KRACKing WPA2 and Mitigating Future Attacks

Mathy Vanhoef — @vanhoefm

CRYPTO Workshop on Attacks (WAC), Santa Barbara, 18 August 2018

KU LEUVEN DistriNet

Overview

Key reinstalls in 4-way handshake

Misconceptions

Practical impact

Channel validation

Overview

Key reinstalls in 4-way handshake

Misconceptions

Practical impact

Channel validation

The 4-way handshake

Used to connect to any protected Wi-Fi network

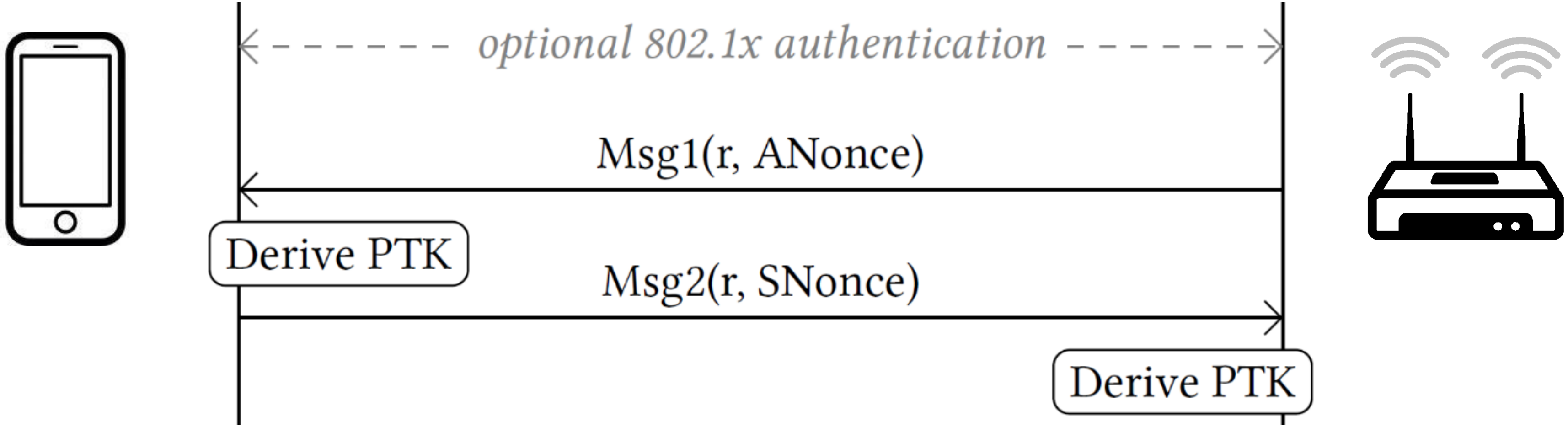
- Provides mutual authentication
- Negotiates fresh PTK: pairwise transient key

Appeared to be secure:

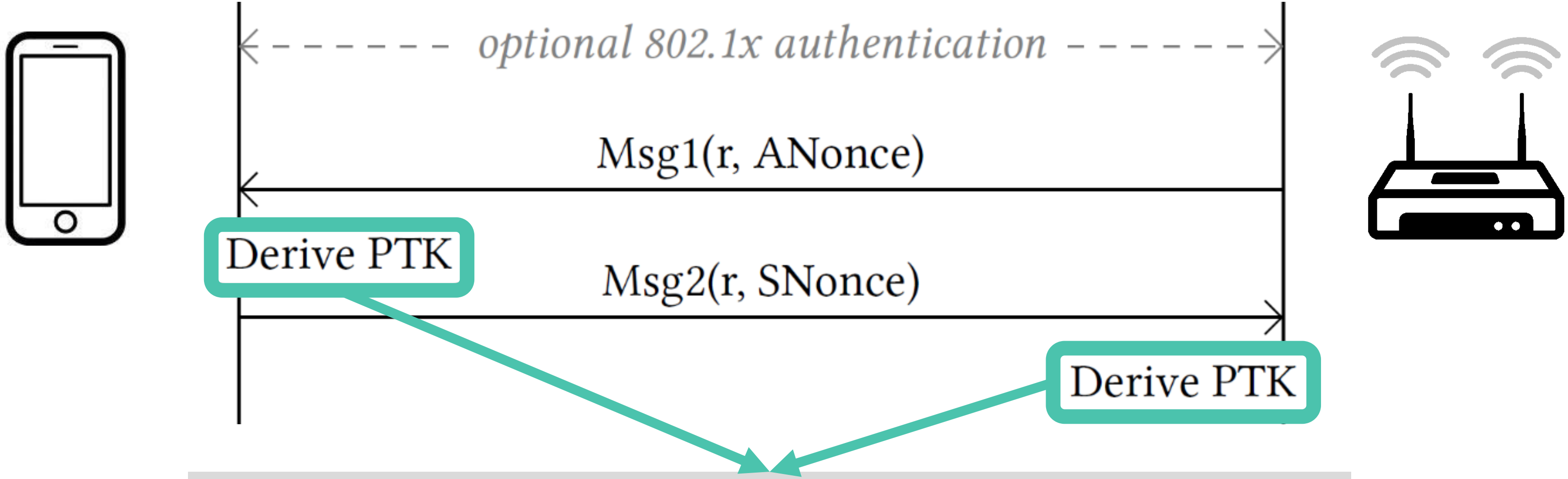
- No attacks in over a decade (apart from password guessing)
- Proven that negotiated key (PTK) is secret
- Encryption protocol also proven secure

4-way handshake (simplified)

4-way handshake (simplified)

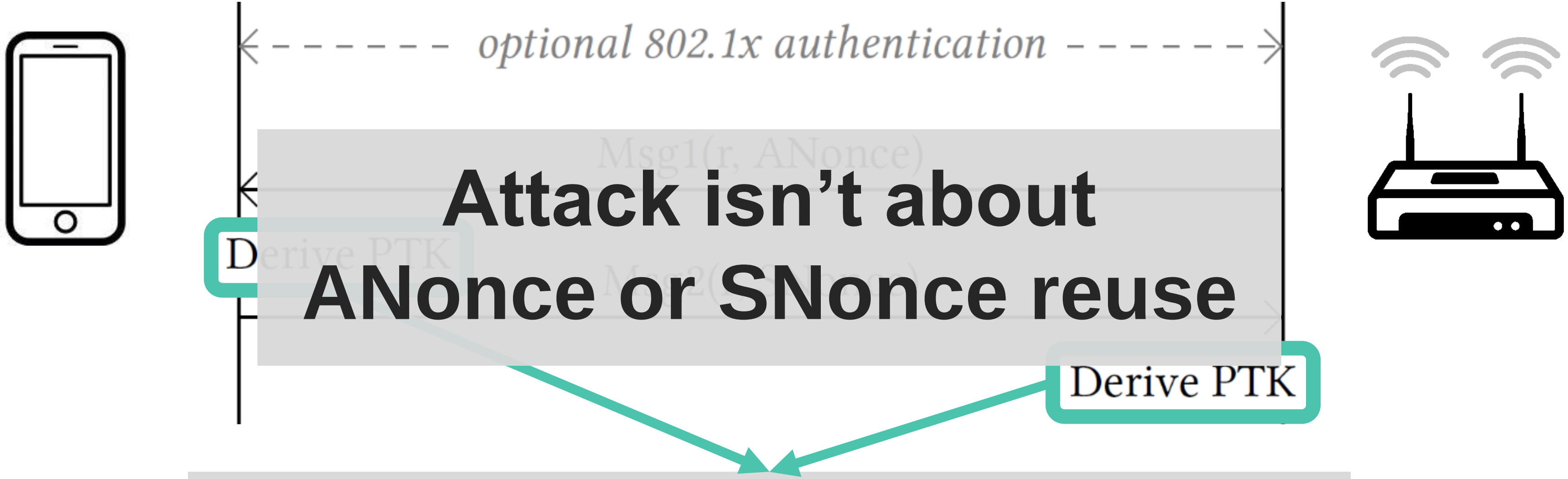


4-way handshake (simplified)



PTK = Combine(shared secret, ANonce, SNonce)

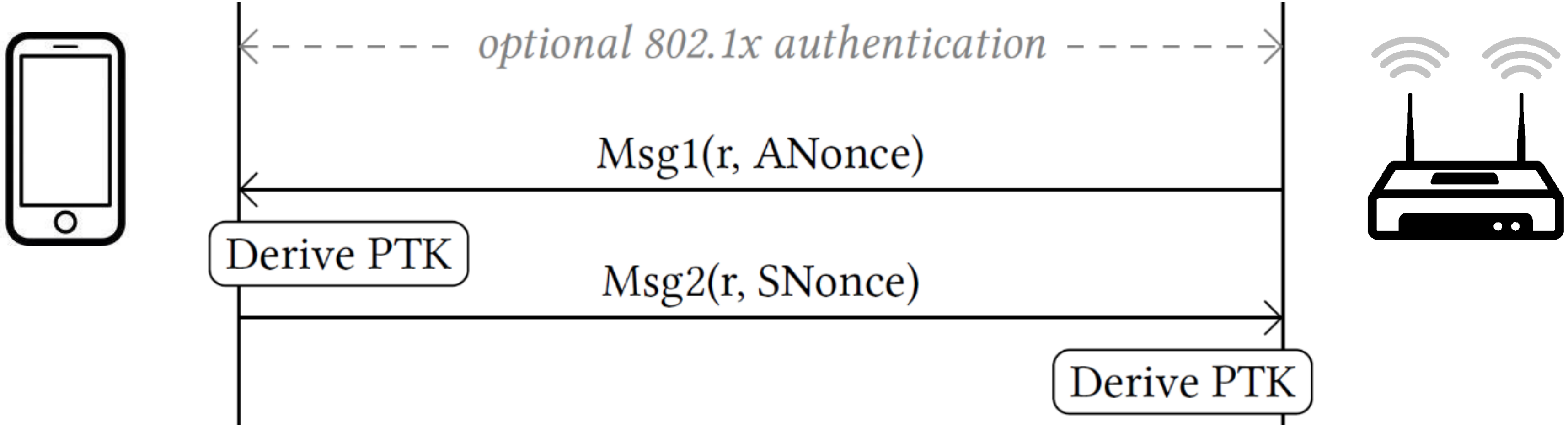
4-way handshake (simplified)



