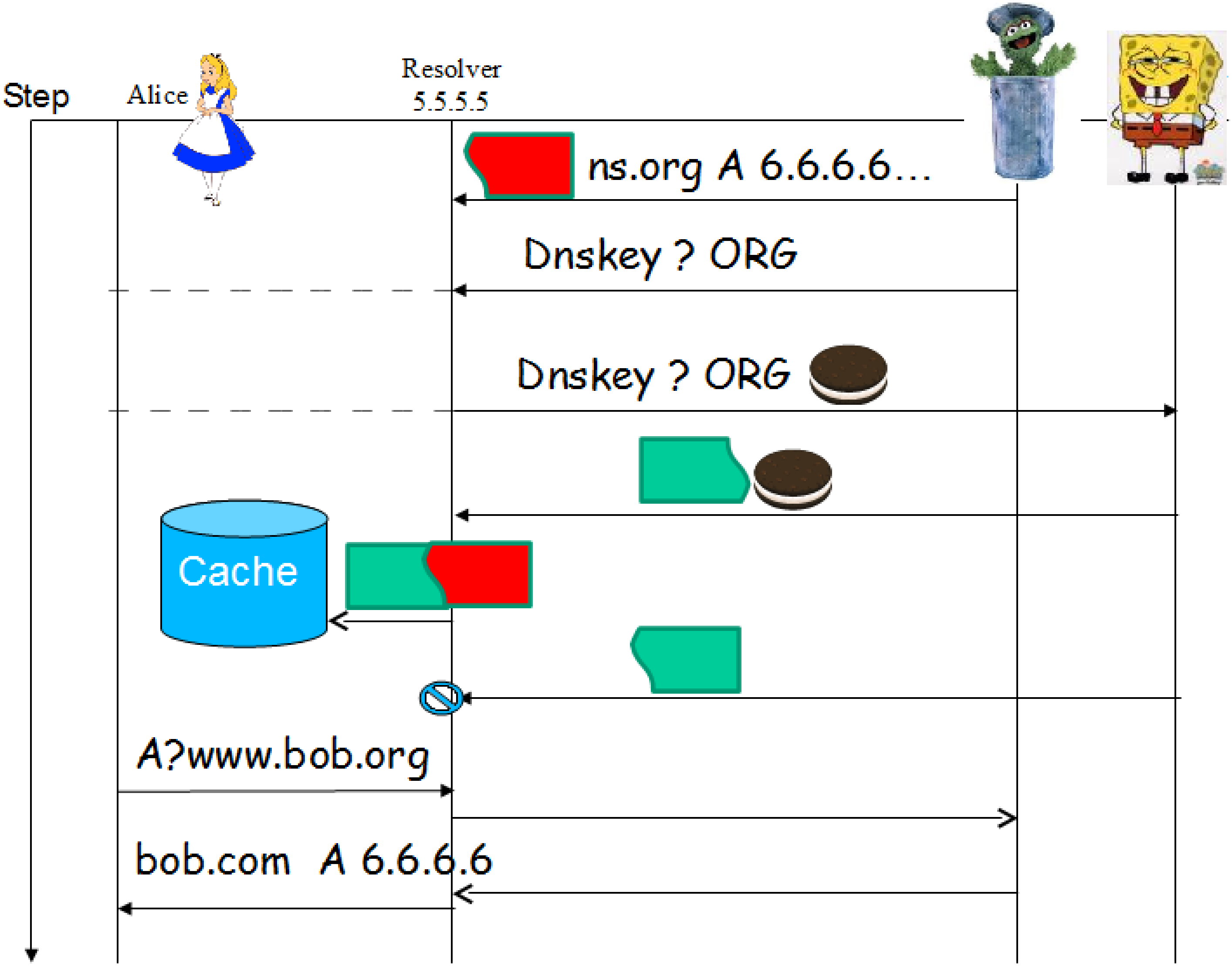
Off-Path Discarding and Modifying

- We show off-path can discard and modify fragments!!
  - Exploit fragmentation for poisoning!
- In reality fragmentation is rare (<1%)
- But, off-path attacker can **cause** fragmentation!!
  - Two methods:

