KRACKing WPA2 in Practice Using Key Reinstallation Attacks

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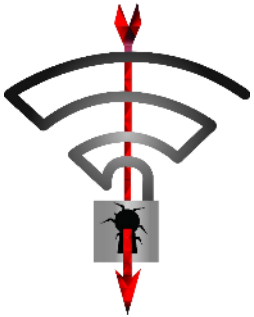
BlueHat IL, 24 January 2018

KU LEUVEN DistriNet

Overview



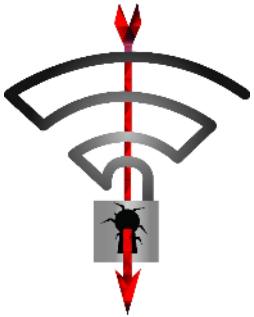
Key reinstalls in
4-way handshake

Misconceptions

Practical impact

Lessons learned

Overview



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The 4-way handshake

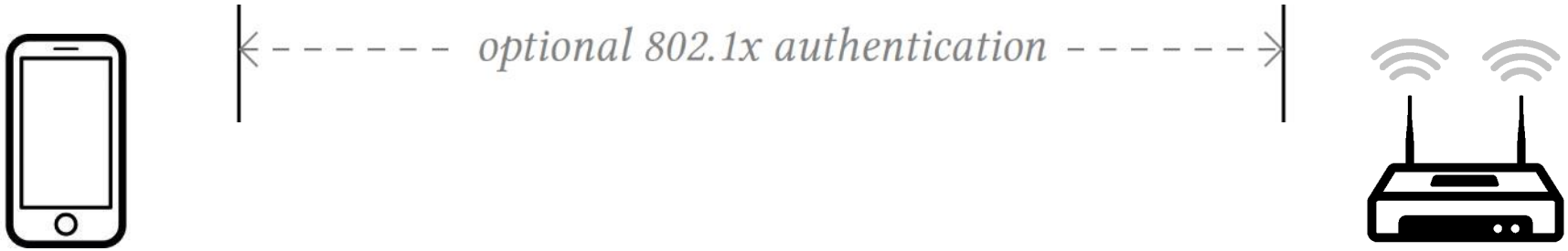
Used to connect to any protected Wi-Fi network

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

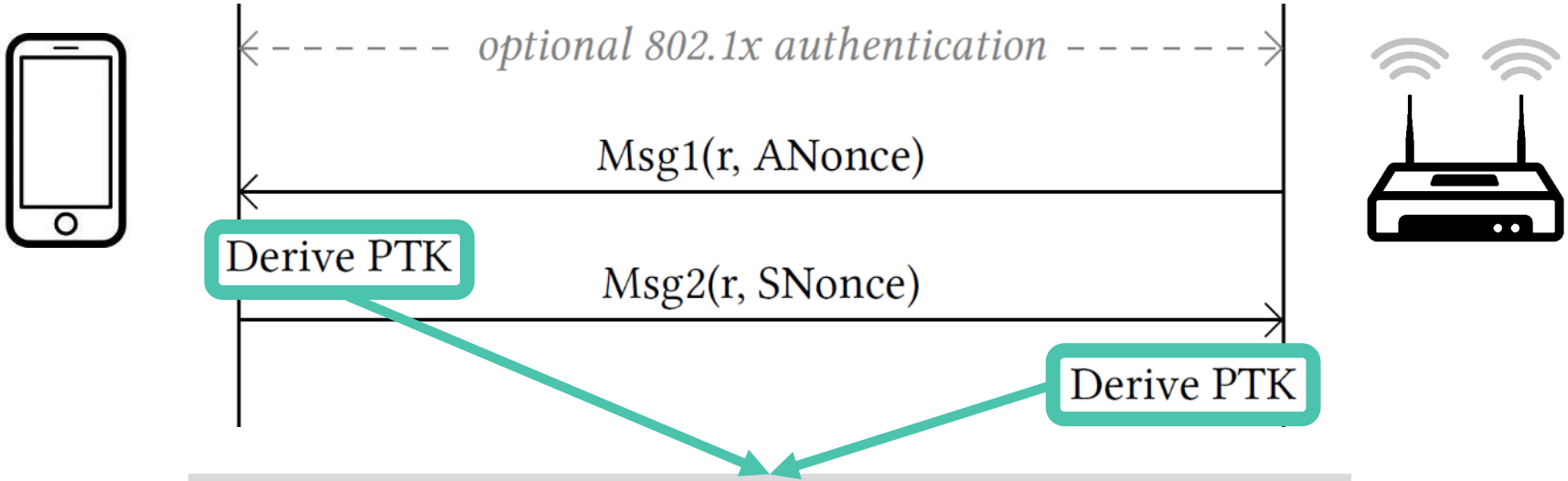
Appeared to be secure:

- No attacks in over a decade (apart from password guessing)
- Proven that negotiated key (PTK) is secret[1]
- And encryption protocol proven secure[7]

4-way handshake (simplified)

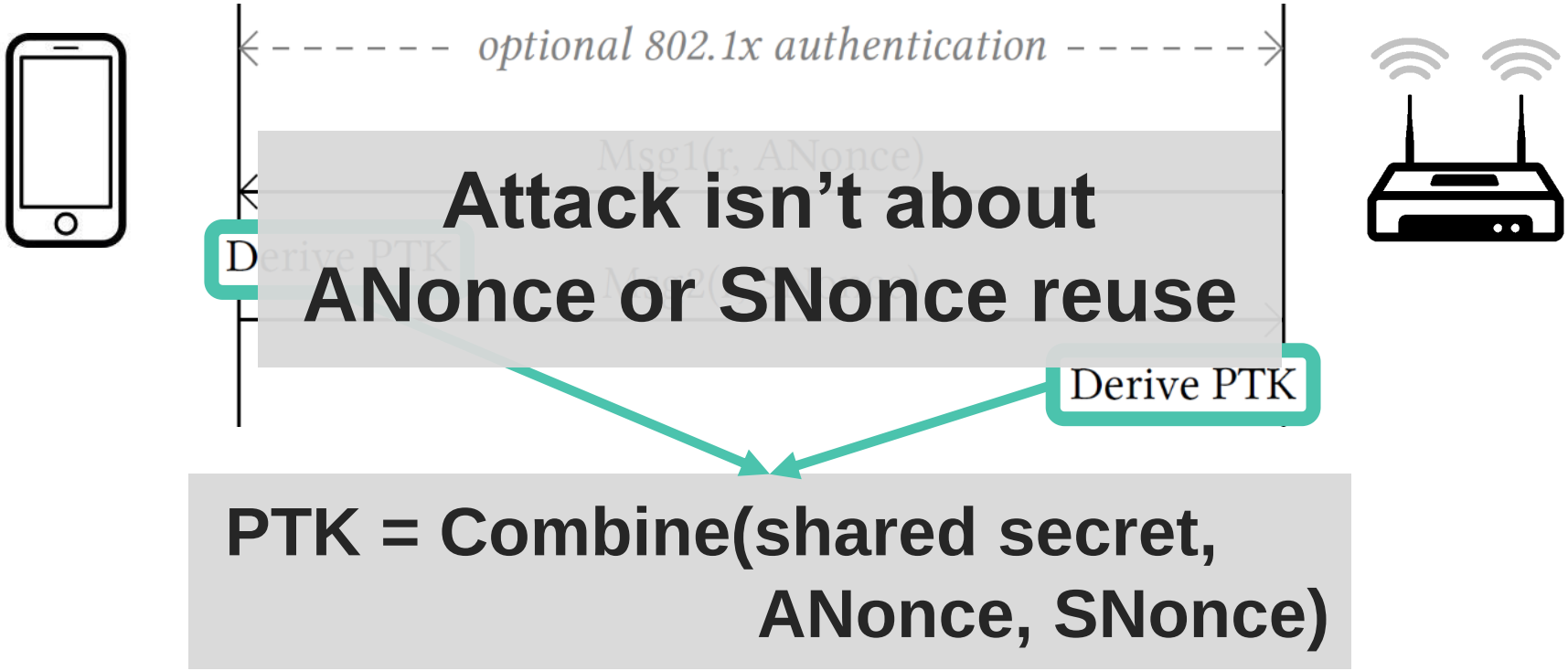


4-way handshake (simplified)

