Poison Over Troubled Forwarders: A Cache Poisoning Attack Targeting DNS Forwarding Devices

Xiaofeng Zheng, Chaoyi Lu, Jian Peng, Qiushi Yang, Dongjie Zhou, Baojun Liu, Keyu Man, Shuang Hao, Haixin Duan and Zhiyun Qian

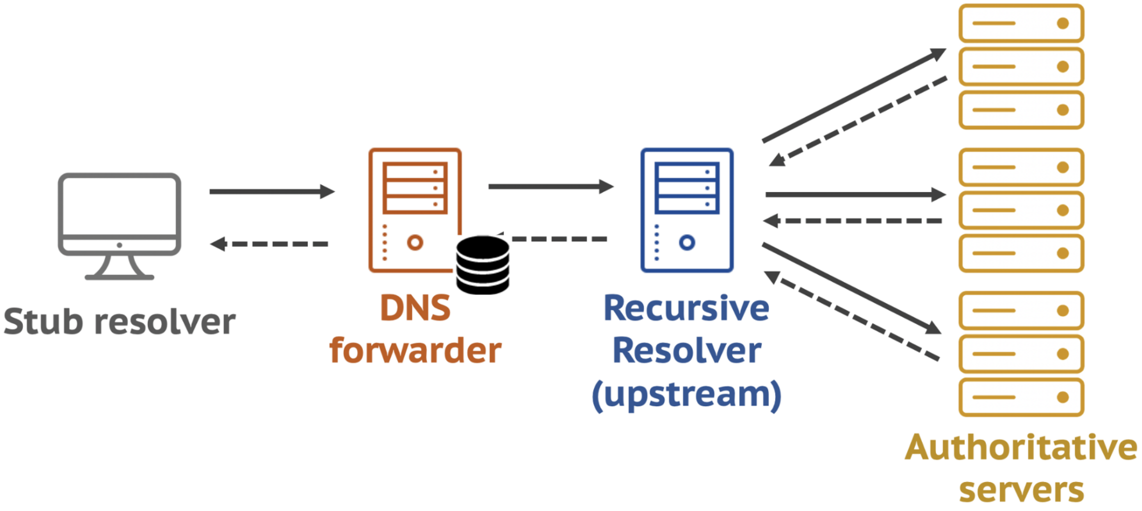
奇安信 QI-ANXIN

UC RIVERSIDE

UT DALLAS The University of Texas at Dallas

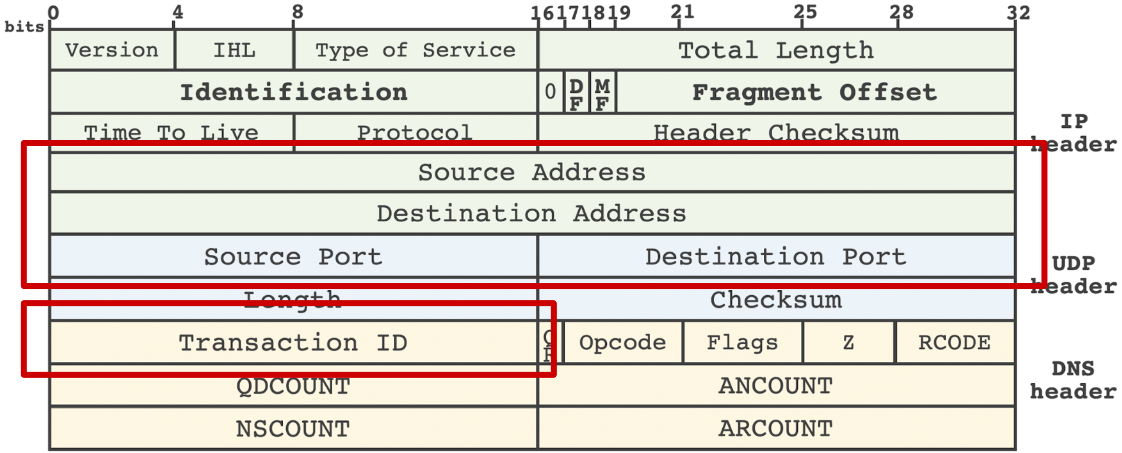
DNS Forwarder

- Devices standing in between stub and recursive resolvers
  - E.g., home routers, open Wi-Fi networks
  - Can have caching abilities
  - **Relies on the integrity of upstream resolvers**



DNS Cache Poisoning Attacks

- Forging attacks targeting recursive resolvers
  - Craft a DNS answer which matches the query’s metadata
  - Example: Kaminsky Attack (2008)
  - Mitigation: **increase randomness of DNS packet**



bits 0 4 8 16 17 18 19 21 25 28 32

Version | IHL | Type of Service | Total Length

Identification | 0 | DF | MF | **Fragment Offset**

Time To Live | Protocol | Header Checksum

Source Address

Destination Address

Source Port | Destination Port

Length | Checksum

Transaction ID | QR | Opcode | Flags | Z | RCODE

QDCOUNT | ANCOUNT

NSCOUNT | ARCOUNT

IP header

UDP header

DNS header

RFC 5452:

*DNS resolver implementations should use **randomized** ephemeral port numbers and DNS transaction IDs*

Threat Model: Overview

- Defragmentation attacks targeting DNS forwarders
  - **Reliably** forces DNS response fragmentation
  - Targets **arbitrary victim domain names**

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1. Attacker & DNS forwarder locate in the same LAN
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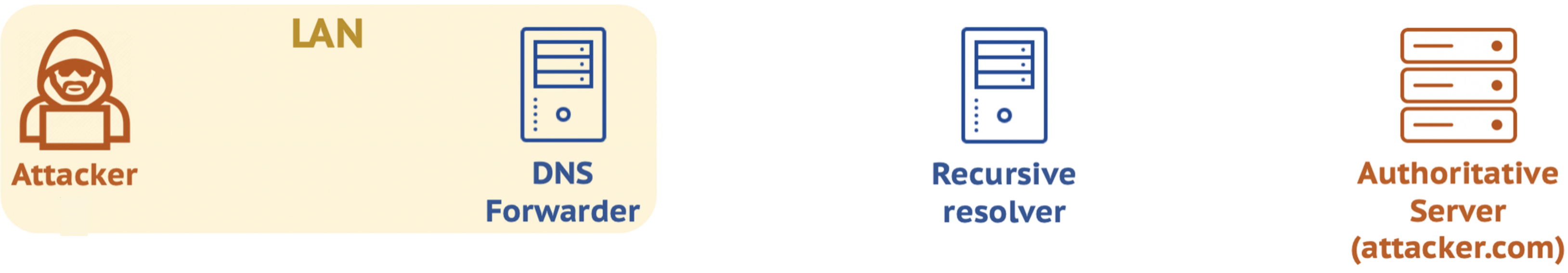
2. Use attacker's own domain name and authoritative server



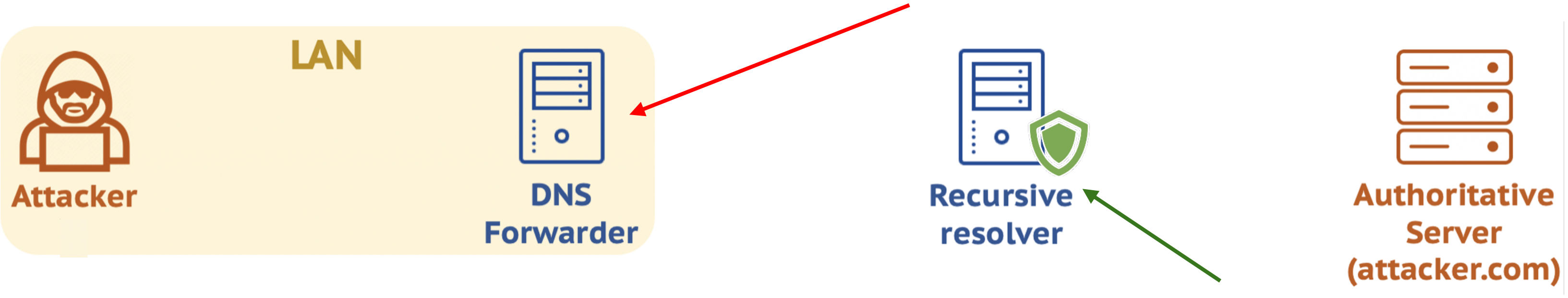
Insight on Forwarder Roles

- Defragmentation attacks targeting DNS forwarders
  - **Reliably** forces DNS response fragmentation
  - Targets **arbitrary victim domain names**

1. Attacker & DNS forwarder locate in the same LAN
(e.g., in open Wi-Fi networks)

Relies on recursive resolvers
Target of cache poisoning

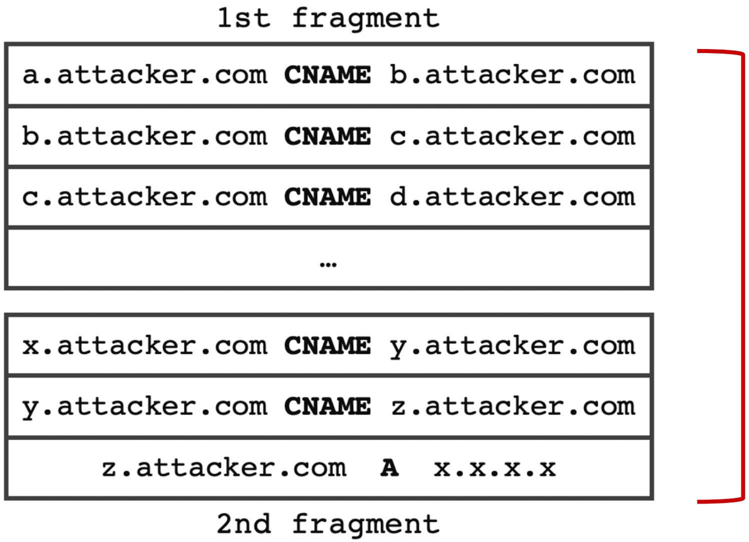
2. Use attacker's own domain name and authoritative server



