How WPA2 got KRACKed using Key Reinstallation Attacks

Mathy Vanhoef — @vanhoefm

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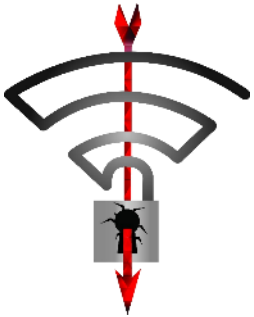
KU LEUVEN DistriNet

Overview



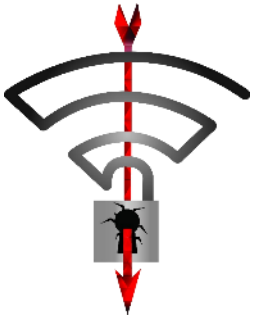
Key reinstalls in
4-way handshake

Misconceptions

Practical impact

Lessons learned

Overview



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The 4-way handshake

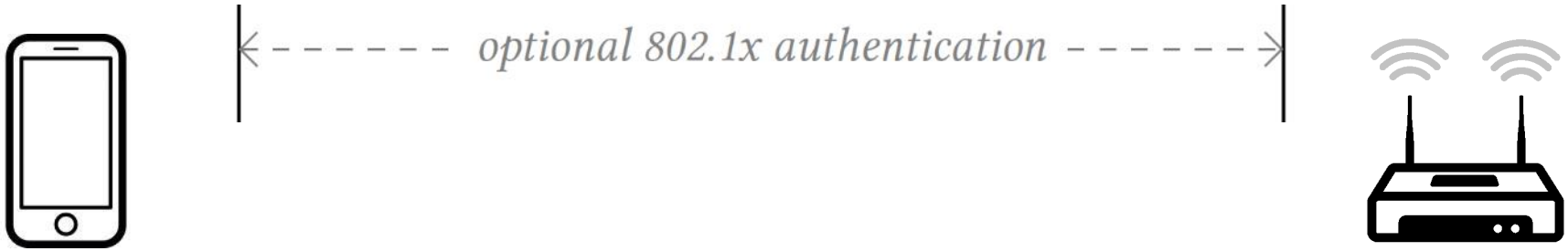
Used to connect to any protected Wi-Fi network

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

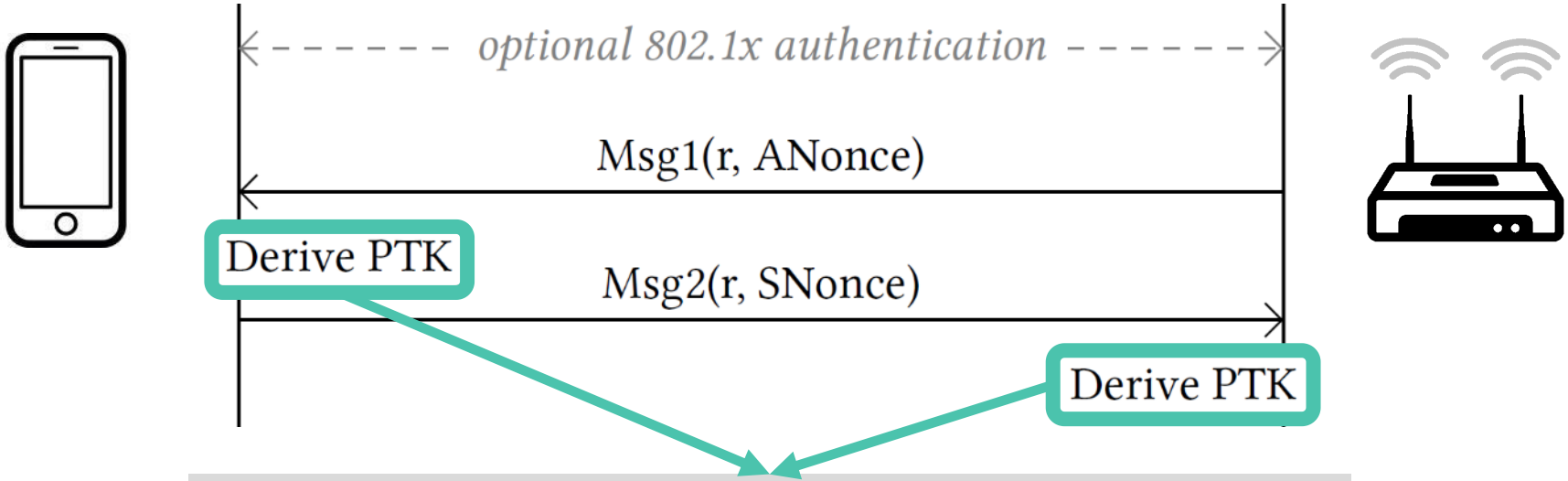
Appeared to be secure:

- 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)

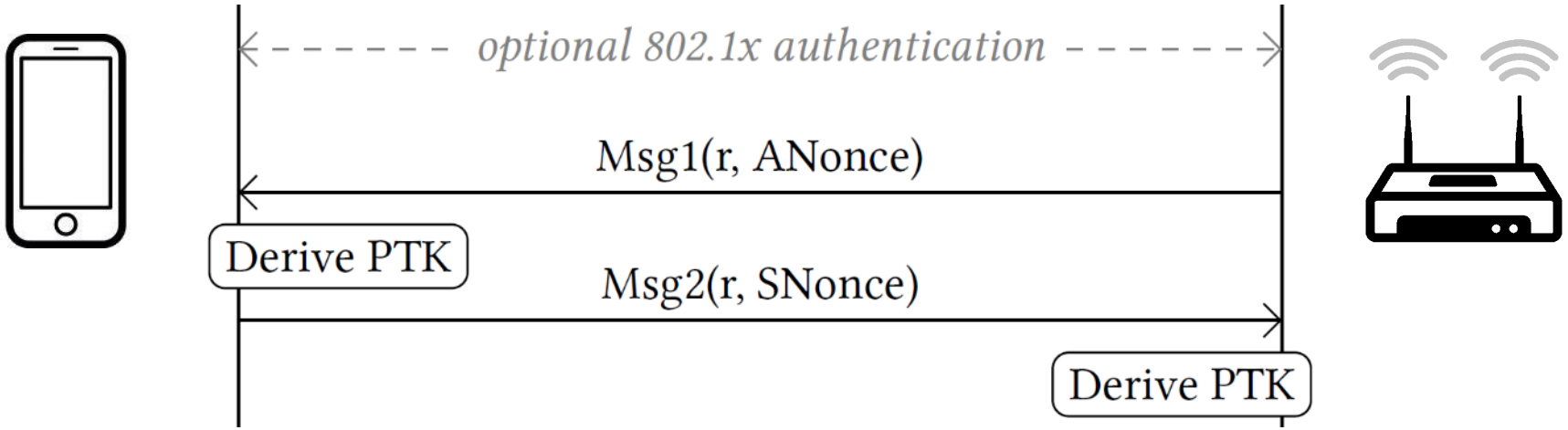


4-way handshake (simplified)

