Mathy Vanhoef

New Flaws in WPA-TKIP

@vanhoefm

Brucon 2012

Why listen to me?

universiteit hasselt

ERNST & YOUNG
Quality In Everything We Do

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Gandanur

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FWO VLAANDEREN

KATHOLIEKE UNIVERSITEIT LEUVEN

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- `0x00` The WPA-TKIP protocol
- `0x04` Denial of Service
- `0x08` Demo
- `0x0C` Beck & Tews attack
- `0x10` Fragmentation attack
- `0x14` Performing a port scan

The WPA-TKIP Protocol

We will cover:

- Connecting
- Sending & receiving packets
- Quality of Service (QoS) extension

Design Constraints:

- Must run on legacy hardware
- Uses (hardware) WEP encapsulation

4-way handshake

- Defined by EAPOL and results in a session key
- What you normally capture & crack

Protocol	Length	Info
802.11	287	Beacon frame, SN=23
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EAPOL	151	Key (msg 1/4)
802.11	28	Acknowledgement, Fl
EAPOL	175	Key (msg 2/4)
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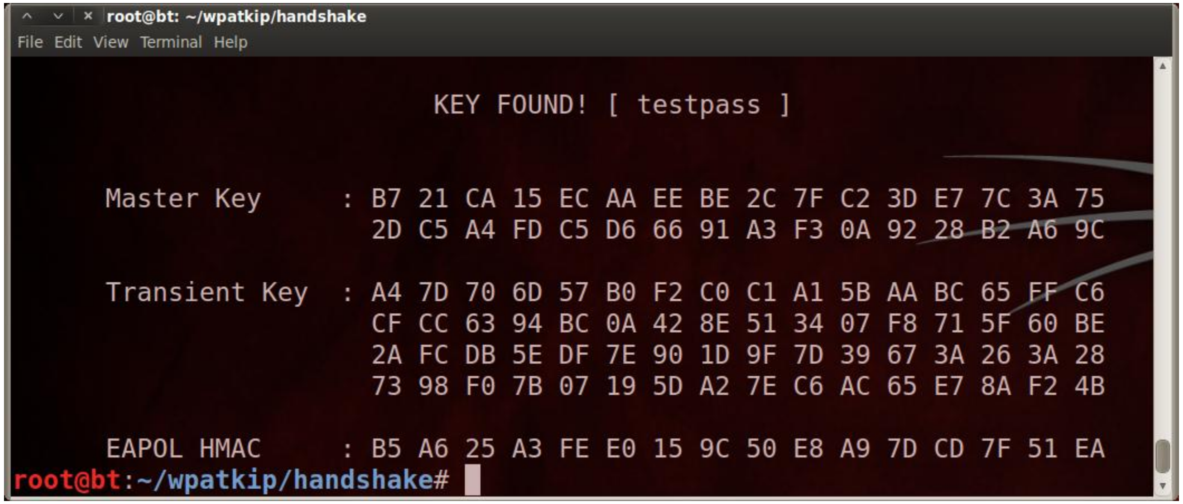
802.11	28	Acknowledgement, Fl
EAPOL	177	Key
802.11	28	Acknowledgement, Fl
EAPOL	151	Key (msg 2/4)
802.11	28	Acknowledgement, Fl
802.11	203	QoS Data, SN=3, FN=
802.11	28	Acknowledgement, Fl
802.11	171	QoS Data, SN=2, FN=



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- Result of handshake is 512 bit session key
- Renewed after rekeying timeout (1 hour)

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- DataEncr key: used to encrypt packets

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EAPOL protection	DataEncr	MIC1	MIC2

- DataEncr key: used to encrypt packets
- MIC keys (Message Integrity Code):
  - Verify integrity of data. But why two?

Why two MIC keys?

- WPA-TKIP designed for old hardware
  - Couldn't use strong integrity checks (CCMP)
- New algorithm called Michael was created
  - Weakness: plaintext + MIC reveals MIC key

- To improve security two MIC keys are used
  - MIC1 for AP to client communication
  - MIC2 for client to AP communication

Sending Packets

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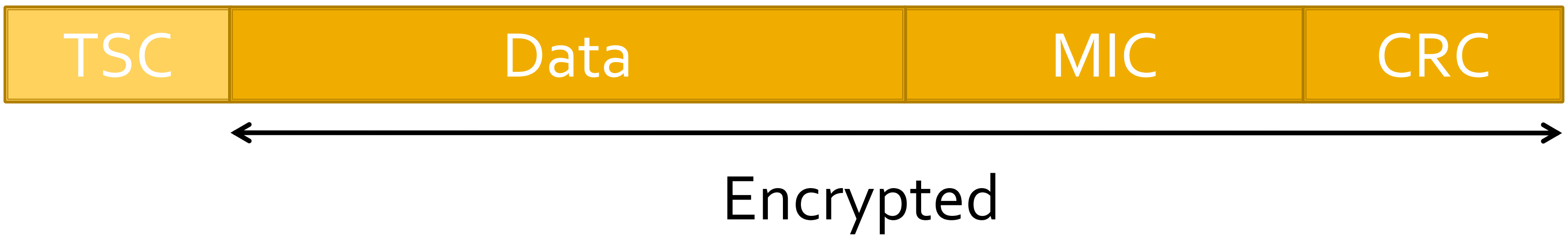

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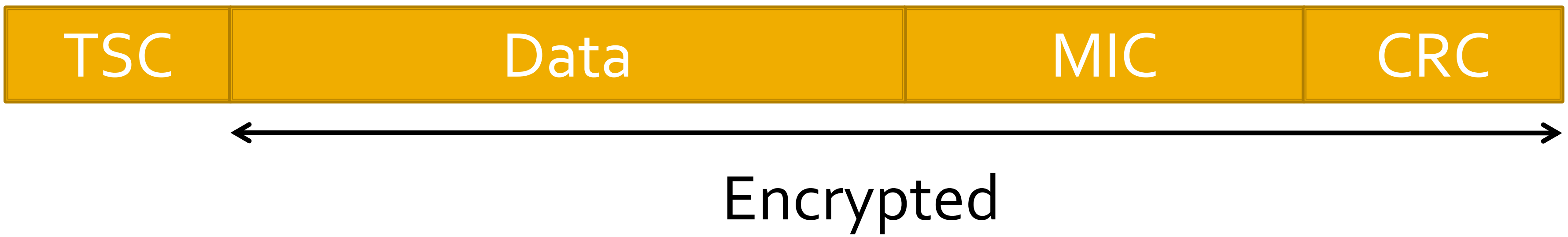

