Caffé Latte with a Free Topping of Cracked WEP

Retrieving WEP Keys From Road-Warriors

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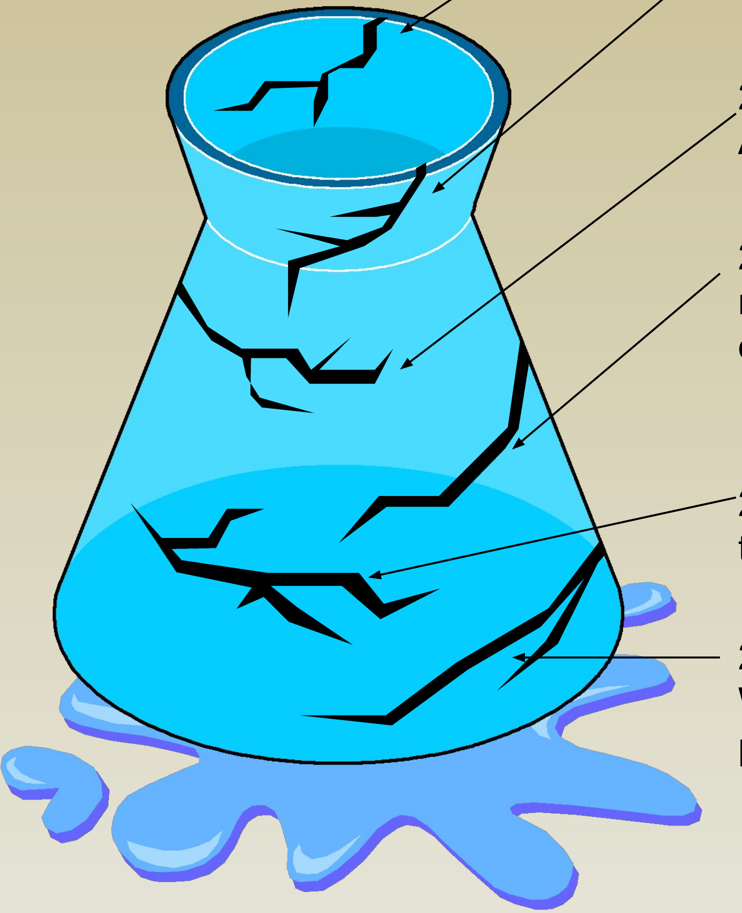
www.airtightnetworks.net

Cracks in WEP -- Historic Evolution

IEEE WG admitted that WEP cannot hold any water. Recommended users to upgrade to WPA, WPA2



2001 - The insecurity of 802.11, Mobicom, July 2001
N. Borisov, I. Goldberg and D. Wagner.

2001 - Weaknesses in the key scheduling algorithm of RC4.
S. Fluhrer, I. Mantin, A. Shamir. Aug 2001.

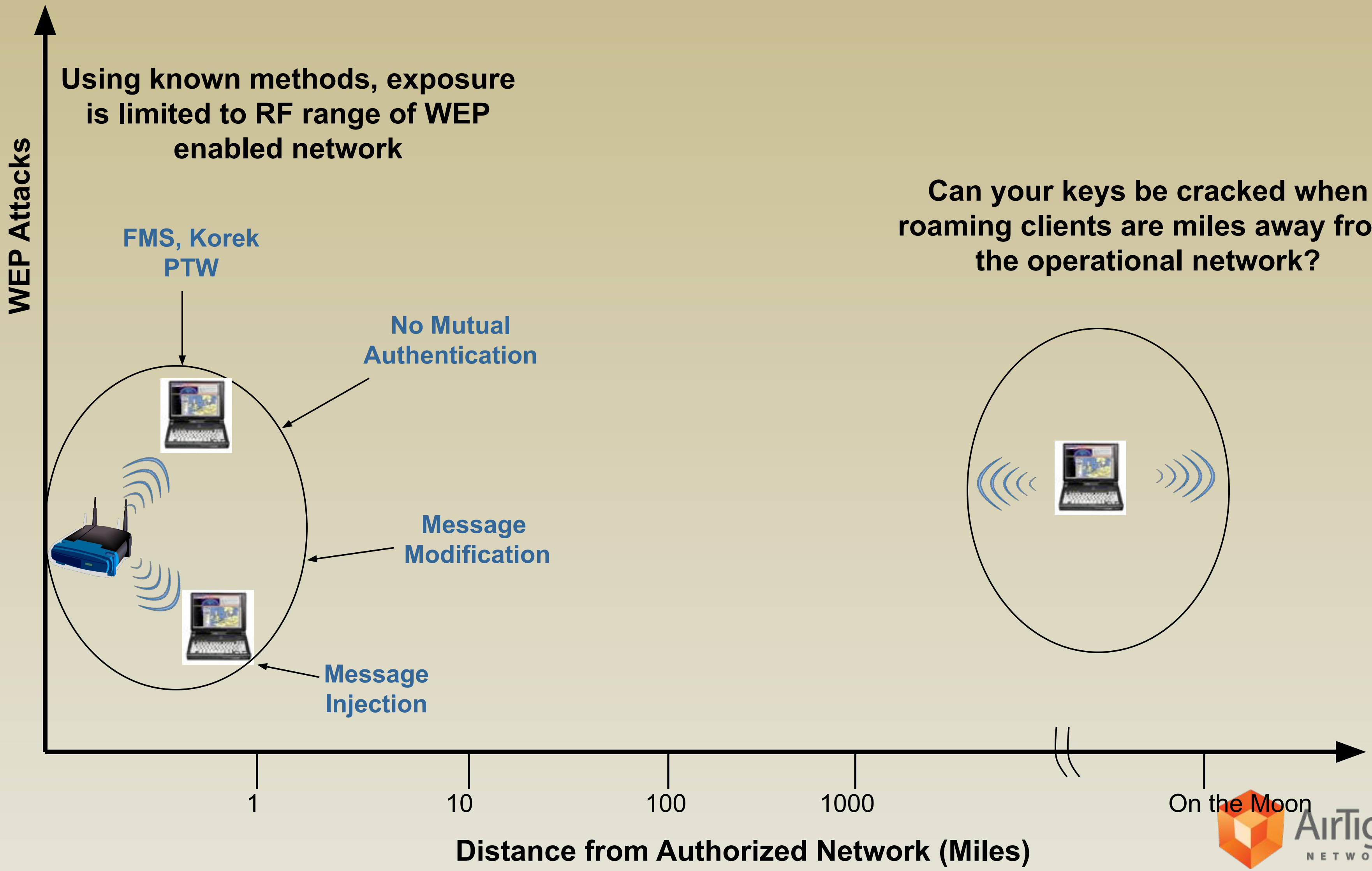
2002 - Using the Fluhrer, Mantin, and Shamir Attack to Break WEP
A. Stubblefield, J. Ioannidis, A. Rubin.

2004 – KoreK, improves on the above technique and reduces the complexity of WEP cracking. We now require only around 500,000 packets to break the WEP key.

2005 – Adreas Klein introduces more correlations between the RC4 key stream and the key.

2007 – PTW extend Andreas technique to further simplify WEP Cracking. Now with just around 60,000 – 90,000 packets it is possible to break the WEP key.

