Breaking Network Protocols:
When Established Protocols Meet New Threat Models

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Keynote, IFIP WG 11.4 “Network & Distributed Systems Security” Workshop. May 16, 2024.

KU LEUVEN DistriNet

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)
  - 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 completely broke an established protocol in practice*
- 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

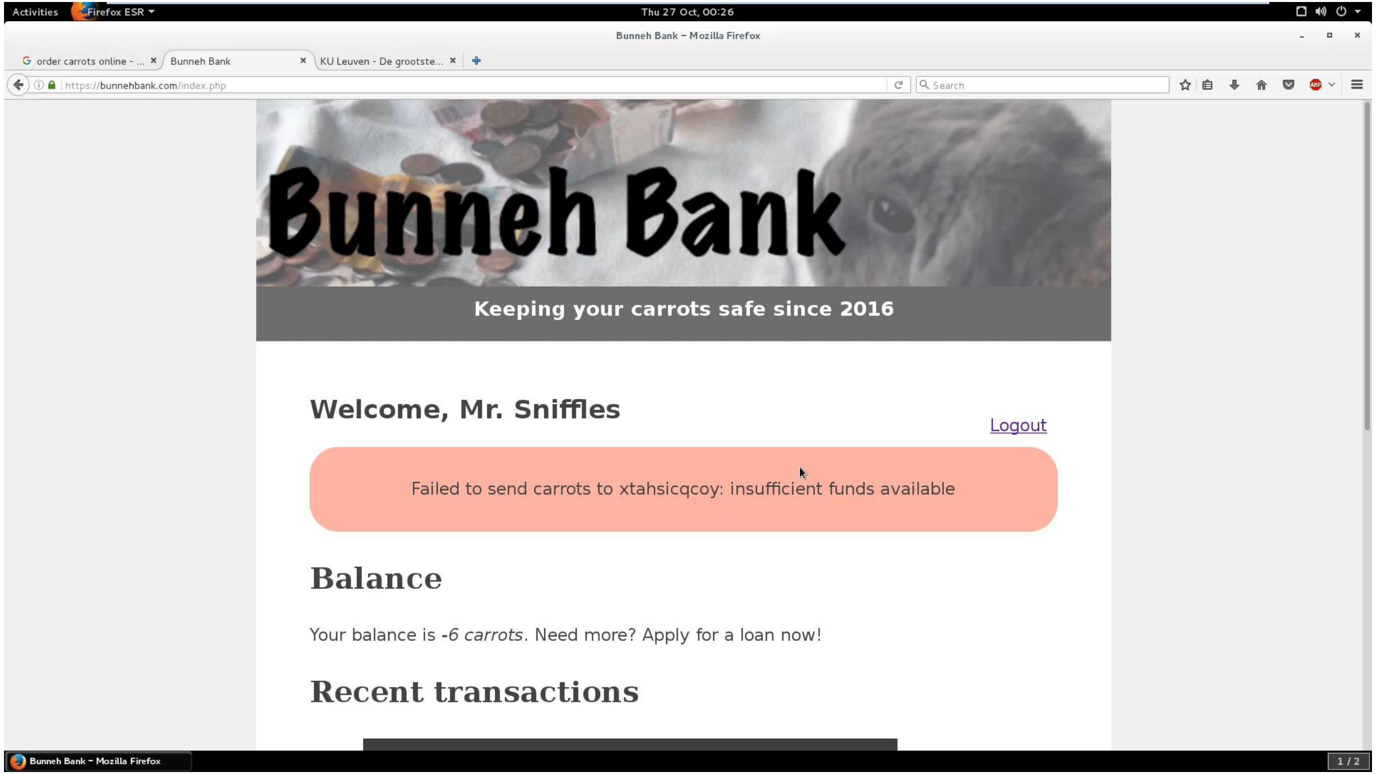
CRIME and BREACH attack

- Abused compression at the TLS and HTTP level to leak information in response, e.g., **leak CRSF tokens**
- Assumed execution of malicious JavaScript + network MitM
  - Network MitM was used to measure length of response

TIME and HEIST attack

- Like BREACH abuses compression to recover CRSF 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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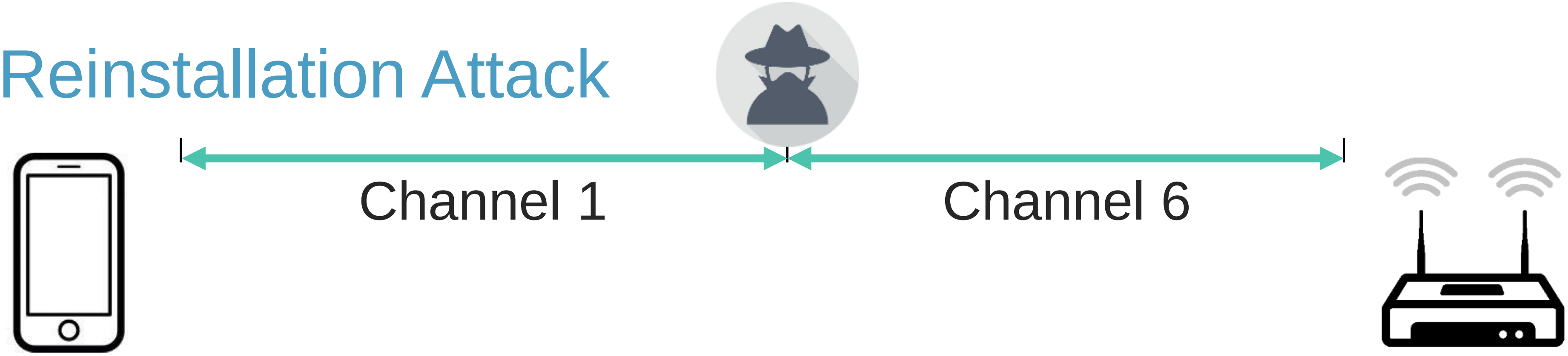
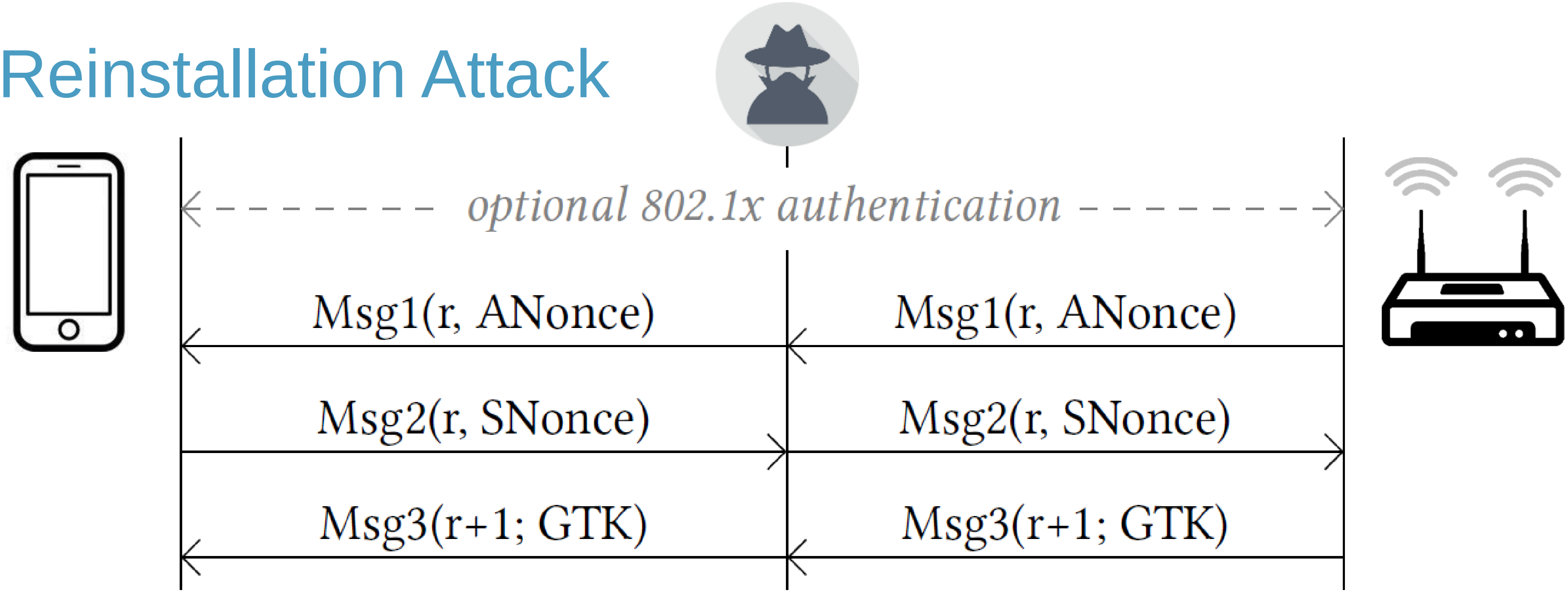
Reinstallation Attack



