Predicting, Decrypting, and Abusing WPA2/802.11 Group Keys

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Security of Wi-Fi group keys?

Protect broadcast and multicast Wi-Fi frames:

- All clients share a copy of the group key

Security of groups keys not yet properly investigated!

- In contrast with preshared & pairwise keys …

Analyze security of group key during its full lifetime!

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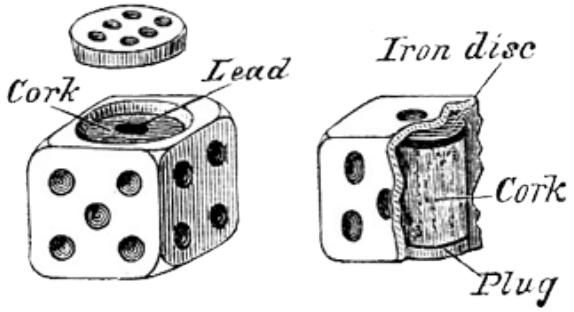
Contributions: Security of Group Keys



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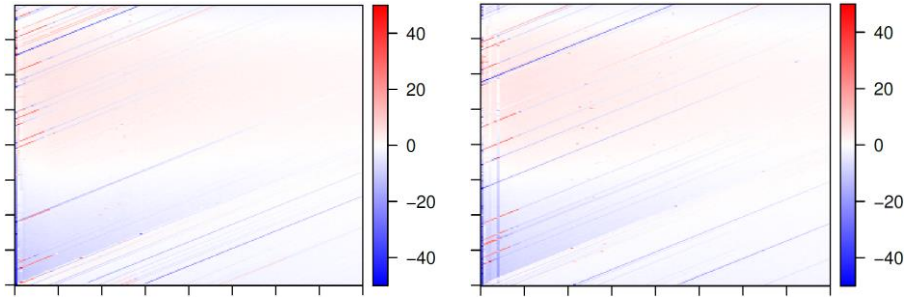
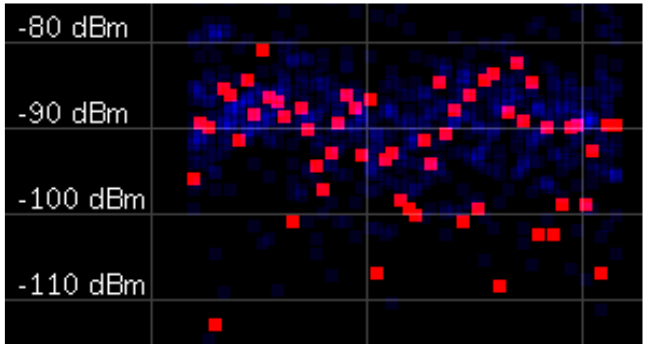


Force RC4 in handshake

Inject & decrypt all traffic



New Wi-Fi tailored RNG

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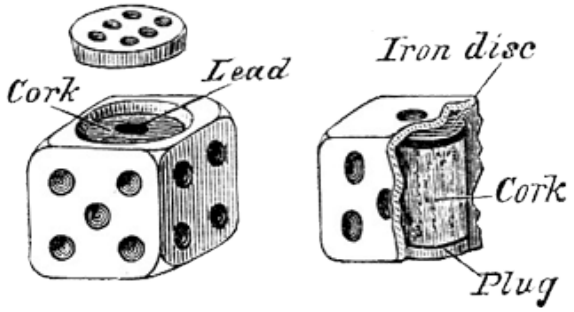

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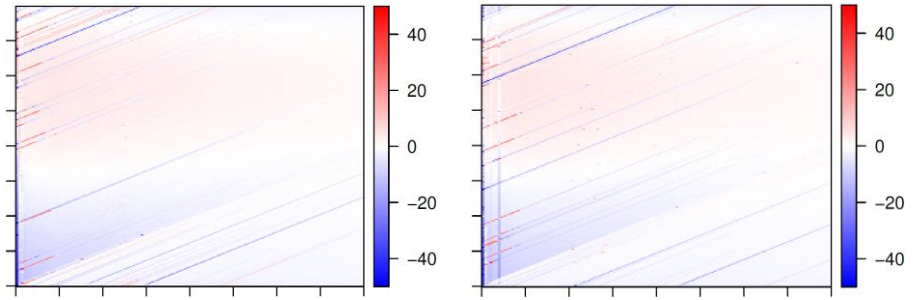

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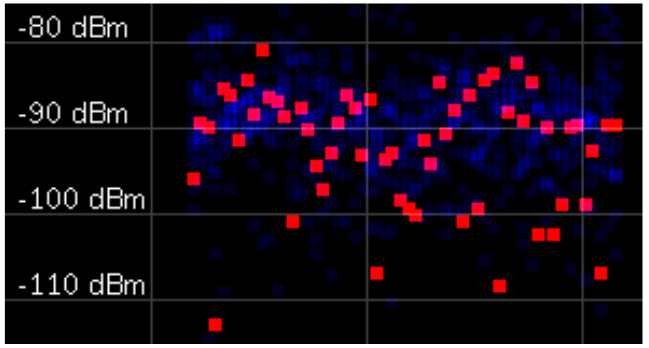

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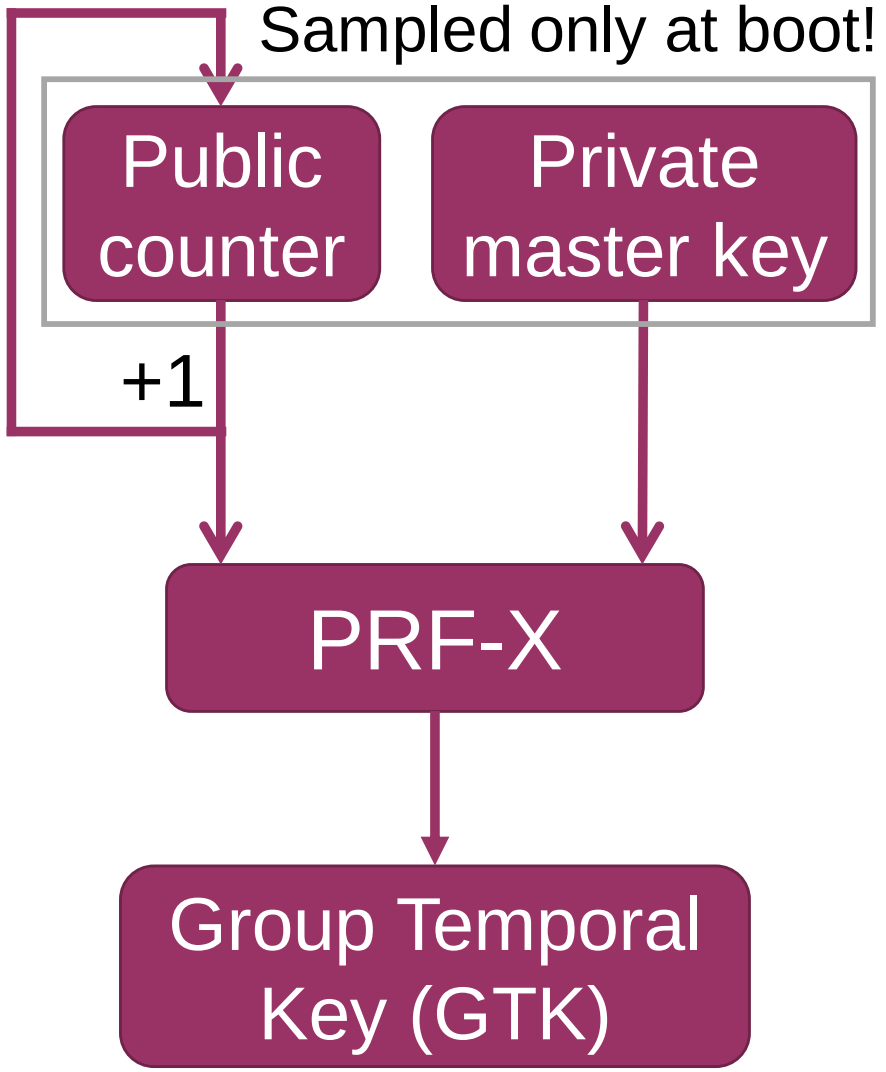
How are group keys generated?