WEP Attacks – exposure area



Using known methods, exposure is limited to RF range of WEP enabled network

FMS, Korek PTW

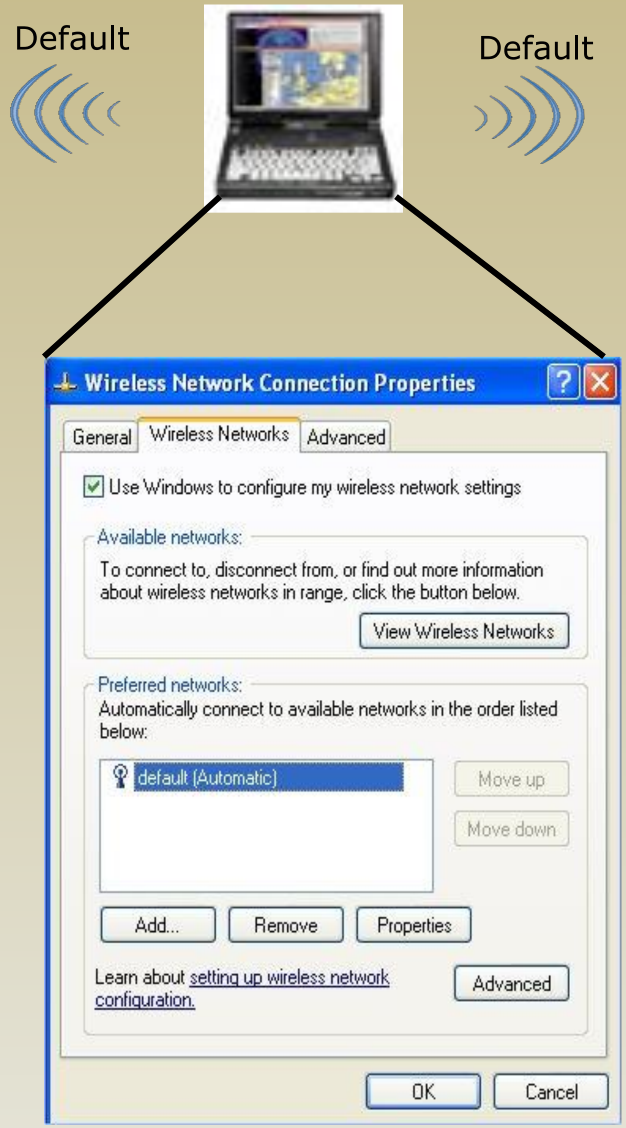
No Mutual Authentication

Message Modification

Message Injection

Can your keys be cracked when roaming clients are miles away from the operational network?

Observation #1



Wireless Network Connection Properties

General | Wireless Networks | Advanced

☑ Use Windows to configure my wireless network settings

Available networks:

To connect to, disconnect from, or find out more information about wireless networks in range, click the button below.

View Wireless Networks

Preferred networks:

Automatically connect to available networks in the order listed below:

default (Automatic)

Move up | Move down

Add... | Remove | Properties

Learn about setting up wireless network configuration.

Advanced

OK | Cancel

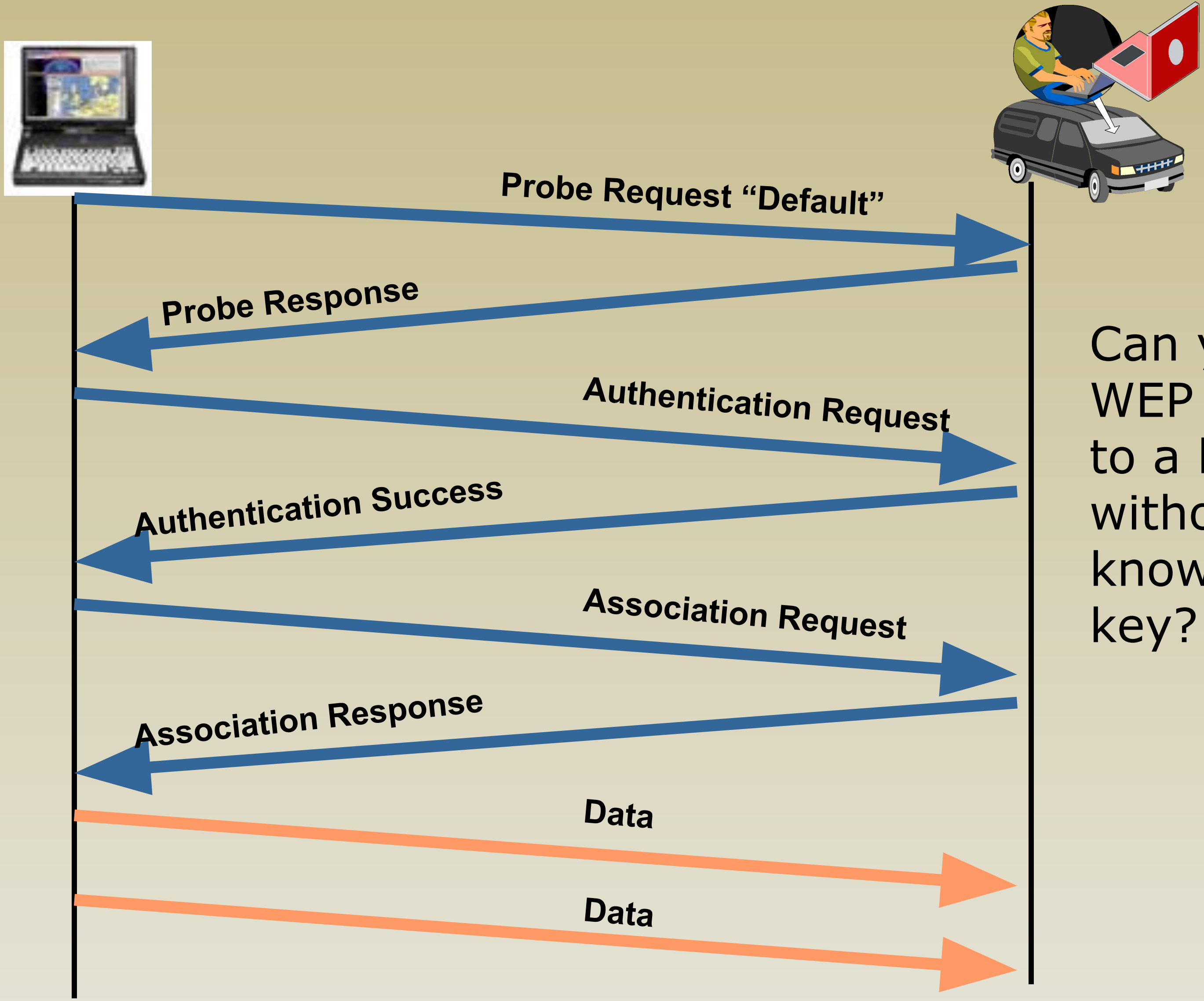
- Can we somehow have an isolated Client generate WEP encrypted data packets using the authorized network's key?

- Windows caches the WEP key of networks in its PNL

- To crack WEP all we need is encrypted data packets
  - 80K for PTW attack
  - 500K for KoreK attack

- It does not matter if these packets come from the AP or the Client

Observation #2



Can you force a WEP client connect to a honey pot without having knowledge of the key?

