Discovering Logical Vulnerabilities in the Wi-Fi Handshake Using Model-Based Testing

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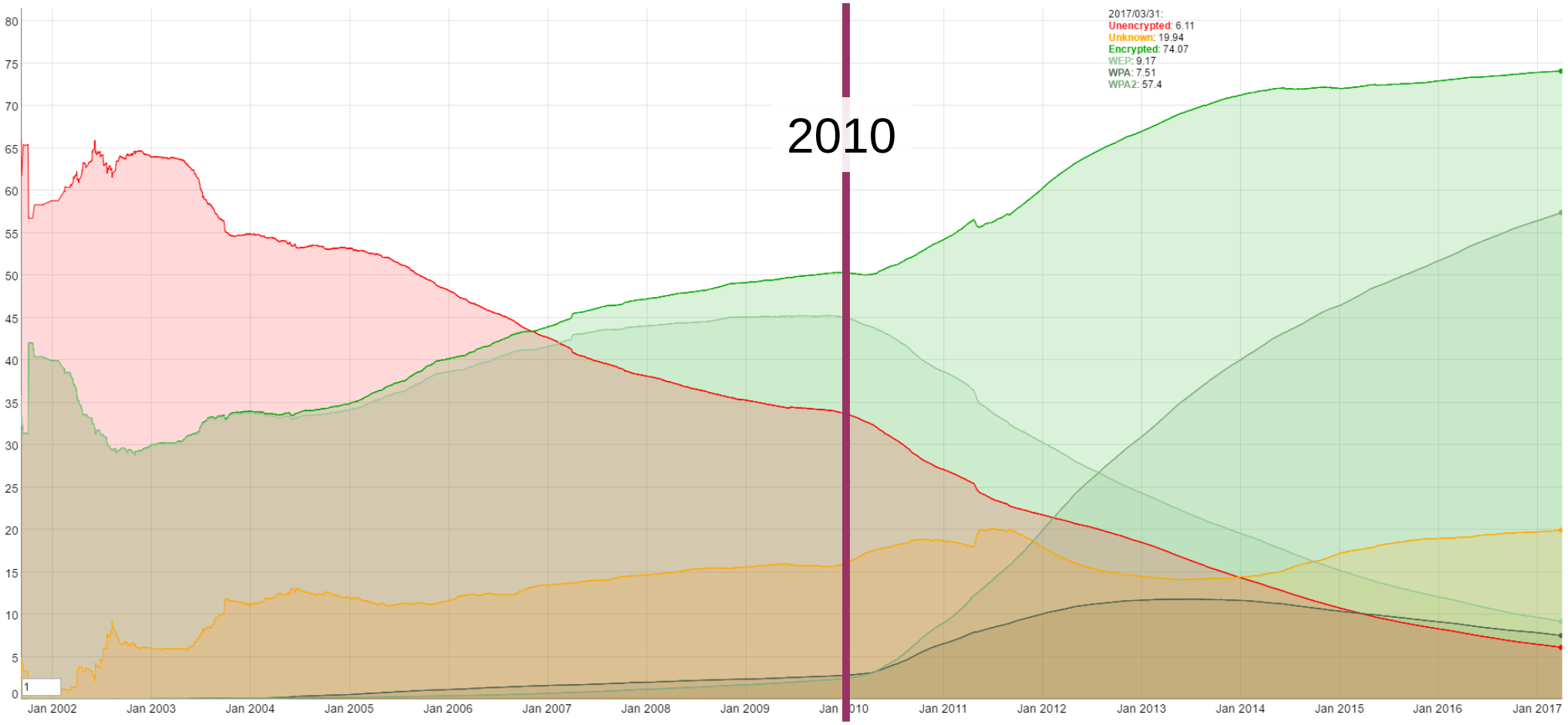
Asia CCS 2017

DistriNet

Introduction

More and more Wi-Fi network use encryption:



Most rely on the Wi-Fi handshake to generate session keys

How secure is the Wi-Fi handshake?

Design: formally analyzed and proven correct (CCS 2005)

Security of implementations?

