KRACKing WPA2 and Mitigating Future Vulnerabilities

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HackPra, Ruhr-Universität Bochum, 18 July 2018

Overview

Key reinstalls in
4-way handshake

Misconceptions

Practical impact

Channel validation

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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
- And encryption protocol proven secure

4-way handshake (simplified)

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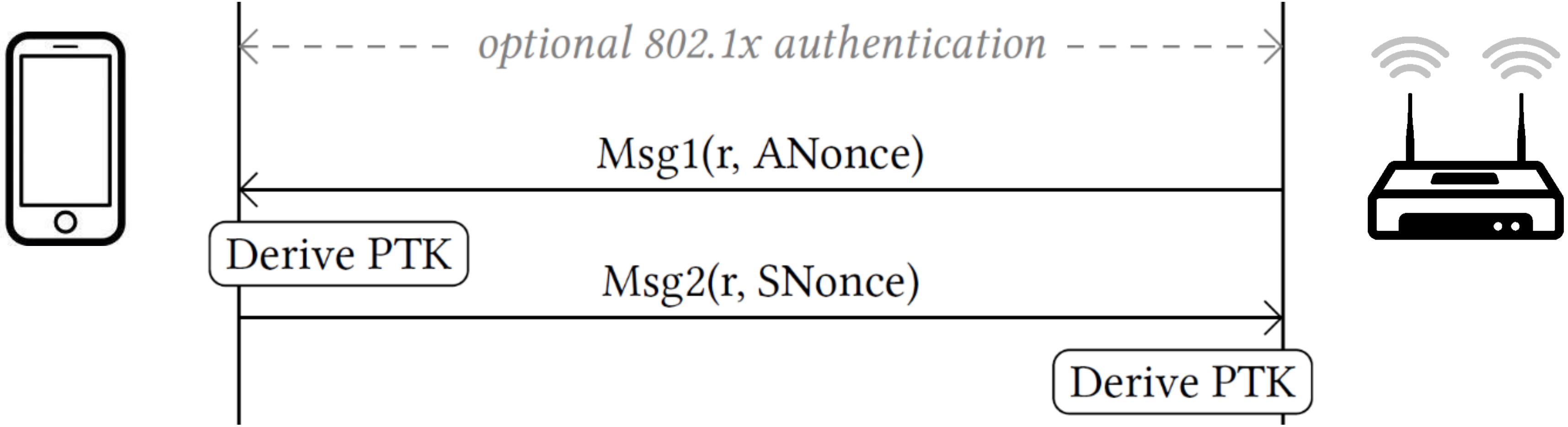
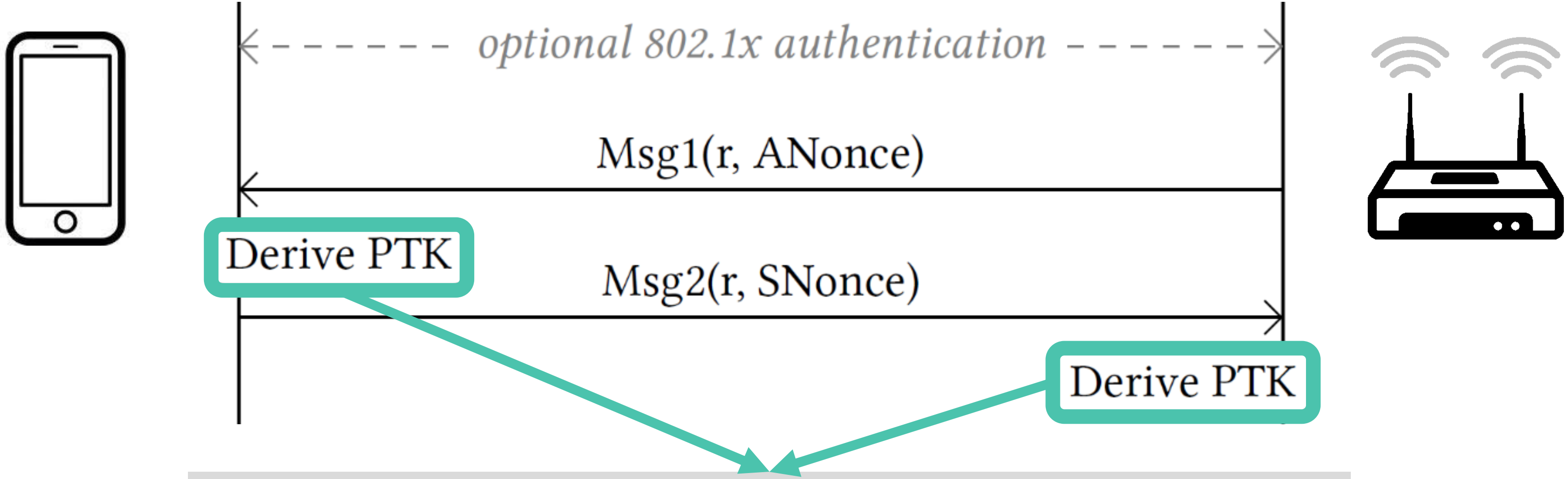
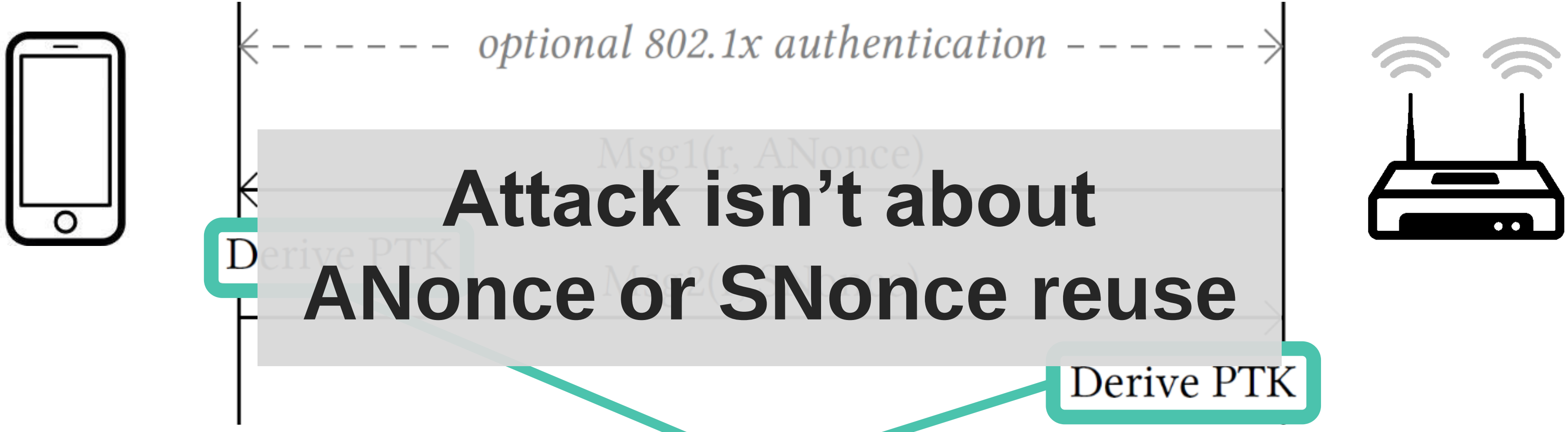


4-way handshake (simplified)



PTK = Combine(shared secret, ANonce, SNonce)

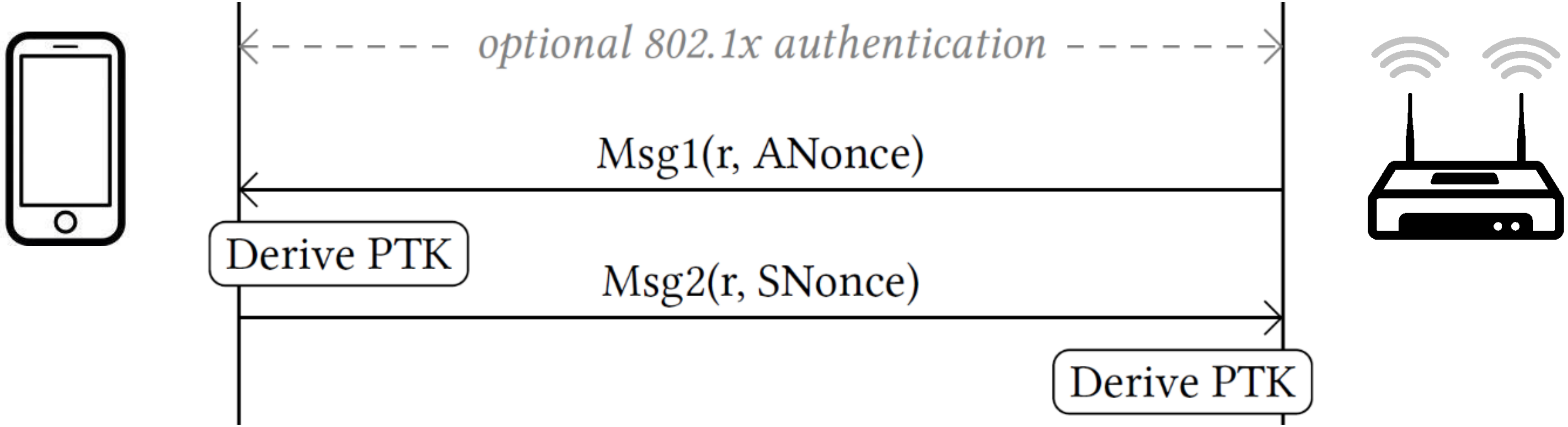
4-way handshake (simplified)



Attack isn't about ANonce or SNonce reuse

PTK = Combine(shared secret, ANonce, SNonce)

4-way handshake (simplified)



