Improved KRACK Attacks Against WPA2 Implementations

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OPCDE, Dubai, 7 April 2018

KU LEUVEN DistriNet

Overview

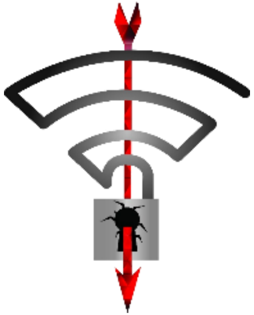
Key reinstalls in 4-way handshake

New KRACKs

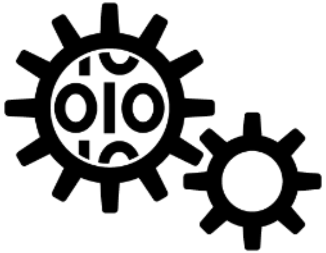
Practical impact

Lessons learned

Overview



Key reinstalls in 4-way handshake



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The 4-way handshake

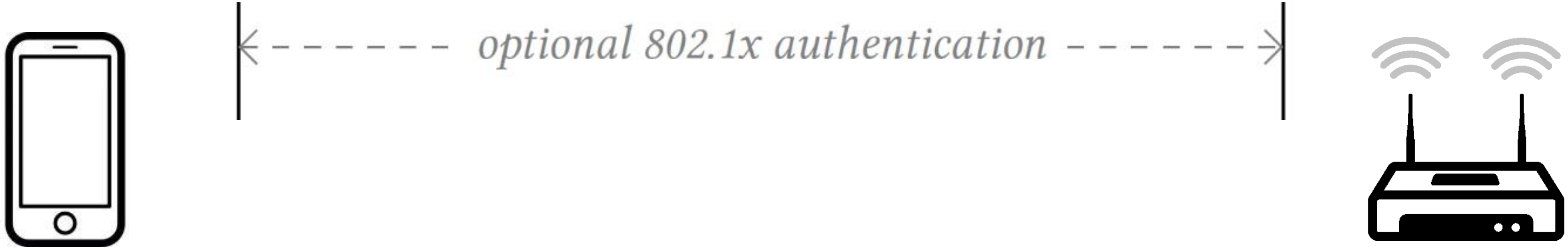
Used to connect to any protected Wi-Fi network

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

Appeared to be secure:

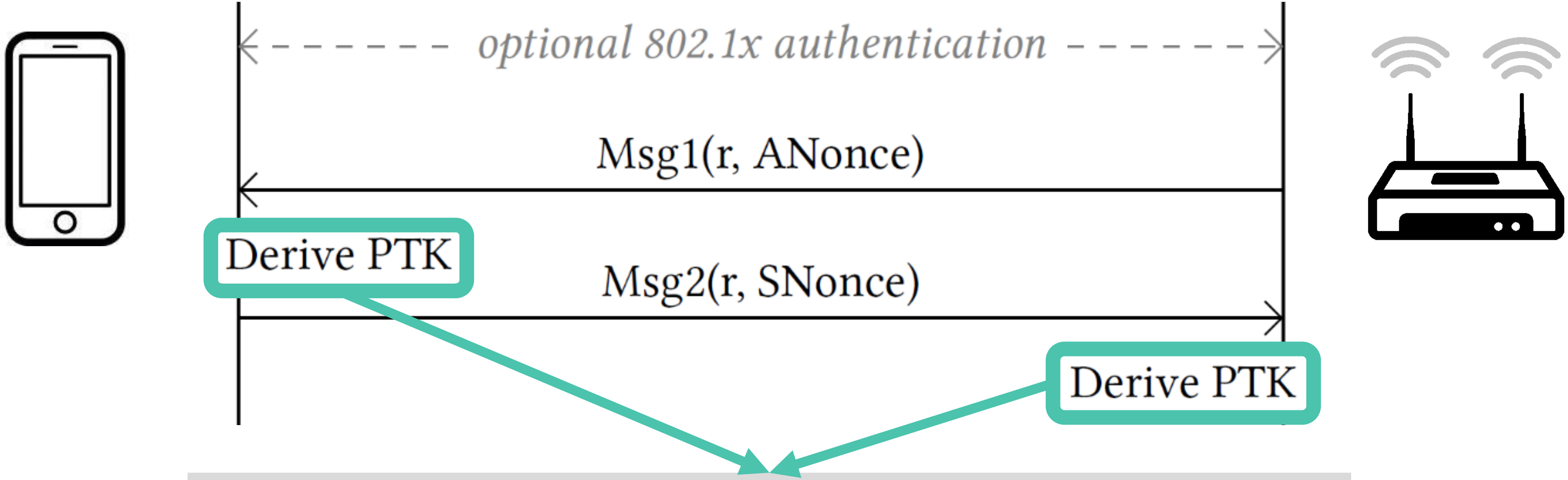
- No attacks in over a decade (apart from password guessing)
- Proven that negotiated key (PTK) is secret[1]
- And encryption protocol proven secure[5]

4-way handshake (simplified)



optional 802.1x authentication

4-way handshake (simplified)



optional 802.1x authentication

Msg1(r, ANonce)

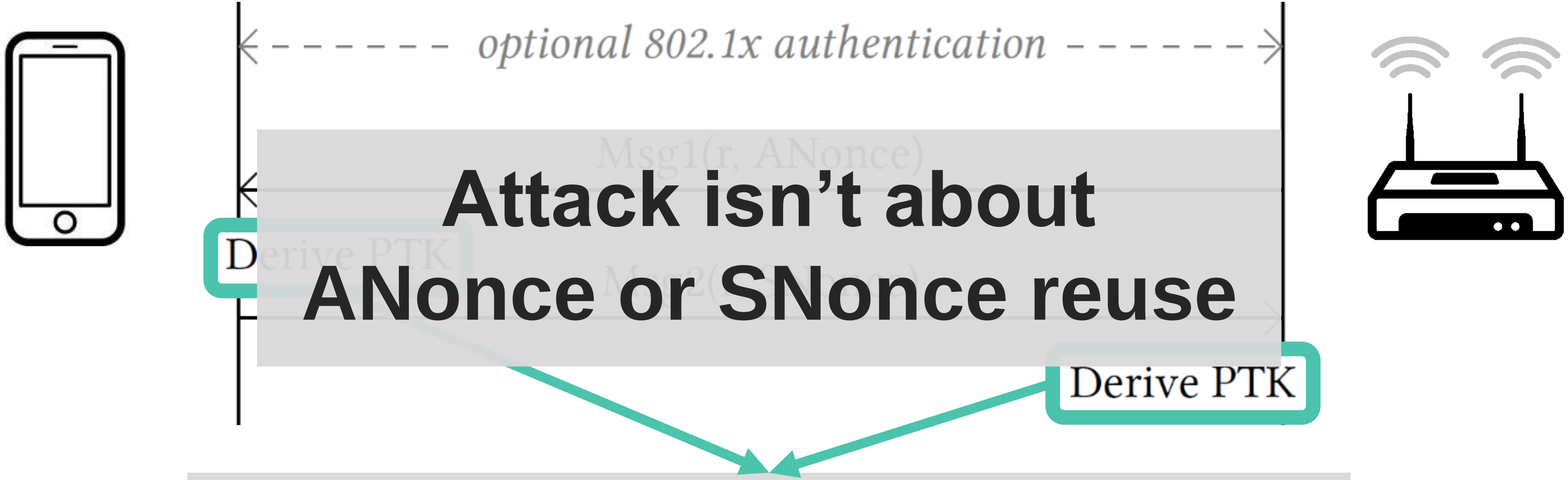
Derive PTK

Msg2(r, SNonce)

Derive PTK

PTK = Combine(shared secret, ANonce, SNonce)

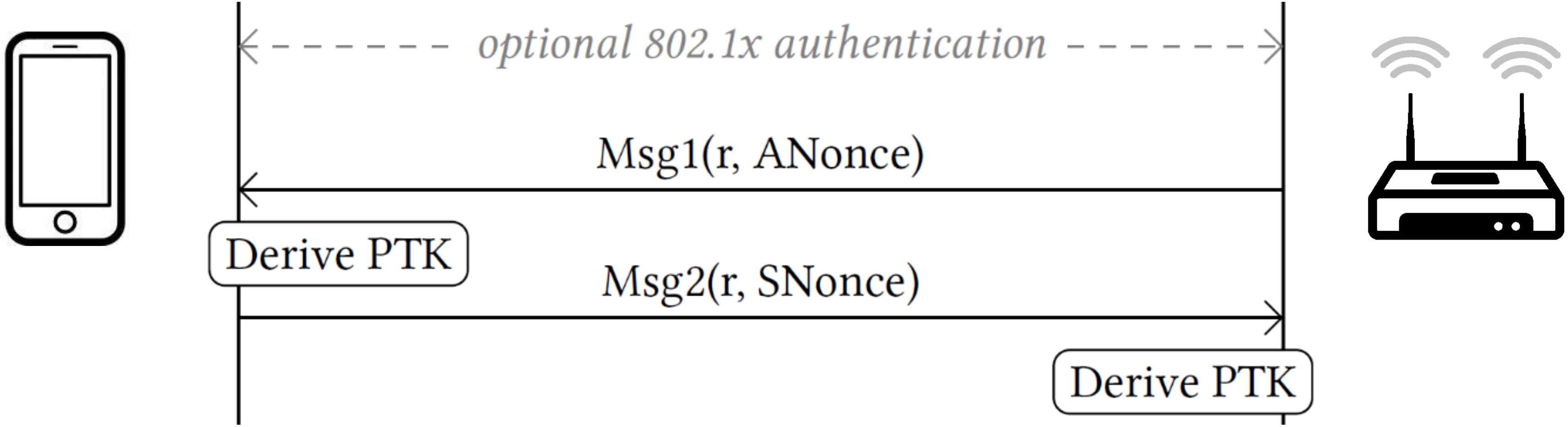
4-way handshake (simplified)



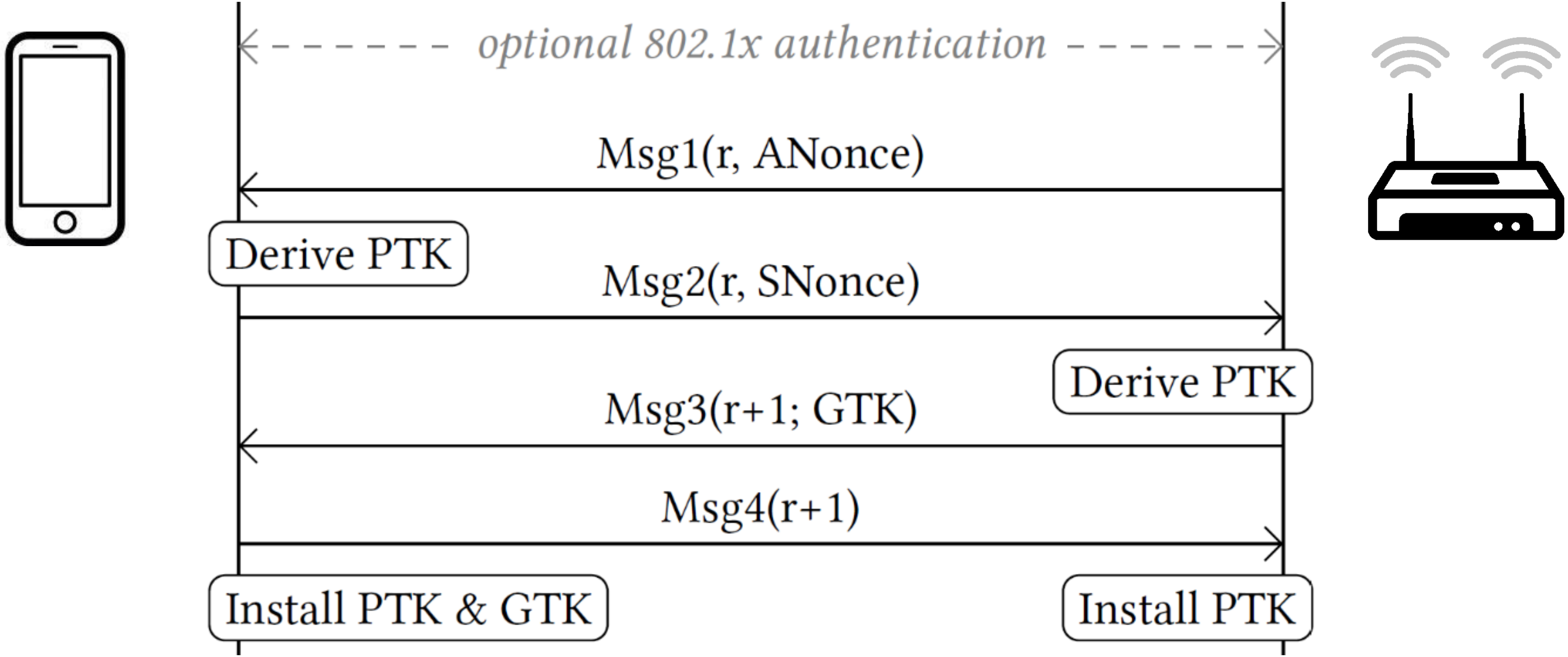
Attack isn’t about ANonce or SNonce reuse