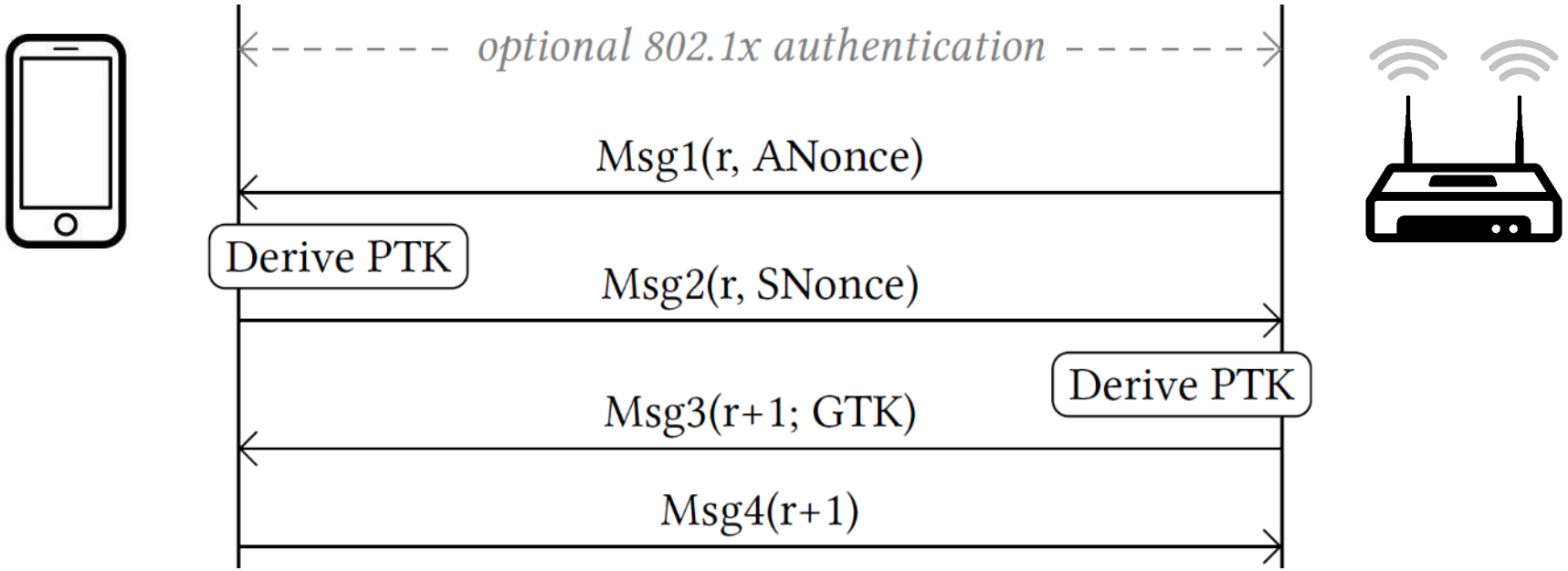


PTK = Combine(shared secret, ANonce, SNonce)

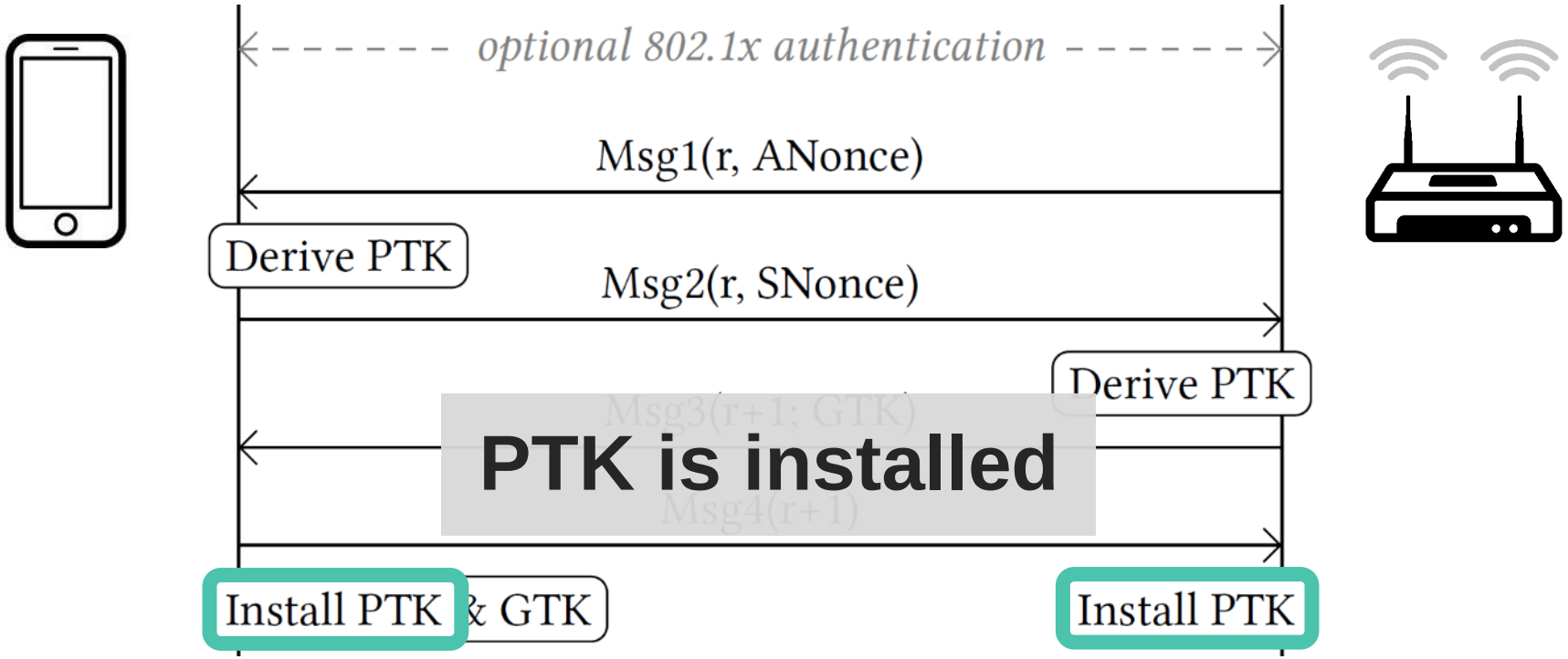
4-way handshake (simplified)