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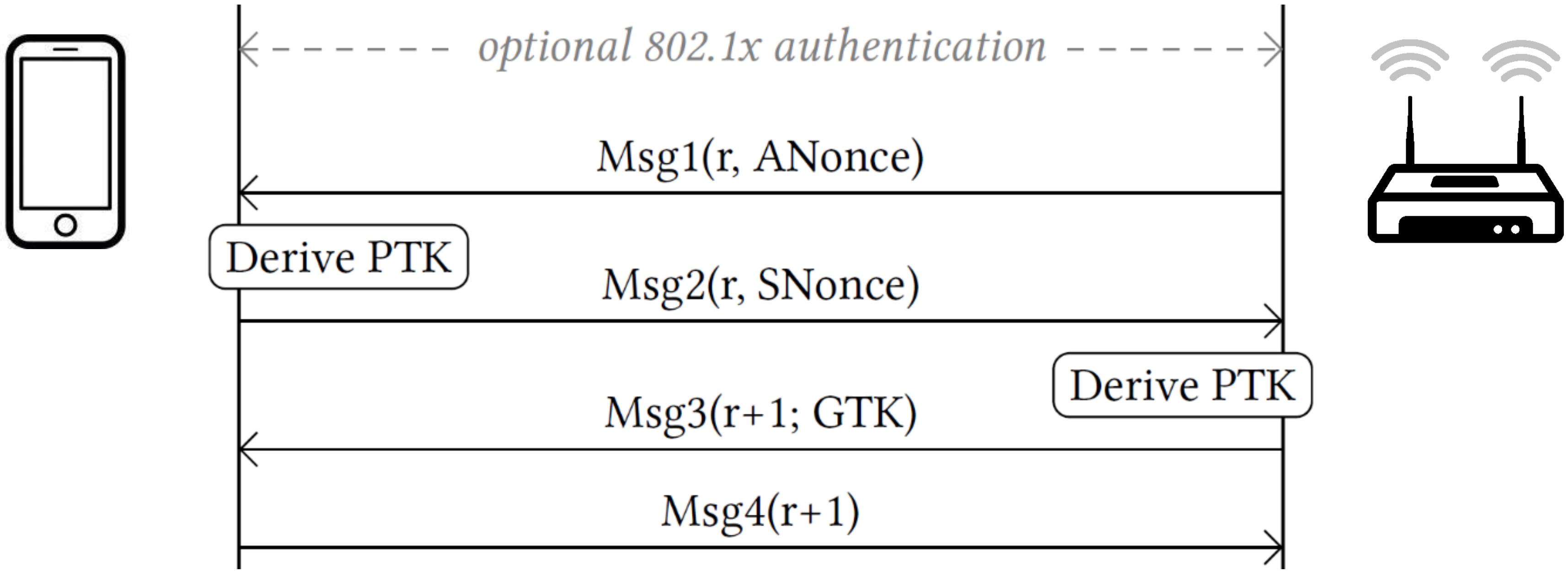

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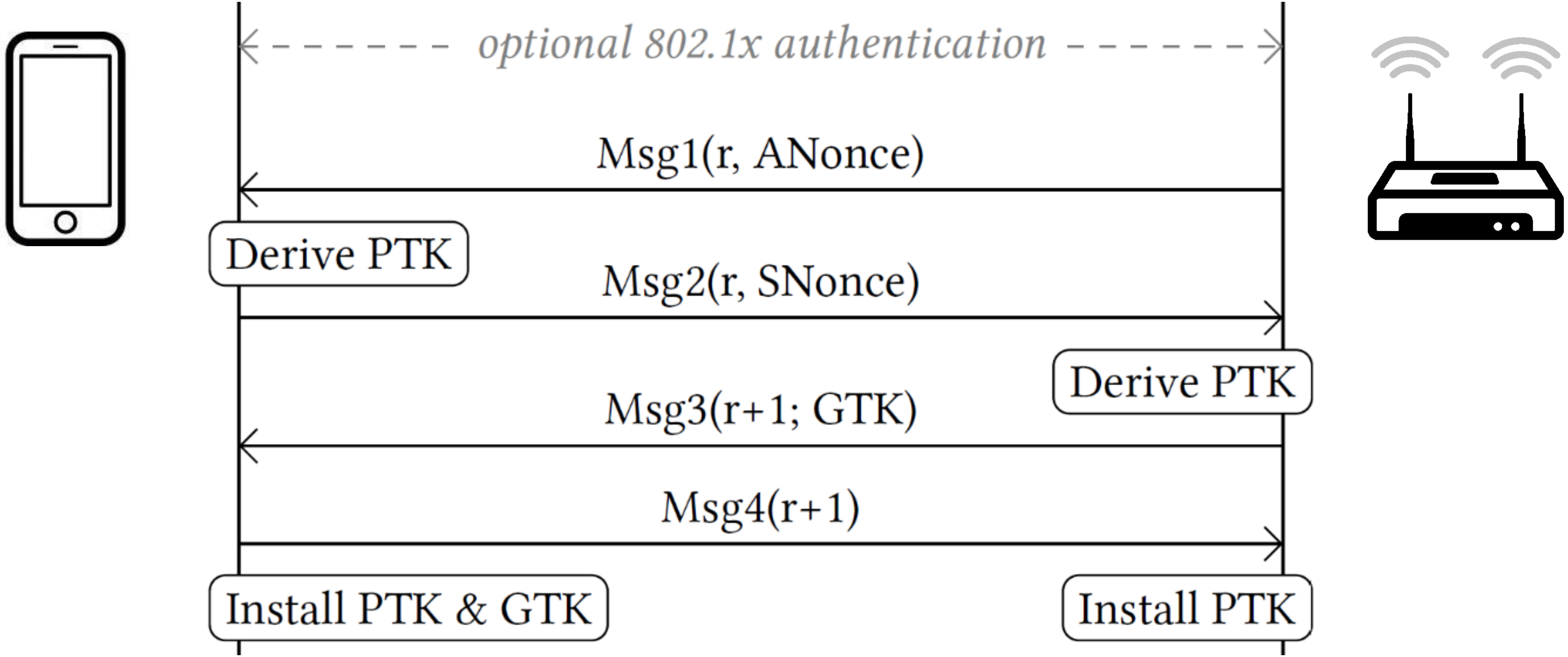

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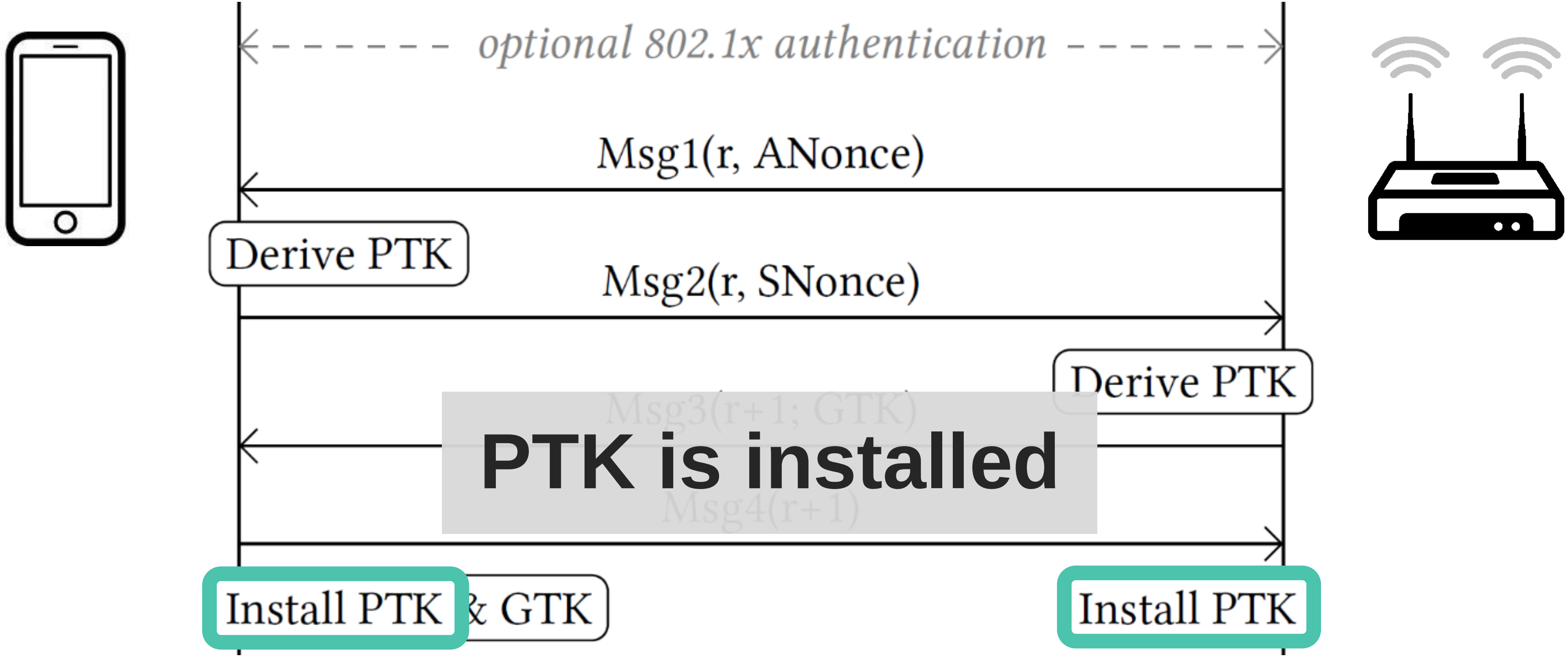