PTK = Combine(shared secret, ANonce, SNonce)

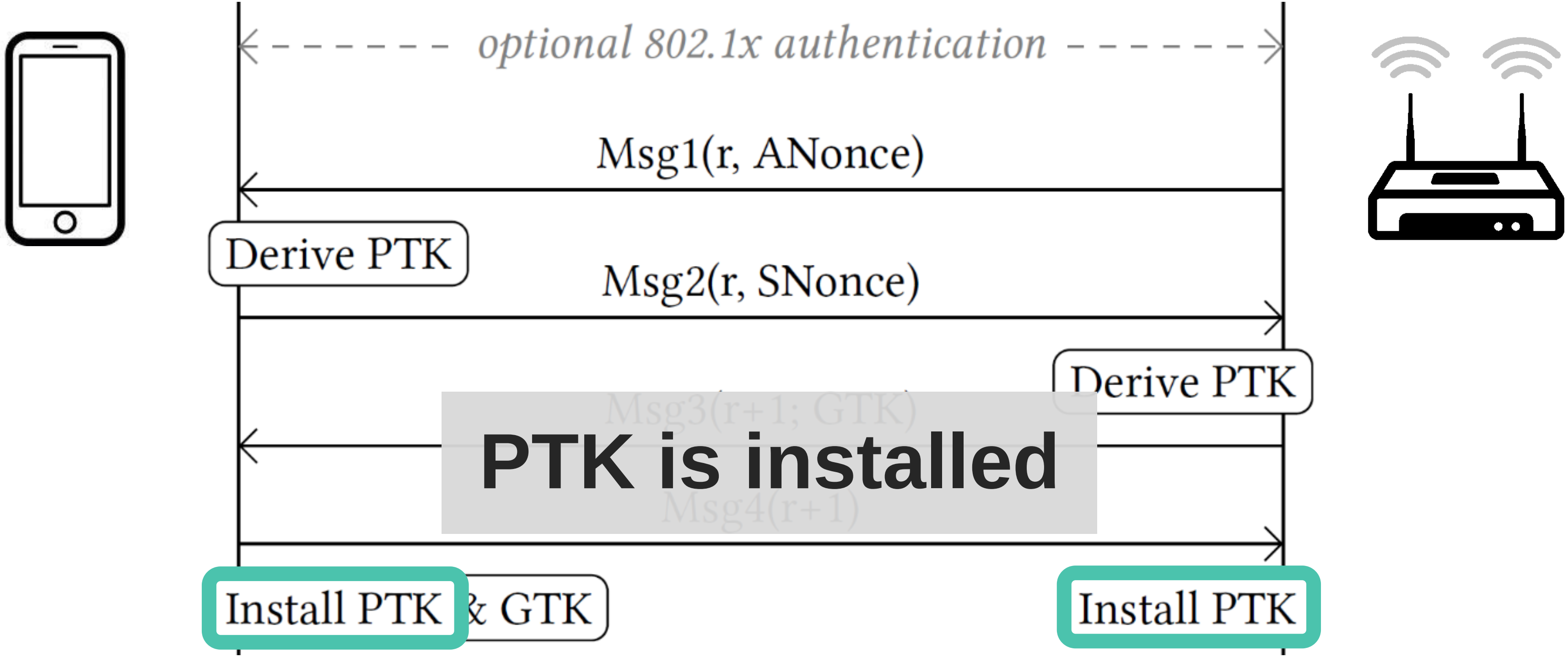
4-way handshake (simplified)



4-way handshake (simplified)

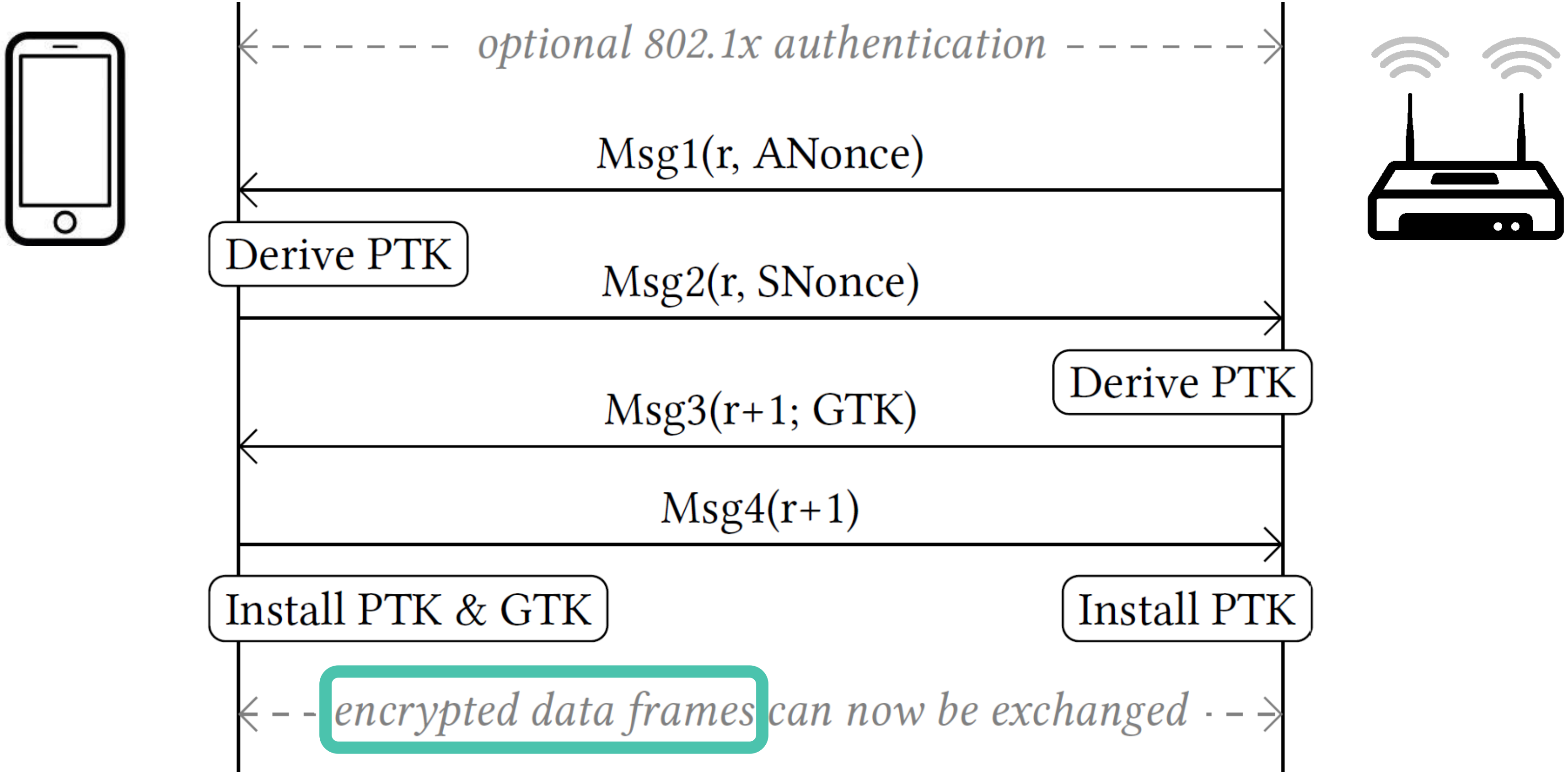


4-way handshake (simplified)



PTK is installed

4-way handshake (simplified)



optional 802.1x authentication

Msg1(r, ANonce)

Derive PTK

Msg2(r, SNonce)

Derive PTK

Msg3(r+1; GTK)

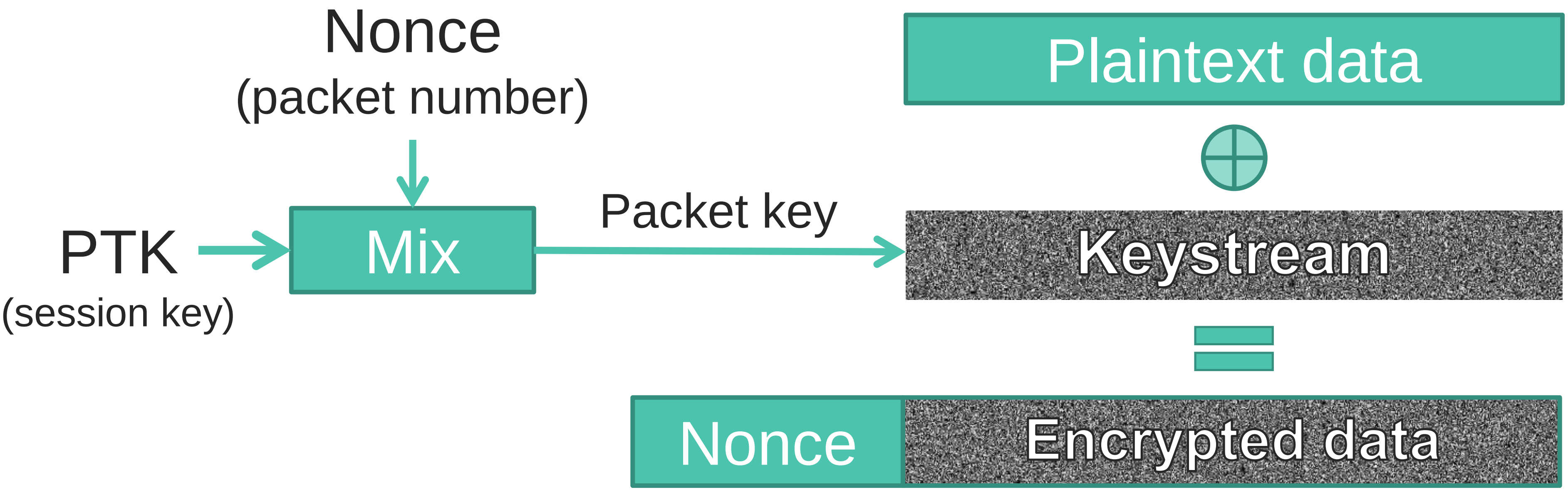
Msg4(r+1)

Install PTK & GTK

Install PTK

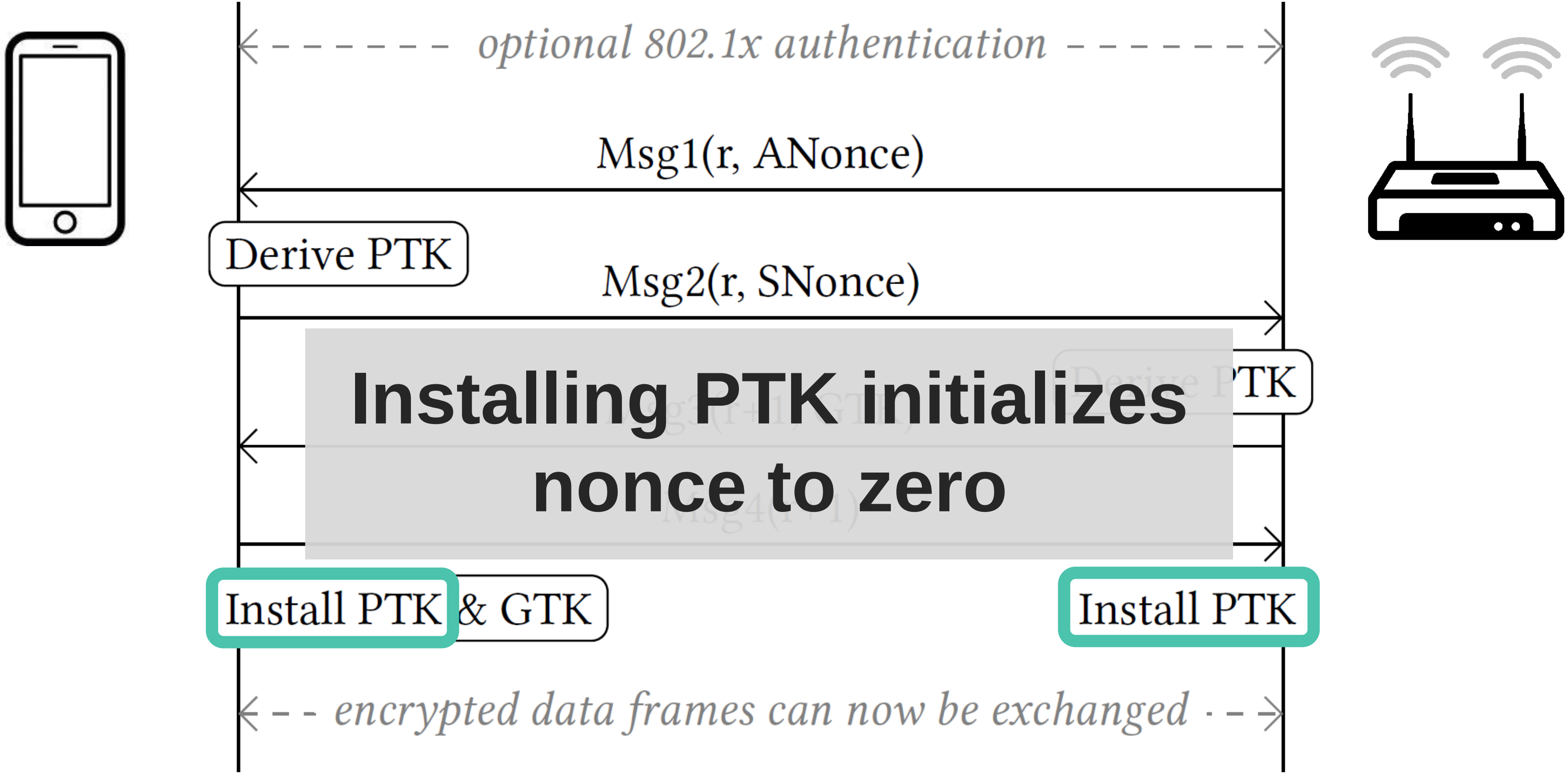
encrypted data frames can now be exchanged