Group key hierarchy:

- AP generates public counter and secret master key
- Derive group temporal keys (GTKs)

Entropy only introduced at boot

- If master key is leaked, all group keys become known



How are random numbers generated?

802.11 standard has example Random Number Generator

- §11.1.6a: "… can generate cryptographic-quality randomness"
- Annex M.5: "This solution is expository only"

Inconsistent description of RNG's security guarantees!

- How secure is the design of the 802.11 RNG?
- How many platforms implement this RNG?

802.11 RNG: Main Design

The 802.11 RNG is a stateless function returning 32 bytes

- Collects entropy on-demand
- Entropy extracted from frame arrival times and clock jitter

Deviates from traditional RNG design:

- No entropy pools being maintained
- Entropy only extracted from events when the RNG is being invoked

802.11 RNG: Entropy sources

Frame arrival times:

- Collected by repeatedly starting & aborting 4-way handshake
- Problem: AP is blacklisted after several handshake failures

Clock jitter and drift:

- Note: Router's current time is leaked in beacons
- Problem: No minimum time resolution → small clock jitter

Surely no one implemented this...?

Weakened 802.11 RNG

Depends on OS

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Weakened 802.11 RNG

Depends on OS

MediaTek RNG: Linux-based APs

Uses custom Linux drivers:

- Implements 802.11's RNG using only clock jitter
- Uses *jiffies* for current time: at best millisecond accuracy

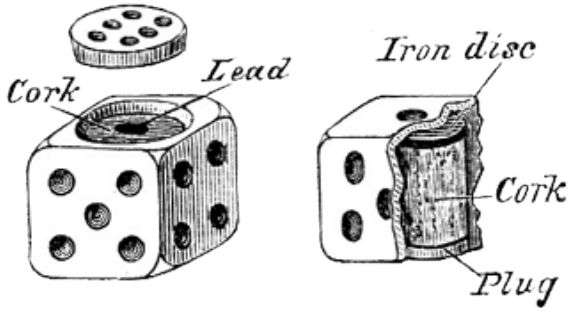
RT-AC51U

OpenCL

~3 mins

GMK & GTK

Contributions: Security of Group Keys



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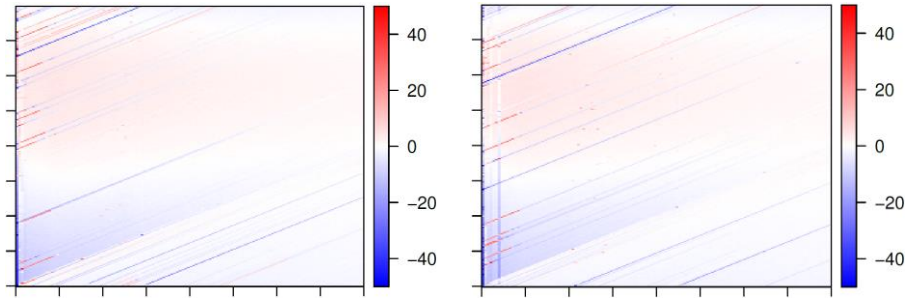

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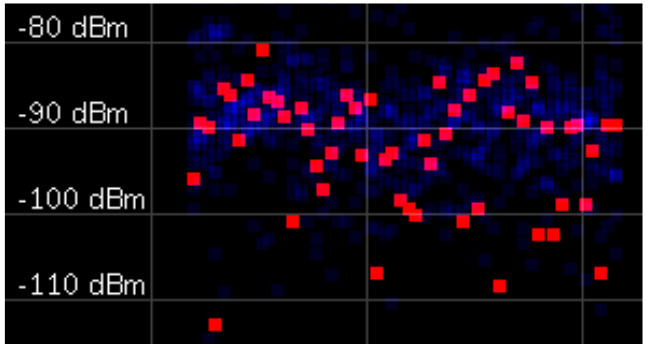

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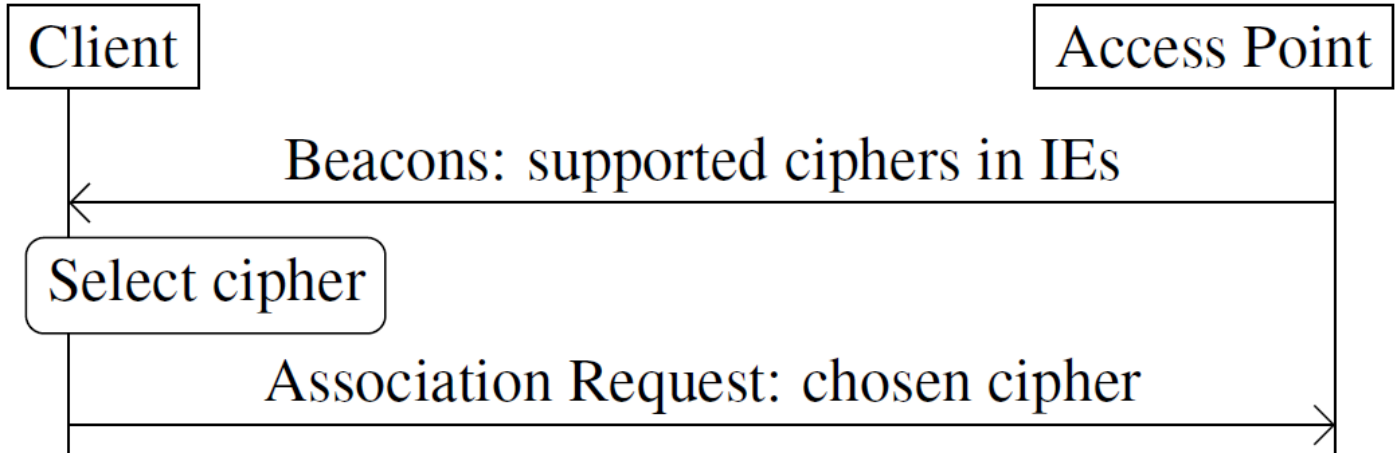
Simplified 4-way hanshake



