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

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About me: Amir Herzberg

- Associate professor, Computer Science @ Bar Ilan
- Previously: many years in industry (e.g. 10 @ IBM)
- Main areas:
  - Network security, esp. Internet protocols
  - Denial of Service: attacks and defenses
  - Applied cryptography
  - Secure e-commerce and payments
  - Secure usability, esp. phishing
  - Anonymity

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??]

Everyone is worried about Security…

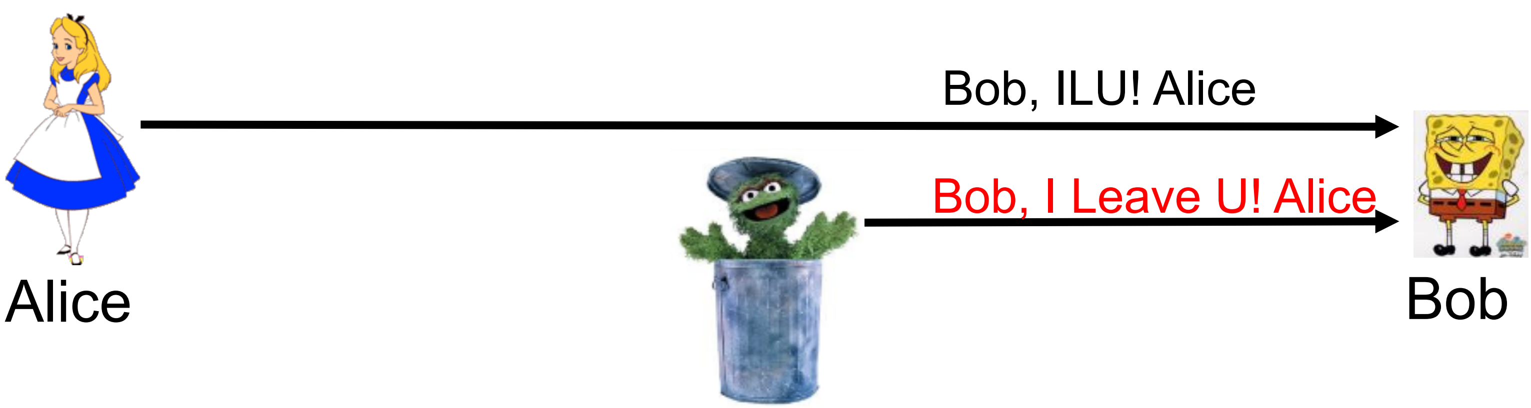
- So, why isn't crypto used more?
  - SSL/TLS/IPsec <6% of traffic, DNSSEC <1%, BGPsec ~ 0%, …
- Why? Illusion of security due to two false myths:
  - Most attackers are only off-path, not MitM
  - Simple, client-only challenge-response defenses suffice against off-path attackers

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?

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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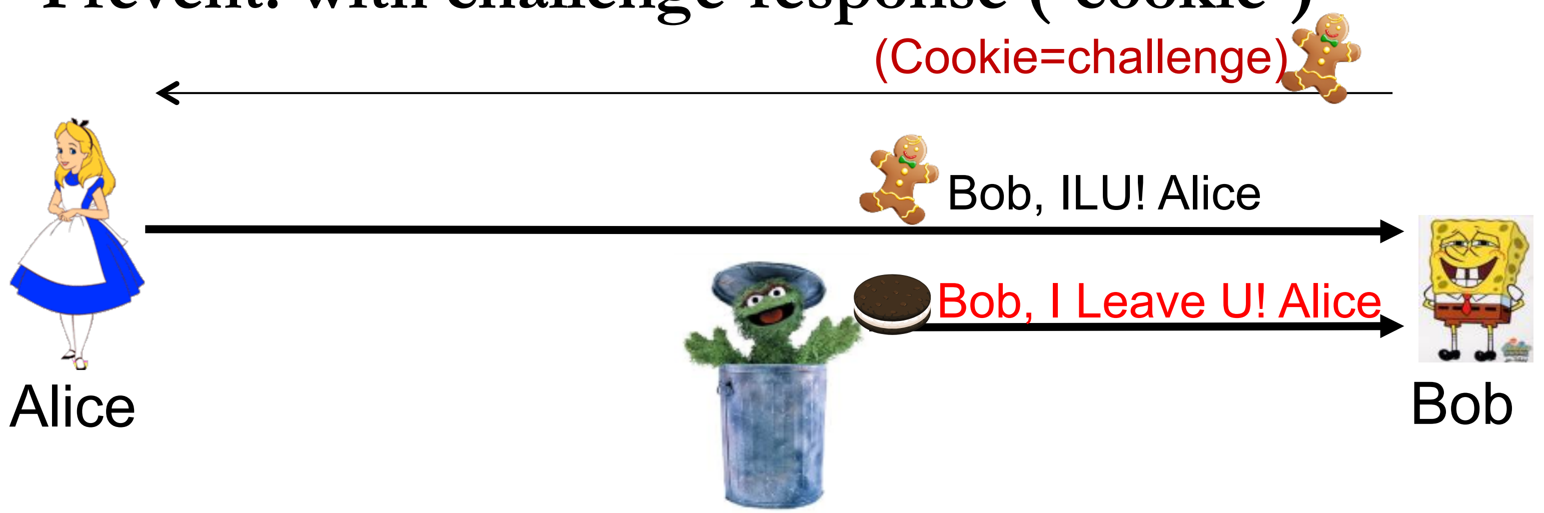

Challenge-Response: **What Can Go Wrong?**

- 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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- Why? Illusion of security due to two false myths:
  - Most attackers are only off-path, not MitM
  - Simple, client-only challenge-response defenses suffice against off-path attackers
- Reality:
  - MitM capabilities: via WiFi, BGP hijacking, …
  - **Off-path attacks against TCP & DNS [Today: simplified]**