1. Trigger requests whose responses fragment
   - E.g., DNSSEC protected
2. Attacker registered domain



Modify Long DNSSEC Responses



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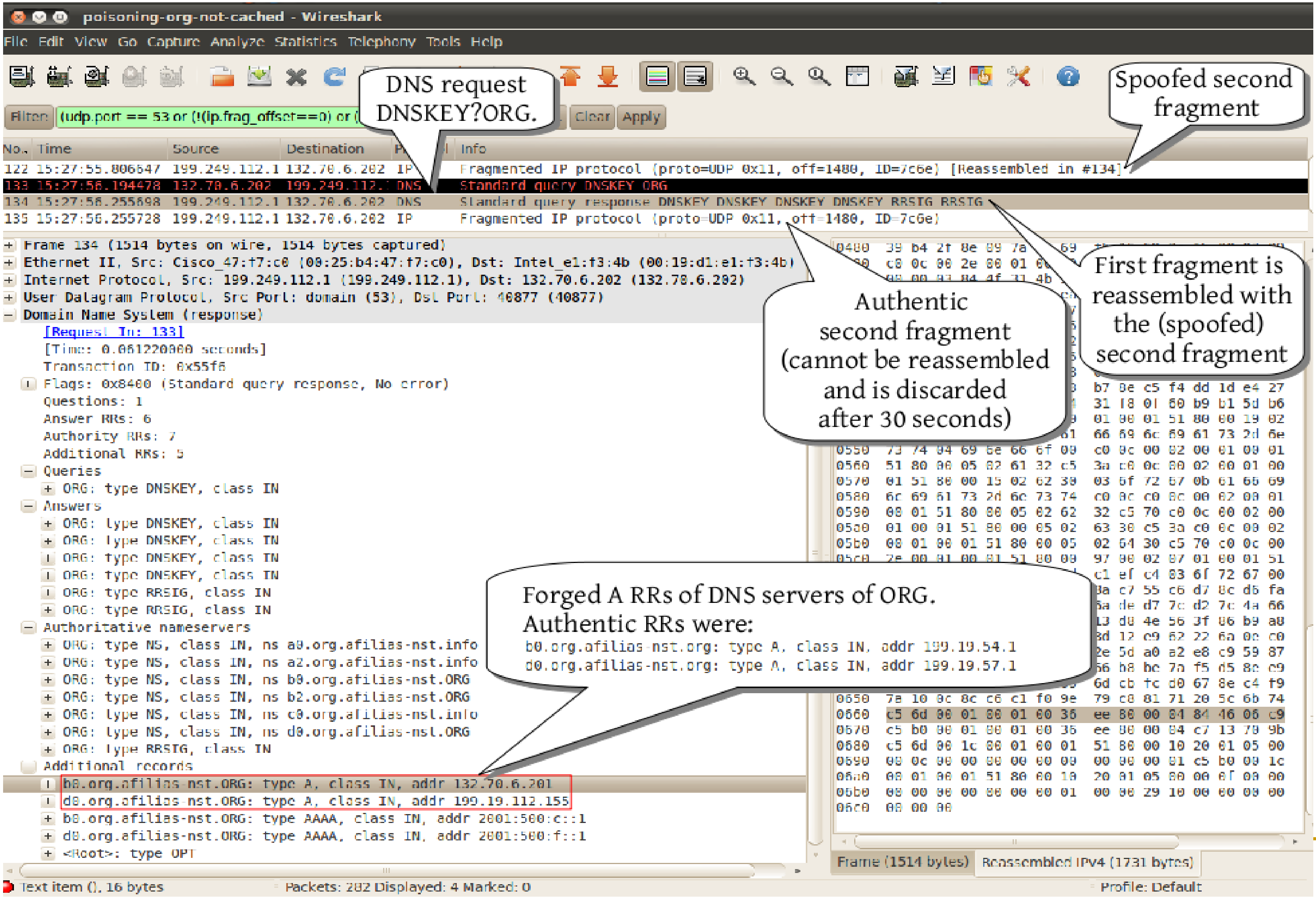
Poisoning DNSKEY Response


poisoning-org-not-cached - Wireshark
File Edit View Go Capture Analyze Statistics Telephony Tools Help
Filter: (udp.port == 53 or (!(ip.frag_offset==0) or (
Clear Apply

DNS request DNSKEY?ORG.