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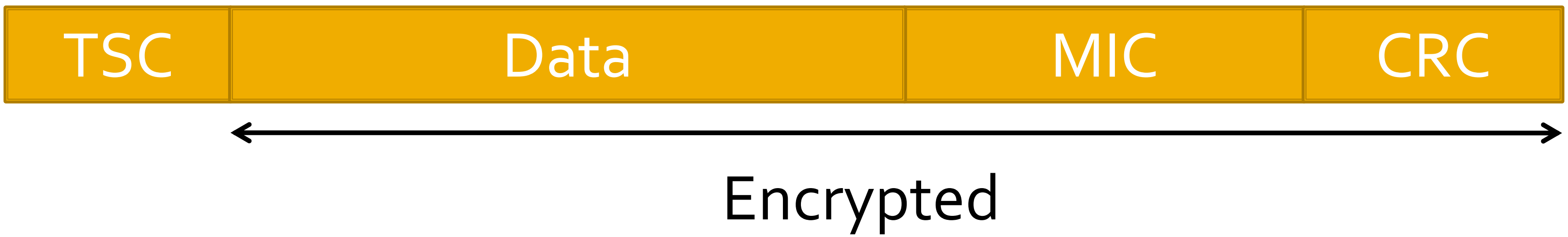

- WEP decapsulation:
  - Verify TSC to prevent replays

Receiving Packets

TSC	Data	MIC	CRC

Encrypted

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Receiving Packets

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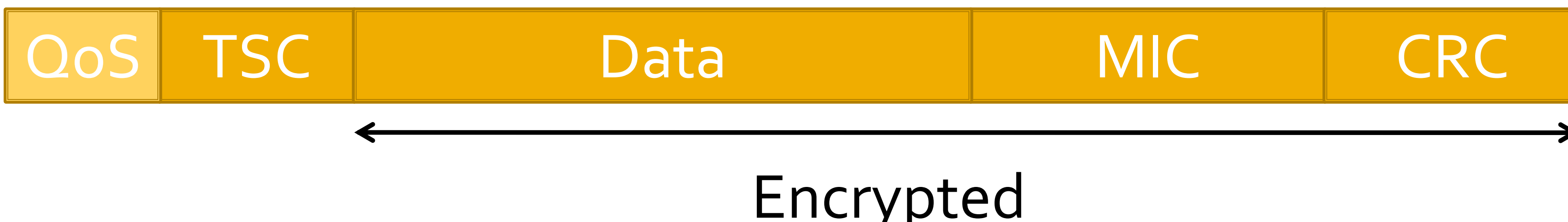
Defense mechanism on MIC failure:

- Client sends MIC failure report to AP
- AP silently logs failure
- Two failures in 1 min: network down for 1 min

Quality of Service (QoS)

- Defines several QoS channels
- Implemented by new field in 802.11 header



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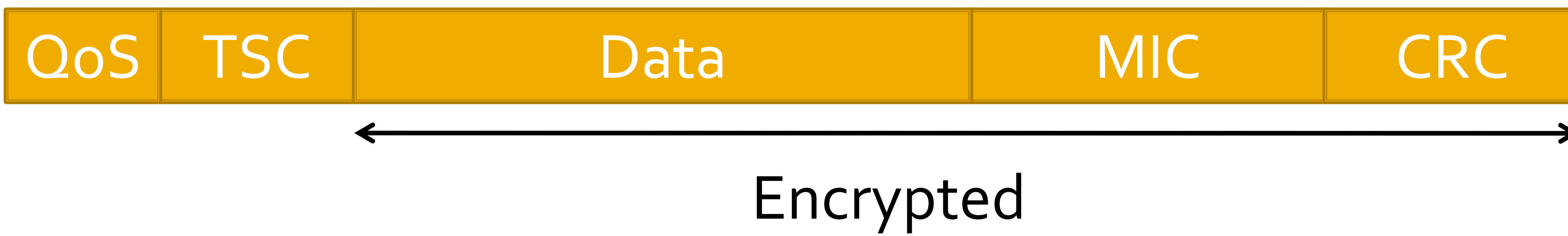

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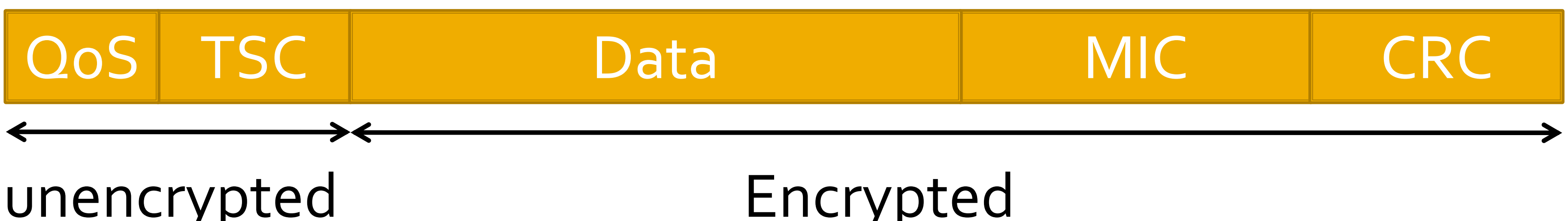

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QoS	TSC	Data	MIC	CRC
unencrypted		Encrypted		

- Individual replay counter (TSC) per channel
- Used to pass replay counter check of receiver!

For Example:

Channel	TSC
0: Best Effort	4000
1: Background	0
2: Video	0
3: Voice	0

- Support for up to 8 channels
- But WiFi certification only requires 4

Integrity check and encryption

- MIC = Michael(MAC dest,
  MAC source,
  MIC key,
  priority,
  data)

- Rc4key = MixKey(MAC transmitter,
  key,
  TSC)

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- What happens when the priority is changed?

Changing the priority

- Capture packet, change priority, replay

On Reception :

- Verify replay counter
- Decrypt packet using RC4
- Verify CRC (leftover from WEP)
- Verify MIC to assure authenticity

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On Reception :

▪ Verify replay counter	OK
▪ Decrypt packet using RC4	OK
▪ Verify CRC (leftover from WEP)	OK
▪ Verify MIC to assure authenticity	**FAIL**

→ Do this twice: Denial of Service

If QoS is disabled?