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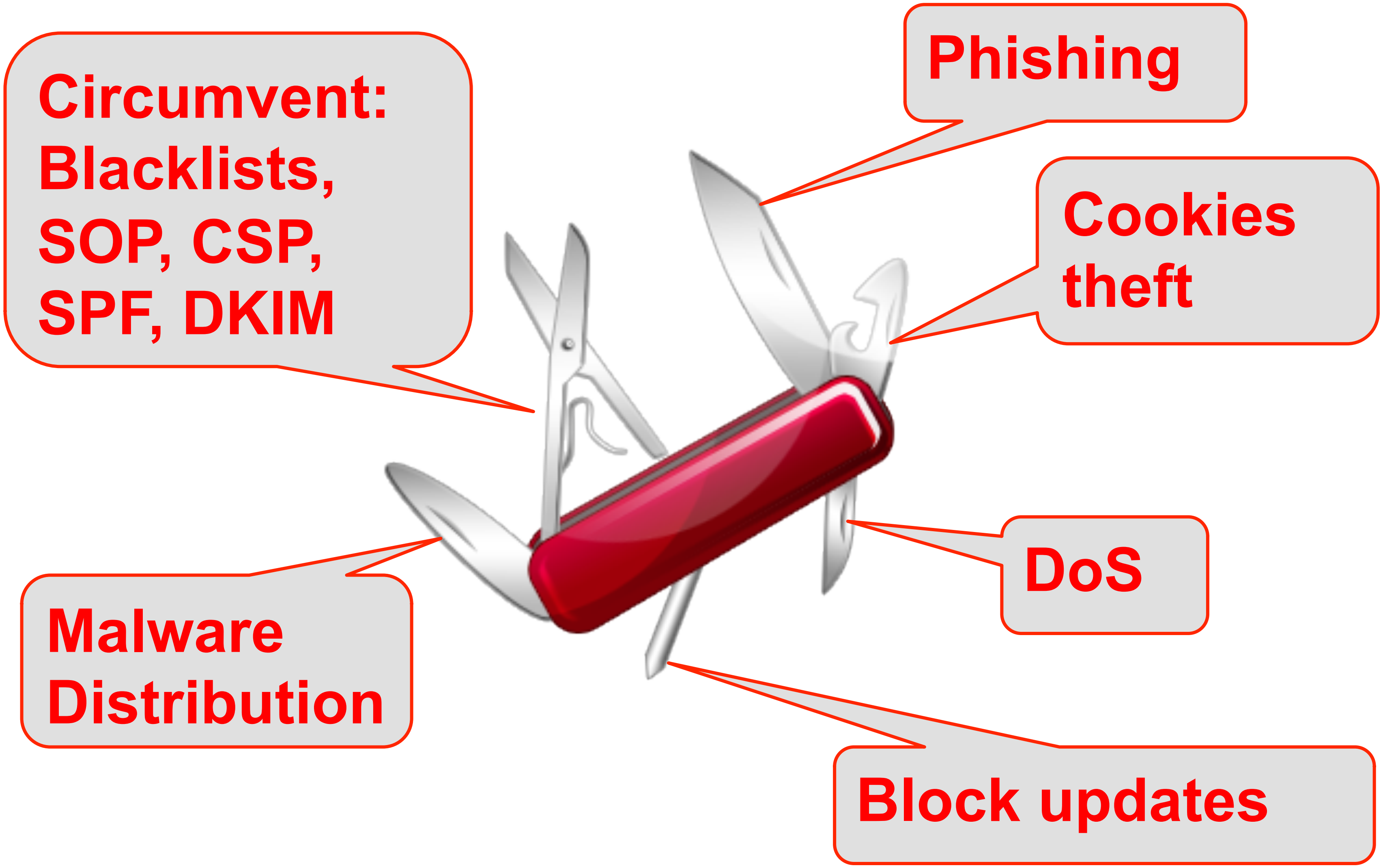
DNS Poisoning: the Hacker's Knife



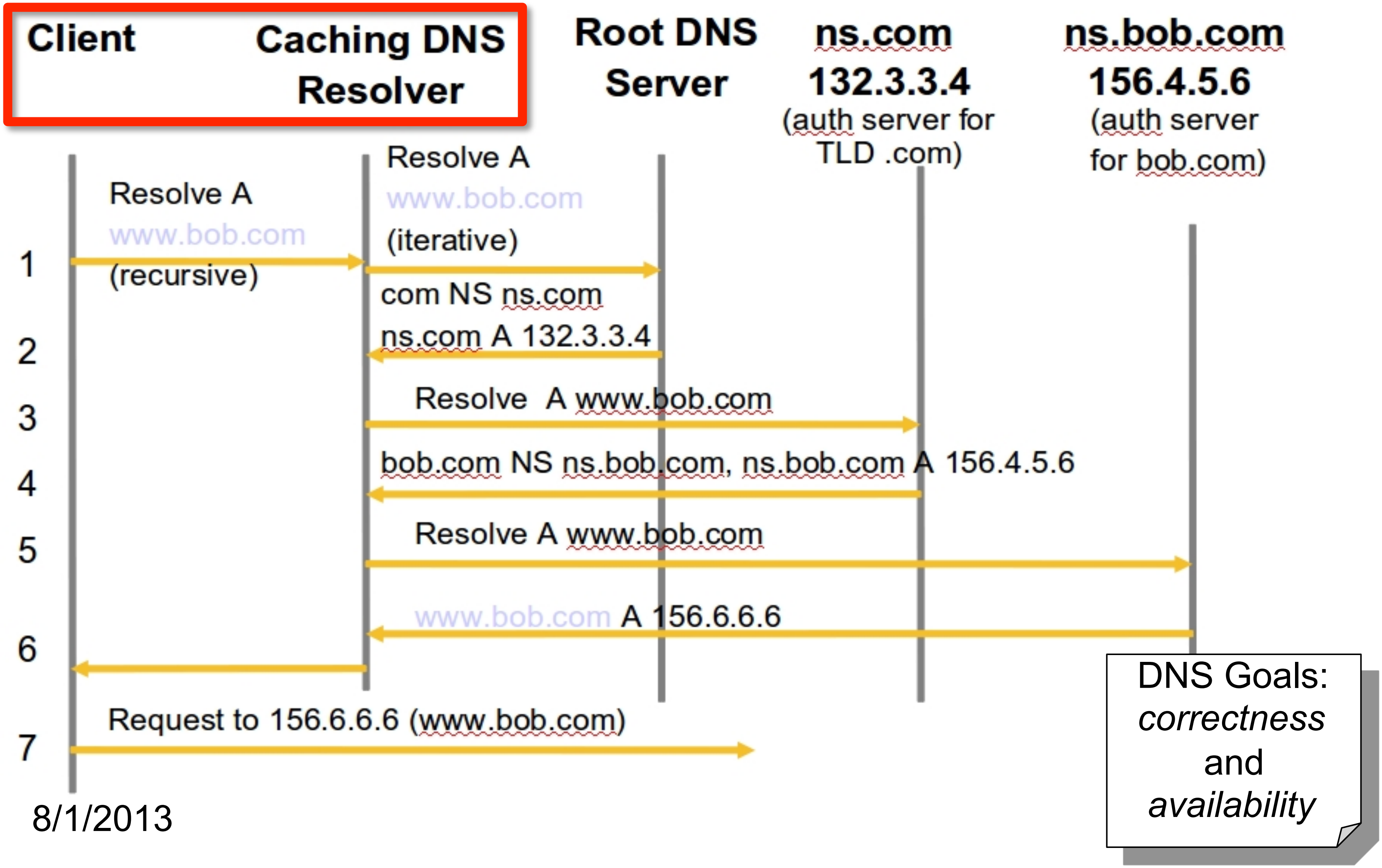
Exploiting Poisoning (and Injecting)

- Circumvent Name/Address server identification
  - Browser's Same Origin Policy (SOP) defenses
    - XSS (Cross-Site Scripting)
    - Steal `HTTP cookies/credentials'
  - Phishing, defacement, malware distribution
  - Fake policies: CSP, SPF, DKIM, black-lists
- Long-lived, multi-user attacks: exploit caching of…
  - DNS mappings (resolver/client cache)
  - HTTP objects (in browser/proxy; scripts, HTML, …)