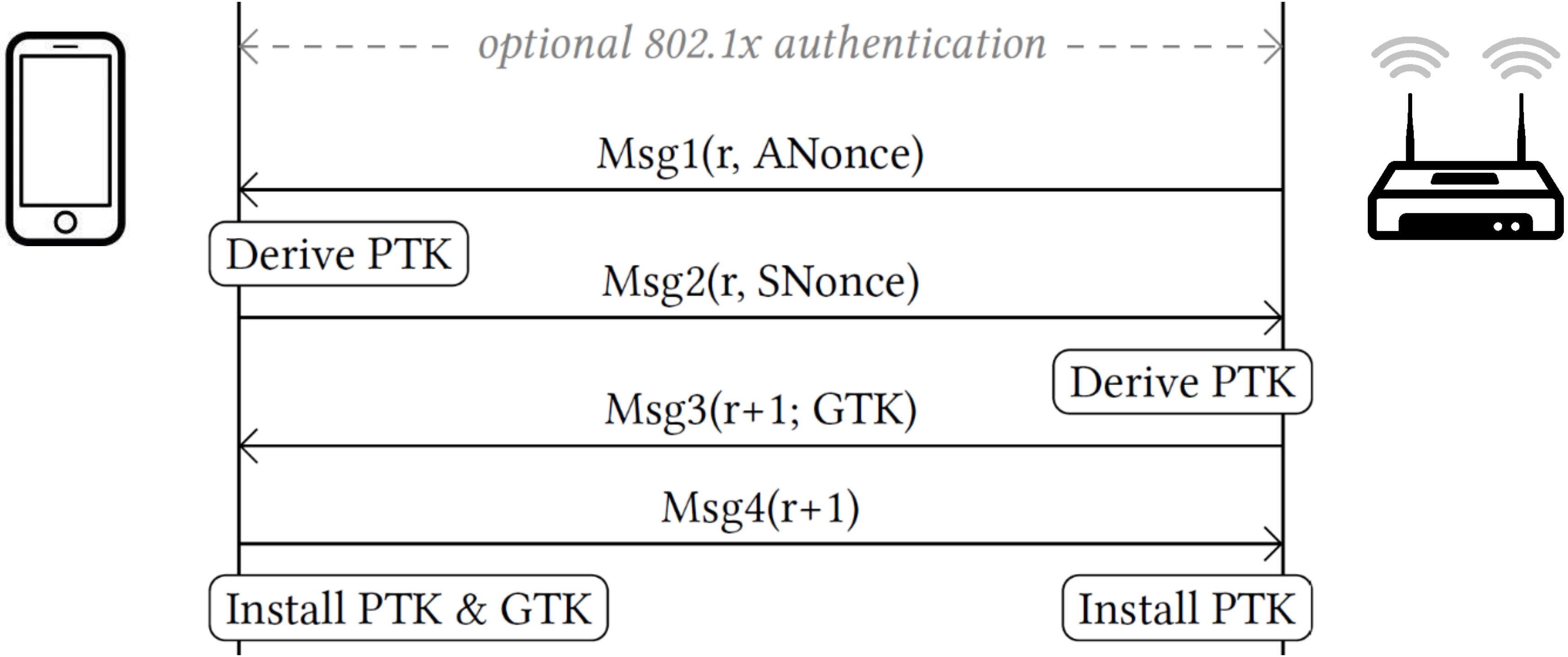
Attack isn't about ANonce or SNonce reuse

PTK = Combine(shared secret, ANonce, SNonce)

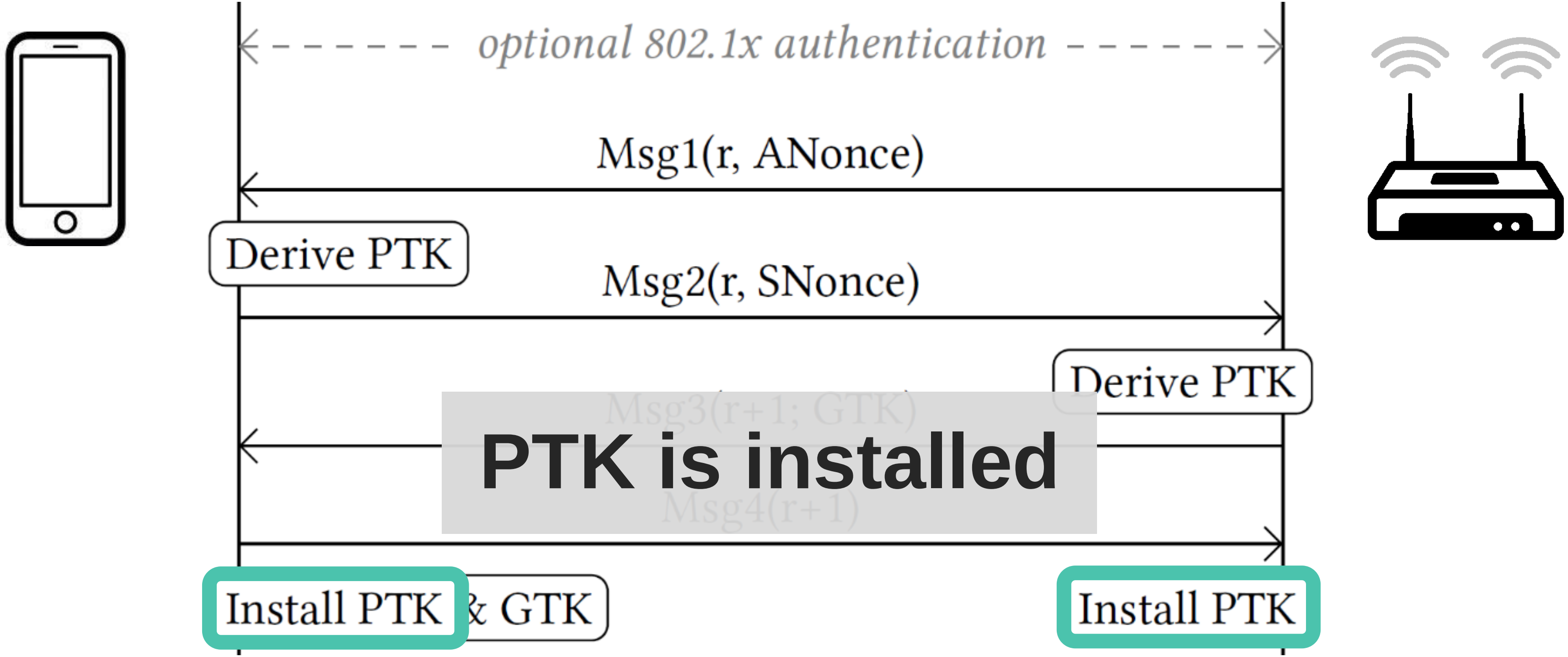
4-way handshake (simplified)



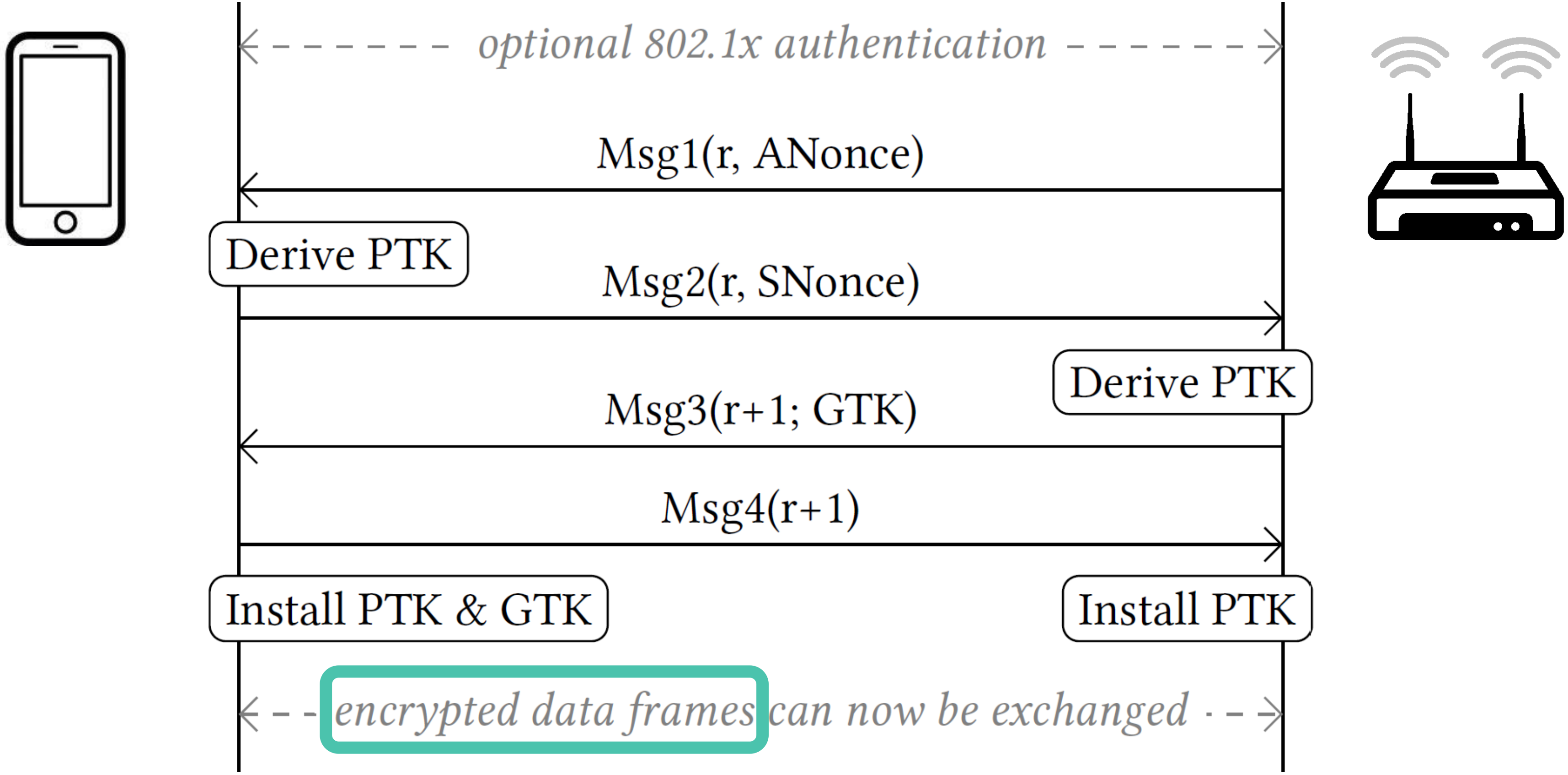
4-way handshake (simplified)