- Some works fuzz network discovery stage
- Many stages are not tested, e.g. 4-way handshake.
- But do not tests for logical implementation bugs

→ Objective: test implementations of the full Wi-Fi handshake for logical vulnerabilities

Background: the Wi-Fi handshake

Main purposes:

- Network discovery
- Mutual authentication & negotiation of pairwise session keys
- Securely select cipher to encrypt data frames

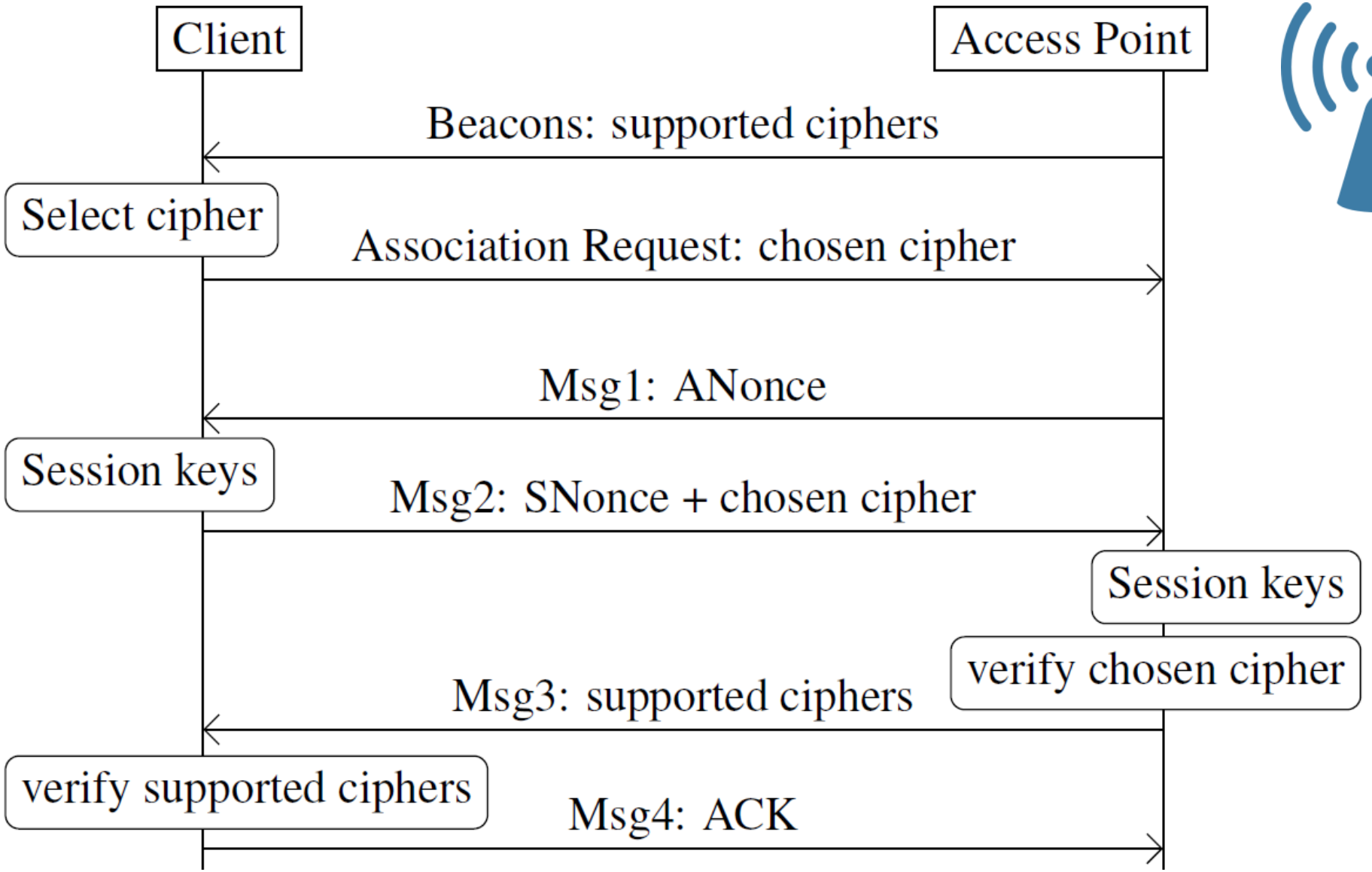
WPA-TKIP

Short-term solution that sacrificed some security, so it could run on old WEP-compatible hardware

