

WiFuzz: Detecting and Exploiting Logical Flaws in the Wi-Fi Cryptographic Handshake

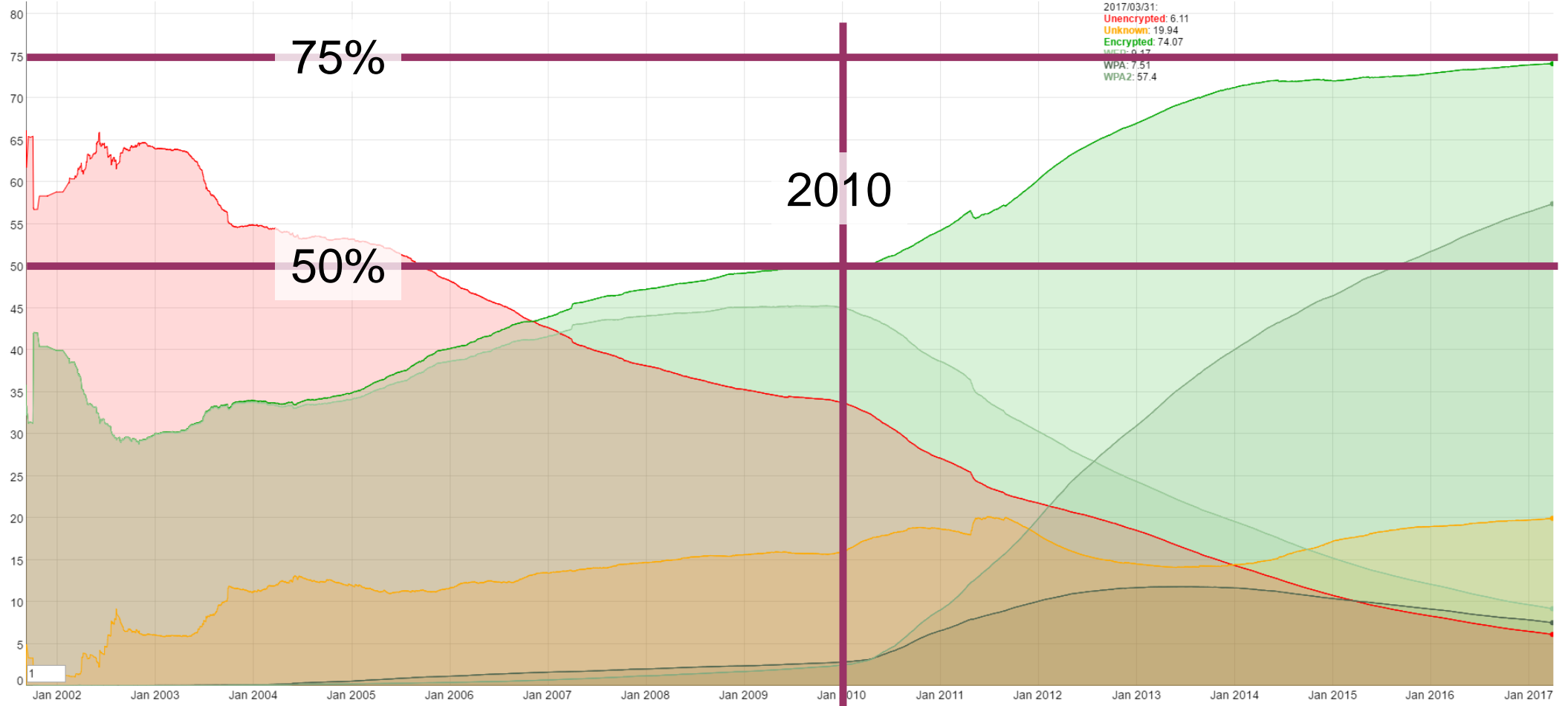
Mathy Vanhoef - @vanhoefm

Black Hat, 27 July 2017

In collaboration with Domien Schepers and Frank Piessens

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 secure¹

Security of implementations?

- Some works fuzz network discovery stage²
- 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

¹ C. He, M. Sundararajan, A. Datta, A Derek, and J. Mitchell. A modular correctness proof of IEEE 802.11i and TLS.

² L. Butti and J. Tinnes. Discovering and exploiting 802.11 wireless driver vulnerabilities.

Background: the Wi-Fi handshake

Main purposes:

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



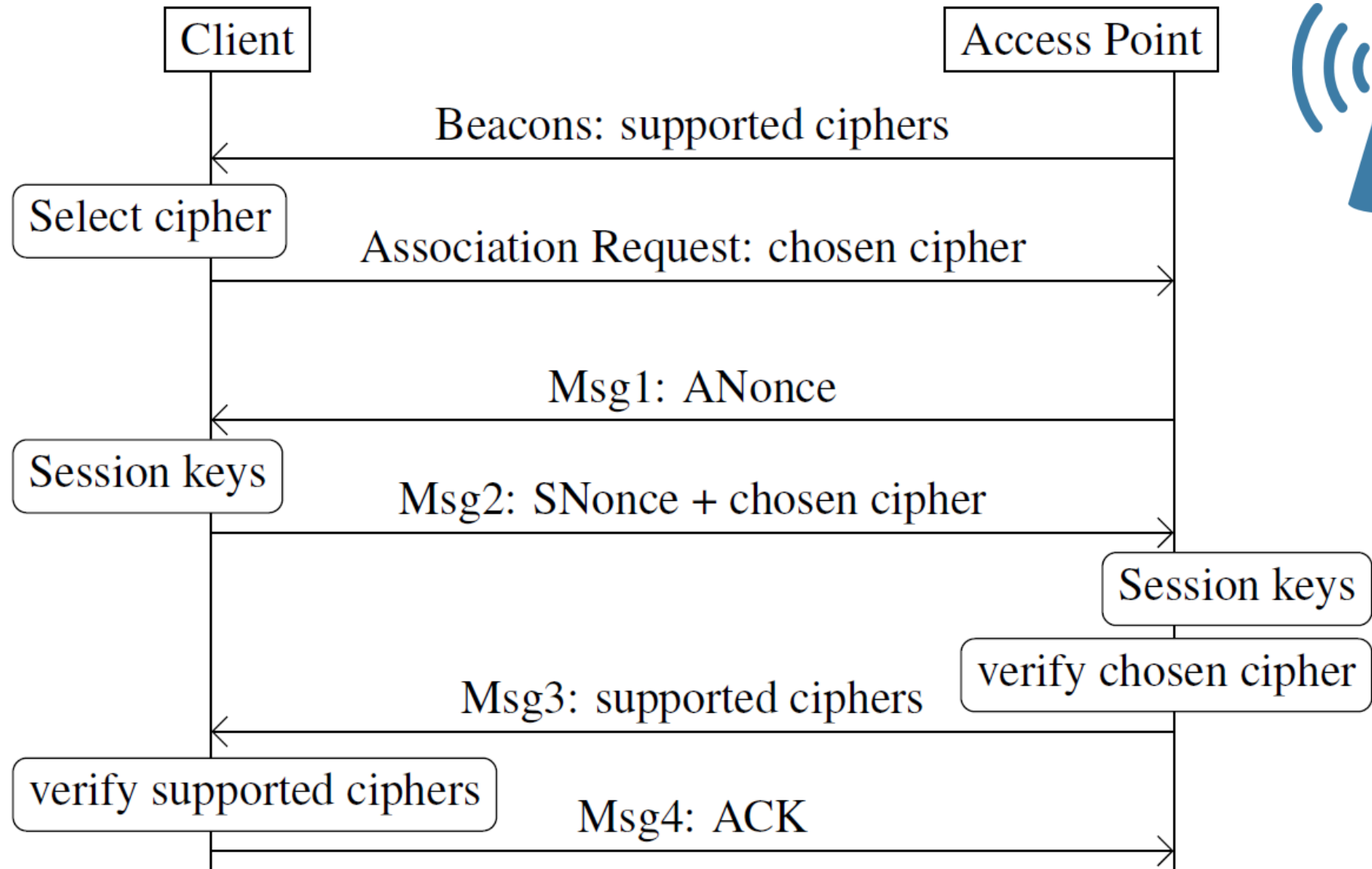
WPA-TKIP

Short-term solution: reduced security
so it could run on old hardware

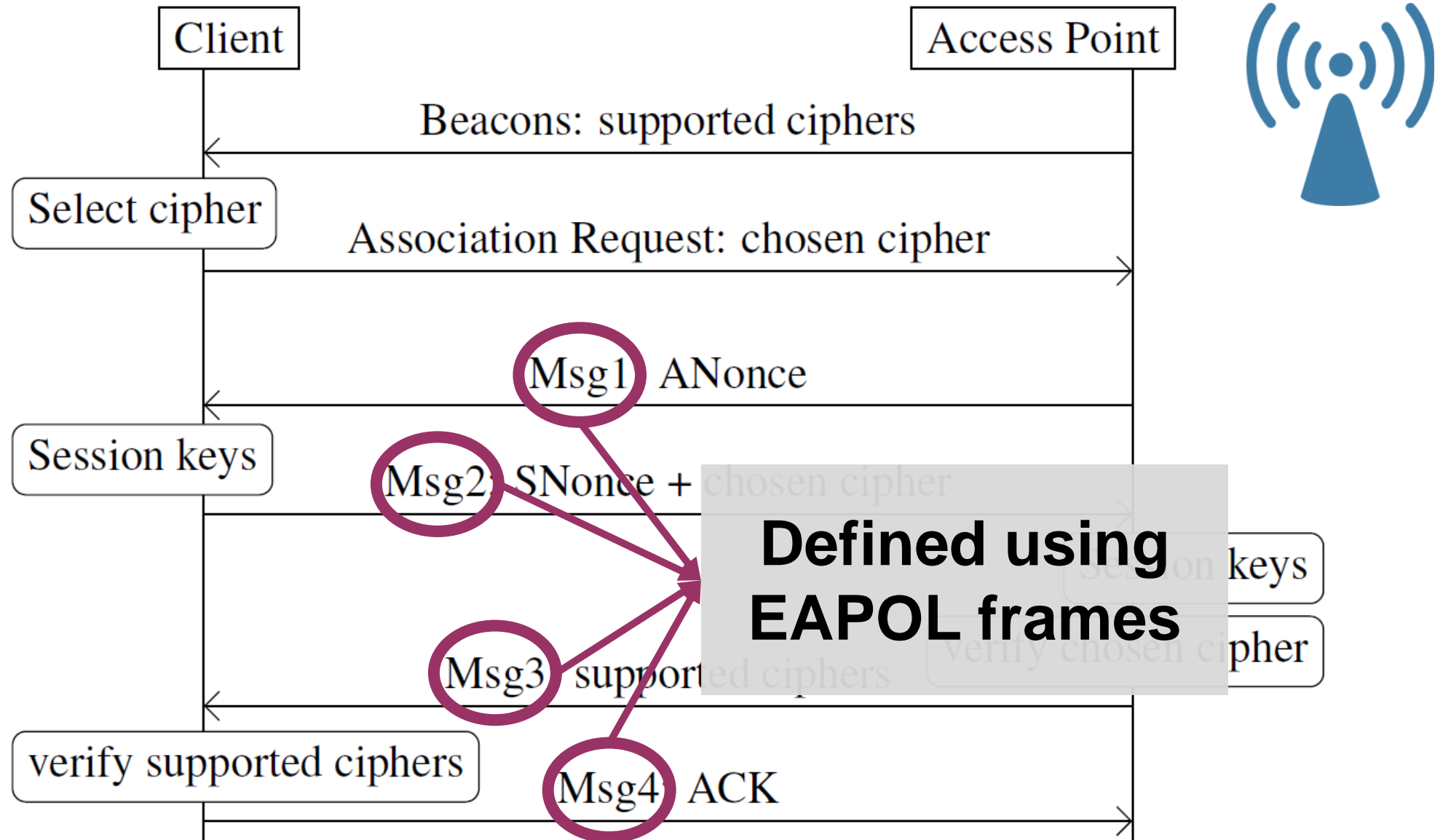
AES-CCMP

Long-term solution based on
modern cryptographic primitives

Wi-Fi handshake (simplified)

