When Network Protocols Meet New Threat Models

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Introduction

Goal of this talk:

› Explain some interesting network attacks + demos ☺

› Common theme: attacks are enabled by novel threat model

I will use the word “threat model” rather informally:

› In some attacks, the adversary is given extra capabilities

› In other attacks, the focus is more on new attack techniques

Agenda

- Attacks that introduced new threat models:
  - **The BEAST and HEIST attack (TLS/HTTPS)**
  - The Multi-Channel MitM (KRACK)
  - Outbound Connections (FragAttacks)
  - Client Isolation (Framing Frames)
  - DNS Spoofing & VPNs (TunnelCrack)
- Conclusion

The BEAST attack against SSL/TLS

- Phillip Rogaway (‘95): CBC encryption can be attacked when the Initialization Vectors (IVs) are predictable
- Fixed in TLS1.1, but TLS1.0 was still very common
  - “It’s hard to abuse, so not important to fix”
- Duong & Rizzo (‘11): attacked CBC in practice by assuming **malicious JavaScript in the browser + network MitM**
  - And extended attack to achieve full plaintext recovery
  - Sudden scramble to update implementations

Reference: One Bad Apple: Backwards Compatibility Attacks on State-of-the-Art Cryptography

The BEAST Threat Model

- Arguably most influential contribution was the threat model:
  - Attack can execute JavaScript in the victim's browser
  - And attacker can intercept (encrypted) network traffic
- *This **new threat model** completely broke TLS 1.0*
- The "BEAST threat model" was (and is) used in many works
  - In many attacks against RC4, including our RC4 NOMORE attack
  - Many TLS attacks (Lucky13, Bleichenbacher attacks, DROWN)
  - In the **CRIME and BREACH attack** to abuse compression

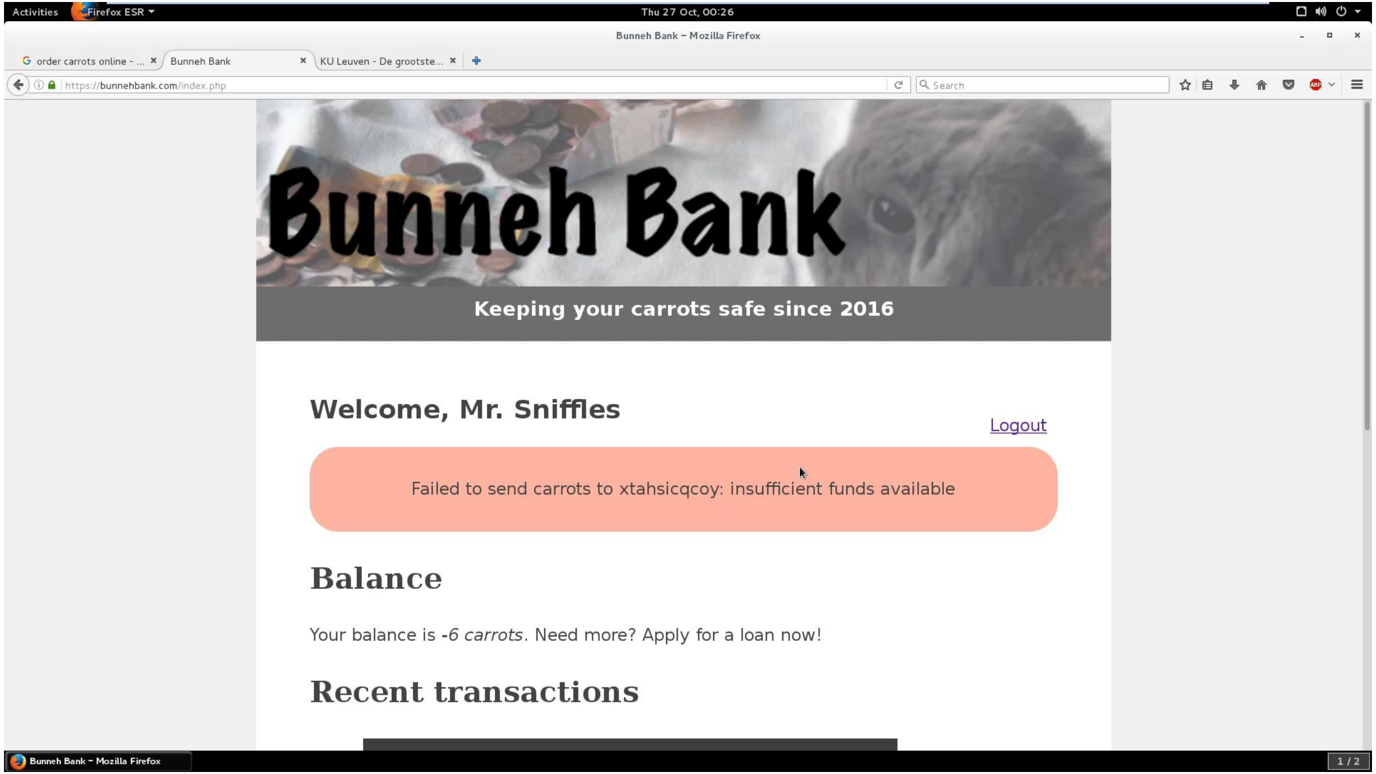
Abusing compression: CRIME and BREACH

- Abuse compression in TLS/HTTPS to leak data in response
- Idea is to make a page reflect the guessed **CRSF token**
  - Correct guess results in smaller response due to efficient compression
- Like BEAST, relied on malicious JavaScript + network MitM
  - Network MitM was used to measure length of response

HEIST attack: also abuses compression to recover CRF token

- But uses **timing side-channels instead of needing MitM**

DEMO: HEIST Attack



Reflection

- The new “BEAST threat model” enabled various follow-up works to construct more practical attacks
- Some attacks were further improved to reduce the required capabilities of the attacker

“Attacks only get better, they never get worse.”

— Bruce Schneier

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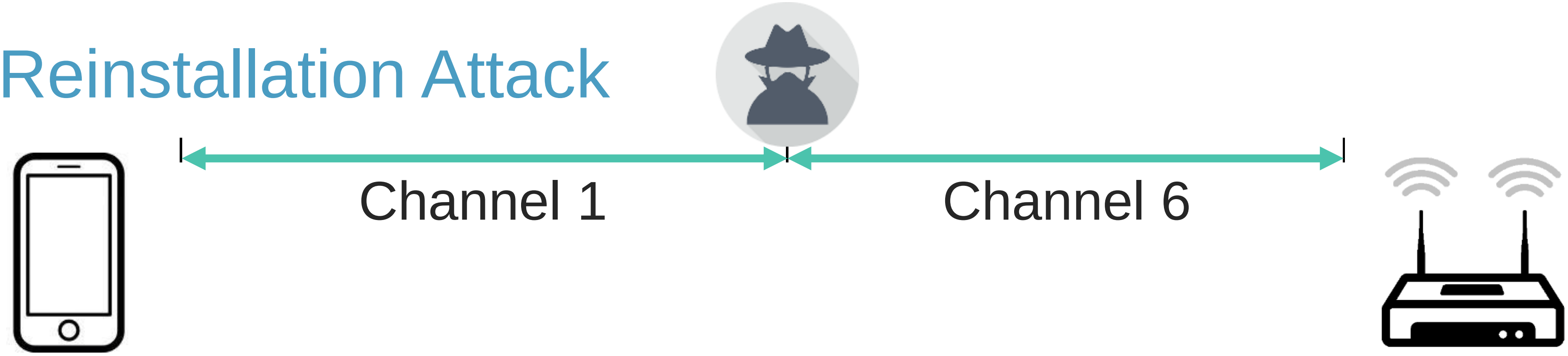
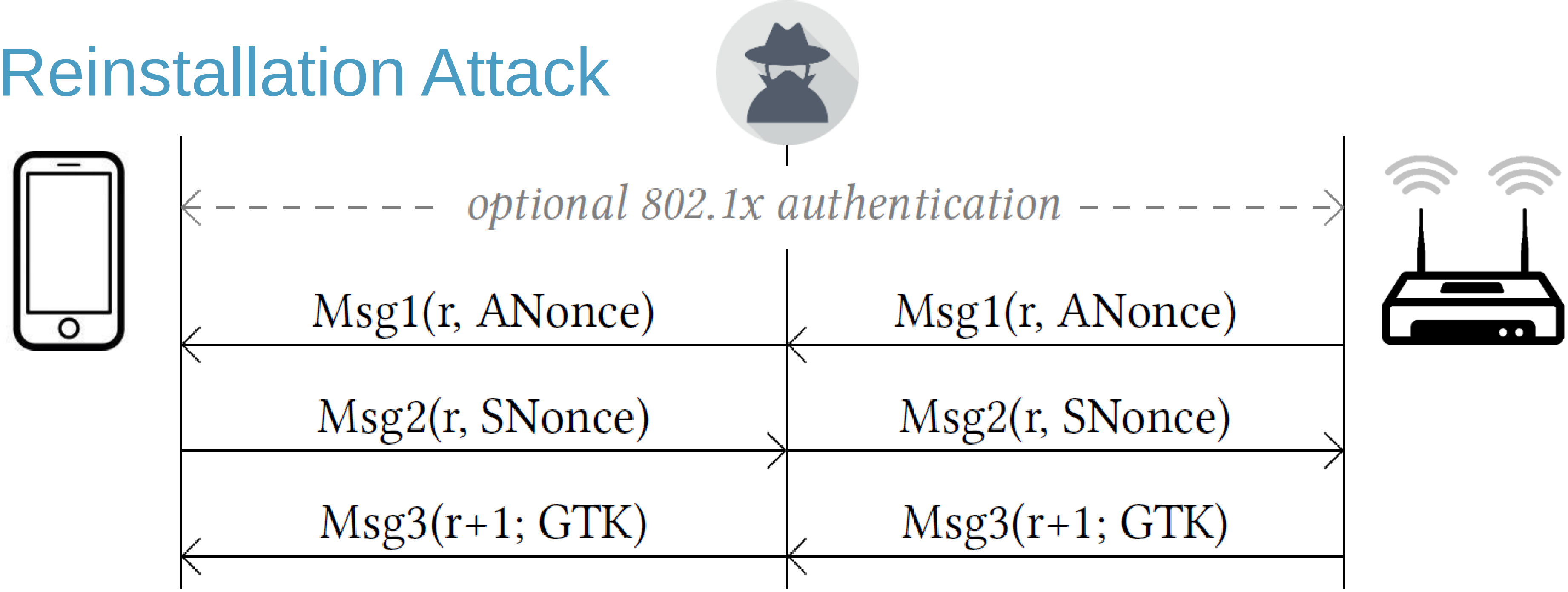
Reinstallation Attack



➔ Called a “Multi-Channel MitM” (MC-MitM)