- Disadvantage: attack fails if QoS is disabled
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[Cryptanalysis for RC4 and breaking WEP/WPA-TKIP]

Time for action: Demo!

Attacker: VMWare vs. Victim: Windows

Comparison

- Example: network with 20 connected clients

- Deauthentication attack:
  - Must continuously sends packets
  - Say 10 deauths per client per second
  - (10 * 60) * 20 = 12 000 frames per minute
- New attack
  - 2 frames per minute

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- Simplified: each byte is decrypted by sending a modified packet for all 256 possible values:
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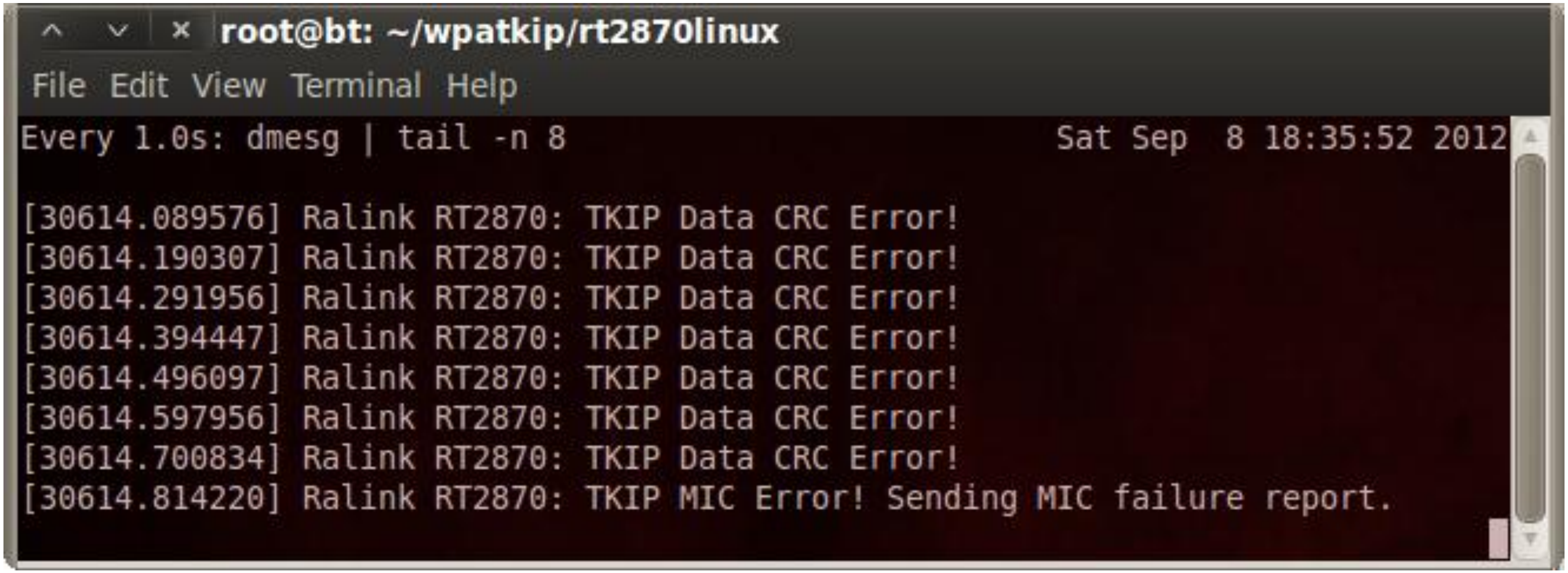
- **MIC key for AP to client**

Beck & Tews Attack



- Takes 12 minutes to execute
- Limited impact: injection of 3-7 small packets

Injecting more packets?

What is needed to inject packets:

- MIC key
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- MIC key
  - Result of Beck & Tews attack
- Unused replay counter
  - Inject packet on unused QoS channel
- Keystream corresponding to replay counter
  - Beck & Tews results in only one keystream…
  - **How can we get more?** First need to know RC4!

Background: RC4 algorithm

- Stream cipher
- XOR-based

This means:

Ciphertext

$\oplus$

Plaintext

=

Keystream

→ Predicting the plaintext gives the keystream

Predicting packets

Simplified:

- All data packets start with LLC header
- Different for APR, IP and EAPOL packets
- Detect ARP & EAPOL based on length
- Everything else: IP

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- All data packets start with LLC header
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- Practice: almost no incorrect guesses!
- Gives us 12 bytes keystream for each packet

Using short keystreams

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If only we could somehow combine them…
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- Using 802.11 fragmentation we can combine 16 keystreams to send one large packet