Caffé Latte – Attack timelines

- Every spoofed Association gives us encrypted data packets (either DHCP or ARP)
- Send a De-auth, process repeats, keep collecting the trace
- Timelines for cracking the WEP key for various network configurations assuming 500k packets is as follows:

Network Configuration	Approximate Cracking time
Shared + DHCP	3 days
Shared + Static IP	1.5 days
Open + DHCP	6 days
Open + Static IP	2 days

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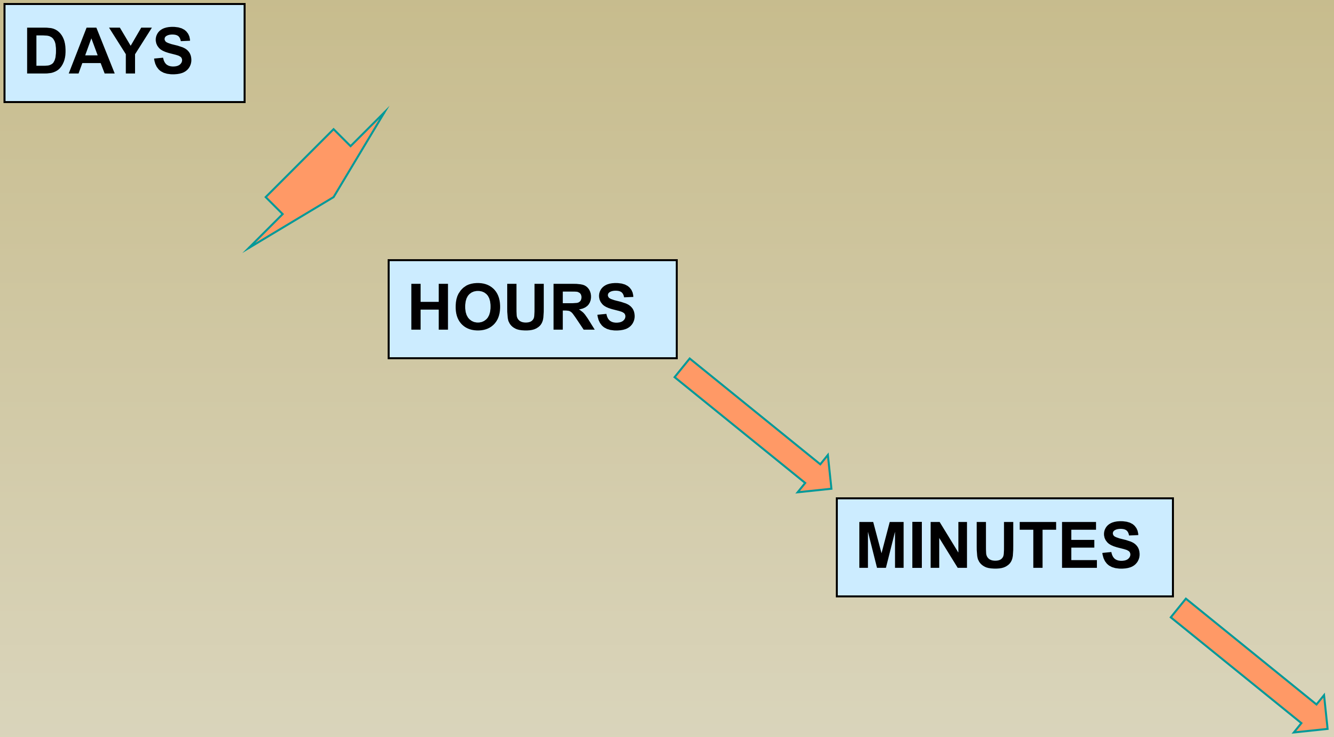
Can we speed it up?



DAYS

HOURS

MINUTES

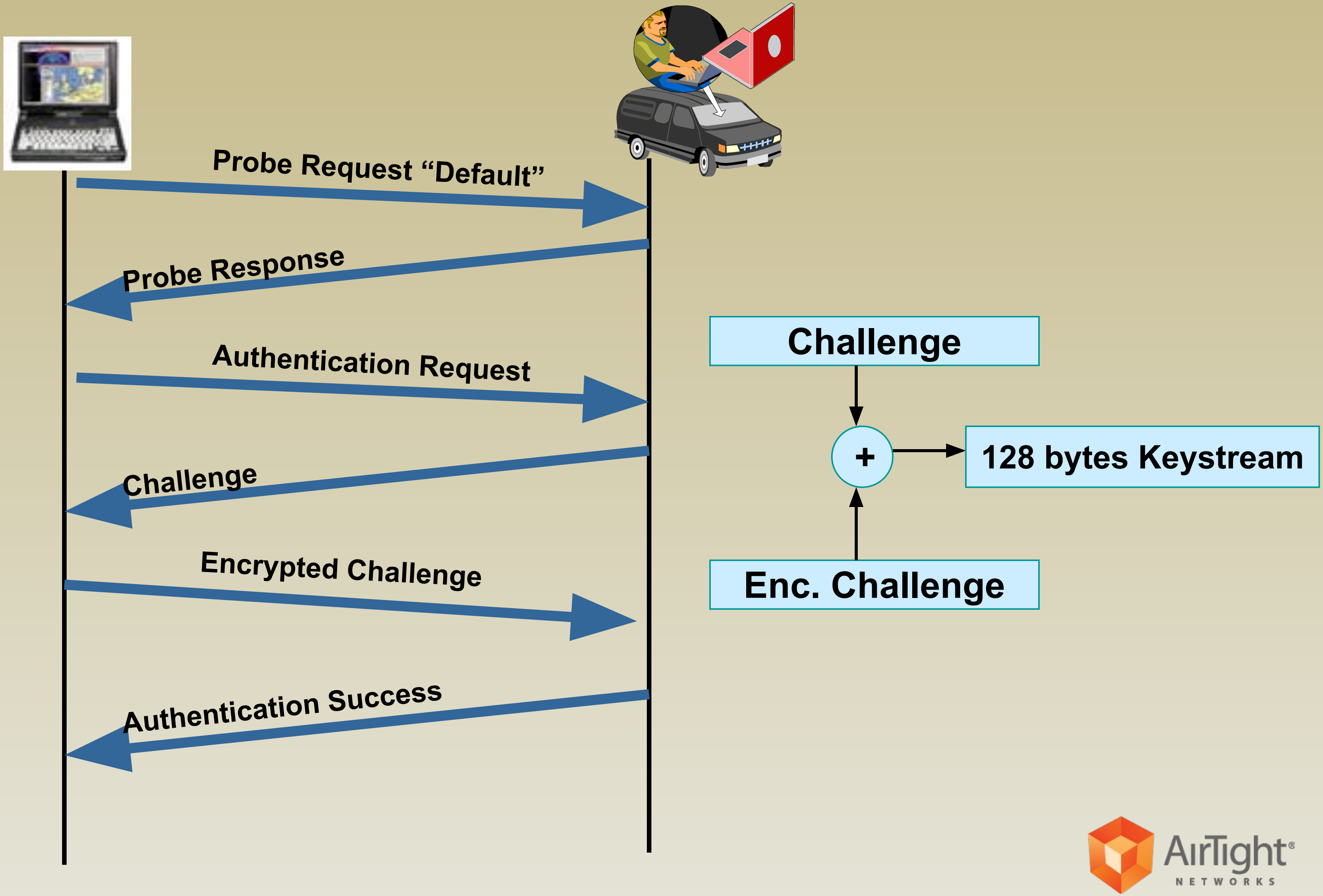
Problem Formulation

Network Configuration	Approximate Cracking time
Shared + DHCP	3 days
Shared + Static IP	1.5 days
Open + DHCP	6 days
Open + Static IP	2 days