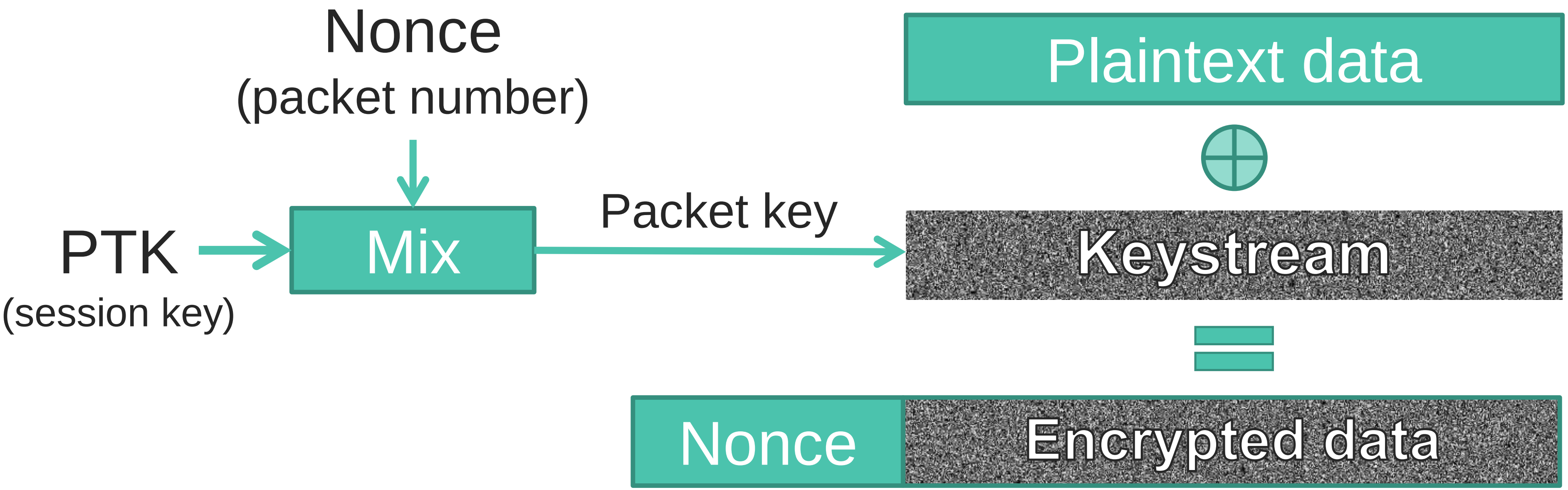
4-way handshake (simplified)



4-way handshake (simplified)

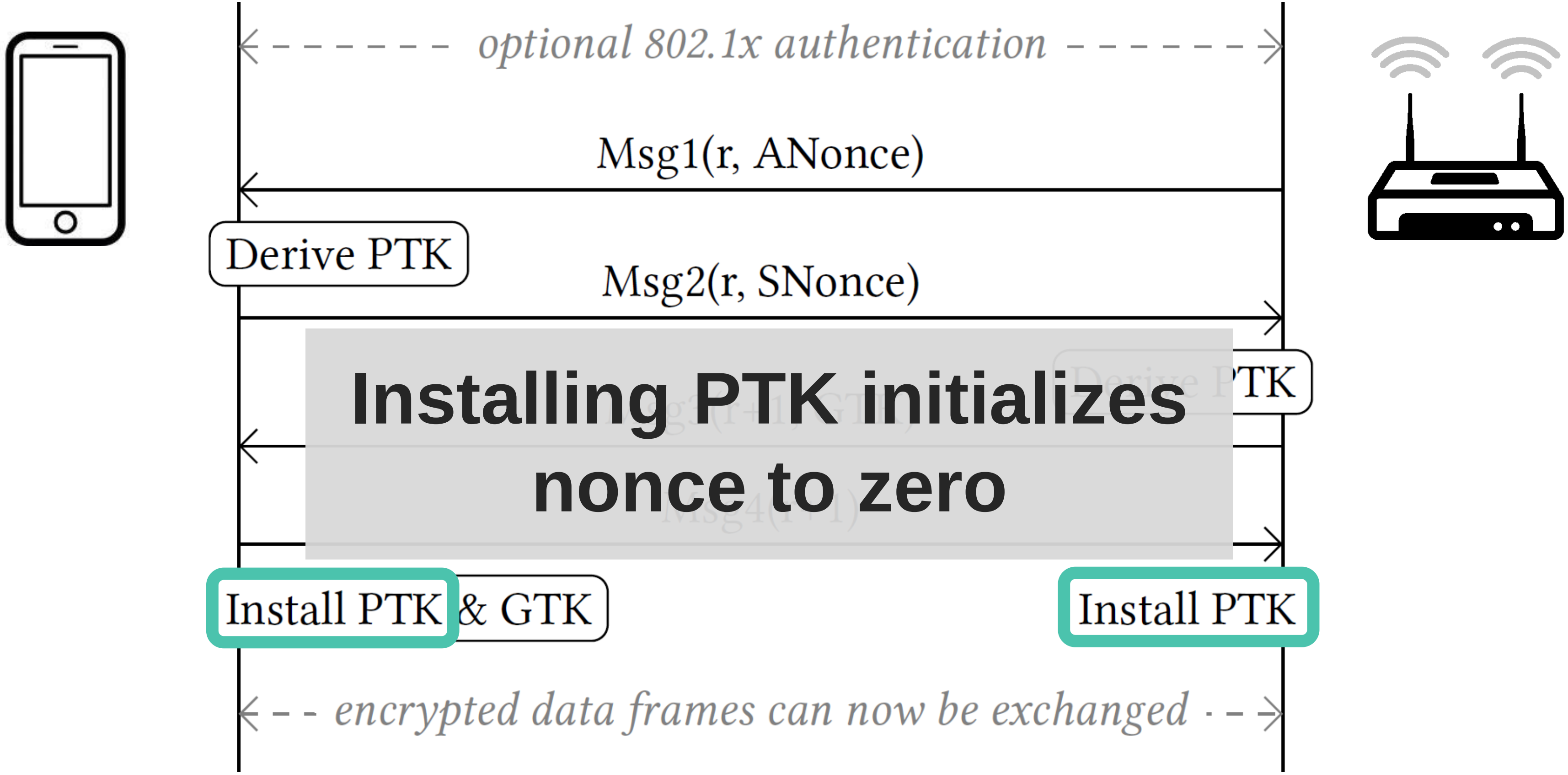


Frame encryption (simplified)

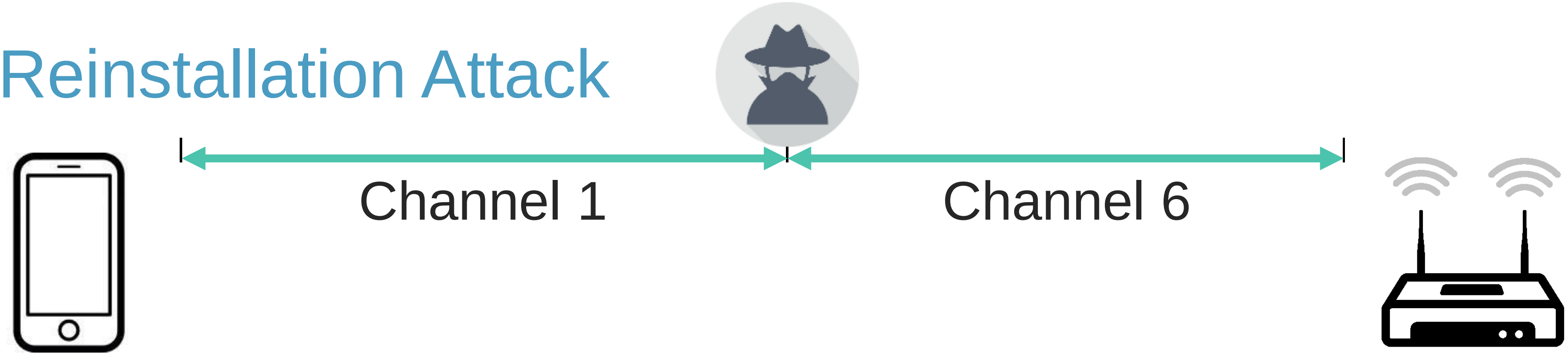


→ Nonce reuse implies keystream reuse (in all WPA2 ciphers)