Security checks (e.g., DNSSEC)

Attacker’s Oversized DNS Response

- CNAME chain
  - Use dummy **CNAME records** to enlarge attacker’s DNS response



1st fragment

a.attacker.com **CNAME** b.attacker.com

b.attacker.com **CNAME** c.attacker.com

c.attacker.com **CNAME** d.attacker.com

…

x.attacker.com **CNAME** y.attacker.com

y.attacker.com **CNAME** z.attacker.com

z.attacker.com **A** x.x.x.x

2nd fragment

> 1,500 Bytes (Ethernet MTU)

Always produce fragments

Attacker's Oversized DNS Response

- CNAME chain
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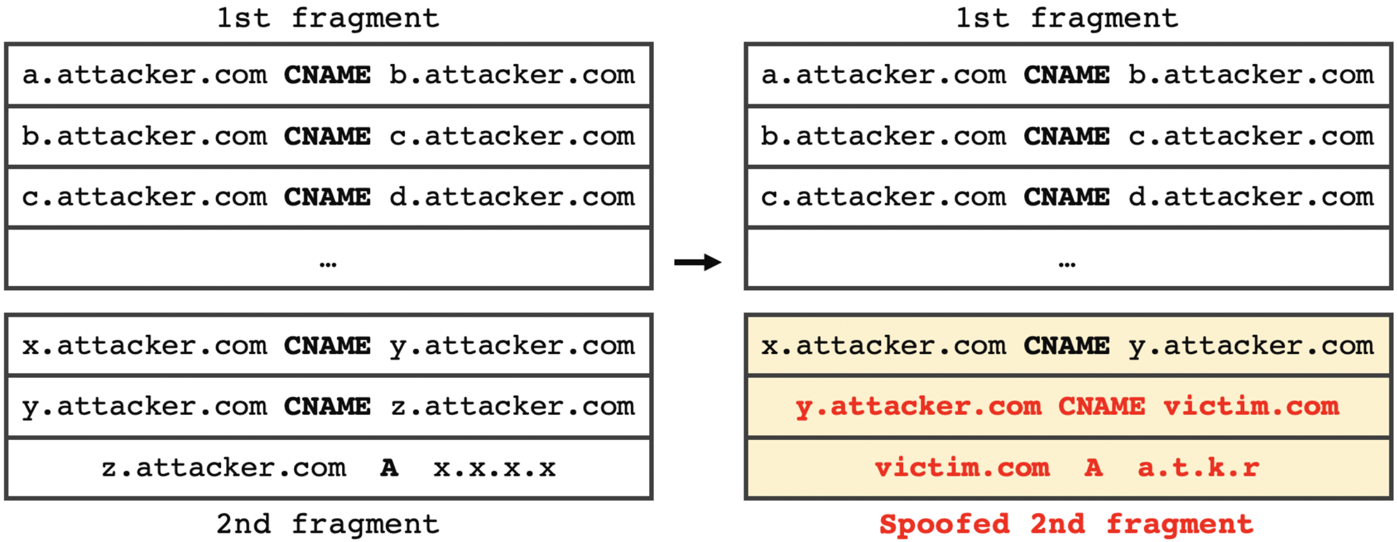
  - Use CNAME to **point attacker's domain to any victim**



What the recursive resolver sees

```
1st fragment
a.attacker.com CNAME b.attacker.com
b.attacker.com CNAME c.attacker.com
c.attacker.com CNAME d.attacker.com
…

x.attacker.com CNAME y.attacker.com
y.attacker.com CNAME z.attacker.com
z.attacker.com  A  x.x.x.x
2nd fragment
```

→

```
1st fragment
a.attacker.com CNAME b.attacker.com
b.attacker.com CNAME c.attacker.com
c.attacker.com CNAME d.attacker.com
…

x.attacker.com CNAME y.attacker.com
y.attacker.com CNAME victim.com
victim.com  A  a.t.k.r
Spoofed 2nd fragment
```