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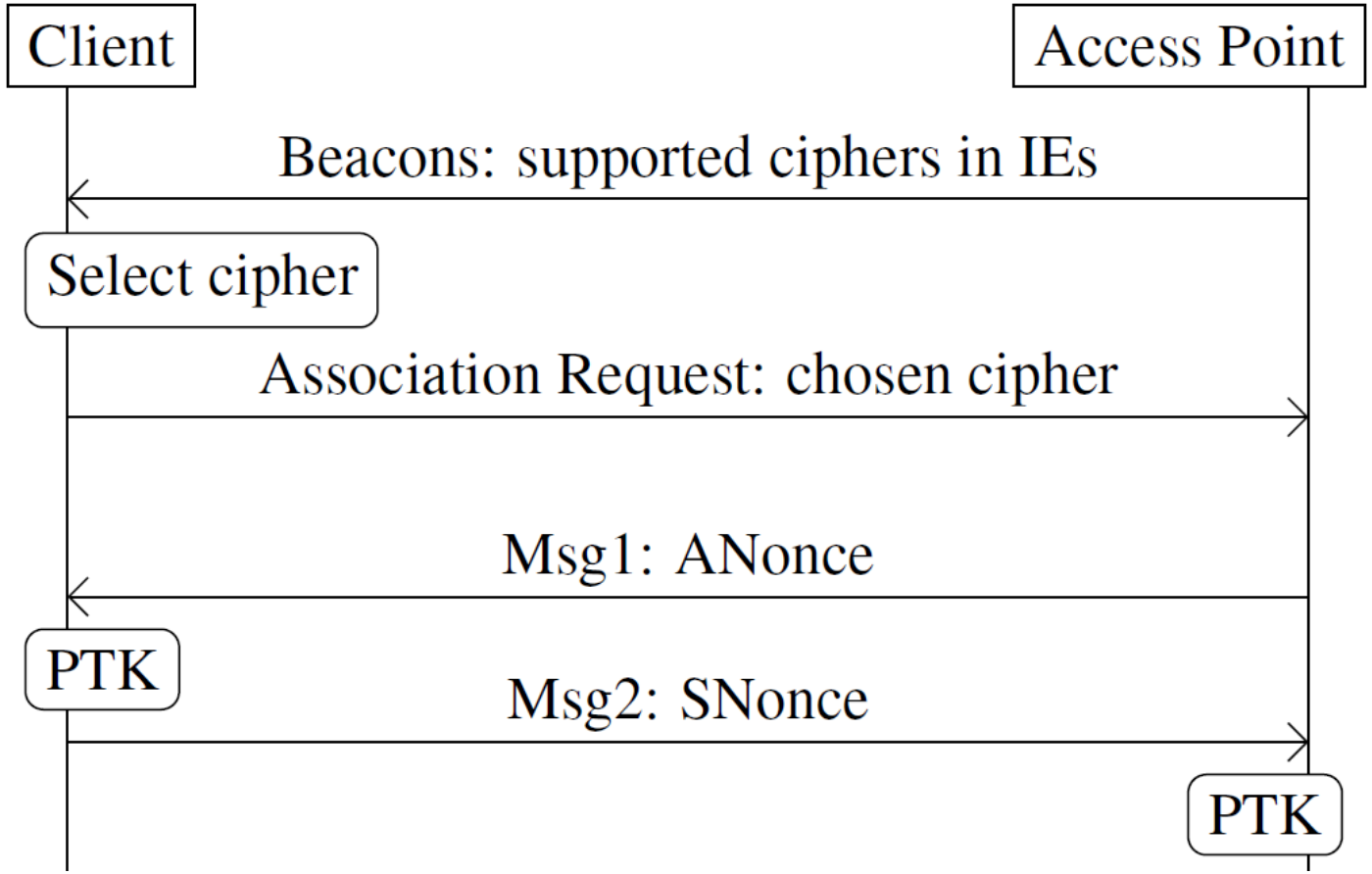

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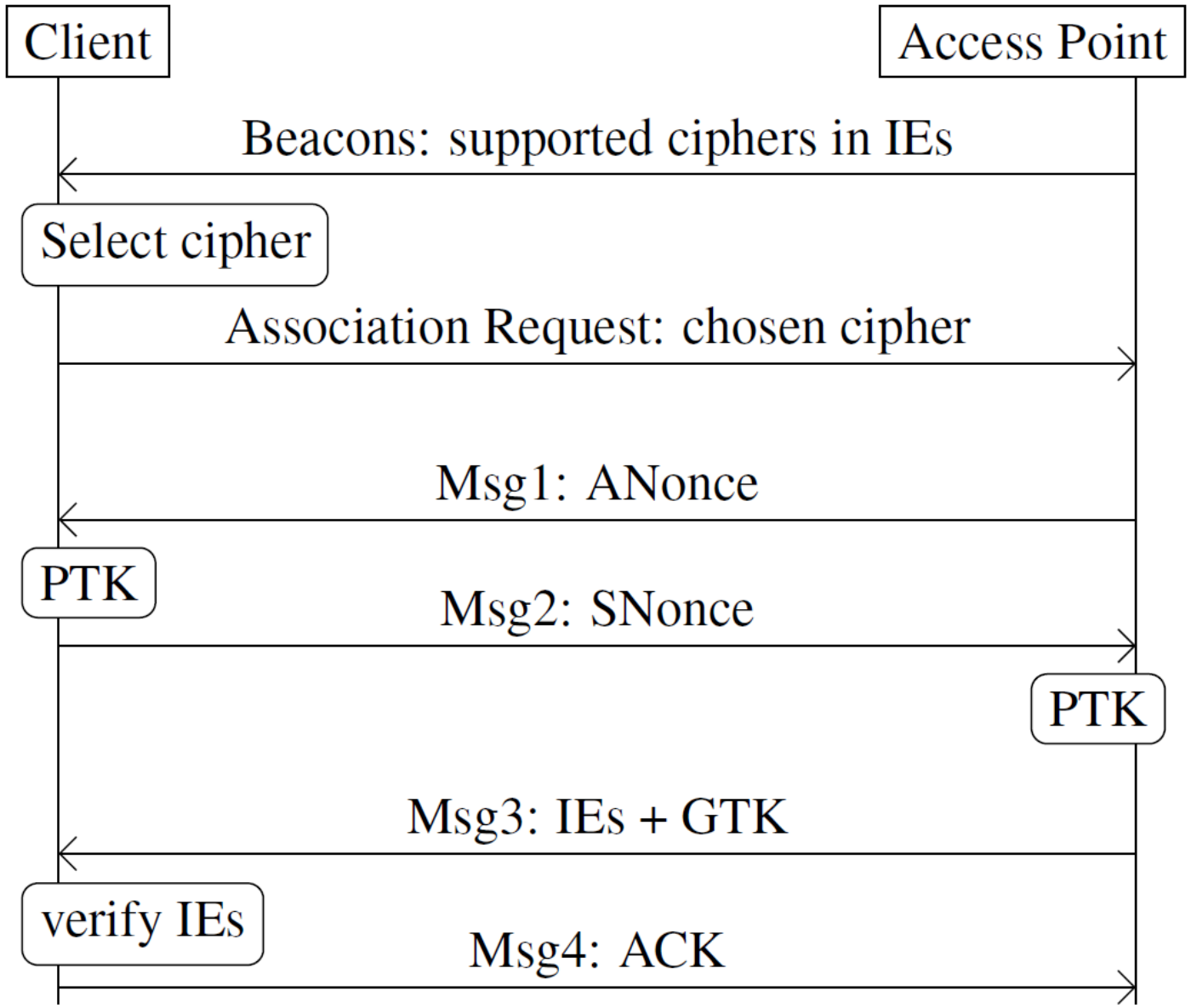