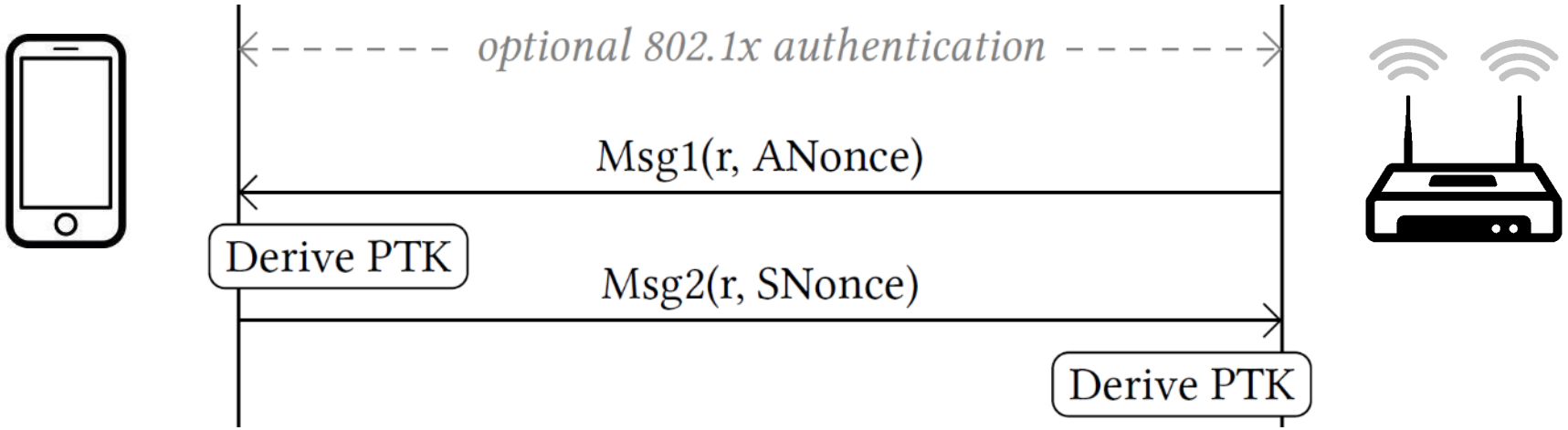


PTK = Combine(shared secret, ANonce, SNonce)

4-way handshake (simplified)



4-way handshake (simplified)



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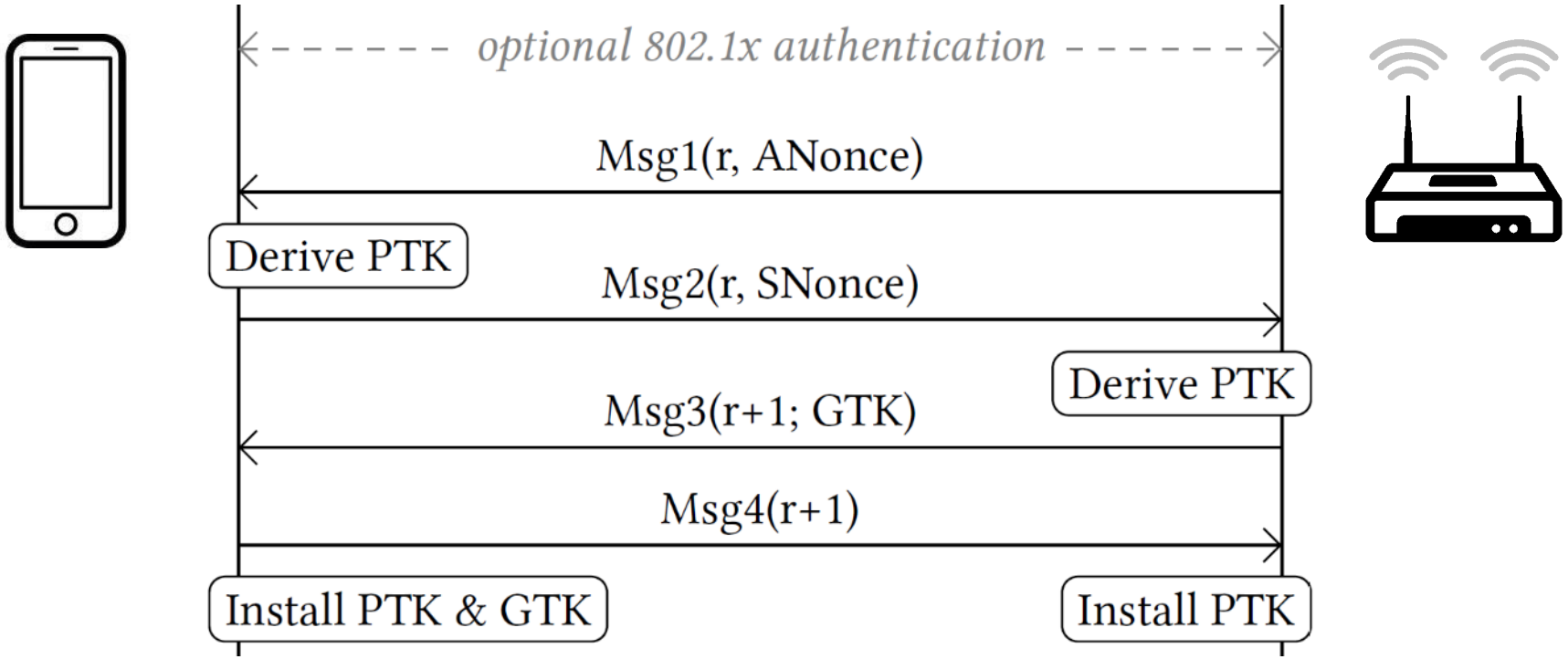
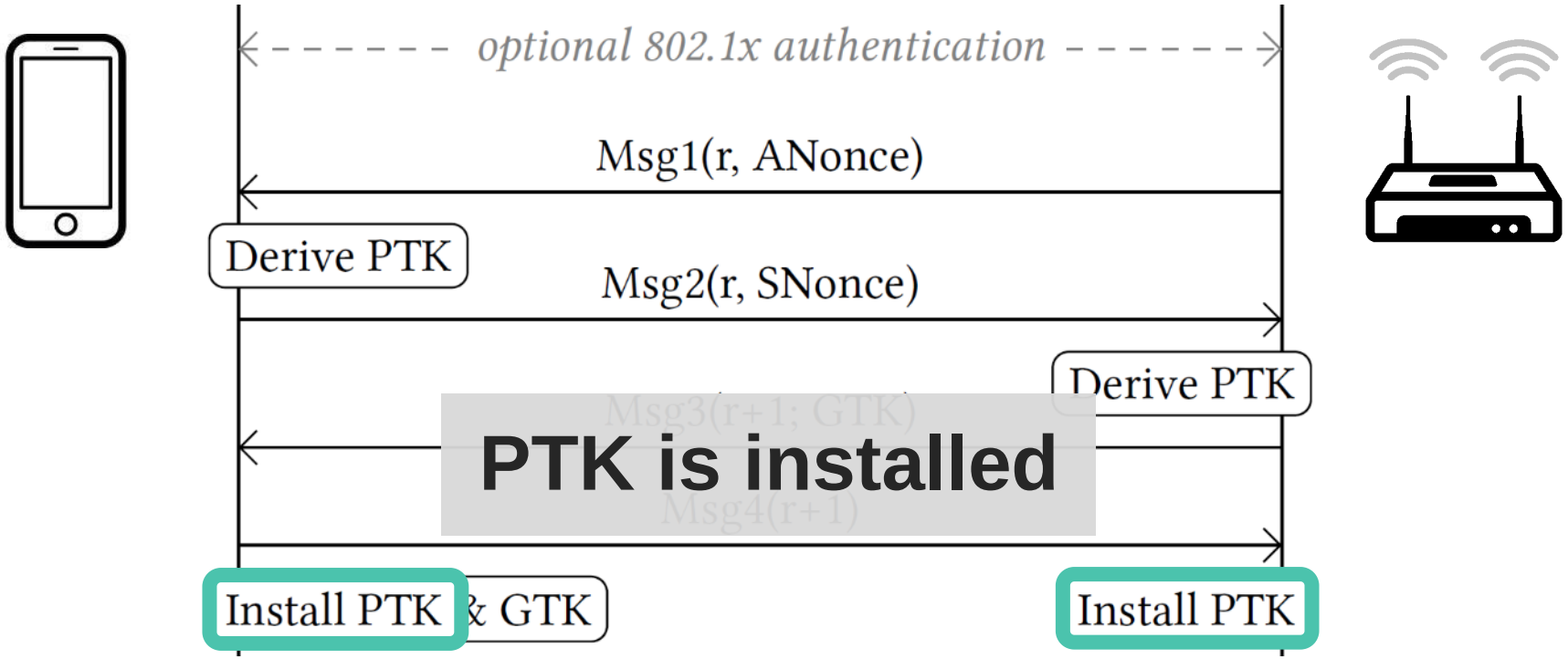