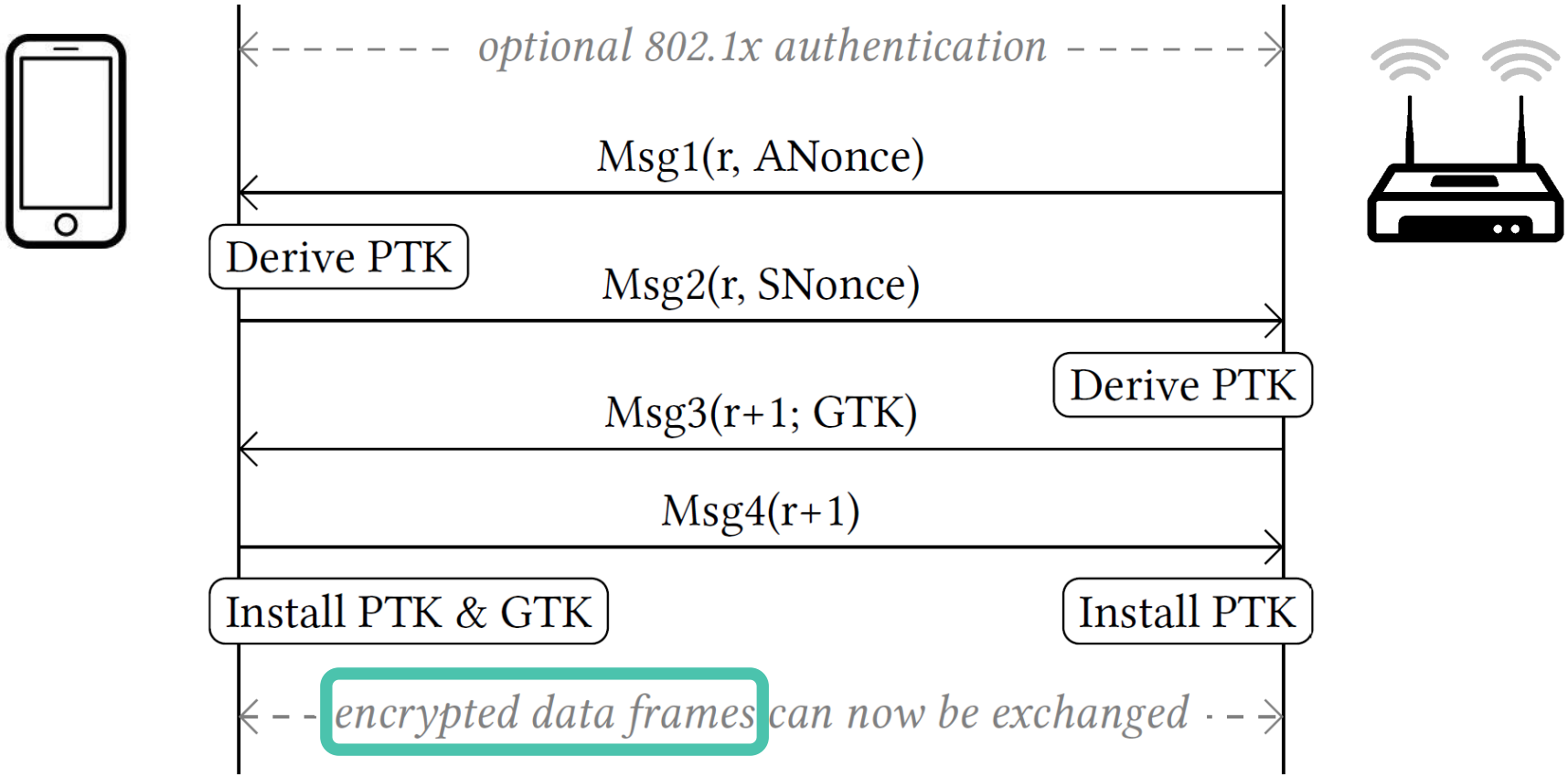
4-way handshake (simplified)



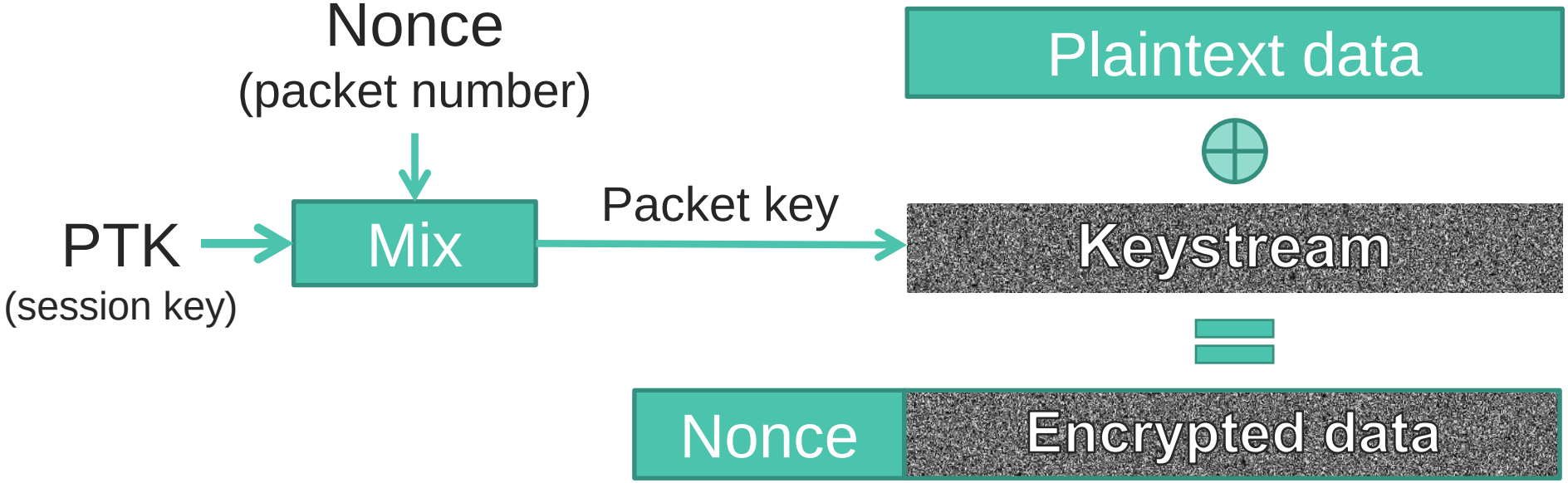
4-way handshake (simplified)