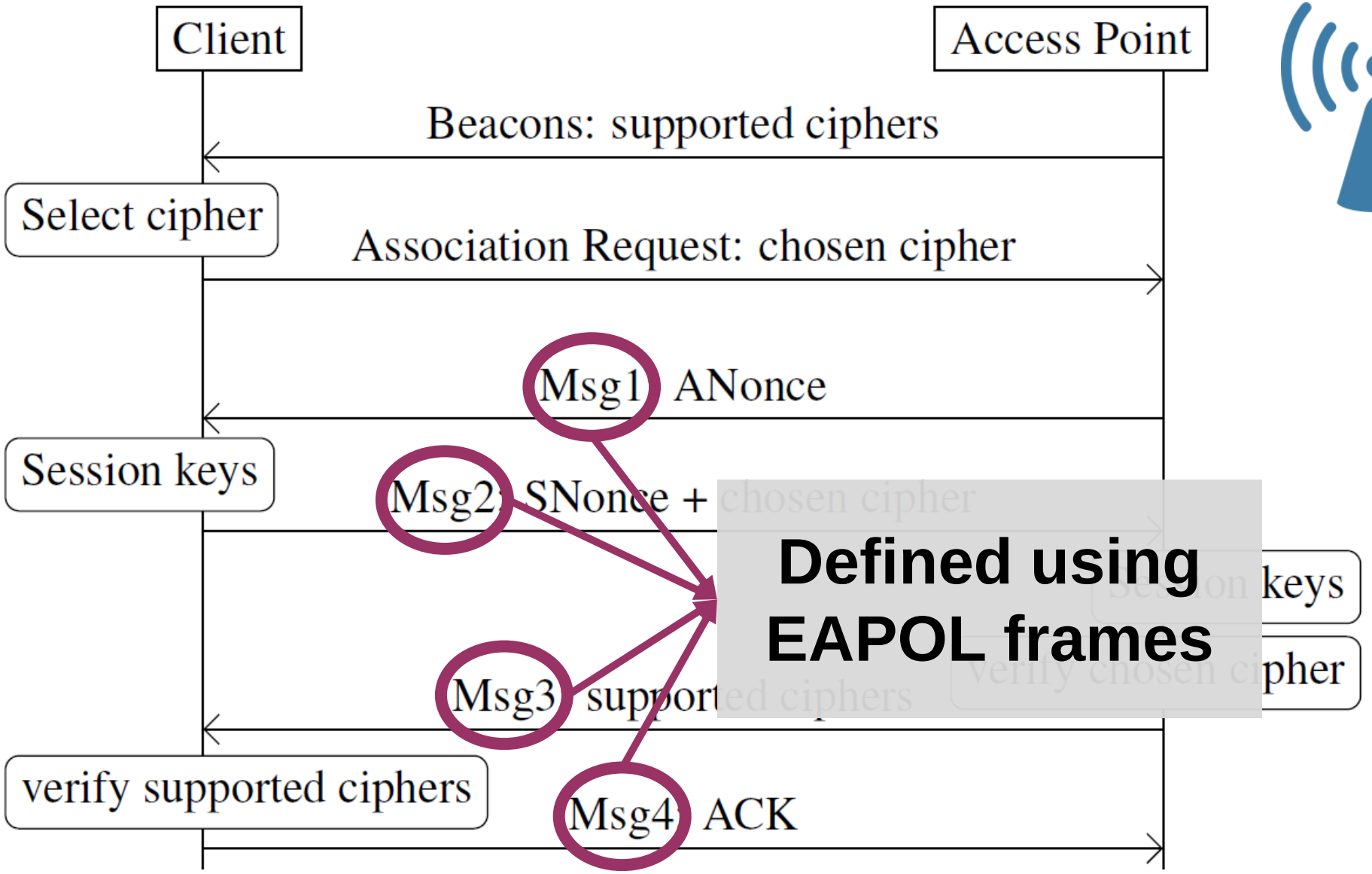
AES-CCMP

Long-term solution based on modern cryptographic primitives