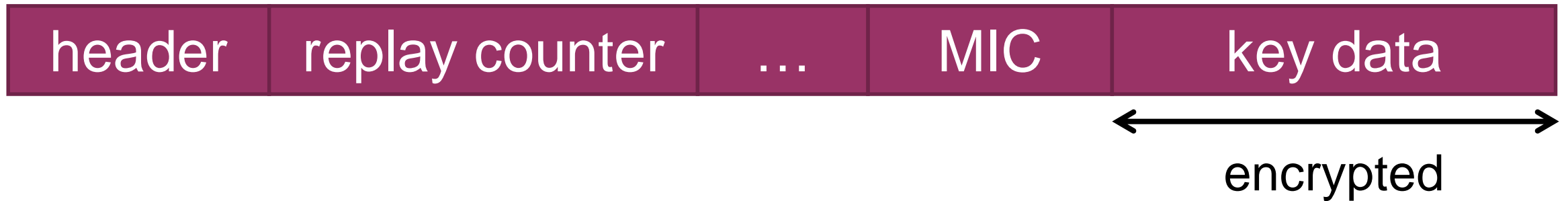


Wi-Fi handshake (simplified)

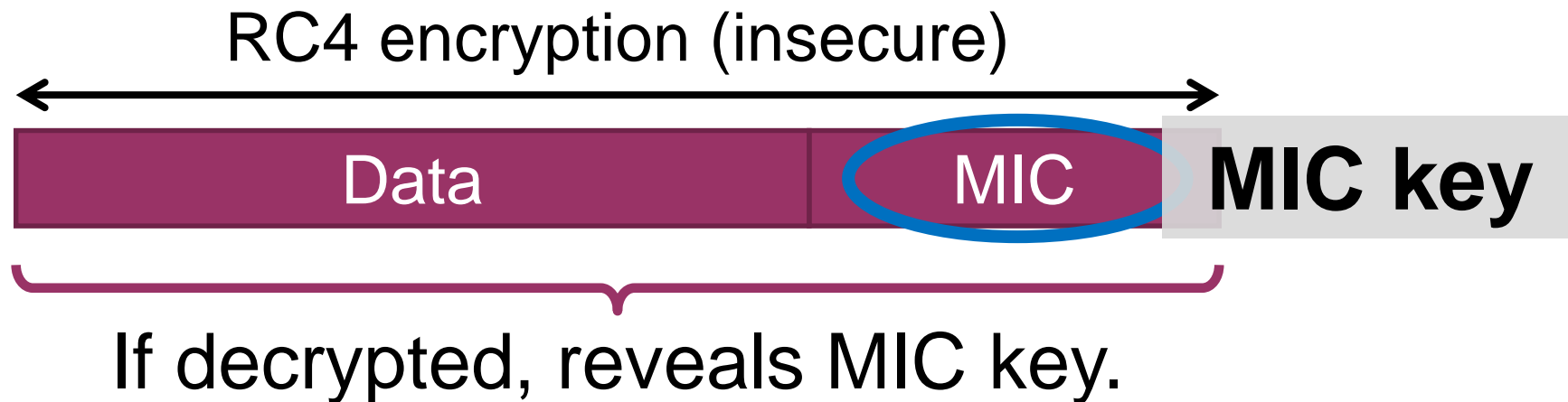


Frame Layouts

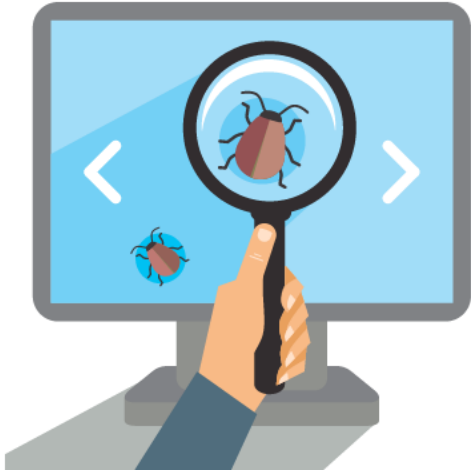
- EAPOL frame:



- WPA-TKIP frame:



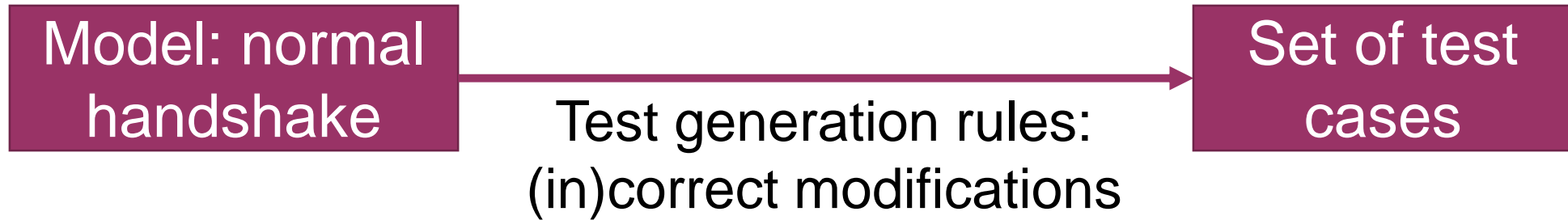
How to test implementations?