What the DNS forwarder sees

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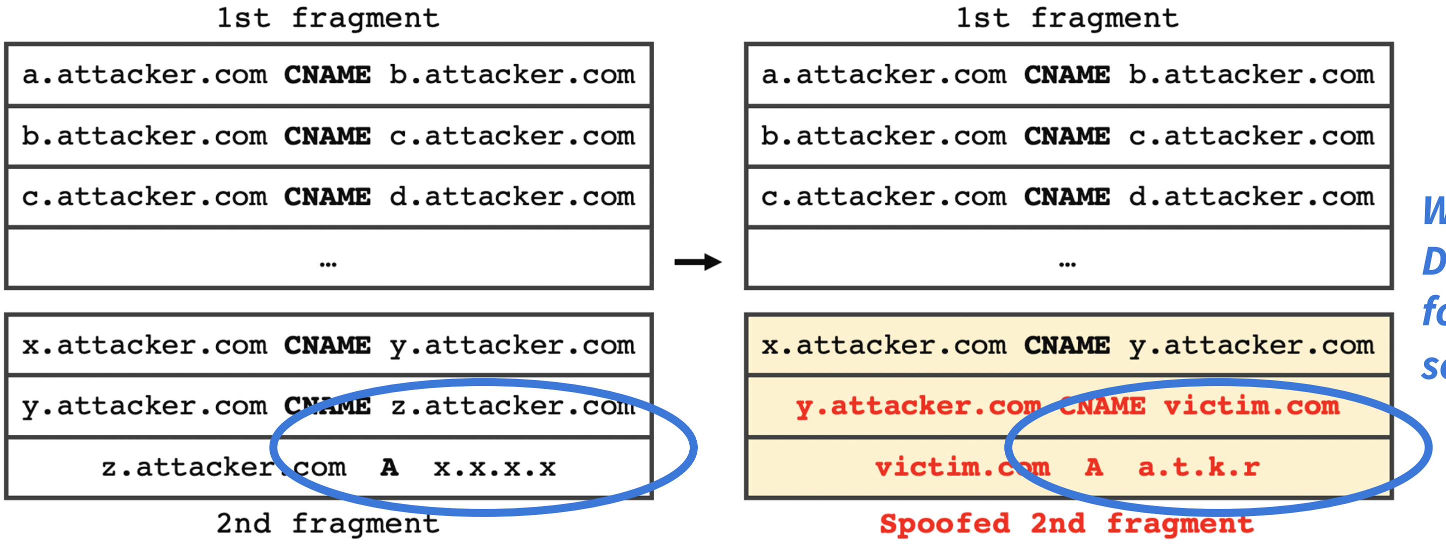