4-way handshake (simplified)



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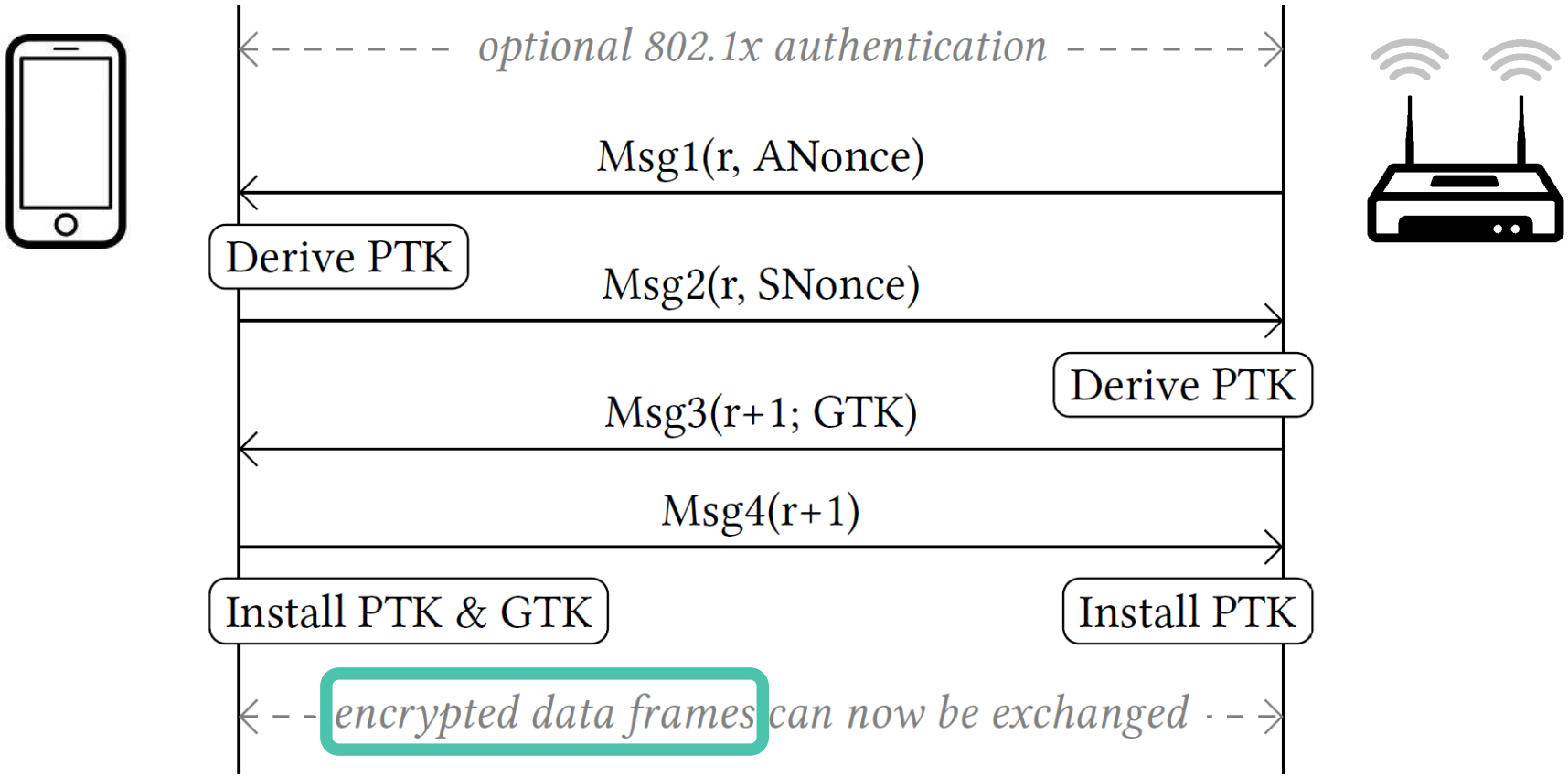
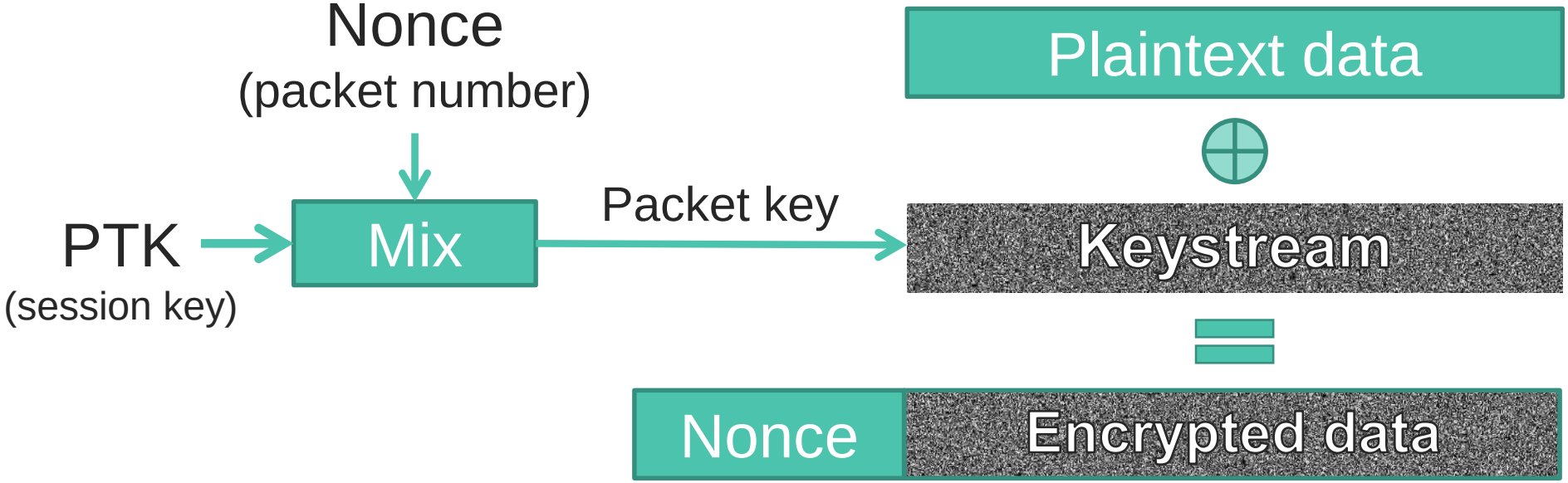
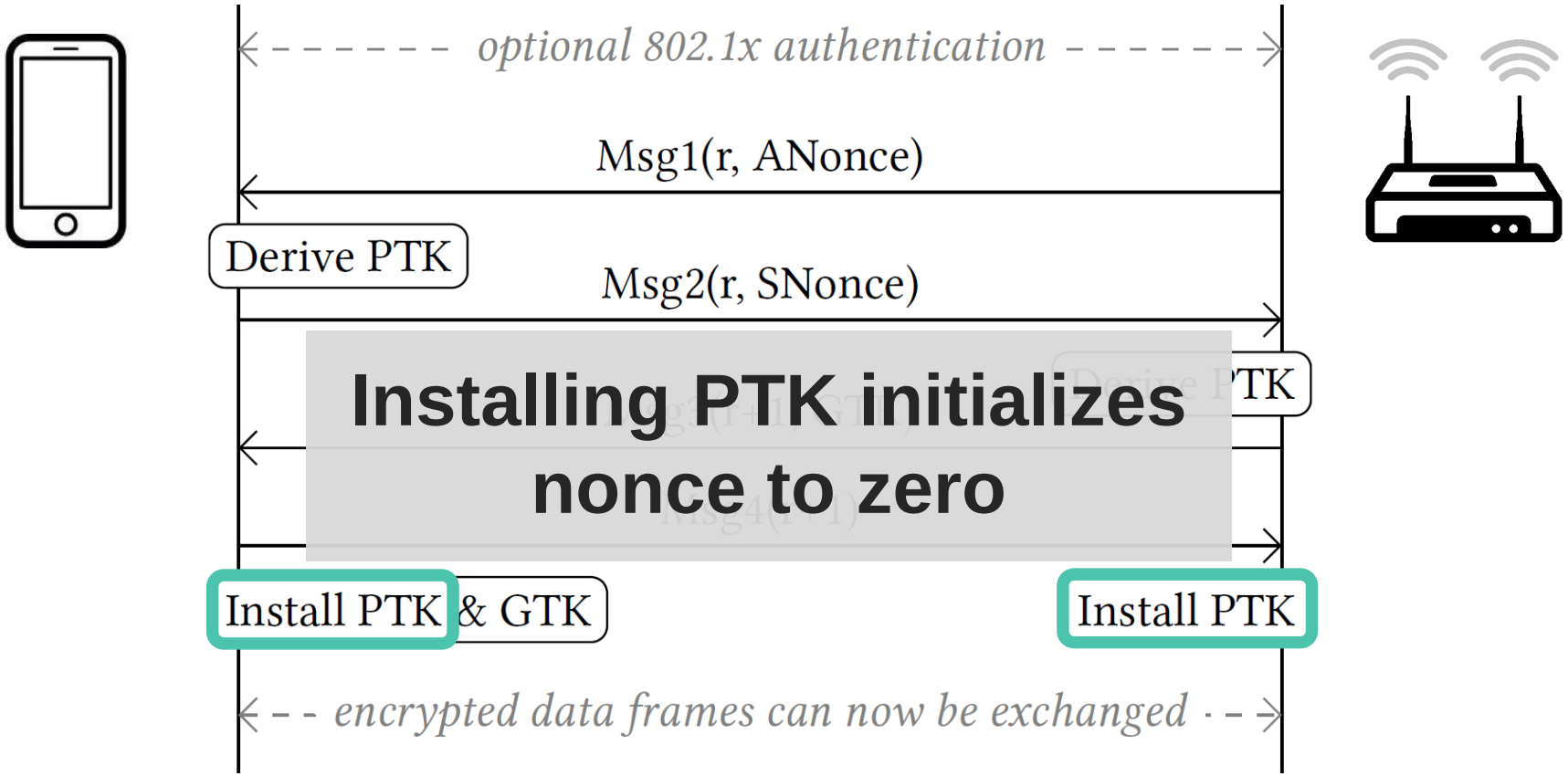