A solution is complete **Only if**:

- Solve for all network configurations
- Key cracking should be done by the time a user finishes sipping a cup of coffee

Caffé latte – Shared + DHCP



Probe Request "Default"

Probe Response

Authentication Request

Challenge

Encrypted Challenge

Authentication Success

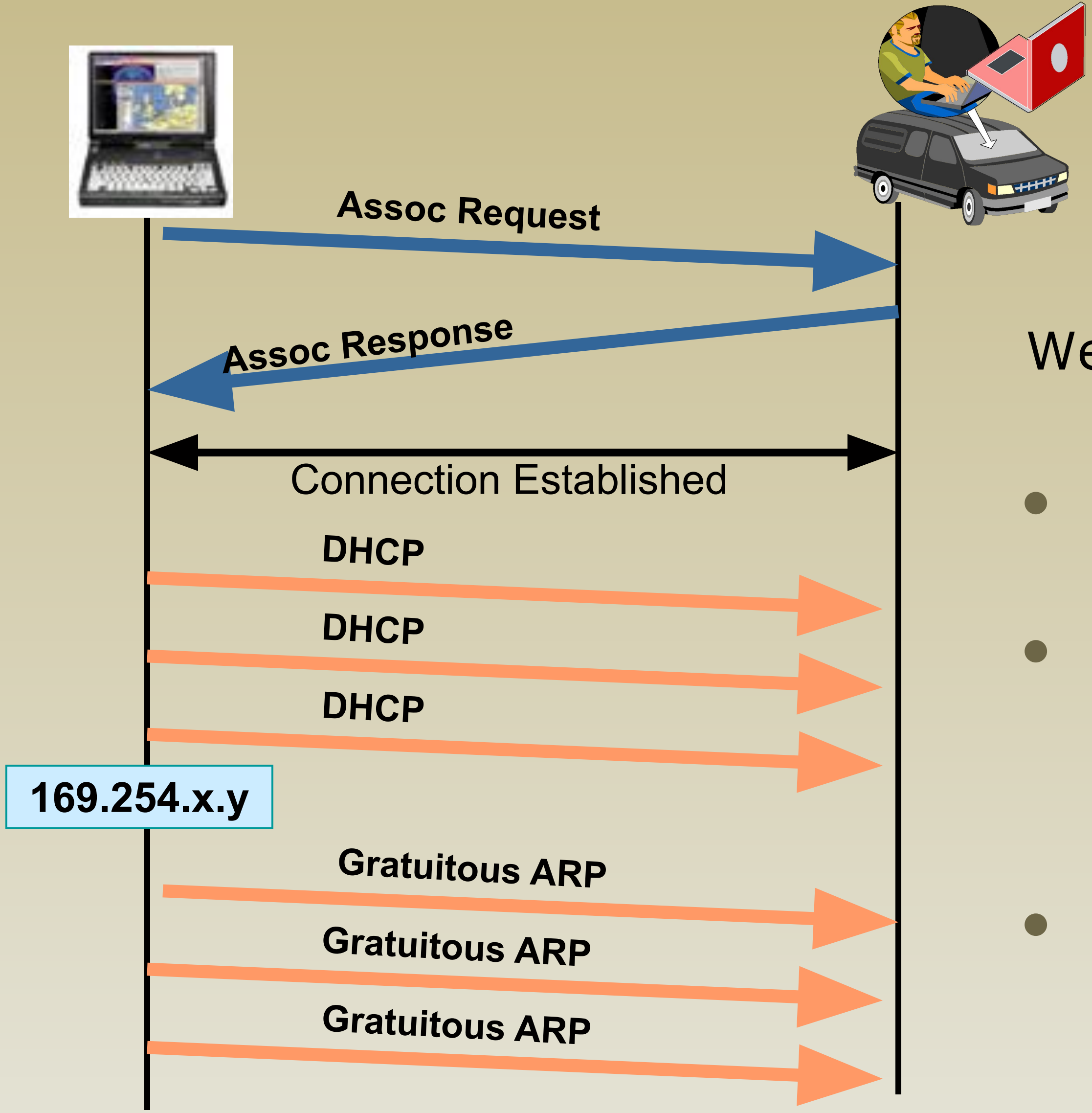
Challenge

+

128 bytes Keystream

Enc. Challenge

Caffe latte – Shared + DHCP (2)