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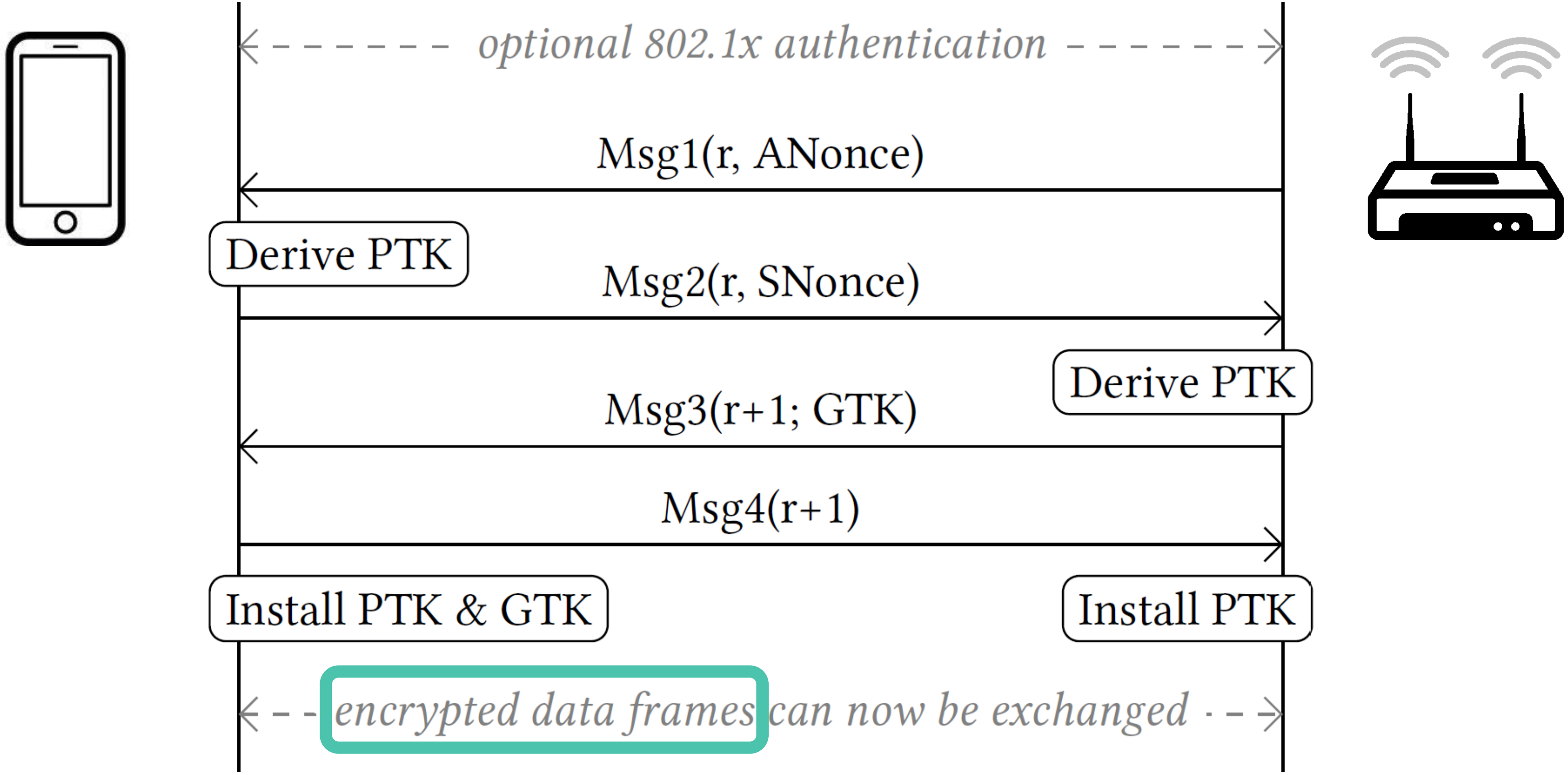
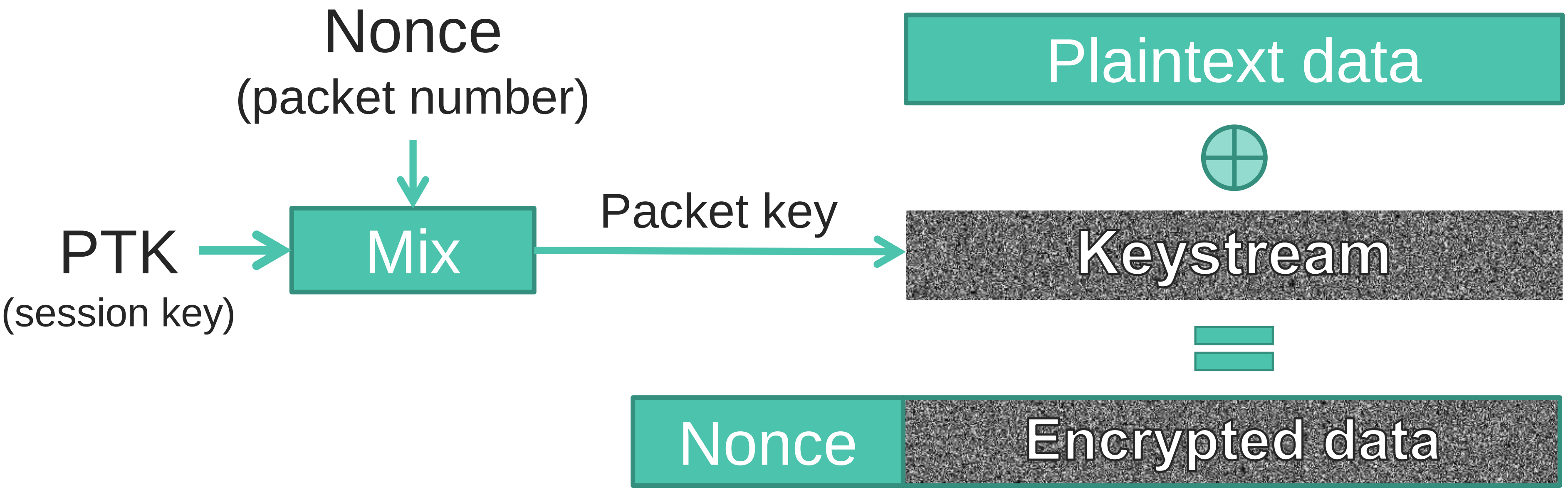
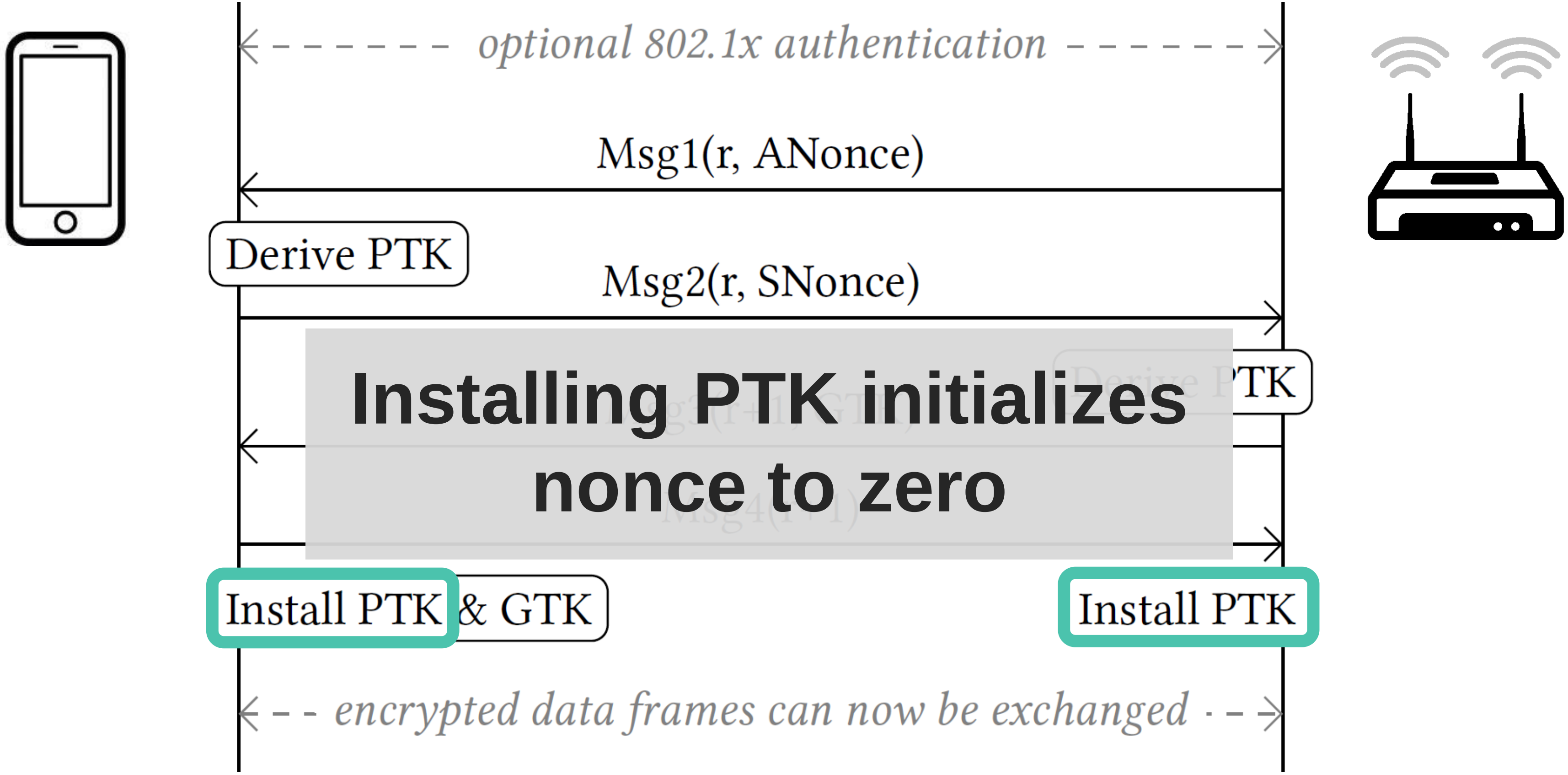


Frame encryption (simplified)



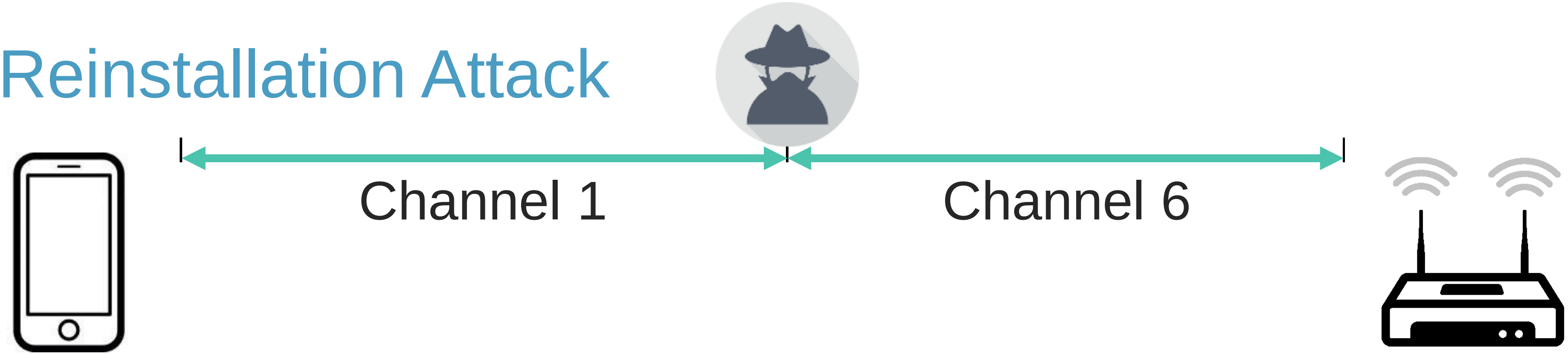
→ Nonce reuse implies keystream reuse (in all WPA2 ciphers)

4-way handshake (simplified)