Reinstallation Attack

Reinstallation Attack



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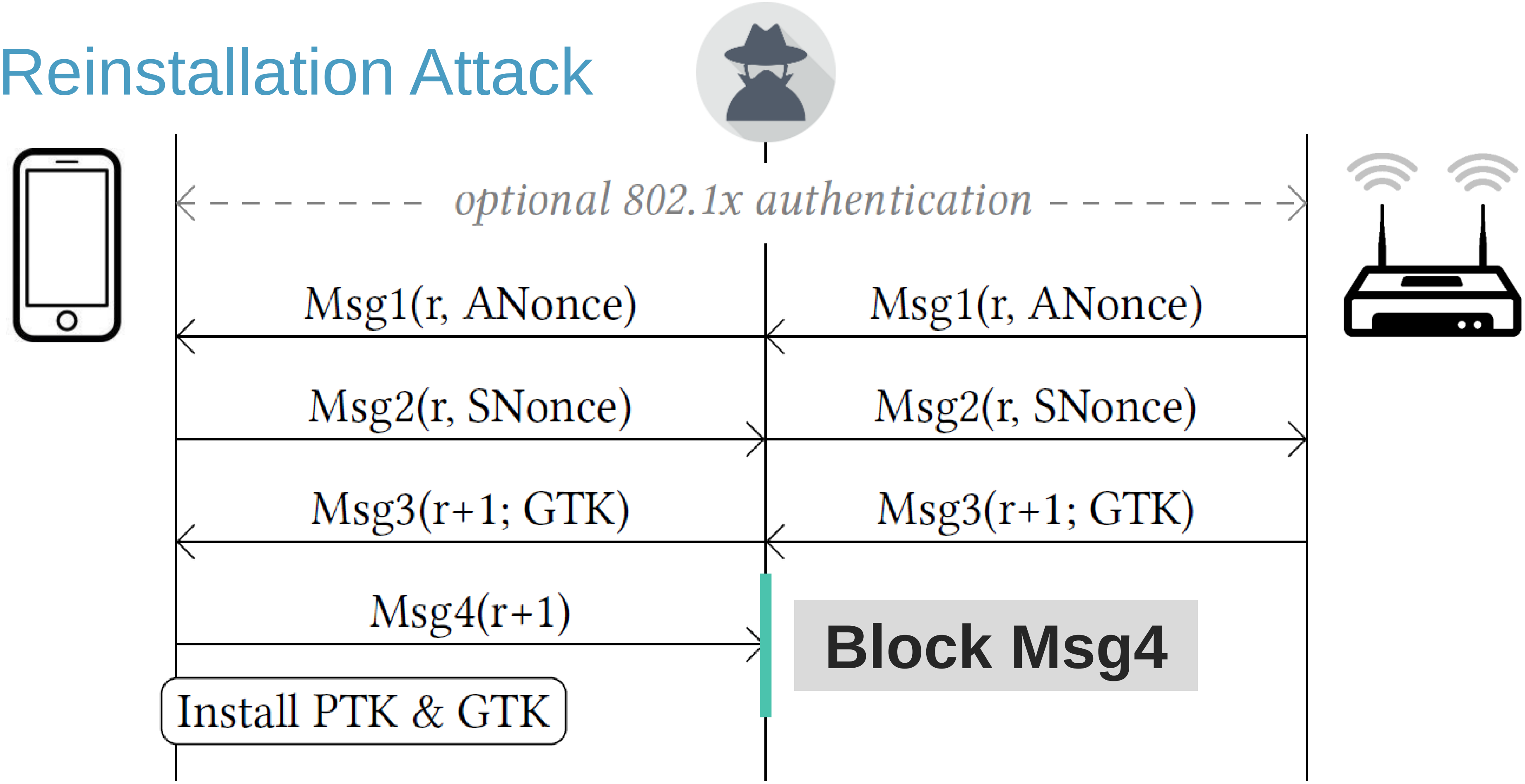
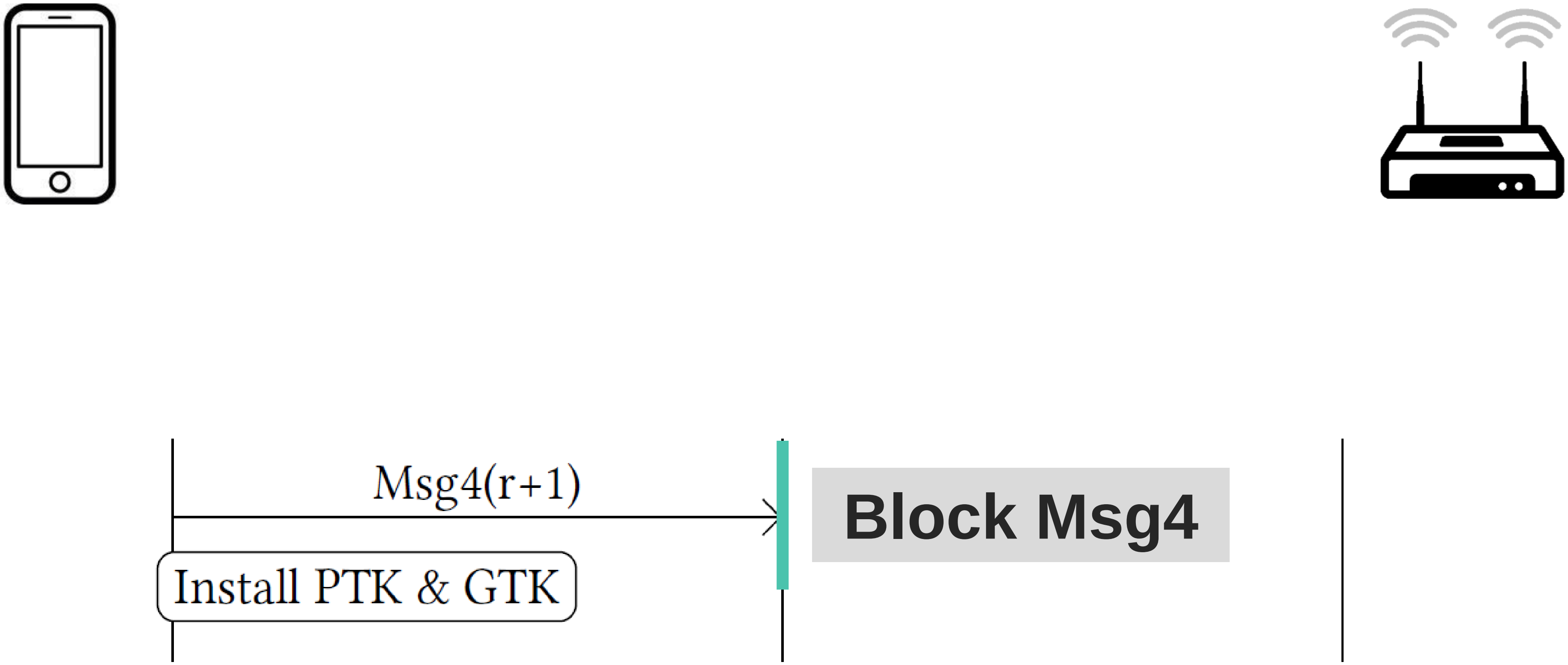


Reinstallation Attack



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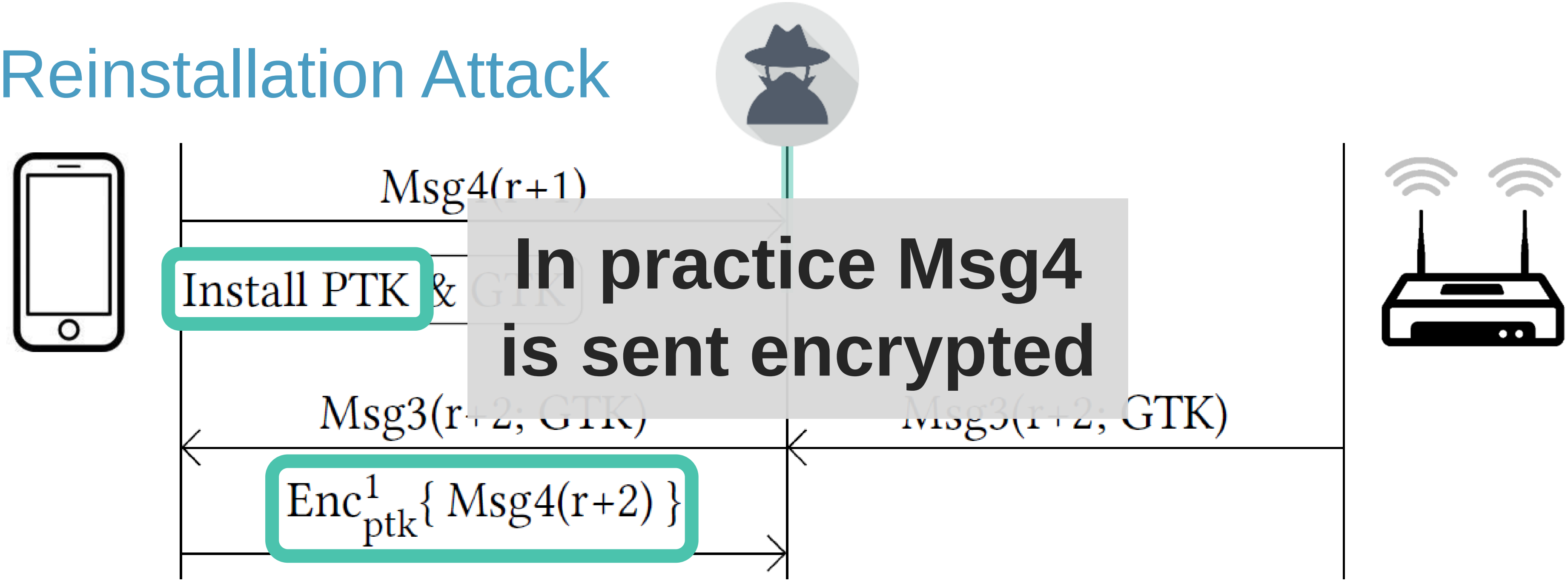
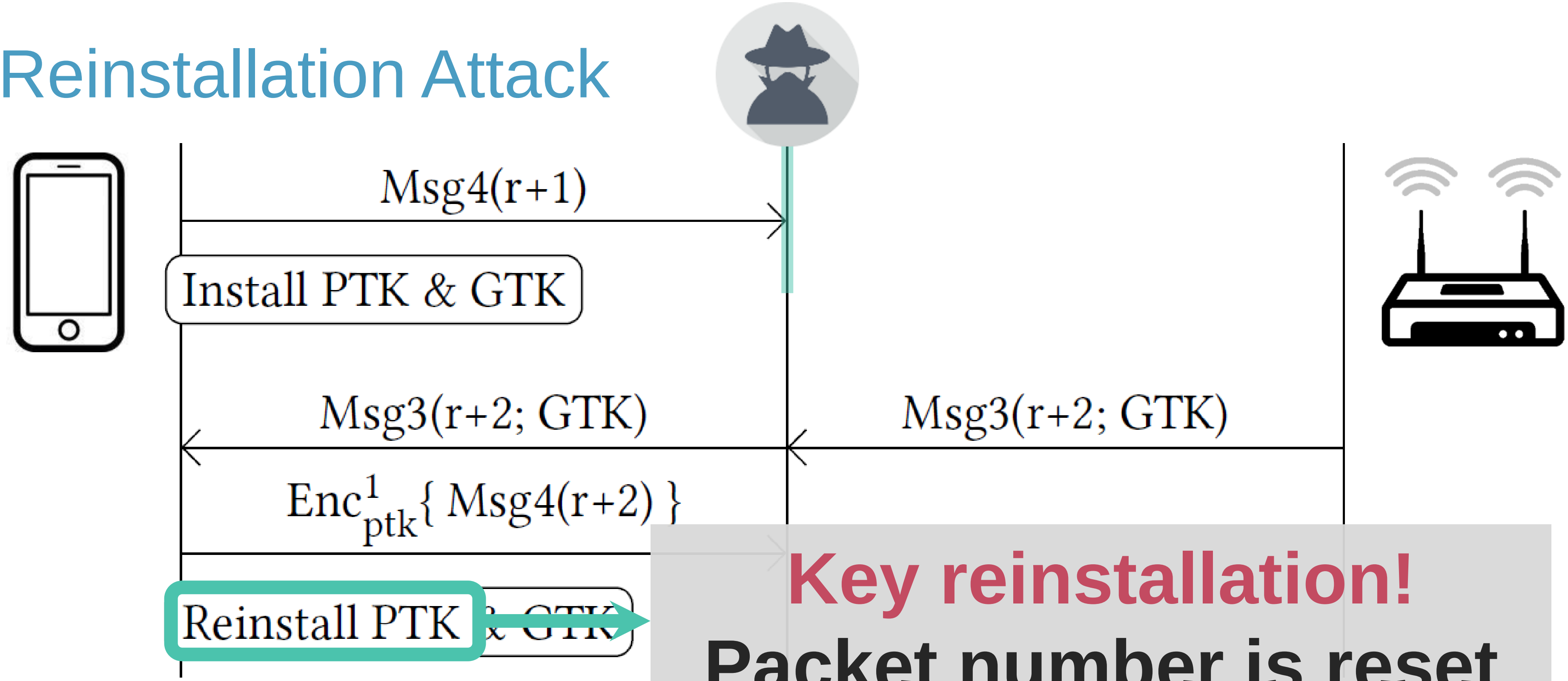


In practice Msg4 is sent encrypted

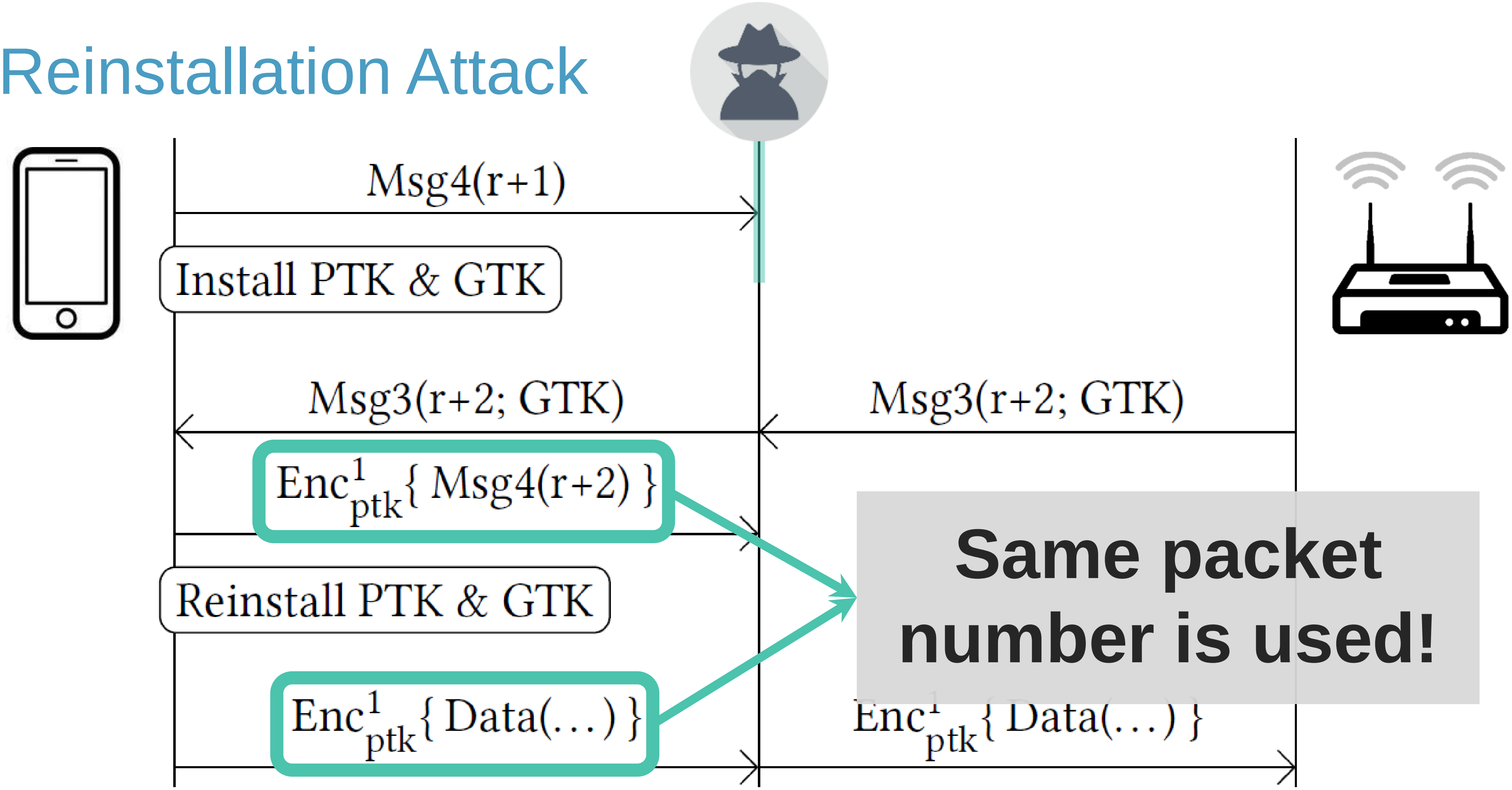
Reinstallation Attack



Key reinstallation!