Spoofed second fragment

```
No. Time            Source        Destination   Protocol Info
122 15:27:55.806647 199.249.112.1 132.70.6.202  IP       Fragmented IP protocol (proto=UDP 0x11, off=1480, ID=7c6e) [Reassembled in #134]
133 15:27:56.194478 132.70.6.202  199.249.112.1 DNS      Standard query DNSKEY ORG
134 15:27:56.255698 199.249.112.1 132.70.6.202  DNS      Standard query response DNSKEY DNSKEY DNSKEY DNSKEY RRSIG RRSIG
135 15:27:56.255728 199.249.112.1 132.70.6.202  IP       Fragmented IP protocol (proto=UDP 0x11, off=1480, ID=7c6e)
```

```
+ Frame 134 (1514 bytes on wire, 1514 bytes captured)
+ Ethernet II, Src: Cisco_47:f7:c0 (00:25:b4:47:f7:c0), Dst: Intel_e1:f3:4b (00:19:d1:e1:f3:4b)
+ Internet Protocol, Src: 199.249.112.1 (199.249.112.1), Dst: 132.70.6.202 (132.70.6.202)
+ User Datagram Protocol, Src Port: domain (53), Dst Port: 40877 (40877)
- Domain Name System (response)
    [Request In: 133]
    [Time: 0.061220000 seconds]
    Transaction ID: 0x55f6
  + Flags: 0x8400 (Standard query response, No error)
    Questions: 1
    Answer RRs: 6
    Authority RRs: 7
    Additional RRs: 5
  - Queries
    + ORG: type DNSKEY, class IN
  - Answers
    + ORG: type DNSKEY, class IN
    + ORG: type DNSKEY, class IN
    + ORG: type DNSKEY, class IN
    + ORG: type DNSKEY, class IN
    + ORG: type RRSIG, class IN
    + ORG: type RRSIG, class IN
  - Authoritative nameservers
    + ORG: type NS, class IN, ns a0.org.afilias-nst.info
    + ORG: type NS, class IN, ns a2.org.afilias-nst.info
    + ORG: type NS, class IN, ns b0.org.afilias-nst.ORG
    + ORG: type NS, class IN, ns b2.org.afilias-nst.ORG
    + ORG: type NS, class IN, ns c0.org.afilias-nst.info
    + ORG: type NS, class IN, ns d0.org.afilias-nst.ORG
    + ORG: type RRSIG, class IN
  - Additional records
    + b0.org.afilias-nst.ORG: type A, class IN, addr 132.70.6.201
    + d0.org.afilias-nst.ORG: type A, class IN, addr 199.19.112.155
    + b0.org.afilias-nst.ORG: type AAAA, class IN, addr 2001:500:c::1
    + d0.org.afilias-nst.ORG: type AAAA, class IN, addr 2001:500:f::1
    + <Root>: type OPT
```

```
0400  39 b4 2f 8e 89 7a
      c8 0c 00 2e 00 01
                                 b7 0e c5 f4 dd 1d e4 27
                                 31 18 01 60 b9 b1 5d b6
                                 01 00 01 51 80 00 19 02
                                 66 69 6c 69 61 73 2d 6e
0550  73 74 04 69 6e 66 6f 00    c0 0c 00 02 00 01 00 01
0560  51 80 00 05 02 61 32 c5    3a c0 0c 00 02 00 01 00
0570  01 51 80 00 15 02 62 30    03 6f 72 67 0b 61 66 69
0580  6c 69 61 73 2d 6e 73 74    c0 0c c0 0c 00 02 00 01
0590  00 01 51 80 00 05 02 62    32 c5 70 c0 0c 00 02 00
05a0  01 00 01 51 80 00 05 02    63 30 c5 3a c0 0c 00 02
05b0  00 01 00 01 51 80 00 05    02 64 30 c5 70 c0 0c 00
05c0  2e 00 01 00 01 51 80 00    97 00 02 07 01 00 01 51
                                 c1 ef c4 03 6f 72 67 00
                                 8a c7 55 c6 d7 8c d6 fa
                                 6a de d7 7c d2 7c 4a 66
                                 13 d8 4e 56 3f 06 b9 a8
                                 8d 12 c9 62 22 6a 0c c0
                                 2e 5d a0 a2 e8 c9 59 87
                                 56 b8 bc 7a f5 d5 8c c9
                                 6d cb fc d0 67 8e c4 f9
0650  7a 10 0c 8c c6 c1 f0 9e    79 c8 01 71 20 5c 6b 74
0660  c5 6d 00 01 00 01 00 36    ee 80 00 04 84 46 06 c9
0670  c5 b0 00 01 00 01 00 36    ee 80 00 04 c7 13 70 9b
0680  c5 6d 00 1c 00 01 00 01    51 80 00 10 20 01 05 00
0690  00 0c 00 00 00 00 00 00    00 00 00 01 c5 b0 00 1c
06a0  00 01 00 01 51 80 00 10    20 01 05 00 00 0f 00 00
06b0  00 00 00 00 00 00 00 01    00 00 29 10 00 00 00 00
06c0  00 00 00
```