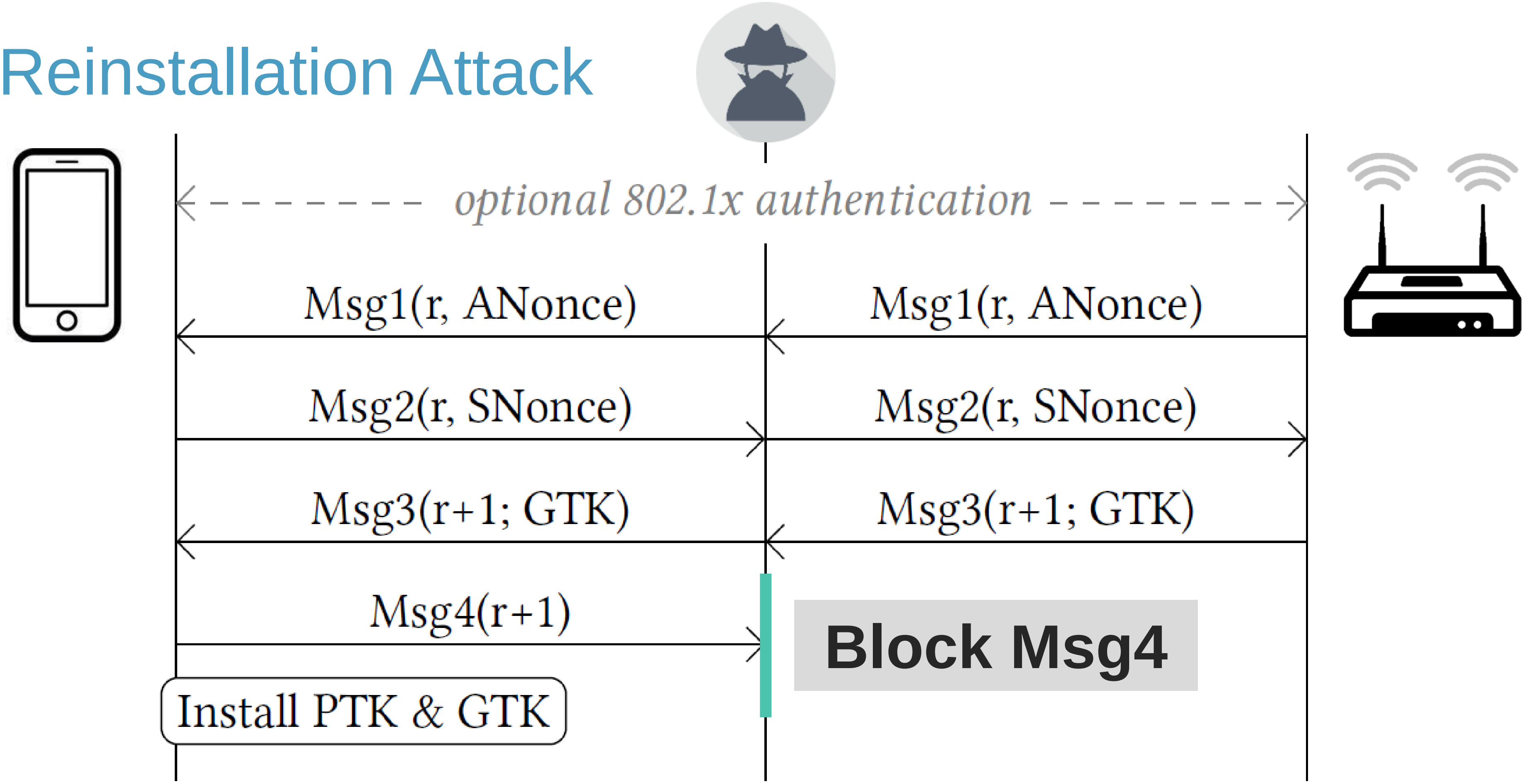
➔ Called a “Multi-Channel MitM” (MC-MitM)