Packet number is reset

Reinstallation Attack



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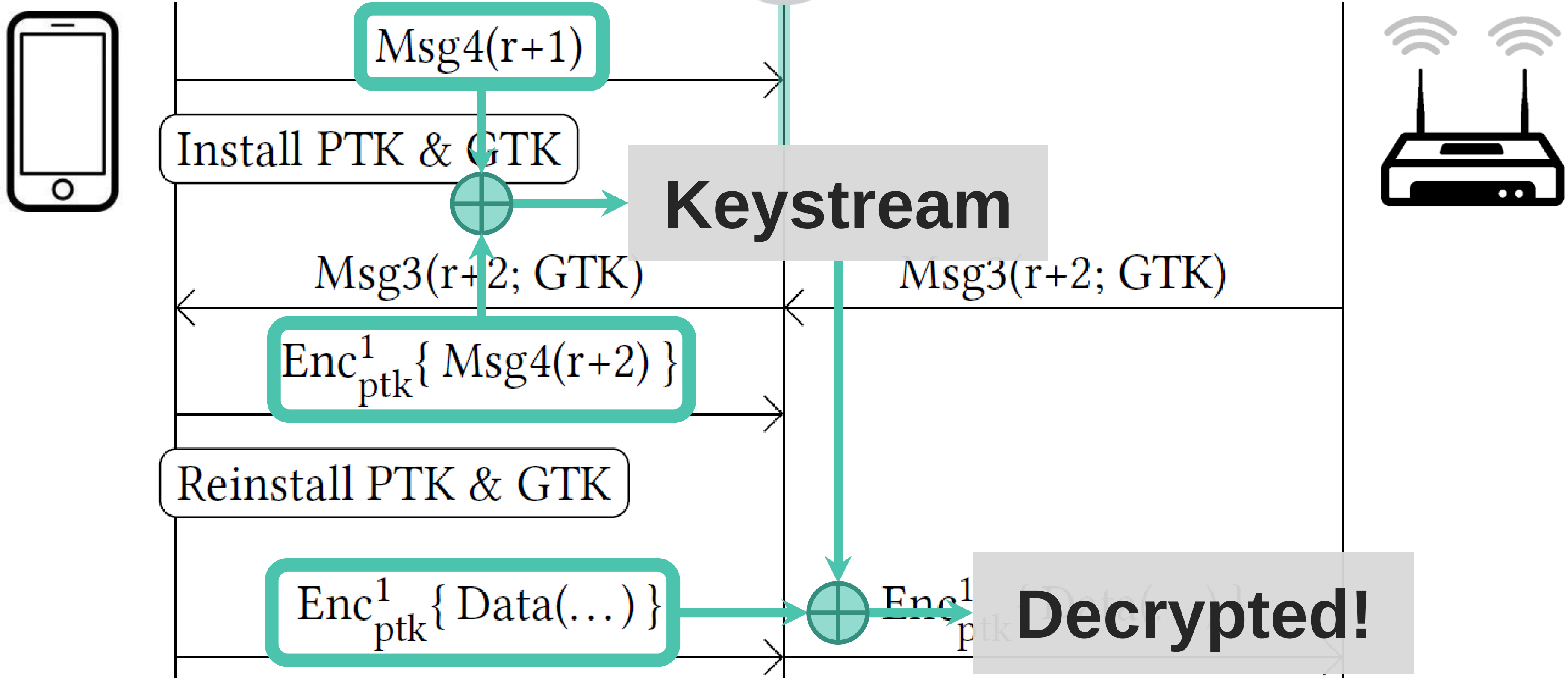

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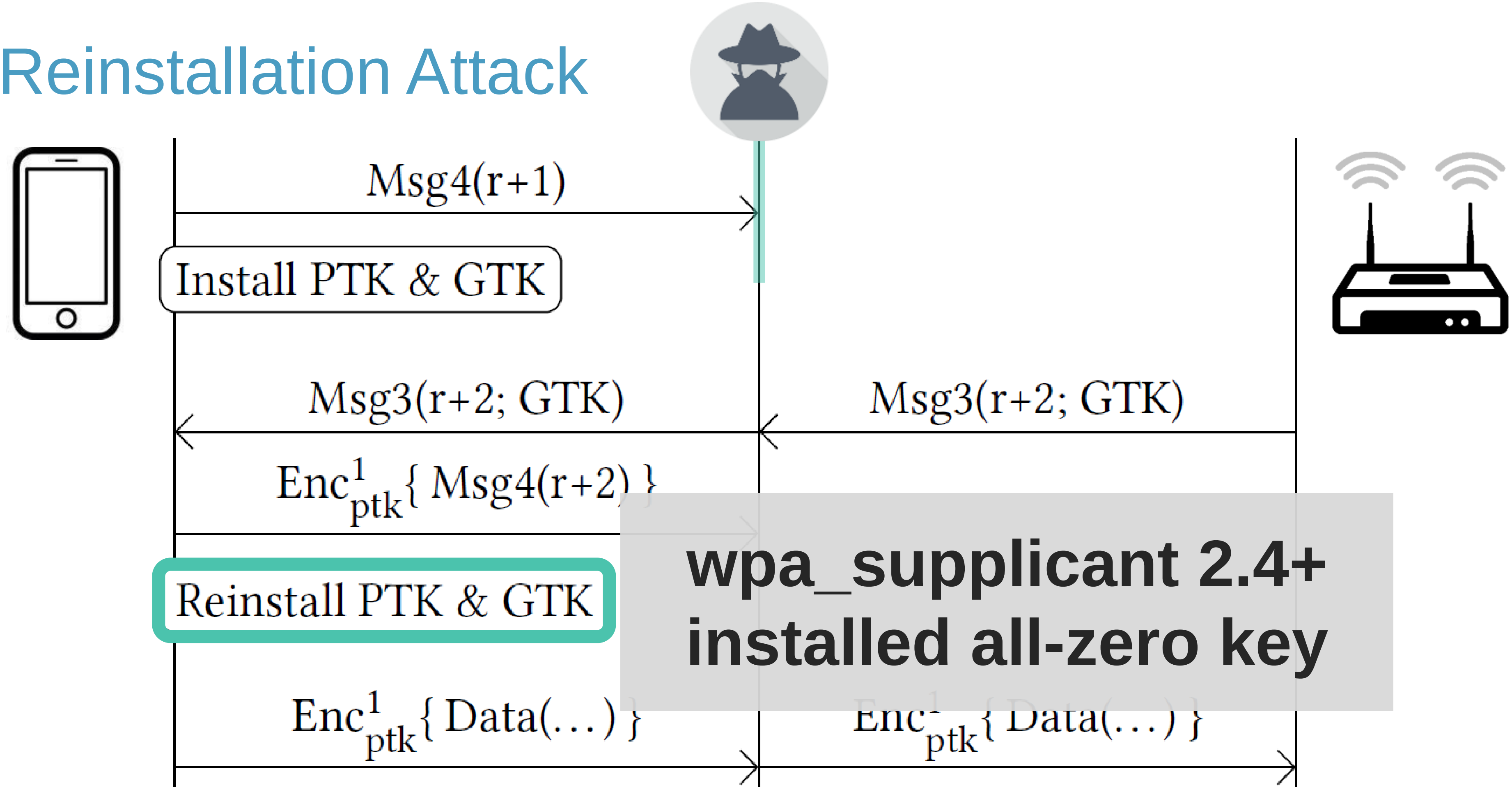
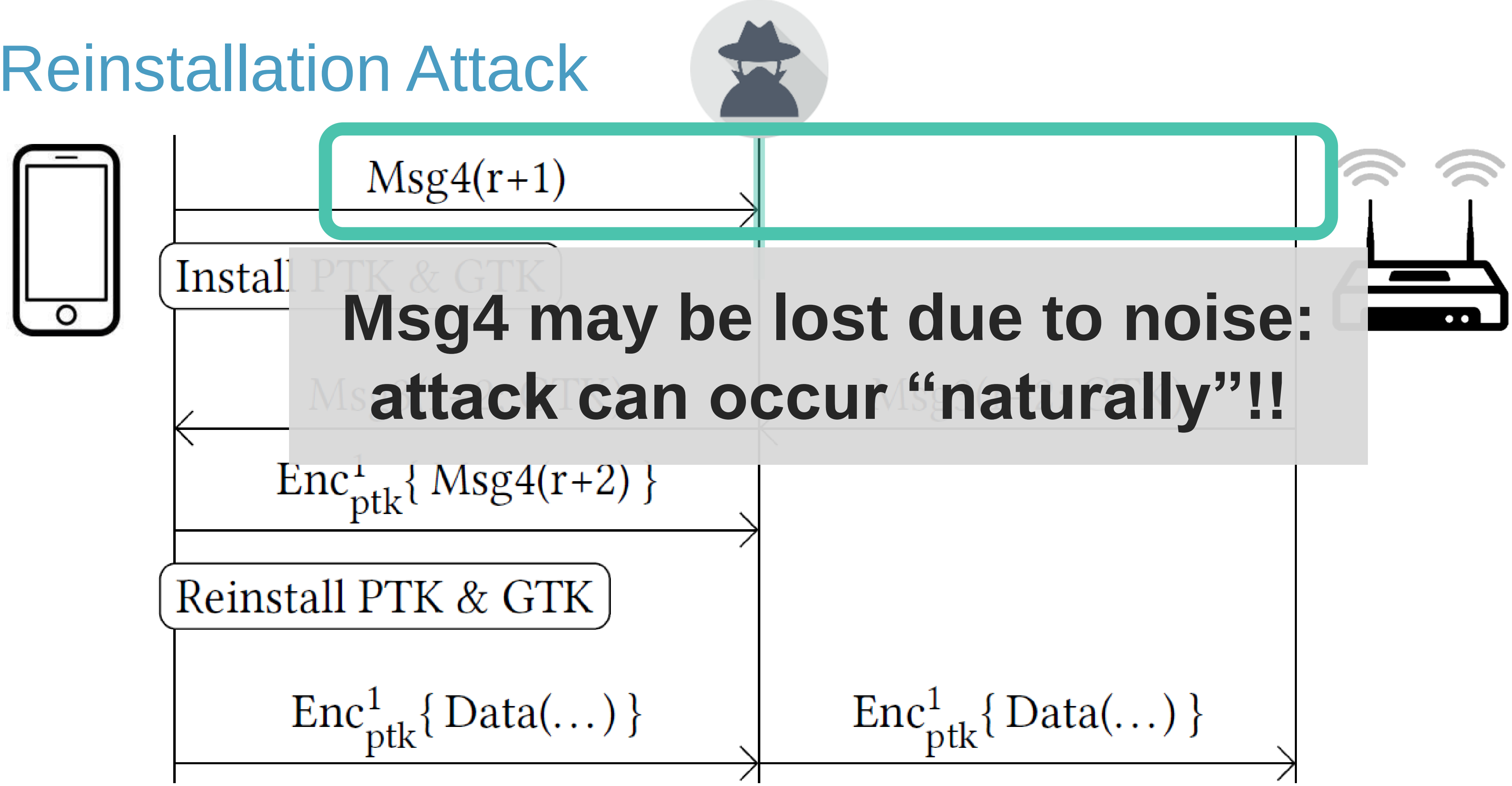


wpa_supplicant 2.4+ installed all-zero key

Reinstallation Attack



Msg4 may be lost due to noise: attack can occur “naturally”!!

Installation of all-zero key was detected (!!)

Bug report on Linux's hostap mailing list:

"While testing with supplicant 2.4 we observed [..]:

4. *We send M4 and install PTK*
5. *We received M3 again*
6. *We send M4 and install PTK*

… we install it as 0 again in step (6)"

[1] An issue with supplicant receiving retranmitted M3 (Atul Joshi)
[2] An issue with supplicant receiving retranmitted M3 (Jouni Malinen)
[3] Fix TK configuration to the driver in EAPOL-Key 3/4 retry case

This bug was then fixed

- “[..] possibility of the authenticator having to retry EAPOL-Key message 3/4 in case the first EAPOL-Key message 4/4 response is lost. That case **ended up trying to reinstall the same TK to the driver**, but the key was not available”
- They didn’t realize an adversary can force this situation
- The MC-MitM threat model allows us to do this reliably!