Frame (1514 bytes)
Reassembled IPv4 (1731 bytes)
Text item (), 16 bytes
Packets: 282 Displayed: 4 Marked: 0
Profile: Default

Authentic second fragment (cannot be reassembled and is discarded after 30 seconds)

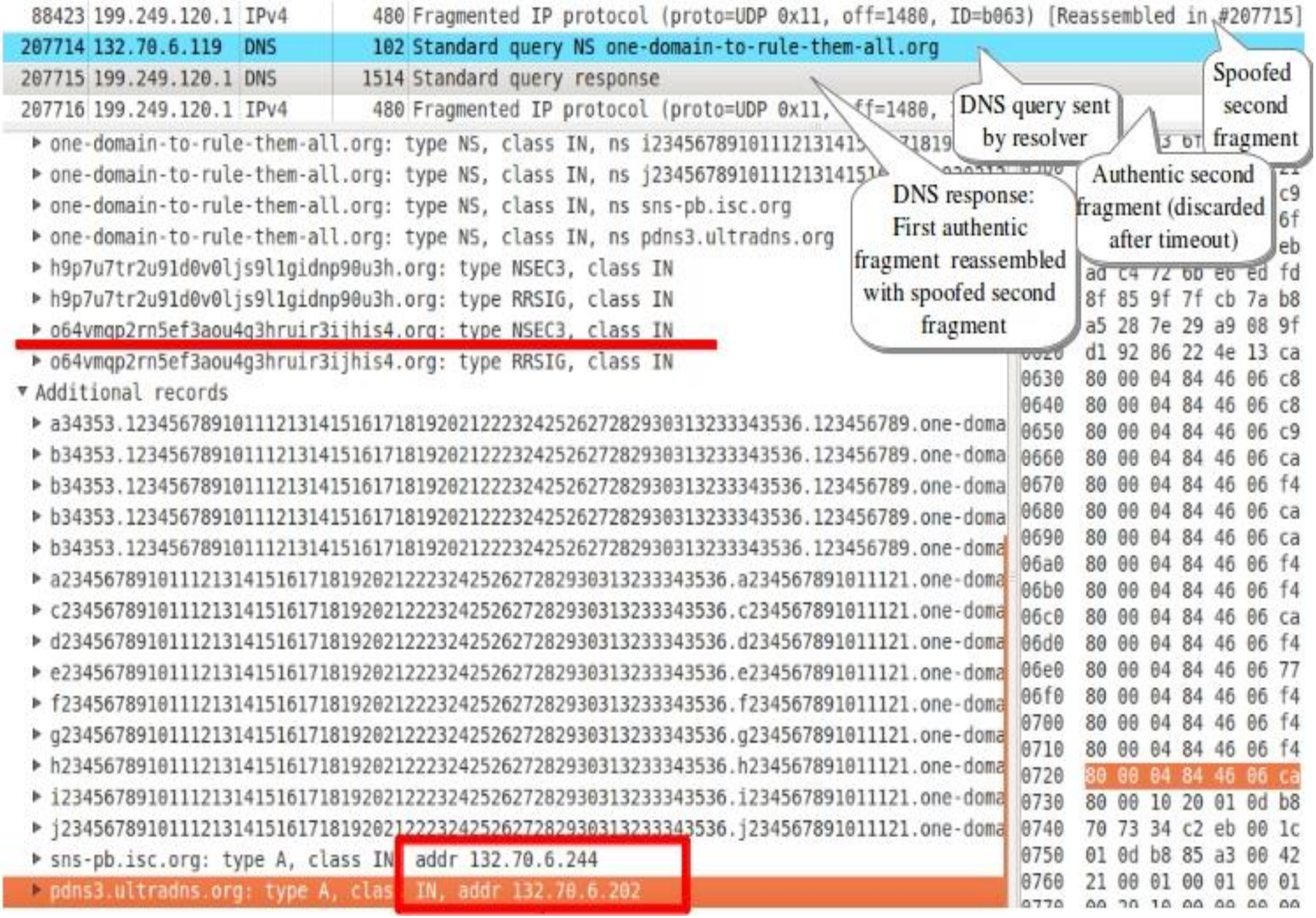
First fragment is reassembled with the (spoofed) second fragment