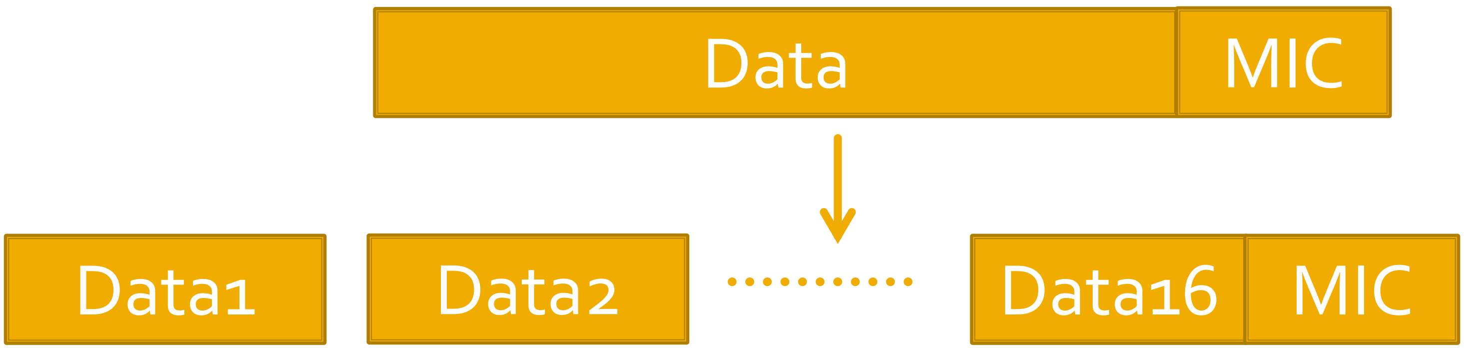
802.11 fragmentation

Data

802.11 fragmentation

- MIC calculated over complete packet

802.11 fragmentation



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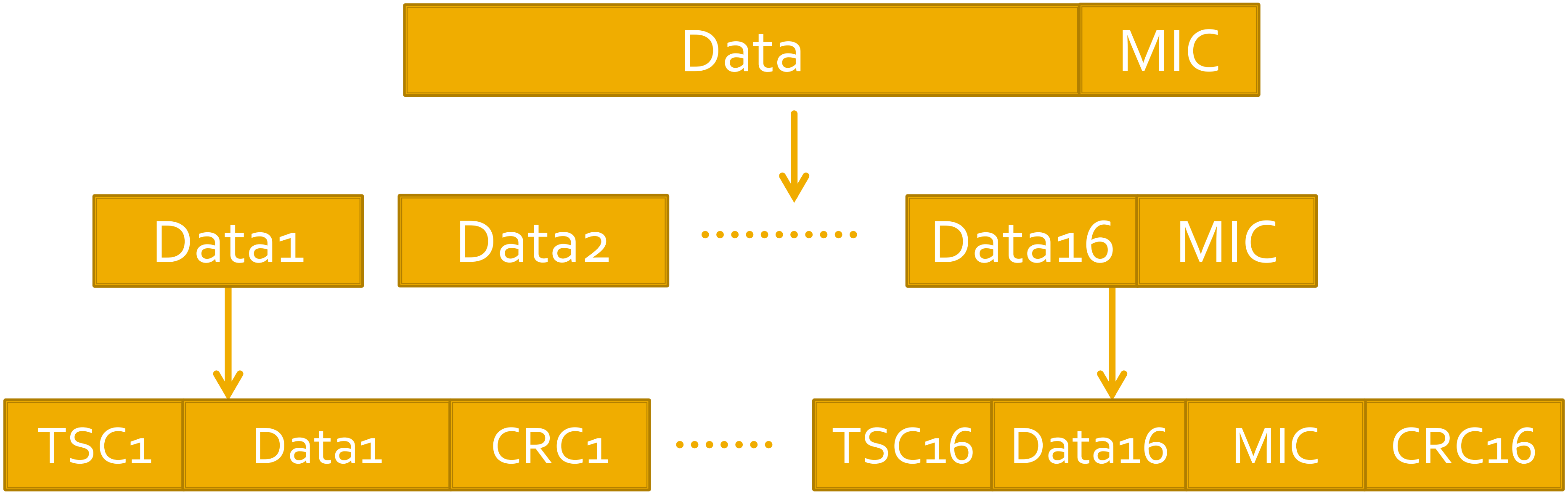

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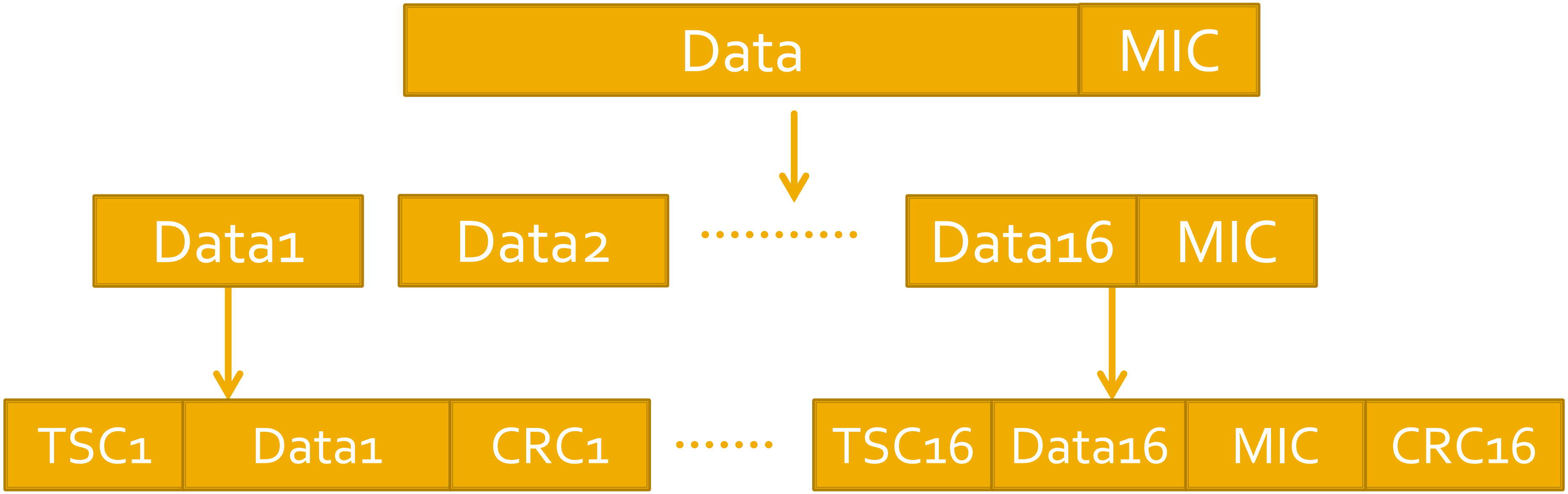
802.11 fragmentation



- MIC calculated over complete packet
- Each fragment has CRC and different TSC
- 12 bytes/keystream: inject 120 bytes of data

Fragmentation Attack

- Beck & Tews attack: MIC key AP to client
- Predict packets & get keystreams
- Combine short keystreams by fragmentation
- Send over unused QoS channel

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What can we do with this?

- ARP/DNS Poisoning
- Sending TCP SYN packets: port scan!

Port scan on TKIP client

A few notes:

- Scan 500 most popular ports
- Detect SYN/ACK based on length
- Avoid multiple SYN/ACK's: send RST

Port scan of internal client:

- Normally not possible
- We are bypassing the network firewall / NAT!