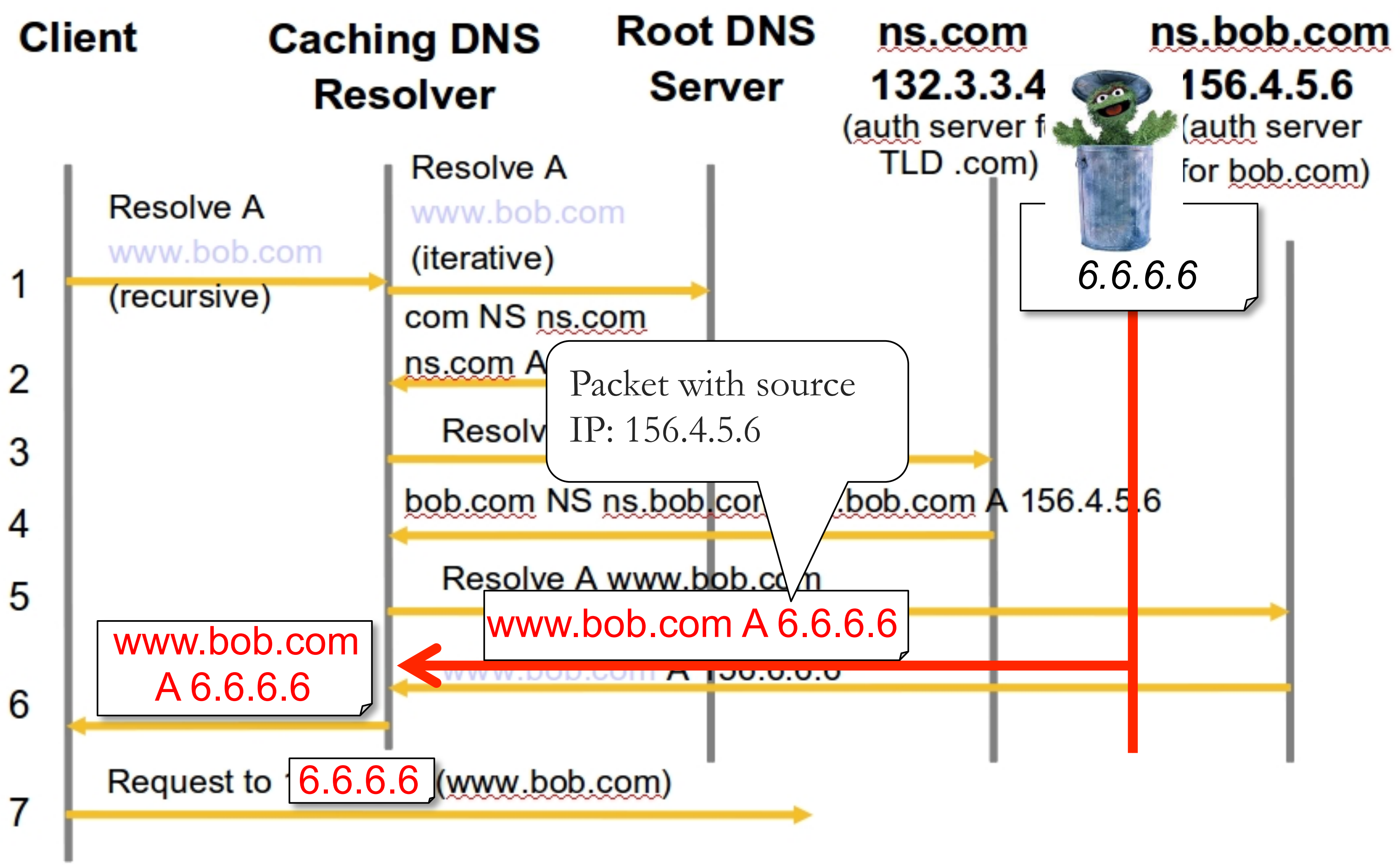
DNS Poisoning

- DNS: Internet directory (domain names → IP,…)
- Maps: Domain-Names to IP addresses, policies, …
- Caching critical for efficiency
  - At clients and at DNS Resolvers (aka proxies, local DNS)
- Poisoning : cache with fake mapping:
  `www.google.com A 6.6.6.6`
- Simple request-response (over UDP), efficient, caching
- Myth: `can't poison' – TTL, 16-bit TXID, source port

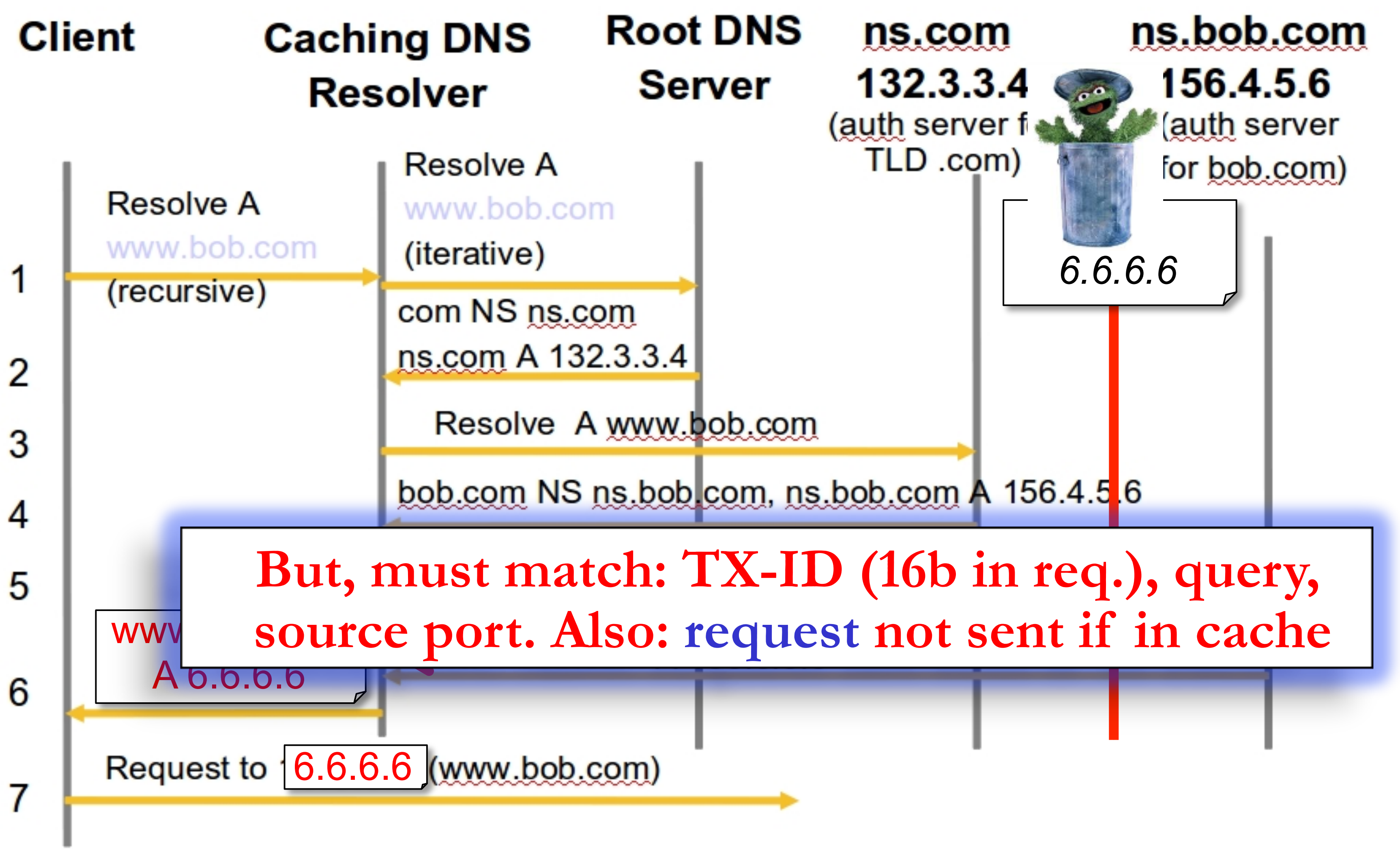
Domain Name System (DNS)