Forged A RRs of DNS servers of ORG.
Authentic RRs were:

```
b0.org.afilias-nst.org: type A, class IN, addr 199.19.54.1
d0.org.afilias-nst.org: type A, class IN, addr 199.19.57.1
```

Causing Long, Fragmented Responses

- Often, attacker doesn’t need to find a long response
- Attacker **causes** a long, fragmented response
  - From a victim NS of a TLD (.ORG, .CO.UK, …)
  - By **registering** an `appropriate’ subdomain
- To cause fragmentation:
  - Register many name servers
  - With long names
- Example? One-Domain-to-Rule-them-All . ORG
  - Or see paper [CNS2013]… or next foil ☺



DNS query sent by resolver
Spoofed second fragment
DNS response: First authentic fragment reassembled with spoofed second fragment
Authentic second fragment (discarded after timeout)

```
 88423 199.249.120.1 IPv4      480 Fragmented IP protocol (proto=UDP 0x11, off=1480, ID=b063) [Reassembled in #207715]
207714 132.70.6.119  DNS       102 Standard query NS one-domain-to-rule-them-all.org
207715 199.249.120.1 DNS      1514 Standard query response
207716 199.249.120.1 IPv4      480 Fragmented IP protocol (proto=UDP 0x11,  ff=1480,
  ▸ one-domain-to-rule-them-all.org: type NS, class IN, ns i123456789101112131415  71819
  ▸ one-domain-to-rule-them-all.org: type NS, class IN, ns j123456789101112131415
  ▸ one-domain-to-rule-them-all.org: type NS, class IN, ns sns-pb.isc.org
  ▸ one-domain-to-rule-them-all.org: type NS, class IN, ns pdns3.ultradns.org
  ▸ h9p7u7tr2u91d0v0ljs9l1gidnp90u3h.org: type NSEC3, class IN
  ▸ h9p7u7tr2u91d0v0ljs9l1gidnp90u3h.org: type RRSIG, class IN
  ▸ o64vmqp2rn5ef3aou4g3hruir3ijhis4.org: type NSEC3, class IN
  ▸ o64vmqp2rn5ef3aou4g3hruir3ijhis4.org: type RRSIG, class IN
▾ Additional records
  ▸ a34353.123456789101112131415161718192021222324252627282930313233343536.123456789.one-doma
  ▸ b34353.123456789101112131415161718192021222324252627282930313233343536.123456789.one-doma
  ▸ b34353.123456789101112131415161718192021222324252627282930313233343536.123456789.one-doma
  ▸ b34353.123456789101112131415161718192021222324252627282930313233343536.123456789.one-doma
  ▸ b34353.123456789101112131415161718192021222324252627282930313233343536.123456789.one-doma
  ▸ a23456789101112131415161718192021222324252627282930313233343536.a234567891011121.one-doma
  ▸ c23456789101112131415161718192021222324252627282930313233343536.c234567891011121.one-doma
  ▸ d23456789101112131415161718192021222324252627282930313233343536.d234567891011121.one-doma
  ▸ e23456789101112131415161718192021222324252627282930313233343536.e234567891011121.one-doma
  ▸ f23456789101112131415161718192021222324252627282930313233343536.f234567891011121.one-doma