Demo: port scan

Random remark:

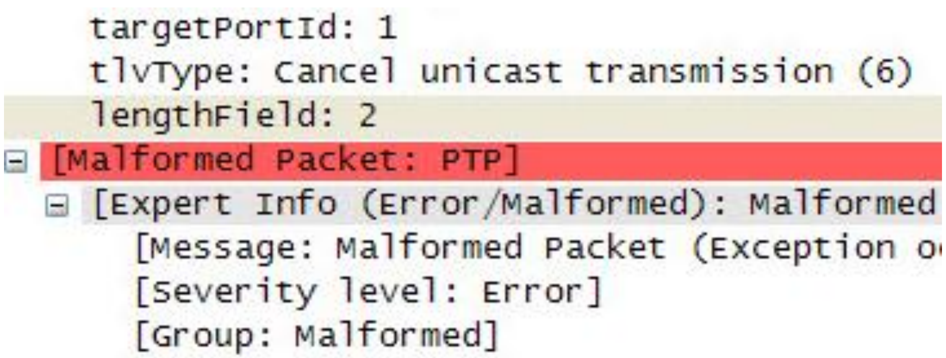
Building packets sucks… ☹

```c
int z;

if ((h80211[0] & 0x0C) != 8)
        return 0; //must be a data packet
if ((h80211[0] & 0x70) != 0)
        return 0;
if ((h80211[1] & 0x40) == 0)
        return 0;

// Get the header length
z = ((h80211[1] & 3) != 3) ? 24 : 30;
if ((h80211[0] & 0x80) == 0x80) /* QoS */
        z += 2;

// Must be a TKIP/CCMP frame
if ((h80211[z + 3] & 0x20) == 0)
        return 0;
```



… until wireshark crashes …

```
root@bt: ~
File Edit View Terminal Help
root@bt:~# wireshark &
[1] 6001
root@bt:~# *** buffer overflow detected ***: wireshark terminated
======= Backtrace: =========
/lib/tls/i686/cmov/libc.so.6(__fortify_fail+0x50)[0xb4885390]
/lib/tls/i686/cmov/libc.so.6(+0xe12ca)[0xb48842ca]
/usr/local/lib/libwireshark.so.2(+0x605980)[0xb561a980]
/usr/local/lib/libwireshark.so.2(+0x9a33f9)[0xb59b83f9]
/usr/local/lib/libwireshark.so.2(+0x9afefb)[0xb59c4efb]
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/usr/local/lib/libwireshark.so.2(+0x9b6fb0)[0xb59cbfb0]
/usr/local/lib/libwireshark.so.2(+0x5ba986)[0xb55cf986]
```
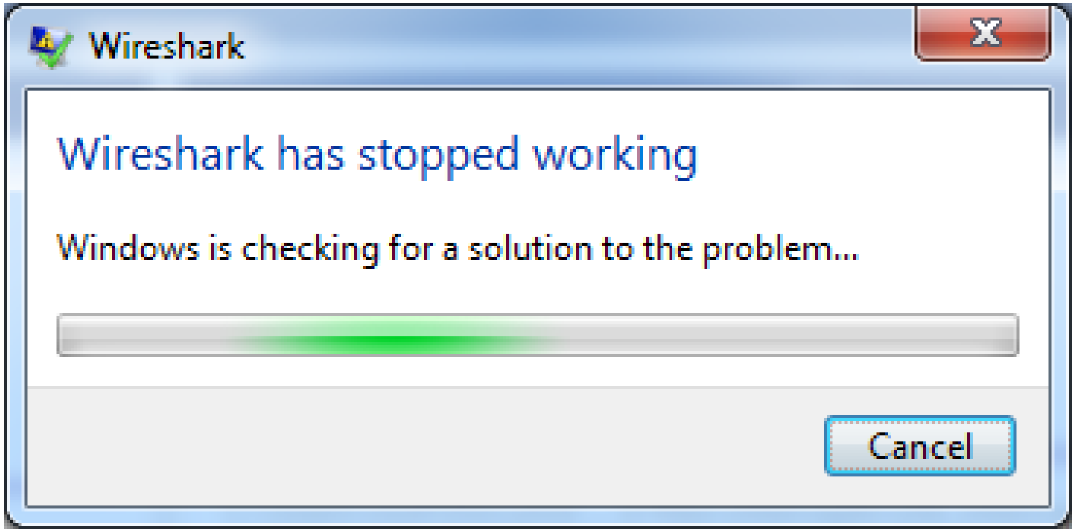

… and it's reproducible

```
tcpdump -i mon0 -w crash.pcap
```



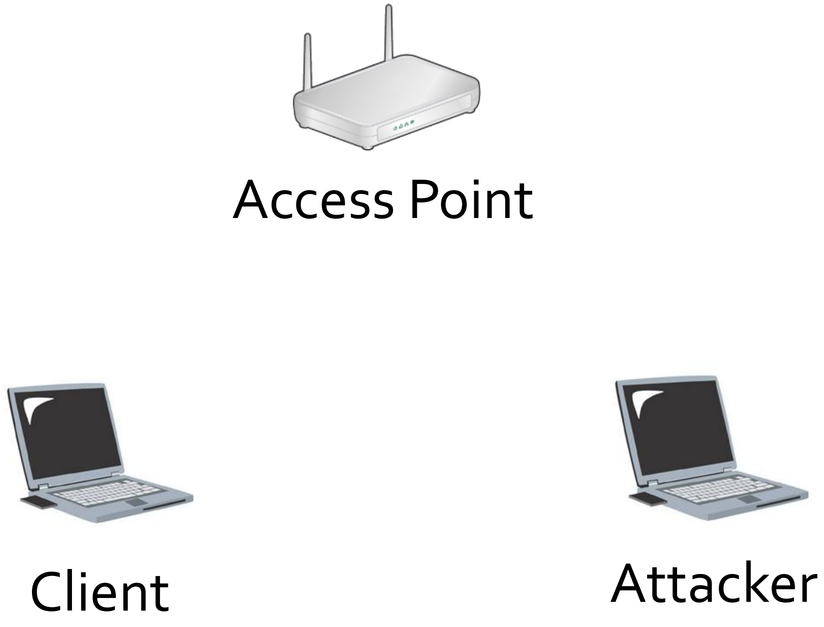
Can we pass the firewall?