DNS Cache Poisoning



DNS Cache Poisoning



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)

DNS Poisoning Timeline

Past
- 16 bit TXID

Present
- Birthday prevention
- Source port
- 0x20 encoding

Future
- **DNSSEC**

2008

Dan's Attack

DNS Checker

2012 NAT-Prediction [Esorics]

2013 Fragmentation [CNS]

Hidden-Resolver [Esorics]

Our results

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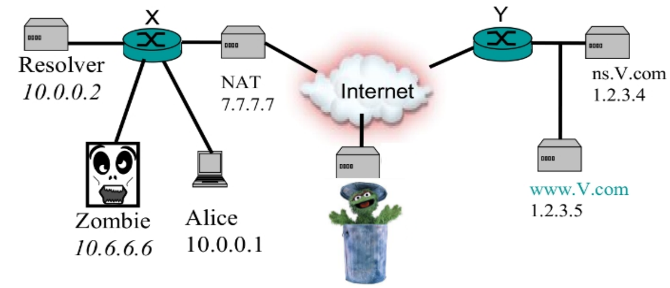
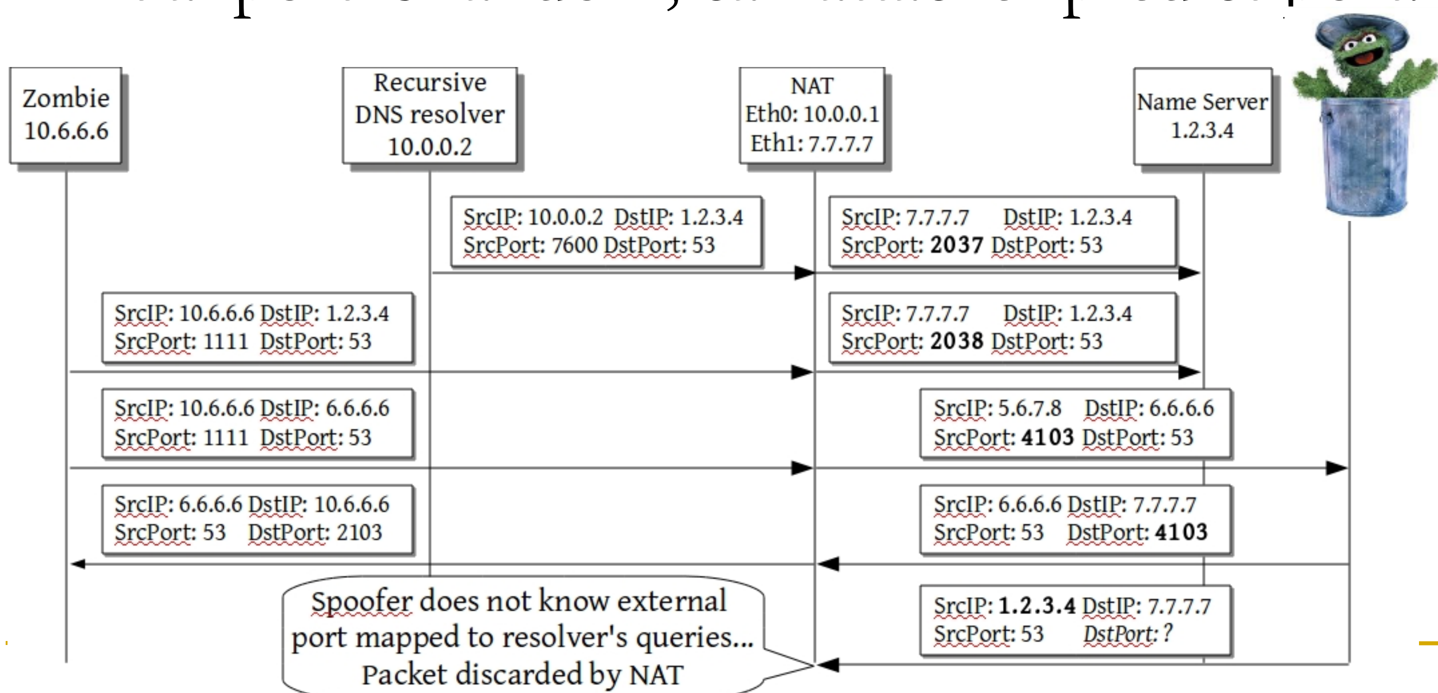
Source Port De-Randomisation Attacks

- **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

- Port re-allocated by NAT
- Few methods; most vulnerable
- E.g., **per-dest incrementing** (Linux)
- Initial port is random; can attacker predict port?

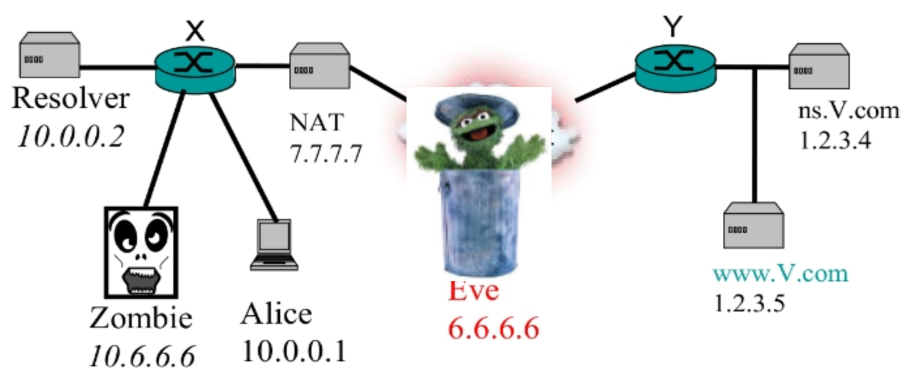




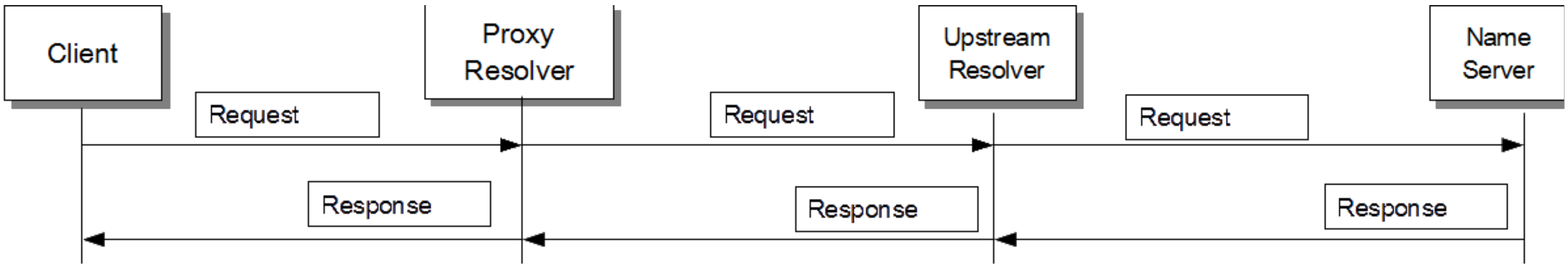
Herzberg and Shulman: DNSSEC, the time has come!