4-way handshake (simplified)

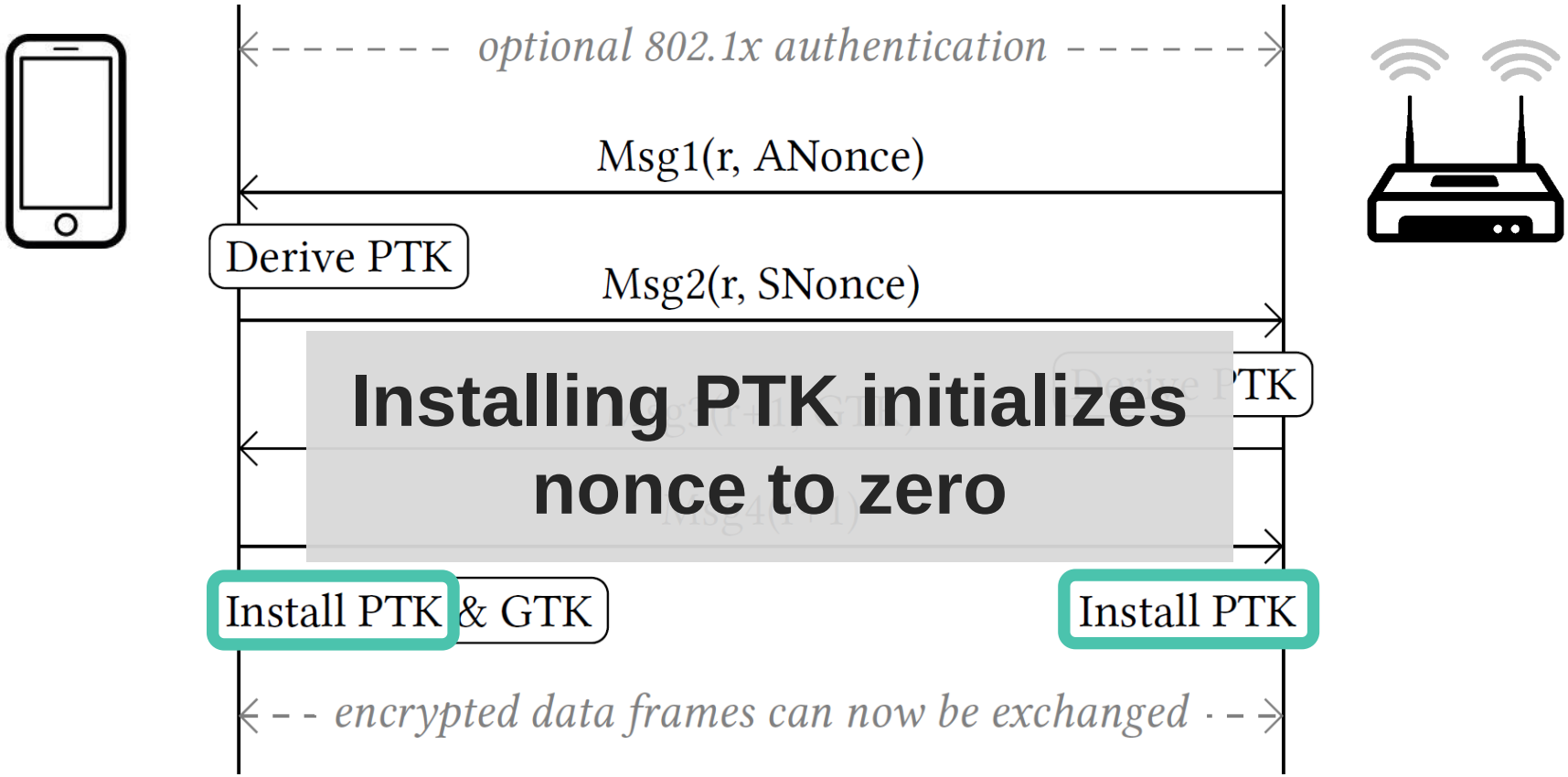


Frame encryption (simplified)



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

4-way handshake (simplified)



Reinstallation Attack

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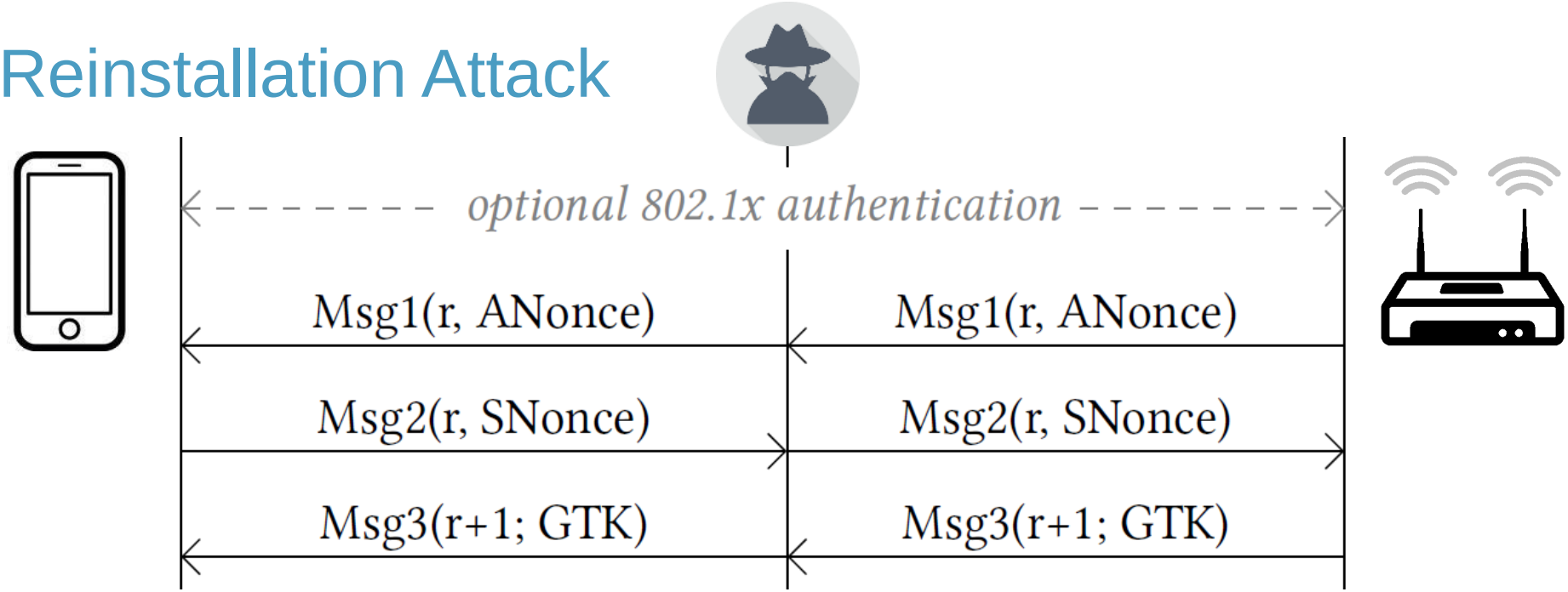