- Target will send outgoing SYN/ACK
- Will this go through the firewall/NAT?
- *Normally* not…

Device	SYN/ACK forwarded?
Scarlet VDSL Box	No
WAG320N	No
OpenBSD/PF	No
DD-WRT	When SPI is disabled

If we can pass NAT

- Realistic in practice?
- Bidirectional traffic is possible



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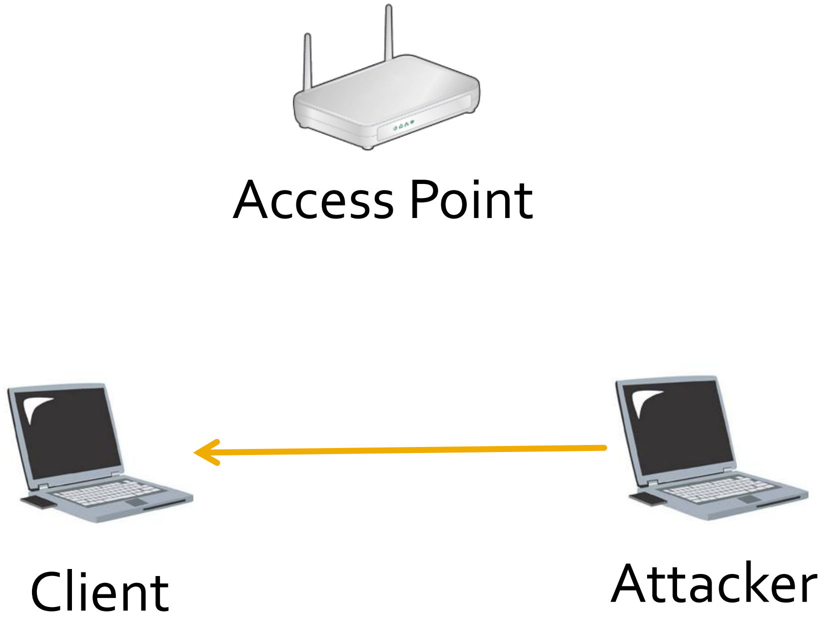

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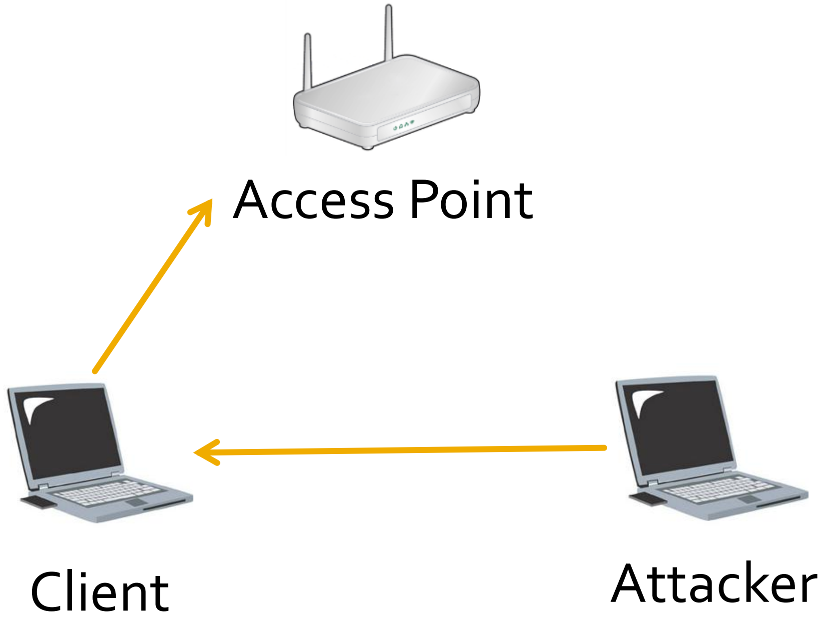

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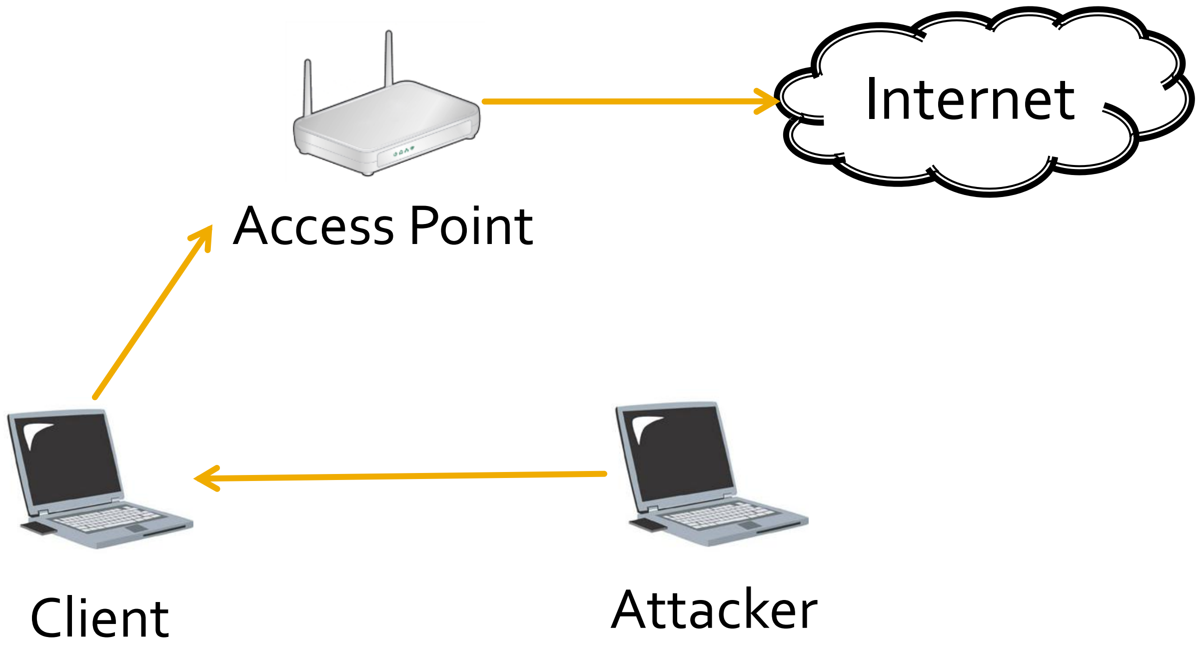