4-way handshake (simplified)

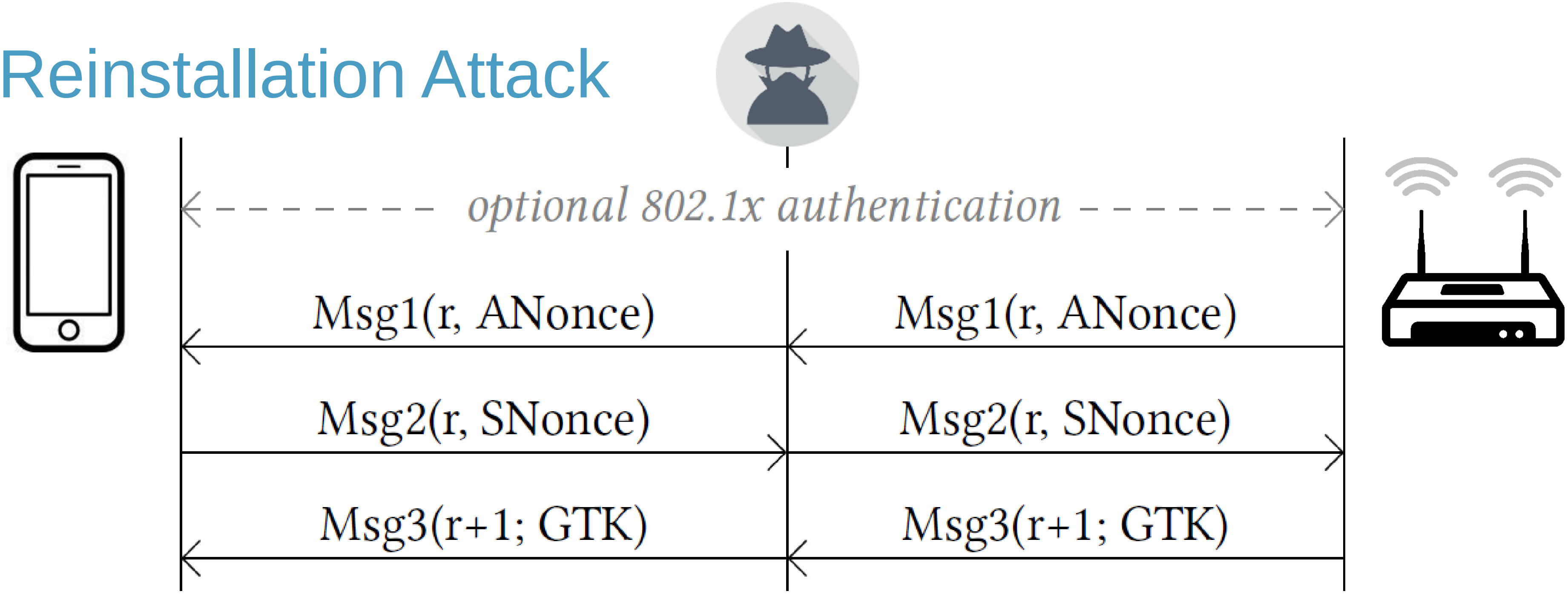


Reinstallation Attack

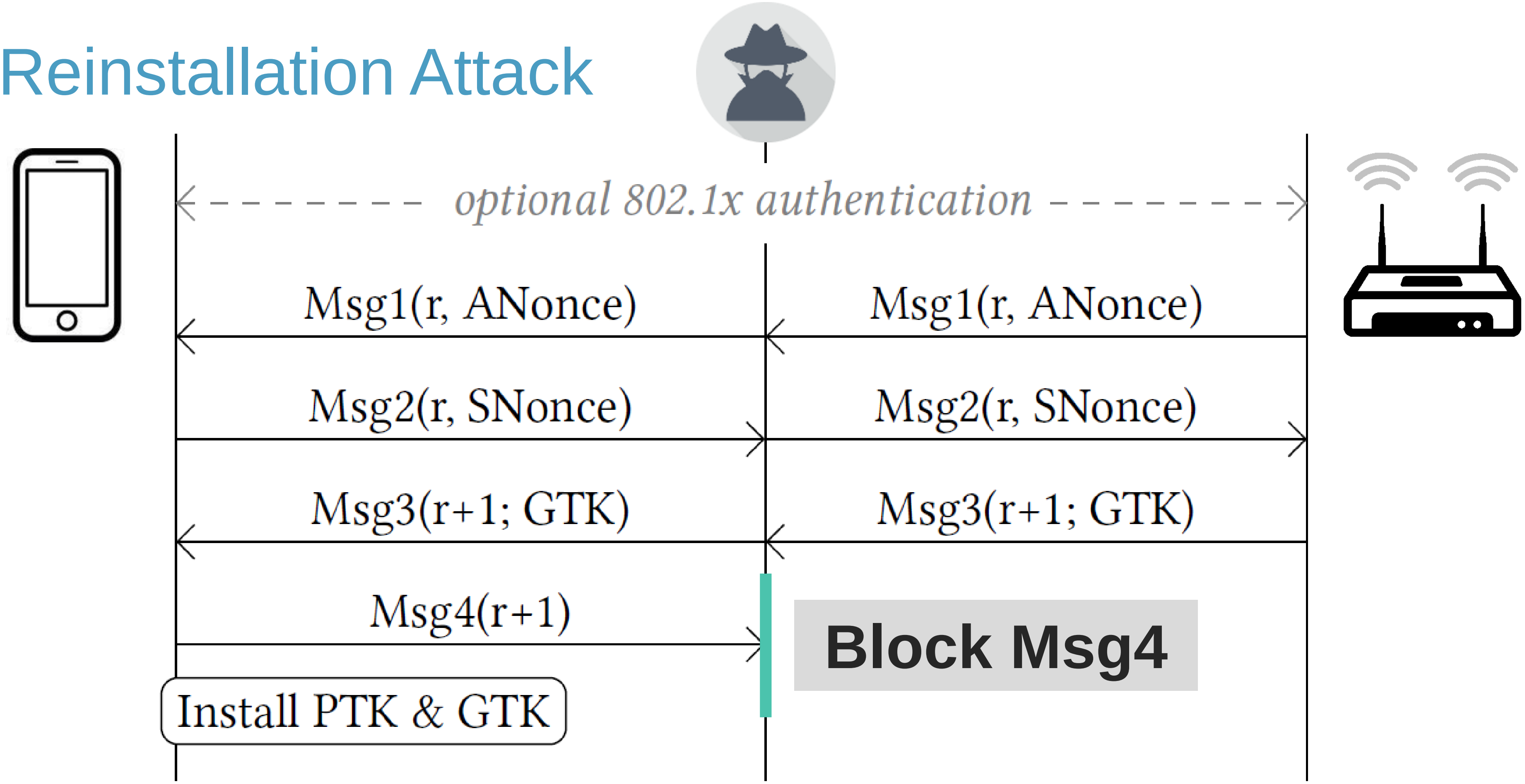


Reinstallation Attack

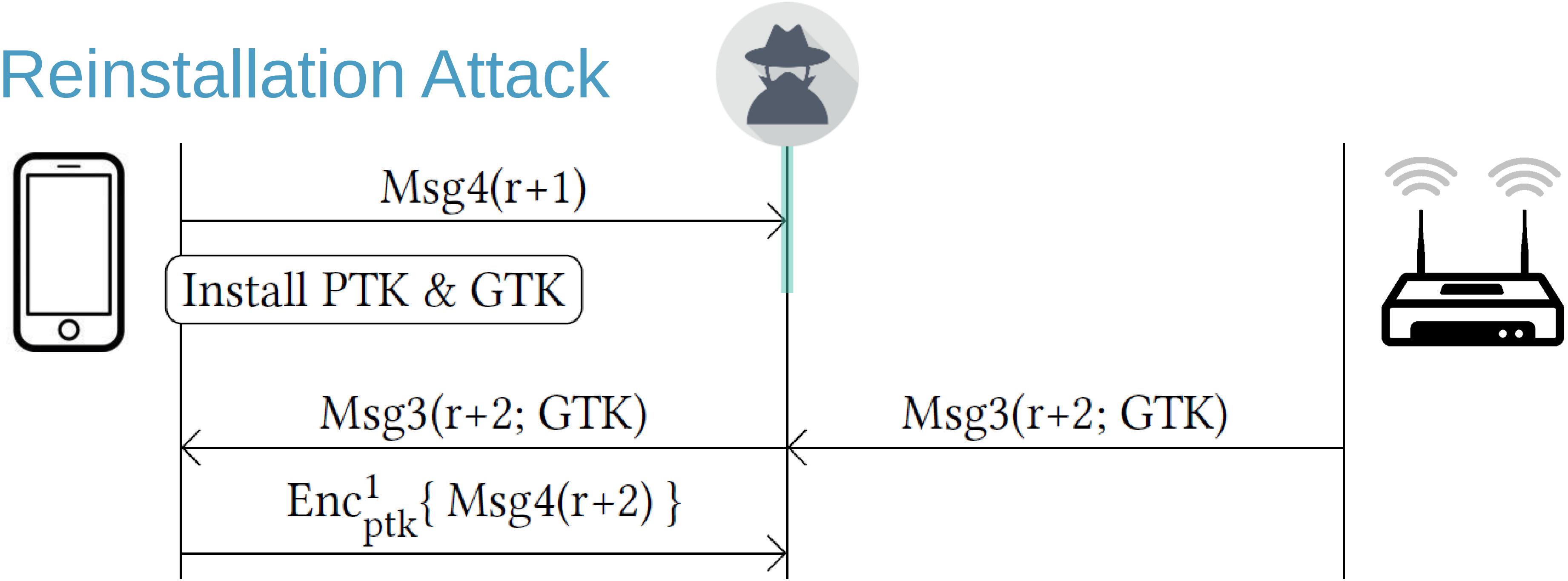
Reinstallation Attack



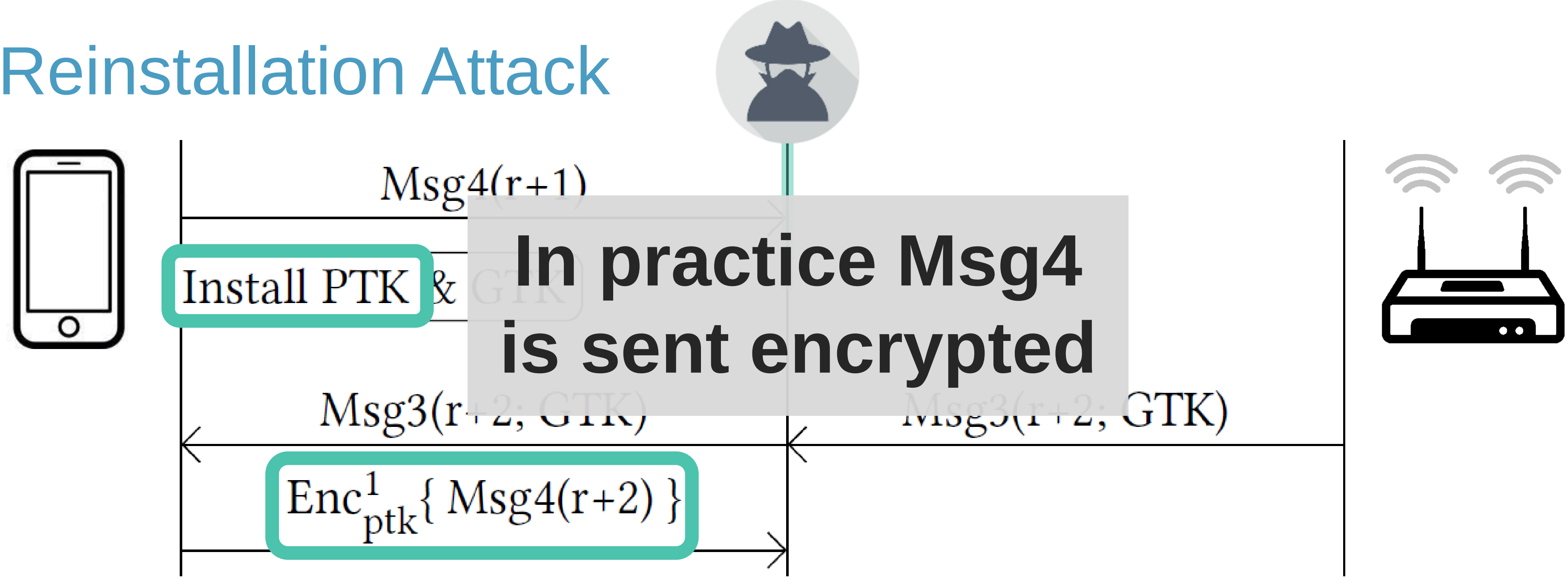
Reinstallation Attack



Reinstallation Attack

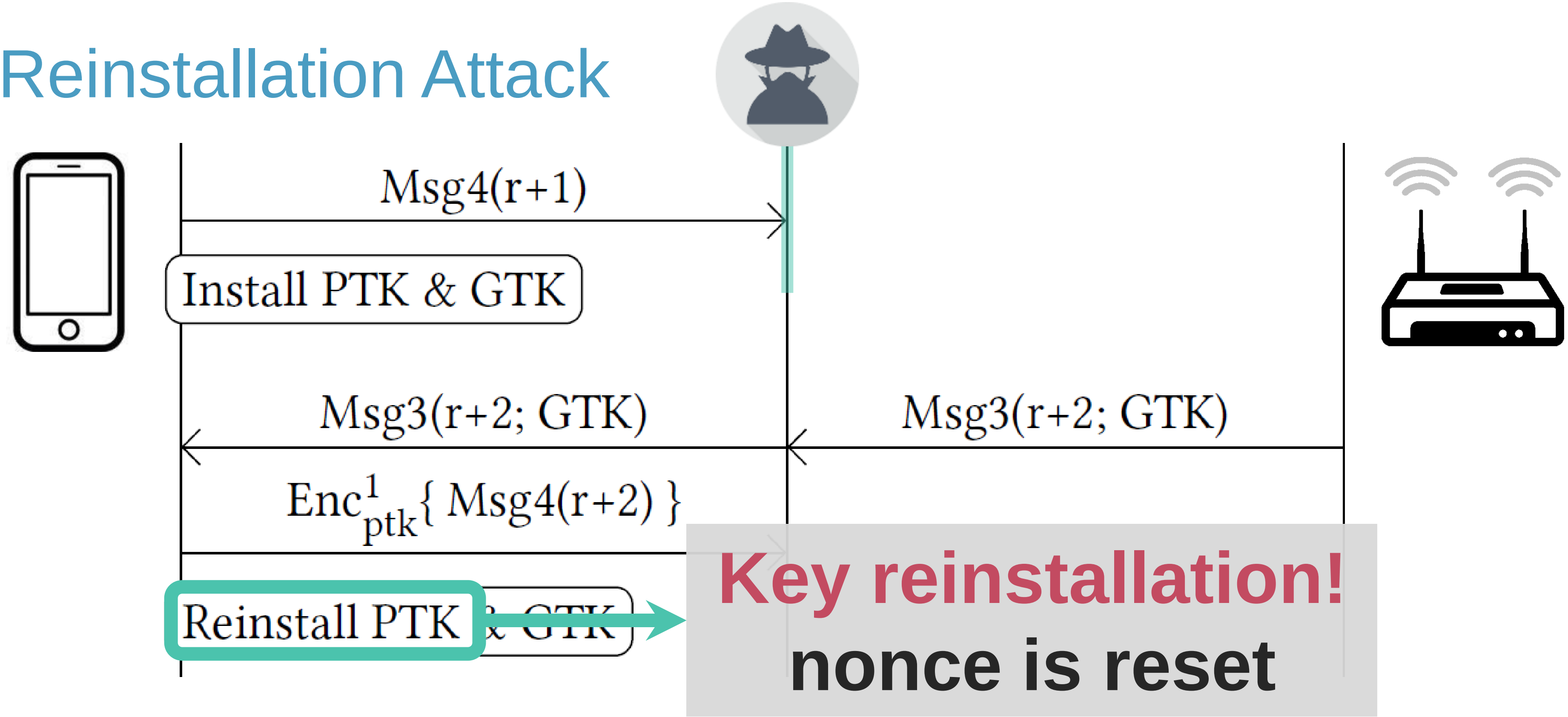


Reinstallation Attack

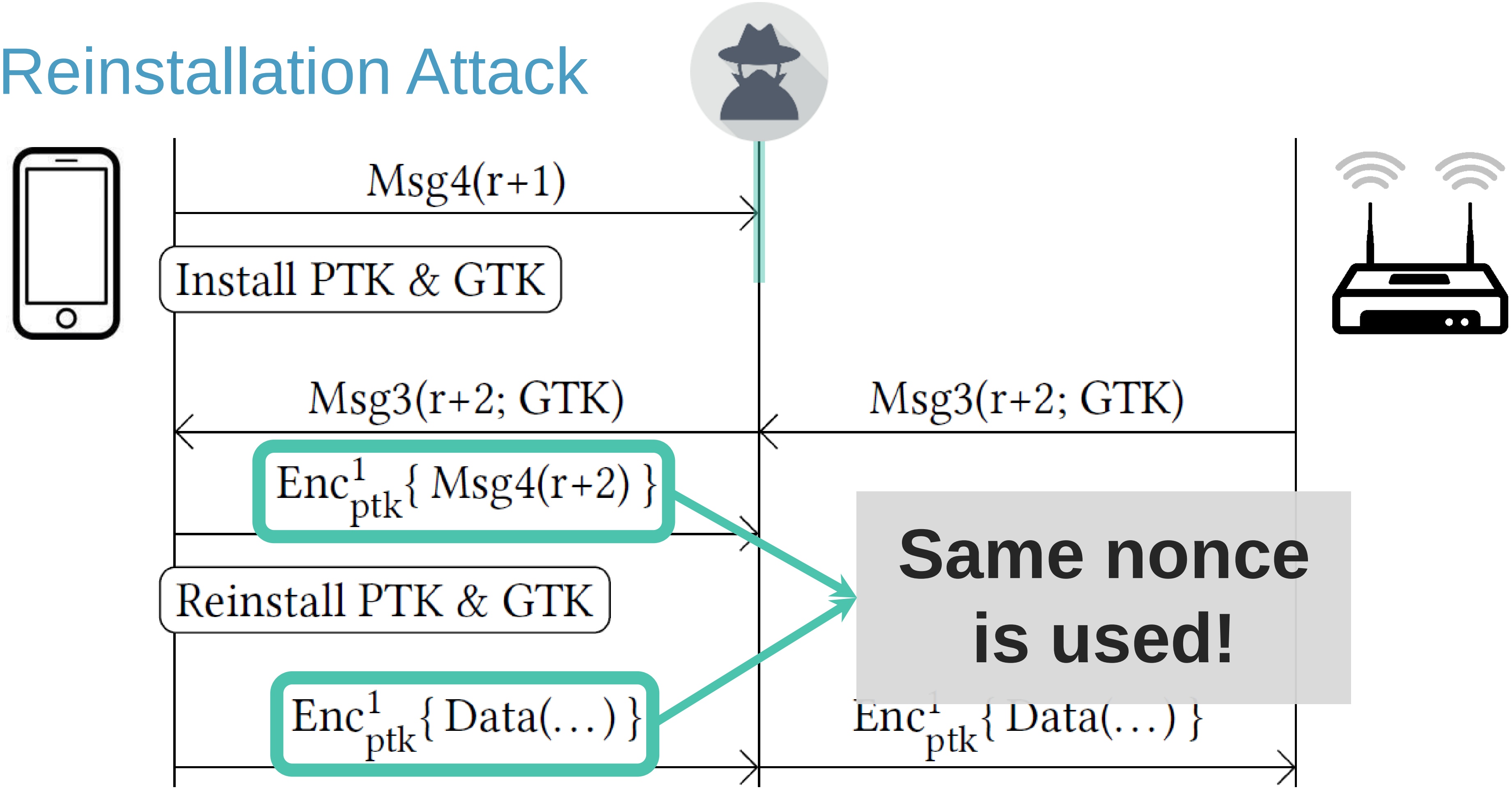


In practice Msg4 is sent encrypted

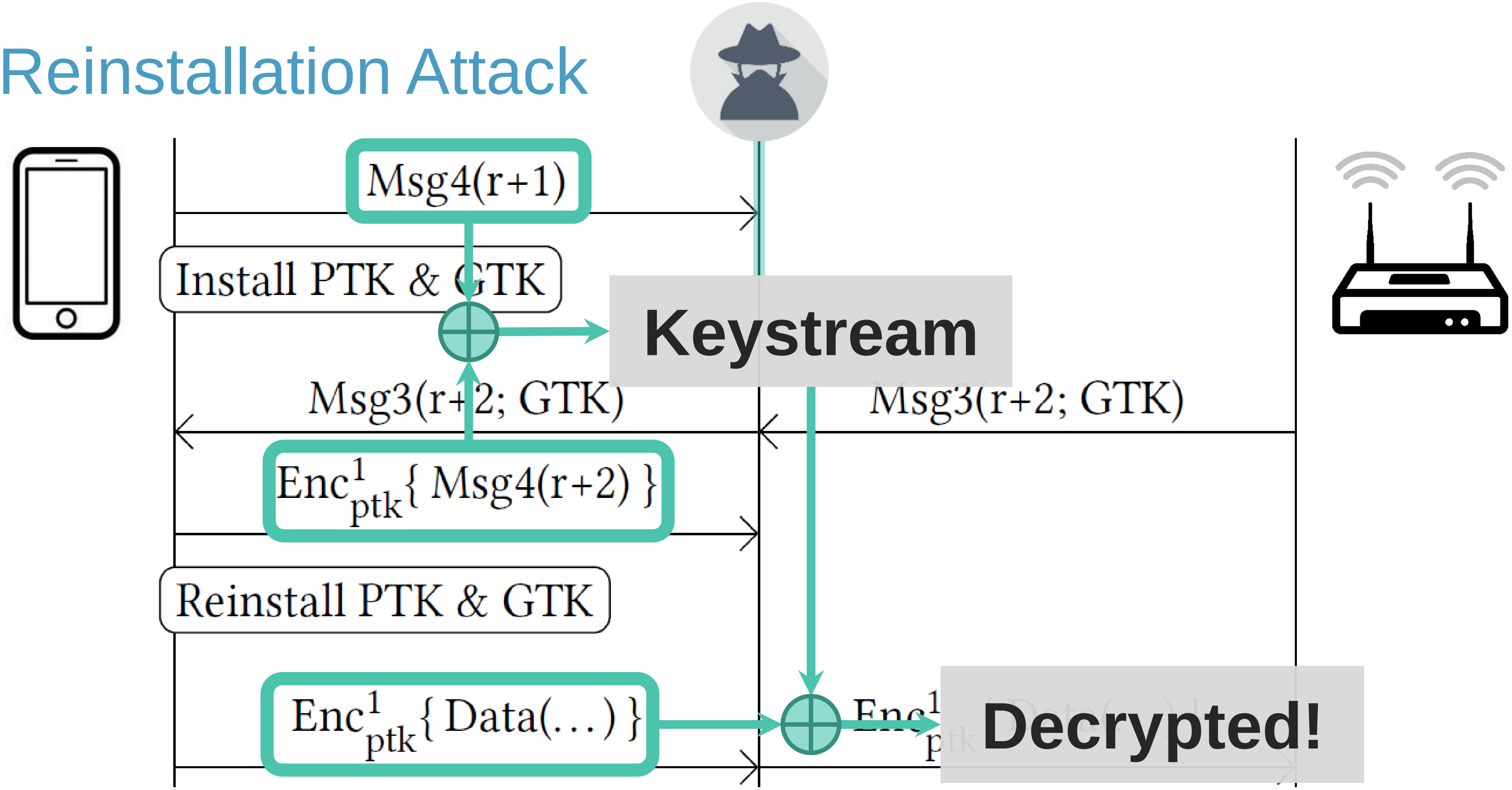
Reinstallation Attack



Reinstallation Attack



Reinstallation Attack



Key Reinstallation Attack

Other Wi-Fi handshakes also vulnerable (CCS'17)

- Group key, FT, and PeerKey handshake

Lesser-known handshakes also vulnerable (CCS'18)

- TDLS, FILS, and WNM handshake

Overview

Key reinstalls in
4-way handshake

Misconceptions

Practical impact

Channel validation

General impact

Transmit nonce reset

Decrypt frames sent by victim

Receive replay counter reset

Replay frames towards victim

Cipher suite specific

AES-CCMP: No practical frame forging attacks

WPA-TKIP:

- Recover Message Integrity Check key from plaintext
- **Forge/inject** frames sent by the device under attack

GCMP (WiGig):

- Recover GHASH authentication key from nonce reuse
- **Forge/inject** frames in **both directions**

Handshake specific

Group key handshake:

- Client is attacked (only AP sends real broadcast frames)
- Can only replay broadcast frames to client

4-way handshake: client is attacked → replay/decrypt/forge

FT handshake (fast roaming = 802.11r):

- Access Point is attacked → replay/decrypt/forge
- **No MitM required, can keep causing nonce resets**