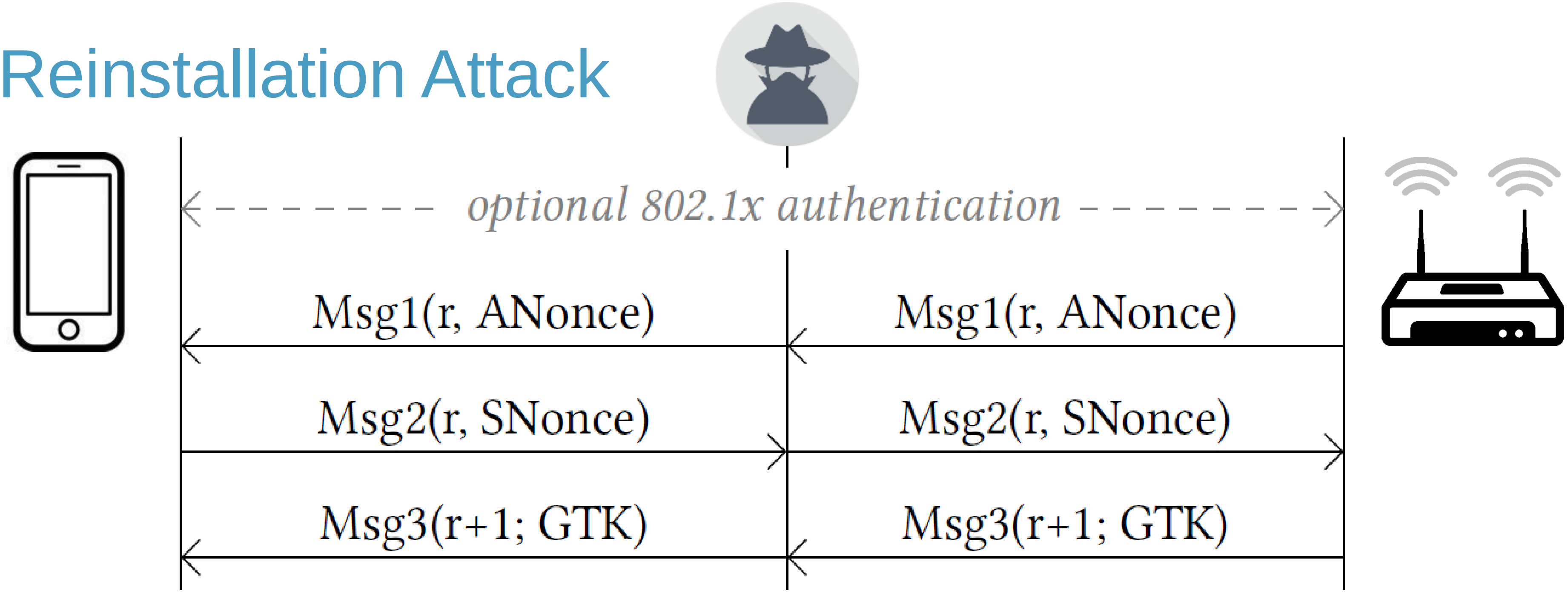
Installing PTK initializes nonce to zero

Reinstallation Attack



Reinstallation Attack

Reinstallation Attack



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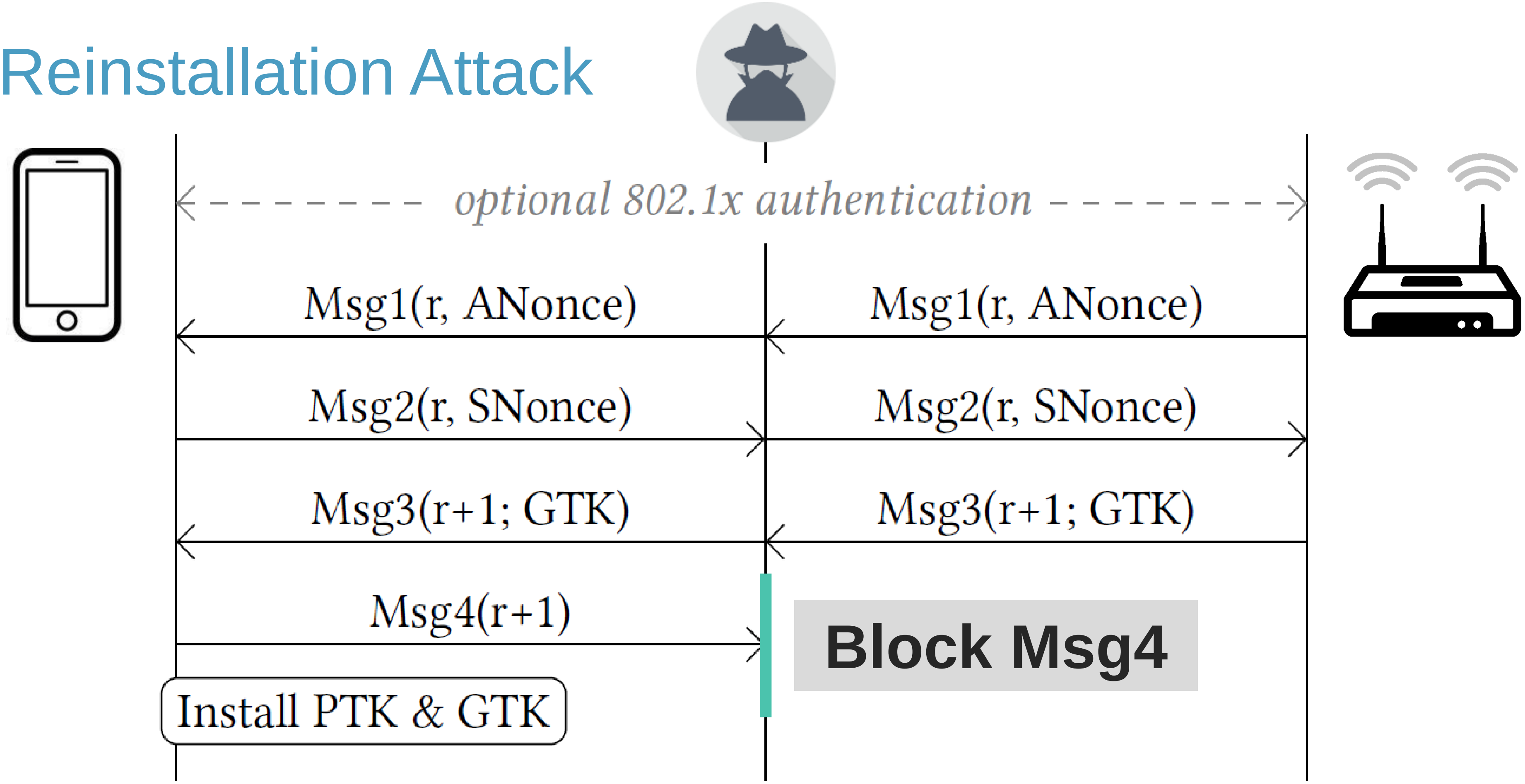

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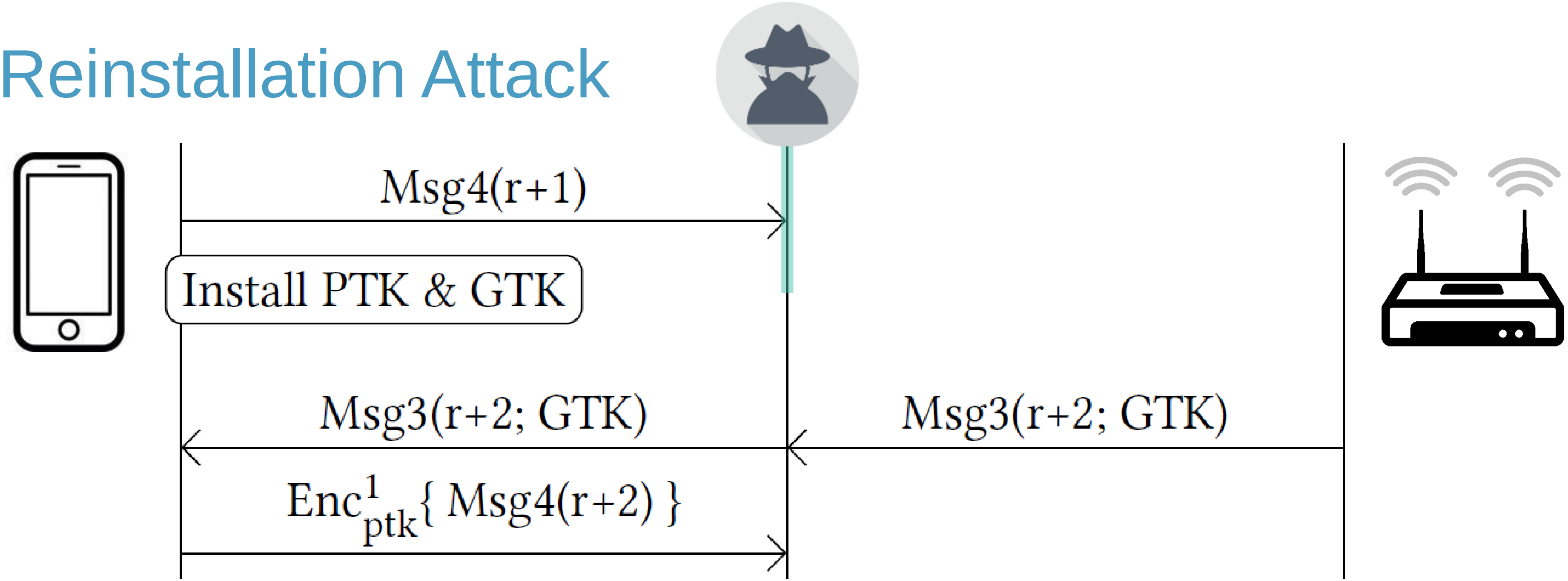