Assoc Request

Assoc Response

Connection Established

DHCP

DHCP

DHCP

169.254.x.y

Gratuitous ARP

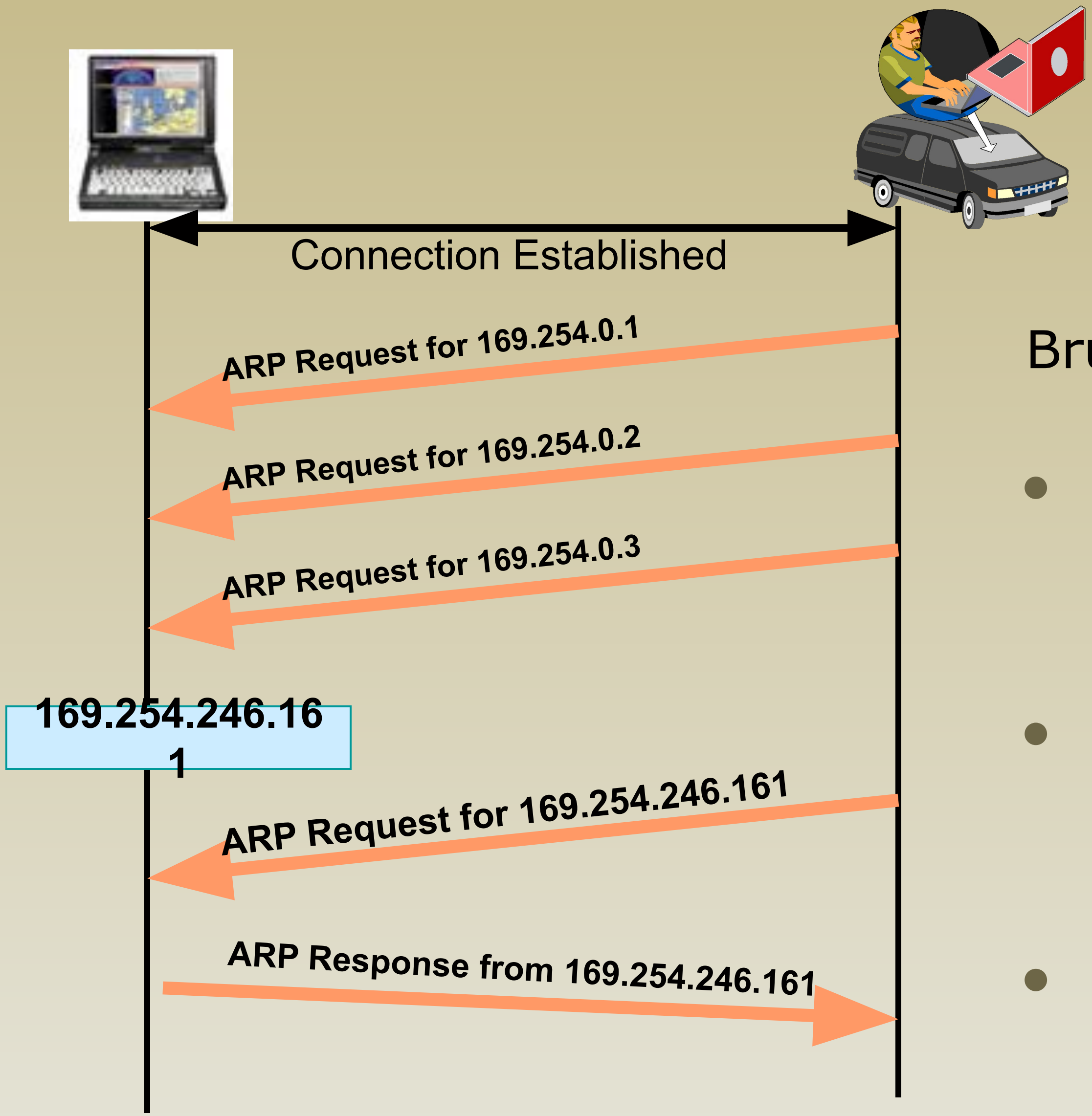
Gratuitous ARP

Gratuitous ARP

We now have:

- 128 bytes of keystream
- Client IP is somewhere between 169.254.0.0 – 169.254.255.255
- Can we find the Client IP?

Caffe latte – Shared + DHCP (3)



Connection Established

ARP Request for 169.254.0.1

ARP Request for 169.254.0.2

ARP Request for 169.254.0.3

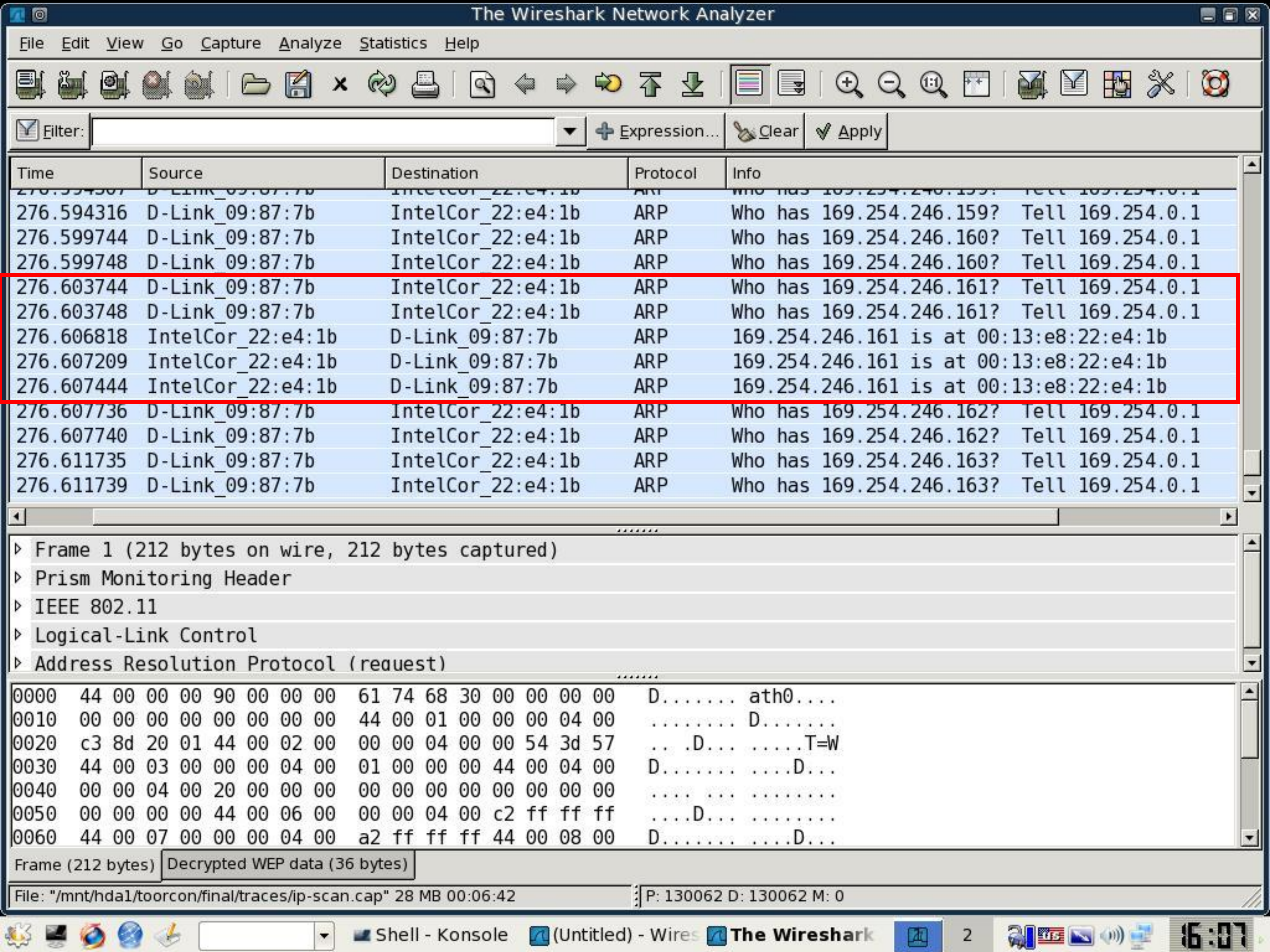
169.254.246.16
1

ARP Request for 169.254.246.161

ARP Response from 169.254.246.161

Brute force the Client IP

- 169.254.0.0 –
169.254.255.255
is ~65,000 space
- ARP Request on wireless is 40 bytes (LLC + ARP +ICV)
- We have a 128 byte key stream from the previous step


The Wireshark Network Analyzer
File Edit View Go Capture Analyze Statistics Help
Filter:
Expression...
Clear
Apply

```
Time        Source              Destination         Protocol  Info
276.594316  D-Link_09:87:7b     IntelCor_22:e4:1b   ARP       Who has 169.254.246.159?  Tell 169.254.0.1
276.599744  D-Link_09:87:7b     IntelCor_22:e4:1b   ARP       Who has 169.254.246.160?  Tell 169.254.0.1
276.599748  D-Link_09:87:7b     IntelCor_22:e4:1b   ARP       Who has 169.254.246.160?  Tell 169.254.0.1
276.603744  D-Link_09:87:7b     IntelCor_22:e4:1b   ARP       Who has 169.254.246.161?  Tell 169.254.0.1
276.603748  D-Link_09:87:7b     IntelCor_22:e4:1b   ARP       Who has 169.254.246.161?  Tell 169.254.0.1
276.606818  IntelCor_22:e4:1b   D-Link_09:87:7b     ARP       169.254.246.161 is at 00:13:e8:22:e4:1b
276.607209  IntelCor_22:e4:1b   D-Link_09:87:7b     ARP       169.254.246.161 is at 00:13:e8:22:e4:1b
276.607444  IntelCor_22:e4:1b   D-Link_09:87:7b     ARP       169.254.246.161 is at 00:13:e8:22:e4:1b
276.607736  D-Link_09:87:7b     IntelCor_22:e4:1b   ARP       Who has 169.254.246.162?  Tell 169.254.0.1
276.607740  D-Link_09:87:7b     IntelCor_22:e4:1b   ARP       Who has 169.254.246.162?  Tell 169.254.0.1
276.611735  D-Link_09:87:7b     IntelCor_22:e4:1b   ARP       Who has 169.254.246.163?  Tell 169.254.0.1
276.611739  D-Link_09:87:7b     IntelCor_22:e4:1b   ARP       Who has 169.254.246.163?  Tell 169.254.0.1
```