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



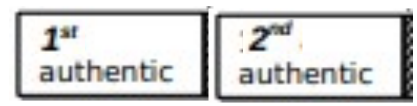
- Upstream DNS resolvers:
- Popular: Google's public-DNS, OpenDNS, many others
- Recommended by experts, vendors
  - E.g., Akamai: 'Customer's primary DNS are not directly exposed to end users, so the risk of cache poisoning and DoS attacks is mitigated'…
- Proxy resolvers often has lower bandwidth,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

Upstream DNS Resolver - Attack

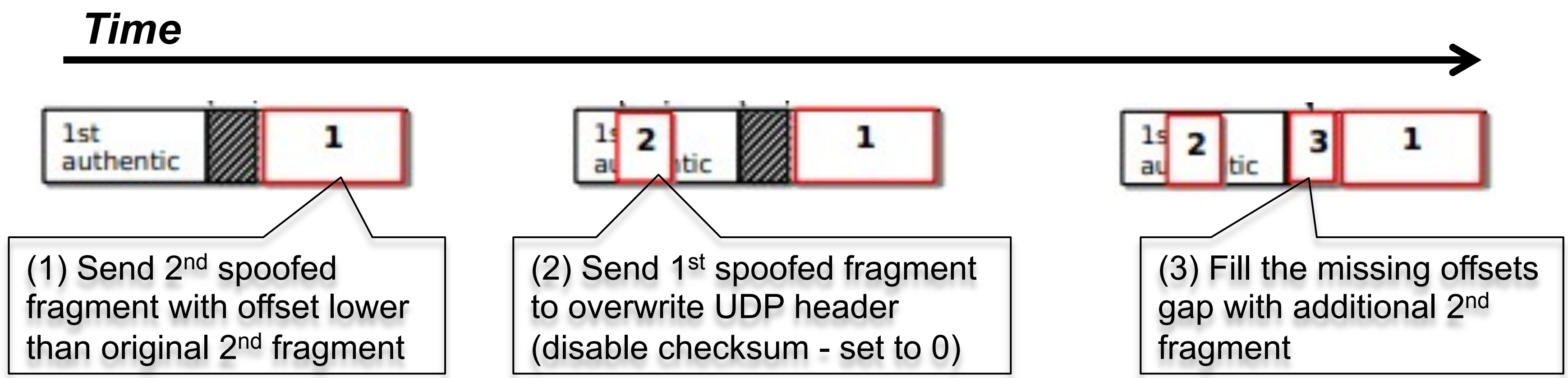
- Poisoning attack in three phases
- Phase 1: find proxy's IP address
  - Many requests with fragmented response… `kill` with spoofed frag
  - Suffices for DoS attack on proxy!
- Phase 2: find fixed/current port #
  - By a more complex frag attack, or by `port overloading'
- Phase 3: `regular' (`Kaminsky')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

Defragmentation-Cache Poisoning

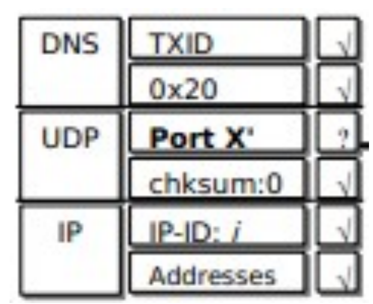
- Response is sent in two fragments:



- Sample each port via 3 fragments:



- Query retransmission when incorrect port
- Referral request: port found



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1st-fragment piggybacking attacks

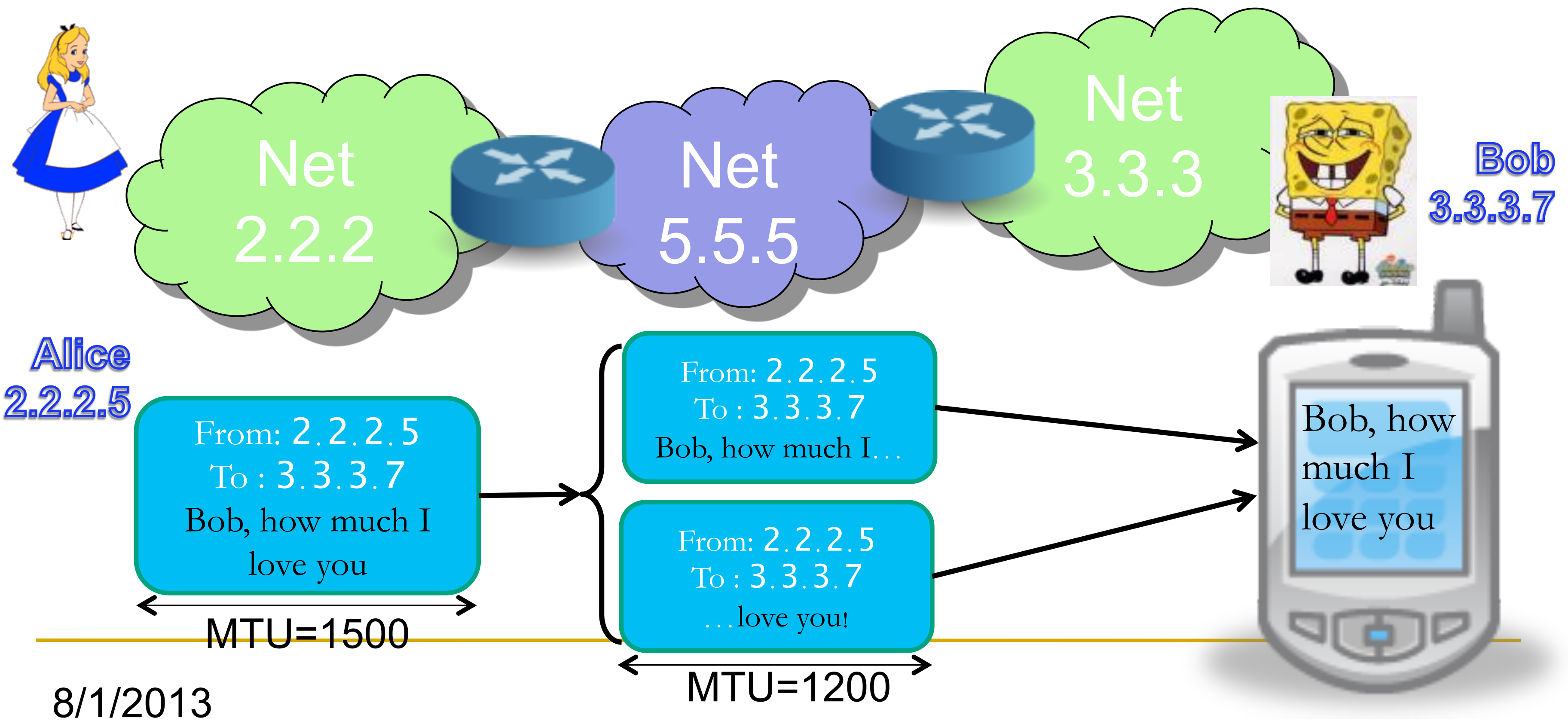
- Cut'n'Paste attack:
- Poison a long, **fragmented** DNS response
  - Source fragmentation will do [works even for IPv6]
- **All `challenges' are in the first fragment!**
  - **TXID, "src" port, even query [e.g., 0x20 defense]**
- Replace 2nd fragment with a fake one!
- Few details and quick recap on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