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The MC-MitM is used in several works now

- The MC-MitM was originally used by us to break WPA-TKIP
- Was used to infer resource sizes in combination with malicious JavaScript, i.e., in a BEAST-like attack
- To exploit an implementation flaw in Broadcom code
- In our “framing frames” attack
- Also used in the FragAttacks research

References:

- Advanced WiFi Attacks Using Commodity Hardware (ACSAC’14)
- Request and Conquer: Exposing Cross-Origin Resource Size (USENIX Sec ’16)
- Discovering Logical Vulnerabilities in the Wi-Fi Handshake Using Model-Based Testing (Asia CCS ’17)
- Framing Frames: Bypassing Wi-Fi Encryption by Manipulating Transmit Queues (USENIX Sec ’23)

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Background

Sending small frames causes high overhead:

This can be avoided by **aggregating frames**:

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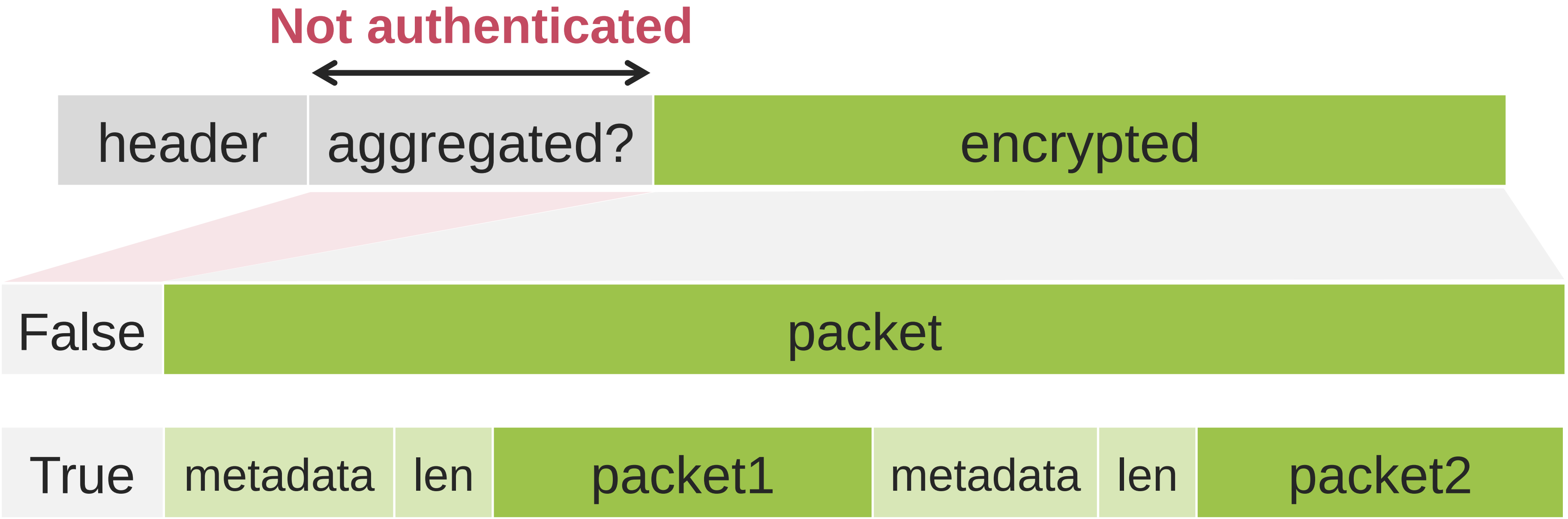
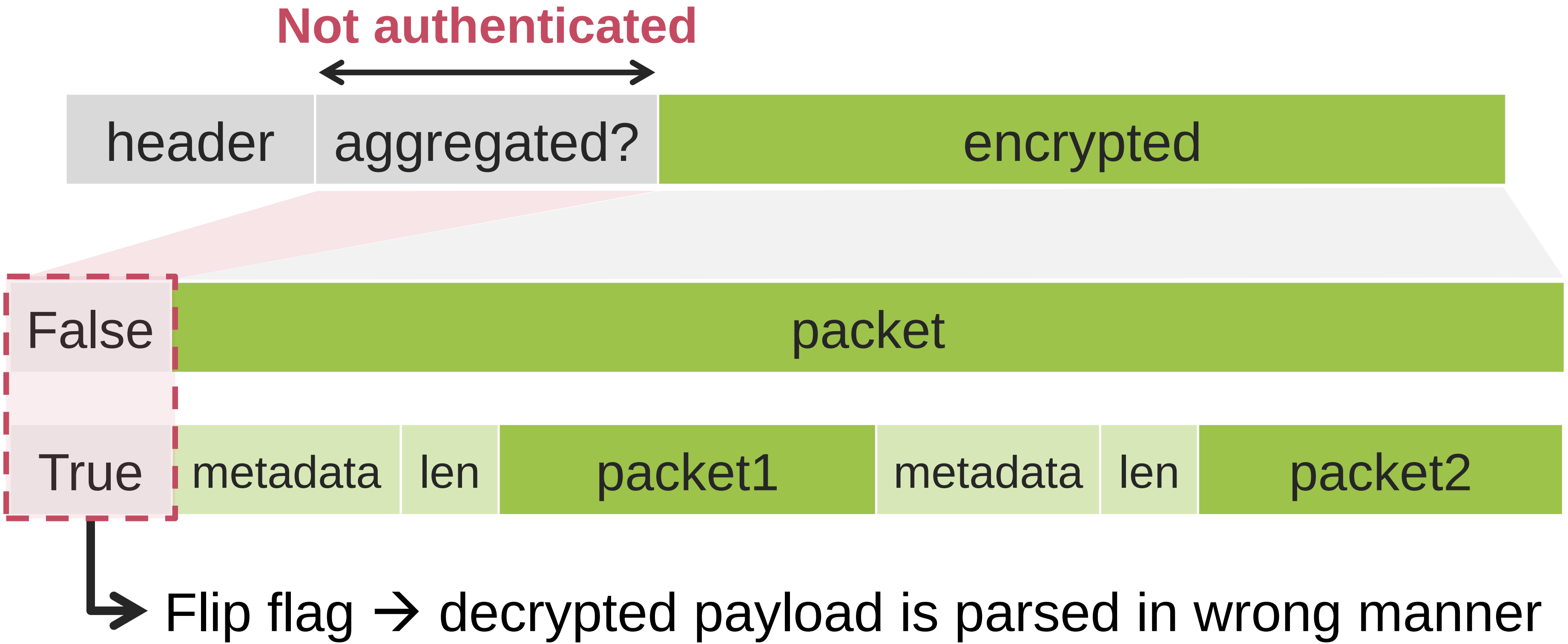
This can be avoided by **aggregating frames**:

Problem: how to recognize aggregated frames?

Aggregation design flaw



Aggregation design flaw



Flip flag → decrypted payload is parsed in wrong manner

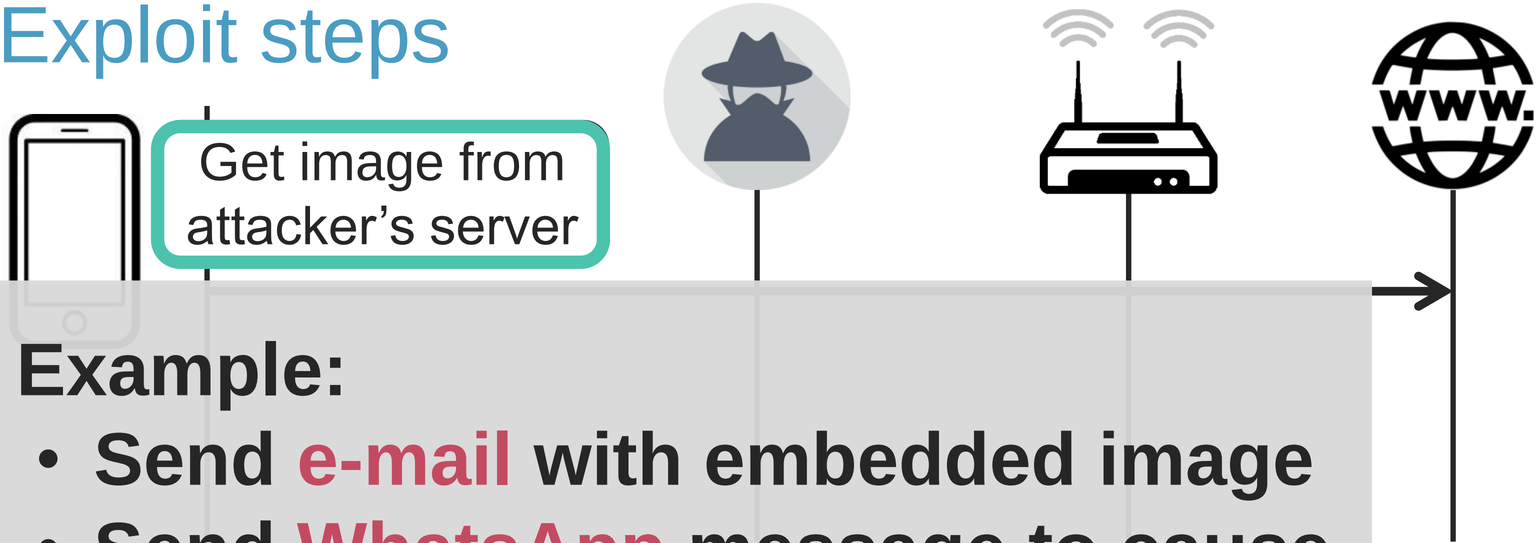
A-MSDU

- Flaw was noticed while 802.11n was being standardized, but implementations based on the draft already existed (2007)
- *“QoS bit 7 should be protected to guard against attack that at minimum leads to a flood of traffic”*
- *“While it is* ***hard to see how this can be exploited****, it is clearly a flaw that is capable of being fixed.”*

→ Exploit by using new threat model ☺ (2021)

[1] Msdu Protection by Nancy Cam-Winget et al. (2007)
[2] Why did nobody notice the aggregation design flaw before?

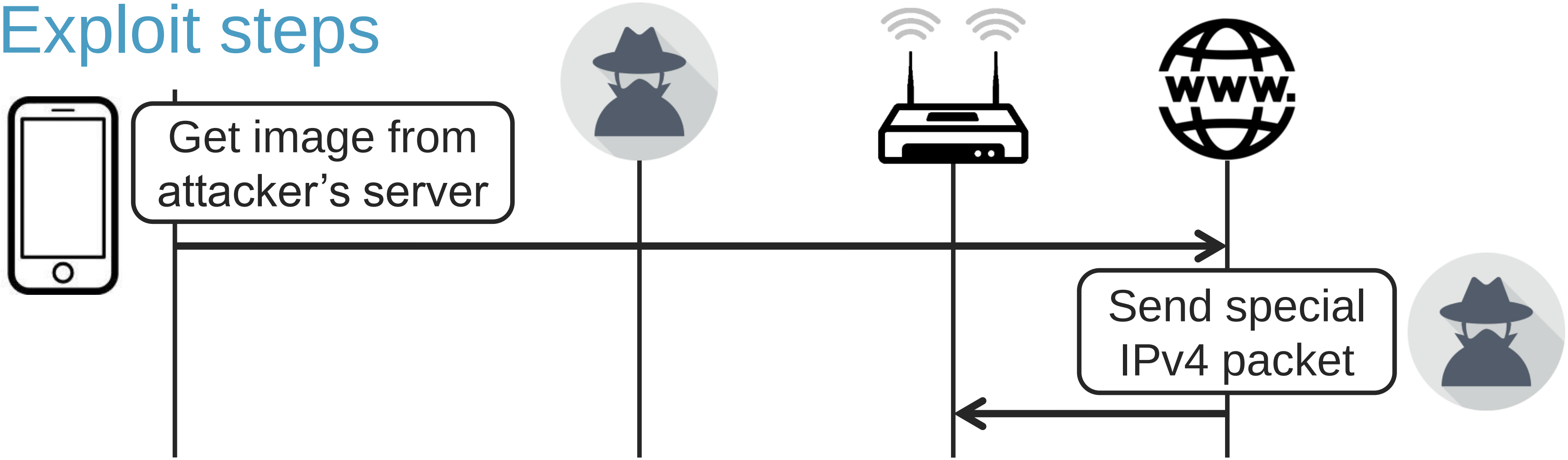
Exploit steps



Example:

- **Send e-mail with embedded image**
- **Send WhatsApp message to cause link/image preview**

Exploit steps



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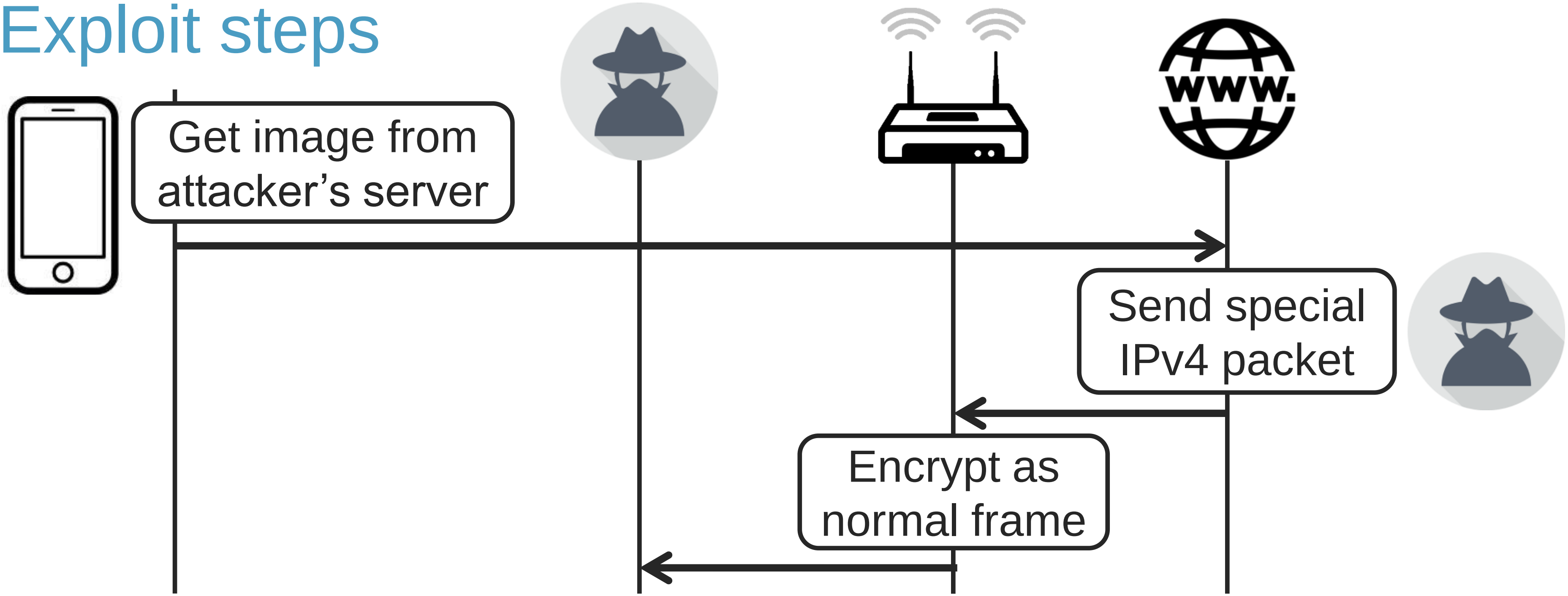