What the recursive resolver sees

1st fragment

a.attacker.com **CNAME** b.attacker.com

b.attacker.com **CNAME** c.attacker.com

c.attacker.com **CNAME** d.attacker.com

…

x.attacker.com **CNAME** y.attacker.com

y.attacker.com **CNAME** z.attacker.com

z.attacker.com **A** x.x.x.x

2nd fragment

→

What the DNS forwarder sees

1st fragment

a.attacker.com **CNAME** b.attacker.com

b.attacker.com **CNAME** c.attacker.com

c.attacker.com **CNAME** d.attacker.com

…

x.attacker.com **CNAME** y.attacker.com

y.attacker.com CNAME victim.com

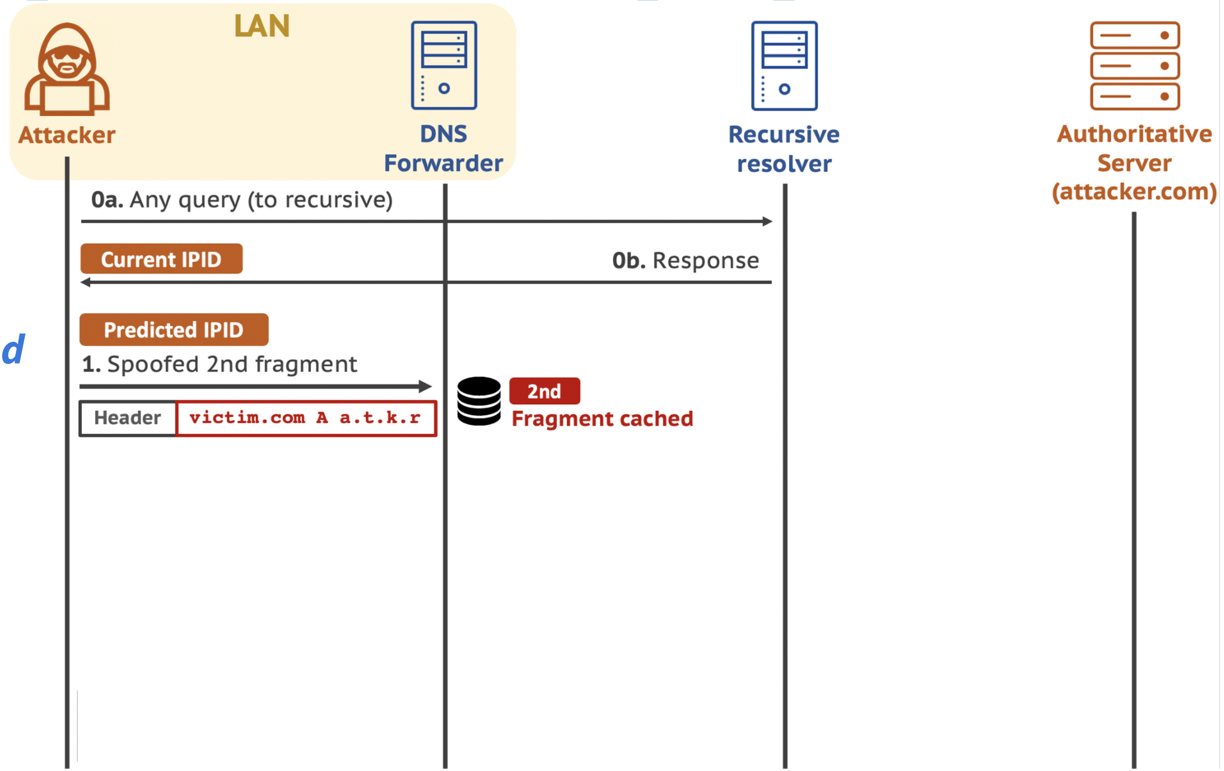
victim.com A a.t.k.r