IP Fragmentation

Nets have a limit on maximal packet size

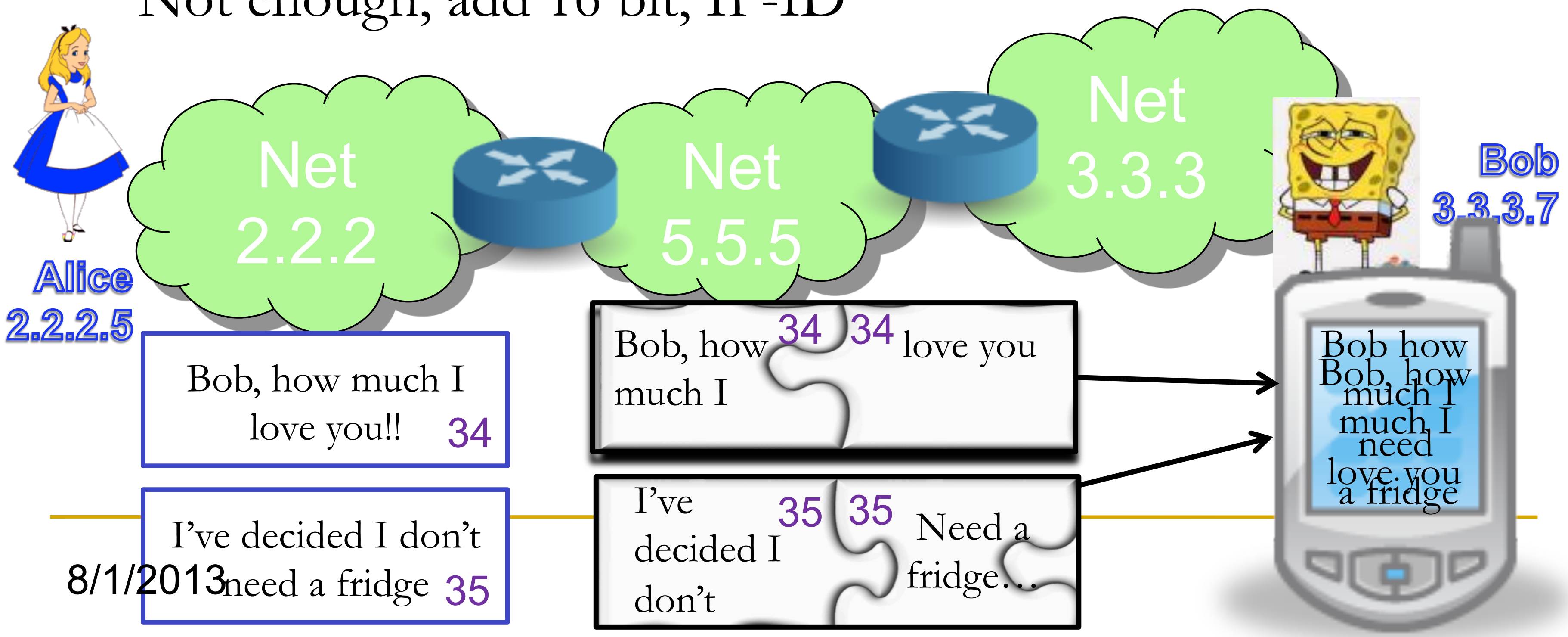
If the packet is larger than the limit: fragmentation

Reassemble at the receiver



Fragment Reassembly

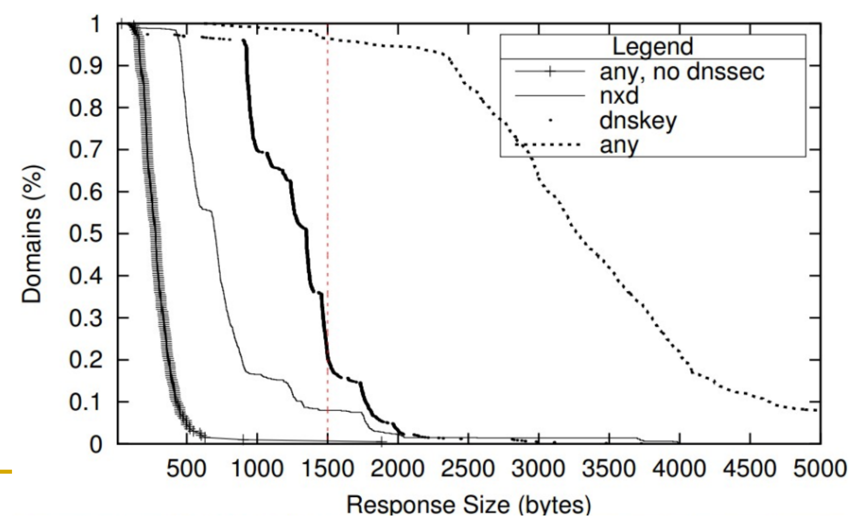
- Bob receives fragments of a packet
- How to reassemble without introducing mistakes
- Identify fragments of the same packet
  - By sender/receiver addresses and protocol (TCP/UDP)
  - Not enough, add 16 bit, IP-ID