Frame encryption (simplified)



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

4-way handshake (simplified)



Reinstallation Attack

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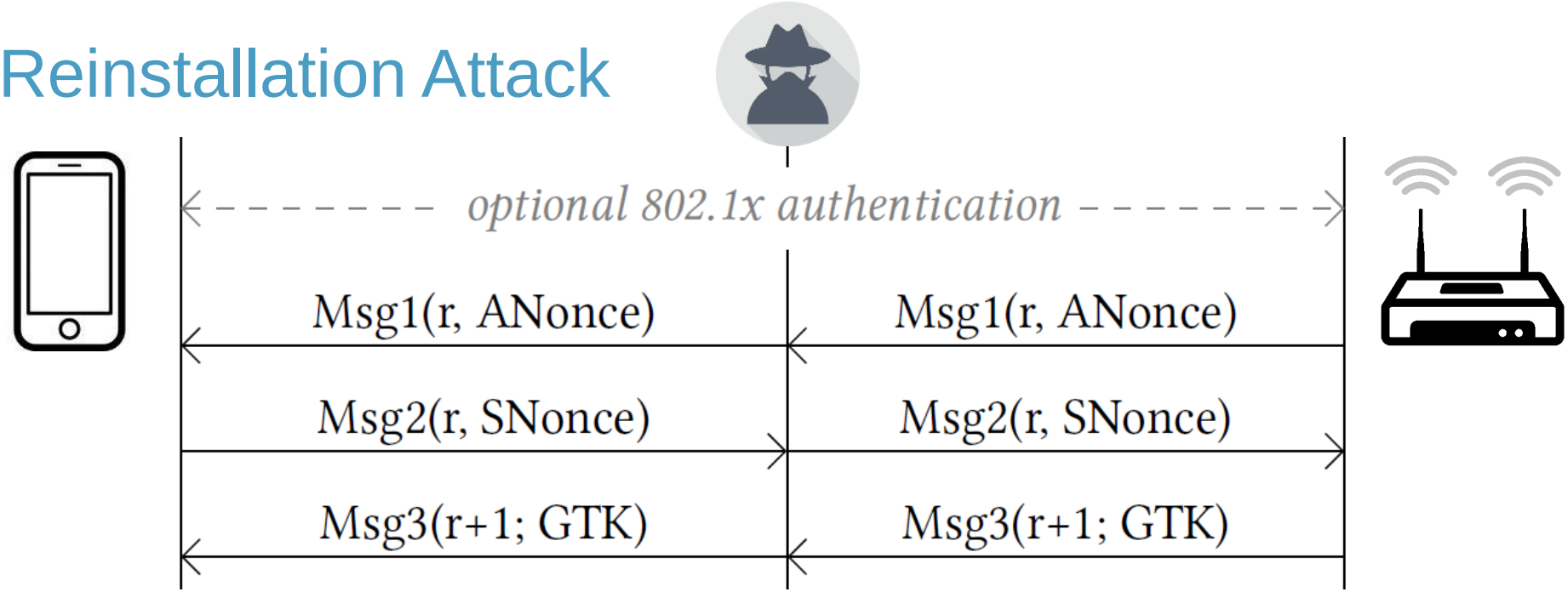

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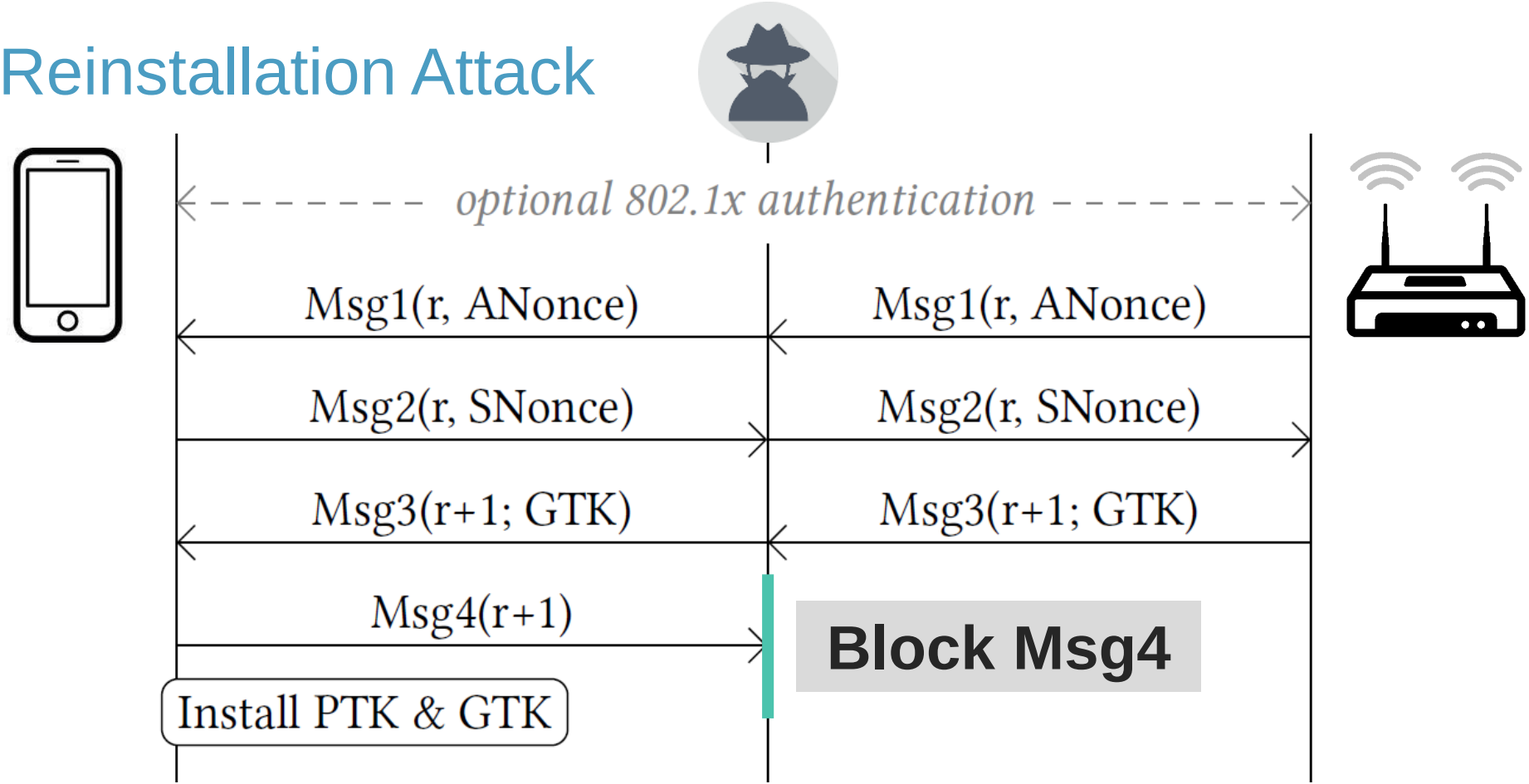