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



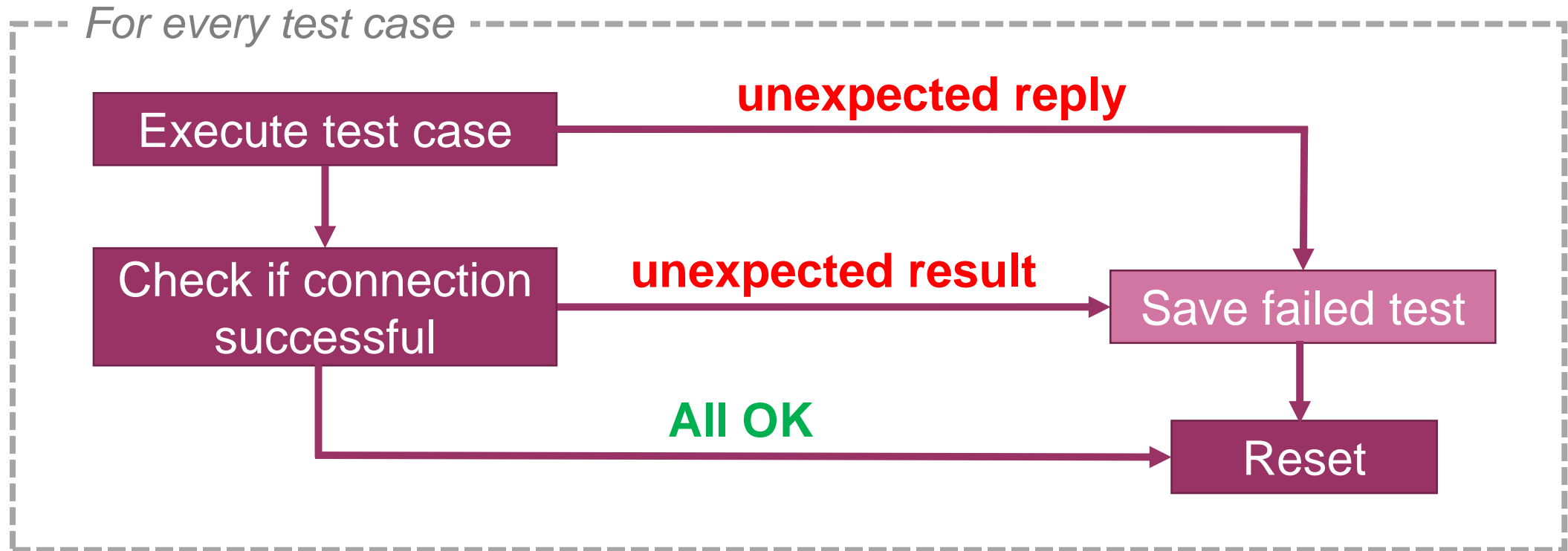
Test generation rules:

- Test various edge cases, allows some creativity
- Are assumed to be independent (avoid state explosion)

A test case defines:

1. Messages to send & expected replies
2. Results in successful connection?

Executing test cases



Afterwards Inspect failed test cases

- Experts determines impact and exploitability

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. Bad EAPOL replay counter
2. Bad EAPOL header (e.g. message ID)
3. Bad EAPOL Message Integrity Check (MIC)
4. Mismatch in selected cipher suite
5. ...

Evaluation

We tested 12 access points:

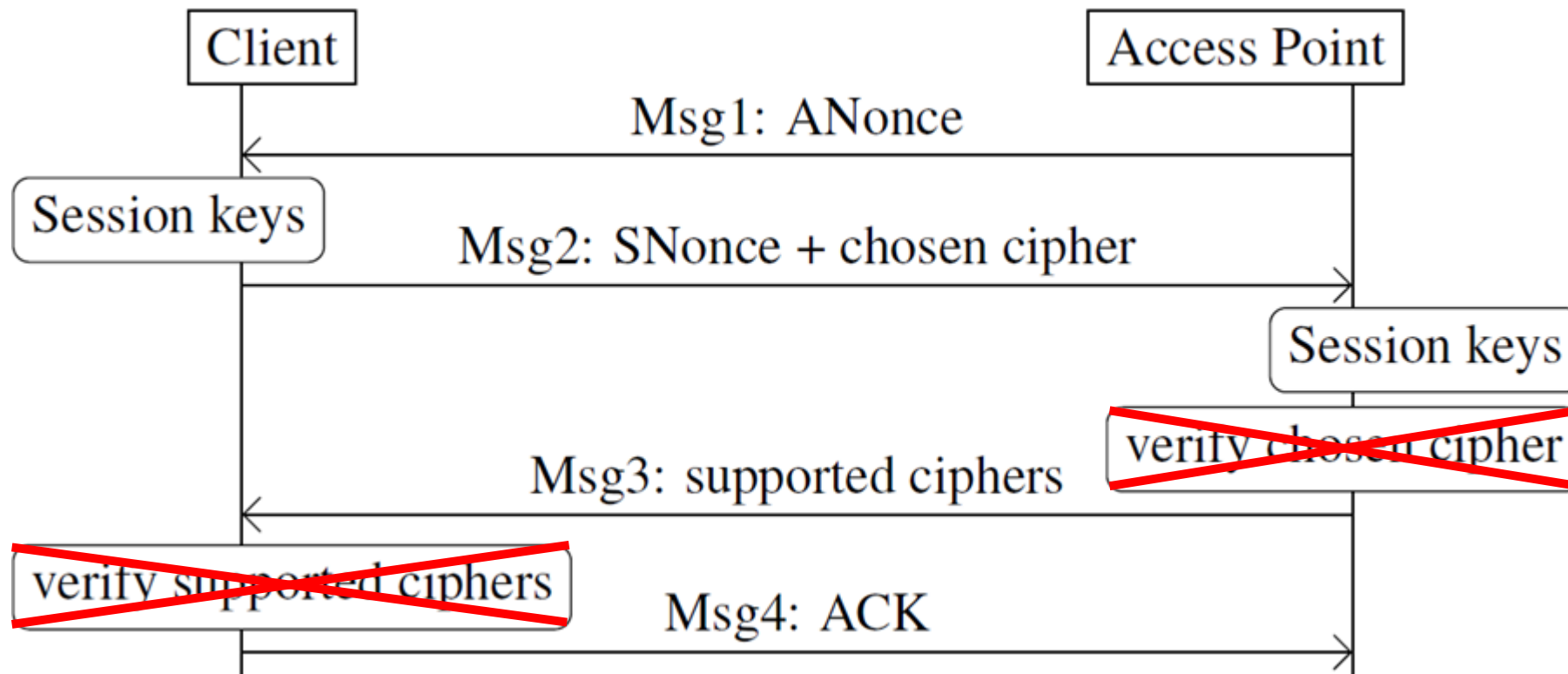
- Open source: OpenBSD, Linux's Hostapd
- Leaked source: Broadcom, MediaTek (home routers)
- Closed source: Windows, Apple, ...
- Professional equipment: Aerohive, Aironet