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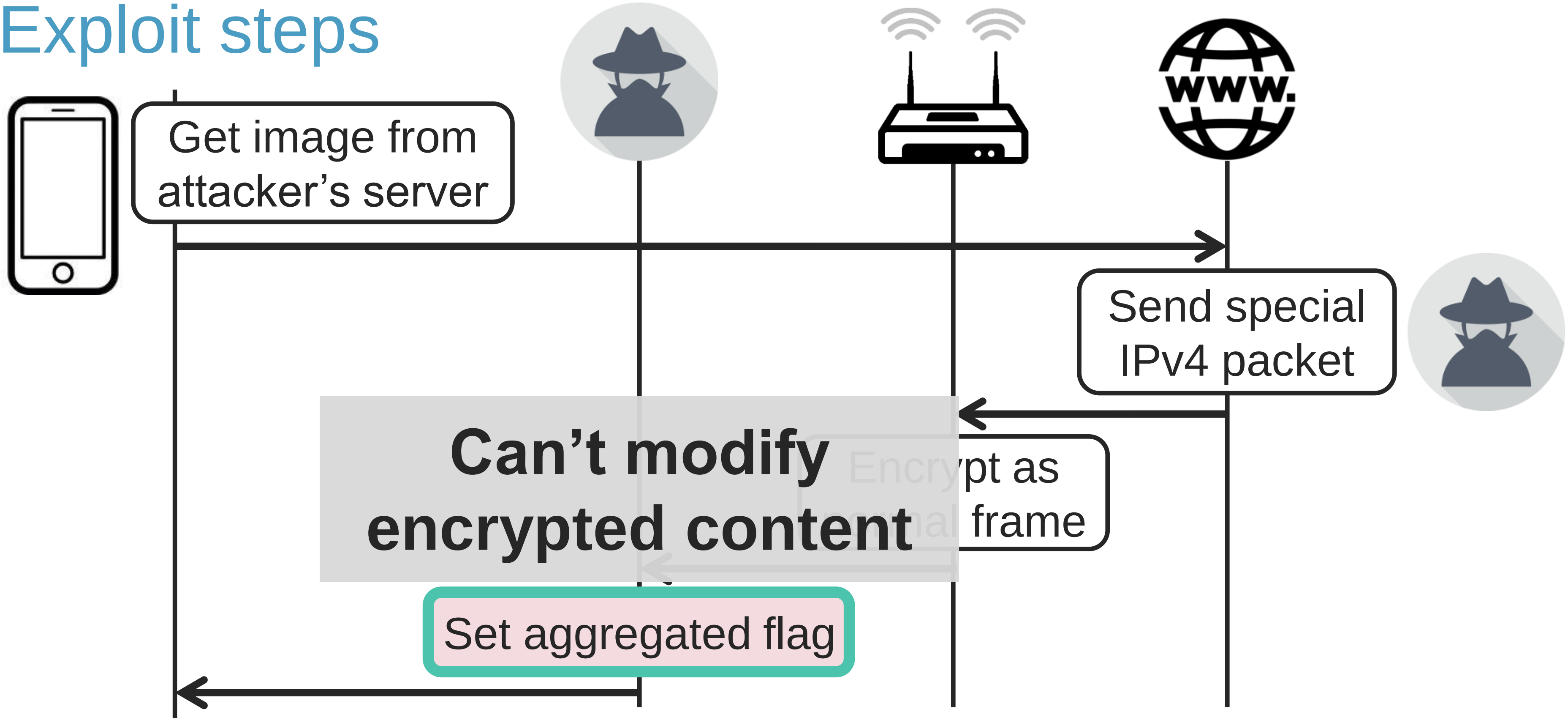

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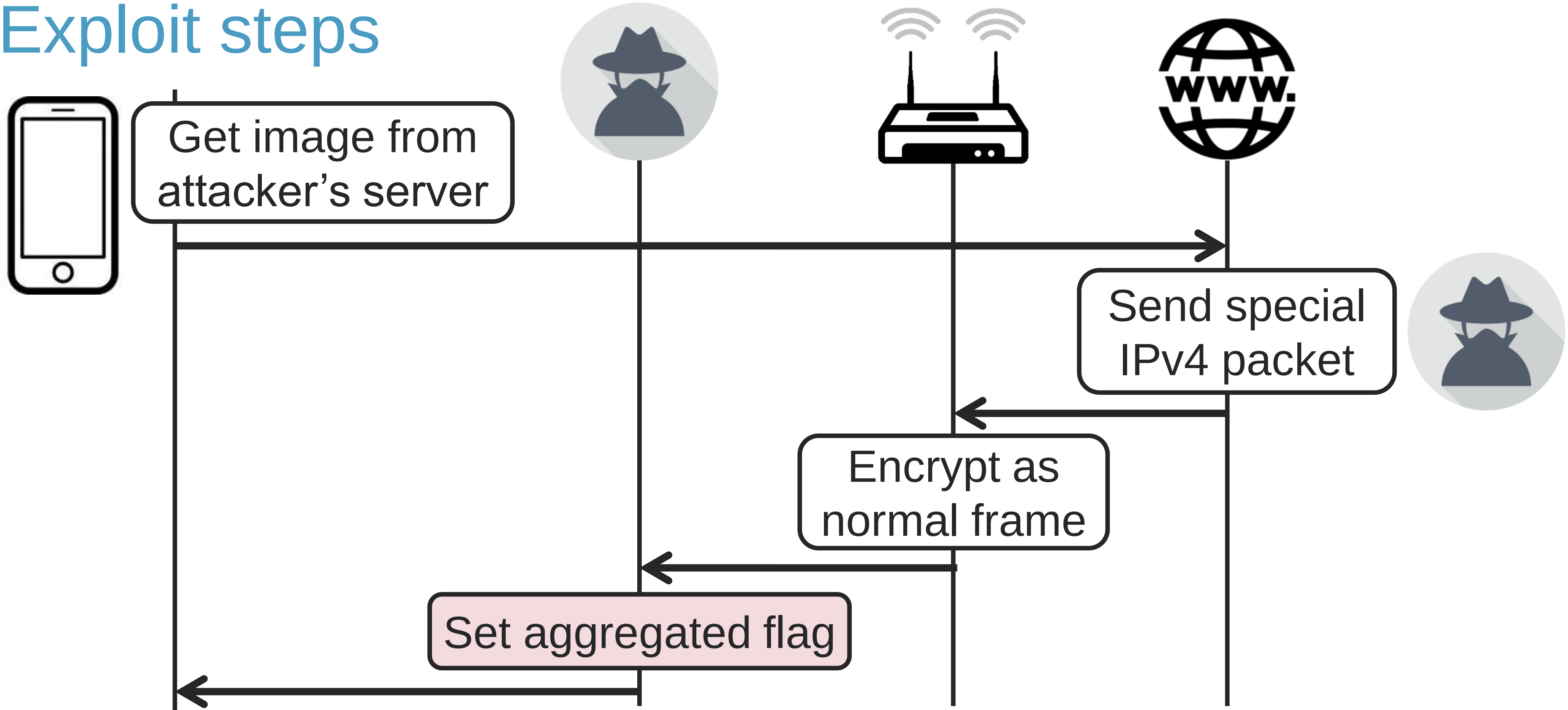
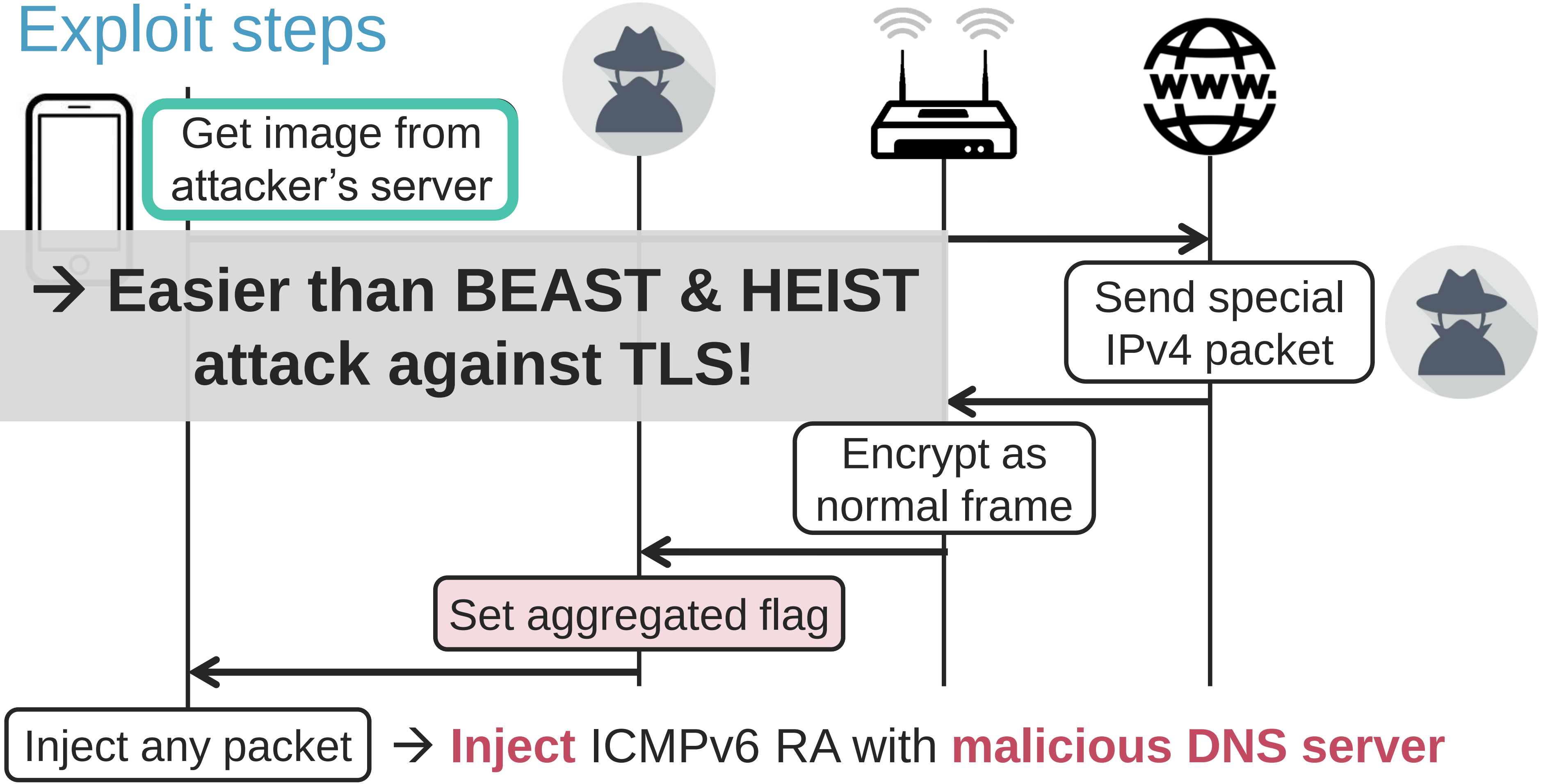


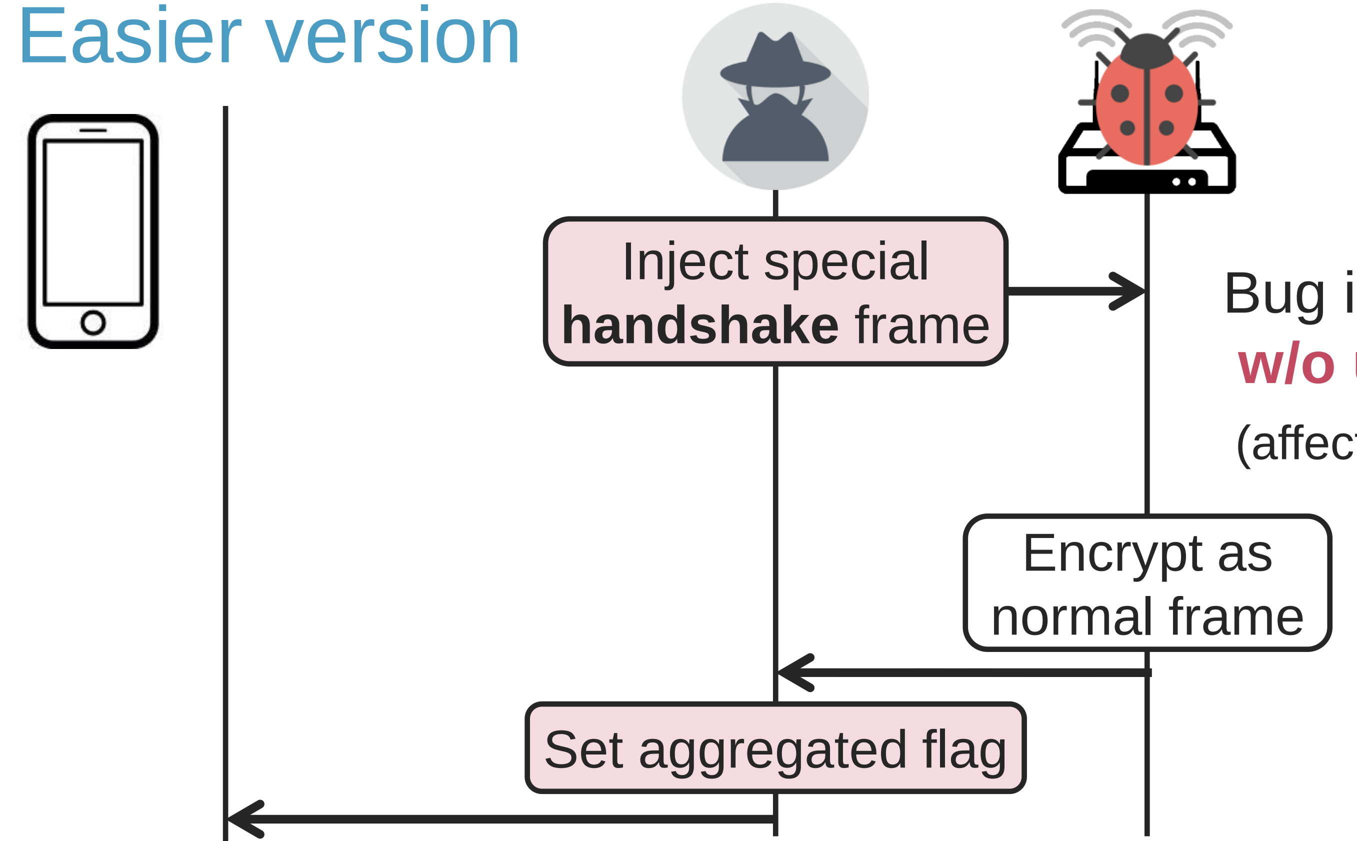
Inject any packet → **Inject** ICMPv6 RA with **malicious DNS server**