  ▸ g23456789101112131415161718192021222324252627282930313233343536.g234567891011121.one-doma
  ▸ h23456789101112131415161718192021222324252627282930313233343536.h234567891011121.one-doma
  ▸ i23456789101112131415161718192021222324252627282930313233343536.i234567891011121.one-doma
  ▸ j23456789101112131415161718192021222324252627282930313233343536.j234567891011121.one-doma
  ▸ sns-pb.isc.org: type A, class IN, addr 132.70.6.244
  ▸ pdns3.ultradns.org: type A, class IN, addr 132.70.6.202
```

```
                                c9
                                6f
                                eb
      ad c4 72 6b e6 ed fd
      8f 85 9f 7f cb 7a b8
      a5 28 7e 29 a9 08 9f
      d1 92 86 22 4e 13 ca
0630  80 00 04 84 46 06 c8
0640  80 00 04 84 46 06 c8
0650  80 00 04 84 46 06 c9
0660  80 00 04 84 46 06 ca
0670  80 00 04 84 46 06 f4
0680  80 00 04 84 46 06 ca
0690  80 00 04 84 46 06 ca
06a0  80 00 04 84 46 06 f4
06b0  80 00 04 84 46 06 f4
06c0  80 00 04 84 46 06 ca
06d0  80 00 04 84 46 06 f4
06e0  80 00 04 84 46 06 77
06f0  80 00 04 84 46 06 f4
0700  80 00 04 84 46 06 f4
0710  80 00 04 84 46 06 f4
0720  80 00 04 84 46 06 ca
0730  80 00 10 20 01 0d b8
0740  70 73 34 c2 eb 00 1c
0750  01 0d b8 85 a3 00 42
0760  21 00 01 00 01 00 01
```

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  - Deploy DNSSEC – correctly… [and fix it, too??]

Still patching after all these years…

- All attacks: real, practical, validated (by others too)
- Resolvers
  - (Smart) pseudo-random port allocation (see paper)
  - Prepend random-length prefix to referral queries
- Name servers:
  - Append random RR
    - Or send random value of EDNS buffer size from NS
    - But…advanced frag attacks may change checksum field – see Esorics'13 paper
- Either: small (non-frag) limit on EDNS (use TCP)
- Registrars: Limit length of subdomain responses

Or… can we just use SSL/TLS ?

- Tempting: forget DNS, just use secure connection!
- Using secure connection **is** a good idea, sure
- But not complete solution:
    - Is web's PKI secure? Hmm…
    - Overhead
    - Unrealistic to expect all web to be fixed
    - Phishing
    - Denial-of-service
    - Non-web applications: **SMTP**, P2P, …
      Even **security:** e.g.: blacklists, SPF, DKIM…

DNSSEC, the time has come!

- These patches are too much, too complex, and:
  - Maybe there's another vulnerability/attack?
  - And what about MitM attacker? Like, is BGP secure?
- And… who said they'll suffice??
- We say: **time to properly use DNSSEC**
- But… some improvements may be needed, too
  - Abolish (insecure) NSEC3 OPT-OUT
  - Add **crypto-agility**, esp. critical to adopt ECDSA !
  - More… See our paper on this (and/or talk to us ☺)

Questions ?

Thank you!