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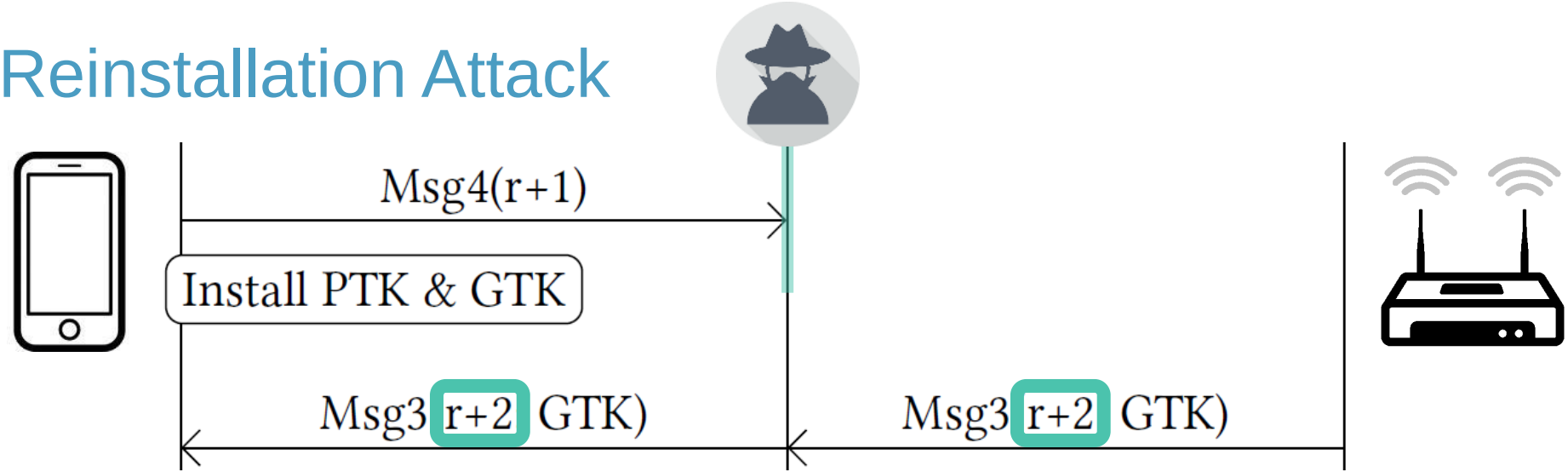
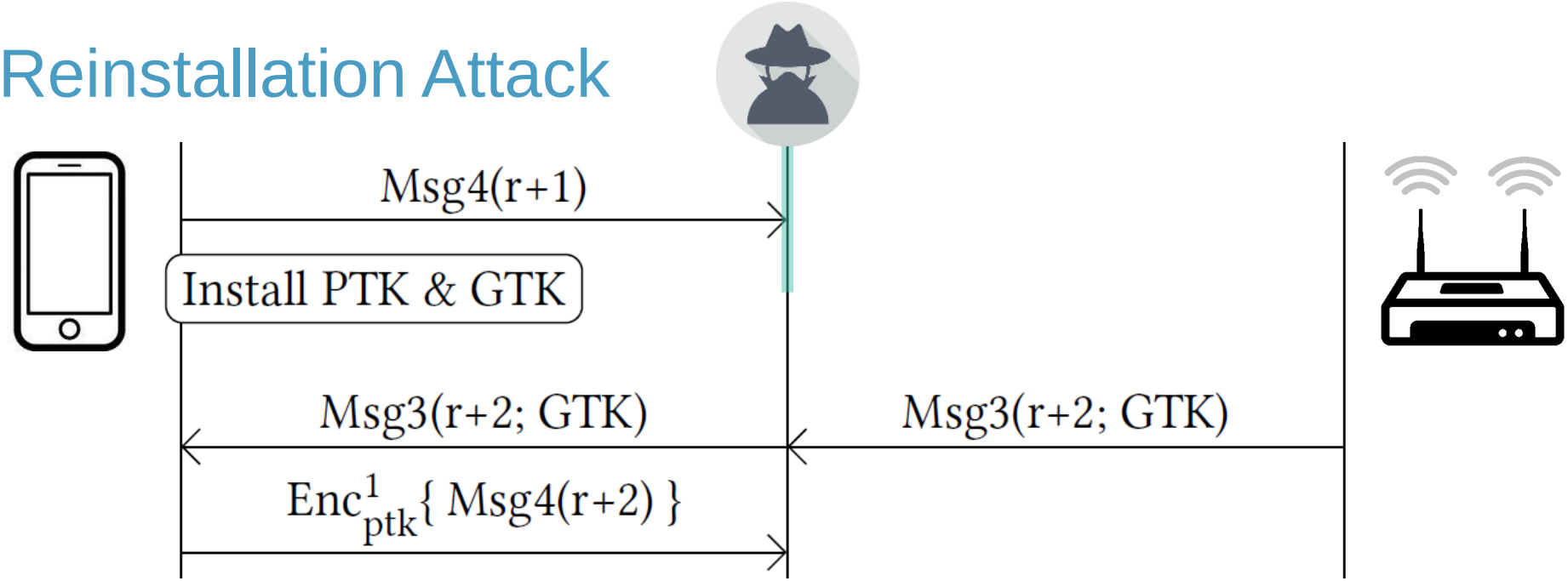
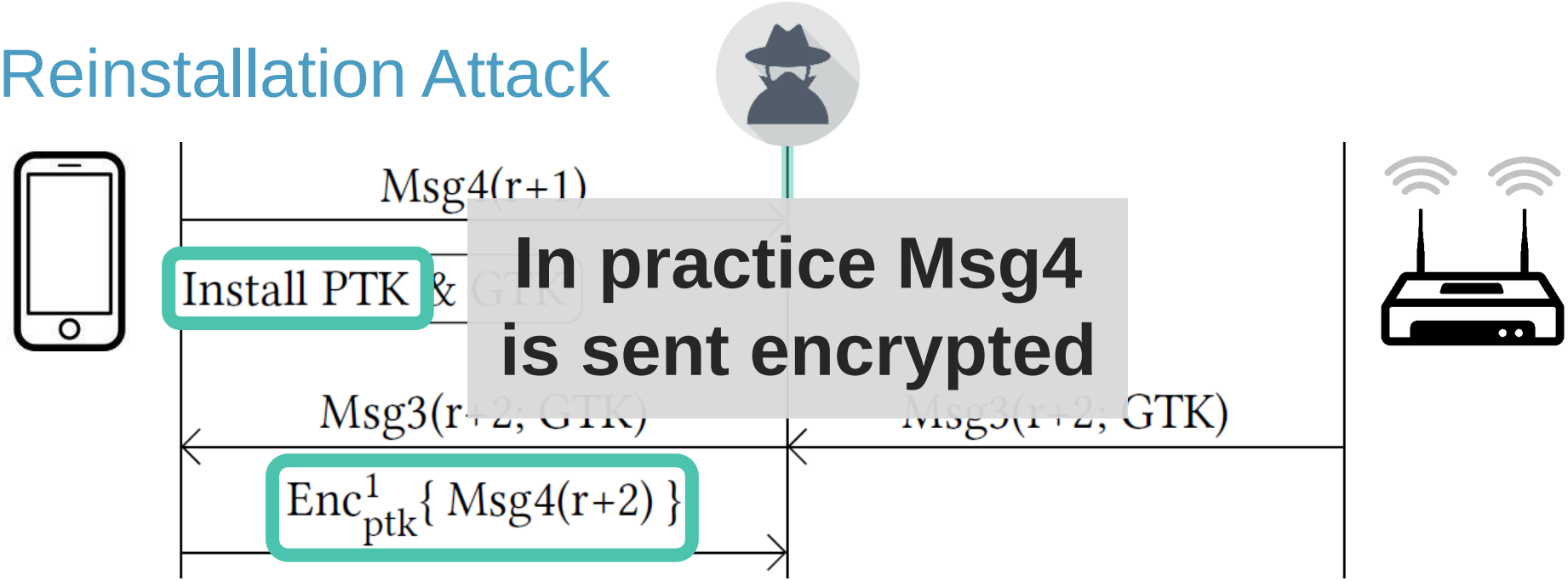