Exploit steps



→ **Inject** ICMPv6 RA with **malicious DNS server**

Easier version

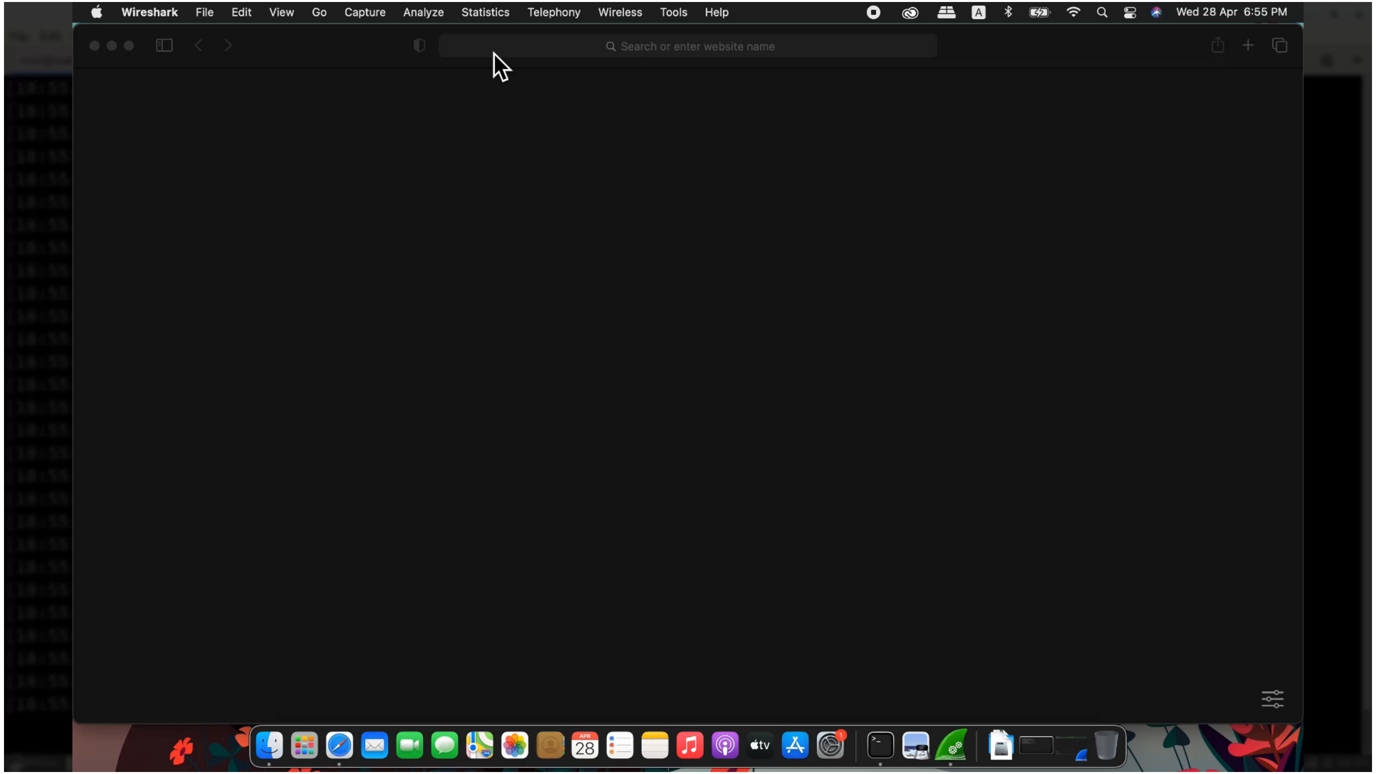


Bug in AP → do attack **w/o user interaction**

(affected $^2/_4$ of home APs)

Inject any packet → **Inject** ICMPv6 RA with **malicious DNS server**

DEMO: FragAttacks A-MSDU Flaw



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Bypassing Wi-Fi client isolation

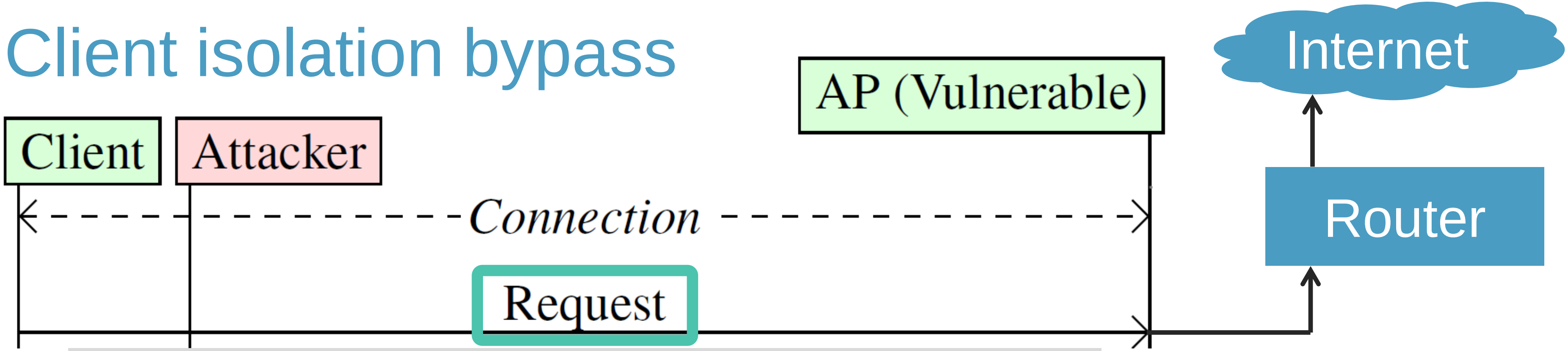
Many networks use **client isolation**. Examples:

- Company network to contain malicious/compromised clients
- Protected hotspots to prevent users attacking each other

- Client isolation is not part of IEEE 802.11 nor WPA*
- “bolted on” by vendors → Wi-Fi meets a new thread model ☺

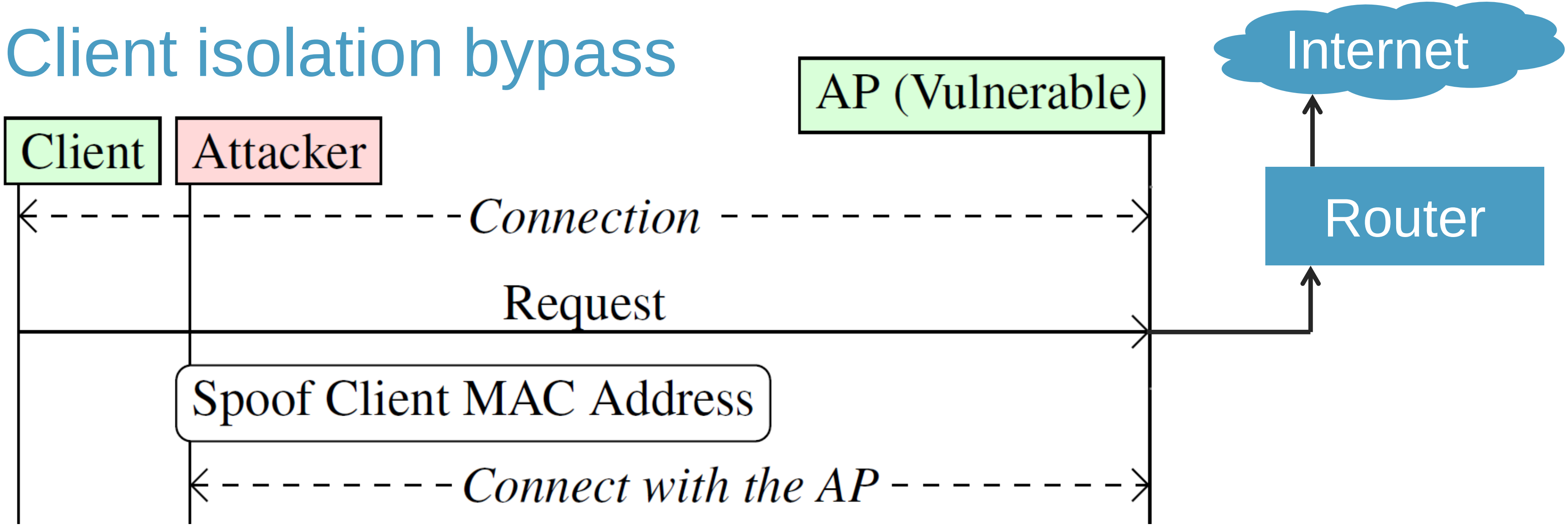
Client isolation bypass

Client isolation bypass



E.g., DNS or HTTP request

Client isolation bypass



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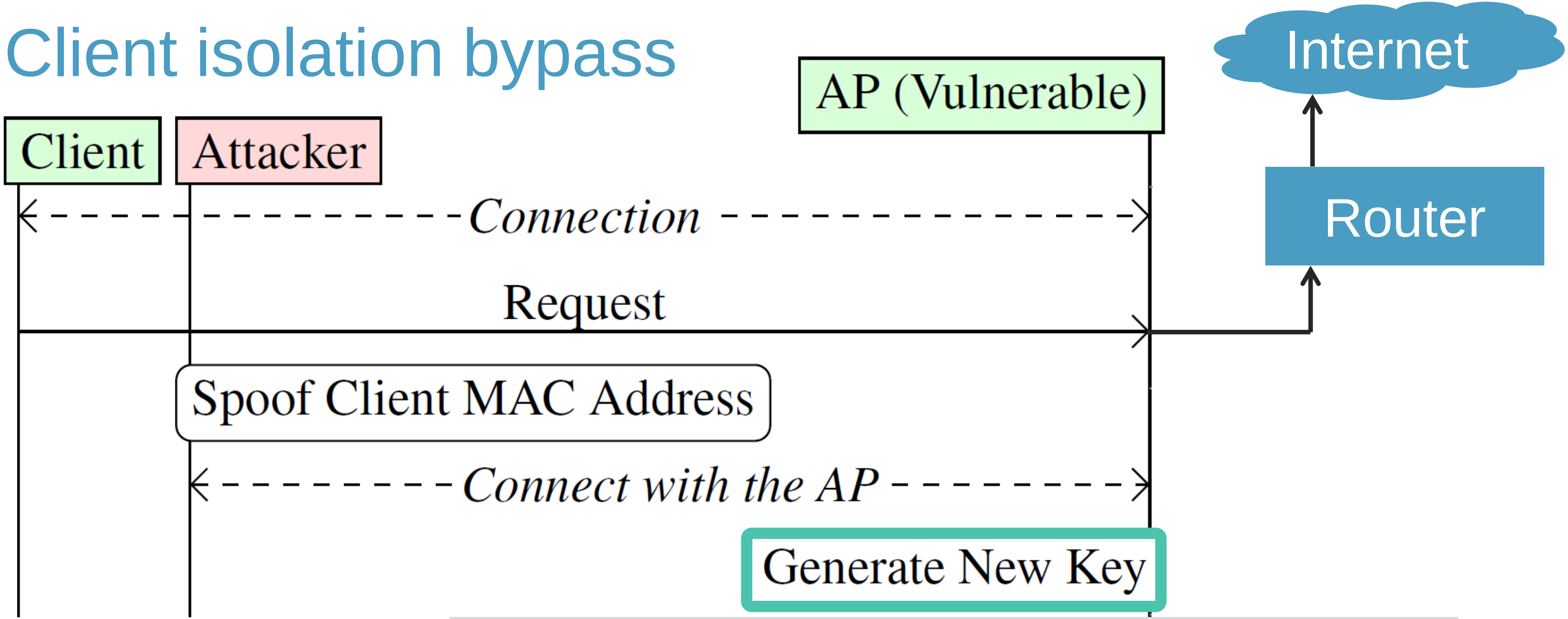
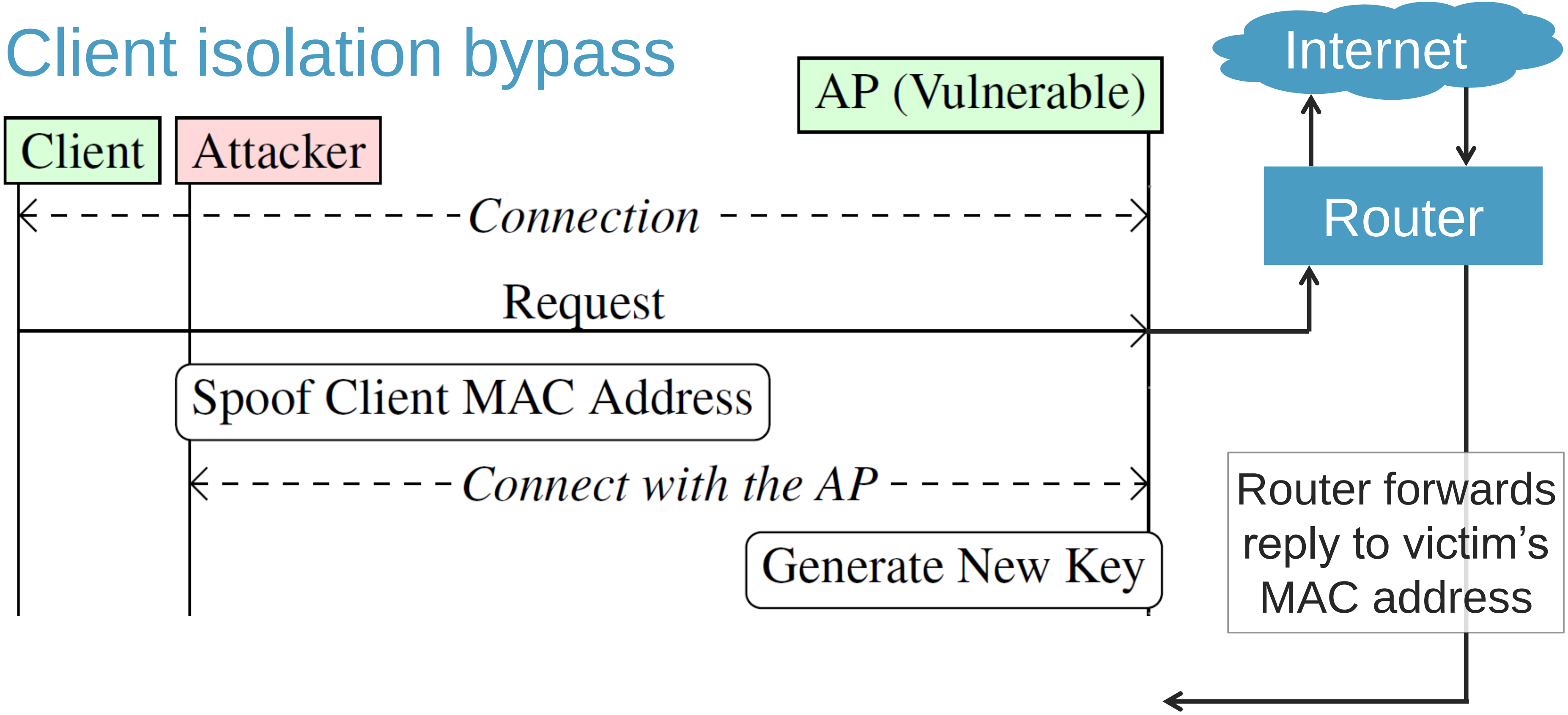