Spoofed 2nd fragment

Flow of Defragmentation Attack

- Defragmentation attacks targeting DNS forwarders

1. Craft spoofed 2nd fragment

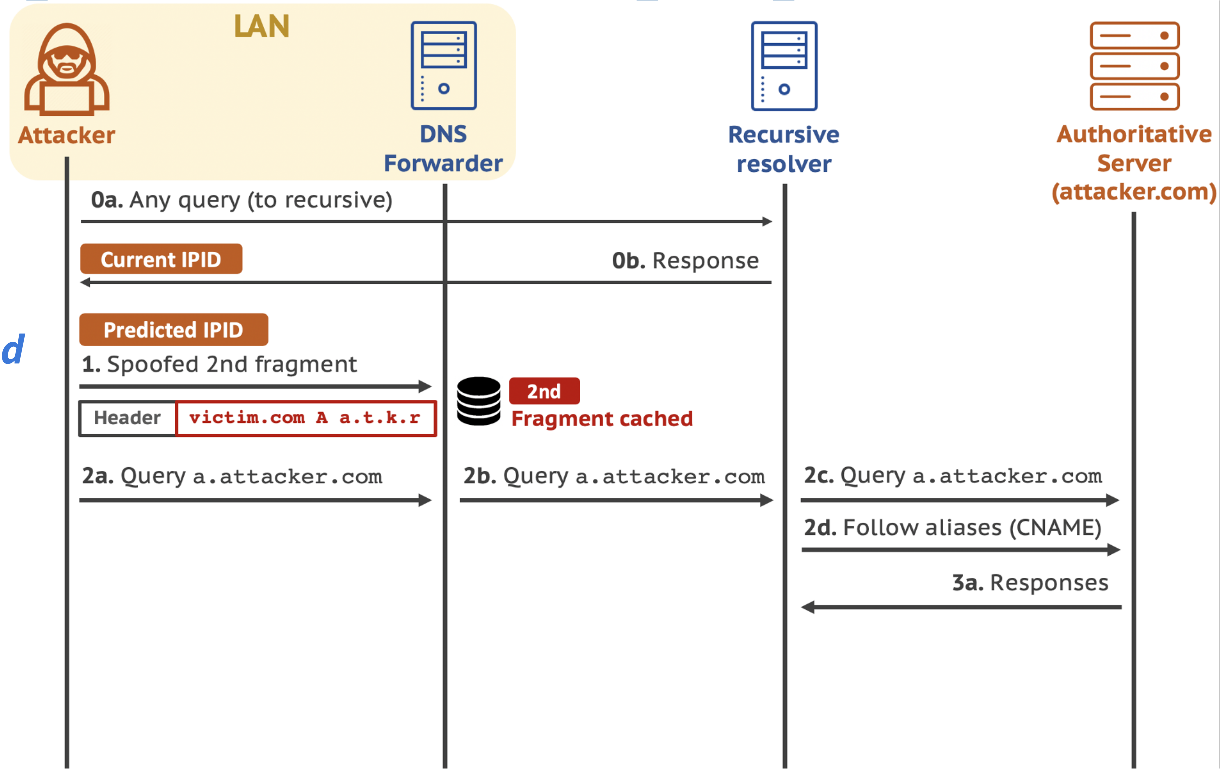


Flow of Defragmentation Attack

- Defragmentation attacks targeting DNS forwarders

1. Craft spoofed 2nd fragment

2. Issue a DNS query



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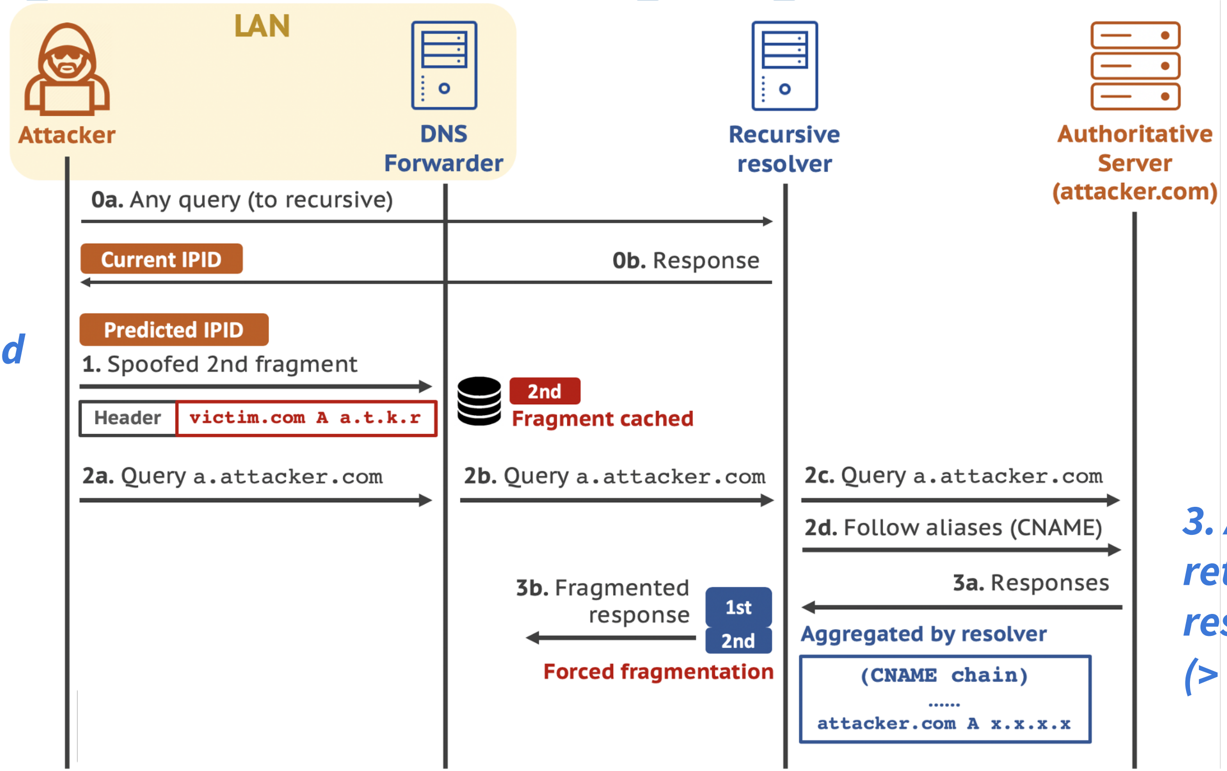

3. Authoritative returns oversized response (> Ethernet MTU)

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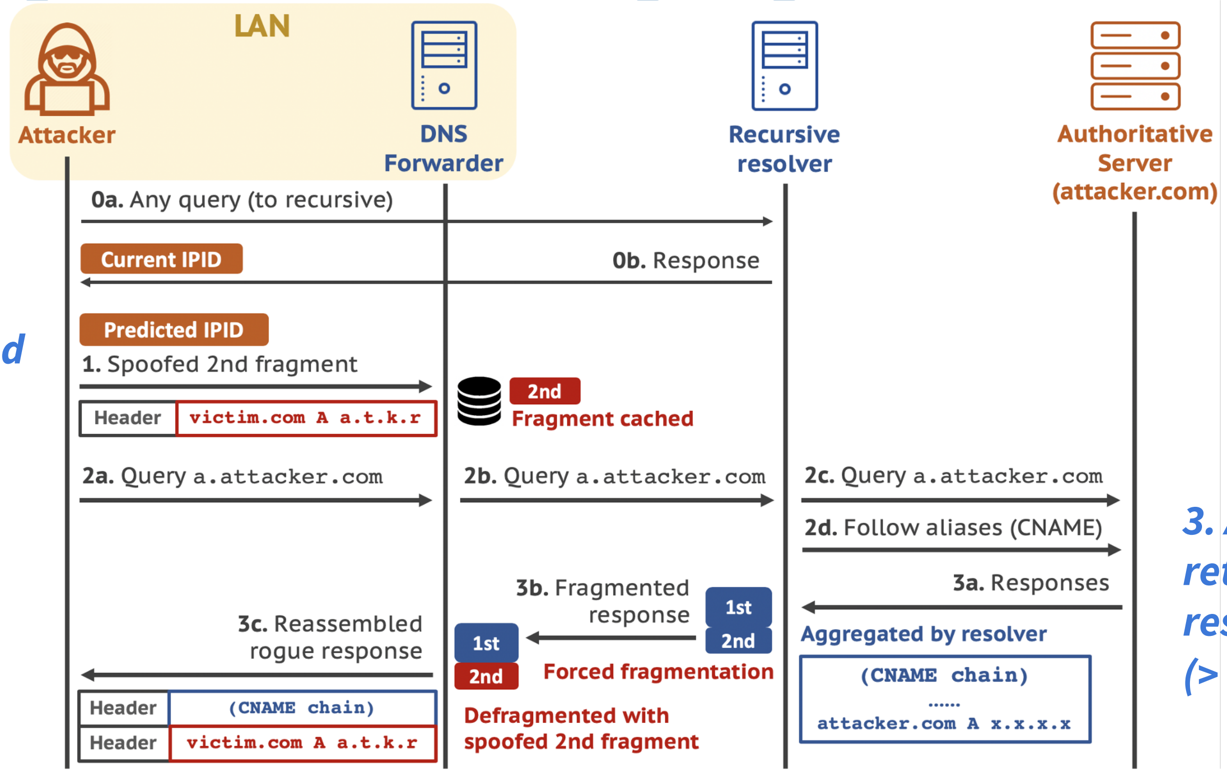
4. Defragment by forwarder