New replay counter

Reinstallation Attack

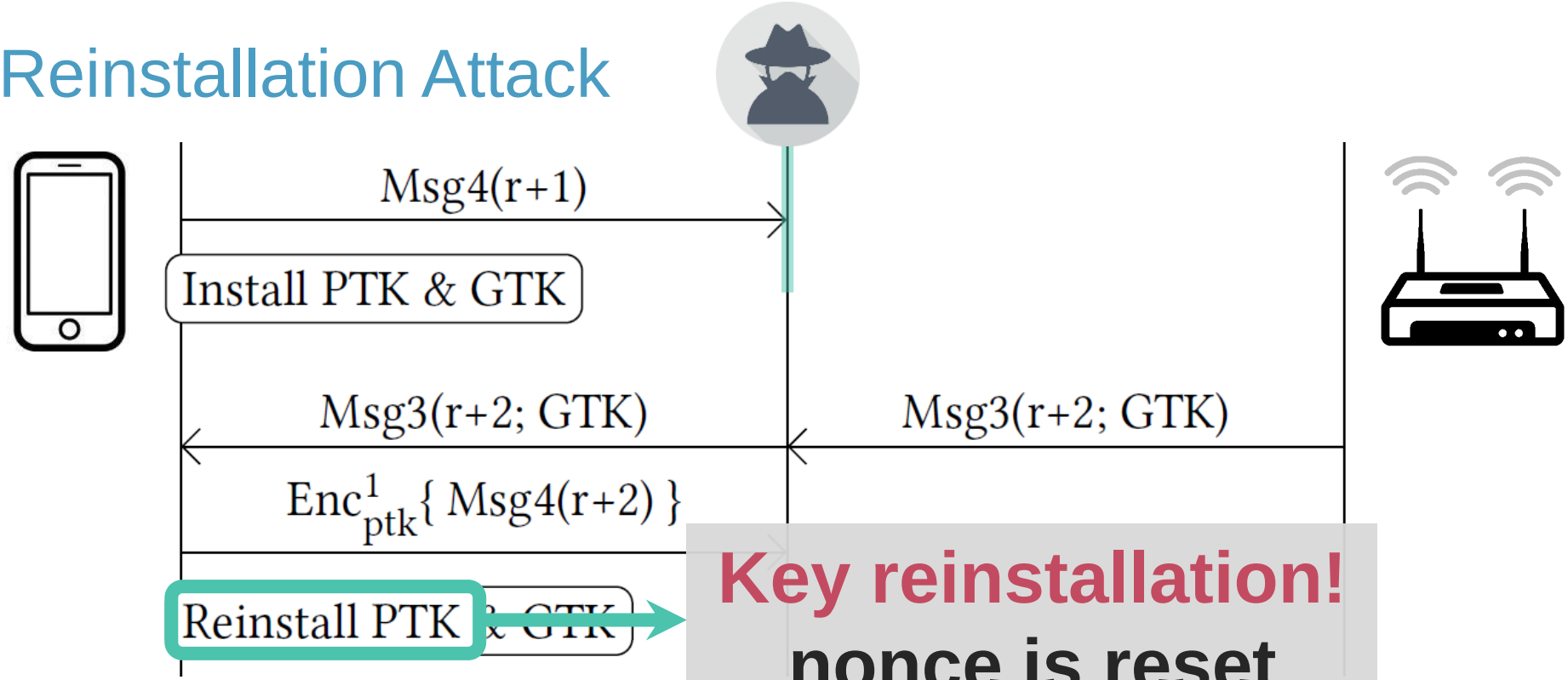


Reinstallation Attack



In practice Msg4 is sent encrypted

Reinstallation Attack



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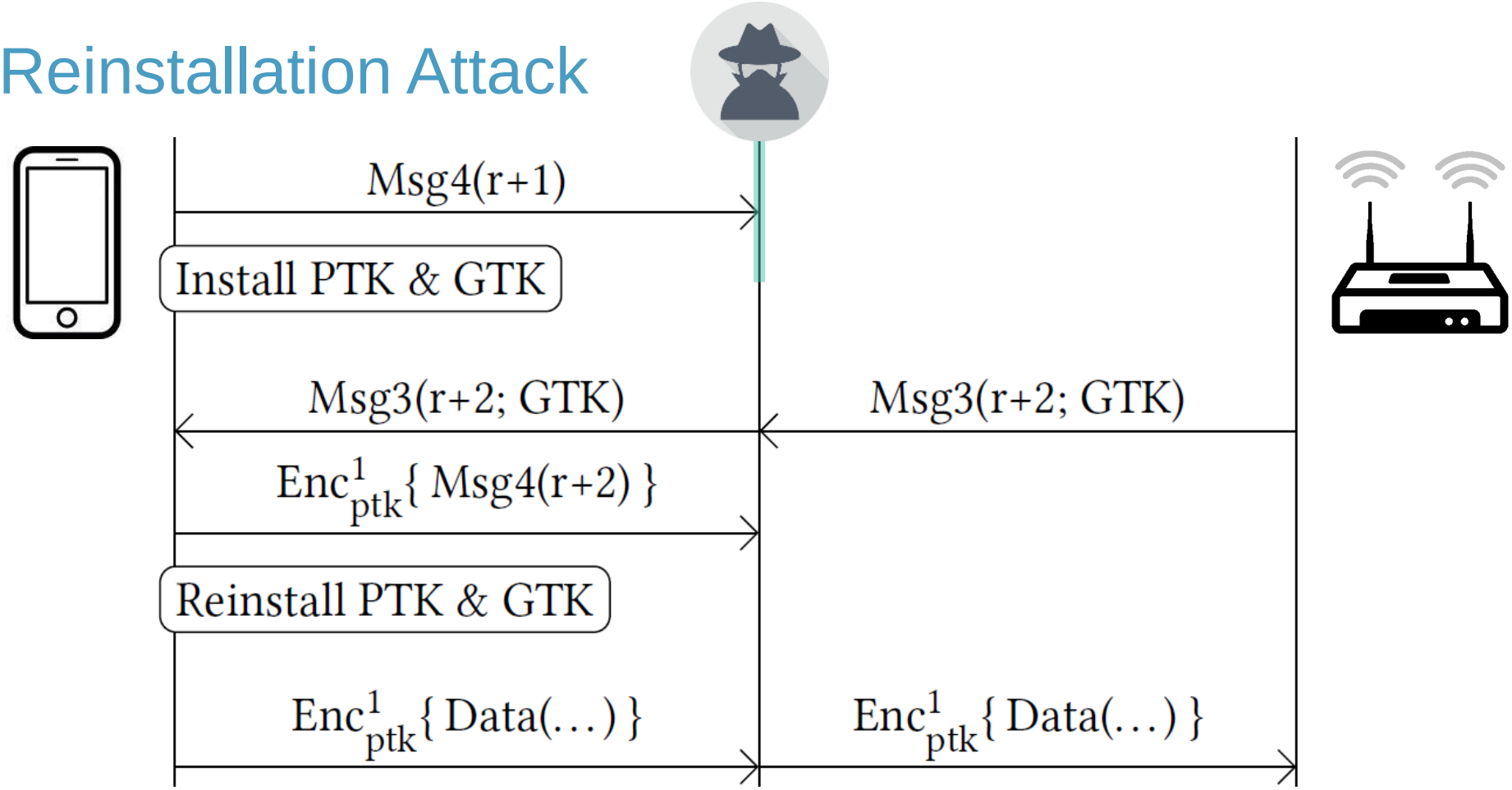