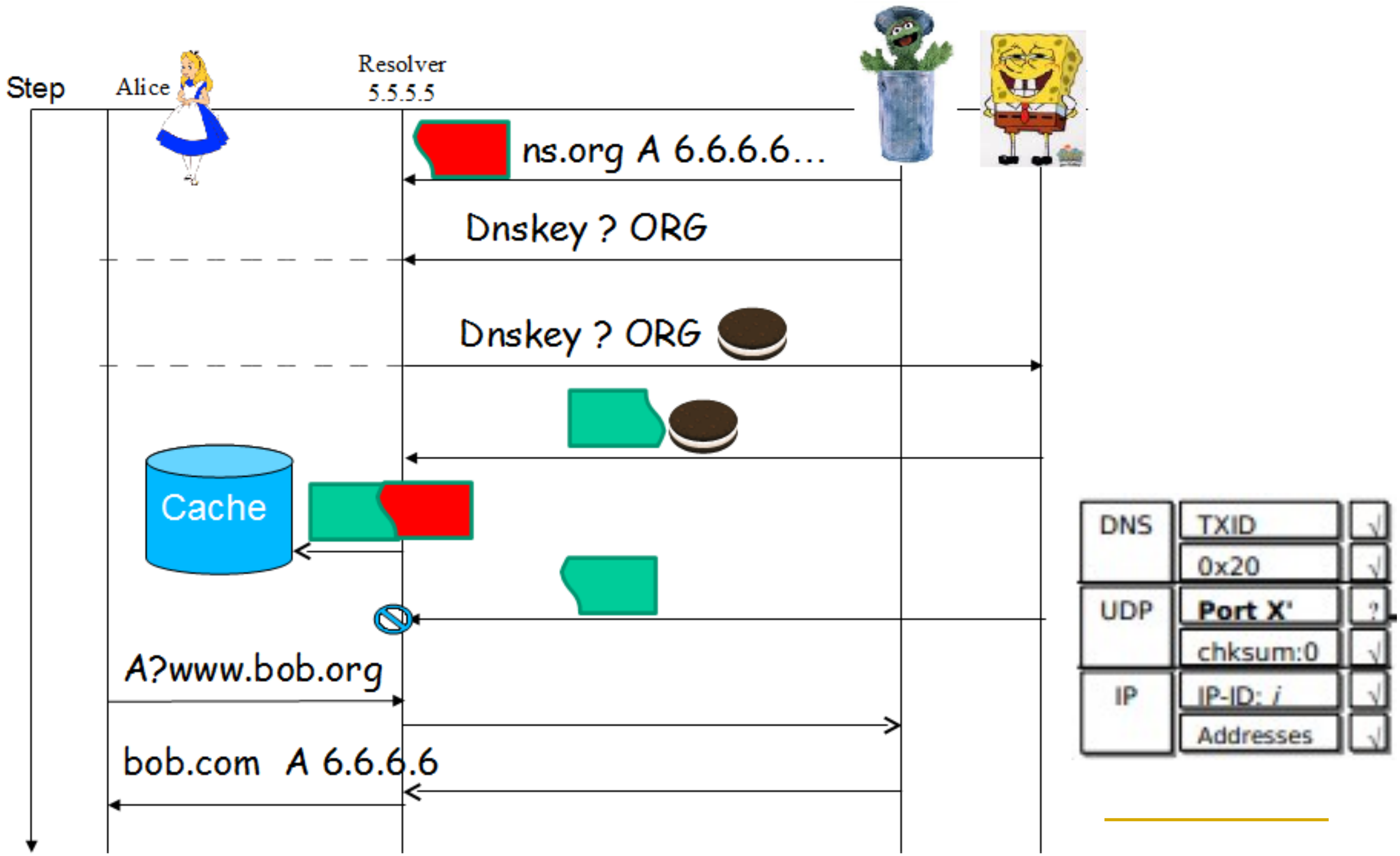
Off-Path Discarding and Modifying

- 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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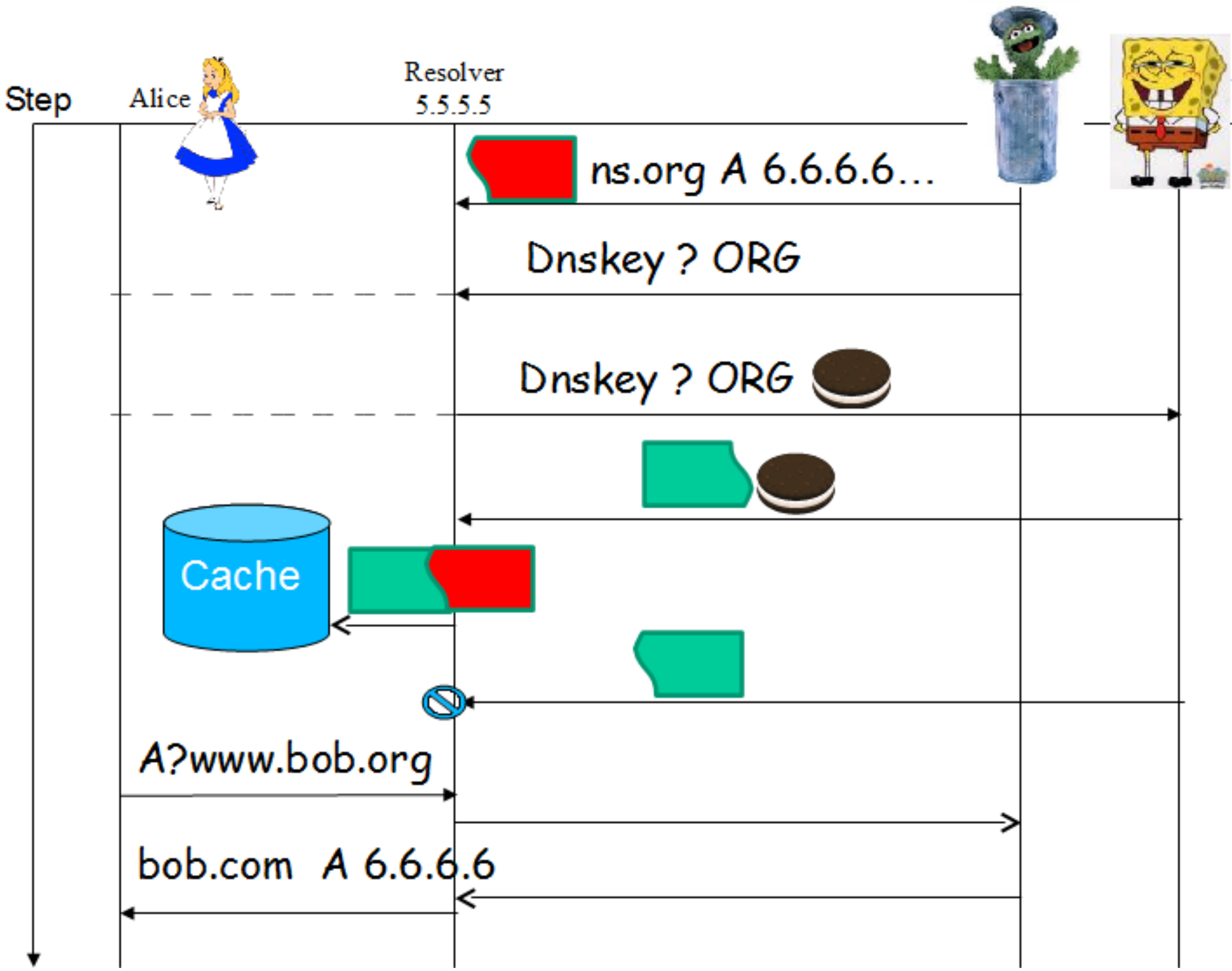
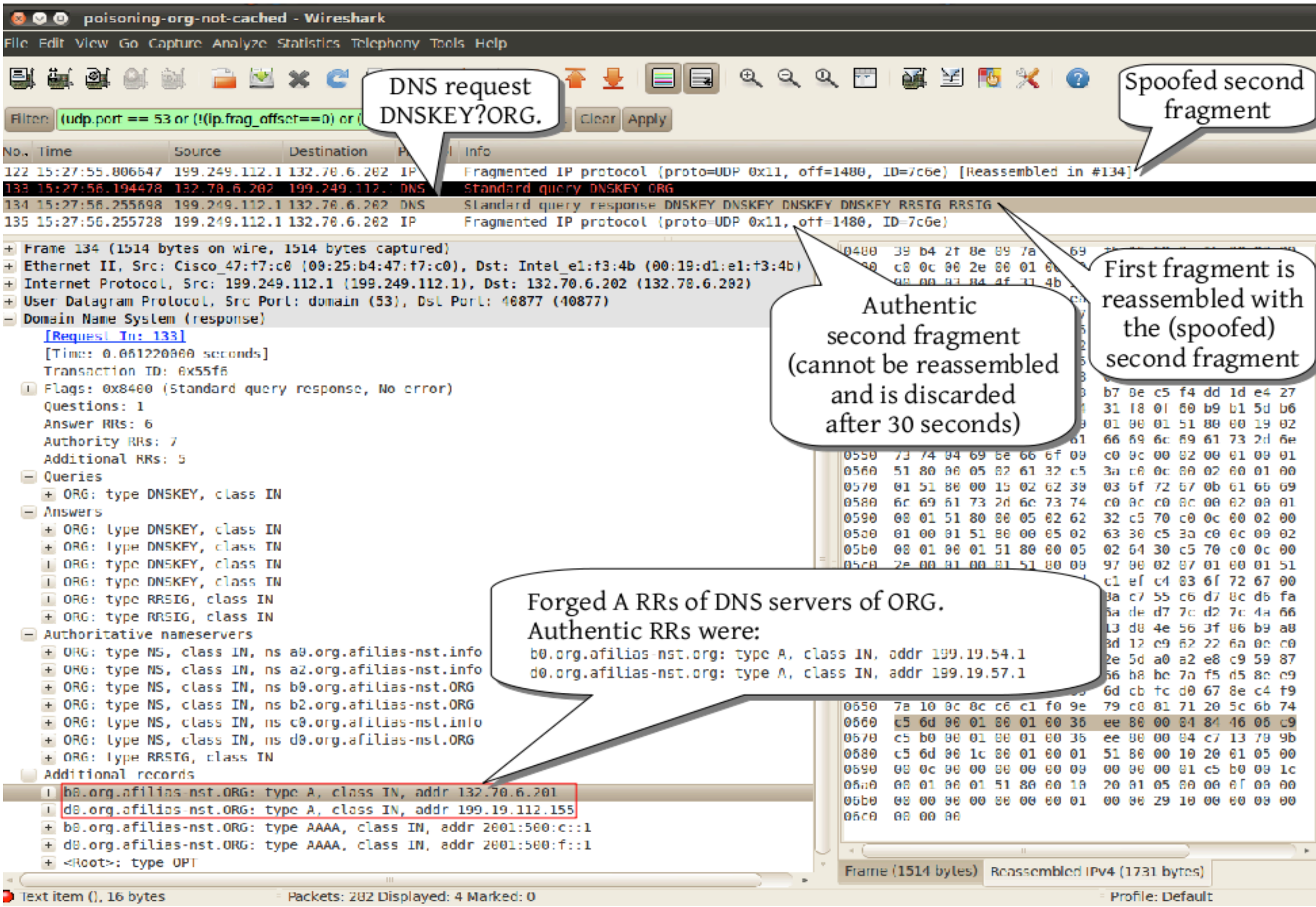