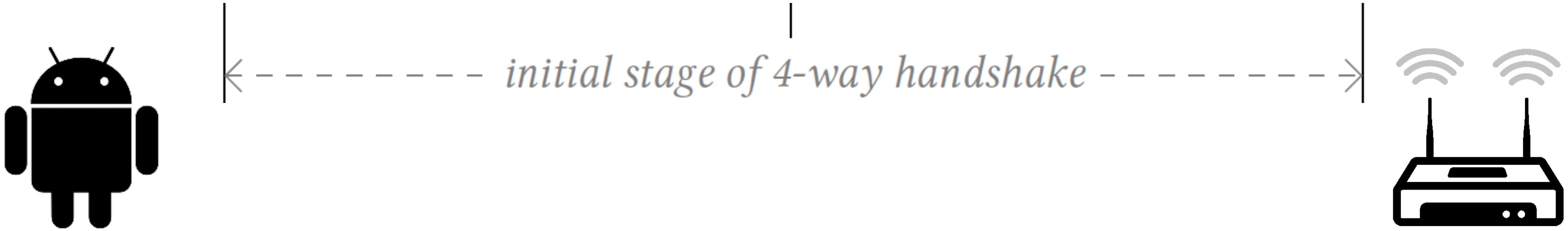
Implementation specific

iOS 10 and Windows: 4-way handshake not affected

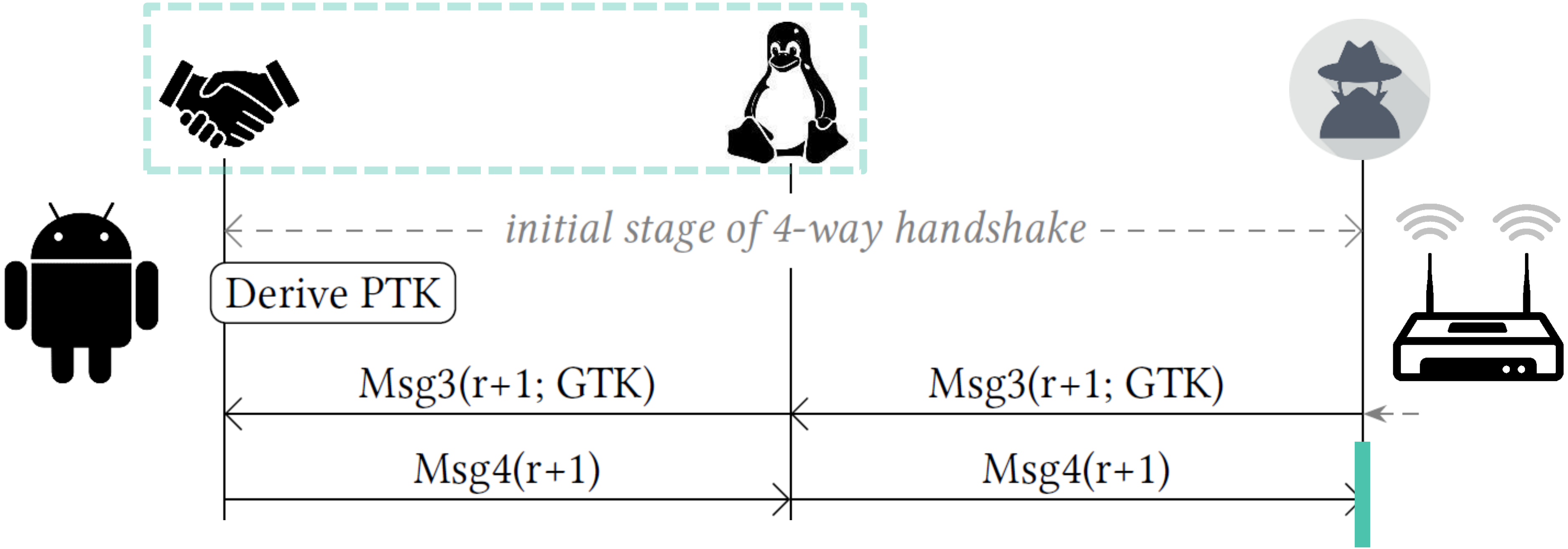
- **Cannot decrypt unicast traffic** (nor replay/decrypt)
- But group key handshake is affected (replay broadcast)
- Note: iOS 11 does have vulnerable 4-way handshake

wpa_supplicant 2.4+

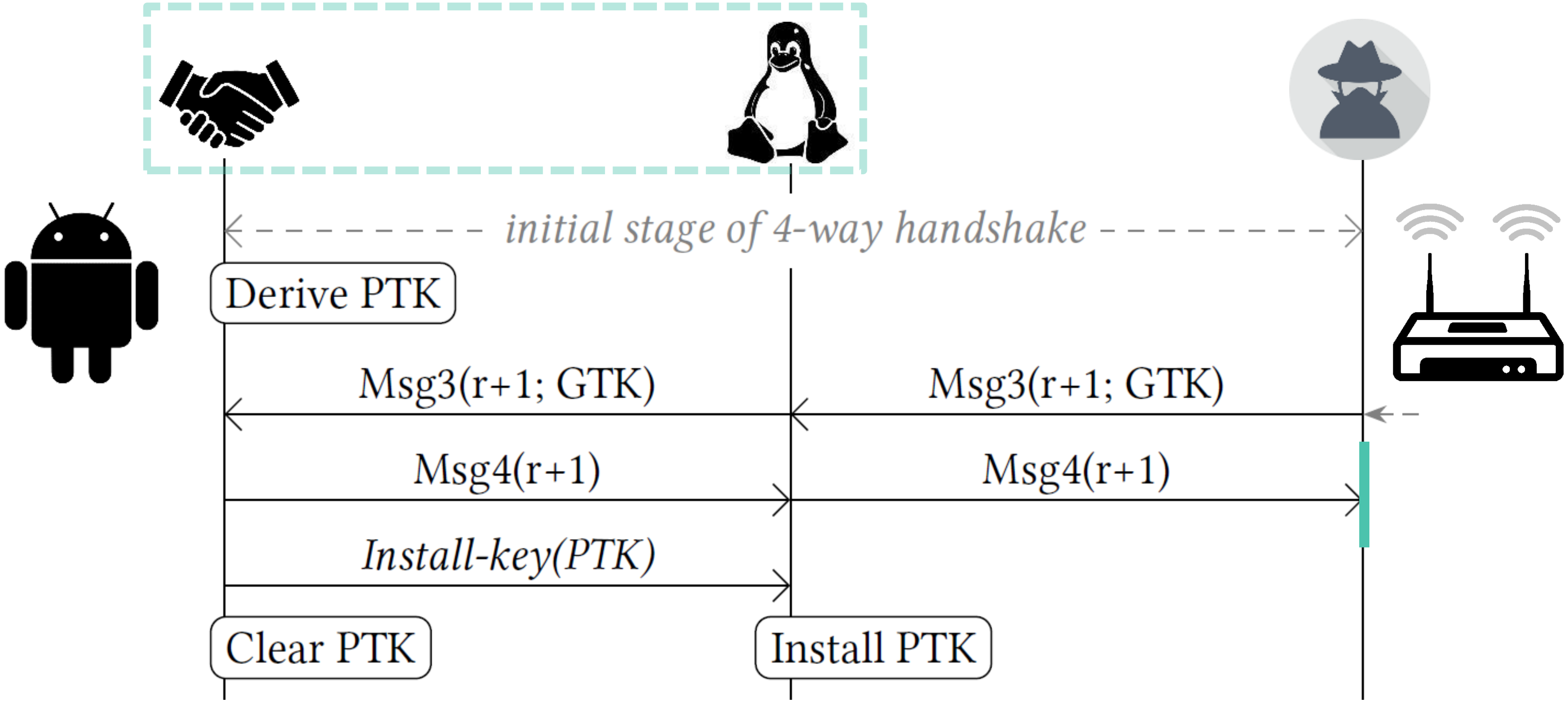
- Client used on Linux and Android 6.0+
- On retransmitted msg3 will **install all-zero key**


initial stage of 4-way handshake

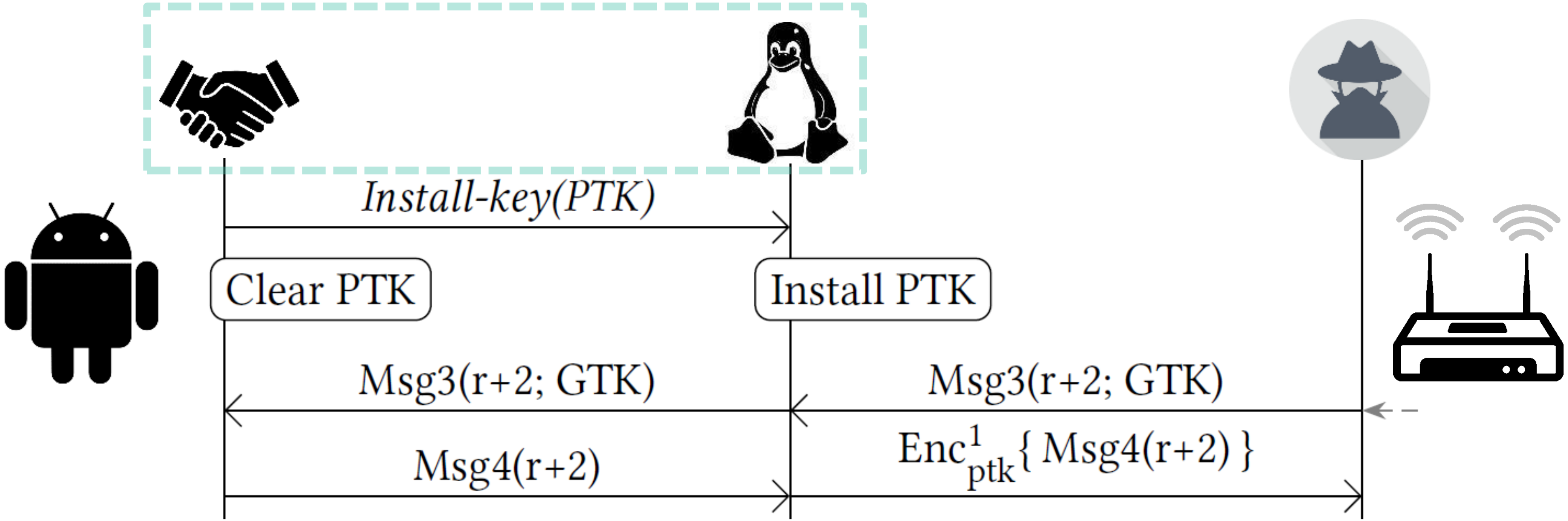

initial stage of 4-way handshake
Android (victim)