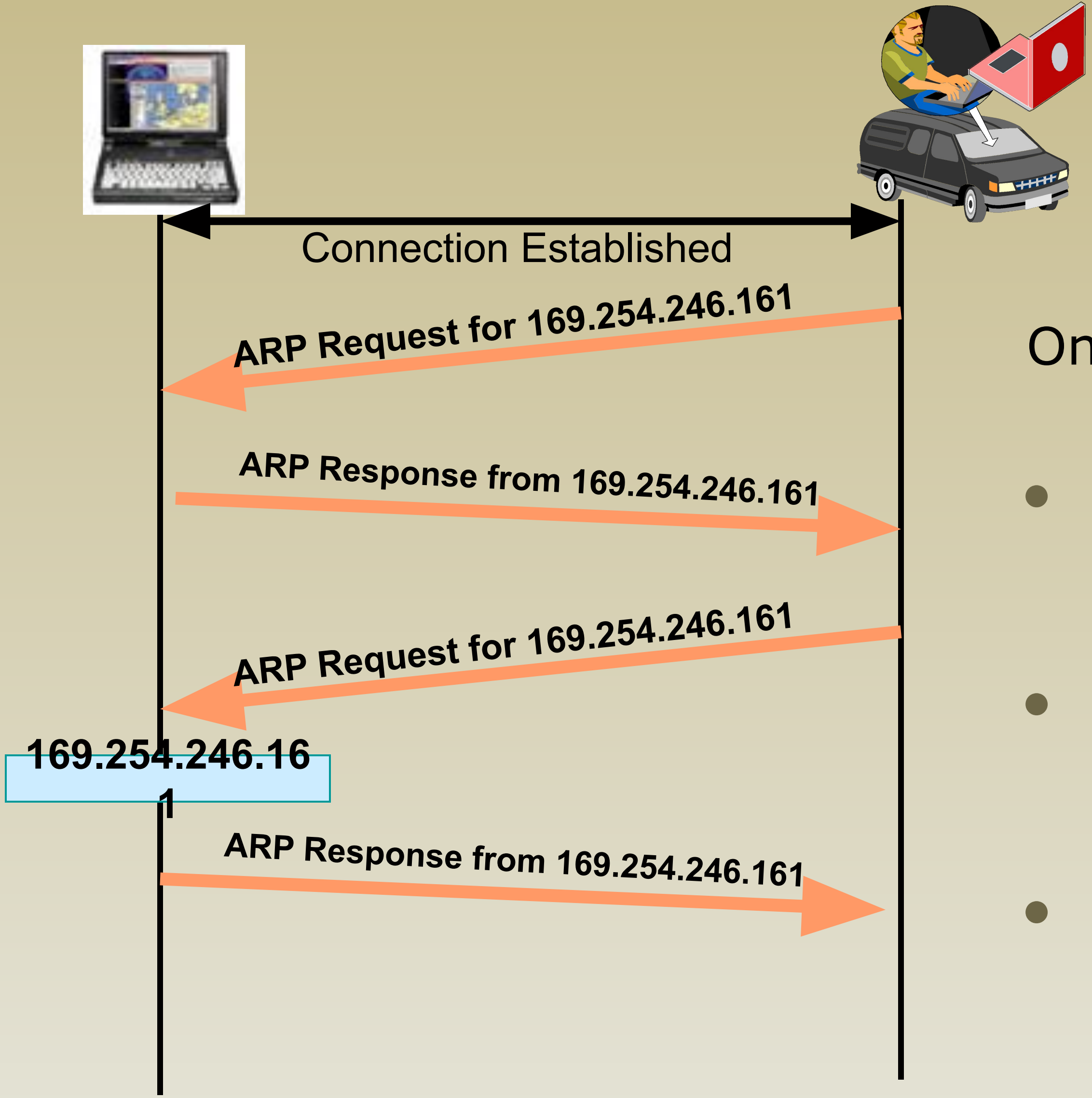
```
▷ Frame 1 (212 bytes on wire, 212 bytes captured)
▷ Prism Monitoring Header
▷ IEEE 802.11
▷ Logical-Link Control
▷ Address Resolution Protocol (request)
```

```
0000  44 00 00 00 90 00 00 00  61 74 68 30 00 00 00 00   D....... ath0....
0010  00 00 00 00 00 00 00 00  44 00 01 00 00 00 04 00   ........ D.......
0020  c3 8d 20 01 44 00 02 00  00 00 04 00 00 54 3d 57   .. .D... .....T=W
0030  44 00 03 00 00 00 04 00  01 00 00 00 44 00 04 00   D....... ....D...
0040  00 00 04 00 20 00 00 00  00 00 00 00 00 00 00 00   .... ... ........
0050  00 00 00 00 44 00 06 00  00 00 04 00 c2 ff ff ff   ....D... ........
0060  44 00 07 00 00 00 04 00  a2 ff ff ff 44 00 08 00   D....... ....D...
```

File: "/mnt/hda1/toorcon/final/traces/ip-scan.cap" 28 MB 00:06:42

P: 130062 D: 130062 M: 0

Caffe latte – Shared + DHCP (4)


Connection Established
ARP Request for 169.254.246.161
ARP Response from 169.254.246.161
ARP Request for 169.254.246.161
169.254.246.16
1
ARP Response from 169.254.246.161

Once the Client IP is known

- Send a flood of ARP Requests
- Client will reply back with ARP Responses
- Start trace collection and run the PTW attack ☺