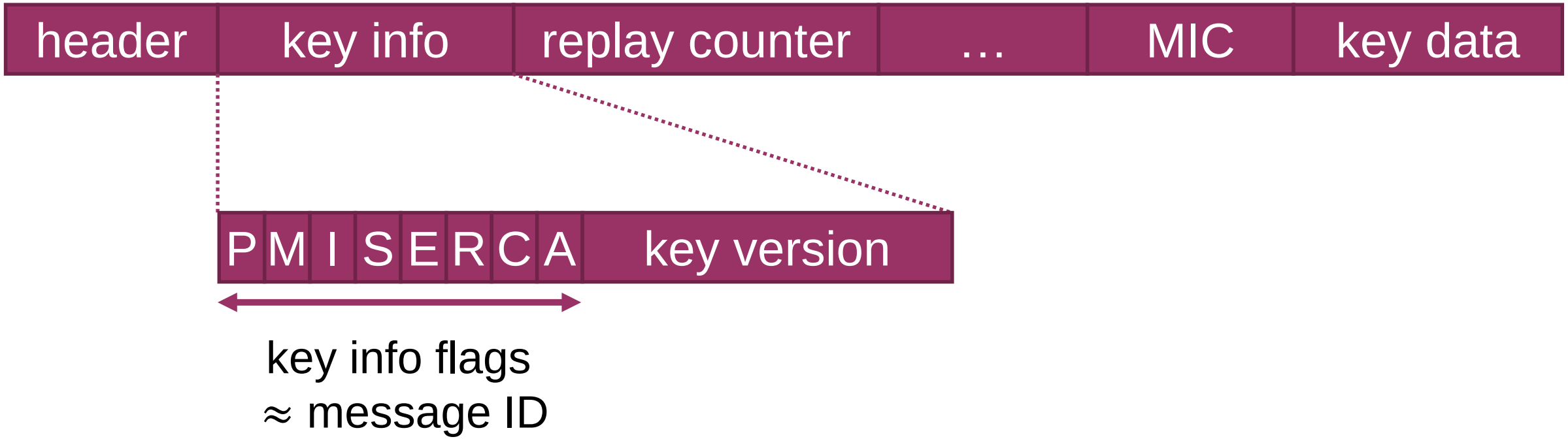
Wi-Fi handshake (simplified)



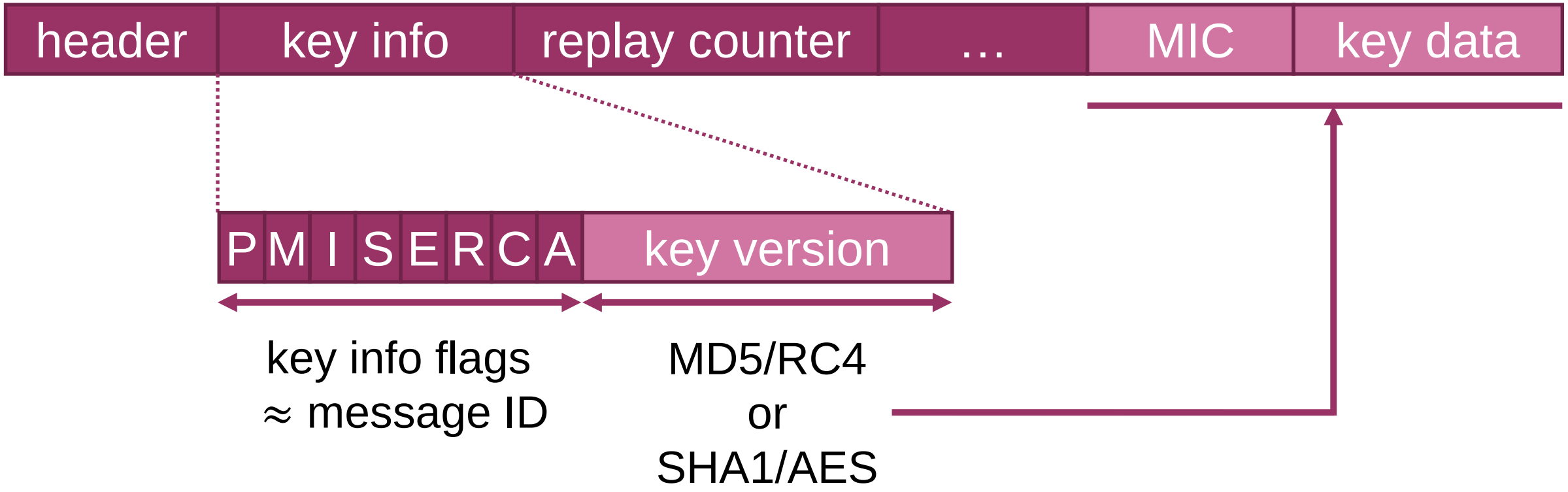
Wi-Fi handshake (simplified)