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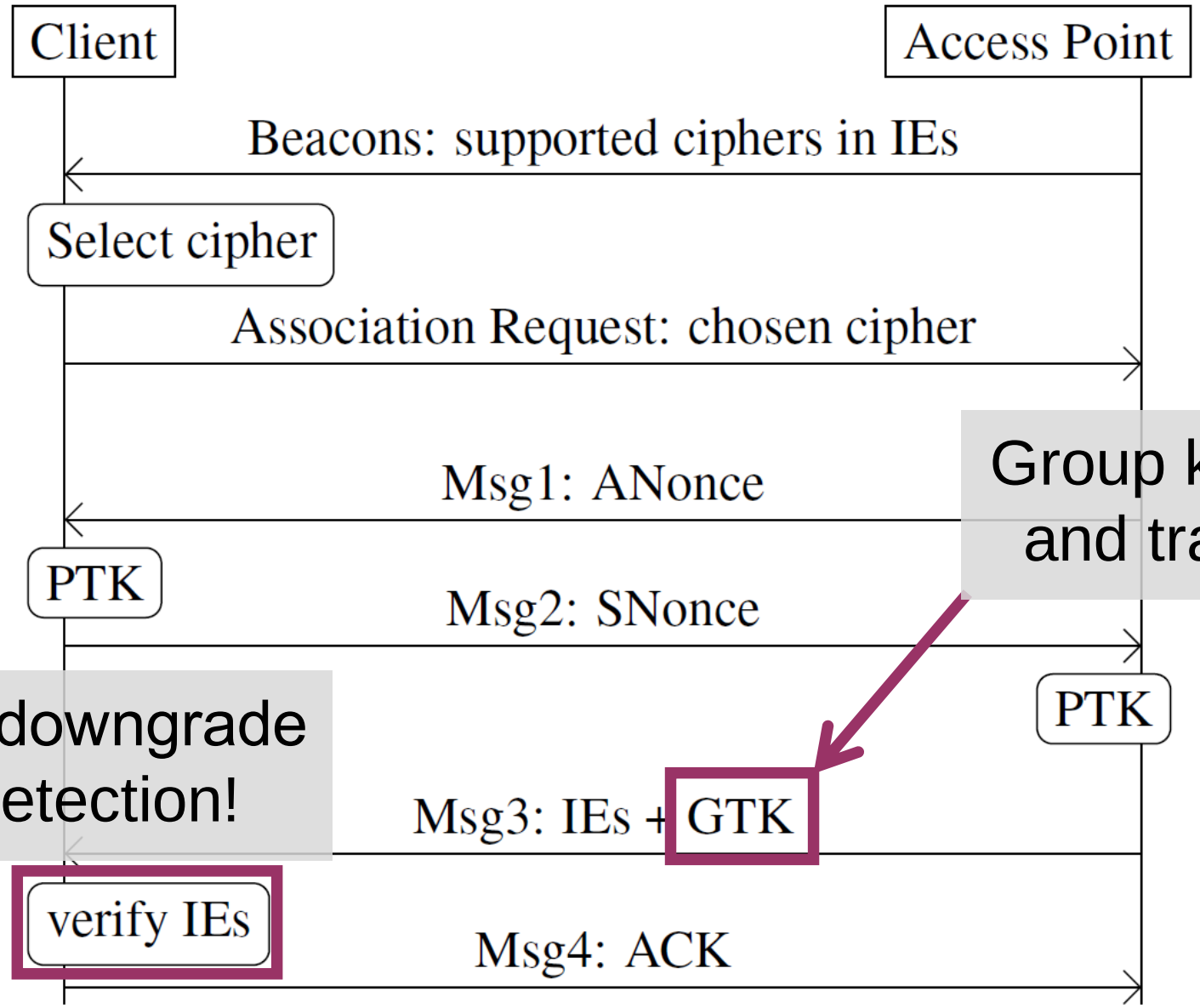

Group key encrypted and transmitted …

… before downgrade attack detection!