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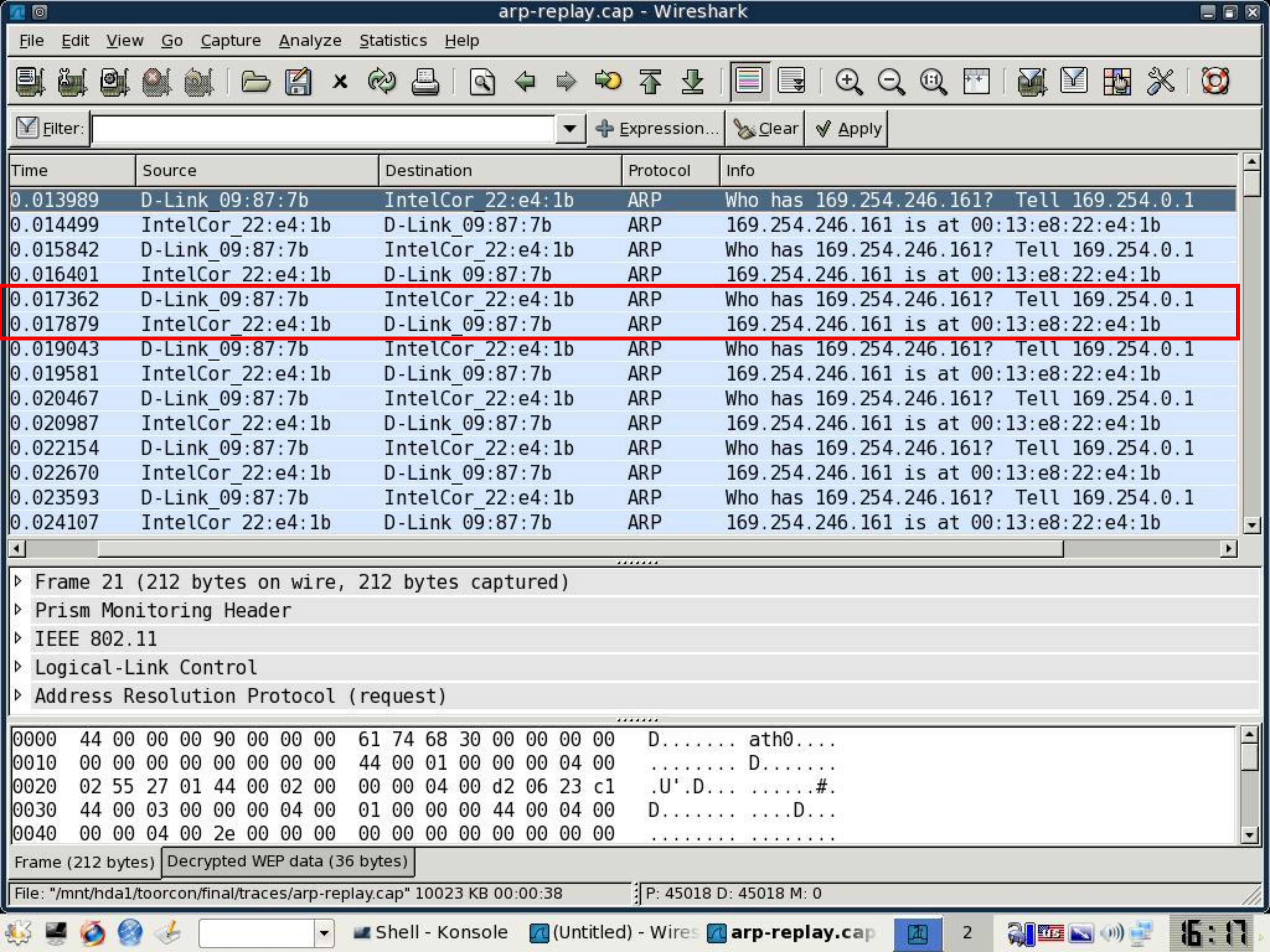


Time	Source	Destination	Protocol	Info
0.013989	D-Link_09:87:7b	IntelCor_22:e4:1b	ARP	Who has 169.254.246.161? Tell 169.254.0.1
0.014499	IntelCor_22:e4:1b	D-Link_09:87:7b	ARP	169.254.246.161 is at 00:13:e8:22:e4:1b
0.015842	D-Link_09:87:7b	IntelCor_22:e4:1b	ARP	Who has 169.254.246.161? Tell 169.254.0.1
0.016401	IntelCor_22:e4:1b	D-Link_09:87:7b	ARP	169.254.246.161 is at 00:13:e8:22:e4:1b
0.017362	D-Link_09:87:7b	IntelCor_22:e4:1b	ARP	Who has 169.254.246.161? Tell 169.254.0.1
0.017879	IntelCor_22:e4:1b	D-Link_09:87:7b	ARP	169.254.246.161 is at 00:13:e8:22:e4:1b
0.019043	D-Link_09:87:7b	IntelCor_22:e4:1b	ARP	Who has 169.254.246.161? Tell 169.254.0.1
0.019581	IntelCor_22:e4:1b	D-Link_09:87:7b	ARP	169.254.246.161 is at 00:13:e8:22:e4:1b
0.020467	D-Link_09:87:7b	IntelCor_22:e4:1b	ARP	Who has 169.254.246.161? Tell 169.254.0.1
0.020987	IntelCor_22:e4:1b	D-Link_09:87:7b	ARP	169.254.246.161 is at 00:13:e8:22:e4:1b
0.022154	D-Link_09:87:7b	IntelCor_22:e4:1b	ARP	Who has 169.254.246.161? Tell 169.254.0.1
0.022670	IntelCor_22:e4:1b	D-Link_09:87:7b	ARP	169.254.246.161 is at 00:13:e8:22:e4:1b
0.023593	D-Link_09:87:7b	IntelCor_22:e4:1b	ARP	Who has 169.254.246.161? Tell 169.254.0.1
0.024107	IntelCor_22:e4:1b	D-Link_09:87:7b	ARP	169.254.246.161 is at 00:13:e8:22:e4:1b

```
▷ Frame 21 (212 bytes on wire, 212 bytes captured)
▷ Prism Monitoring Header
▷ IEEE 802.11
▷ Logical-Link Control
▷ Address Resolution Protocol (request)
```

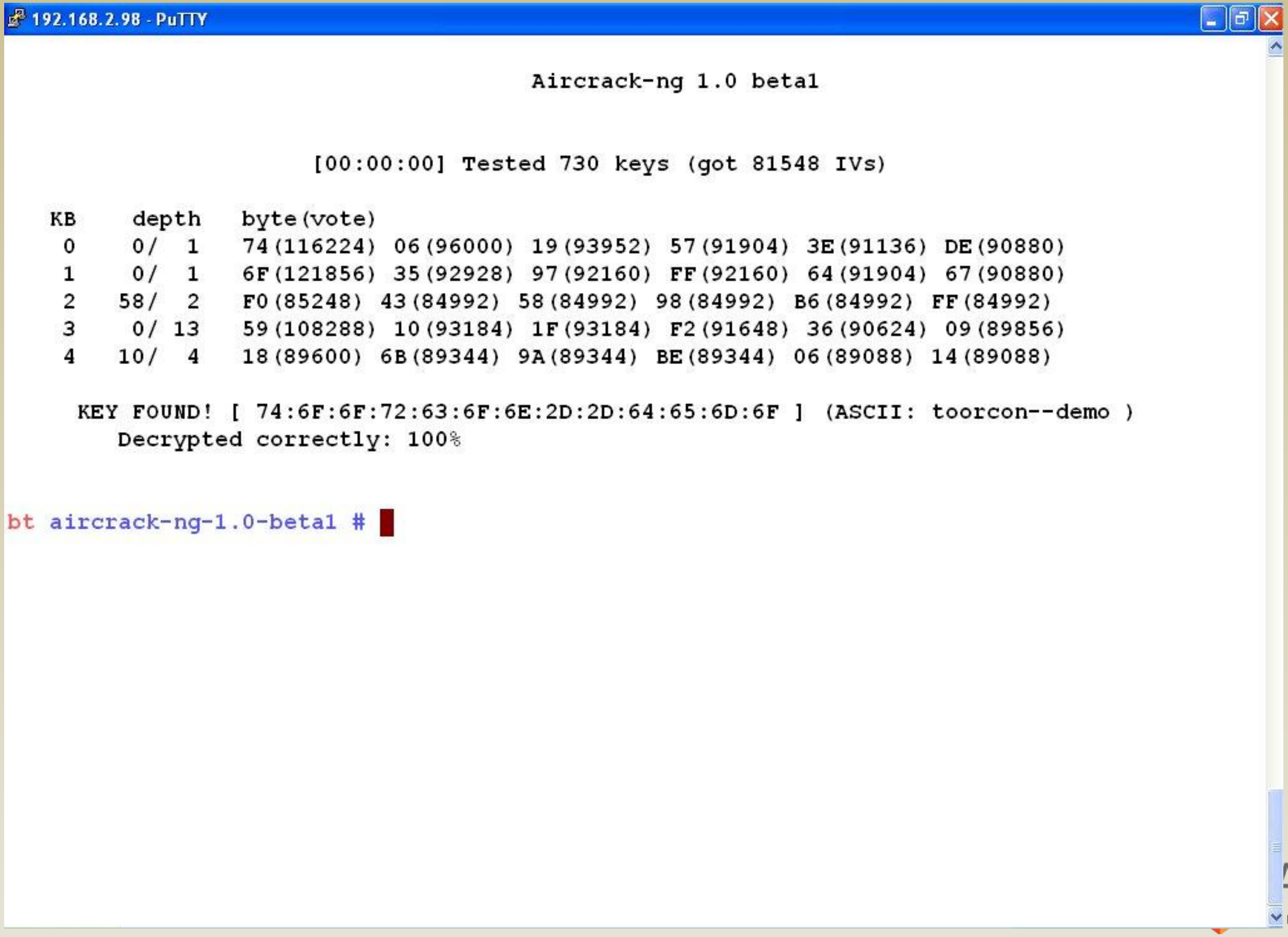
```
0000  44 00 00 00 90 00 00 00  61 74 68 30 00 00 00 00   D....... ath0....
0010  00 00 00 00 00 00 00 00  44 00 01 00 00 00 04 00   ........ D.......
0020  02 55 27 01 44 00 02 00  00 00 04 00 d2 06 23 c1   .U'.D... ......#.
0030  44 00 03 00 00 00 04 00  01 00 00 00 44 00 04 00   D....... ....D...
0040  00 00 04 00 2e 00 00 00  00 00 00 00 00 00 00 00   ........ ........
```