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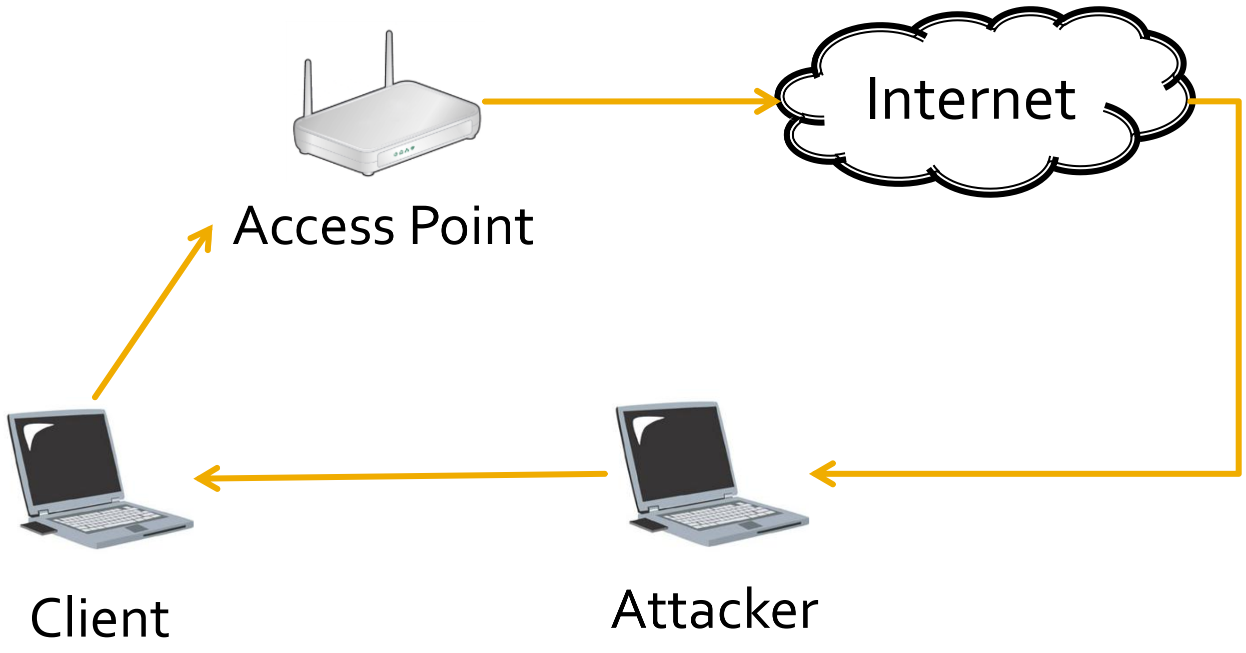

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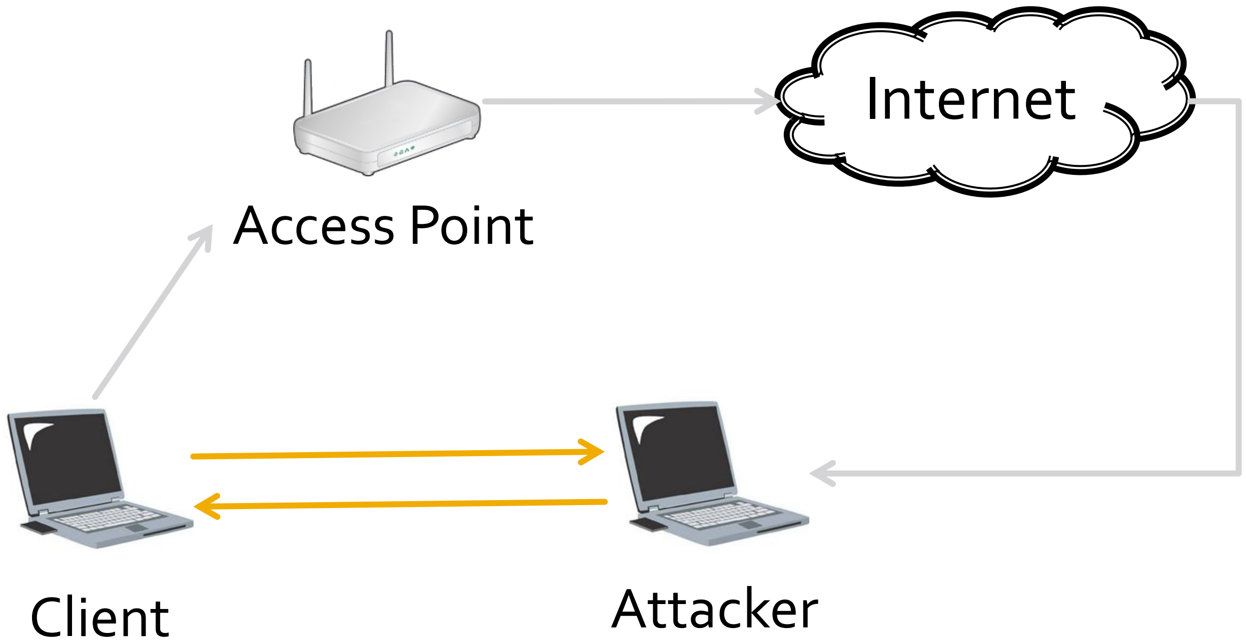
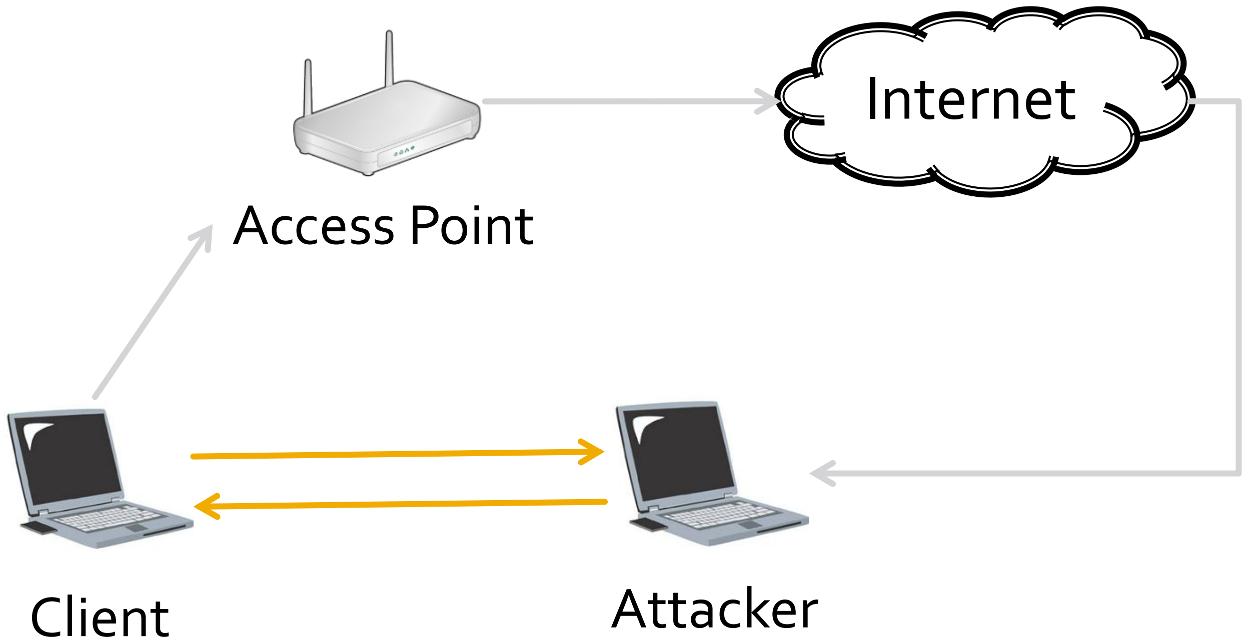