Frame encryption (simplified)



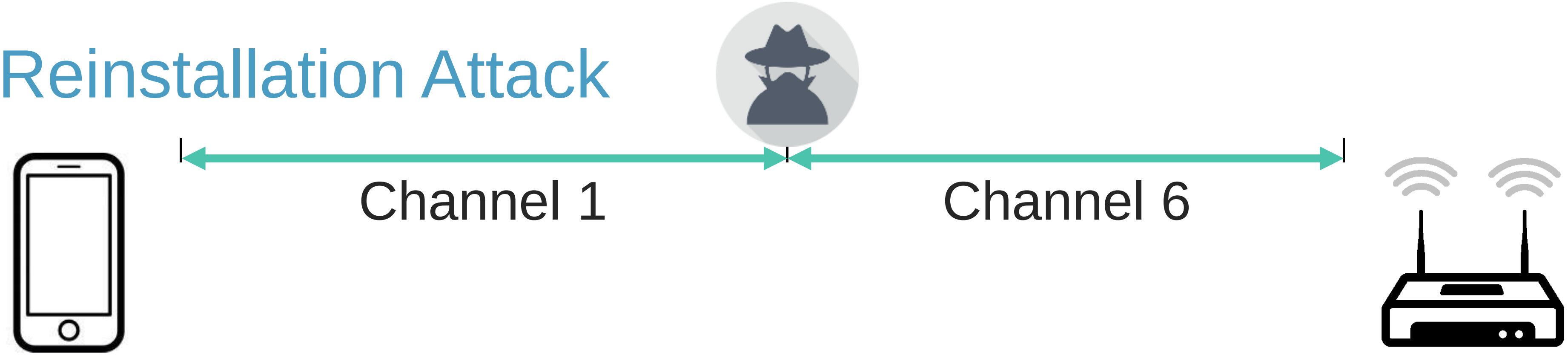
→ Nonce reuse implies keystream reuse (in all WPA2 ciphers)

4-way handshake (simplified)



Installing PTK initializes nonce to zero

Reinstallation Attack



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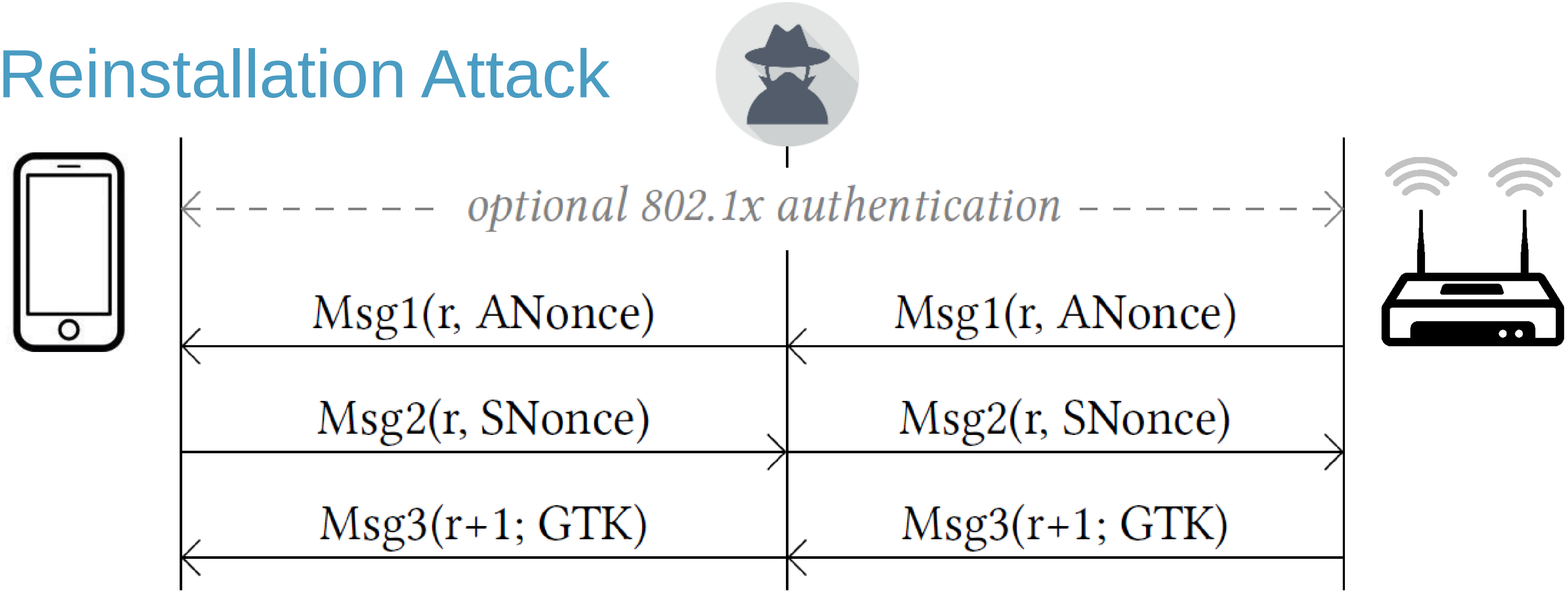

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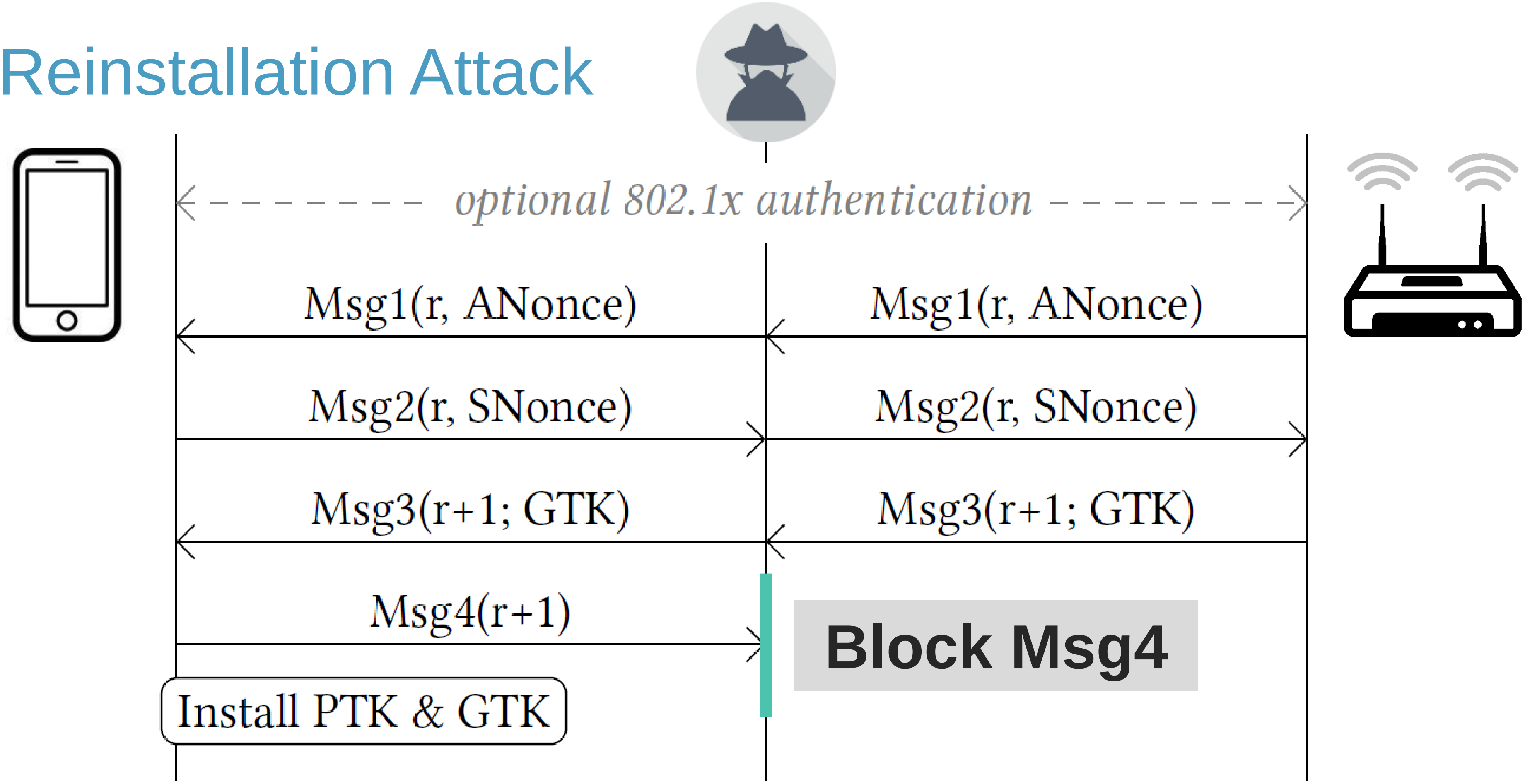
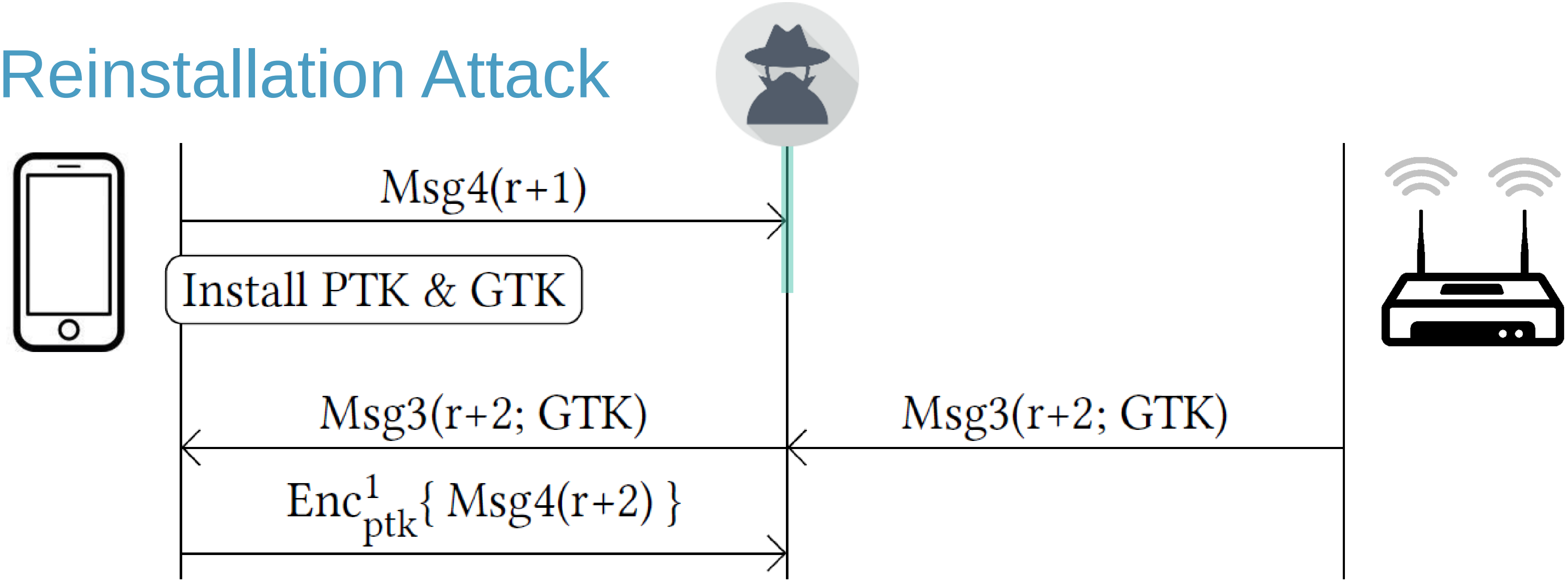


Block Msg4

Reinstallation Attack



Msg4(r+1)