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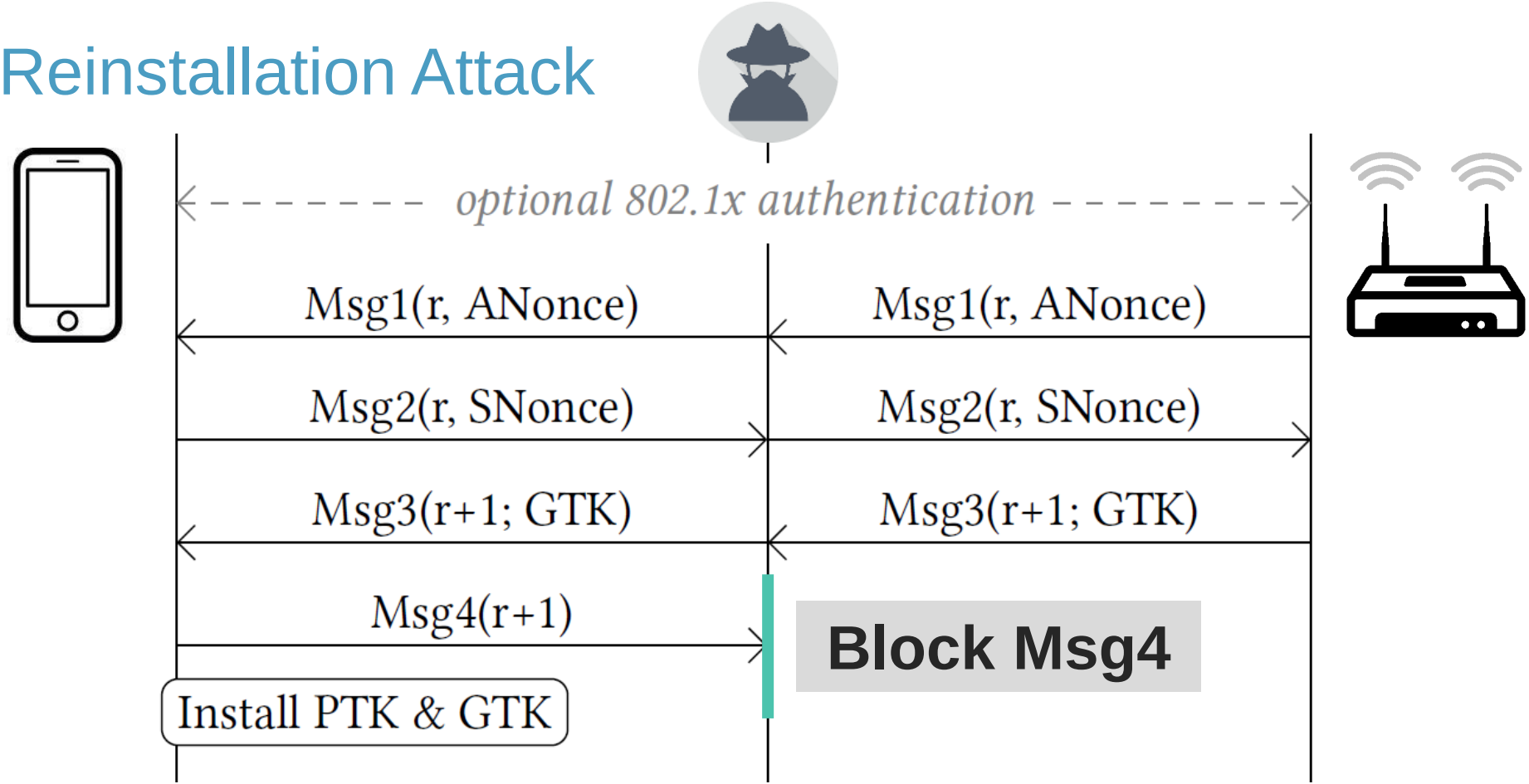

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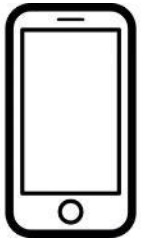