New key is associated with the victim's MAC address

Client isolation bypass



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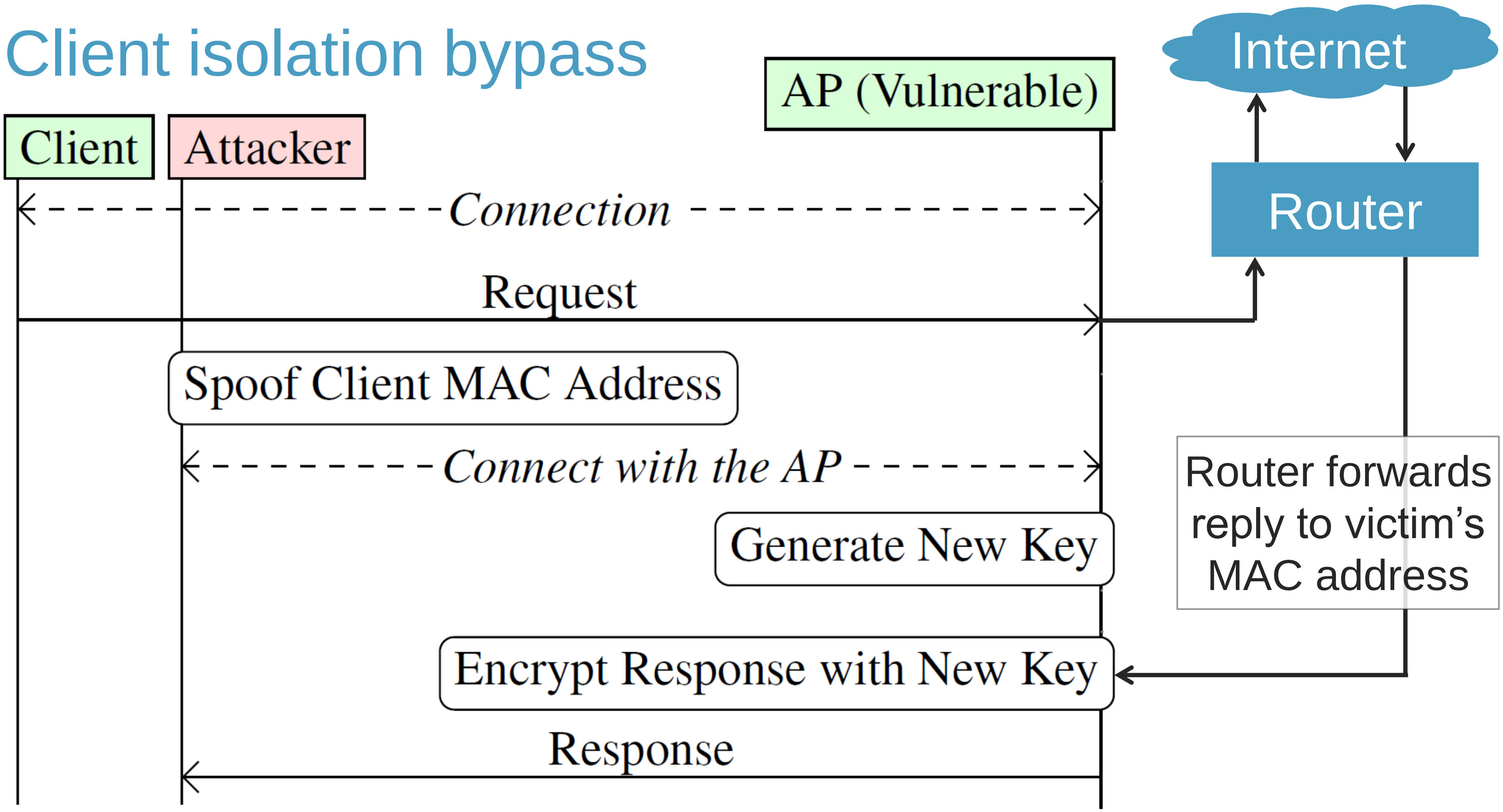

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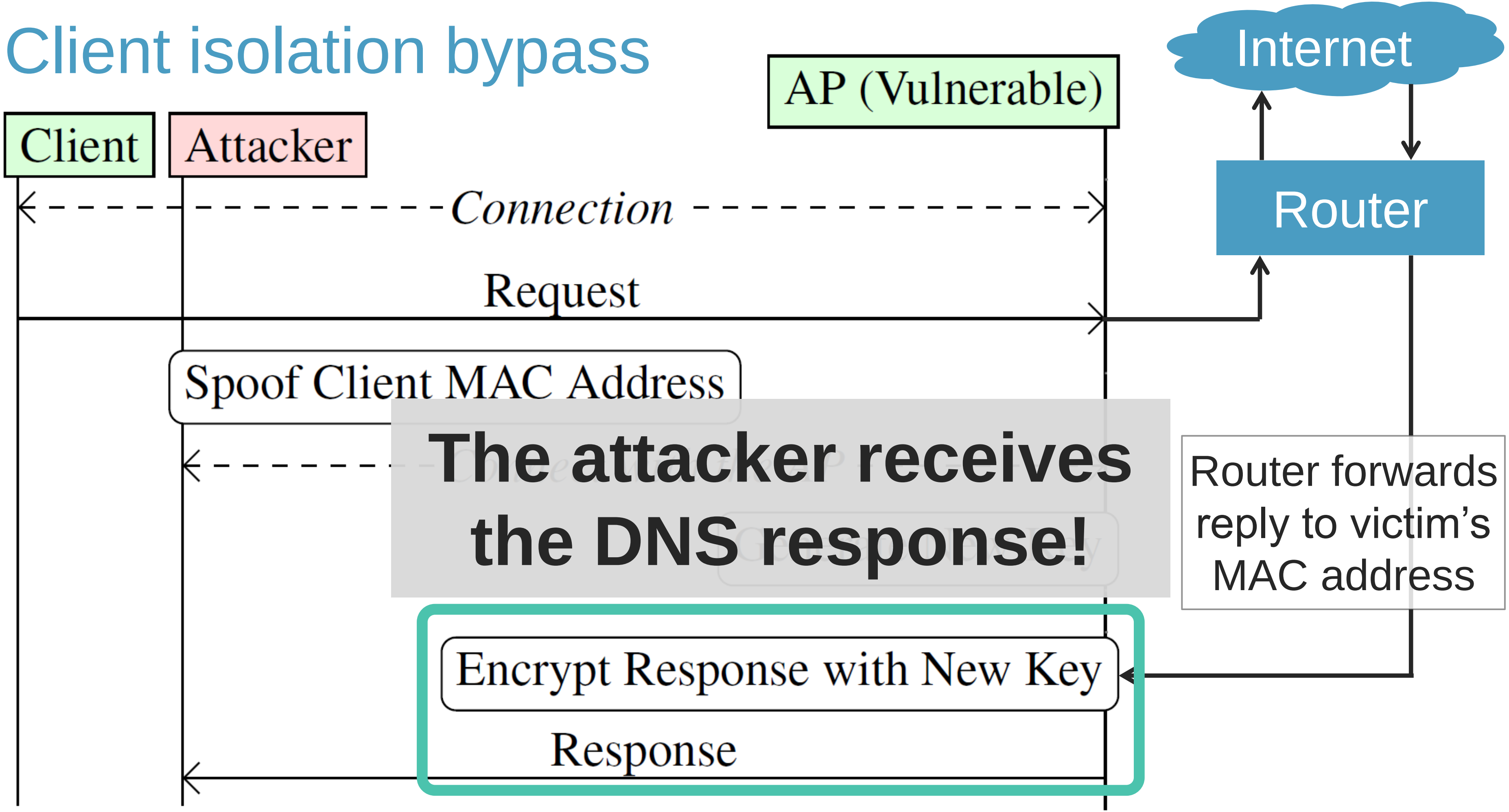

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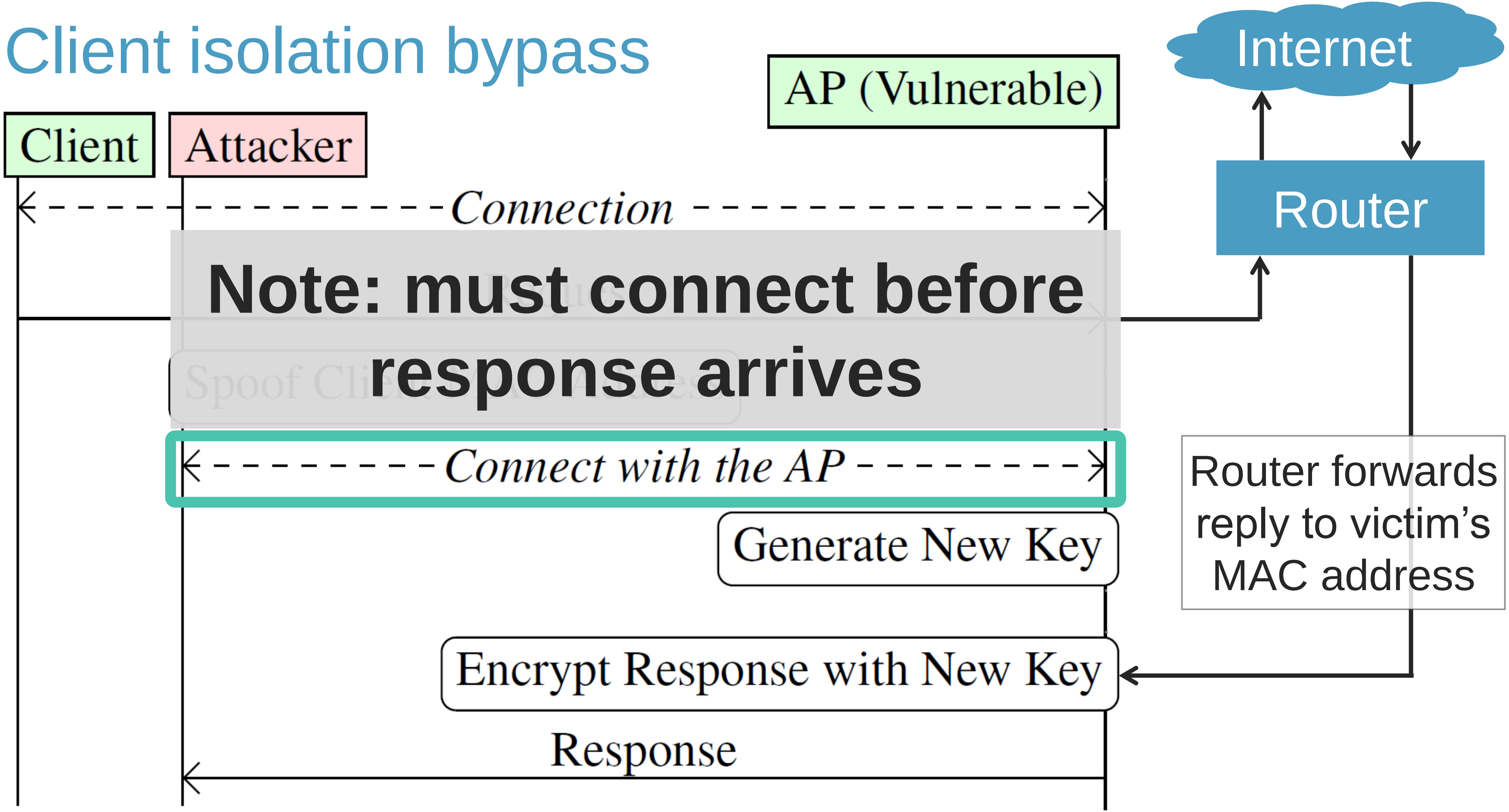