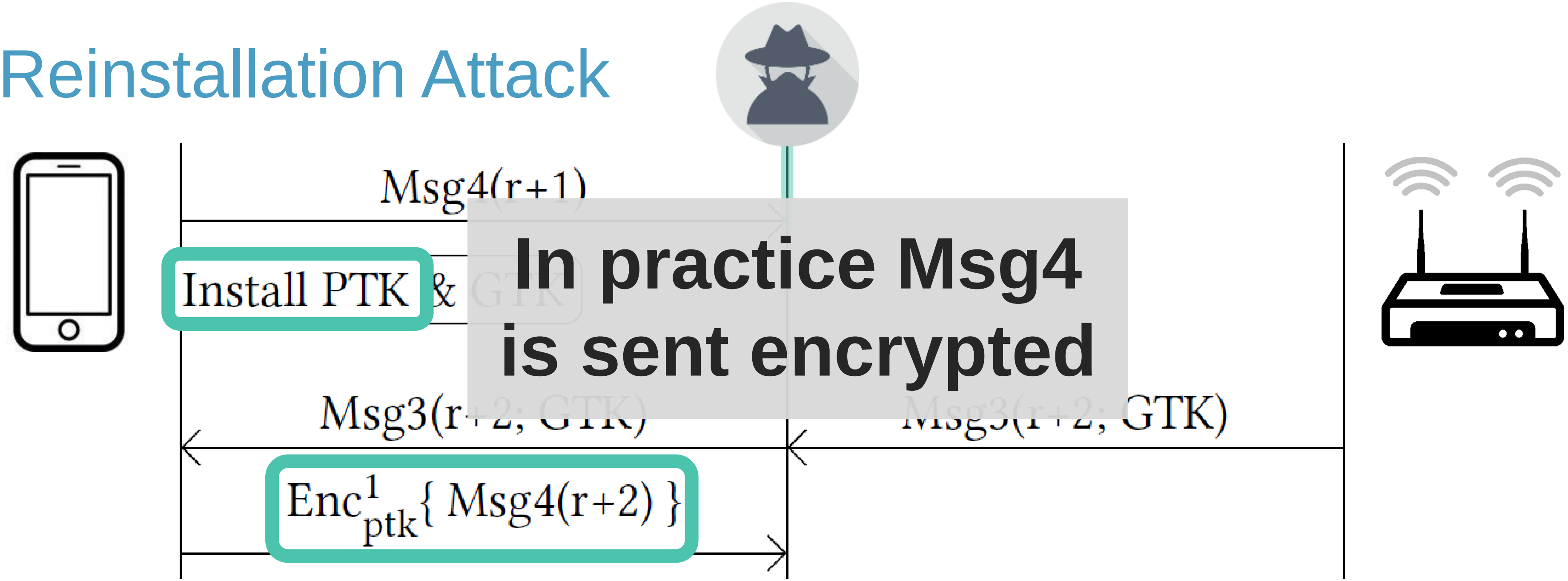
Install PTK & GTK

Msg3(r+2; GTK)

Msg3(r+2; GTK)

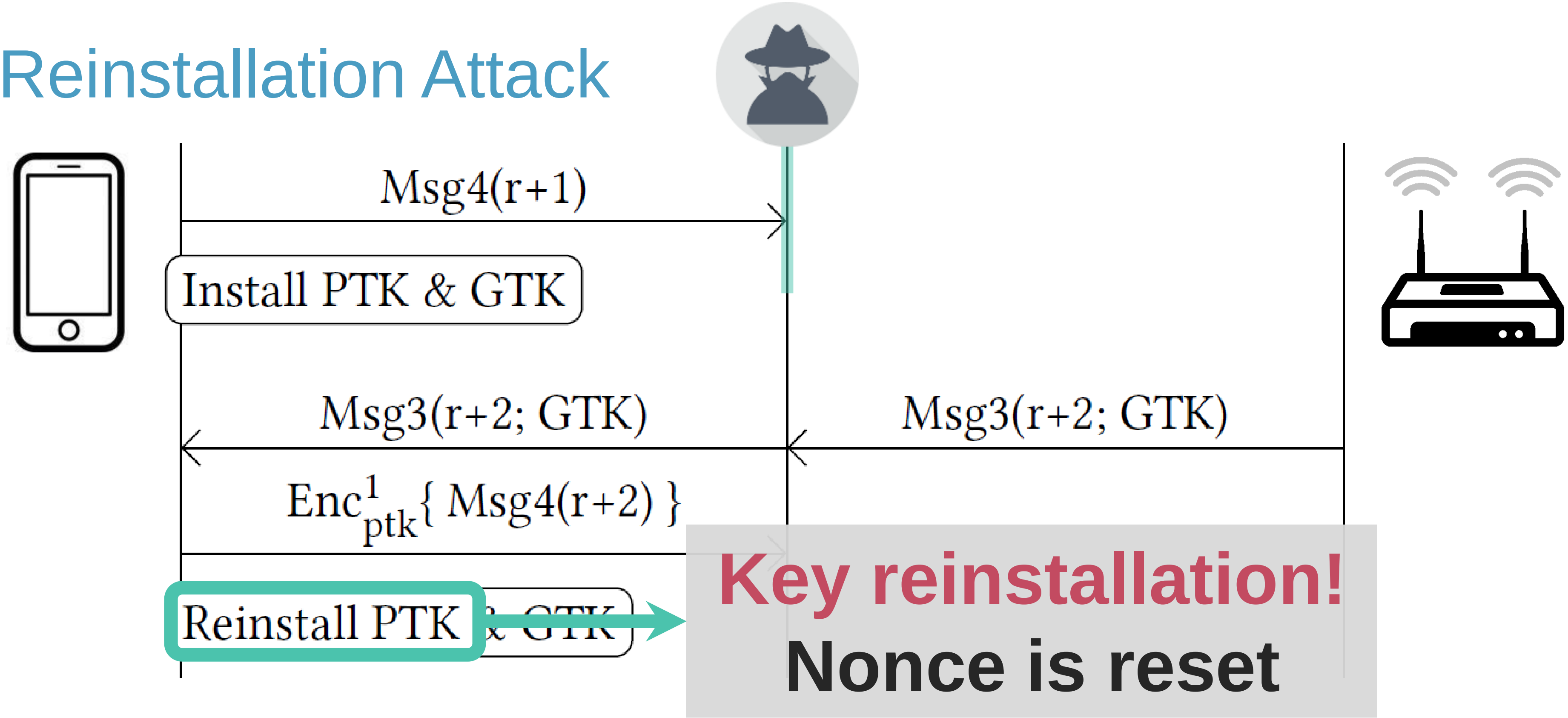
$\mathrm{Enc}^{1}_{\mathrm{ptk}}\{\ \mathrm{Msg4}(r+2)\ \}$

Reinstallation Attack



In practice Msg4 is sent encrypted

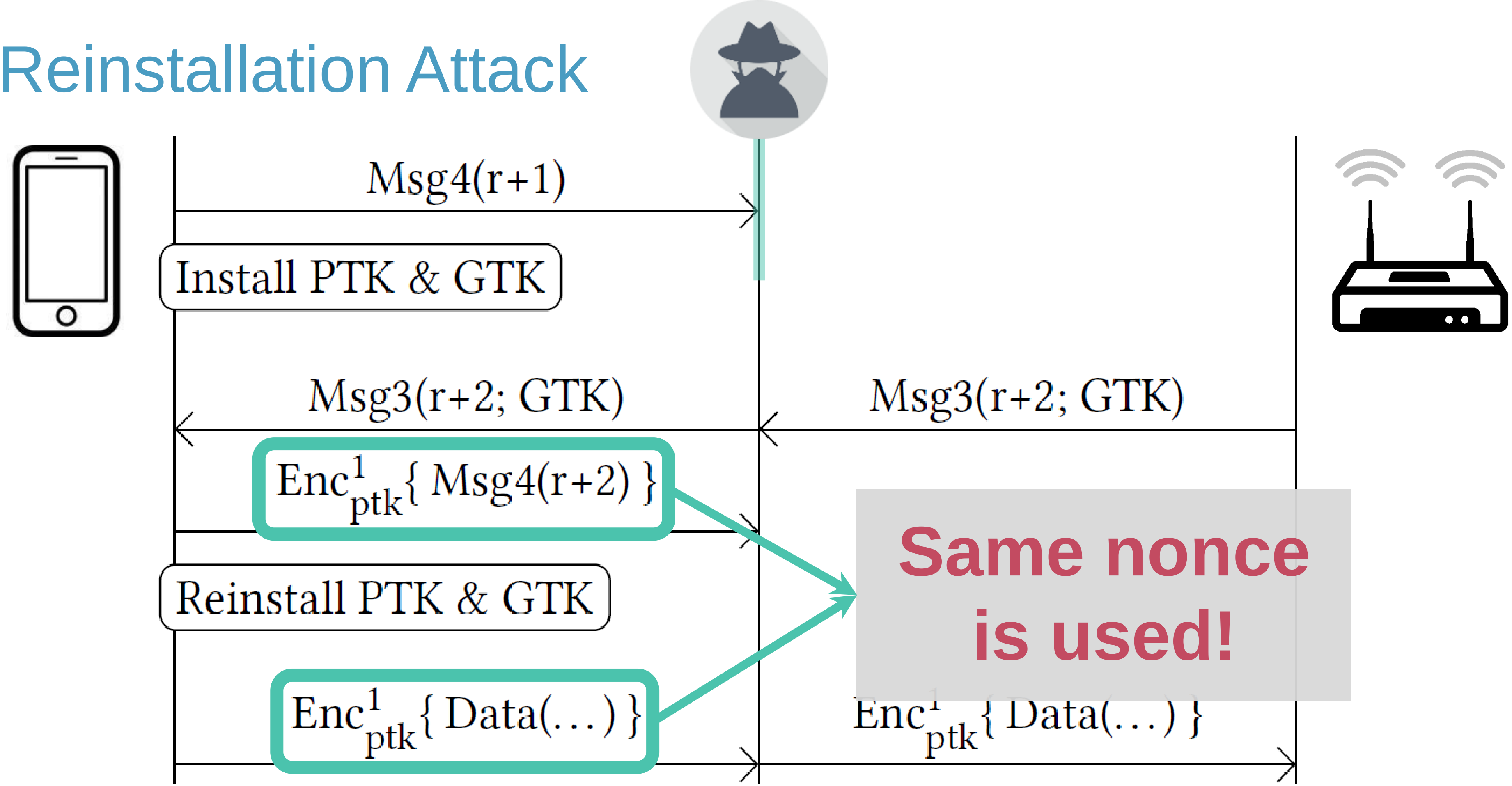
Reinstallation Attack



Key reinstallation!

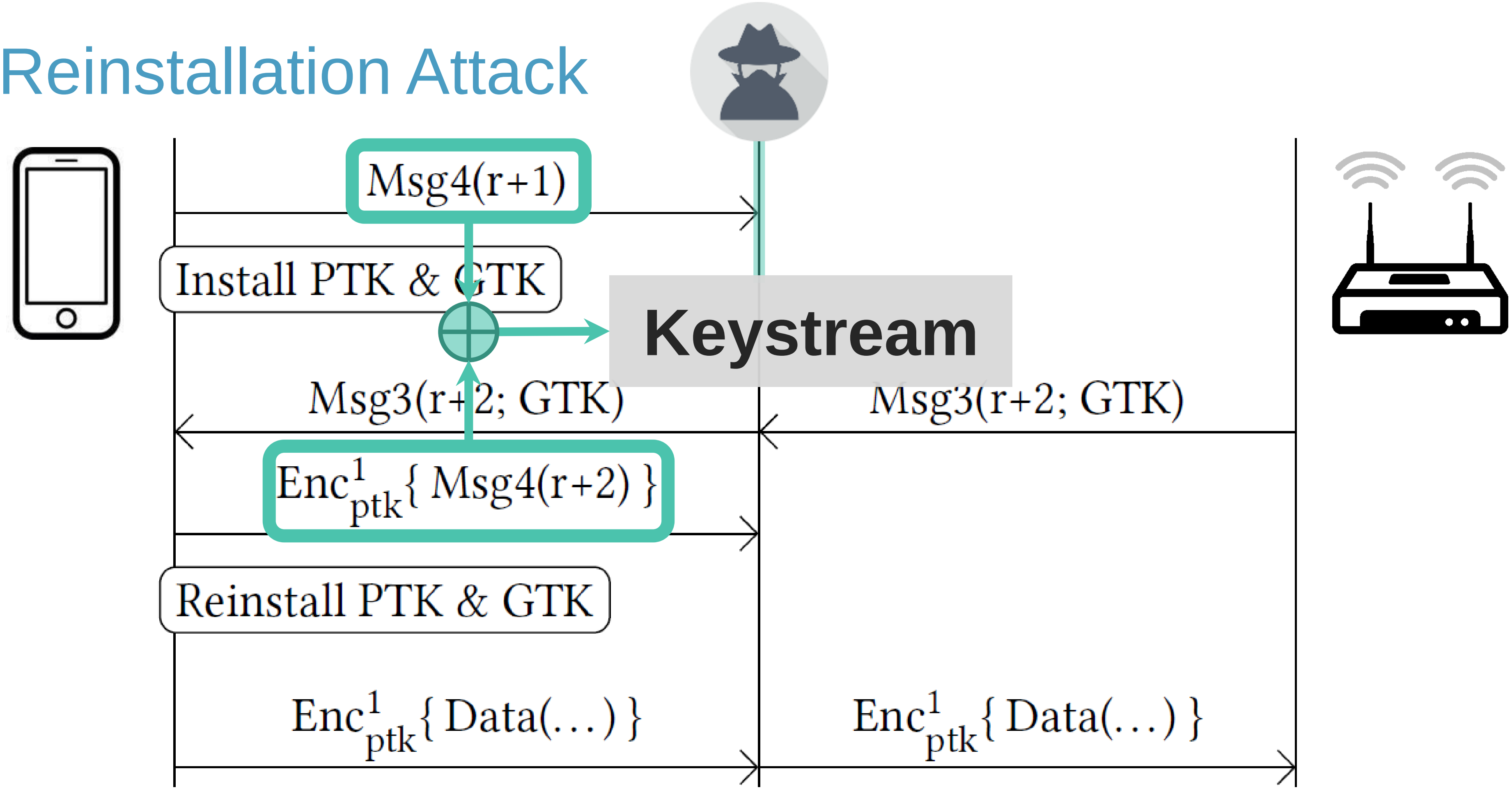
Nonce is reset

Reinstallation Attack


Msg4(r+1)
Install PTK & GTK
Msg3(r+2; GTK)
Msg3(r+2; GTK)
$\text{Enc}^1_{\text{ptk}}\{\text{ Msg4(r+2) }\}$
Reinstall PTK & GTK
$\text{Enc}^1_{\text{ptk}}\{\text{ Data(…) }\}$
$\text{Enc}^1_{\text{ptk}}\{\text{ Data(…) }\}$