Discovered several issues!

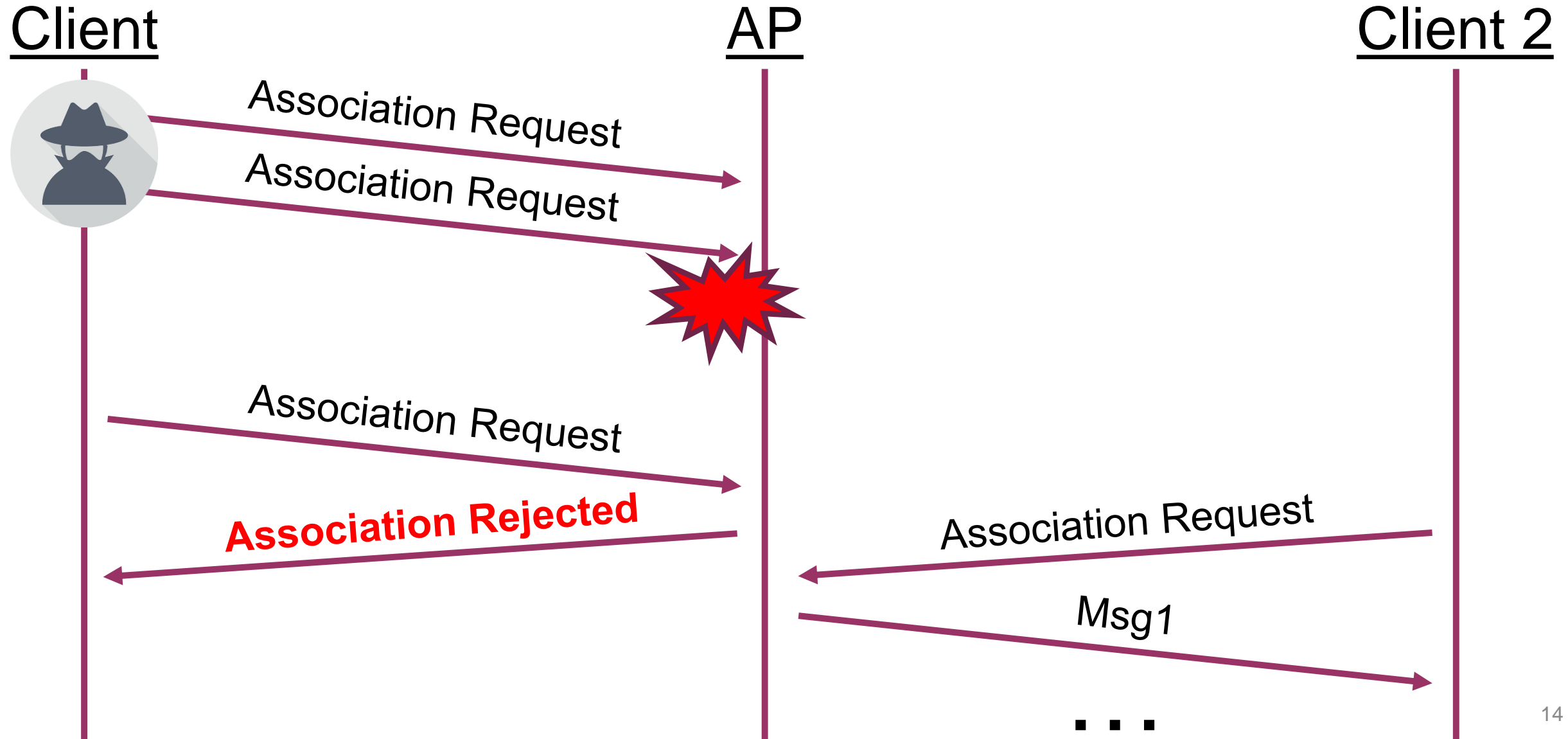
Missing downgrade checks

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



→ Trivial downgrade attack against MediaTek clients

Windows 7 targeted DoS



Windows 7 targeted DoS

Client

AP

Client 2

PoC & Demo

github.com/vanhoefm/blackhat17-pocs

Msg1

...

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:

“**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.”