Reinstallation Attack

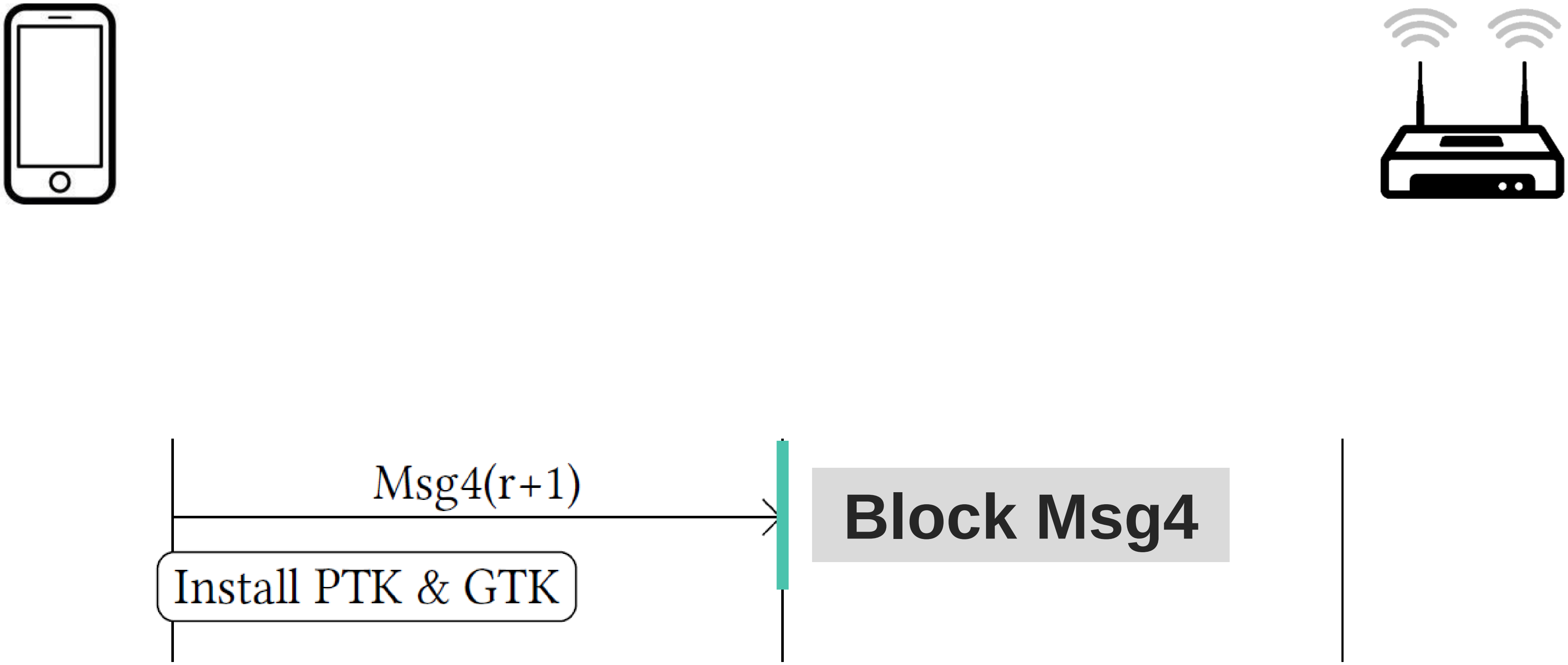
Reinstallation Attack



Reinstallation Attack



Reinstallation Attack



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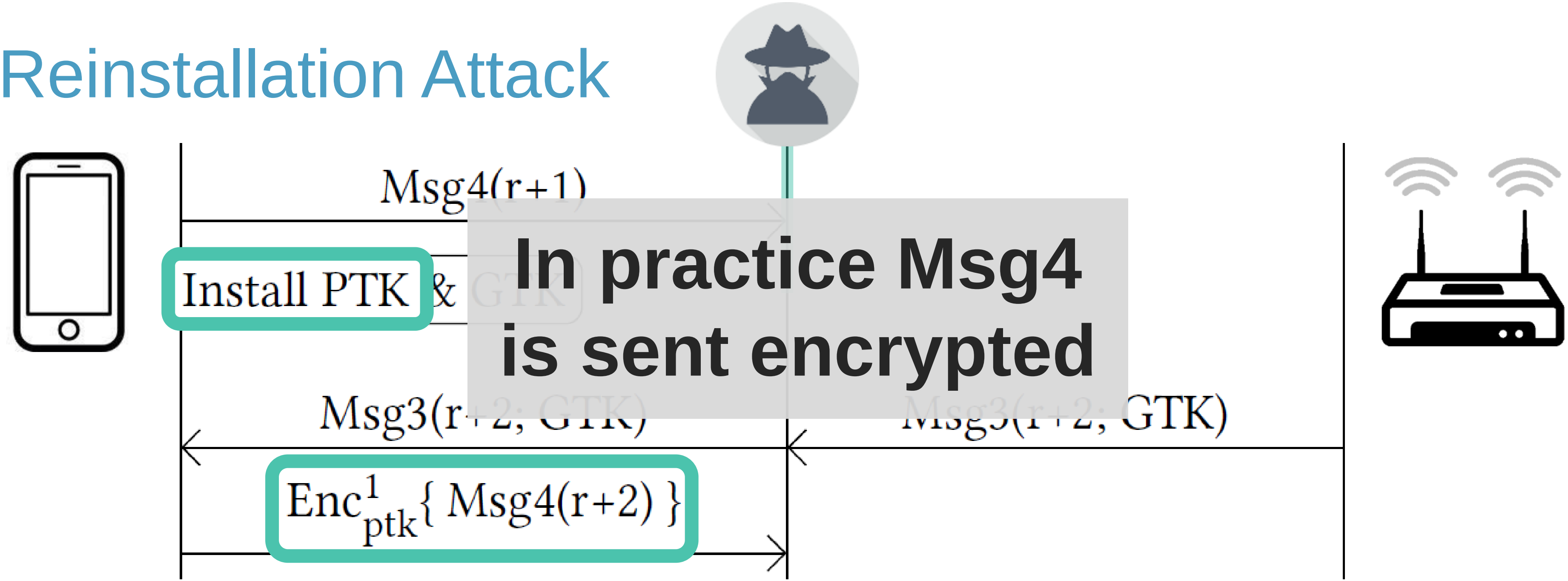
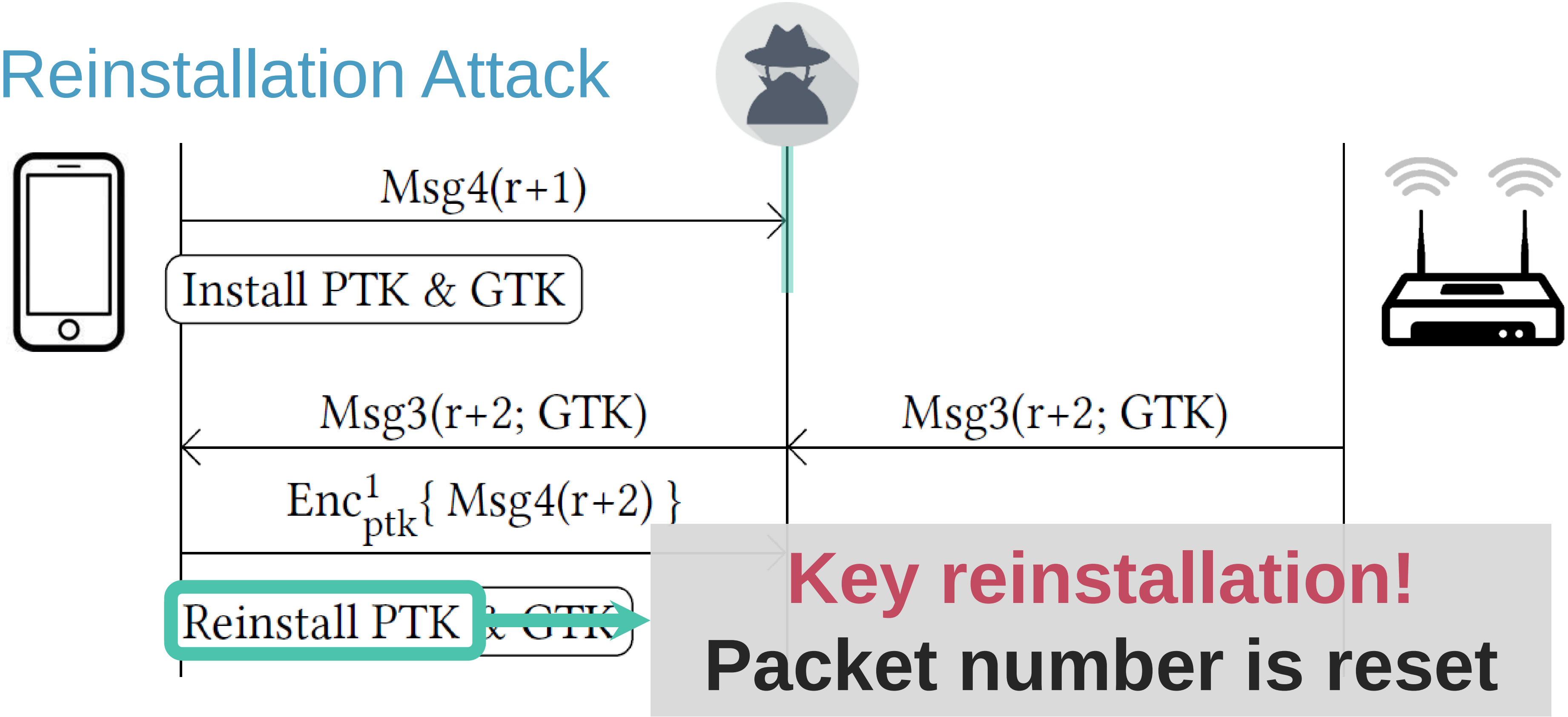


In practice Msg4 is sent encrypted

Reinstallation Attack



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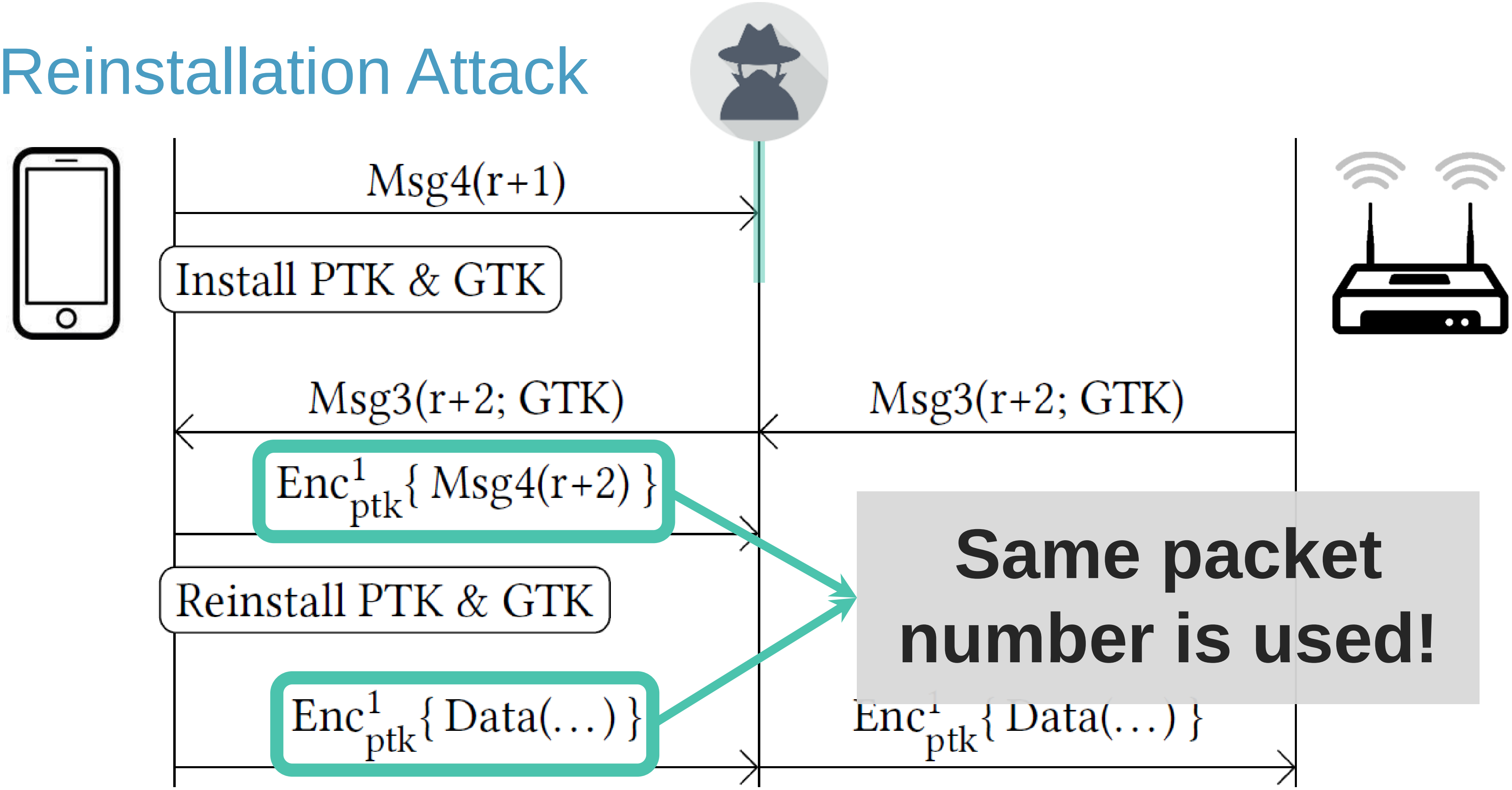