EAPOL frame layout (simplified)



EAPOL frame layout (simplified)



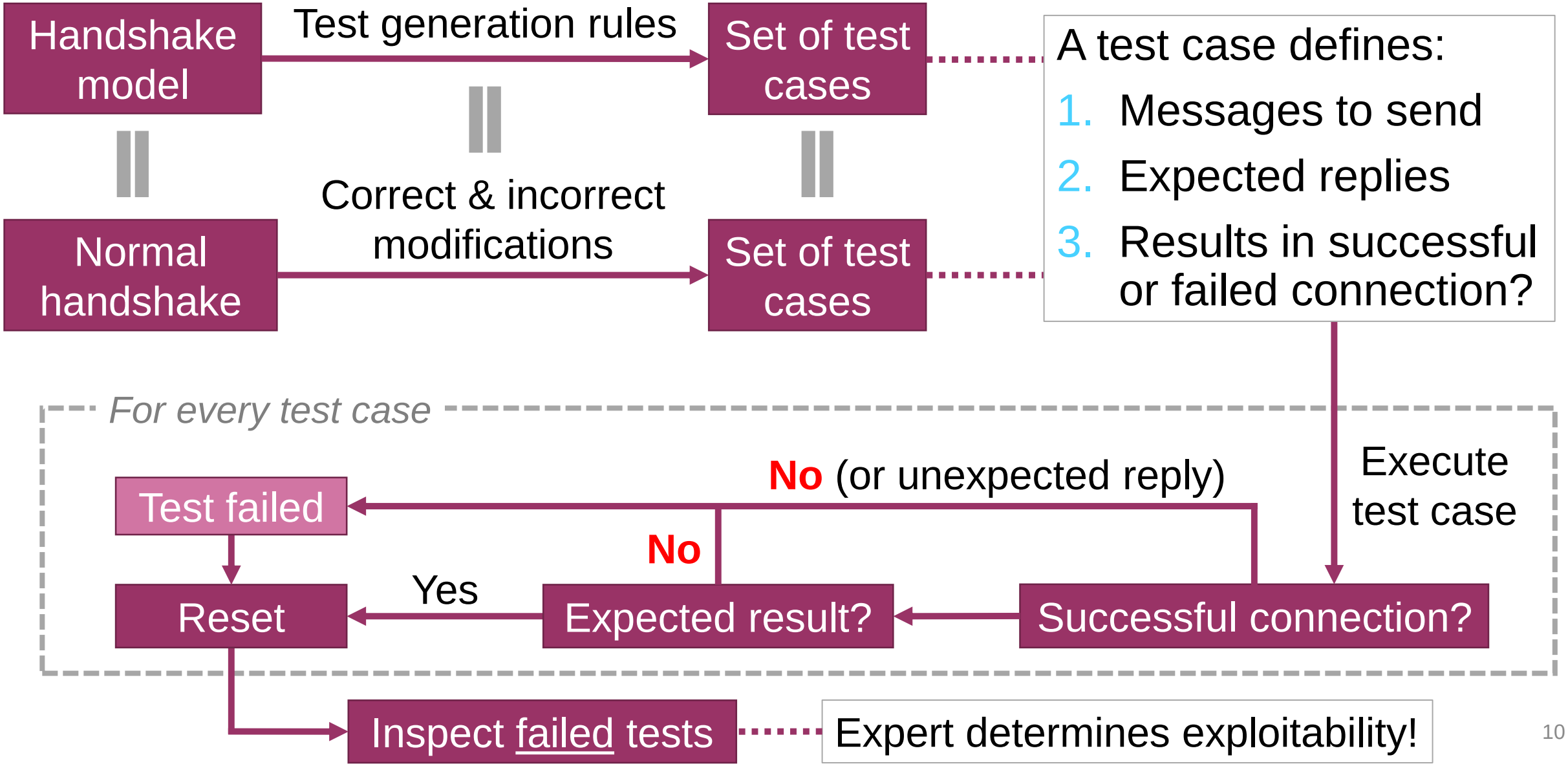
How to test implementations?

Model-based testing!