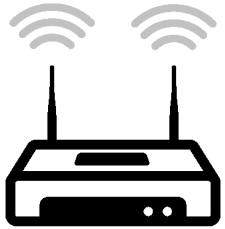

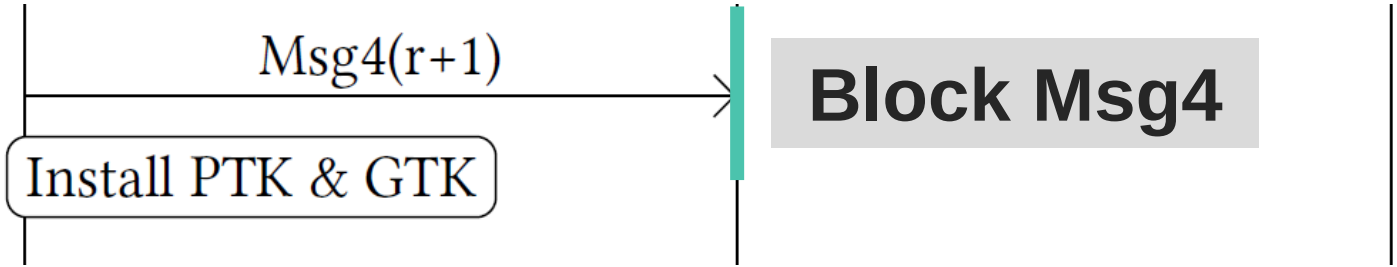

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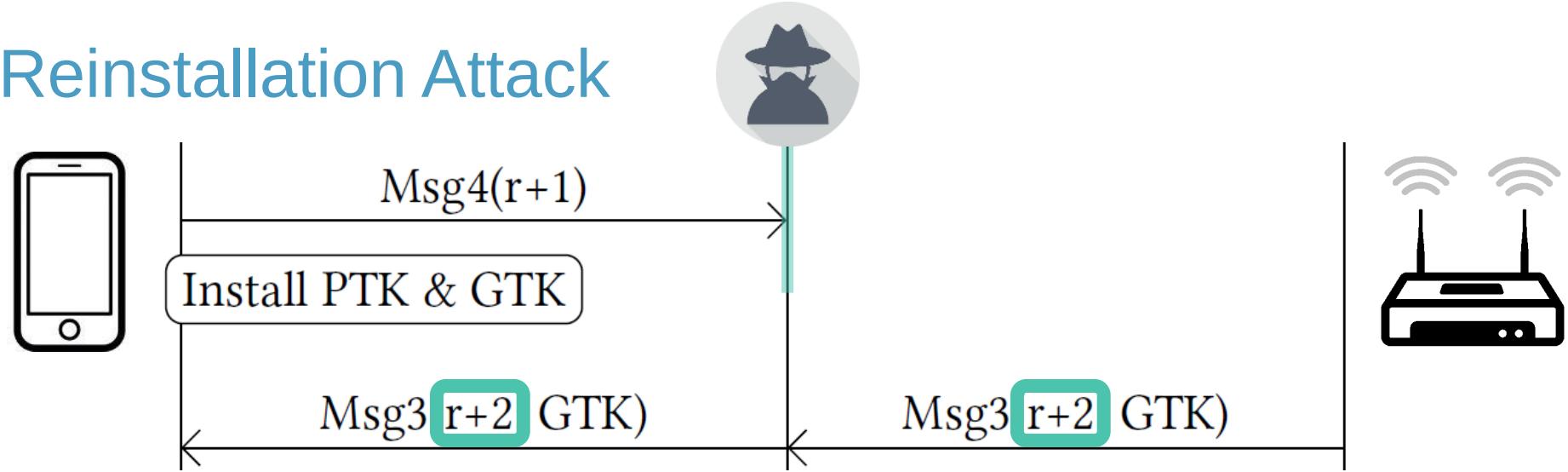
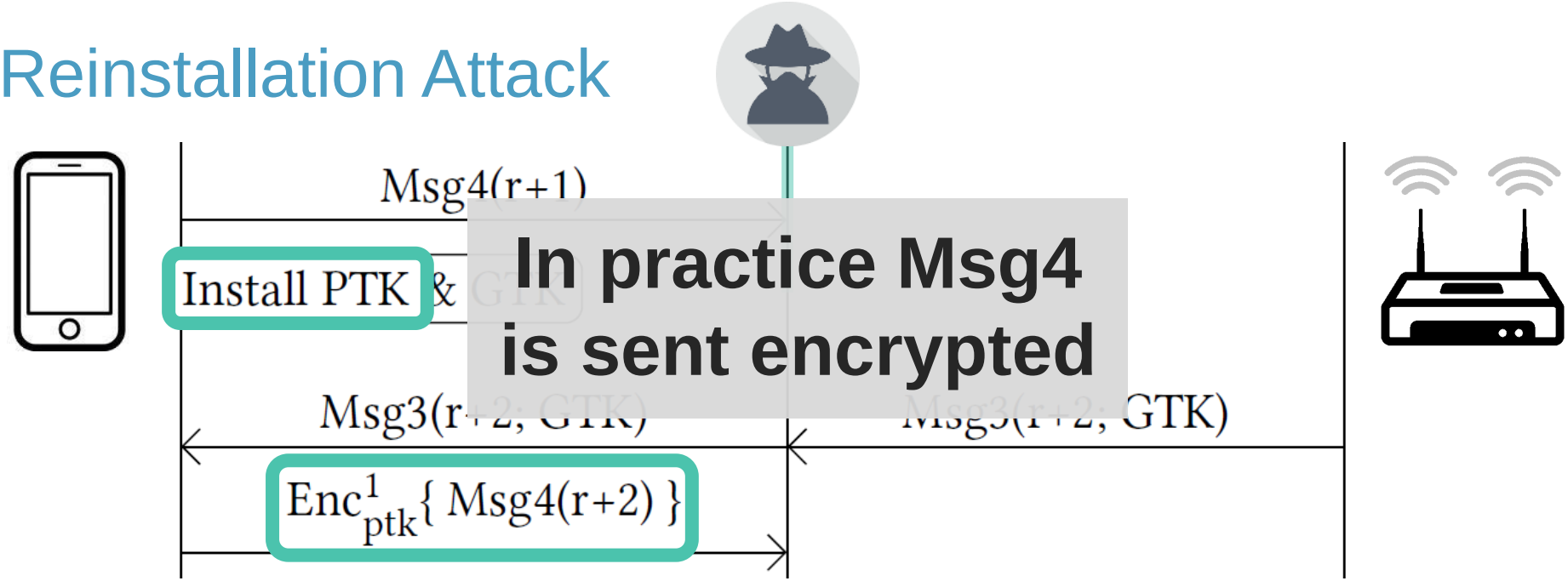