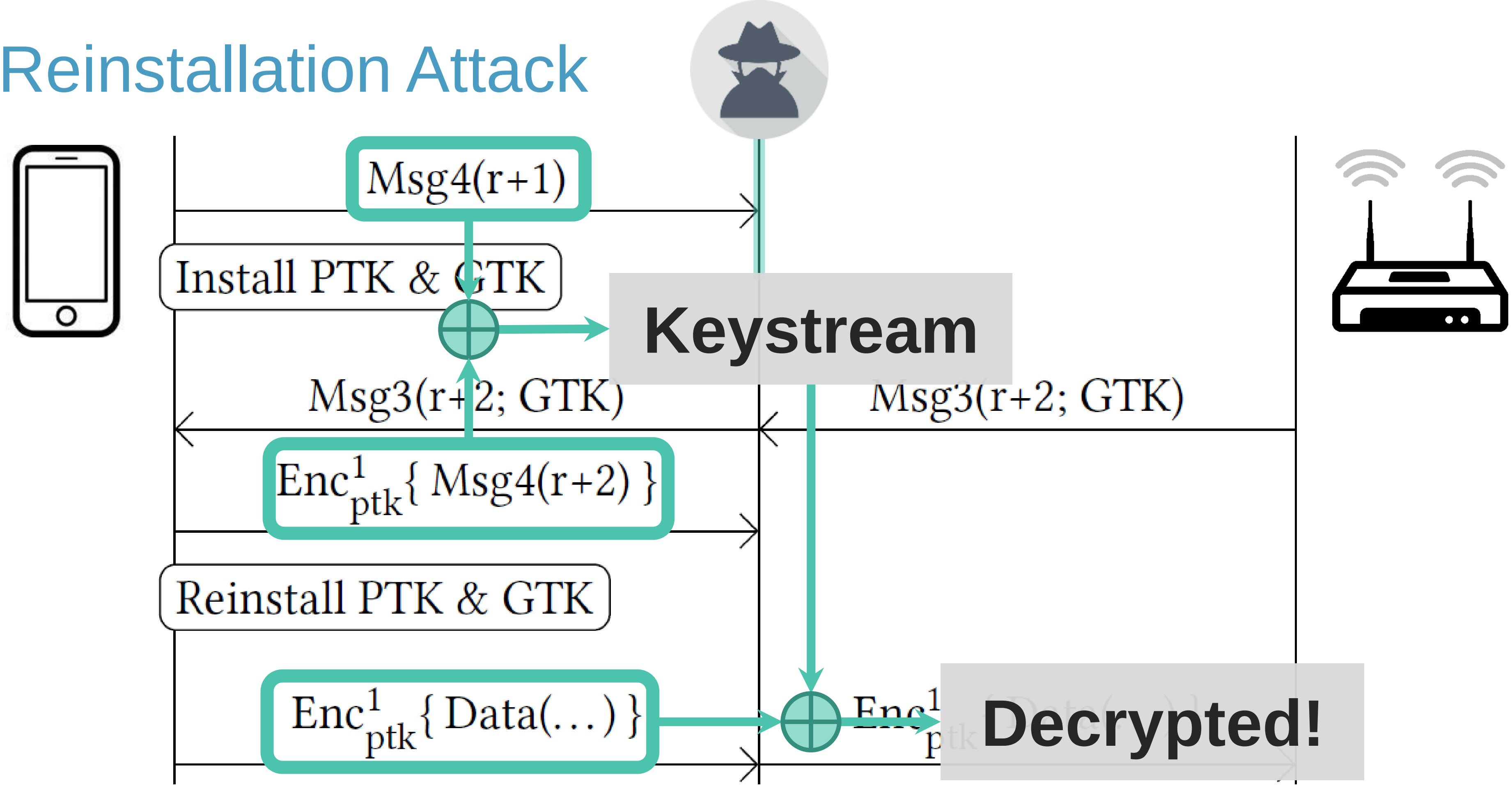
Same nonce is used!

Reinstallation Attack

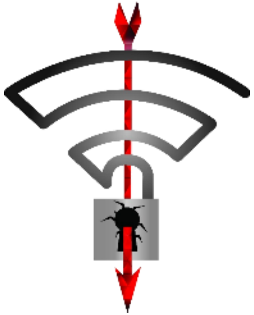


Msg4(r+1)
Install PTK & GTK
Keystream
Msg3(r+2; GTK)
Msg3(r+2; GTK)
$\text{Enc}^1_{\text{ptk}}\{\text{ Msg4(r+2) }\}$
Reinstall PTK & GTK
$\text{Enc}^1_{\text{ptk}}\{\text{ Data(...) }\}$
$\text{Enc}^1_{\text{ptk}}\{\text{ Data(...) }\}$

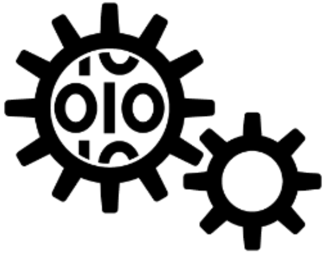
Reinstallation Attack


Msg4(r+1)
Install PTK & GTK
Keystream
Msg3(r+2; GTK)
Msg3(r+2; GTK)
$\text{Enc}^1_{\text{ptk}}\{\text{Msg4(r+2)}\}$
Reinstall PTK & GTK
$\text{Enc}^1_{\text{ptk}}\{\text{Data(...)}\}$
$\text{Enc}^1_{\text{ptk}}\{\text{Data(...)}\}$
Decrypted!

Overview



Key reinstalls in 4-way handshake



New KRACKs

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[2,3]
- **Forge/inject** frames sent by the device under attack

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

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[6]

wpa_supplicant 2.4+

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

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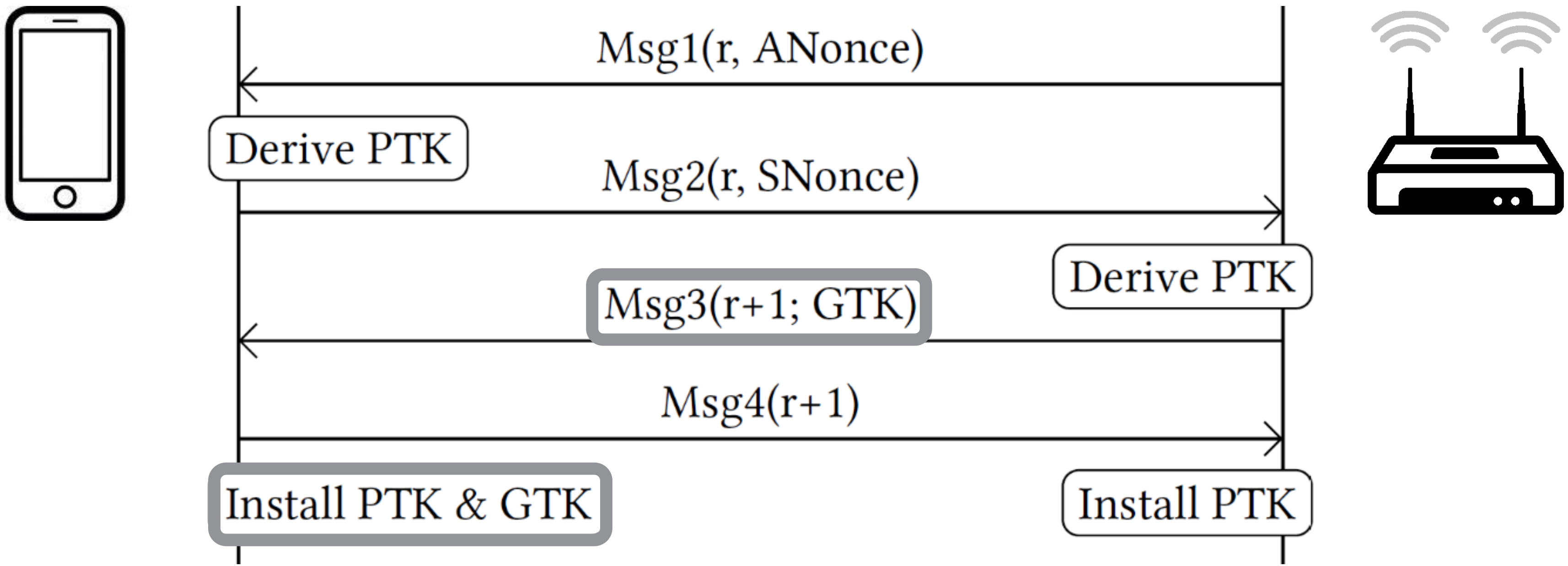
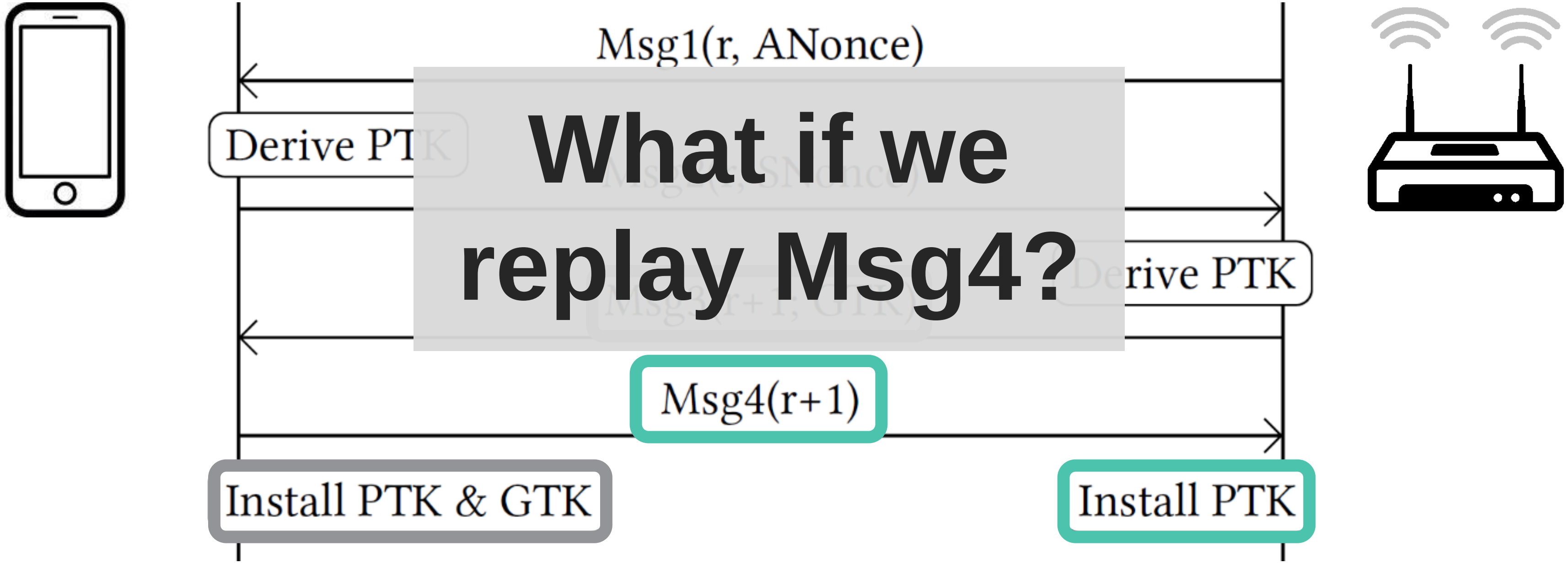
Idea 1: replay other handshake messages?



Idea 1: replay other handshake messages?



What if we replay Msg4?

MediaTek drivers vulnerable!

- Certain MediaTek Drivers accept replayed Msg4's
- Used in 100+ devices → **many vulnerable products**[9]

ASUS RT-AC51U

TP-Link RE370K

Idea 2: A/SNonce renewed during rekey?