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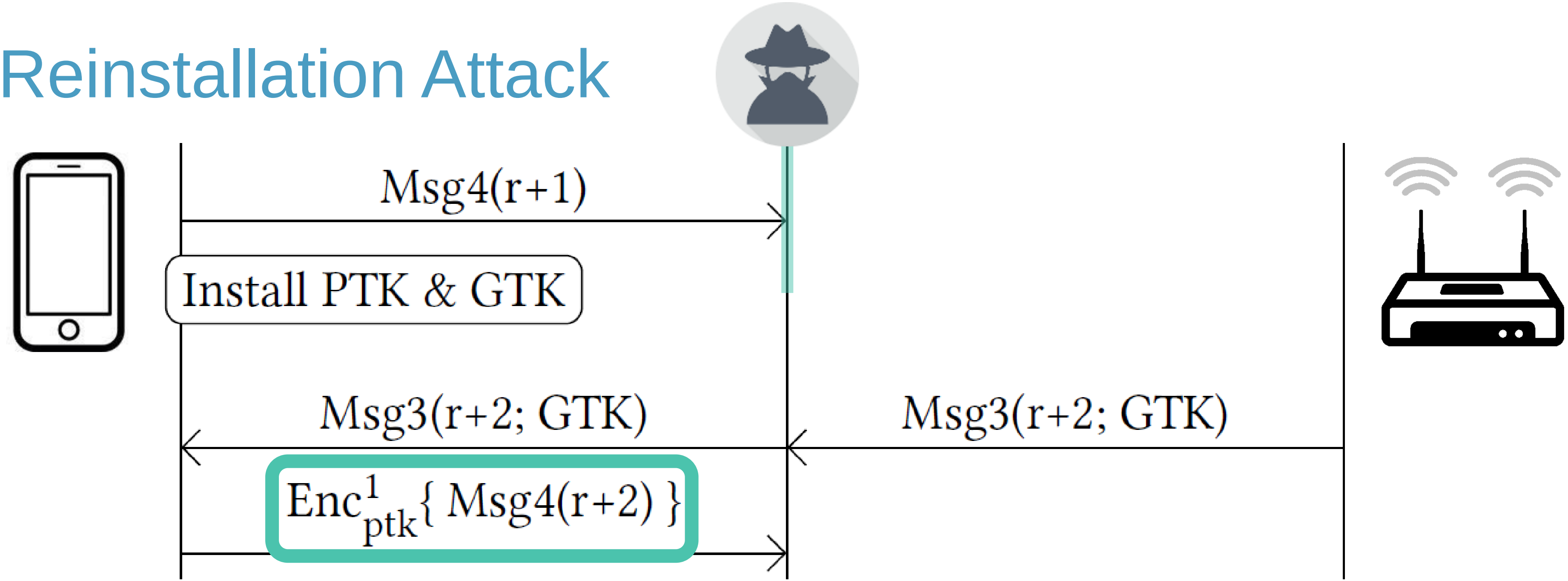

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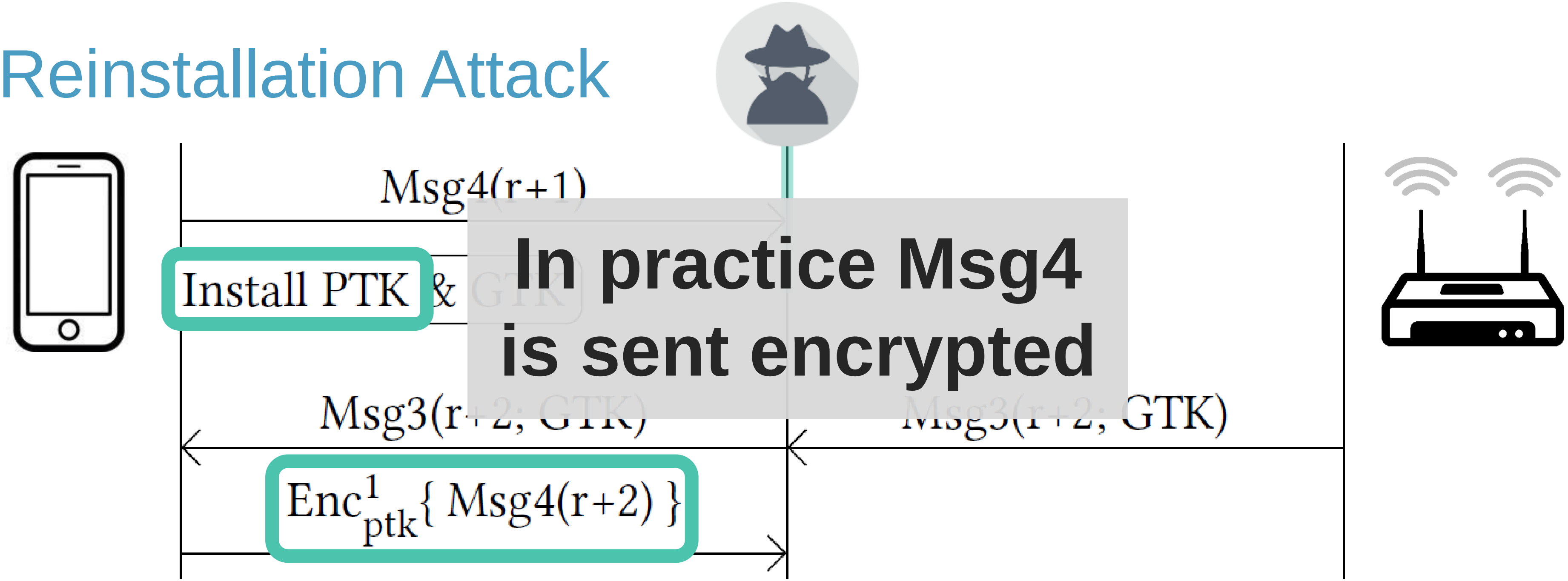
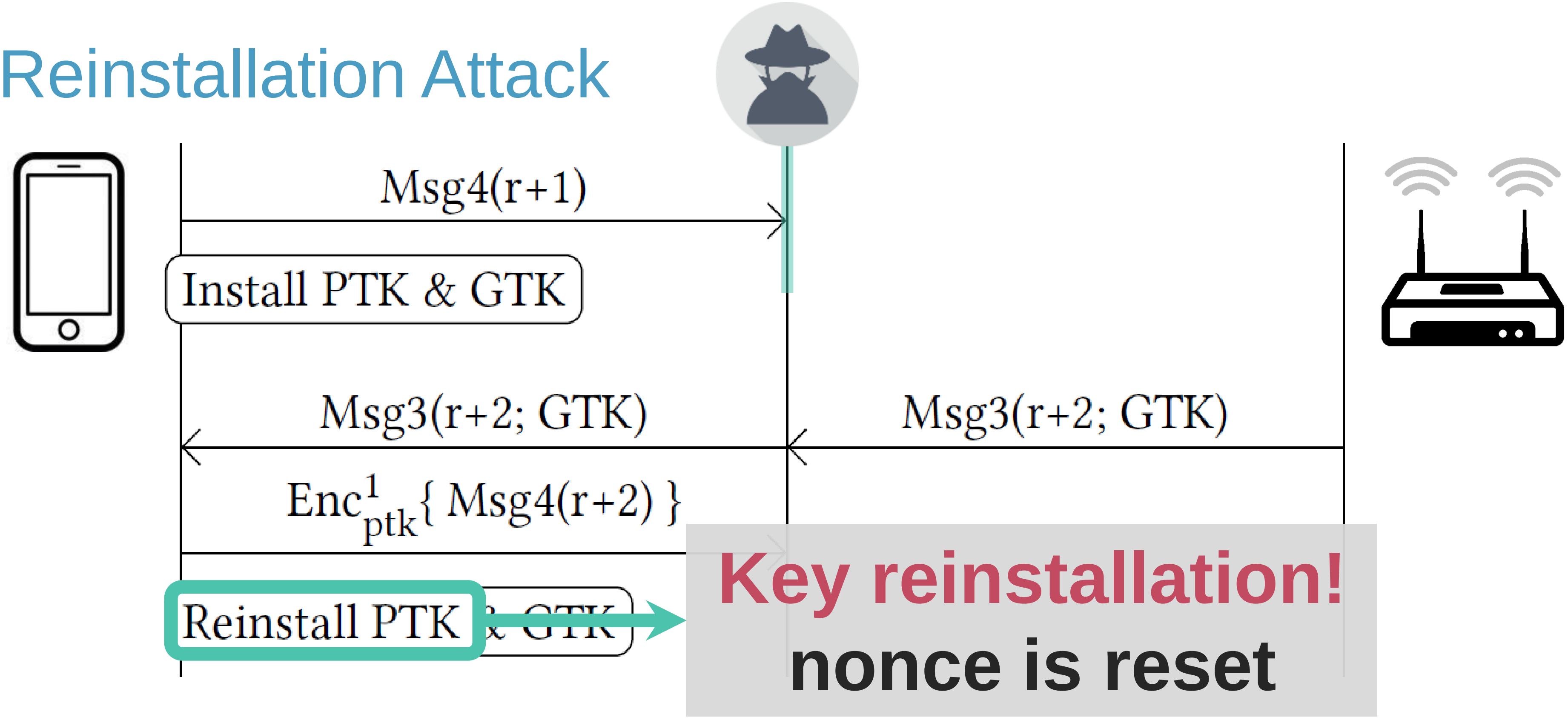