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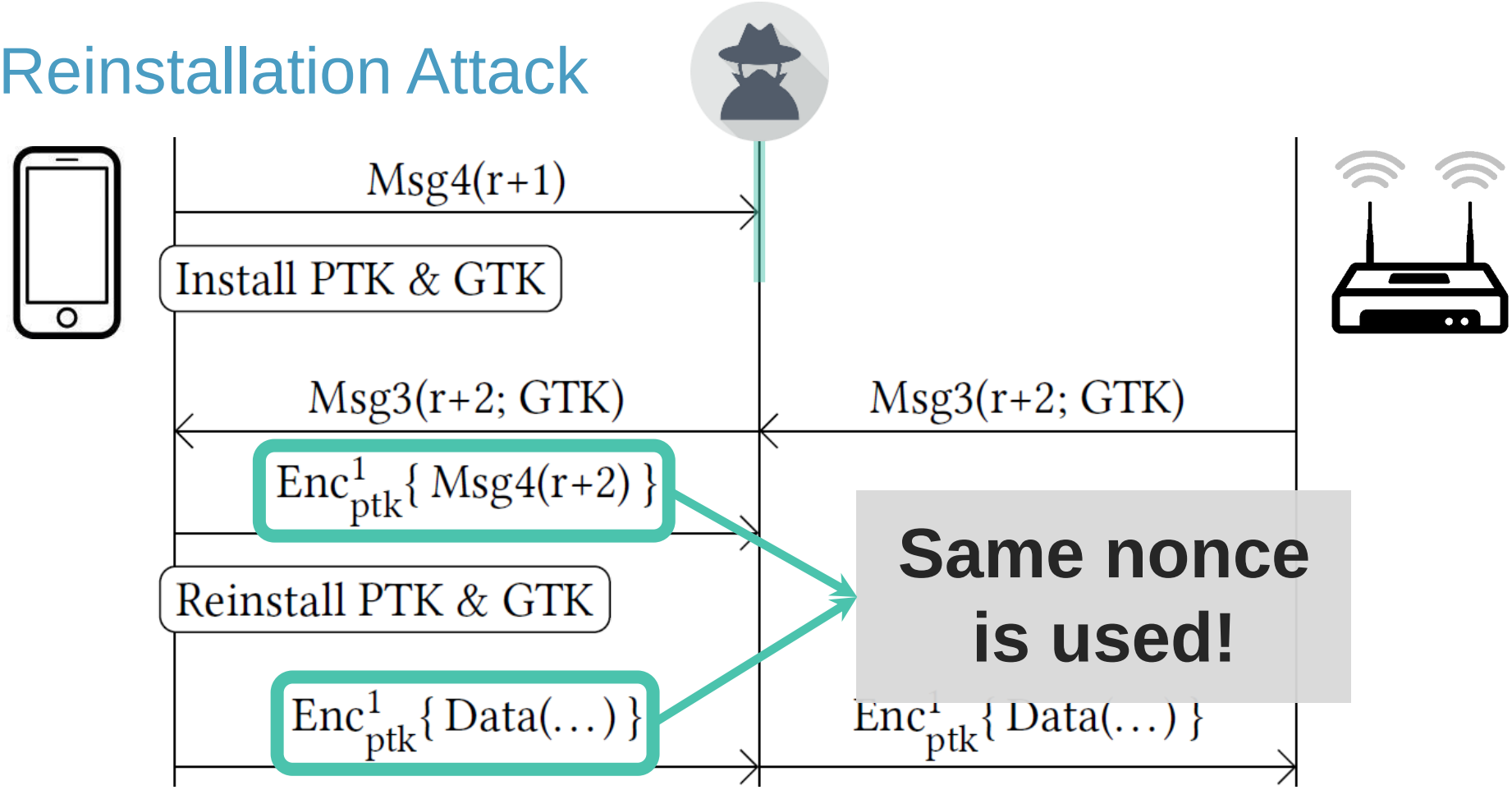

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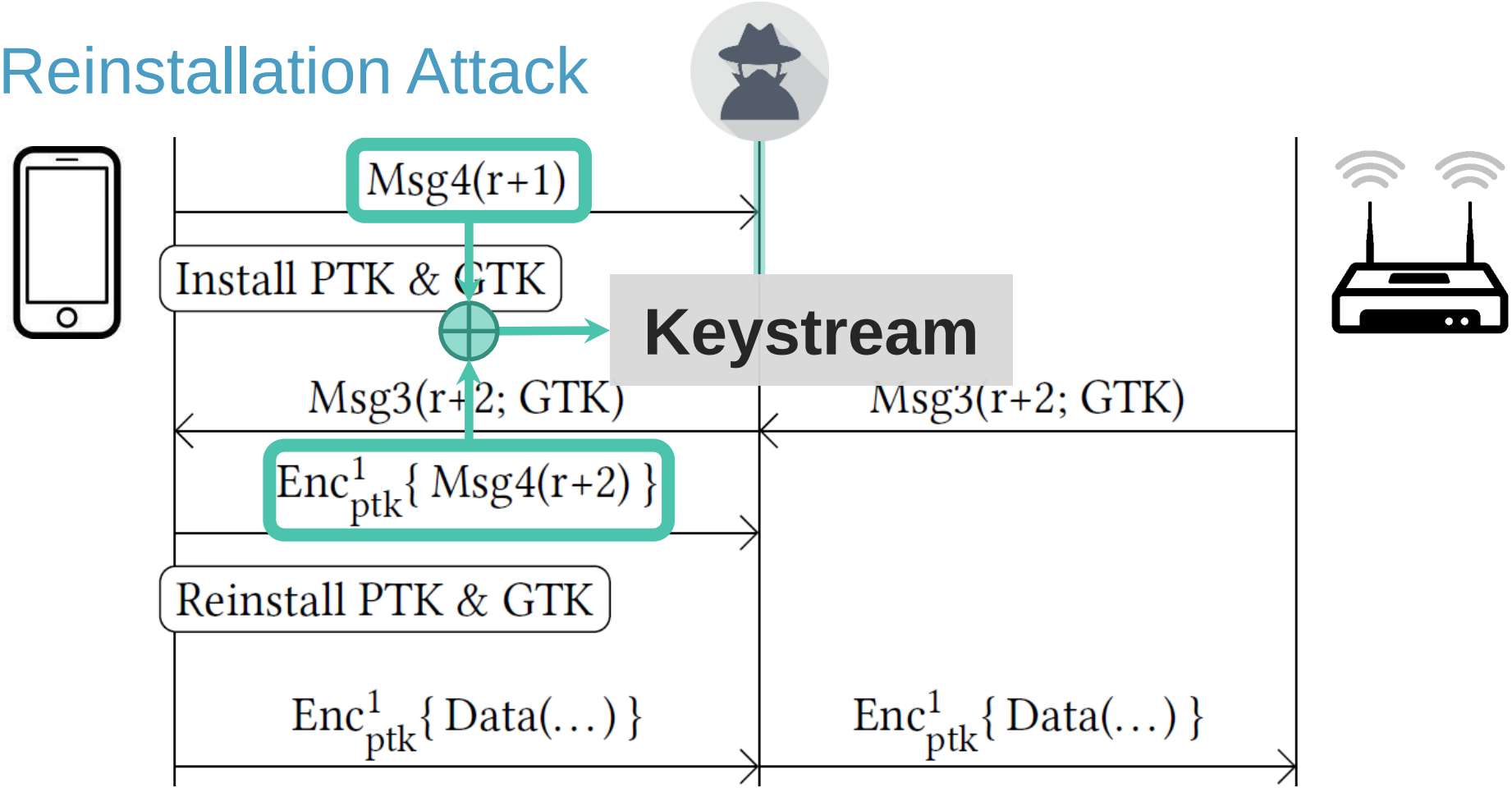