OpenBSD: DoS against AP

Two bugs in OpenBSD:

1. TKIP countermeasures are never stopped
 - Recall: it uses a weak Message Integrity Check (MIC)



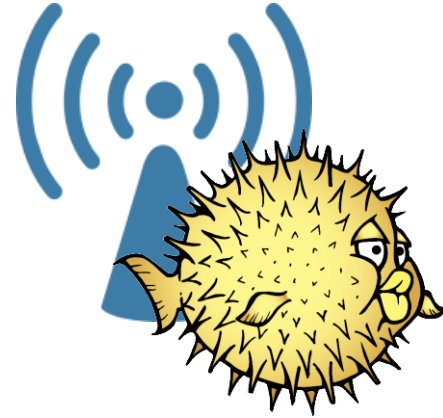
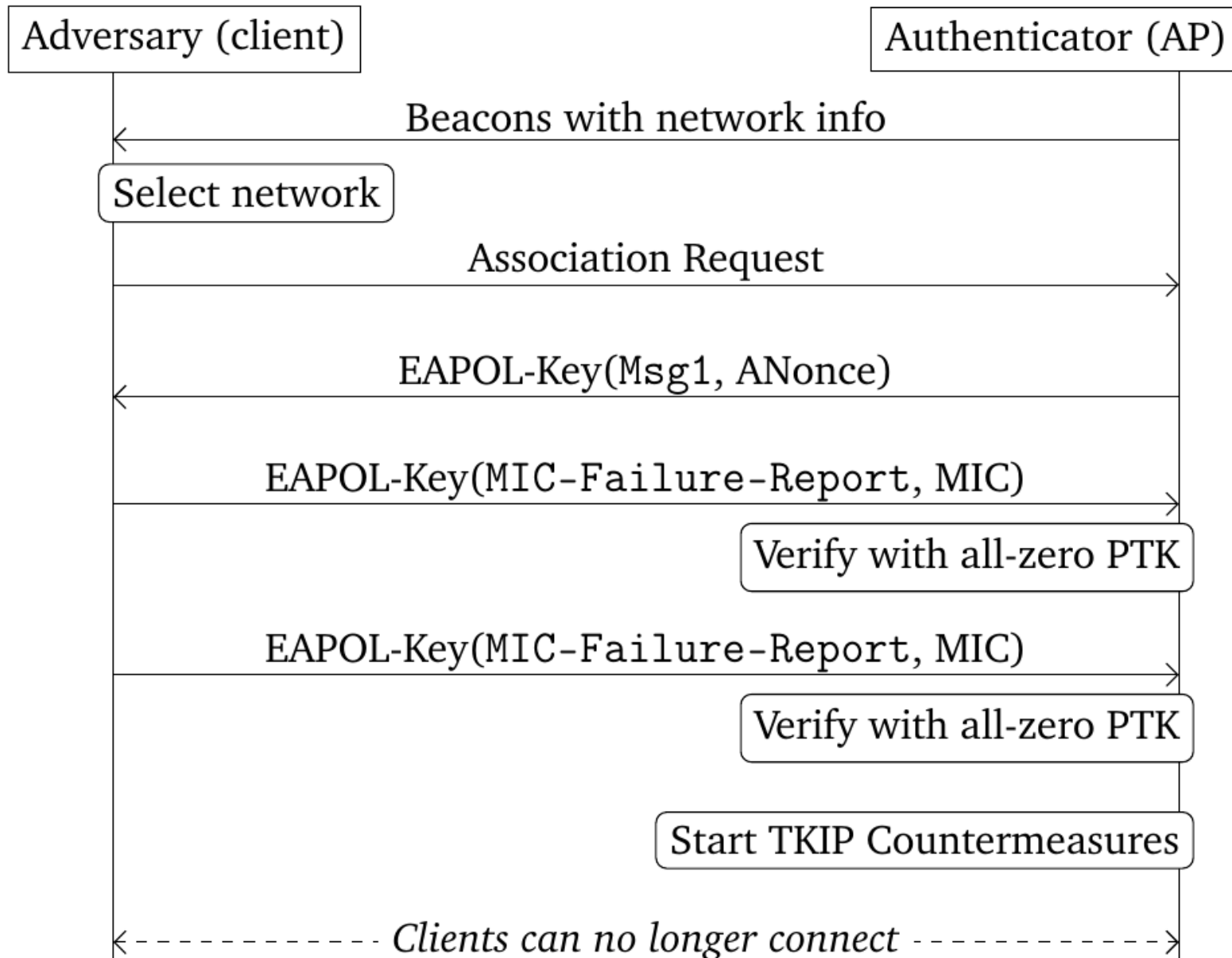
If (two **MIC failures** within a minute)
halt all traffic ~~for 1 minute~~
forever