If we can pass NAT

- Realistic in practice?
- **Can connect to open ports**



Worst case scenario

- Client running SSH server with weak password
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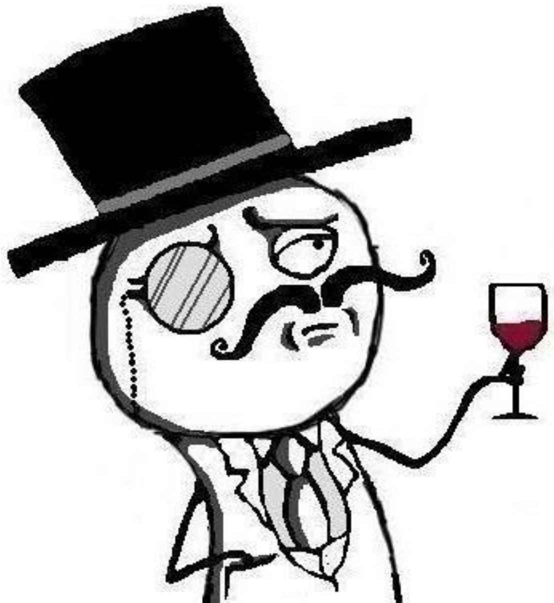
- Dump the network password!



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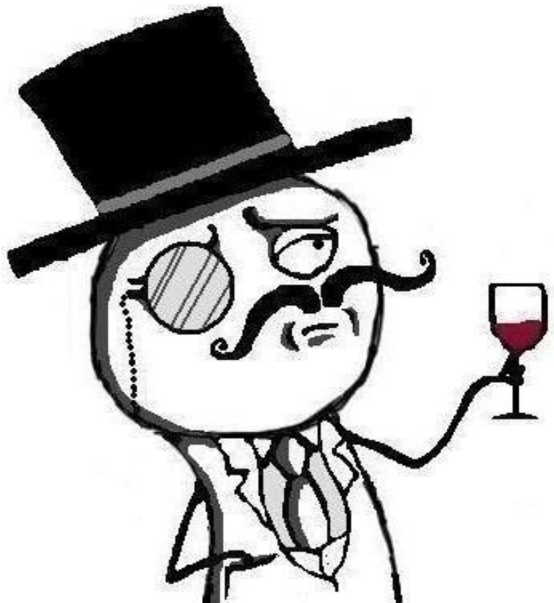

Note: not been tested

Comparison

Beck & Tews:

- Inject 3-7 packets of 28 bytes

Fragmentation:

- Inject *arbitrary* amount of packets
- With a size up to 120 bytes
- Additionally, exploit IP fragmentation to transmit IP packets of arbitrary size

Fun with wireless adapters

Belkin F5D7053:

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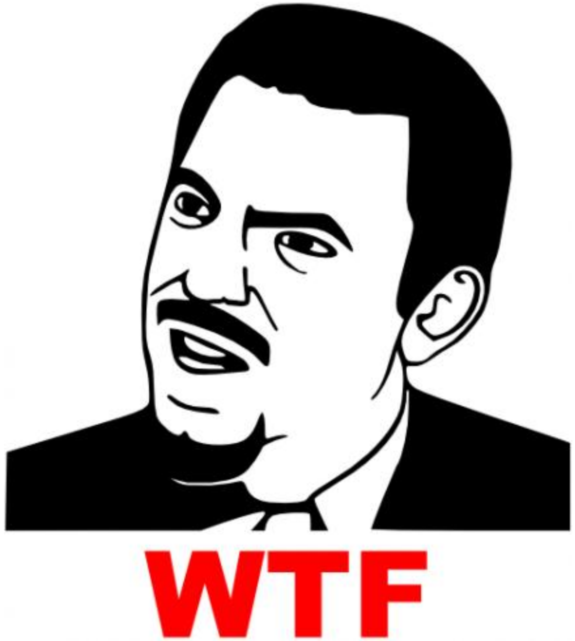

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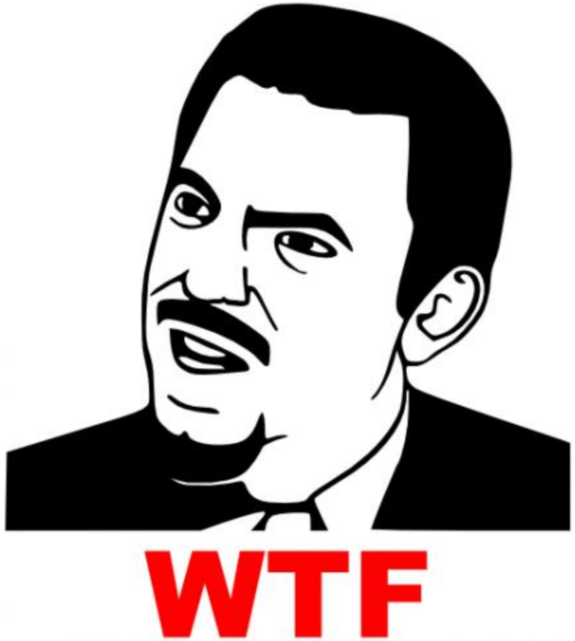

Conclusion

- Very efficient Denial of Service
- Use fragmentation to launch actual attacks

- Forced to use WPA-TKIP?
  - Use short rekeying timeout (2 mins)
  - Disable QoS *and* update drivers (if possible)

- Update to WPA2-AES
  - Specifically set encryption to AES only

Questions?

@vanhoefm

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