- Test if program behaves according to some abstract model
- Proved successful against TLS

  - Apply model-based approach on the Wi-Fi handshake

Model-based testing: our approach



Test generation rules

Test generation rules manipulating messages as a whole:

1. Drop a message
2. Inject/repeat a message

Test generation rules that modify fields in messages:

1. Wrong selected cipher suite in message 2
2. Bad EAPOL replay counter
3. Bad EAPOL key info flags (used to identify message)
4. Bad EAPOL key version (switch SHA1/AES with MD5/RC4)
5. Bad EAPOL Message Integrity Check (MIC)
6. …

Evaluation

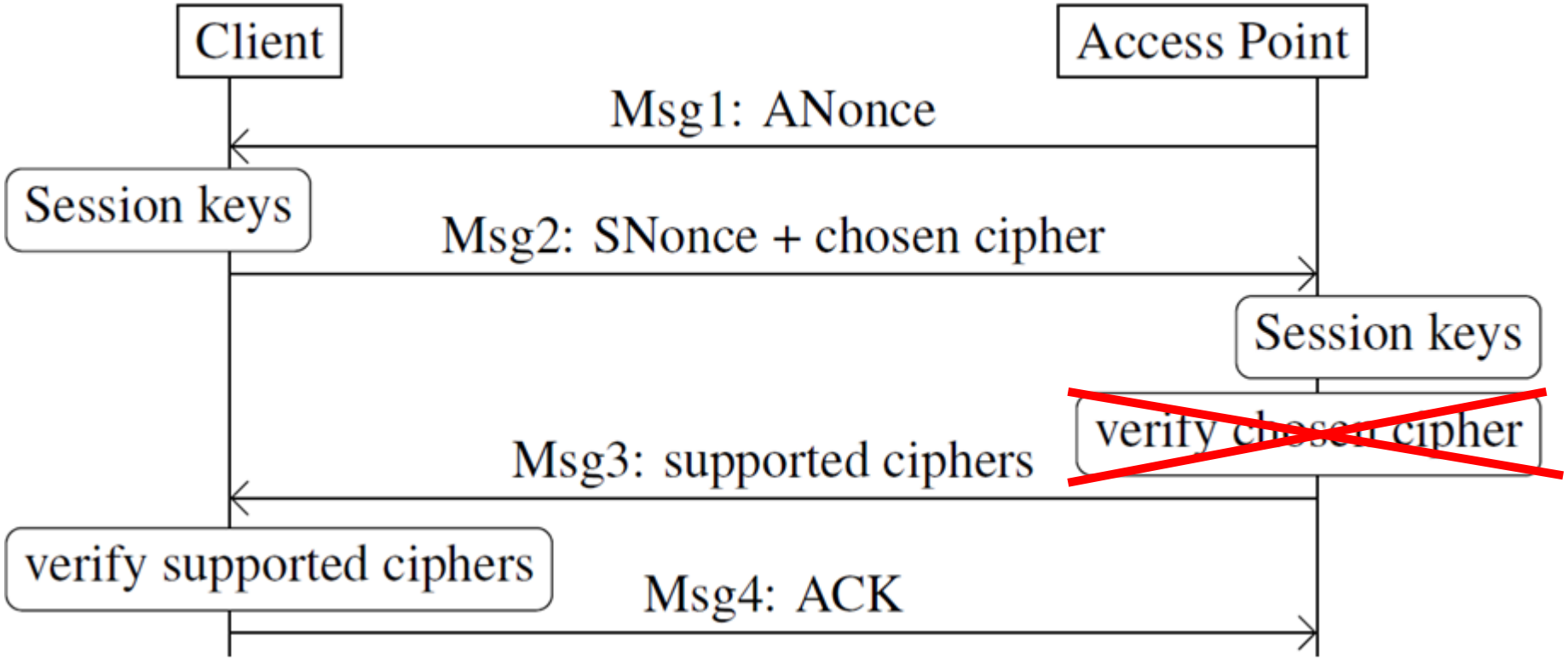
We tested 12 access points:

- Open source: OpenBSD, Linux's Hostapd
- Leaked source: Broadcom, MediaTek (home routers)
- Closed source: Windows, Apple, Telenet
- Professional equipment: Aerohive, Aironet

Discovered several issues!