In practice Msg4 is sent encrypted

Reinstallation Attack



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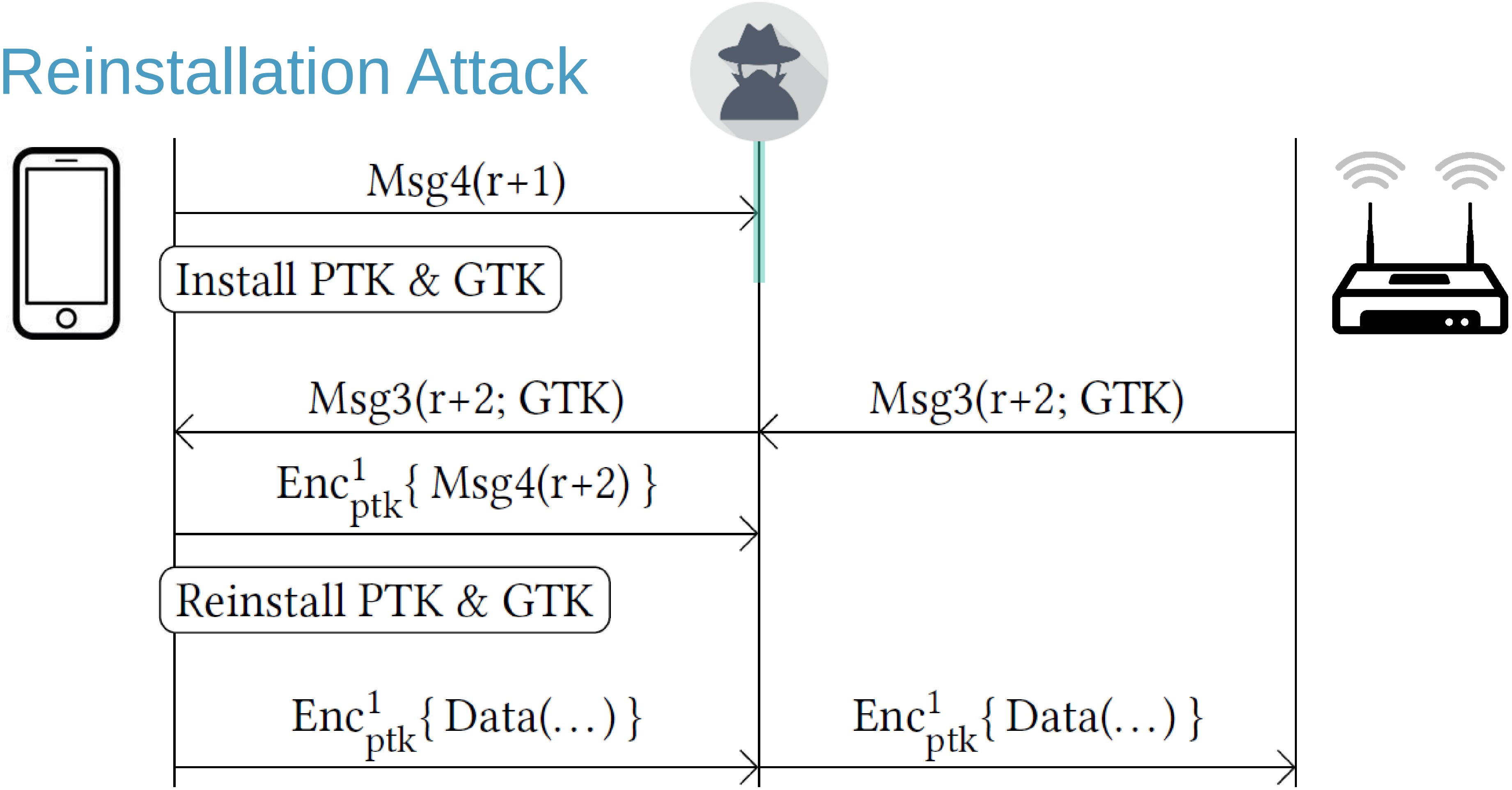
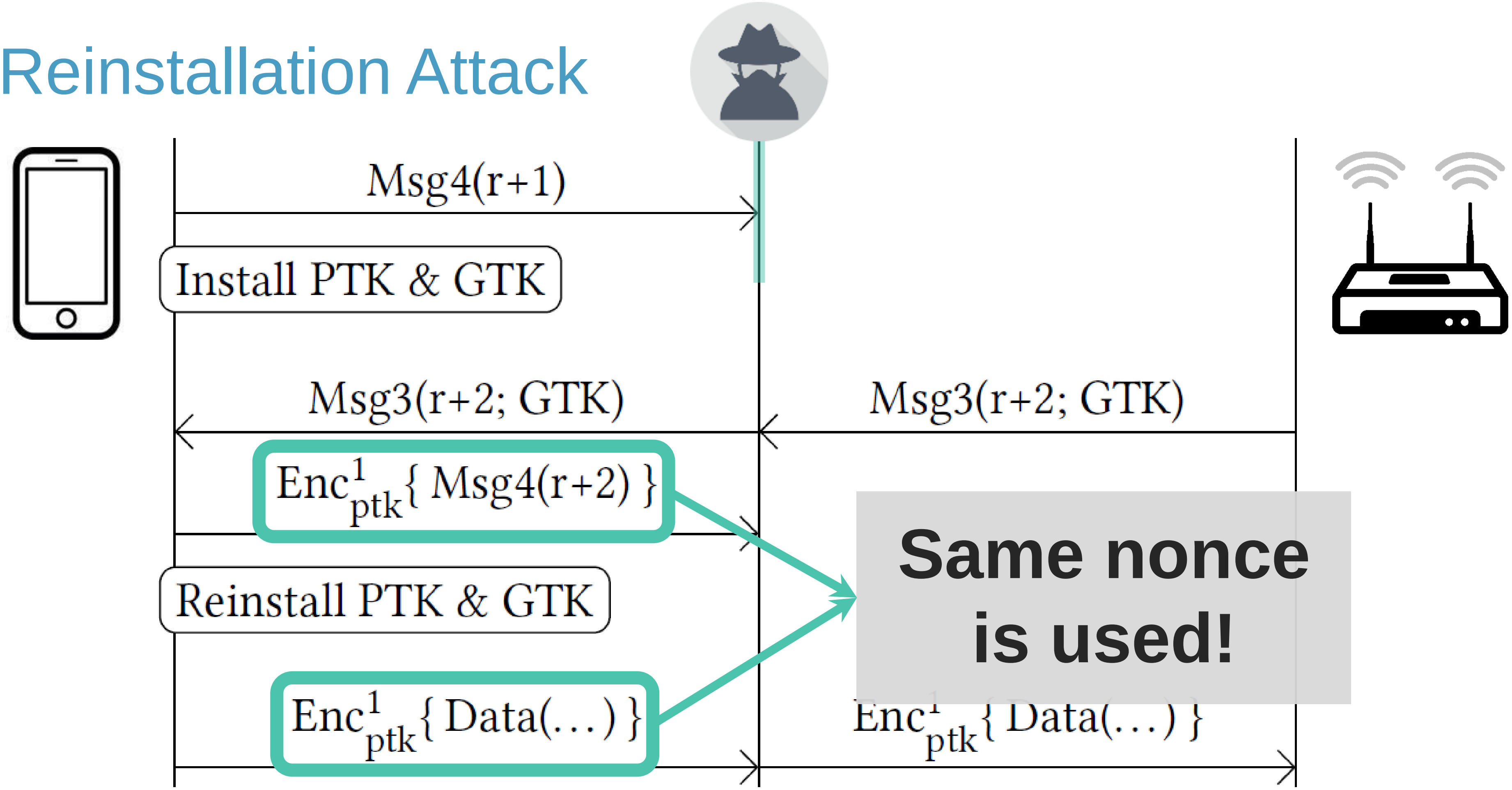
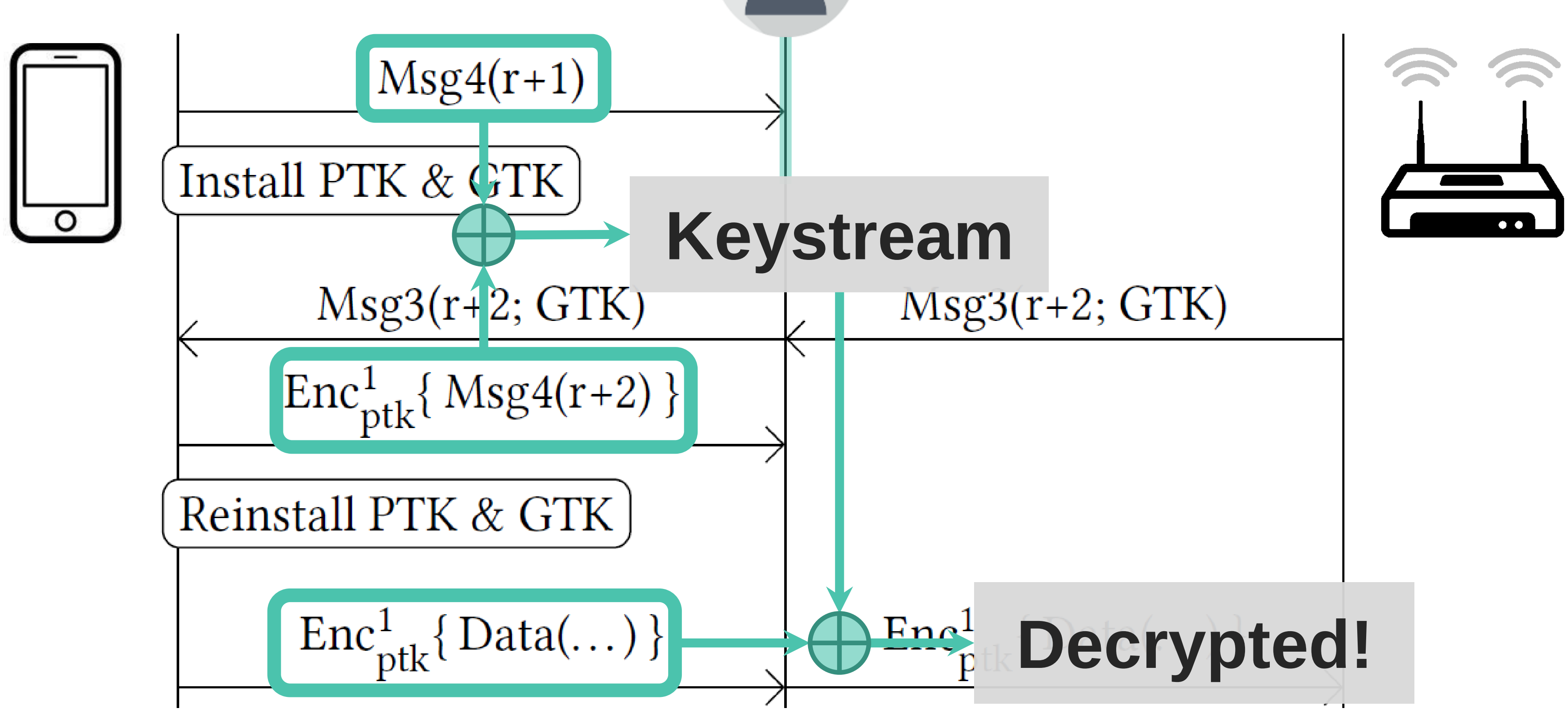


Reinstallation Attack



Reinstallation Attack



Key Reinstallation Attack

Other Wi-Fi handshakes also vulnerable:

- Group key handshake
- FT handshake
- TDLS PeerKey handshake

For details see our CCS'17 paper:

- "Key Reinstallation Attacks: Forcing Nonce Reuse in WPA2"

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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