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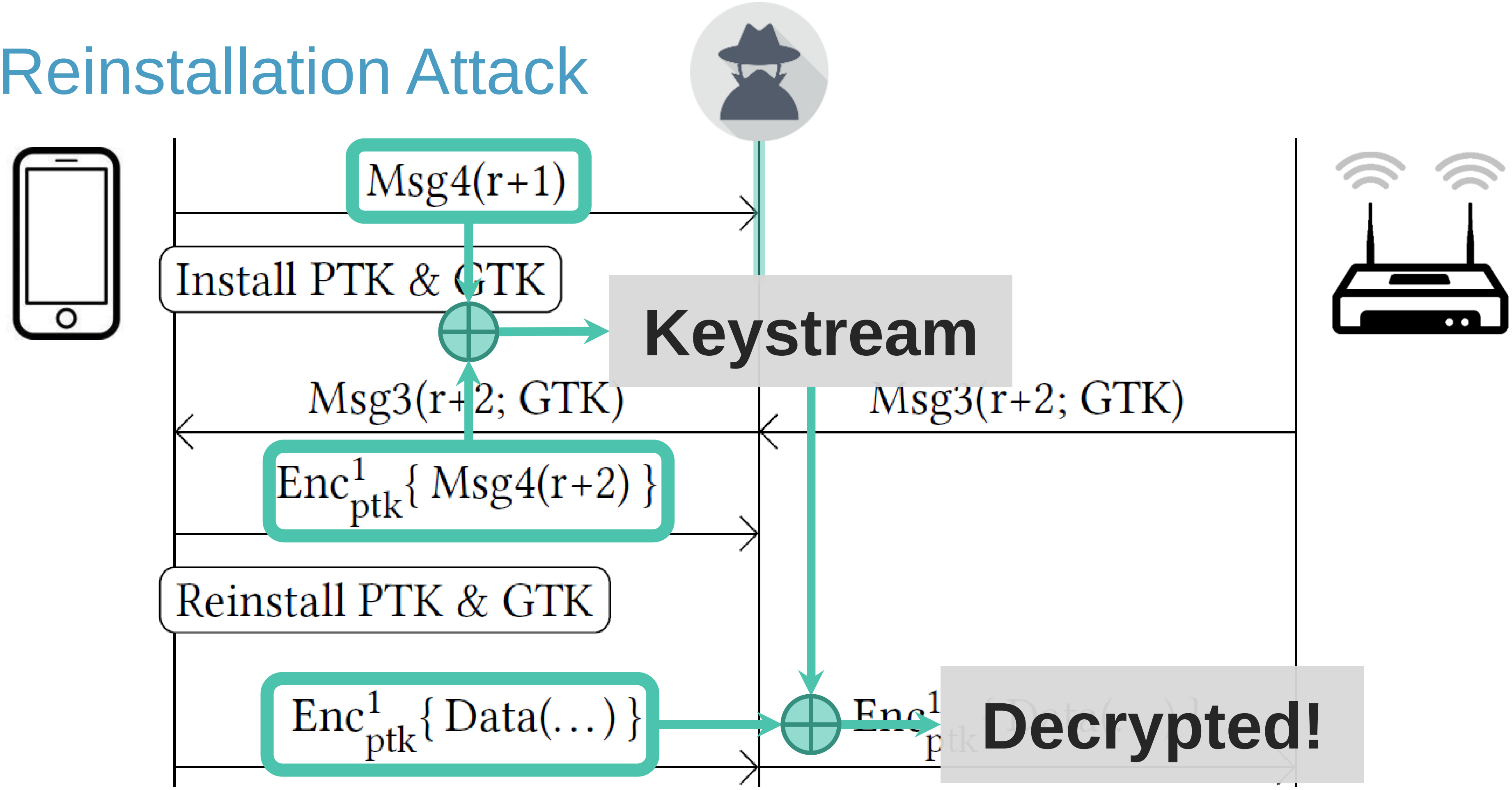

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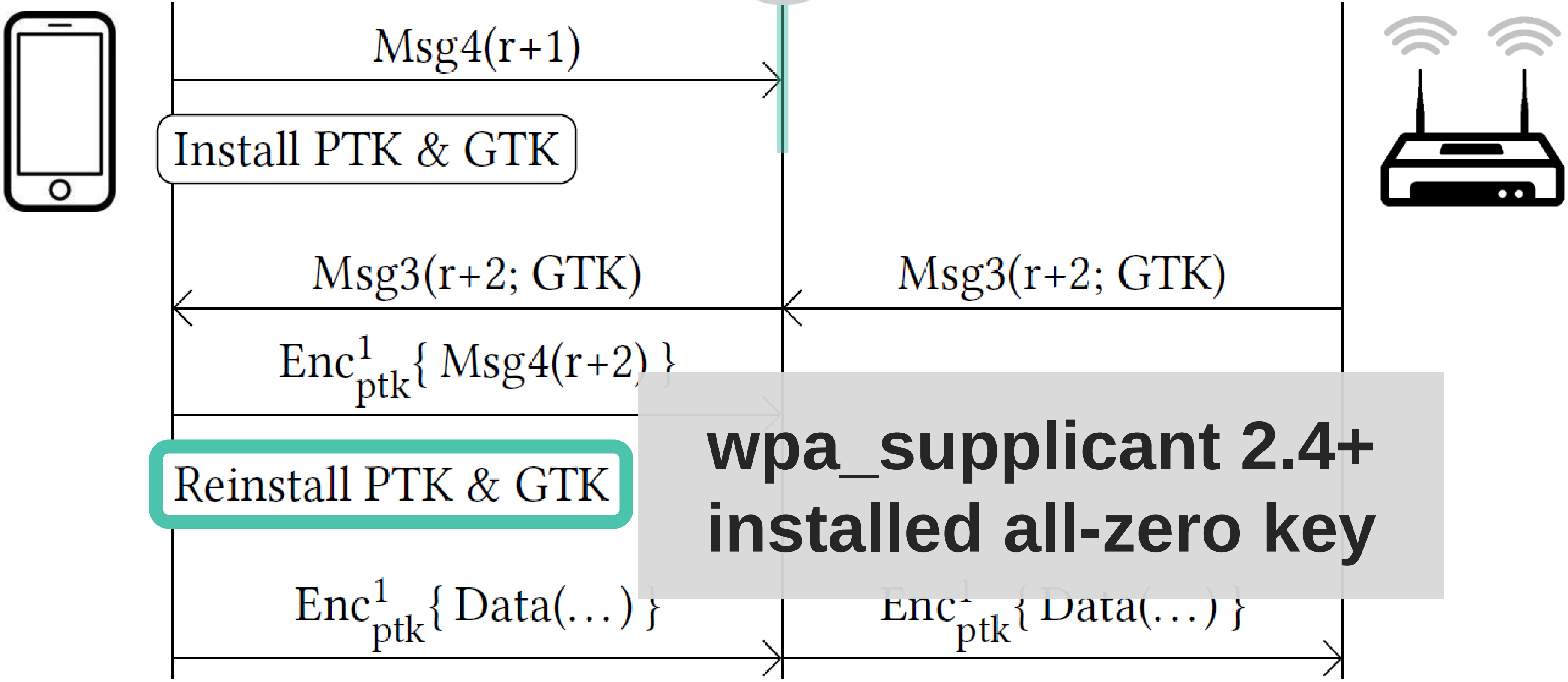
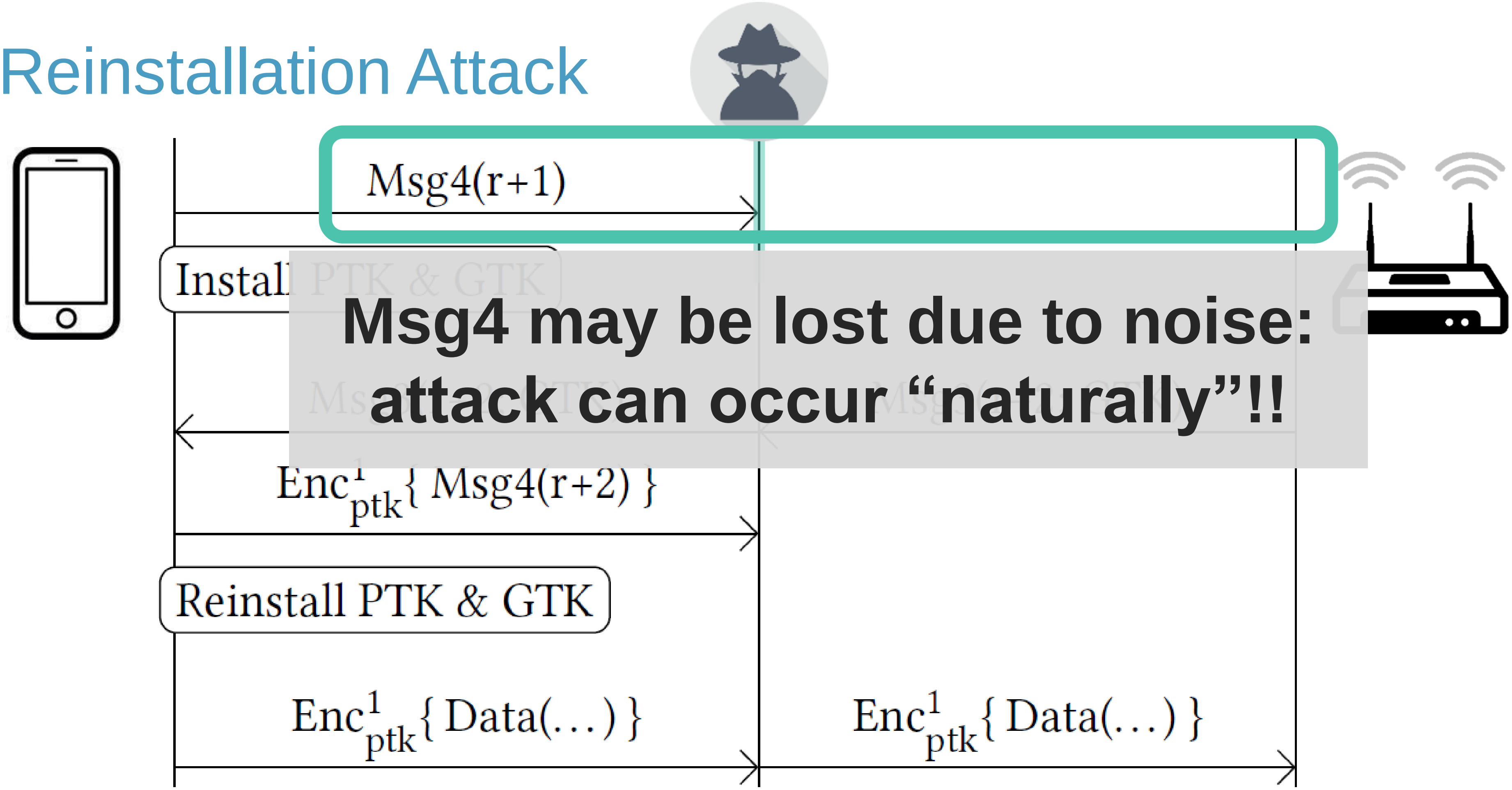