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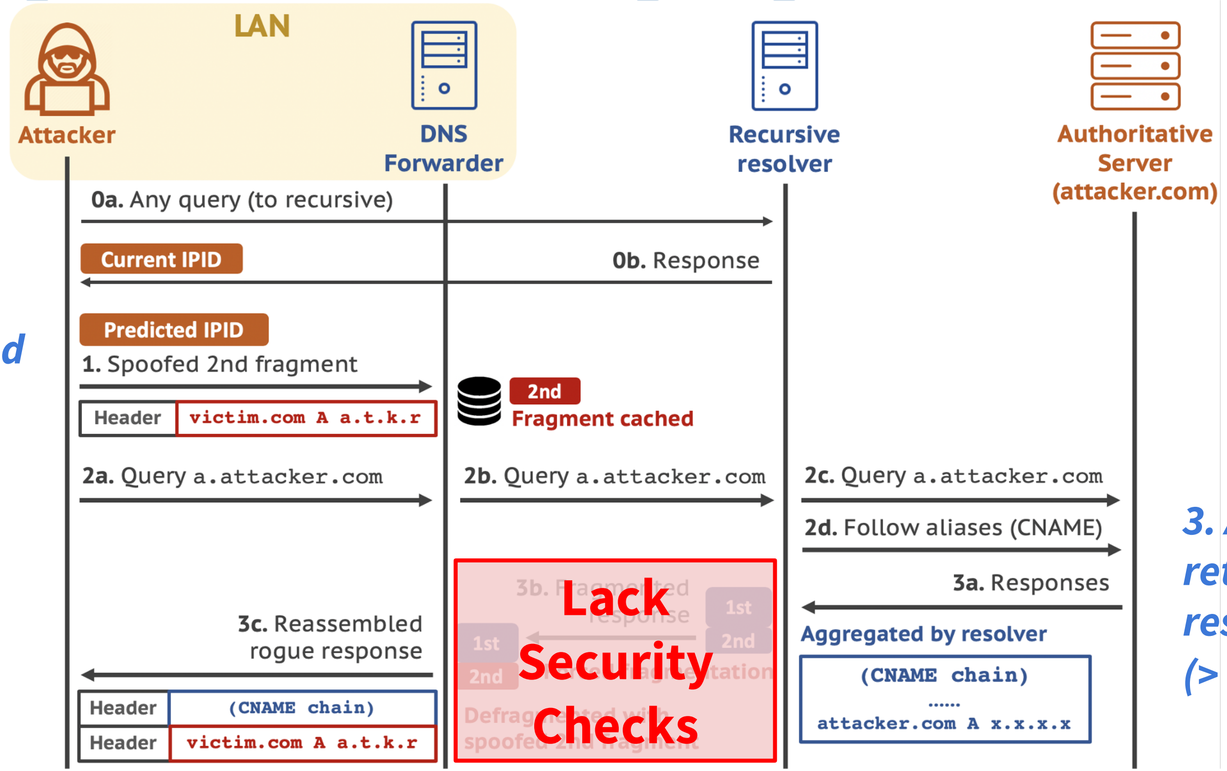