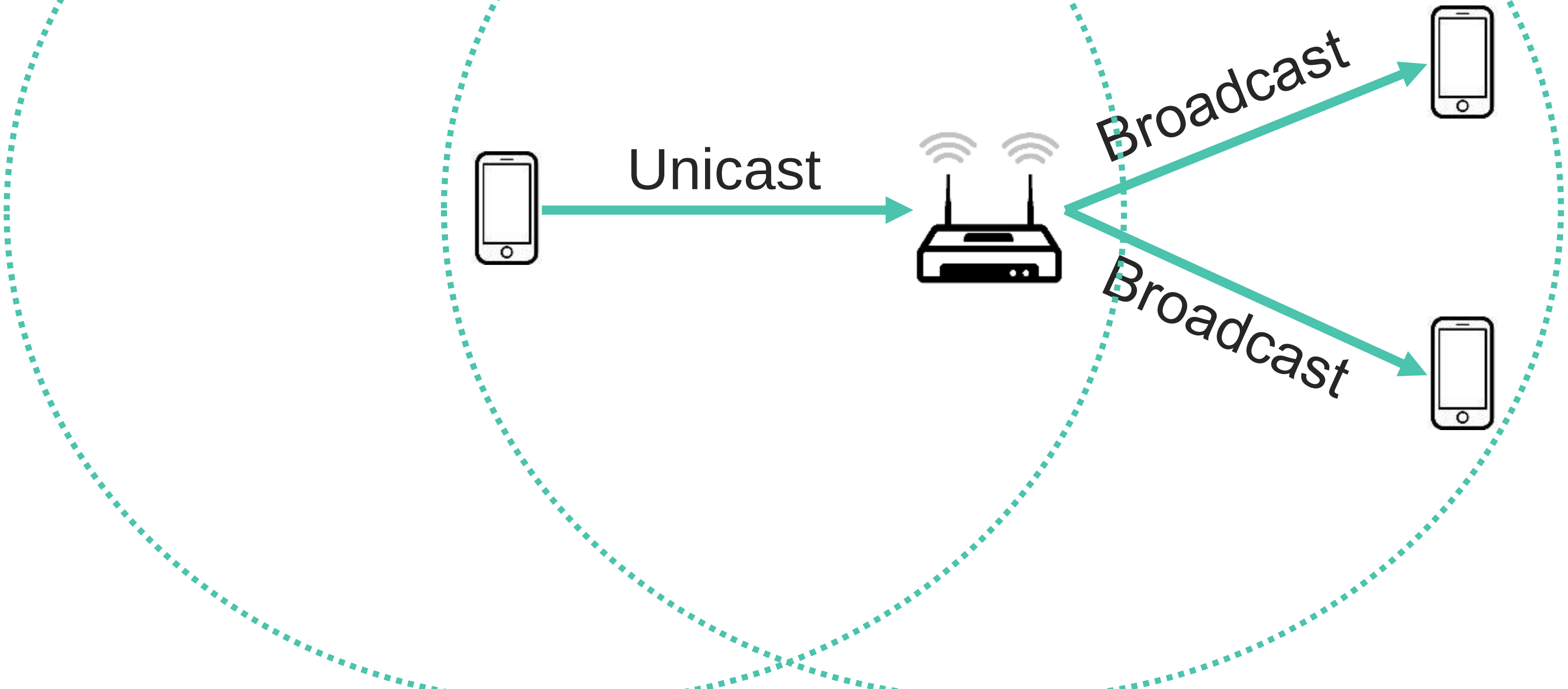
GCMP (WiGig):

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

Handshake specific

Group key handshake:

› Client is attacked, but only AP sends <u>real</u> broadcast frames



Handshake specific

Group key handshake:

- Client is attacked, but 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**

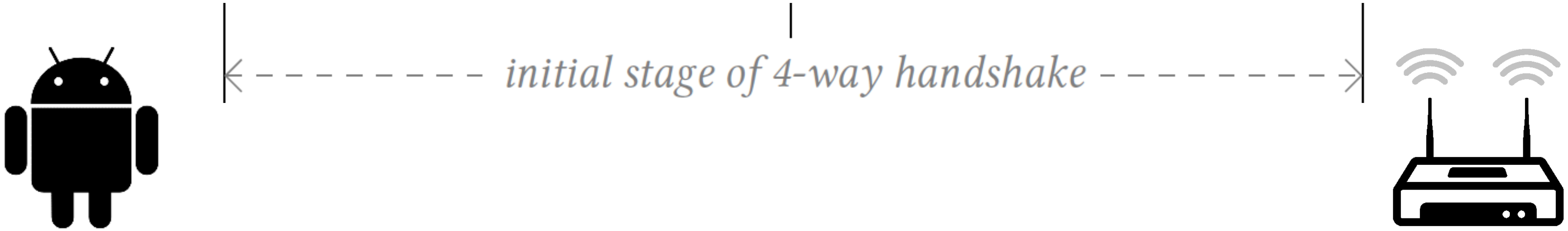
Implementation specific

iOS 10 and Windows: 4-way handshake not affected

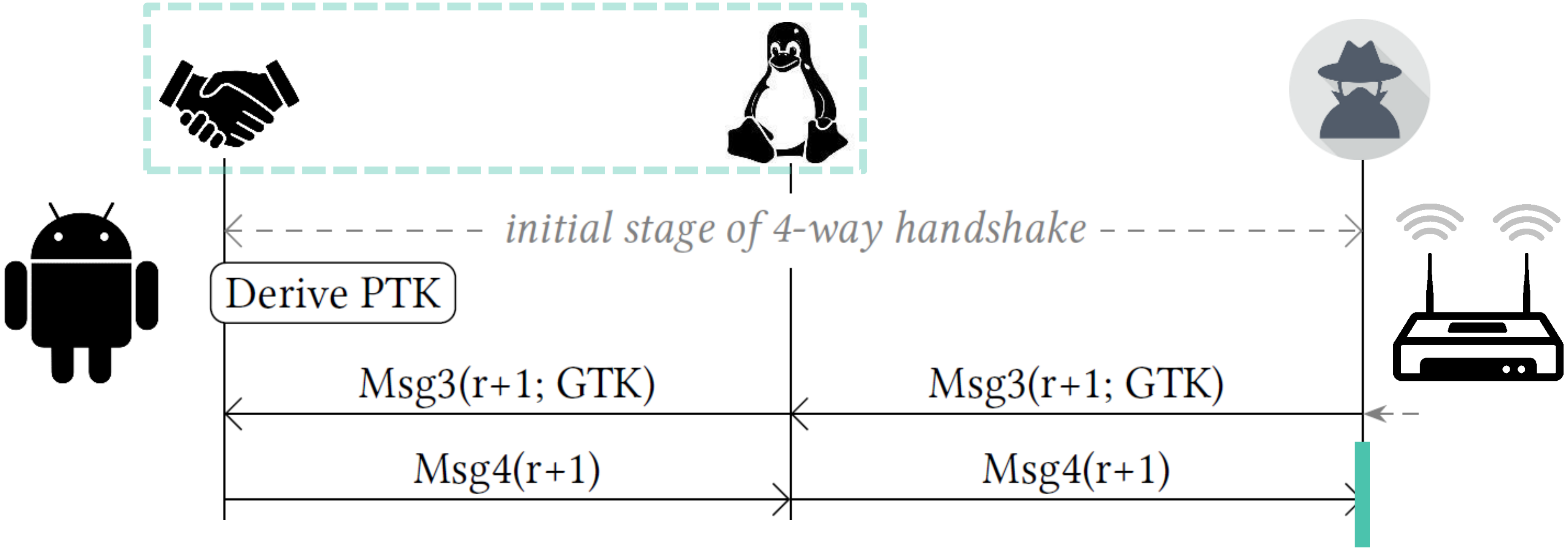
- **Cannot decrypt unicast traffic** (nor replay/decrypt)
- But group key handshake is affected (replay broadcast)
- Note: iOS 11 does have vulnerable 4-way handshake