wpa_supplicant 2.4+ installed all-zero key

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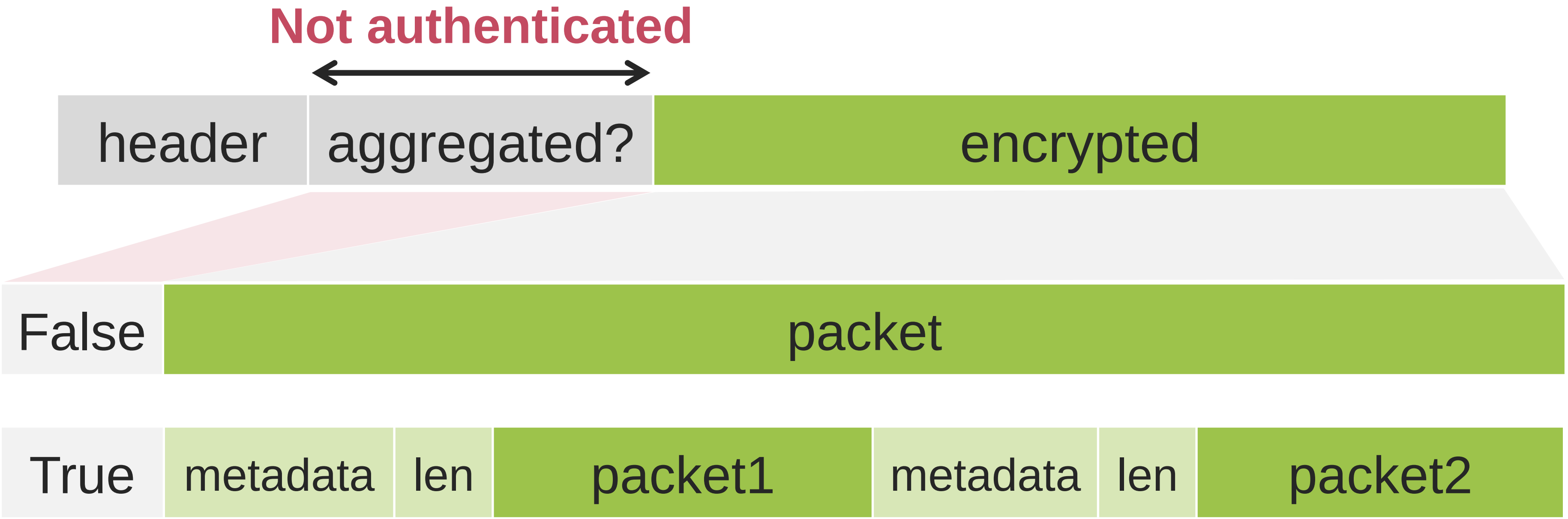
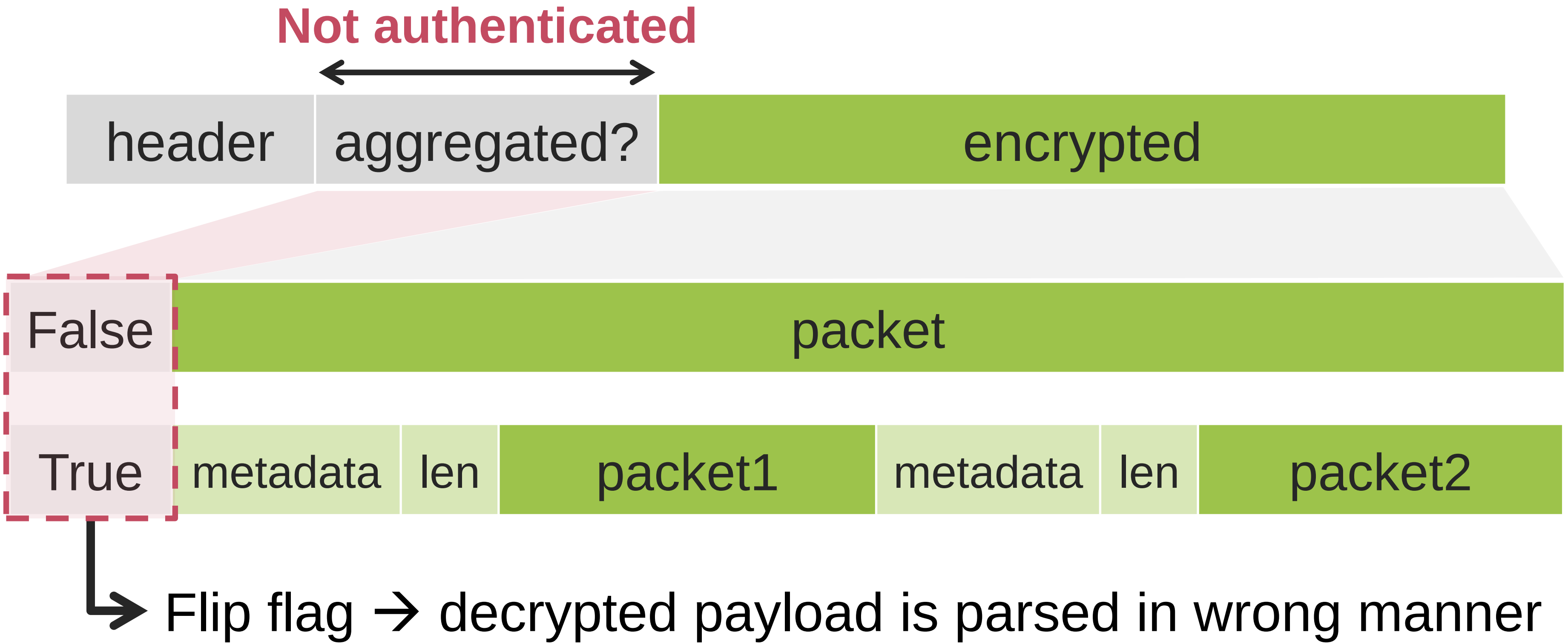
This can be avoided by **aggregating frames**:

Problem: how to recognize aggregated frames?