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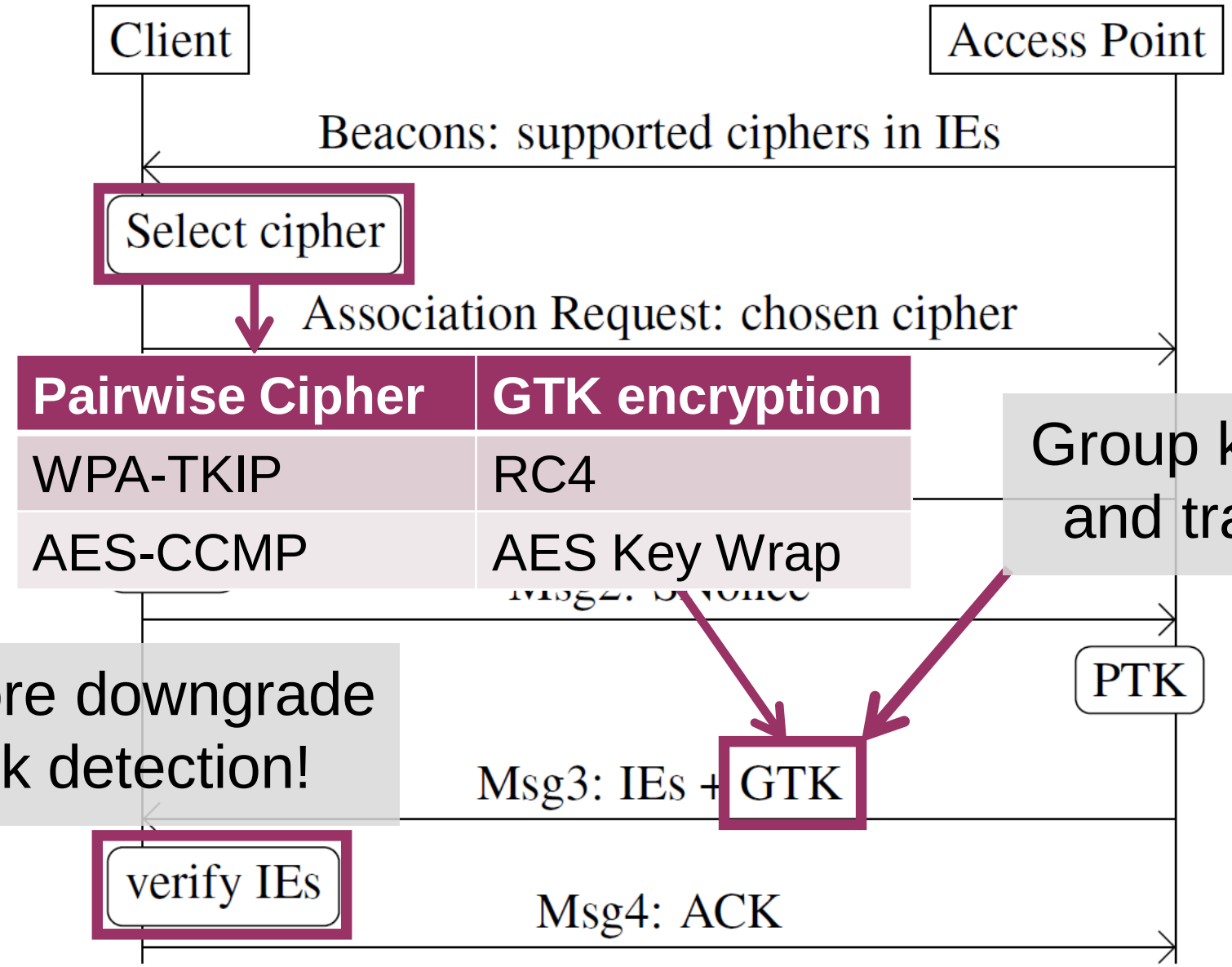

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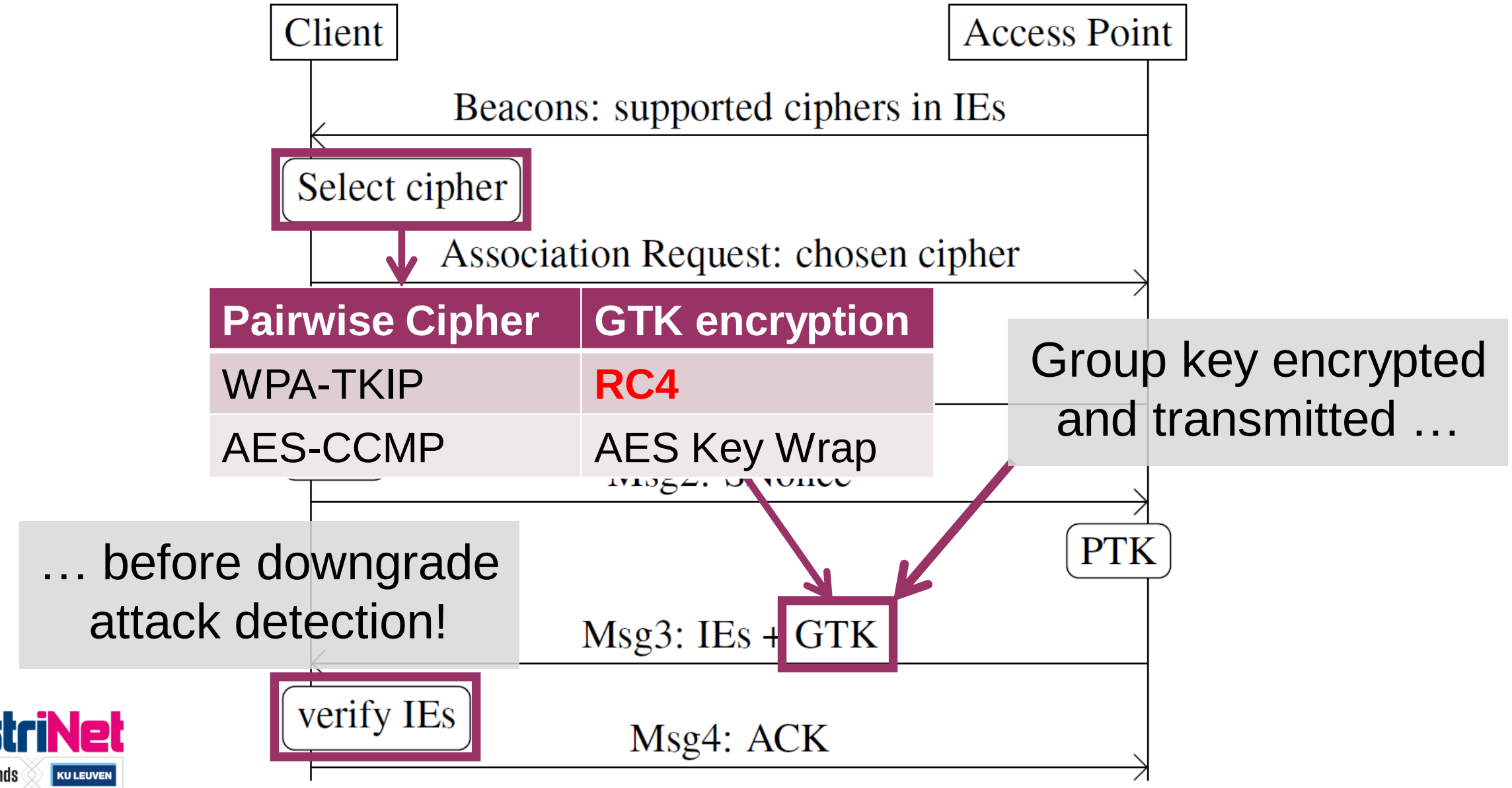
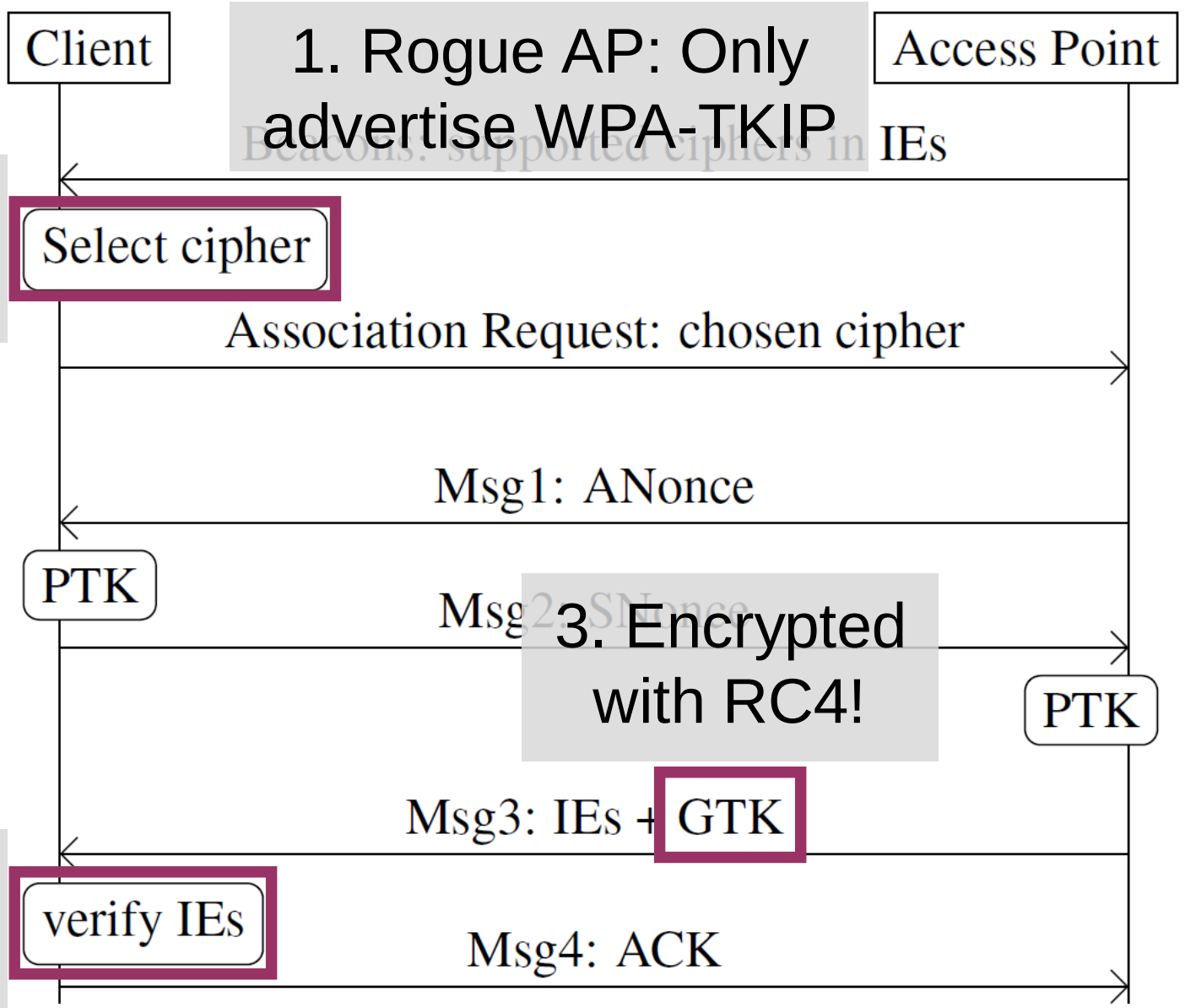