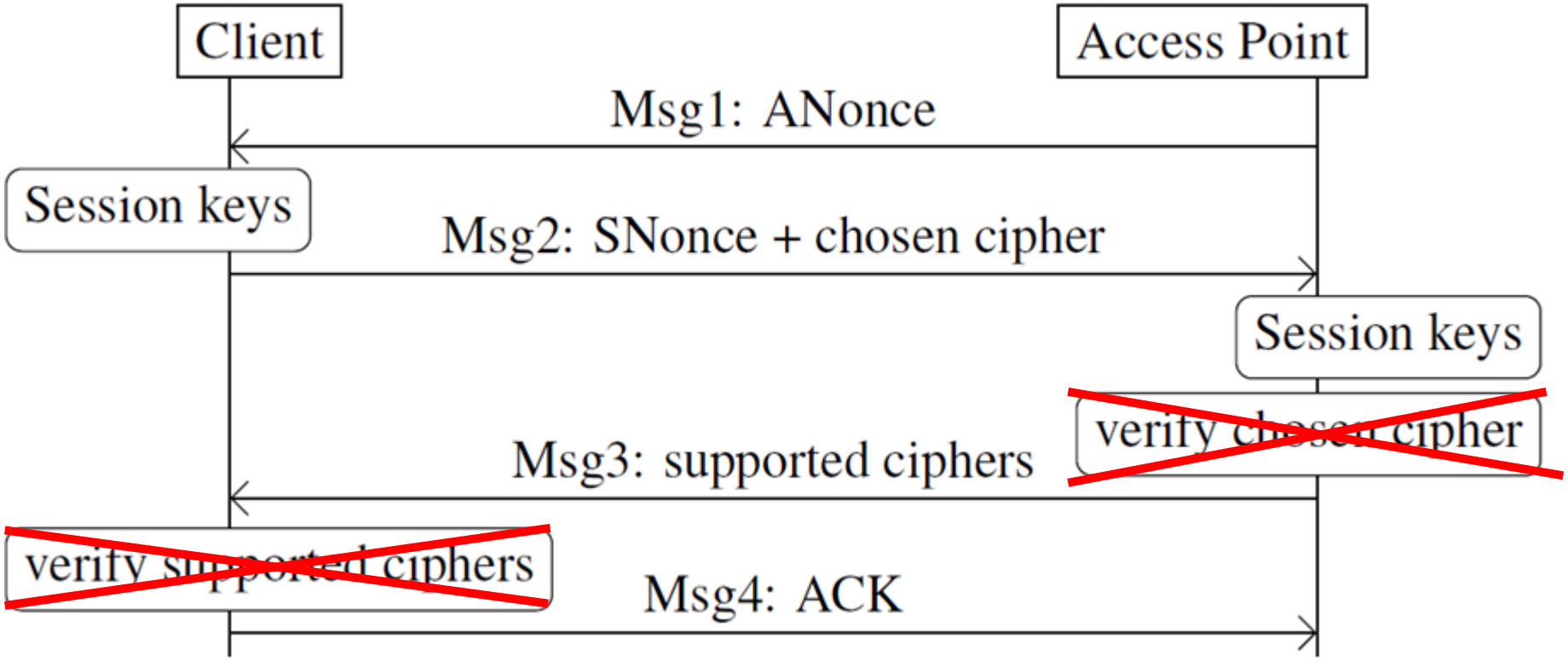
Missing downgrade checks

1. MediaTek & Telenet don’t verify selected cipher in message 2



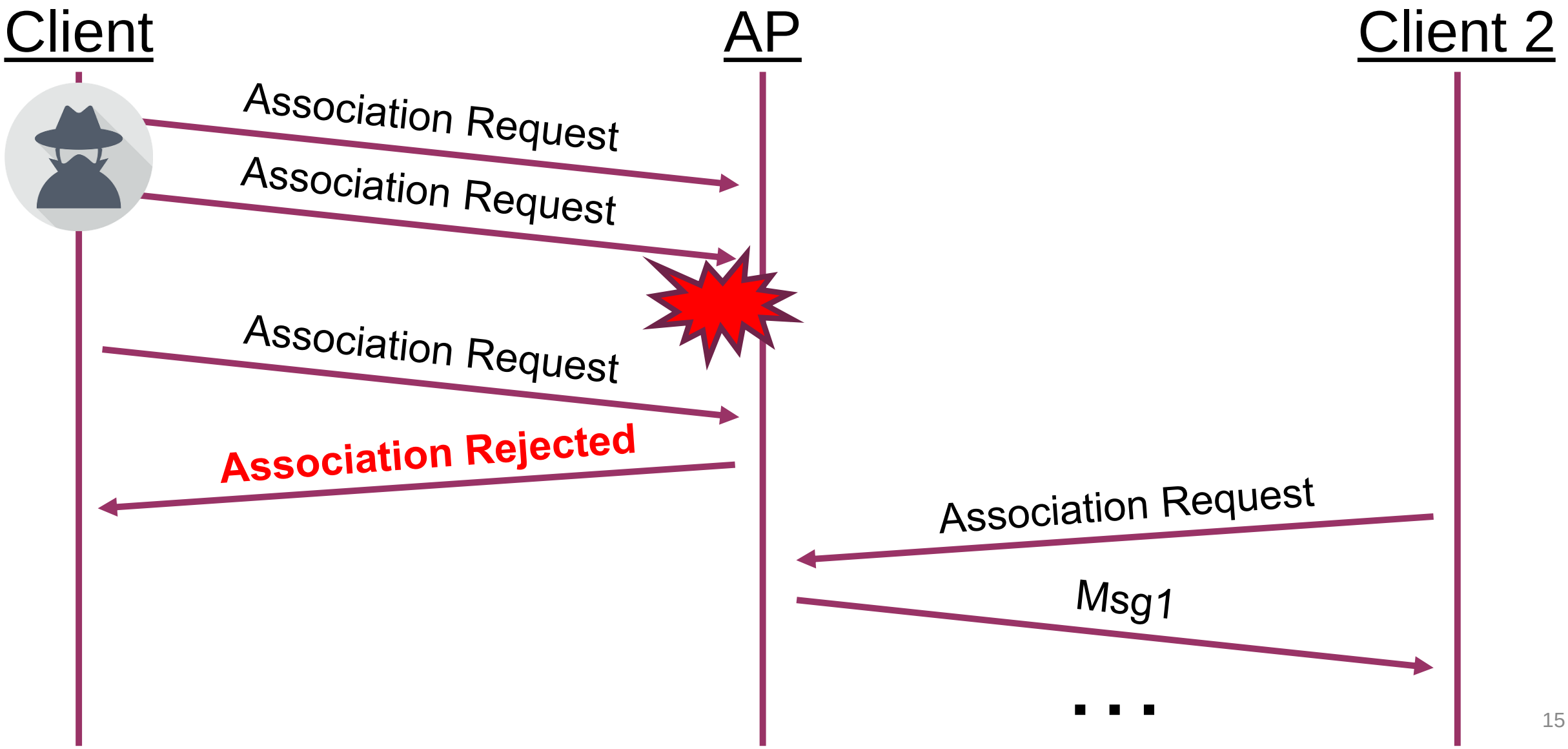
Missing downgrade checks

1. MediaTek & Telenet don't verify selected cipher in message 2
2. MediaTek also ignores supported ciphers in message 3



→ MediaTek clients can be trivially downgraded

Windows 7 targeted DoS



Broadcom downgrade

Broadcom cannot distinguish message 2 and 4

- Can be abused to downgrade the AP to TKIP

Hence message 4 is essential in preventing downgrade attacks

- This highlights incorrect claims in the 802.11 standard
- §11.6.6.8: 4-way handshake analysis mentions that:

"**While Message 4 serves no cryptographic purpose**, it serves as an acknowledgment to Message 3. **It is required to ensure reliability** and to inform the Authenticator that the Supplicant has installed the PTK and GTK and hence can receive encrypted frames."

Other results: see paper!

- Fingerprinting techniques!
- Permanent DoS attack against OpenBSD & Broadcom
- DoS attack against Windows 10, Broadcom, Aerohive
- Inconsistent parsing of selected and supported cipher suite(s)
- …

Conclusion

Overall advantages and disadvantages:

- ✓ Black-box testing mechanism: no source code needed
- ○ But time consuming to implement & requires an expert

Detected several issues, for example:

- Missing checks allowing downgrade attacks
- Several implementation-specific flaws
- …

→ Fairly simple handshake, but still several logical bugs!

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Questions?

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