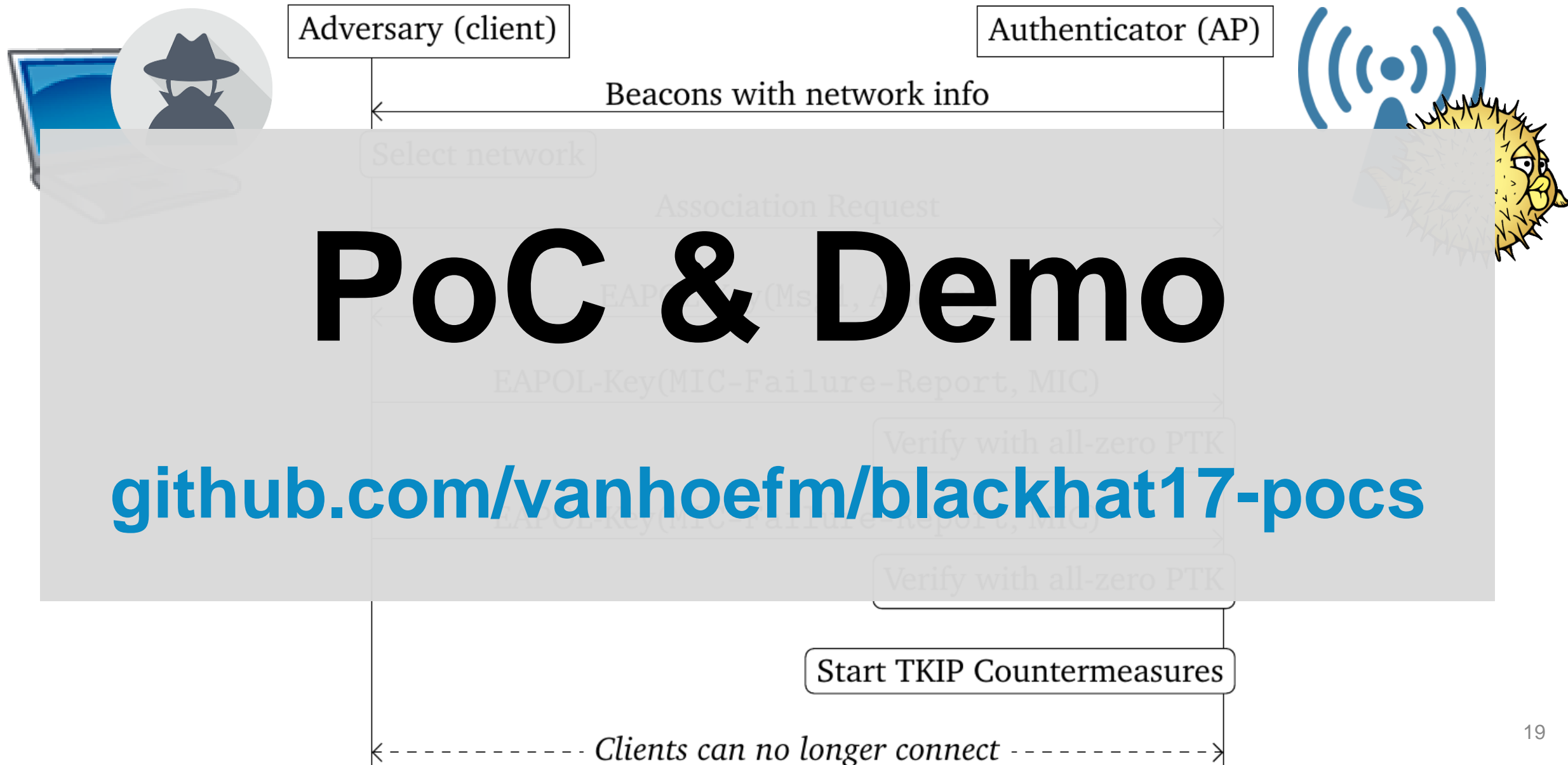
2. MIC failure report accepted before 4-way handshake

Combined: unauthenticated permanent DoS

OpenBSD: DoS against AP



OpenBSD: DoS against AP



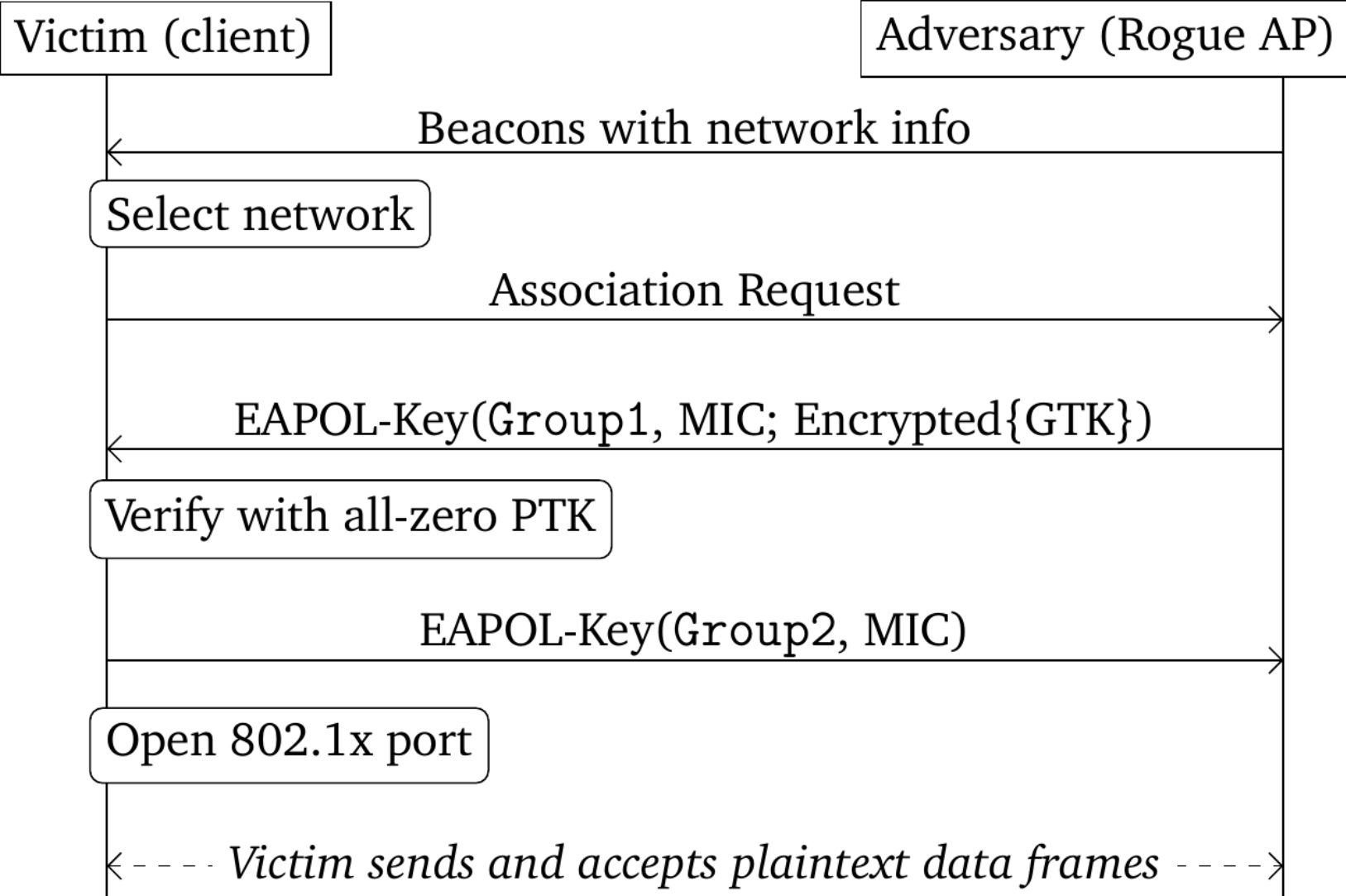
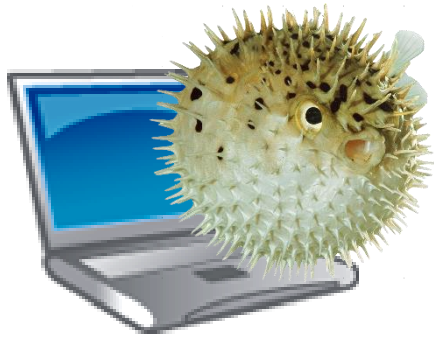
OpenBSD: client man-in-the-middle

Manual inspection of OpenBSD client:
State machine missing!