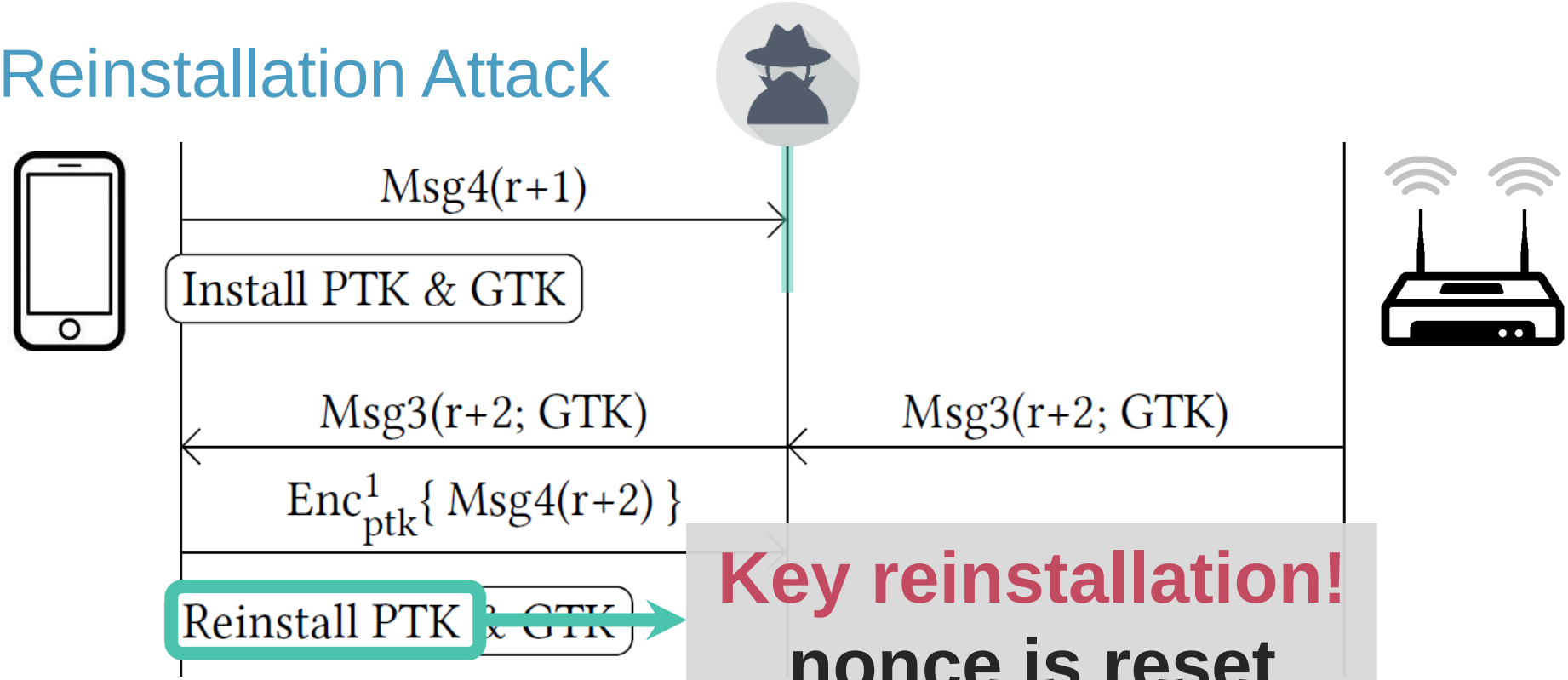
New replay counter

Reinstallation Attack



In practice Msg4 is sent encrypted

Reinstallation Attack



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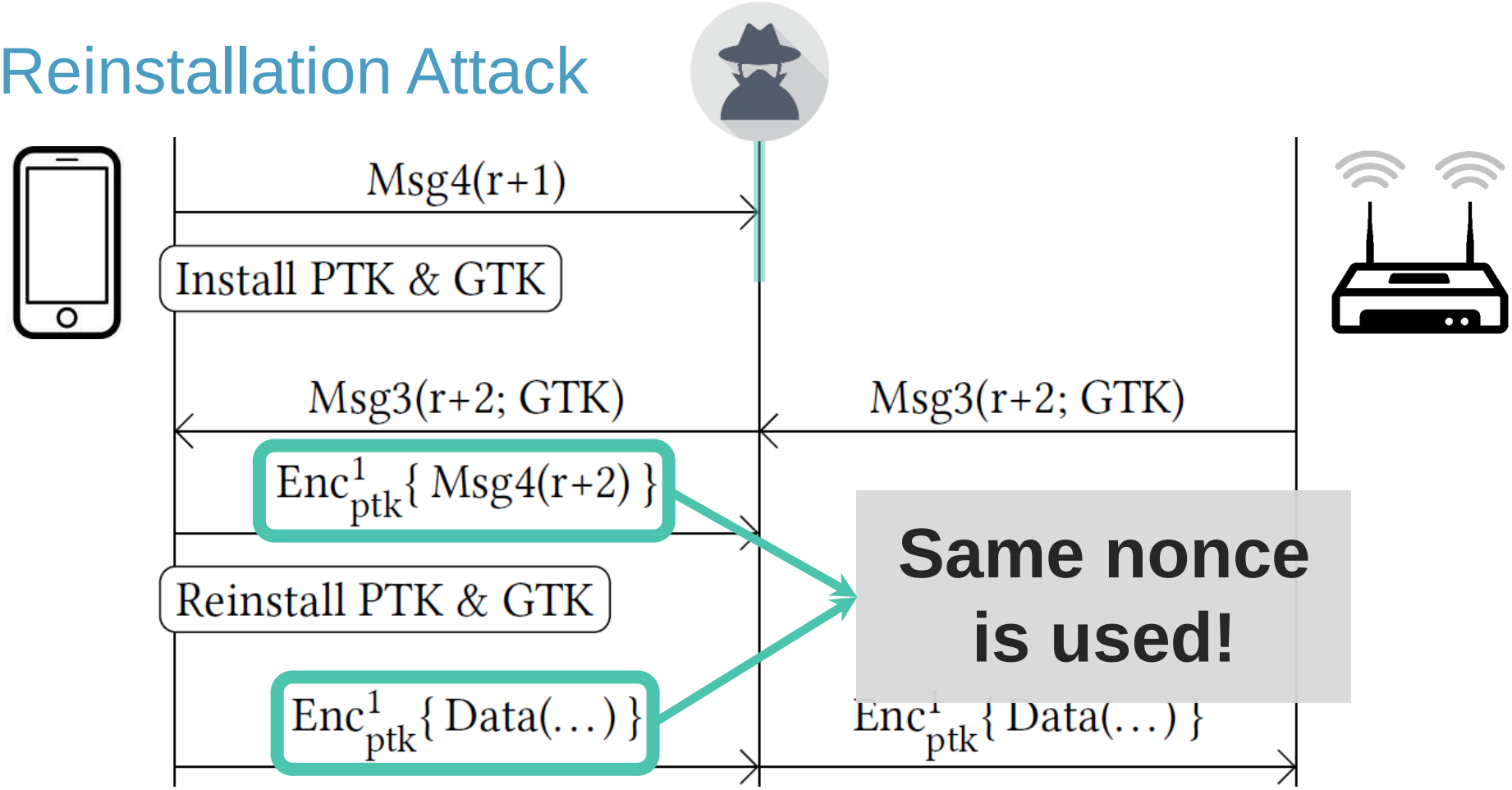