AP can start new handshake to refresh the PTK

- Same messages exchanged as initial handshake
- New ANonce and SNonce must be used

macOS:

- Patched default KRACK attack
- But **reuses the SNonce during a rekey**
- SNonce reuse patched in macOS 10.13.3

Exploiting SNonce reuse

No problem if ANonce does change

- But Linux’s hostapd reused ANonce …
- Previous key was renegotiated and reinstalled
- Can **decrypt old captured traffic**!

Adversary can replay old handshake

- Tricky because messages must now be encrypted
- But feasible under specific circumstances

Idea 3: further audit patches

Several users reported:

“**Patched client still vulnerable**

to group key reinstallations”

- Either our patches are flawed …
- … or device always accepts replayed broadcast frames?!

No broadcast replay checks!

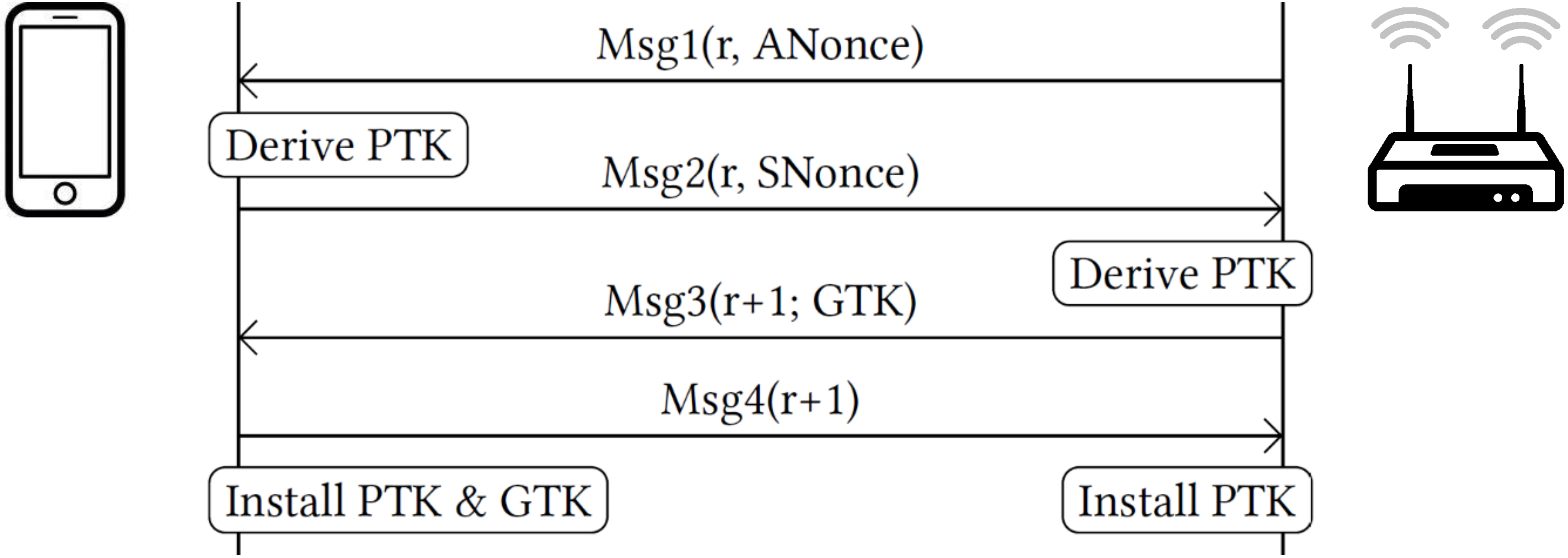
Netis WF-2120

AWUS036NH

Nexus 5X

- 8 of out 16 tested devices vulnerable
- Likely caused by **faulty hardware/firmware decryption**

Related issue: group key improperly installed



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Derive PTK

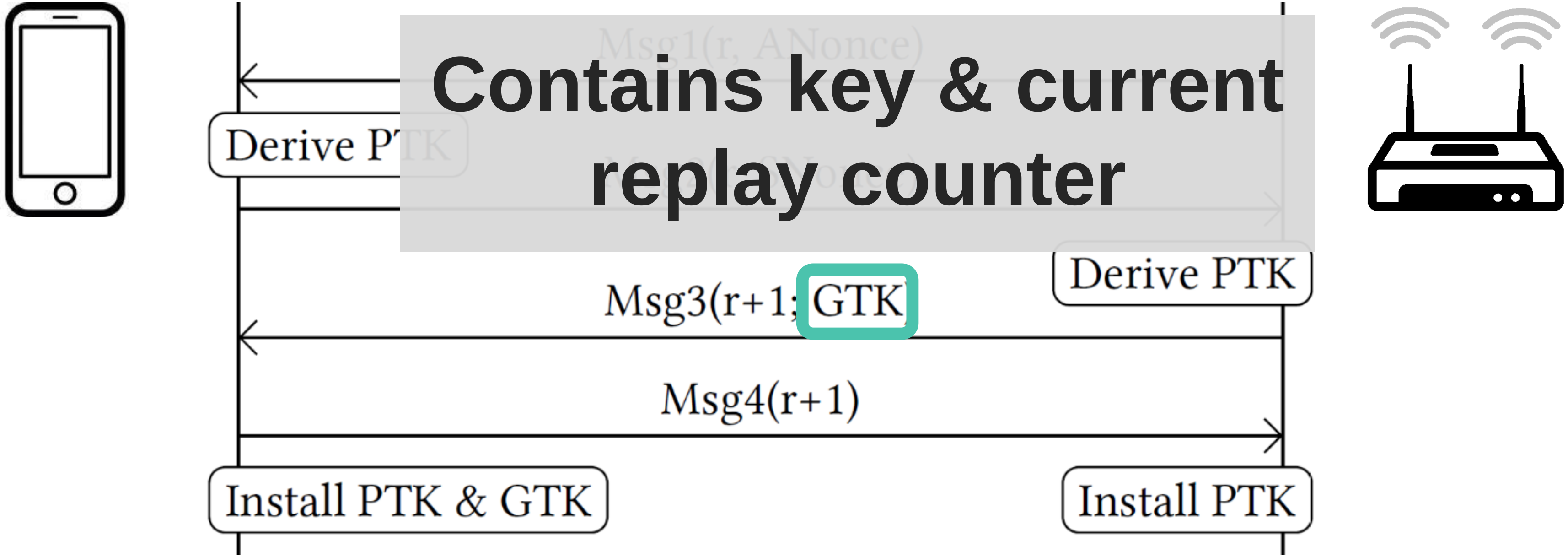
Msg3(r+1; GTK)

Msg4(r+1)

Install PTK & GTK

Install PTK

Related issue: group key improperly installed



Msg1(r, ANonce)

Derive PTK

Contains key & current replay counter

Derive PTK

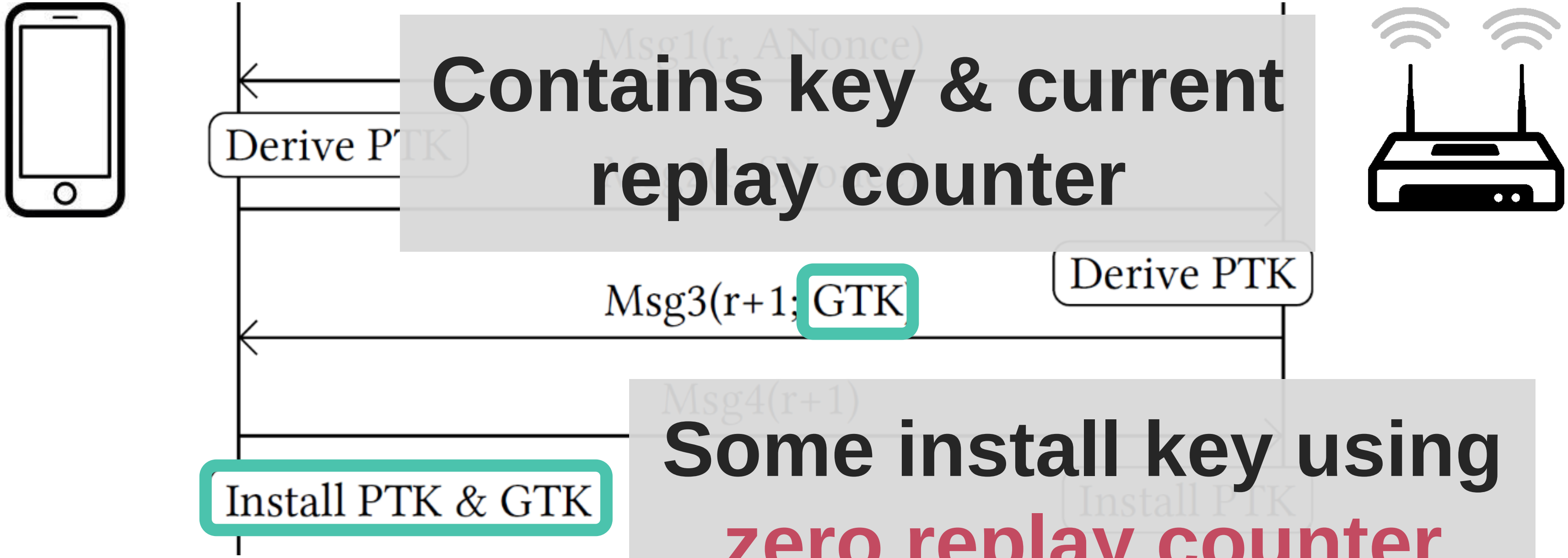
Msg3(r+1; GTK)

Msg4(r+1)

Install PTK & GTK

Install PTK

Related issue: group key improperly installed



Contains key & current replay counter

Some install key using zero replay counter

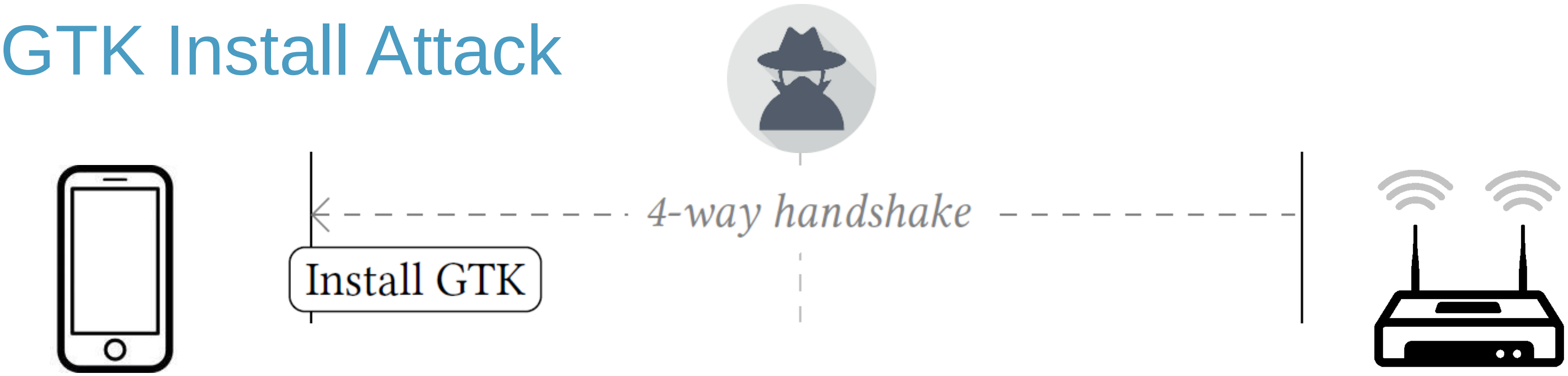
Related issue: group key improperly installed

Affected devices:

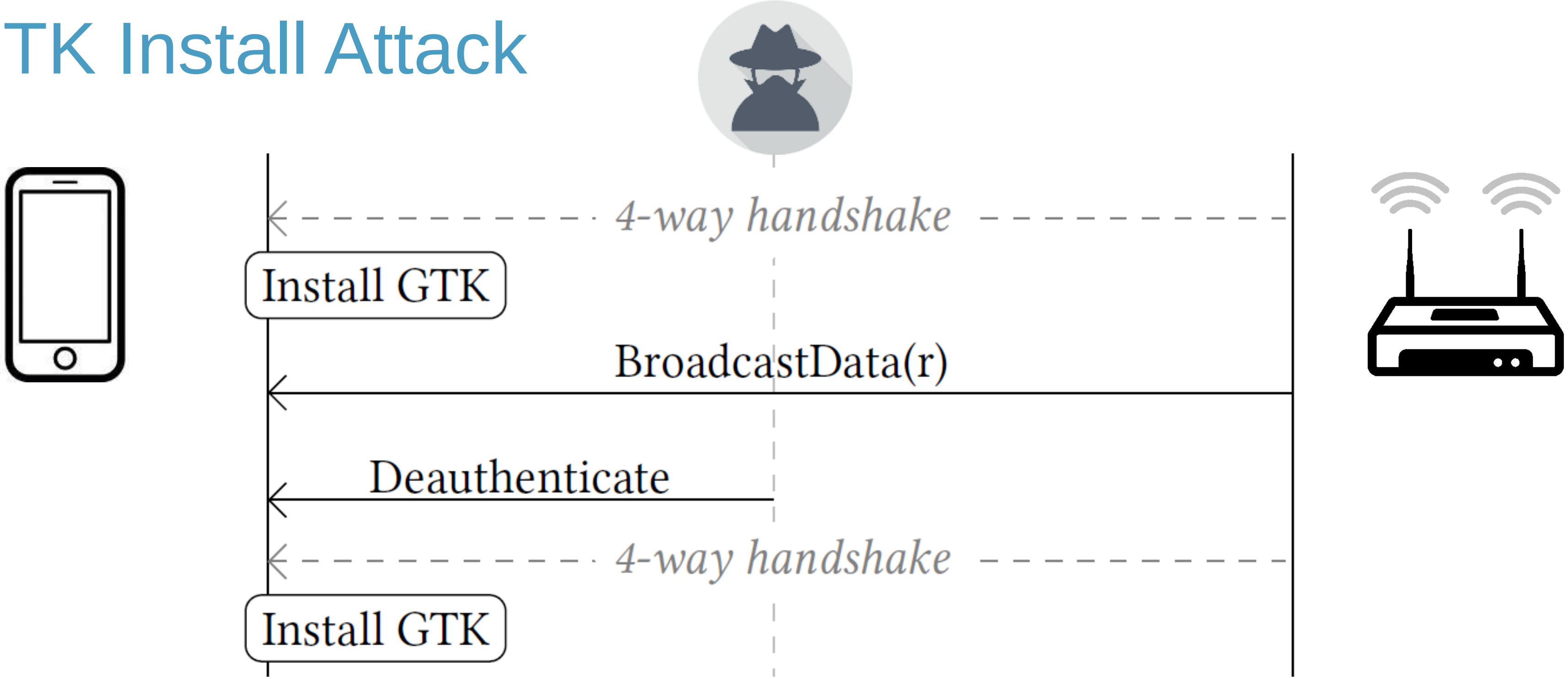
- Samsung S3 LTE
- $POPULAR_CLIENT

How to abuse this?

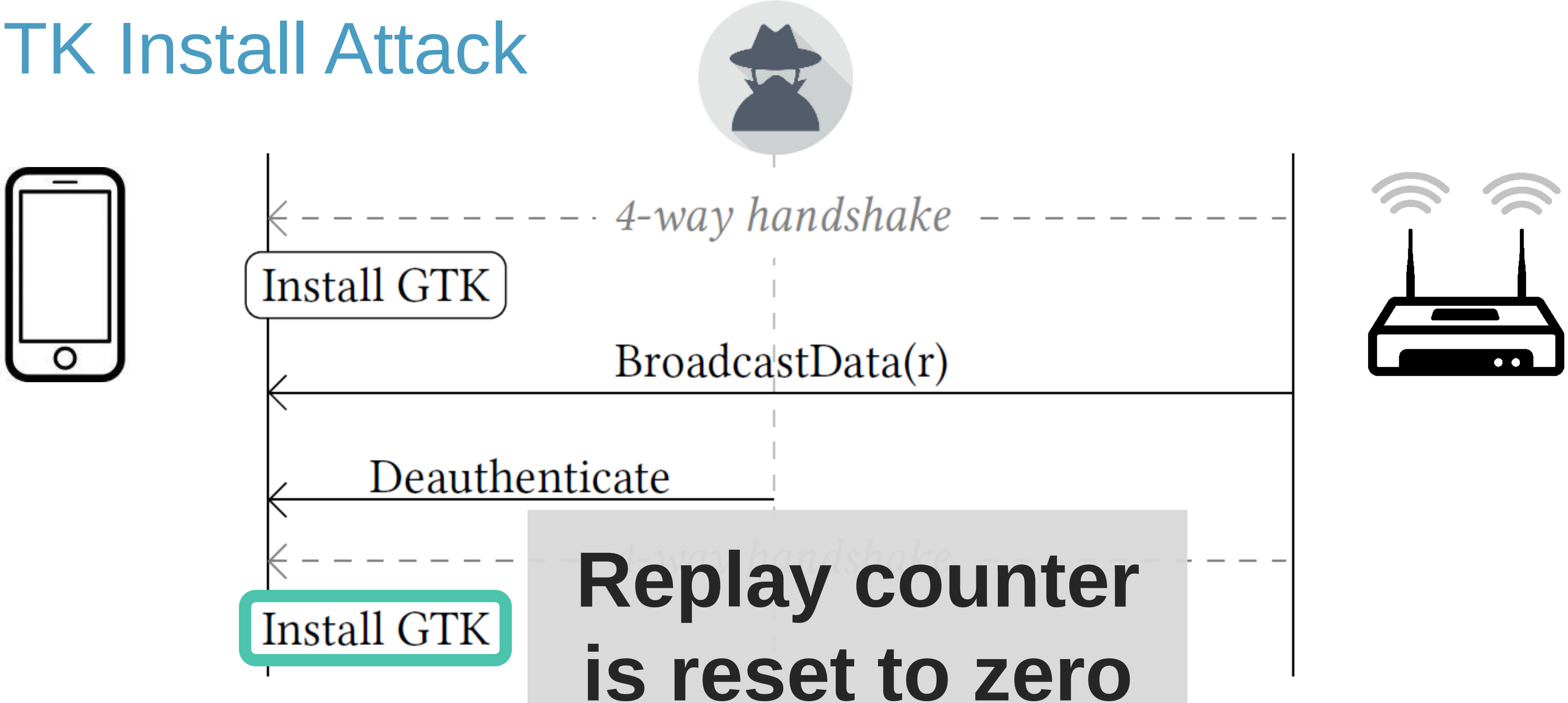
GTK Install Attack



GTK Install Attack

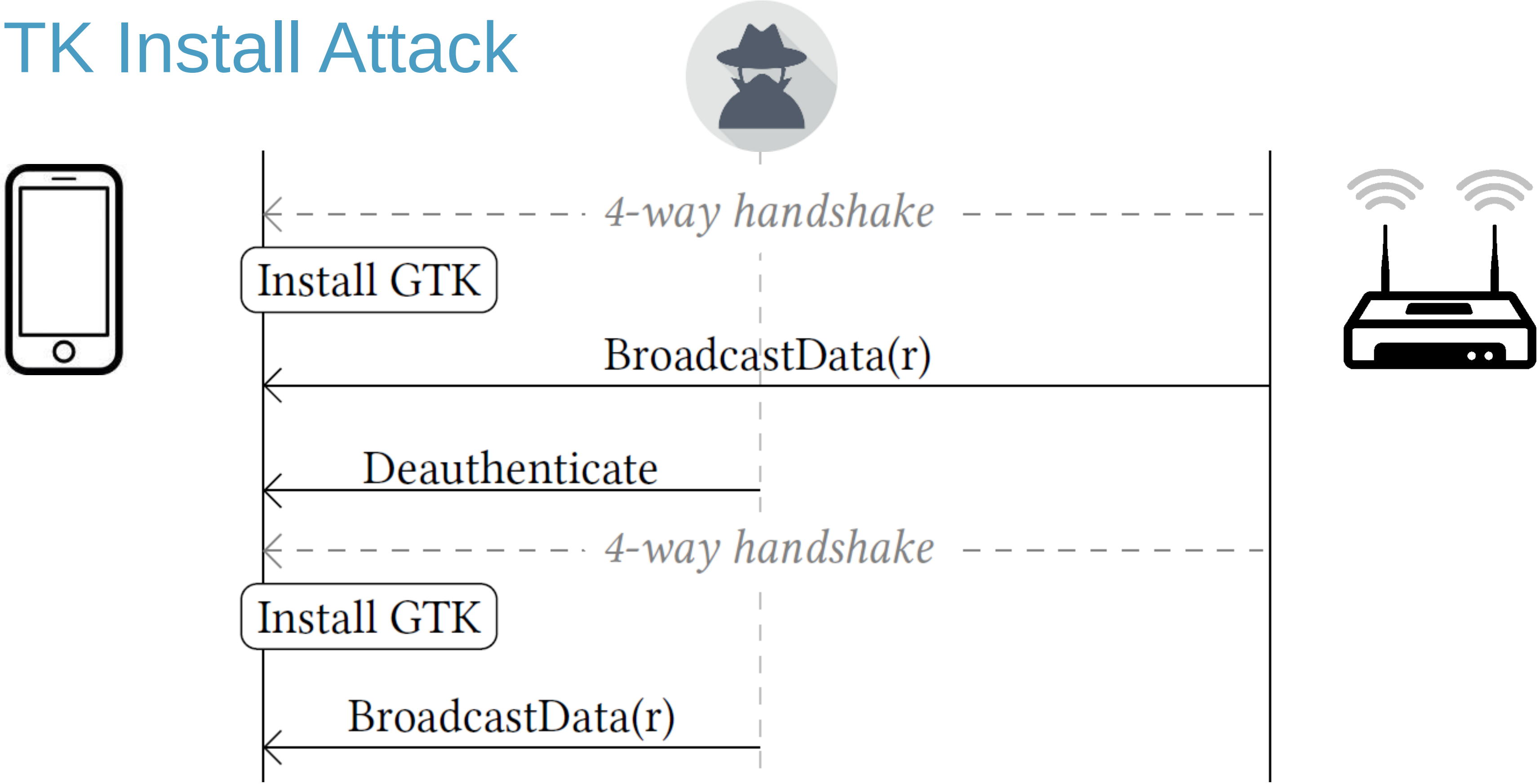


GTK Install Attack



Replay counter is reset to zero

GTK Install Attack



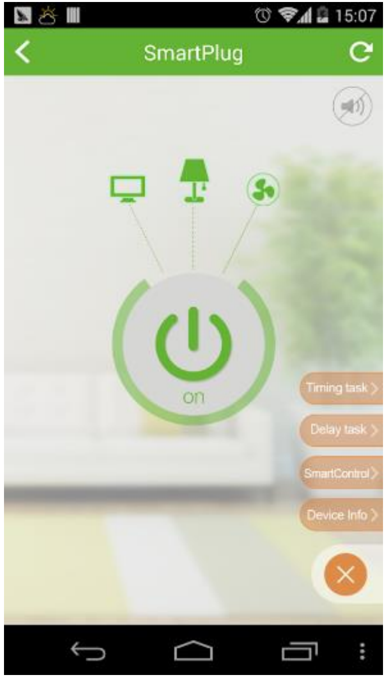
Idea 4: Impact of replaying broadcast frames?