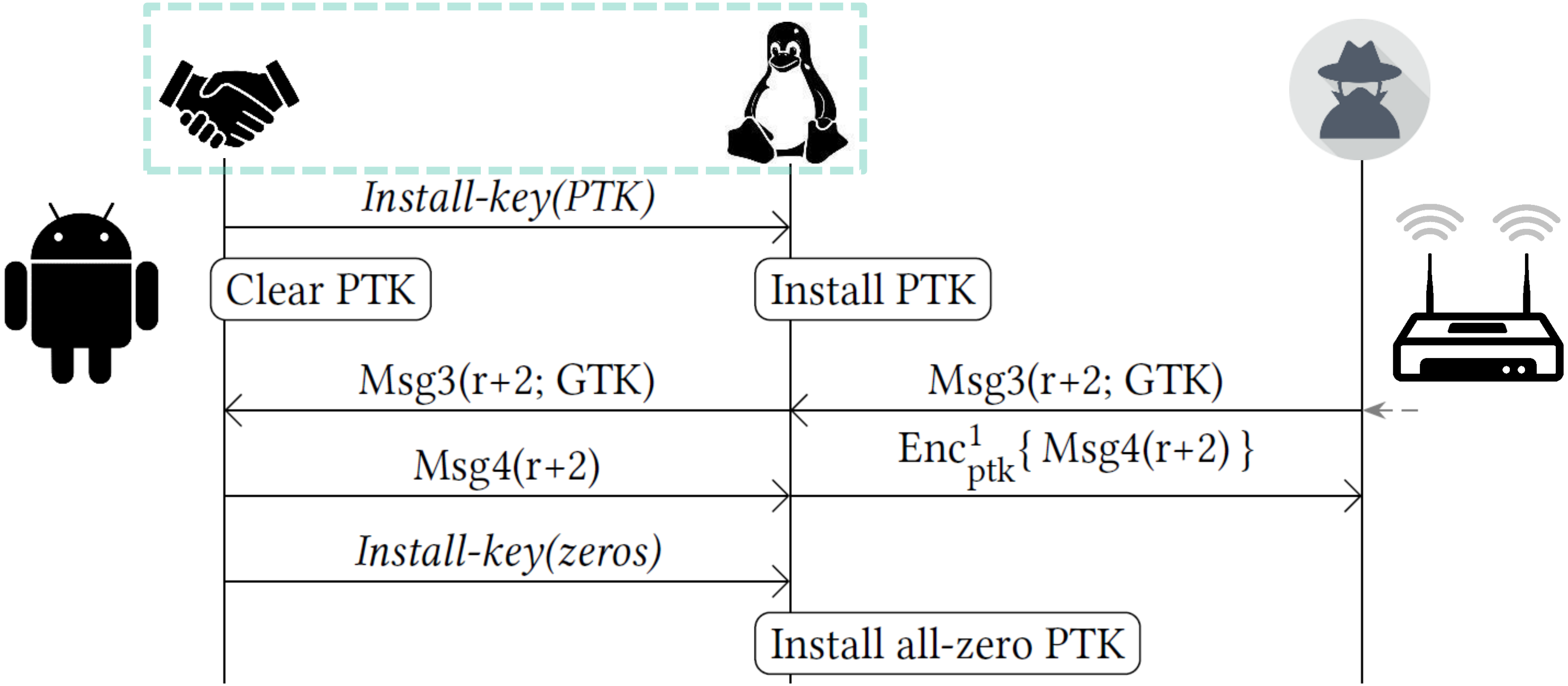
initial stage of 4-way handshake
Derive PTK
Msg3(r+1; GTK)
Msg3(r+1; GTK)
Msg4(r+1)
Msg4(r+1)



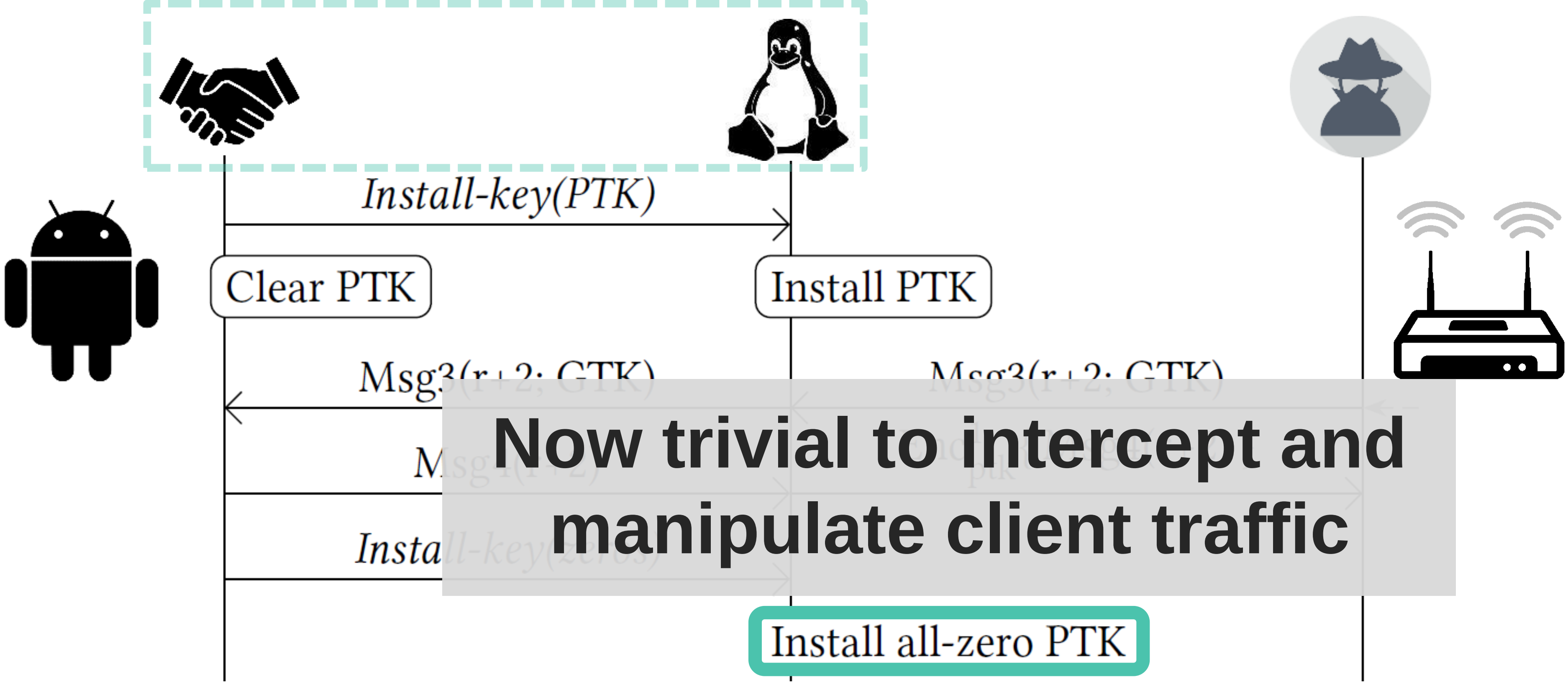
initial stage of 4-way handshake
Derive PTK
Msg3(r+1; GTK)
Msg3(r+1; GTK)
Msg4(r+1)
Msg4(r+1)
Install-key(PTK)
Clear PTK
Install PTK



Install-key(PTK)
Clear PTK
Install PTK
Msg3(r+2; GTK)
Msg3(r+2; GTK)
Enc^1_{ptk} { Msg4(r+2) }
Msg4(r+2)



Install-key(PTK)
Clear PTK
Install PTK
Msg3(r+2; GTK)
Msg3(r+2; GTK)
Msg4(r+2)
$\mathrm{Enc}^{1}_{ptk}\{\ \mathrm{Msg4(r+2)}\ \}$
Install-key(zeros)
Install all-zero PTK



Now trivial to intercept and manipulate client traffic

Is your device (still) affected?

github.com/vanhoefm/krackattacks-scripts

- Tests clients and APs
- Works on Kali Linux

Remember to:

- Disable hardware encryption
- Use a supported Wi-Fi dongle!

Countermeasures

Many clients won't get updates…

AP can prevent (most) attacks on clients!

- Don't retransmit message 3/4
- Don't retransmit group message 1/2

However:

- Impact on reliability unclear
- Clients still vulnerable when connected to unmodified APs

Overview

Key reinstalls in
4-way handshake

Misconceptions

Practical impact

Channel validation

Misconceptions I

Updating only the client or AP is sufficient

› Both <u>vulnerable</u> clients & <u>vulnerable</u> APs must apply patches

Need to be close to network and victim

› Can use special antenna from afar

No useful data is transmitted after handshake

› Trigger new handshakes during TCP connection

Misconceptions II

Obtaining channel-based MitM is hard

- Can use channel switch announcements

Using (AES-)CCMP mitigates the attack

- Still allows decryption & replay of frames

Enterprise networks (802.1x) aren't affected

- Also use 4-way handshake & are affected

Image from "KRACK: Your Wi-Fi is no longer secure" by Kaspersky

Overview

Key reinstalls in
4-way handshake

Misconceptions

Practical impact

Channel validation

Background: new attacks require MitM

Traffic Analysis

- **Capture all** encrypted frames
- **Block** certain encrypted frames

Attacking broadcast WPA-TKIP

- **Block** MIC failures
- **Modify** encrypted frames

ChopChop

Background: new attacks require MitM

Exploit implementation bugs

- **Block** certain handshake messages
- E.g. bugs in 4-way handshake

Other attack scenarios

- See WiSec’18 paper [VBDOP18]
- E.g. **modify** advertised capabilities

Observed threat model

- Attacker manipulates channel and bandwidth
- Exclude low-layer attacks (e.g. beamforming)
- Exclude relay attacks (e.g. AP and client out of range)

Want to make attacks harder, not impossible

≈ stack canaries.

Solution: verify operating channel when connecting

Verifying the current operating channel

Simple, just verify channel number element?

- Say hello to the 802.11 standard
- HT element defines optional 40 MHz bandwidth
- VHT element defines more bandwidths
- And so on …
- **Non-trivial to unambiguously encode channel**

→ We introduce the **OCI element** to encode a channel

Problem: Channel Switch Announcements (CSAs)

Unauthenticated CSAs

› Need to verify securely

Authenticated CSAs

› May not arrive → verify reception

Solution: verify CSA using SA query

Limitations

Other (partial) MitM attacks still possible:

- Adversary can act as repeater
- Physical-layer tricks (e.g. beamforming)

So why use this defense?

- **Remaining attacks are harder & not always possible**
- Straightforward implementation

Standardization & implementation

Part of the upcoming 802.11 standard

March 2018 doc.: IEEE 802.11-17/1807r10

IEEE P802.11
Wireless LANs

Defense against multi-channel MITM attacks via Operating Channel Validation

Implementation is being pushed upstream:

github.com/vanhoefm/hostap-channel-validation

Conclusion

- Flaw is in WPA2 standard
- Proven correct but is insecure!
- Update all clients & check Aps
- New defense: channel validation

Thank you!

Questions?

krackattacks.com