Downgrade attack



Attacking RC4 encryption of GTK

- RC4 Key: 16-byte IV ||16-byte secret key
- First 256 keystream bytes are dropped

Recover repeated encryptions of GTK:

- Requires $\sim 2^{31}$ handshakes: takes >50 years

Countermeasures:

- Disable WPA-TKIP & RC4
- Send GTK after handshake

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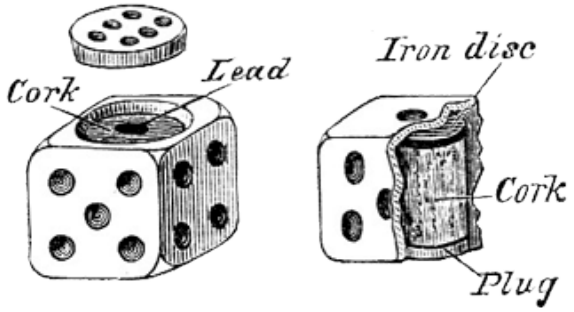
Contributions: Security of Group Keys



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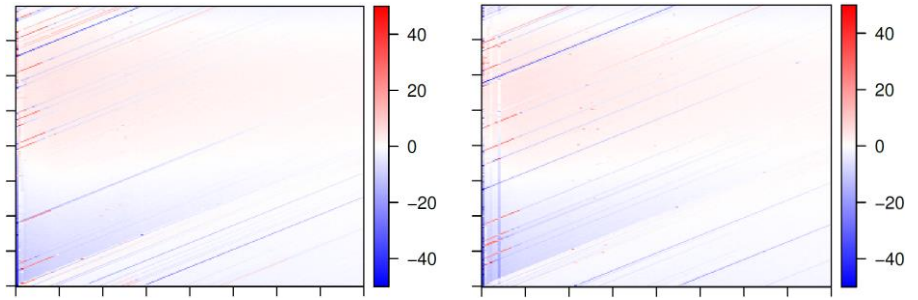

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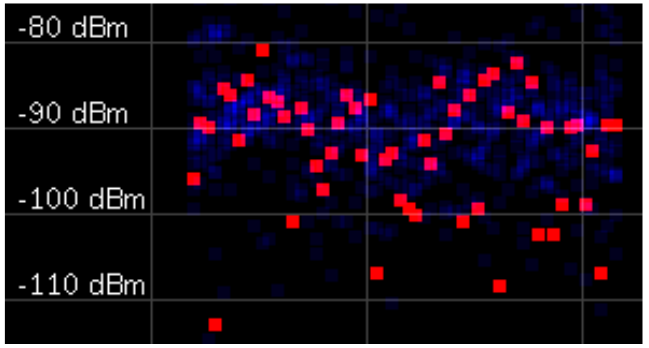

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Abusing the group key: Hole 196?

- Inject unicast IP packet in broadcast Wi-Fi frame
- Detected by “Hole 196” check

Hole 196 check done at network-layer…

… but an AP works at link-layer!