Kankun smart power plug

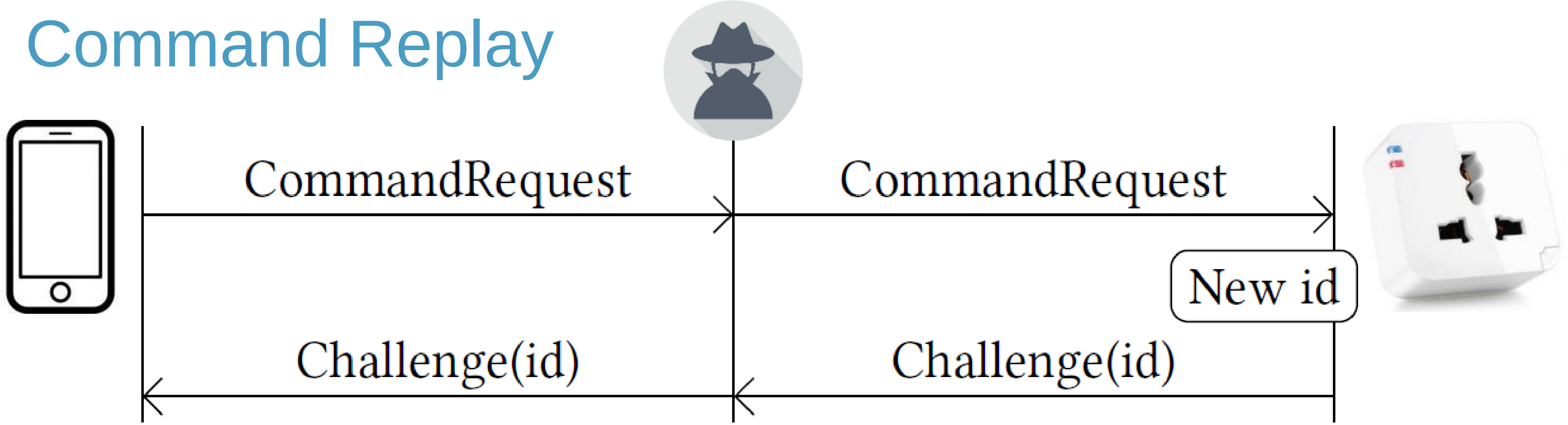
- Android app to control it

Commands are broadcast UDP

- Destination MAC in payload (?!)
- Challenge/response protocol



Command Replay



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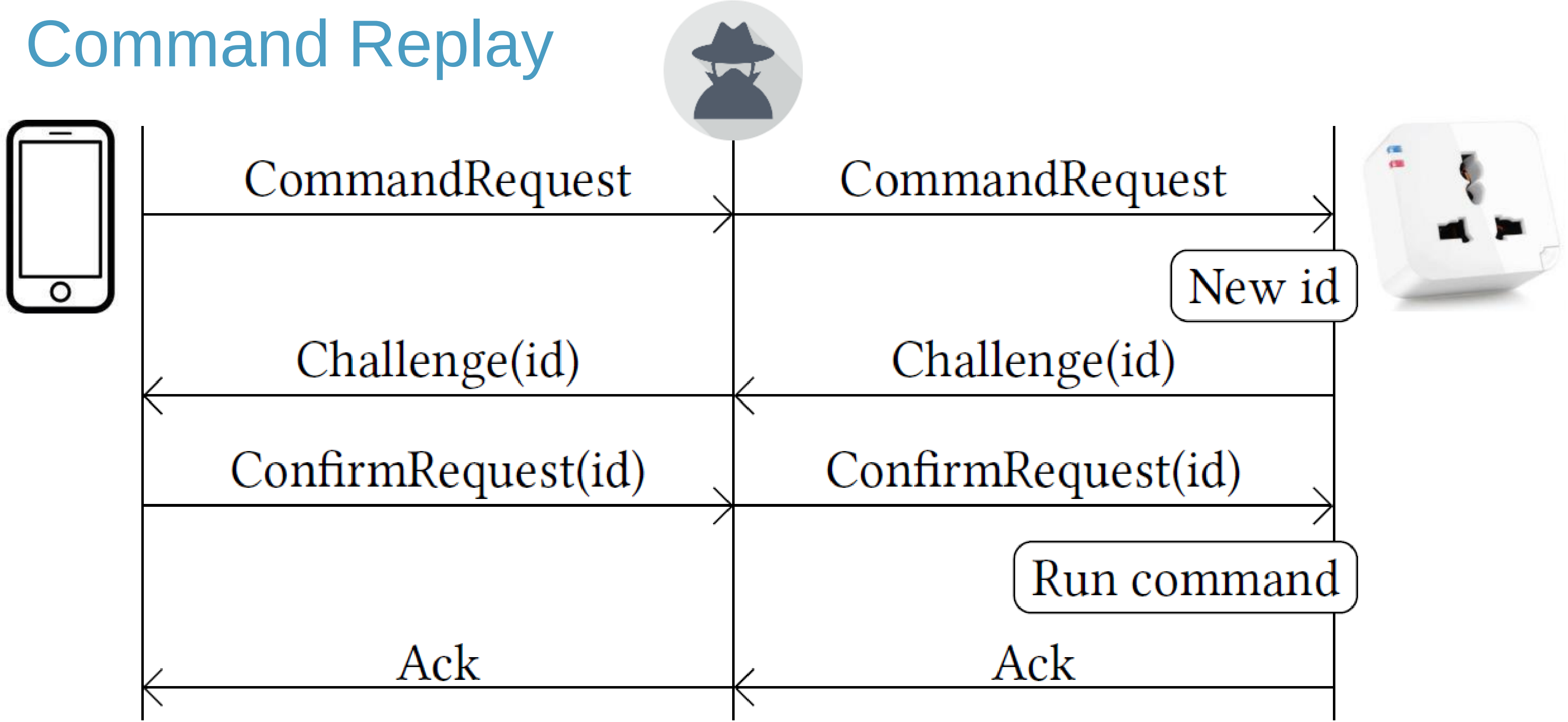
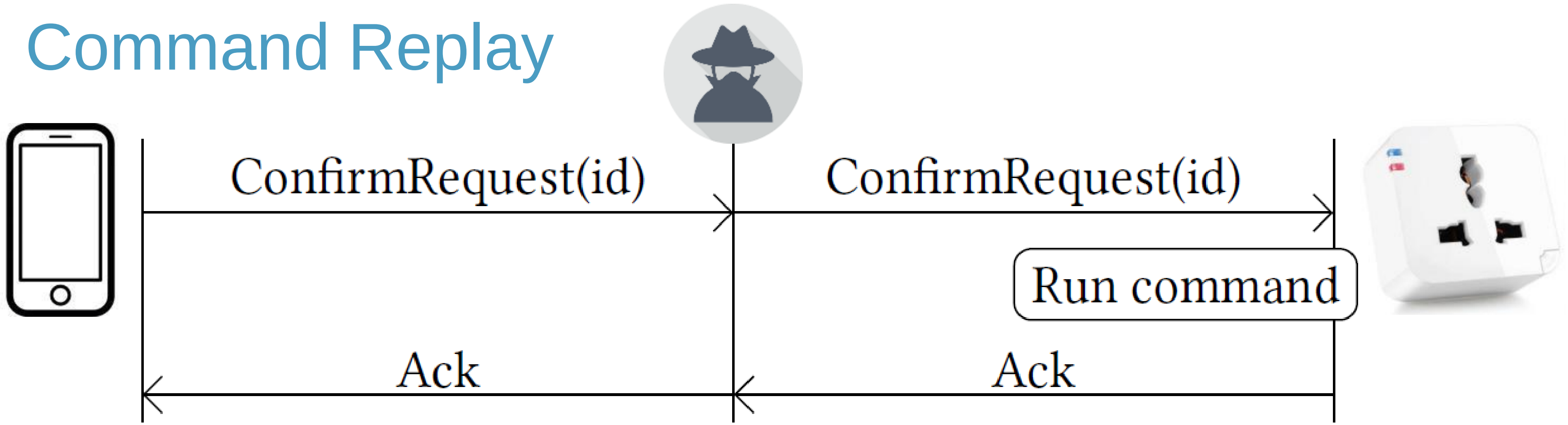
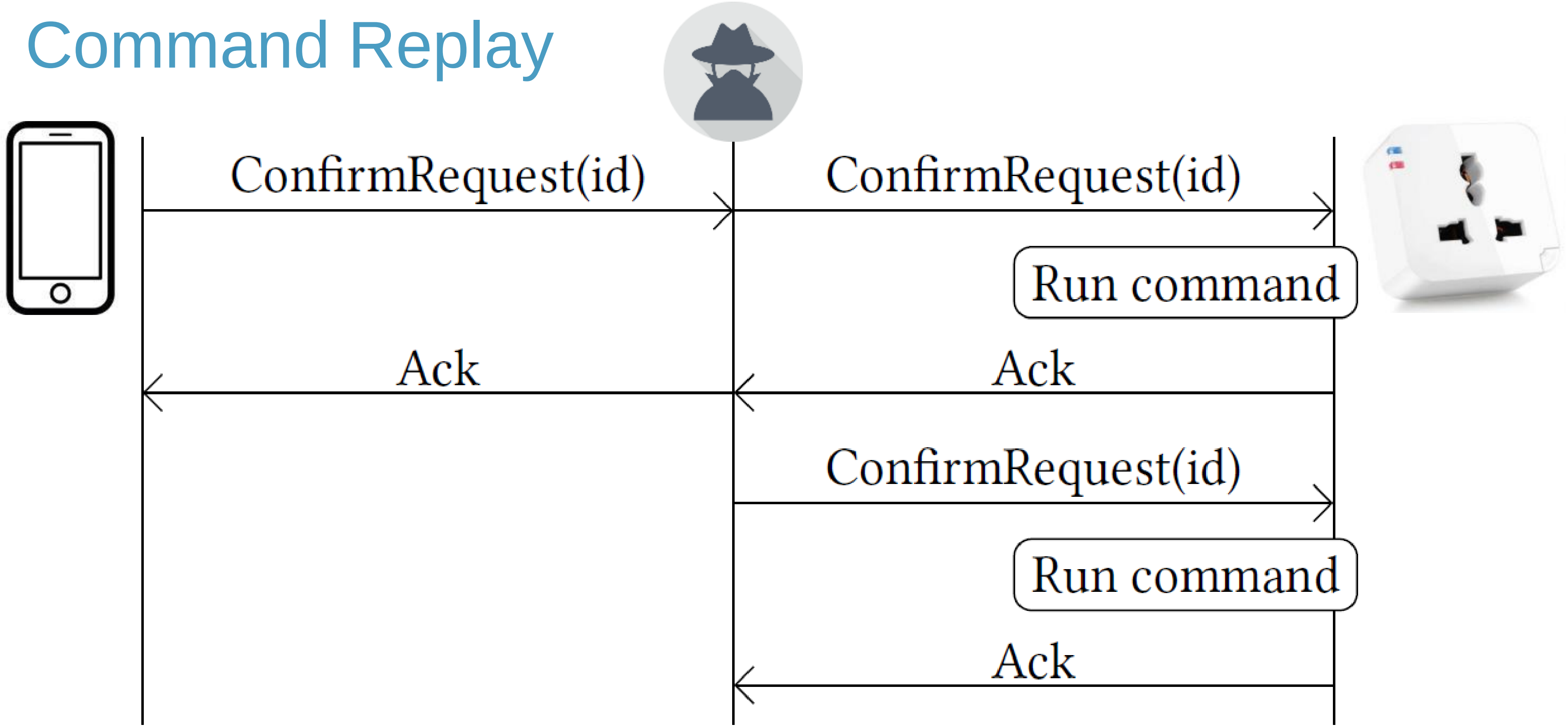


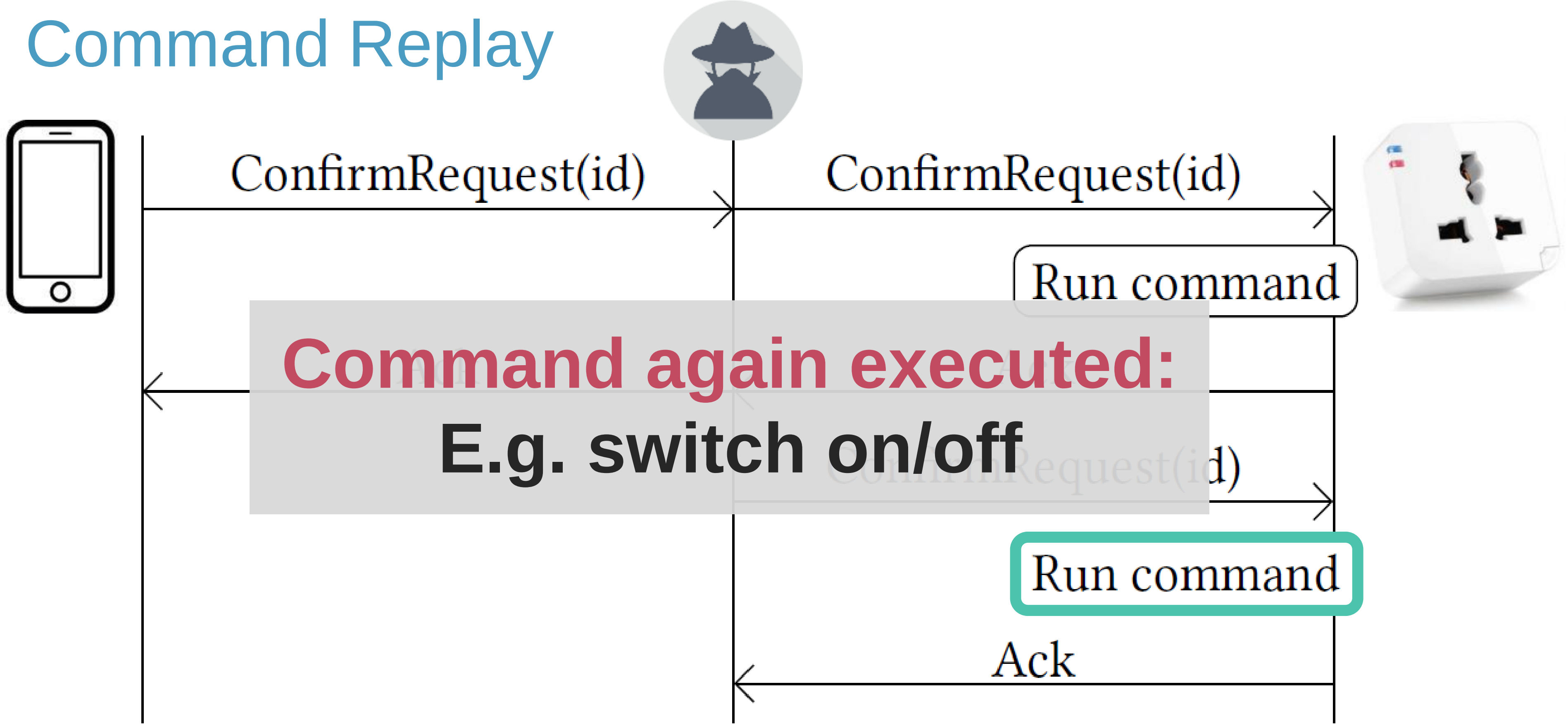
Command Replay



Command Replay



Command Replay



Command again executed:

E.g. switch on/off

Is your device affected?

github.com/vanhoefm/krackattacks-scripts

- Tests clients and APs
- Works on Kali Linux

Remember to:

- Disable hardware encryption
- **Use a proper Wi-Fi dongle!**

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Limitations of formal proofs

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

The combination was not proven secure!

Multi-party vulnerability coordination

Widespread issue! How to disclose?

Guidelines and Practices for Multi-Party Vulnerability Coordination (Draft)[7]

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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