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2. Issue a DNS query

3. Authoritative returns oversized response (> Ethernet MTU)

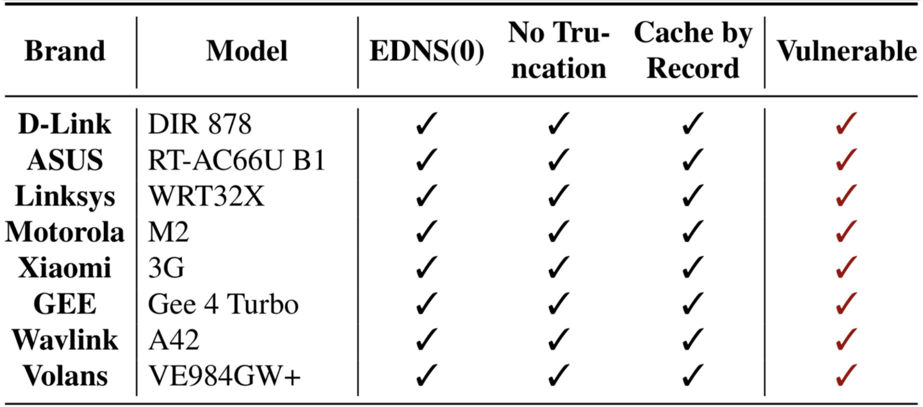
4. Defragment by forwarder

Conditions of Successful Attacks

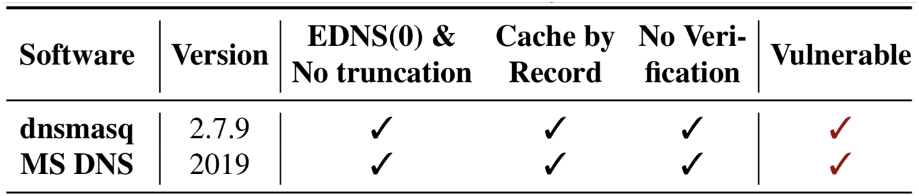
- DNS caching by record
  - The tampered record can be cached separately
- EDNS(0) support
  - Allows transfer of DNS messages larger than 512 Bytes
- No active truncation of DNS response
  - Ensures that the entire oversized response is transfered
- No response verification
  - DNS forwarders rely on upstream resolvers

Vulnerable DNS Software

- Home routers
  - 16 models are tested (by real attacks in controlled environment)
  - **8 models** are vulnerable
- DNS software
  - **2 kinds of popular DNS software** are vulnerable



Brand	Model	EDNS(0)	No Truncation	Cache by Record	Vulnerable
D-Link	DIR 878	✓	✓	✓	✓
ASUS	RT-AC66U B1	✓	✓	✓	✓
Linksys	WRT32X	✓	✓	✓	✓
Motorola	M2	✓	✓	✓	✓
Xiaomi	3G	✓	✓	✓	✓
GEE	Gee 4 Turbo	✓	✓	✓	✓
Wavlink	A42	✓	✓	✓	✓
Volans	VE984GW+	✓	✓	✓	✓



Software	Version	EDNS(0) & No truncation	Cache by Record	No Verification	Vulnerable
dnsmasq	2.7.9	✓	✓	✓	✓
MS DNS	2019	✓	✓	✓	✓

Vulnerable DNS Software

- Home routers
  - 16 models are tested (by real attacks in controlled environment)
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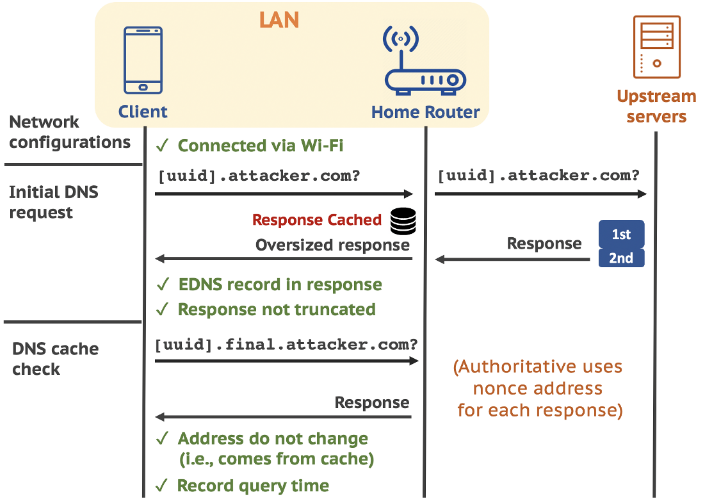
- DNS software
  - **2 kinds of popular DNS software** are vulnerable
- Responsible Disclosure
  - ASUS and D-Link release firmware patches
  - Linksys accepts issue via BugCrowd

Measuring Clients Potentially Under Risk

- Collect vantage points
  - Implement measurement code in a network diagnosis tool
  - **20K clients**, mostly located in China
- Check the forwarder conditions
  - Ethical considerations: no real attack
  - 40% do not support EDNS(0) yet
  - **Estimated vulnerable clients: 6.6%**



Discussion

- Mitigation for DNS forwarders
  - Perform response verification (e.g., DNSSEC)
  - **DNS caching by response (short-term solution)**
- Lack clear guidelines of DNS forwarders
  - What role should they play?
  - What features should be supported?

- An attack targeting DNS forwarders
- Affects forwarder implementations extensively
- Call for more attention on DNS forwarder security

Any Questions?

zxf19@mails.tsinghua.edu.cn