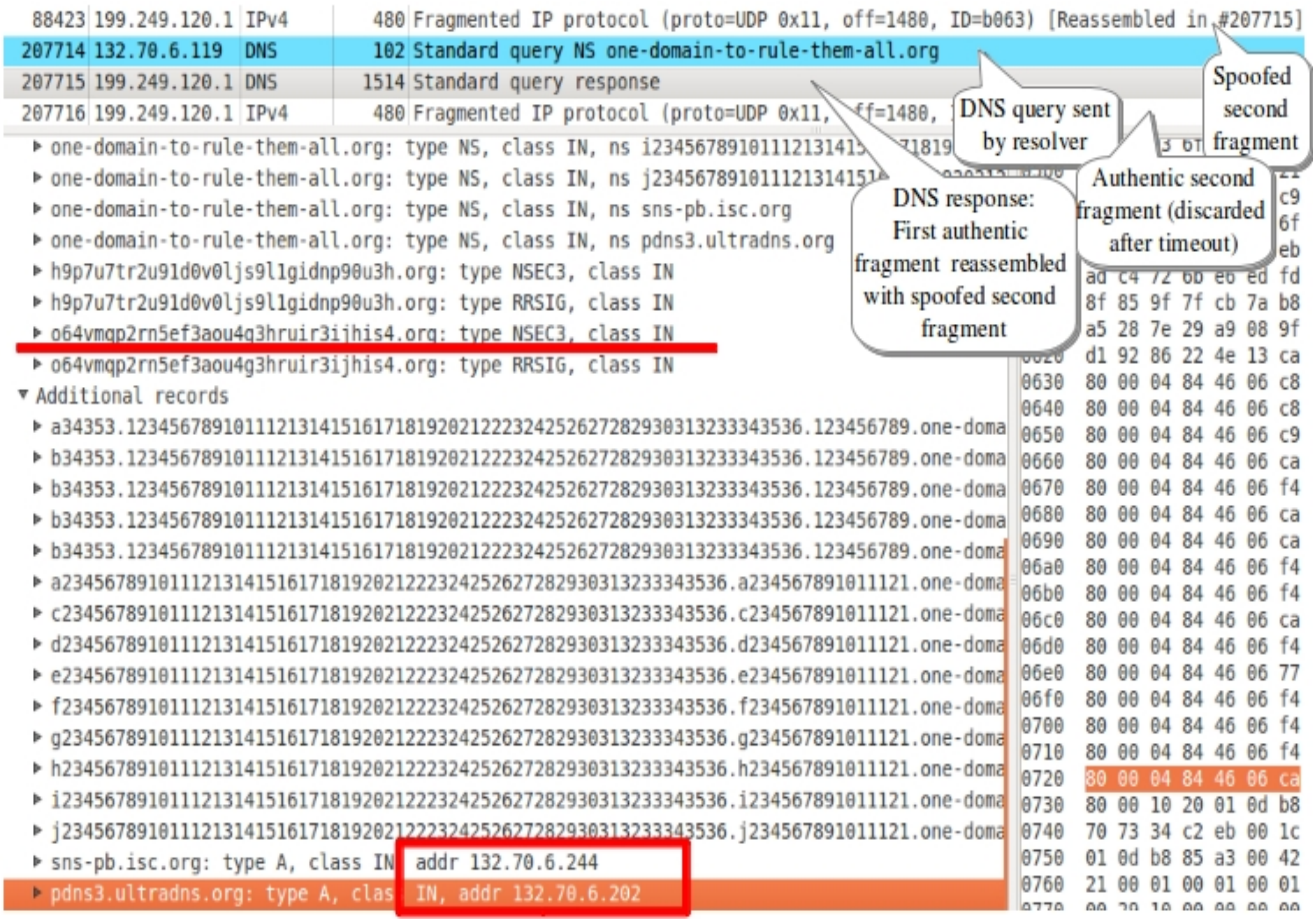


Poisoning DNSKEY Response



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 ☺


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

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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!