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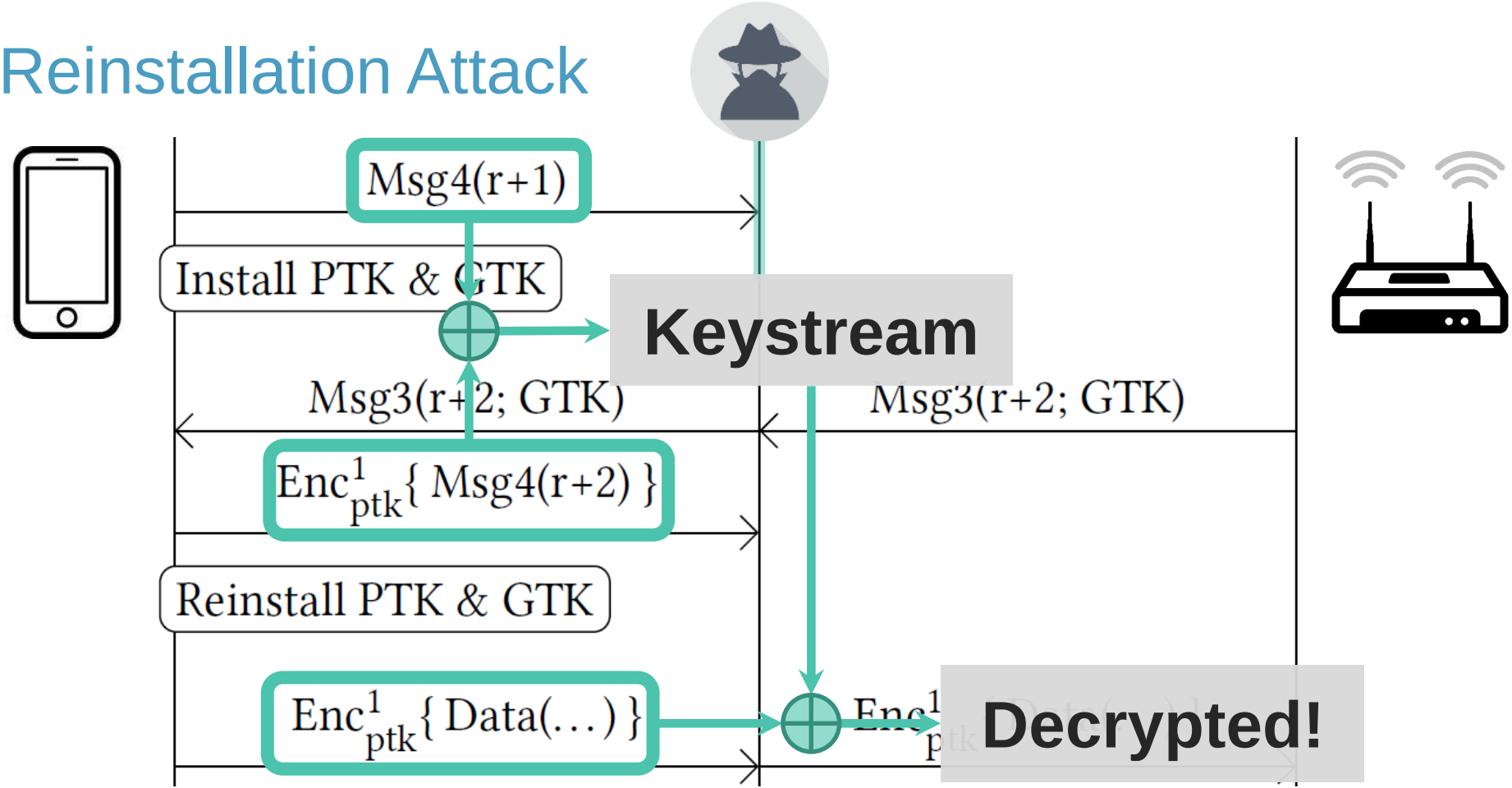

Key Reinstallation Attack

Other Wi-Fi handshakes also vulnerable:

- Group key handshake
- FT handshake
- TDLS PeerKey handshake

For details see our CCS'17 paper[10]:

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

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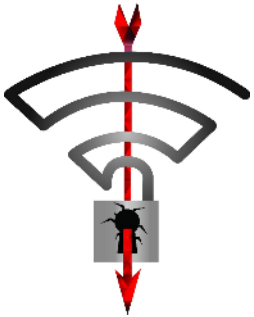


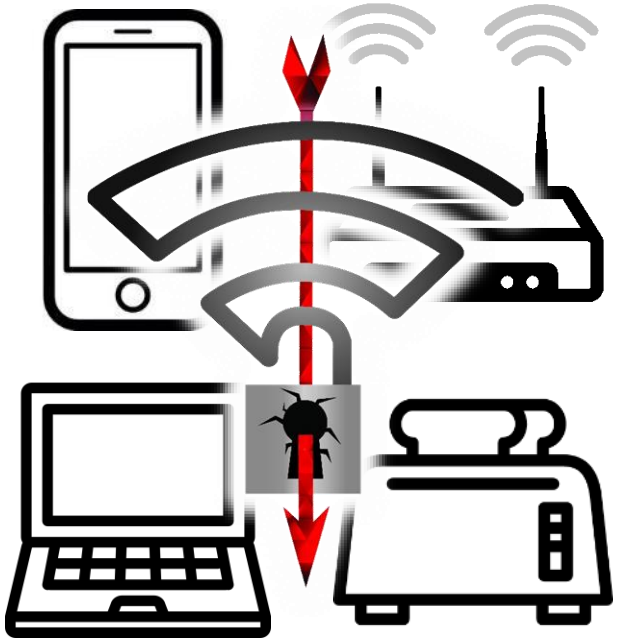
Key reinstalls in
4-way handshake

Misconceptions

Practical impact

Lessons learned

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[4,5]
- **Forge/inject** frames sent by the device under attack

GCMP (WiGig):

- Recover GHASH authentication key from nonce reuse[6]
- **Forge/inject** frames in **both directions**

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[8]

wpa_supplicant 2.4+

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

Is your device 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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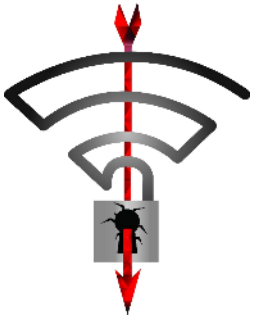

Key reinstalls in
4-way handshake

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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

Must be connected to network as attacker (i.e. have password)

› Only need to be nearby victim and network

Misconceptions II

No useful data is transmitted after handshake

- Trigger new handshakes during TCP connection

Obtaining channel-based MitM is hard

- Nope, can use channel switch announcements

Attack complexity is hard

- Script only needs to be written once …
- … and some are (privately) doing this!

Misconceptions III

Using (AES-)CCMP mitigates the attack

› Still allows decryption & replay of frames

Enterprise networks (802.1x) aren't affected

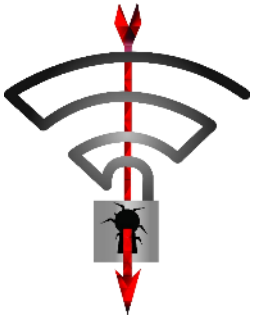
› Also use 4-way handshake & are affected

It's the end of the world!

› Let's not get carried away ☺

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

Overview



Key reinstalls in
4-way handshake

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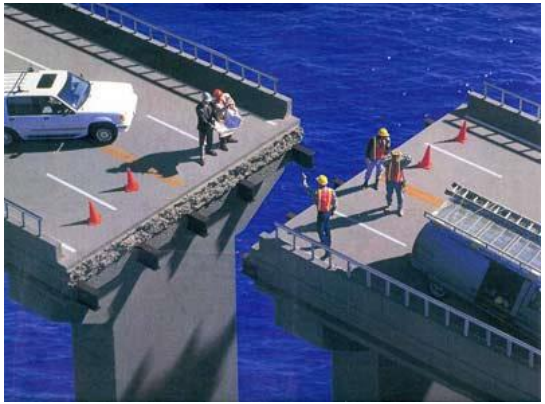
Limitations of formal proofs

- 4-way handshake proven secure
- Encryption protocol proven secure



The combination was not proven secure!

Disclosure coordination: preparation

Flawed standard! How to disclose?

Is it truly a widespread issue?

- Contacted vendors we didn't test ourselves
- They're vulnerable + feedback on report

Determining who to inform?

- Notifying more vendors → higher chance of leaks
- We relied on CERT/CC to contact vendors

Disclosure coordination: planning

Duration of embargo:

- Long: risk of details leaking
- Short: not enough time to patch
- Avoid uncertainty: set clear deadline

Open source patches?

- Developed and tested in private
- Shared 1 week in advance over private mailing lists

Disclosure coordination: leaks

How to handle leaks? E.g. Meltdown and Spectre:

Subject [PATCH] x86/cpu, x86/pti: Do not enable PTI on AMD processors

AMD processors are not subject to the types of attacks that the kernel page table isolation feature protects against. The AMD microarchitecture does not allow memory references, including speculative references, that access higher privileged data when running in a lesser privileged mode when that access would result in a page fault.

- Release **interim advisory** to avoid uncertainty
- Plan for such unwanted early disclosures!

Disclosure coordination: improvements

Provide notification of disclosure?

- E.g. “OpenSSL v1.0.2h will be released on …”
- Mention severity!

Inform more parties?

- When nearing disclosure, gradually inform more vendors
- Reduces impact if less trusted vendors leak details

Handling leaks: NDA for early access to details?

Multi-party vulnerability coordination

These aren’t new lessons! See

Guidelines and Practices for Multi-Party Vulnerability Coordination (Draft)[11]

Remember:

- Goal is to protect users
- There are various opinions

Conclusion

- Flaw is in WPA2 standard
- Proven correct but is insecure!
- Attack has practical impact
- Update all clients & check APs

Thank you!

Questions?

krackattacks.com

References

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