Aggregation design flaw



Aggregation design flaw



Flip flag → decrypted payload is parsed in wrong manner

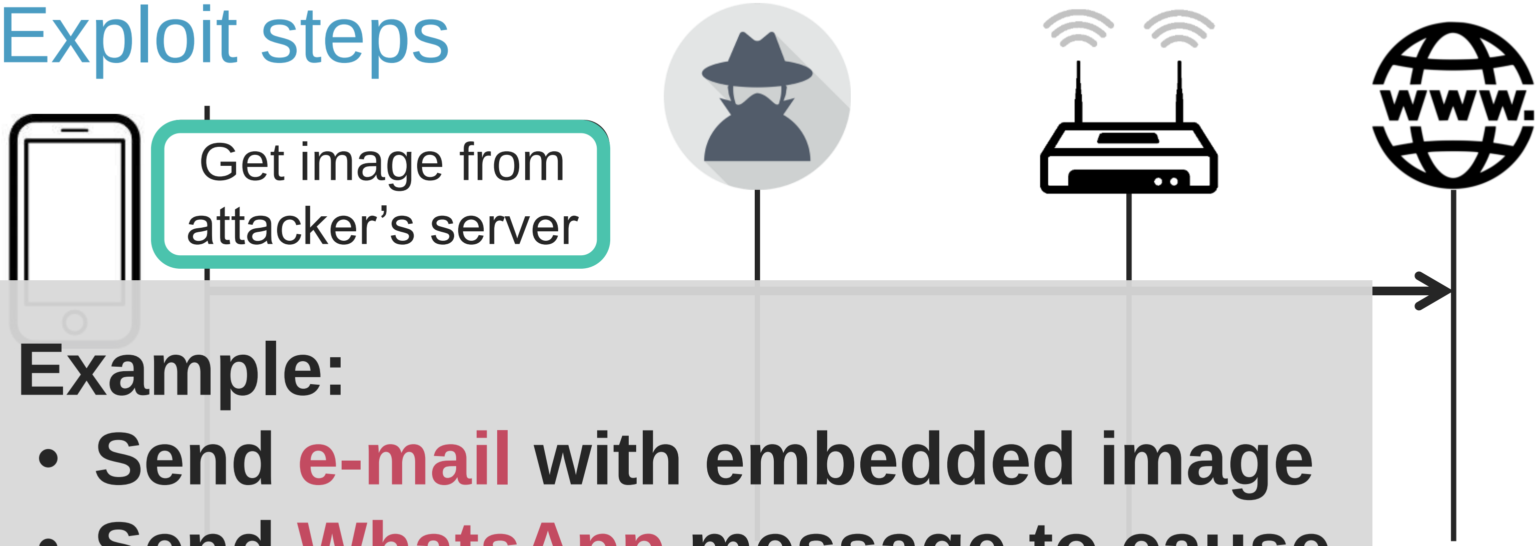
A-MSDU

- 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)

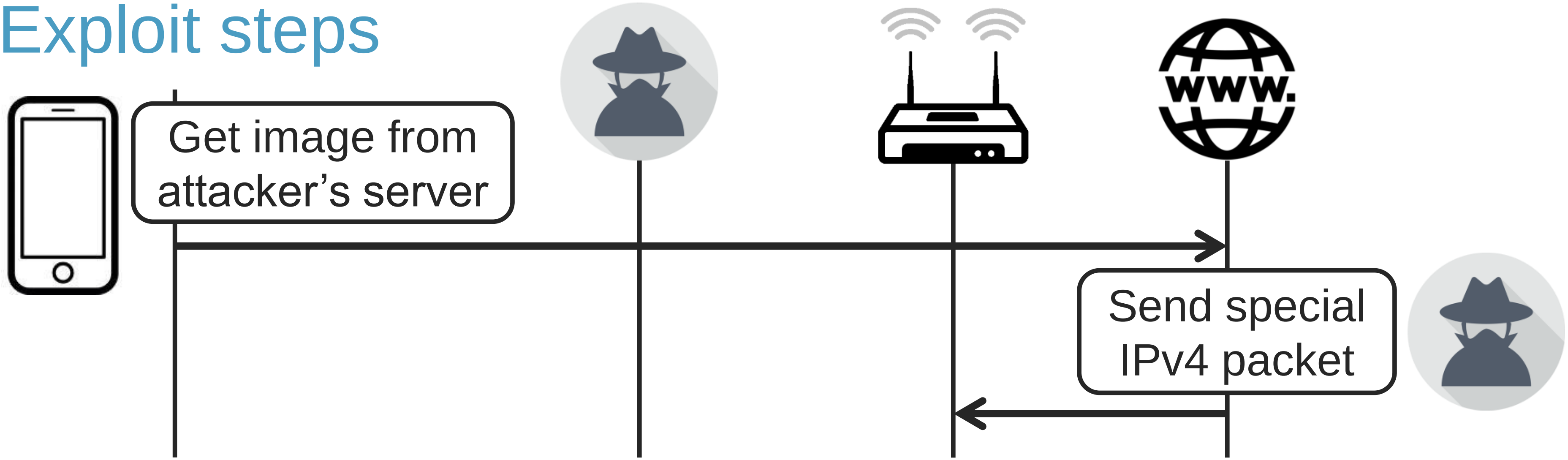
[1] Msdu Protection by Nancy Cam-Winget et al. (2007)
[2] Why did nobody notice the aggregation design flaw before?

Exploit steps



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

Exploit steps



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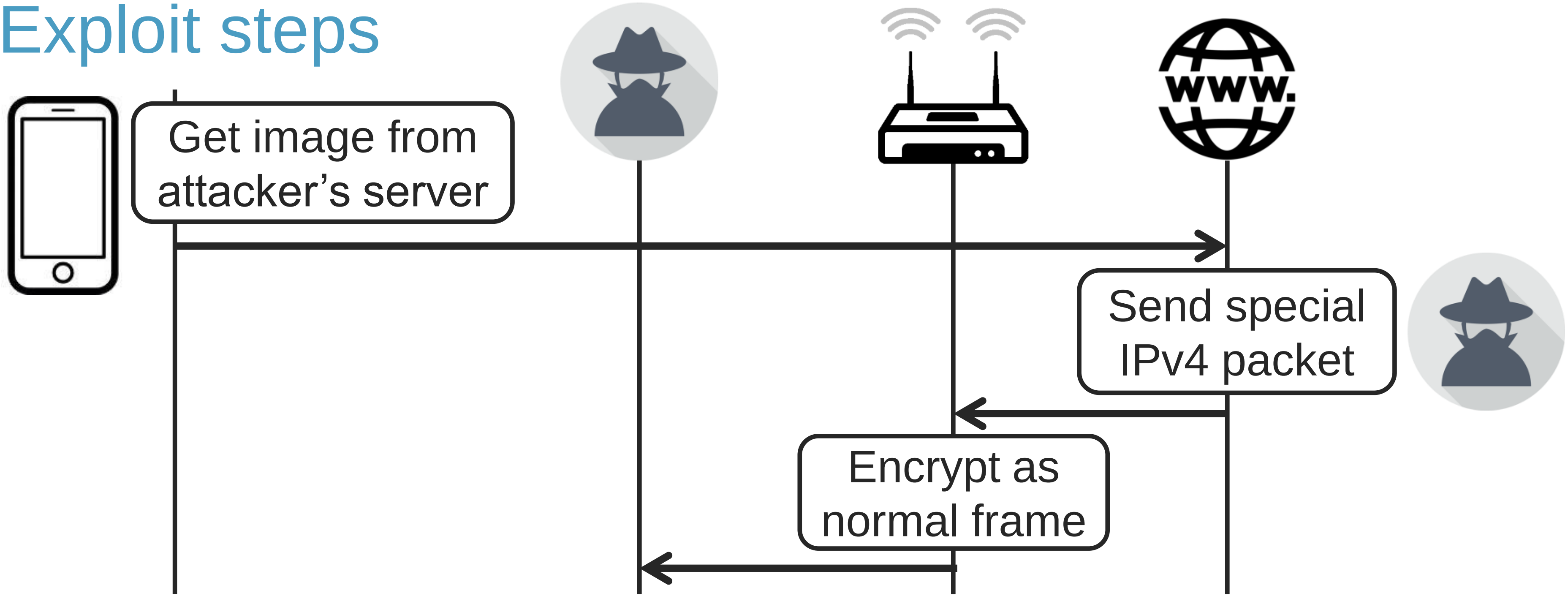