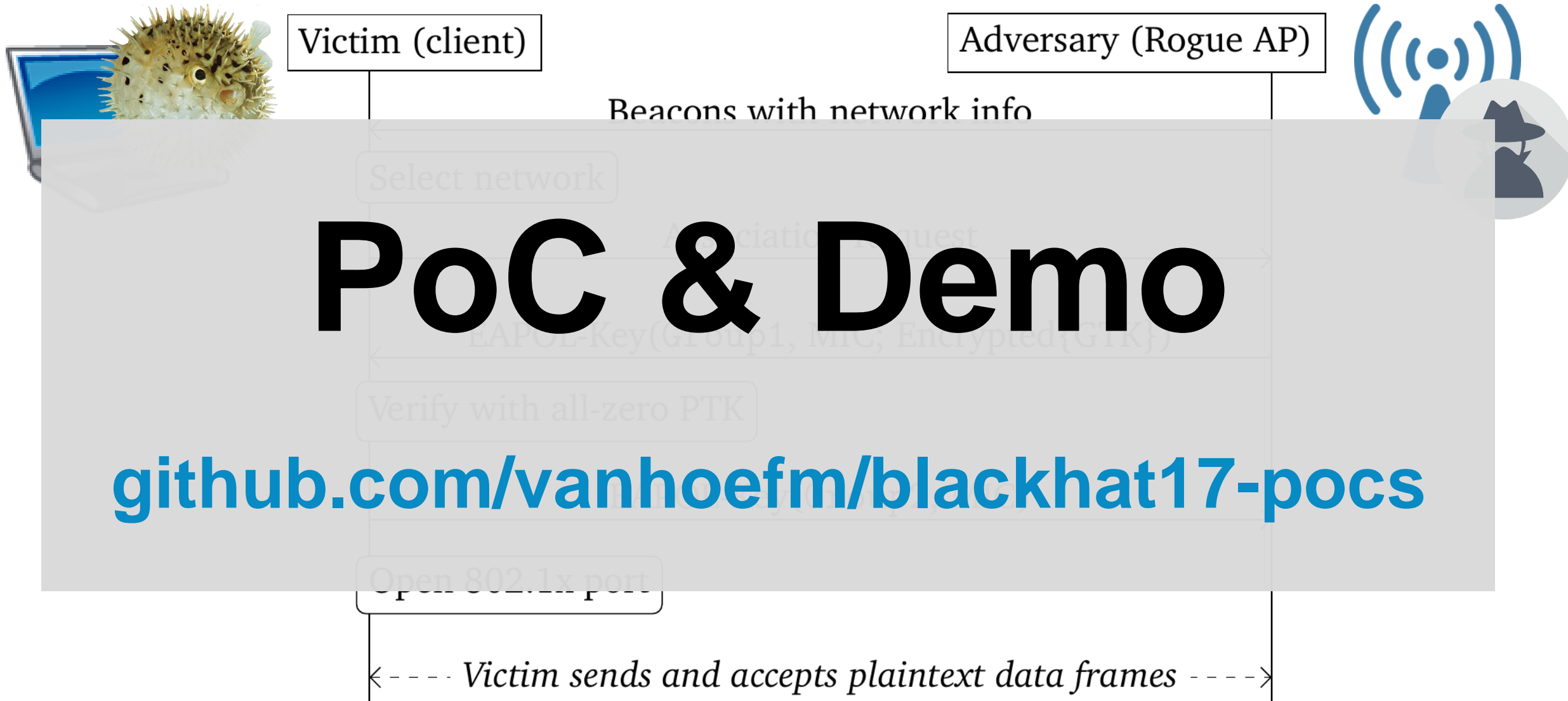


→ Man-in-the-middle against client

OpenBSD: client man-in-the-middle



OpenBSD: client man-in-the-middle



More results



See Black Hat & AsiaCCS paper¹:

- Benign irregularities → fingerprint
- Permanent DoS attack against Broadcom
- DoS attack against Windows 10, Broadcom, Aerohive
- Inconsistent parsing of supported cipher suite list
- ...

¹ M. Vanhoef, D. Shepers, and F. Piessens. Discovering Logical Vulnerabilities in the Wi-Fi Handshake Using Model-Based Testing. 23

Future work!

Current limitations:

- Amount of code coverage is unknown
- Only used well-formed (albeit invalid) packets
- Test generation rules applied independently
- Only tested Access Points (not clients)

But already a promising technique

- ✓ Black-box testing mechanism: no source code needed
- ✓ Fairly simple handshake, but still several **logical** bugs!

Conclusion

Wi-Fi code less secure than expected

- New attacks (will) keep appearing



Need better tools to detect logical flaws

- Current testing framework is basic
- Complex bugs remain undetected

Ongoing results: contact me if your product uses

- Client-side version of WPA1/2
- Other Wi-Fi handshakes: 802.11r, PeerKey, ...



WiFuzz: Detecting and Exploiting Logical Flaws in the Wi-Fi Cryptographic Handshake

Mathy Vanhoef

Questions?



vanhoefm