Forging unicast frames using group key

Abuse AP to bypass Hole 196 check:

Victim

Attacker

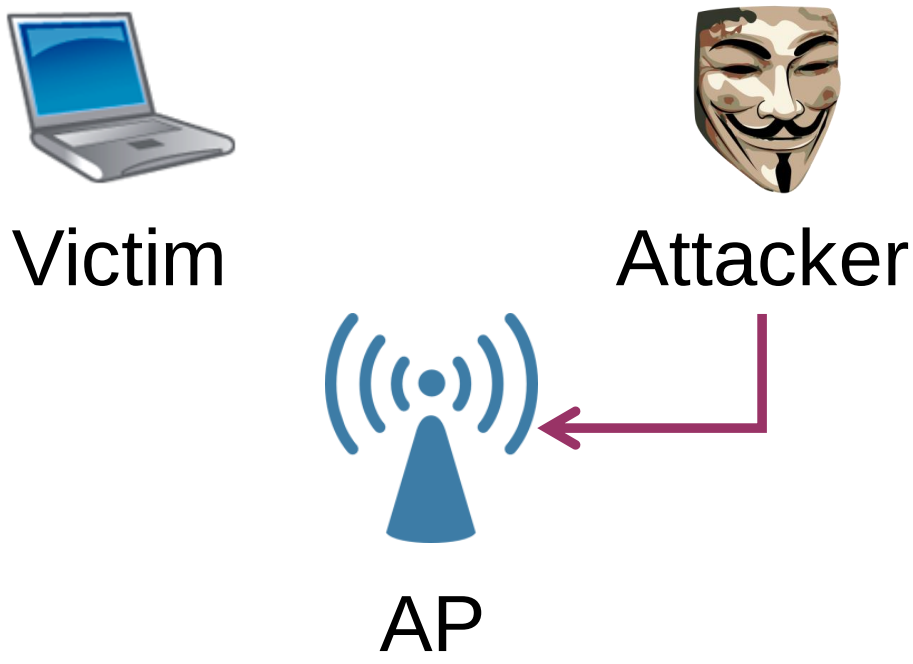
AP

Sender	Destination	Data

Forging unicast frames using group key

Abuse AP to bypass Hole 196 check:

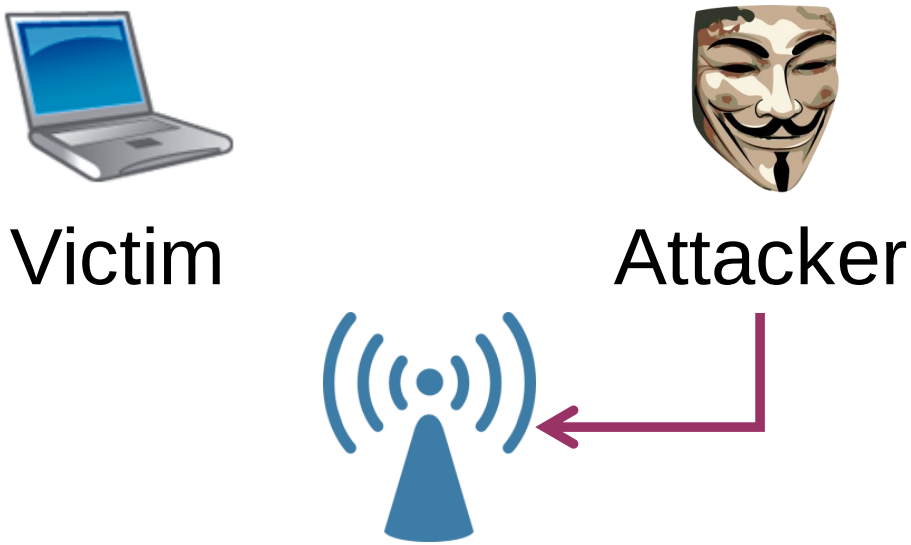
1. Inject as group frame to AP



Forging unicast frames using group key

Abuse AP to bypass Hole 196 check:

1. Inject as group frame to AP
2. AP processes and routes frame



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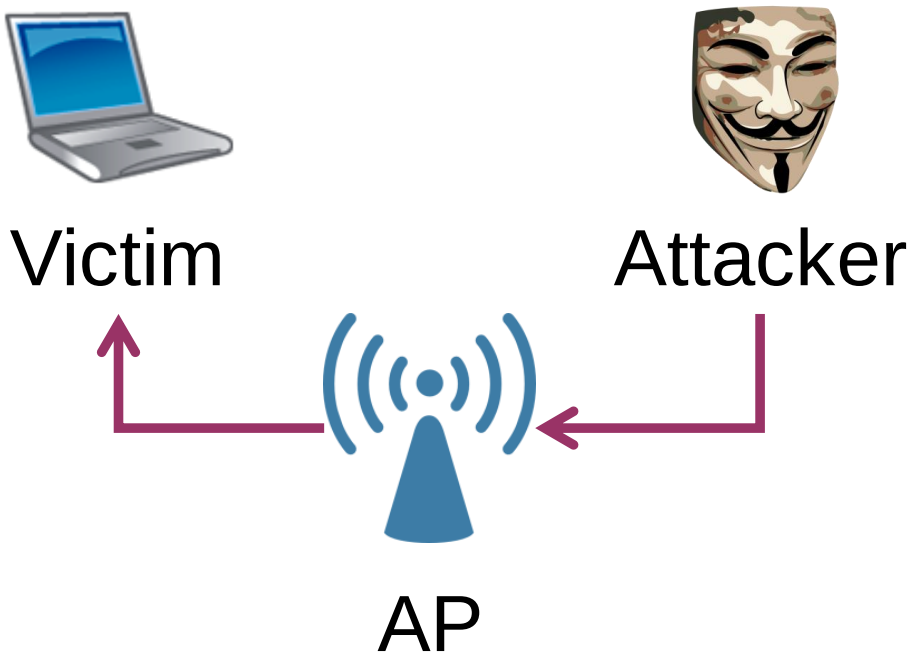

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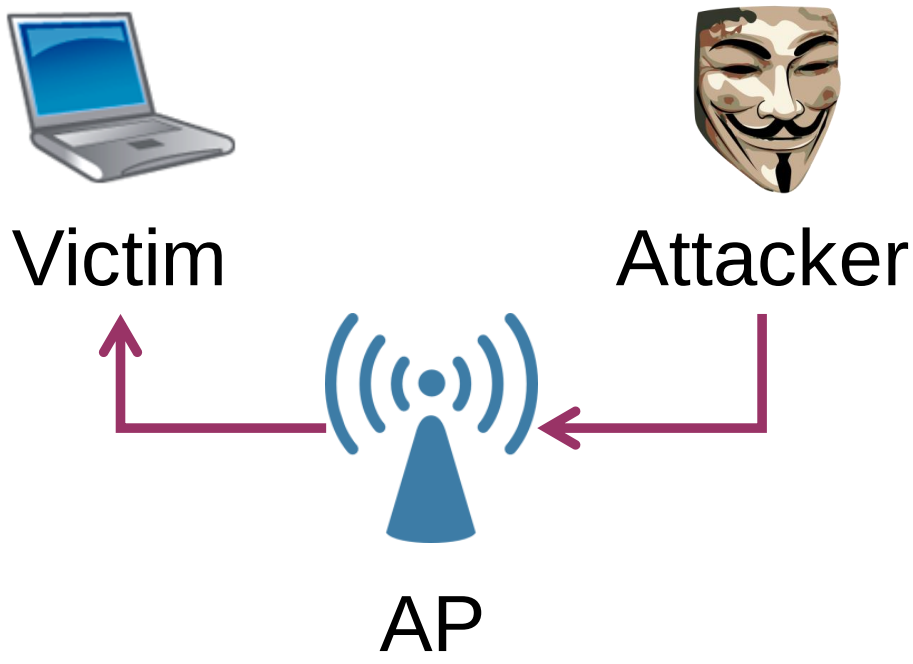