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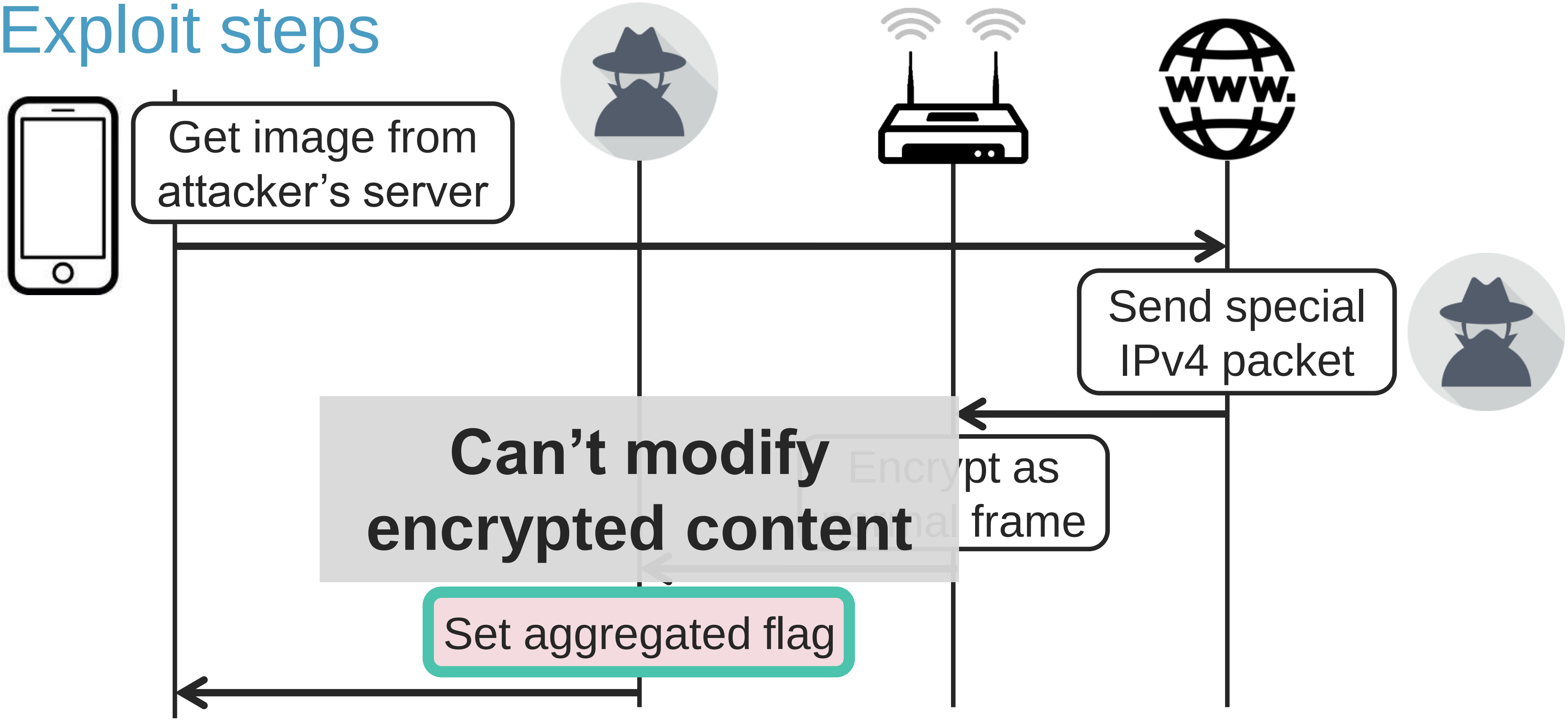

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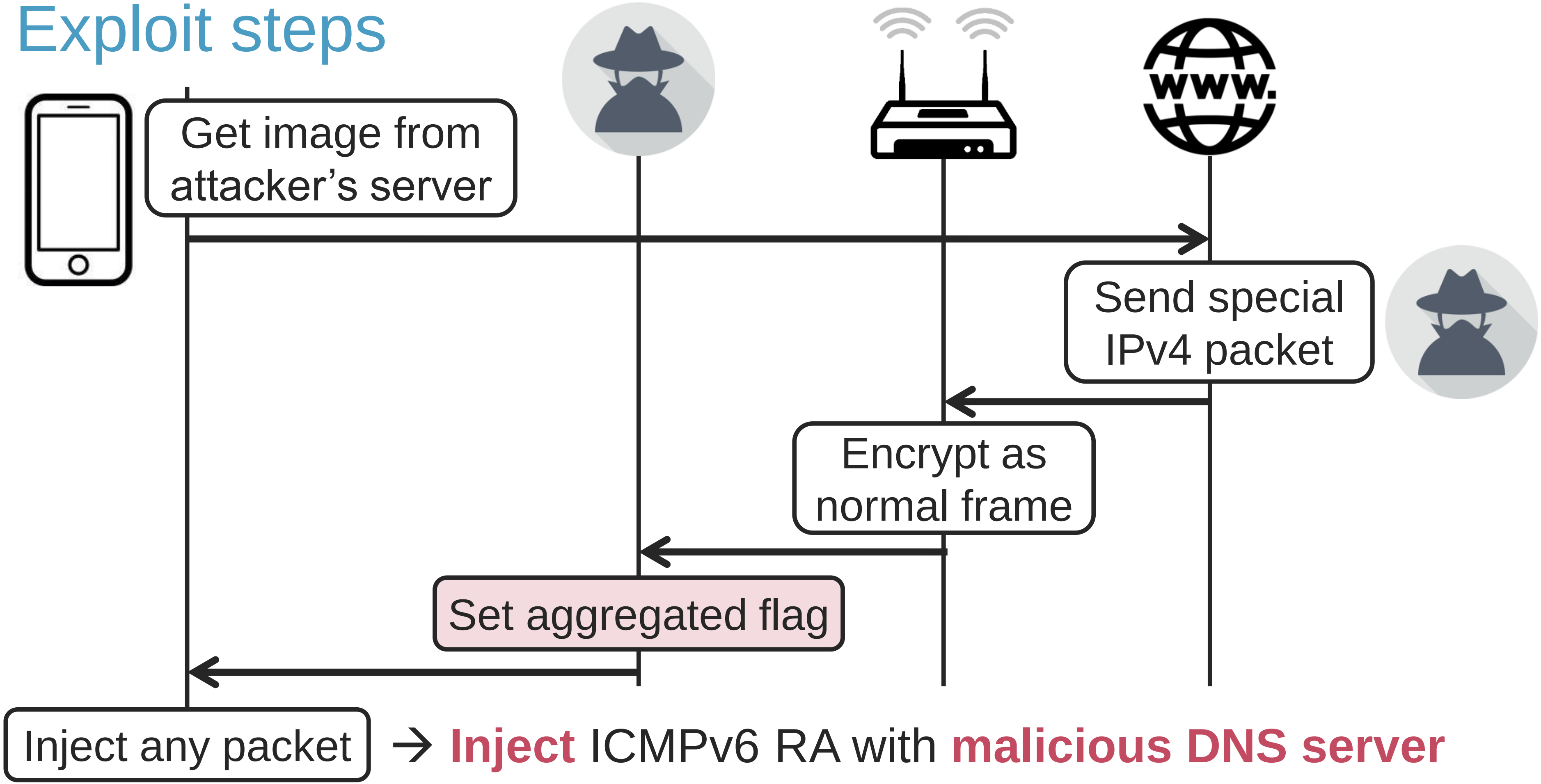
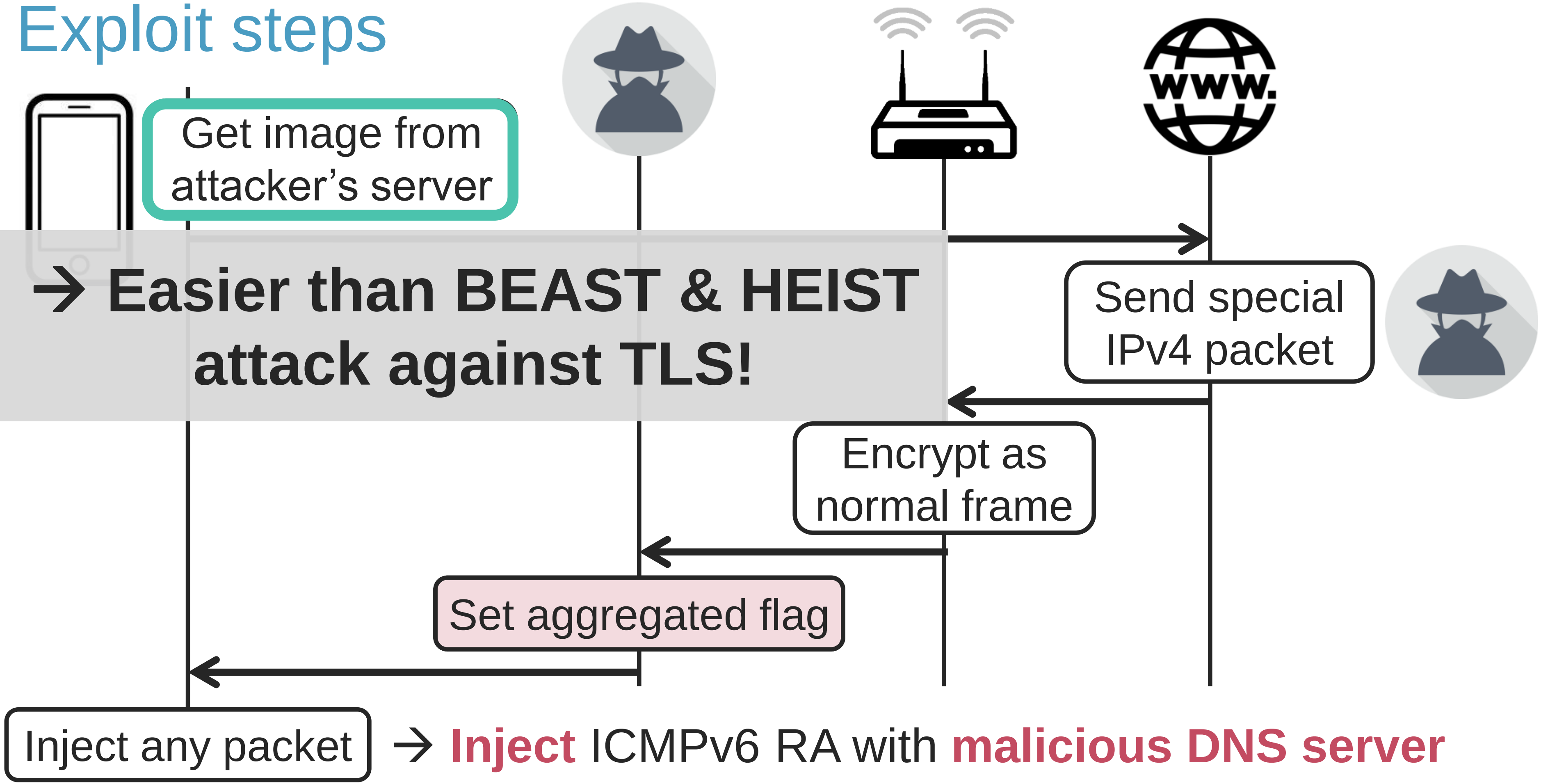