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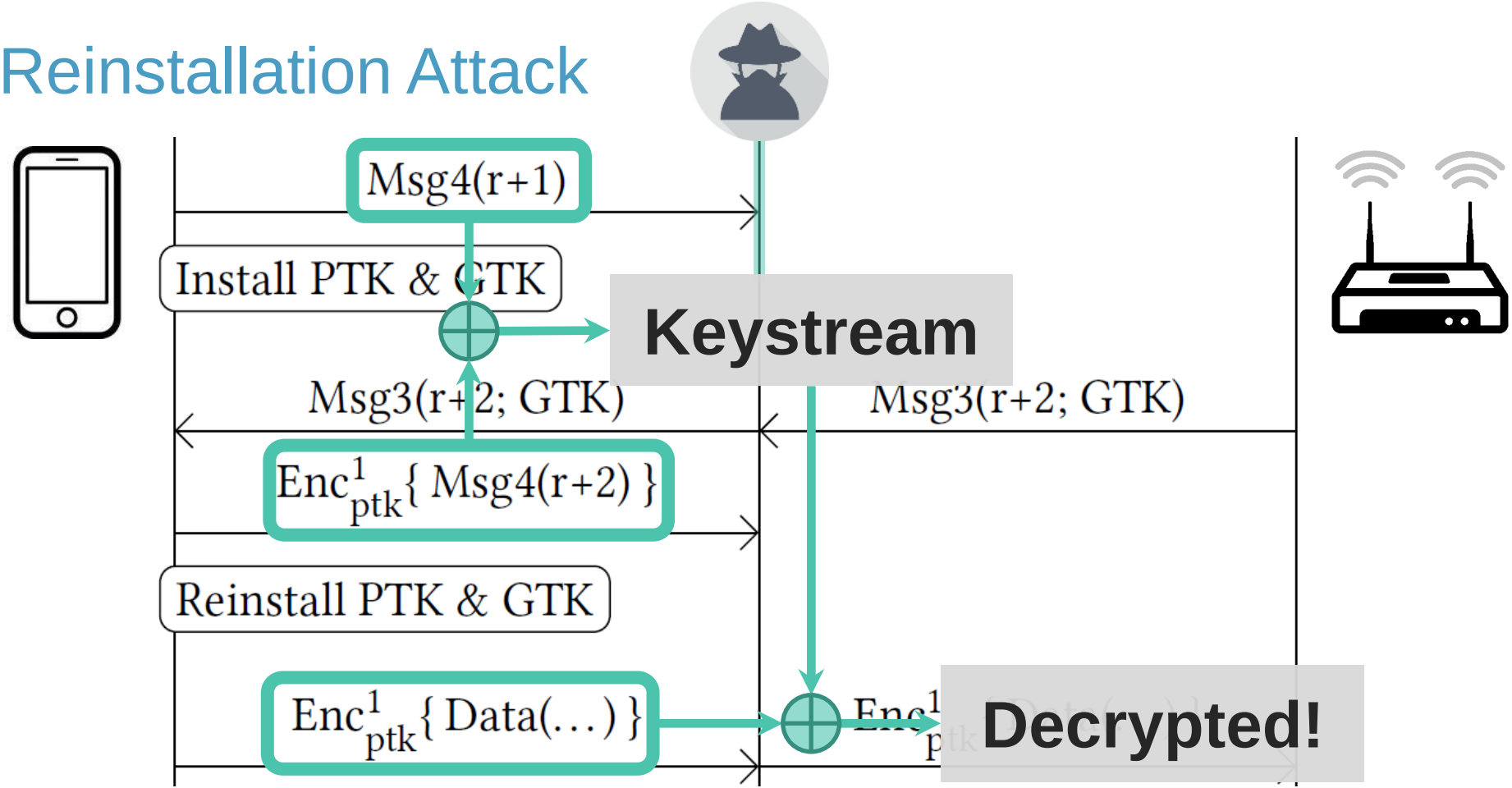

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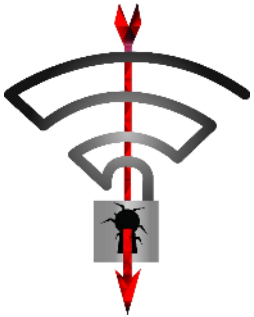

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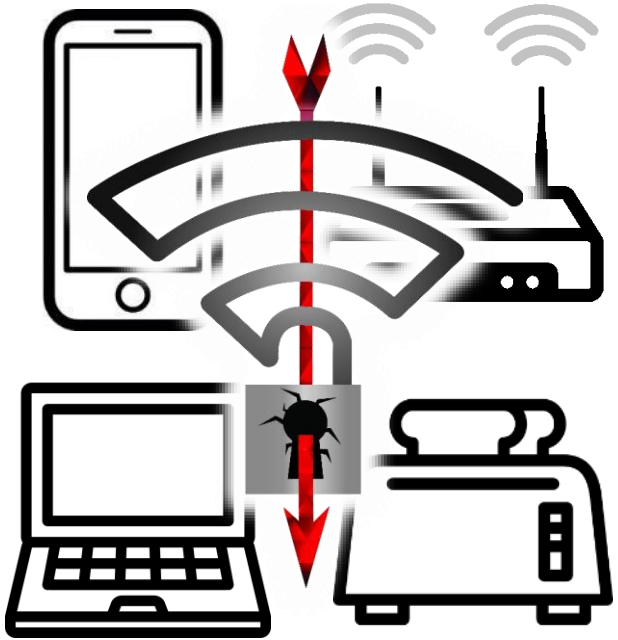
General impact



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

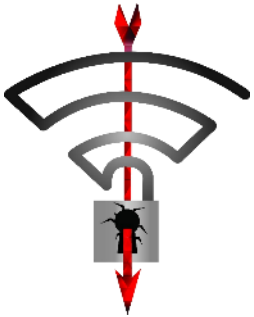
WPA-TKIP:

- Can recover authentication key
- **Forge/inject** frames sent by the device under attack

GCMP (WiGig):

- Can recover authentication key
- **Forge/inject** frames in **both directions**

Overview



Key reinstalls in
4-way handshake

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Misconceptions

Updating only the client or AP is sufficient

› Both vulnerable clients & vulnerable APs must apply patches

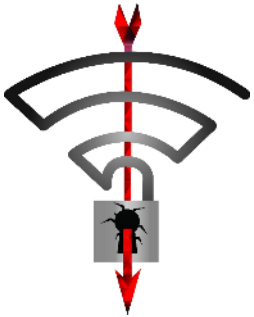
Need to be close to network and victim

› Can use special antenna from afar

Corporate networks (802.1x) aren’t affected

› Also use 4-way handshake & are affected

Overview



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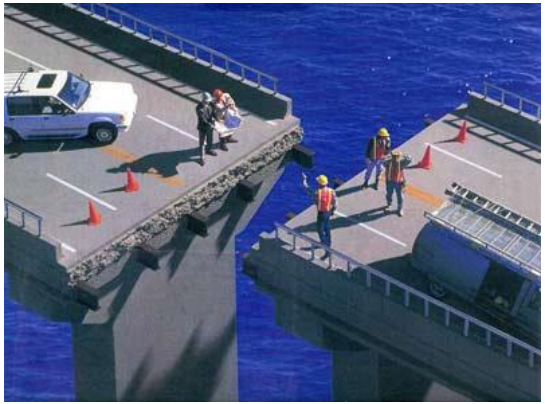
Limitations of formal proofs

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



The combination was not proven secure!

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

Implementation specific

iOS 10 and Windows: 4-way handshake not affected

- **Cannot decrypt or replay traffic**
- But iOS 11 is vulnerable!

wpa_supplicant 2.4+

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