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› Conclusion

Background: VPN client routing table


```
  $ ip route
1 default via tun0
```

1. By default, send packets over tun0 = over the VPN tunnel

Background: VPN client routing table


```
  $ ip route
1 default via tun0
2 2.2.2.2 via eth0
```

1. By default, send packets over tun0 = over the VPN tunnel
2. **ServerIP exception**: avoid re-encryption of VPN packets

We assume secure DNS behavior


```
$ cat /etc/resolv.conf
nameserver 6.6.6.6
```

Can’t trust the network’s DNS server

We assume secure DNS behavior

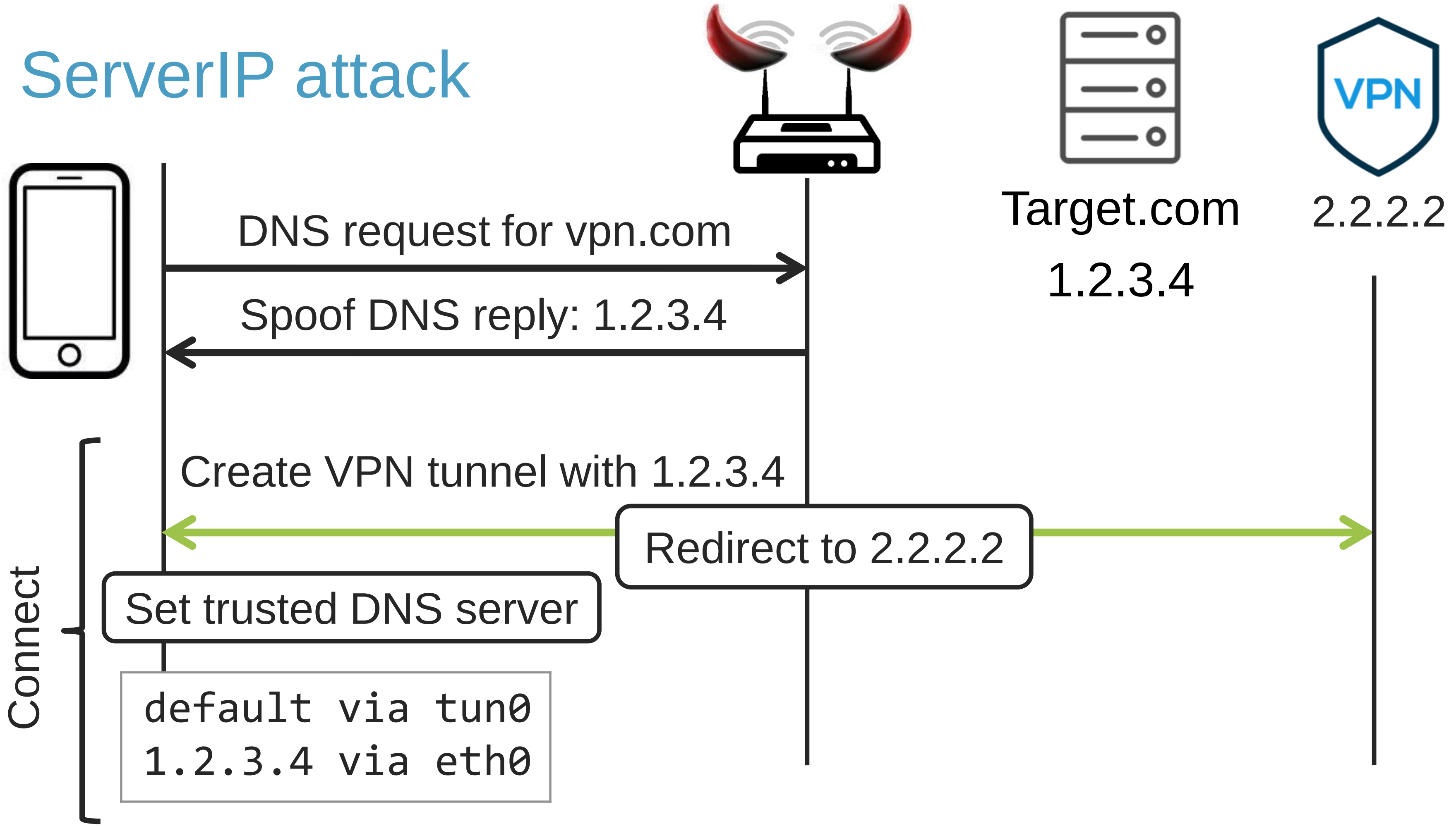
```
$ cat /etc/resolv.conf
nameserver 2.2.2.3
```

Can’t trust the network’s DNS server. Once connected:

1. The VPN client sets a **trusted DNS server**
2. DNS is sent **through the VPN tunnel**

   + we assume other routing-based attacks are prevented

ServerIP attack



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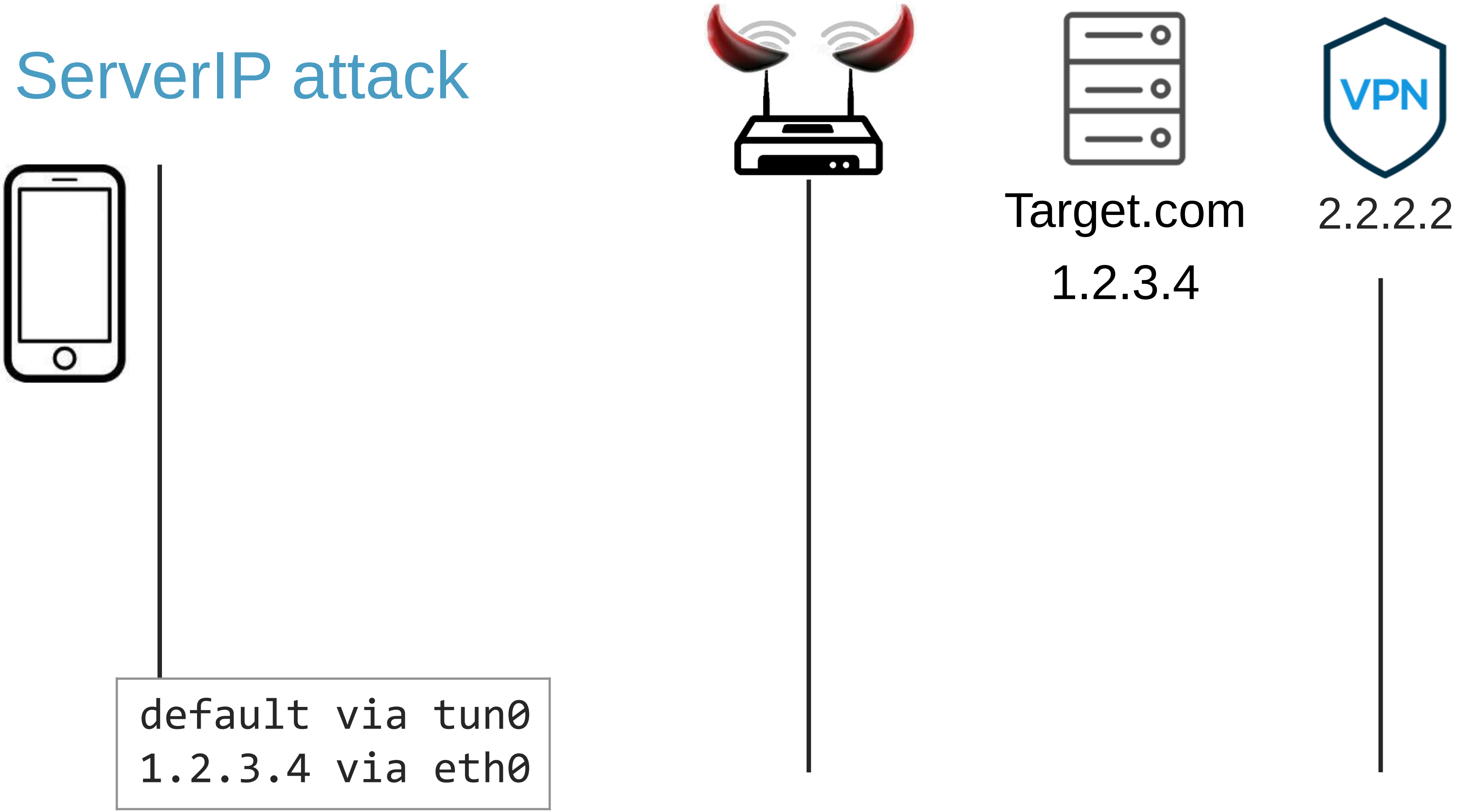

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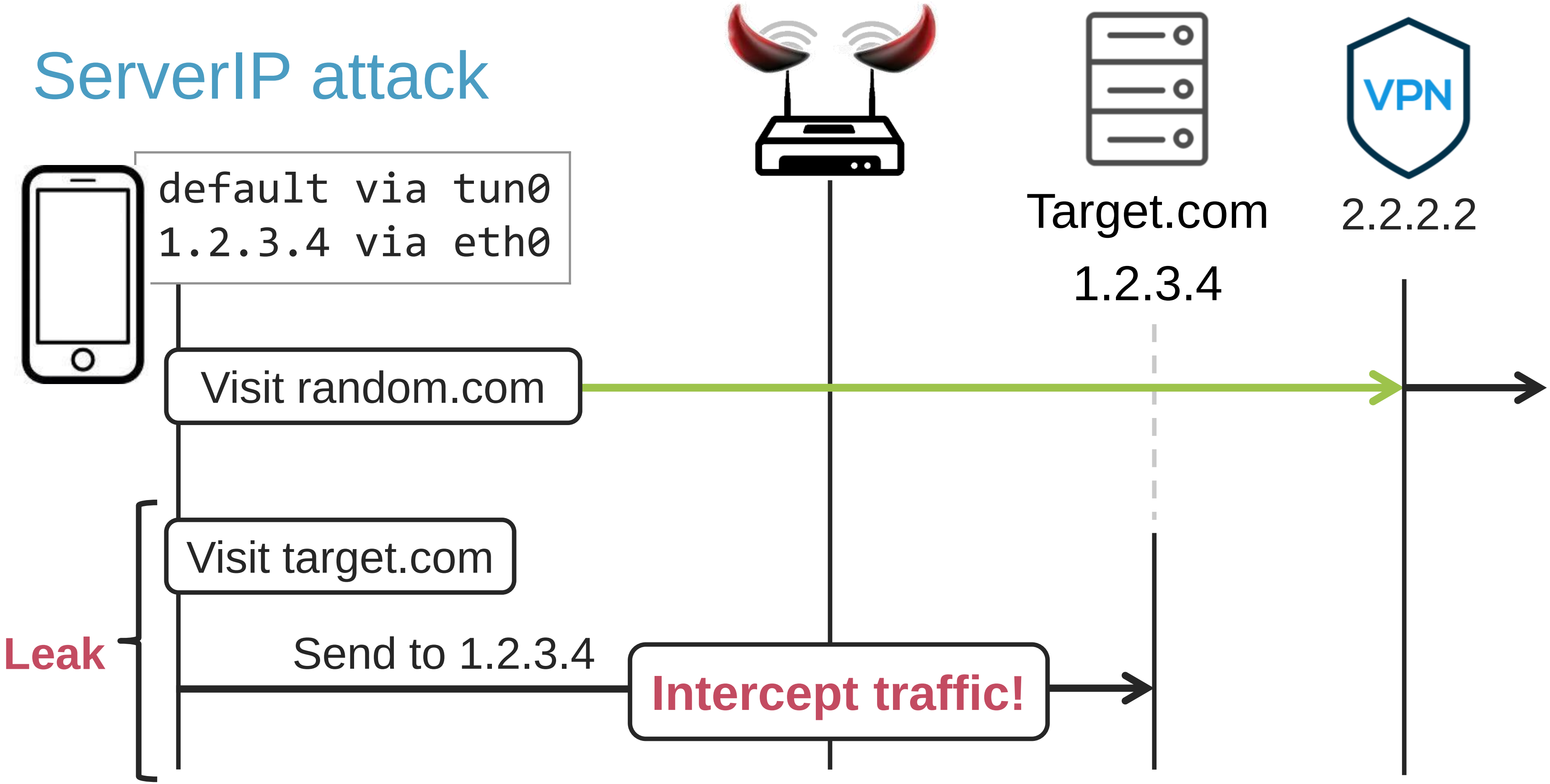

Reflection

- Cryptography of VPNs was widely studied…
- …but not their integration into real-world systems

- Attack the weakest link! In this case the routing tables.
- The DNS poisoning happens *before* VPN is enabled!

Conclusion

- Established protocols, when used in new situations or under new thread models, may become vulnerable to new attacks
- When reading about attacks, learn about the threat model, that may be the most useful thing to know in the long term.
- “Attacks only get better” -- but why?
  - Either by finding new vulnerabilities…
  - …or by considering new threat models!