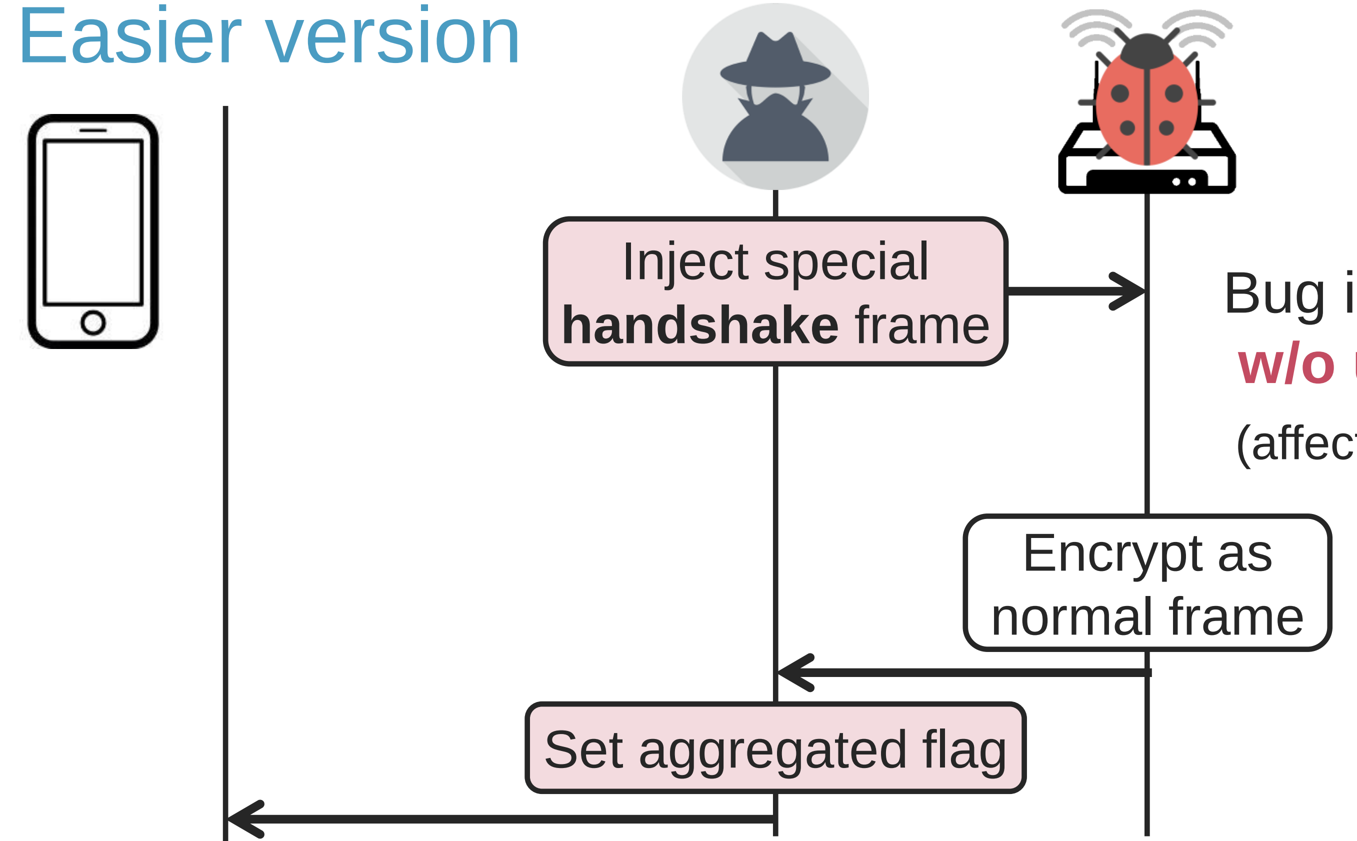
→ **Inject** ICMPv6 RA with **malicious DNS server**

Exploit steps



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

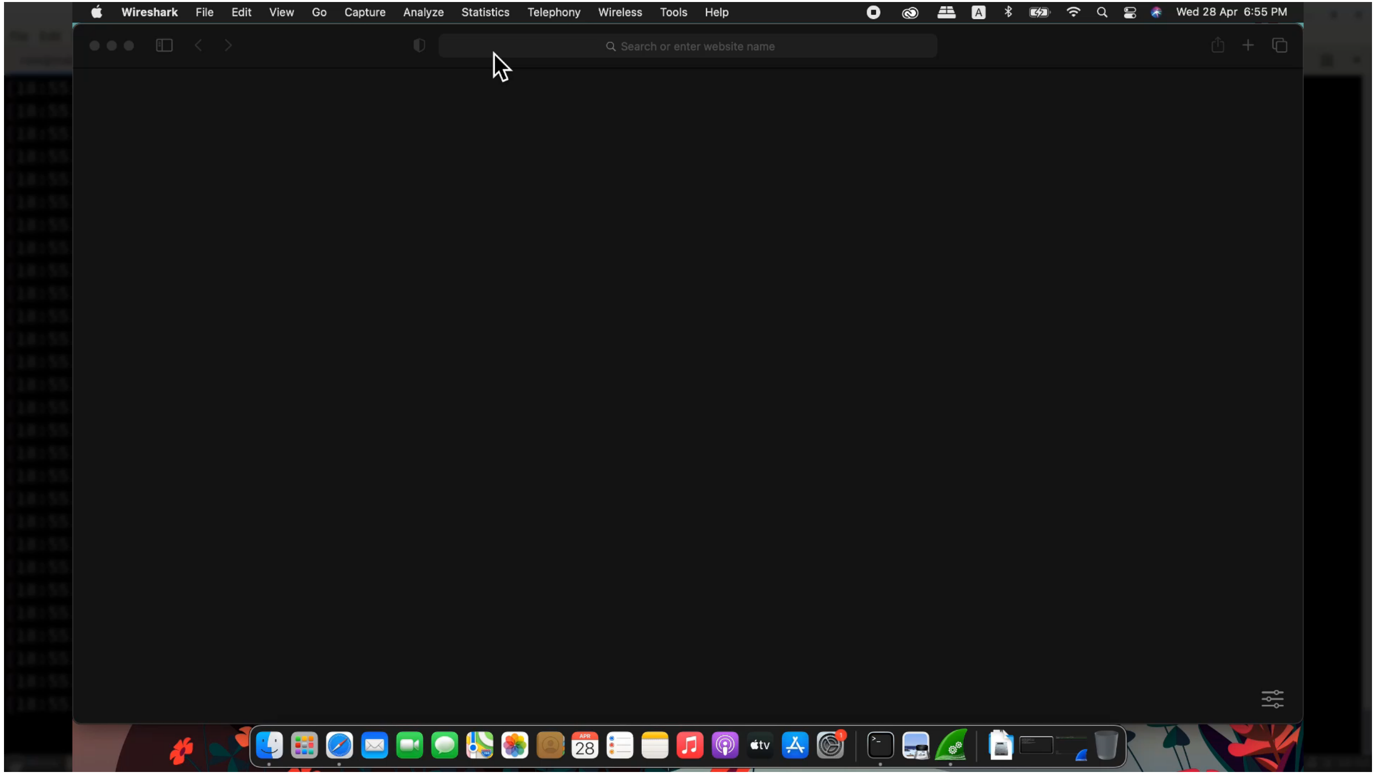
Easier version



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



Conclusion

- Established protocols, when used in new situations and under new thread models, may become vulnerable to new attacks → Keep studying old protocols!
- When reading about attacks, learn about their threat model. That may be the most useful thing to know in the long term.
- Attacks only get better → threat models only get better?