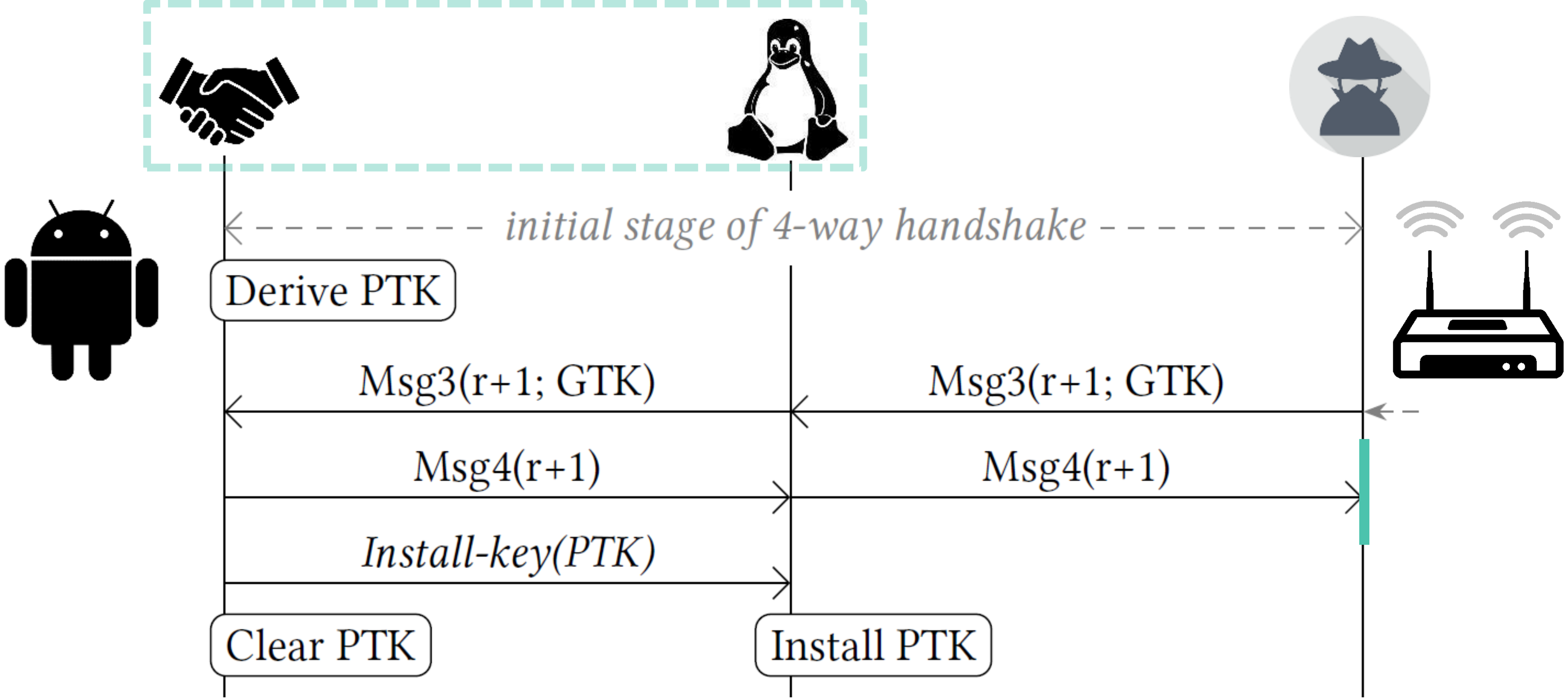
wpa_supplicant 2.4+

- 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)
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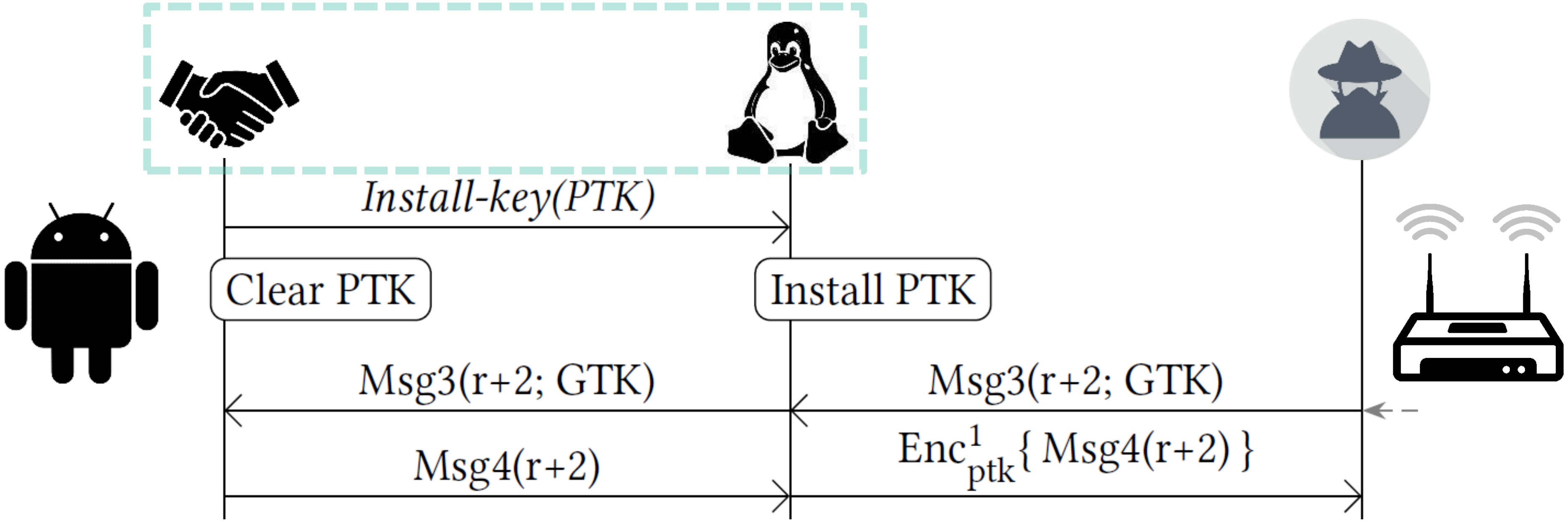
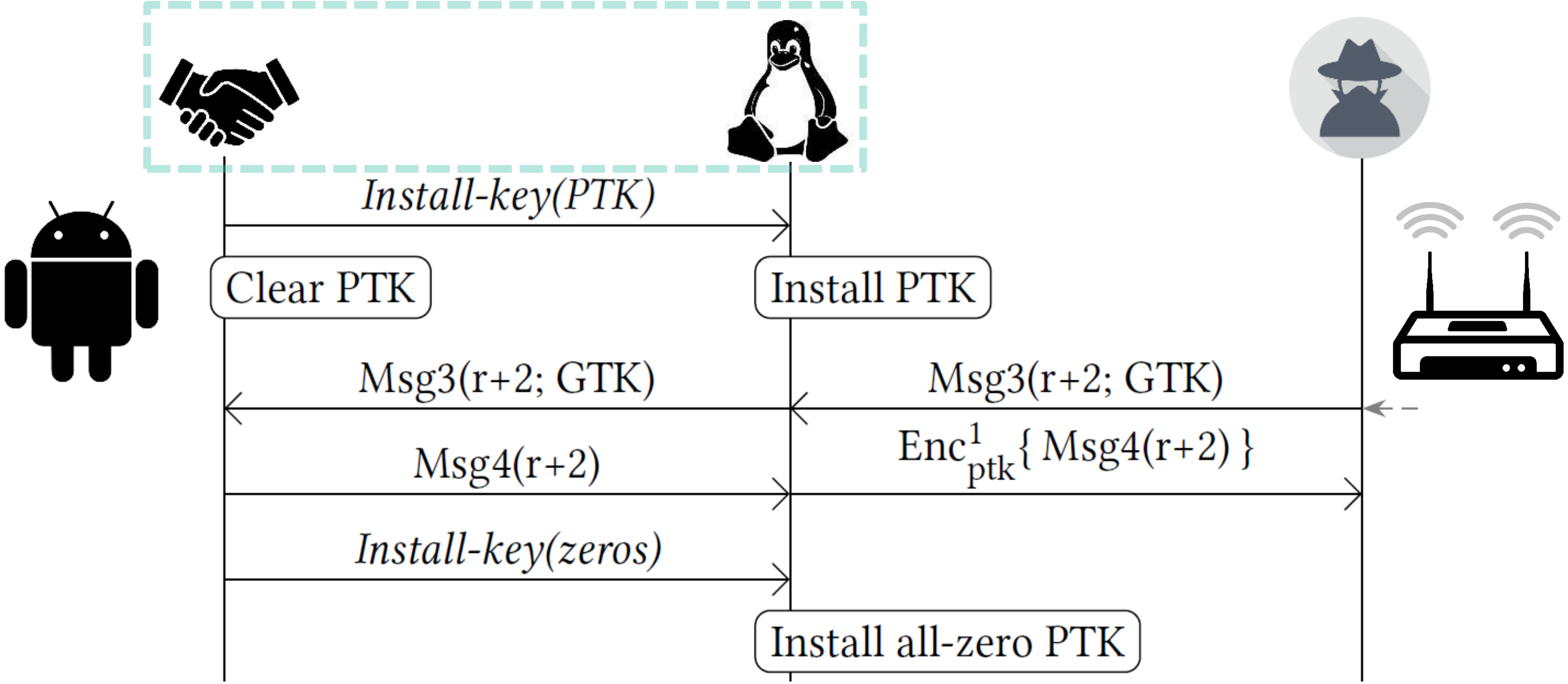
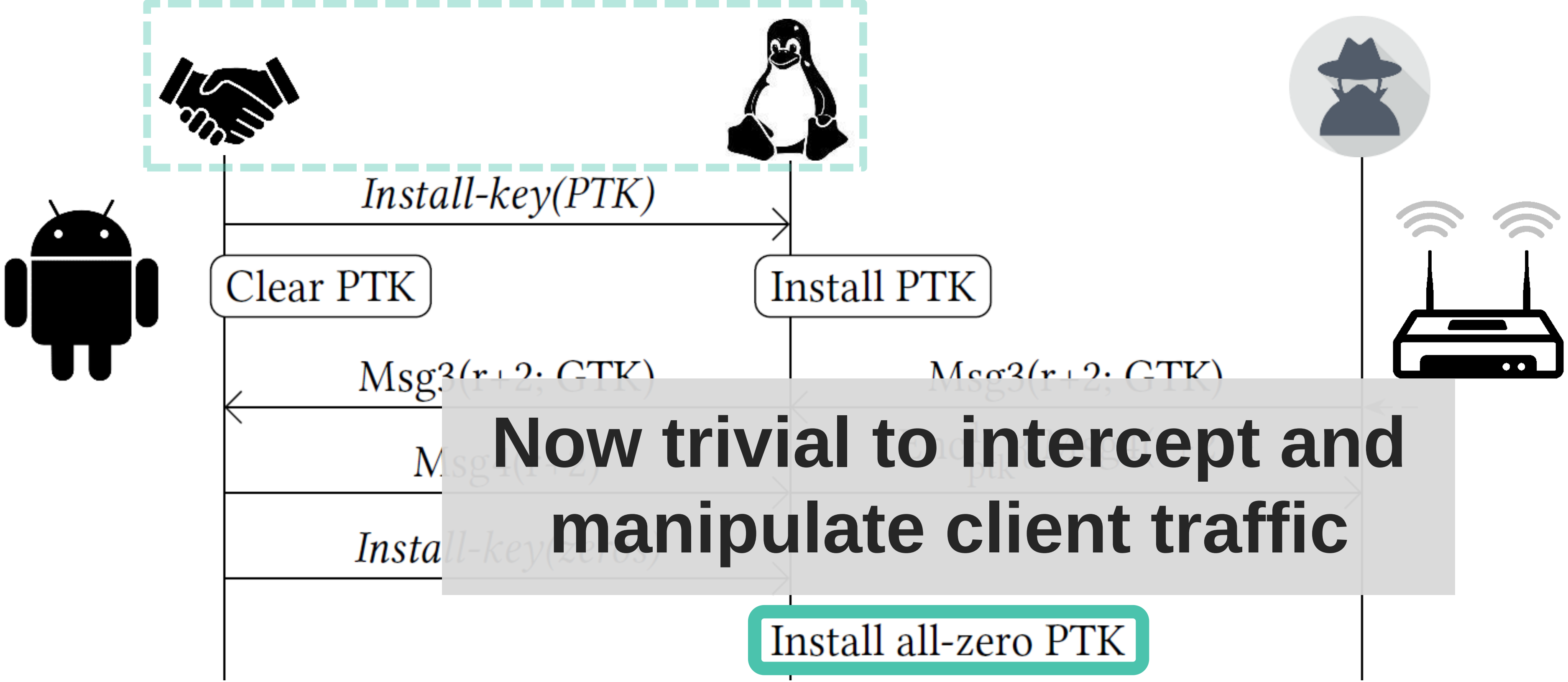
Msg4(r+1)
Install-key(PTK)
Clear PTK
Install PTK


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



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(zeros)
Install all-zero PTK



Now trivial to intercept and manipulate client traffic

Is your devices 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

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Misconceptions I

Updating only the client or AP is sufficient

- Both vulnerable clients & vulnerable 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 III

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

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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

Threat model & defense

- Attacker manipulates channel and bandwidth
- No low-layer attacks (e.g. beamforming)
- No 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

Verify Operating Channel Information (OCI)

Operating Channel Information **(OCI) element:**

Operating class	Channel number	Segment index 1

Defines regulatory domain & bandwidth

Defines secondary channel for 80+80 MHz networks

Defines primary channel

Problem: Channel Switch Announcements (CSAs)

Unauthenticated CSAs

› Need to verify securely

Authenticated CSAs

› May not arrive → verify reception!

Solution: authenticate 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

Will be part of the new 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

PoC: 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