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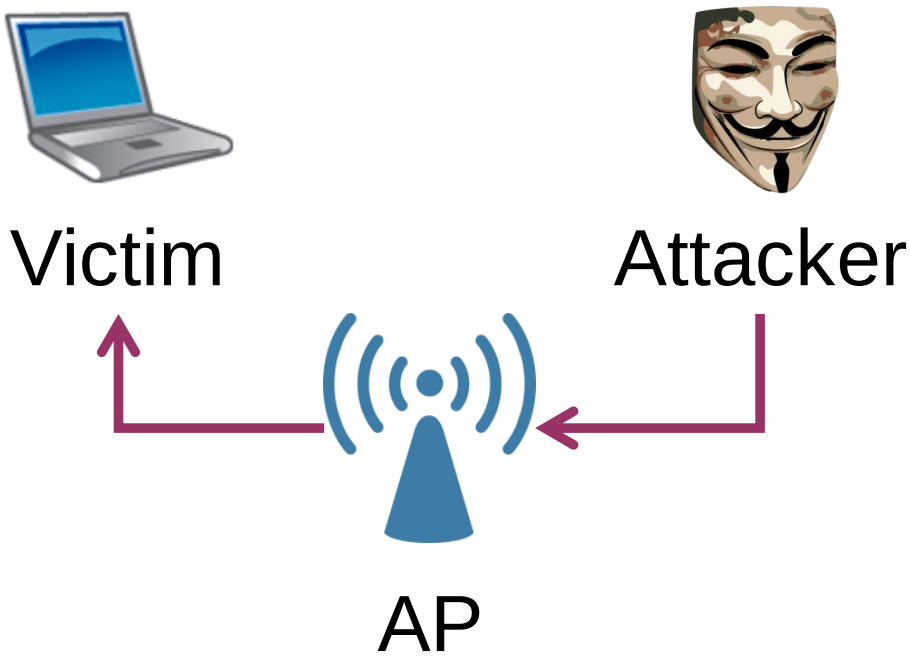


Decrypting all traffic

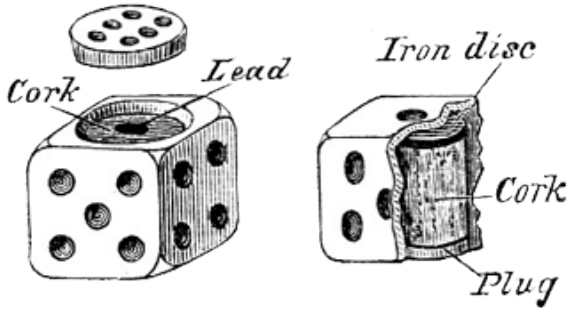
ARP poison to broadcast MAC address

- Poison both router and clients
- Targets network-layer protocols: IPv4, IPv6, …

Countermeasure:

- AP should ignore frames received on broadcast or multicast MAC address.

Contributions: Security of Group Keys



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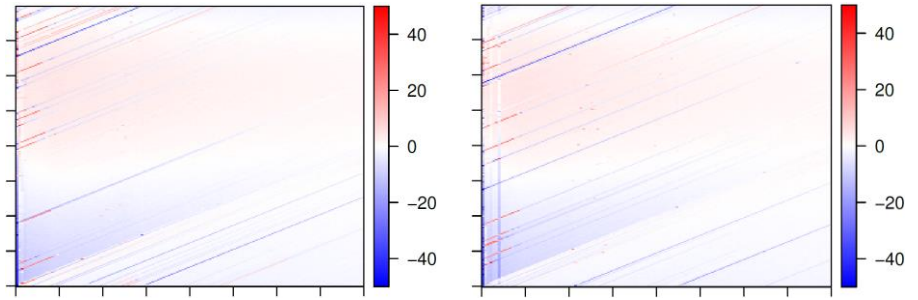

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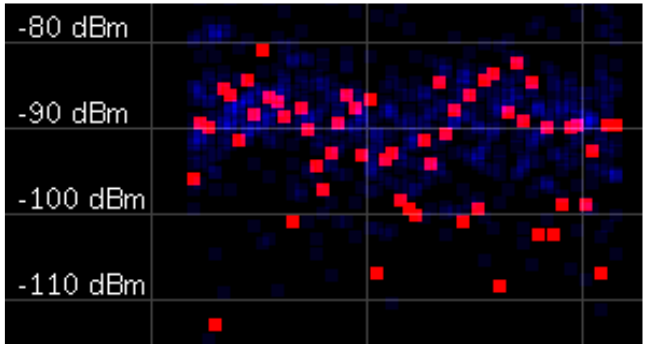

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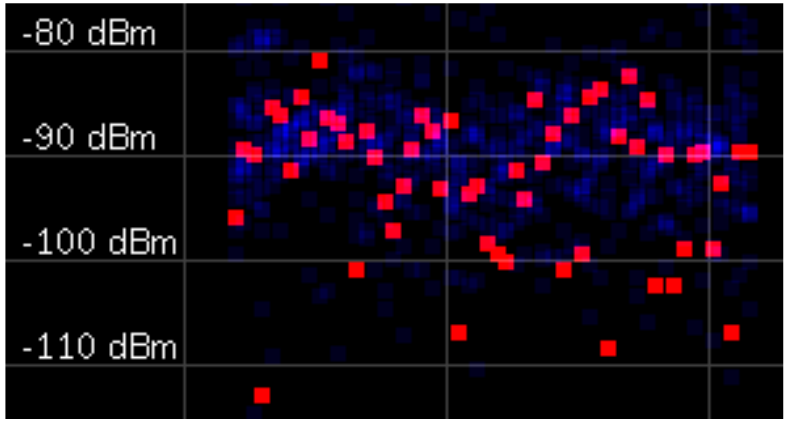
An improved 802.11 RNG

Entropy present on al Wi-Fi chips?

- Wi-Fi signals & background noise



Spectral scan feature in commodity chips:

- Can generate 3 million samples / second
- First XOR samples in firmware
- Extract & manage resulting entropy using known approaches

Additional research needed: performance under jamming?

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Conclusion: lessons learned

1. Use a proper RNG
2. Let AP ignore group-addressed frames
3. Don’t put “expository” security algos in a specification
4. Don’t transmit sensitive data before downgrade detection

Questions?

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