Frame (212 bytes) | Decrypted WEP data (36 bytes)

File: "/mnt/hda1/toorcon/final/traces/arp-replay.cap" 10023 KB 00:00:38 | P: 45018 D: 45018 M: 0

Caffé latte – Shared + DHCP (5)

- Once we have around 80,000 ARP Response packets: ☺ ☺ ☺



```
                                   Aircrack-ng 1.0 beta1


                       [00:00:00] Tested 730 keys (got 81548 IVs)

   KB    depth   byte(vote)
    0    0/  1   74(116224) 06(96000) 19(93952) 57(91904) 3E(91136) DE(90880)
    1    0/  1   6F(121856) 35(92928) 97(92160) FF(92160) 64(91904) 67(90880)
    2   58/  2   F0(85248) 43(84992) 58(84992) 98(84992) B6(84992) FF(84992)
    3    0/ 13   59(108288) 10(93184) 1F(93184) F2(91648) 36(90624) 09(89856)
    4   10/  4   18(89600) 6B(89344) 9A(89344) BE(89344) 06(89088) 14(89088)

     KEY FOUND! [ 74:6F:6F:72:63:6F:6E:2D:2D:64:65:6D:6F ] (ASCII: toorcon--demo )
        Decrypted correctly: 100%


bt aircrack-ng-1.0-beta1 #
```

Caffé Latte for Shared Auth + DHCP - Analysis

- Client IP Discovery phase: 3-4 minutes (send 2 packets for each IP)
- ARP Request/Response Flood: 4-5 minutes (to get around 80,000 packets)
- Key cracking with Aircrack-ng: ~1 minute

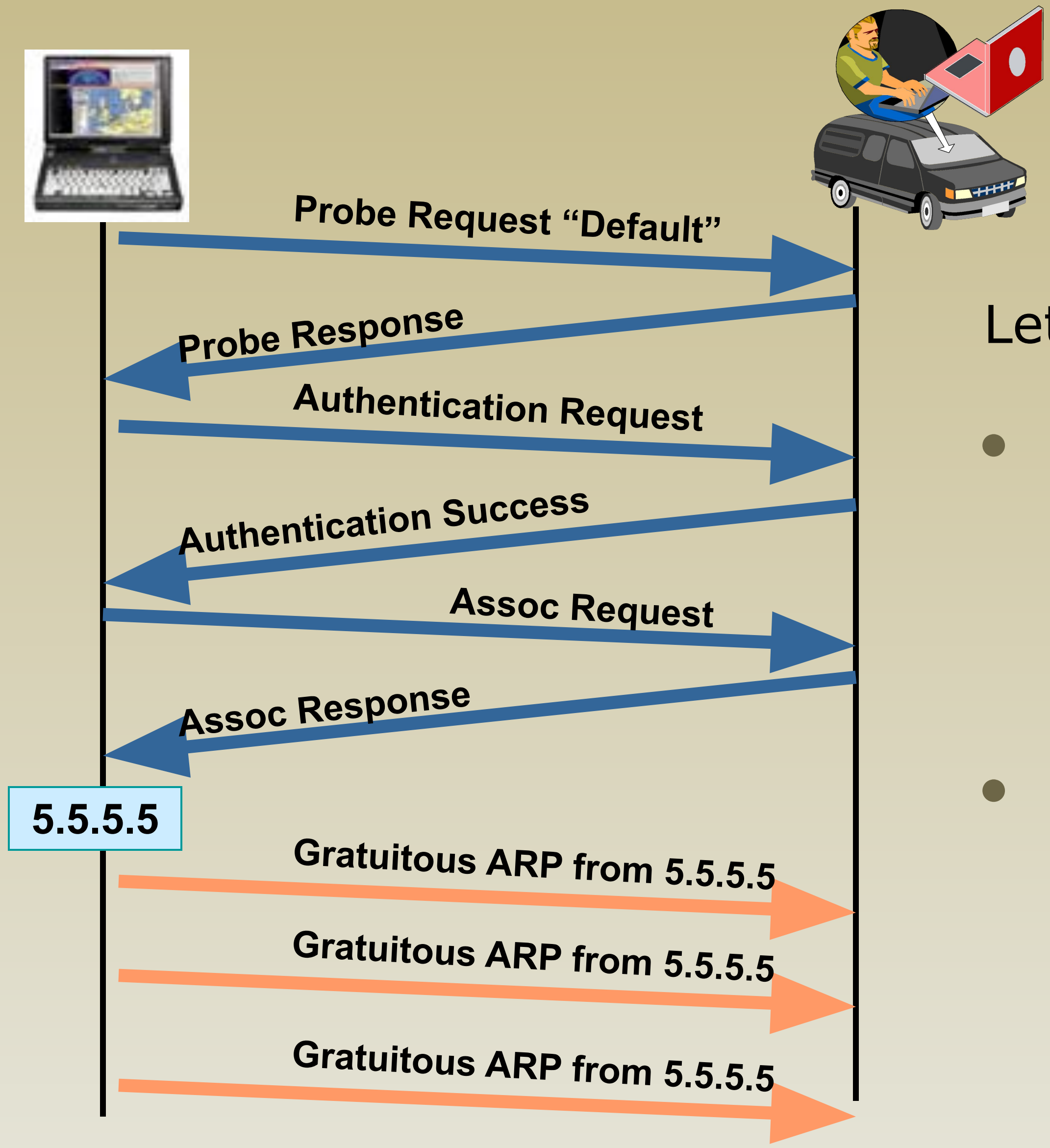
Can this technique be used for the other configurations as well?

Network Configuration	Approximate Cracking time
Shared + DHCP	~ 10 mins
Shared + Static IP	1.5 days
Open + DHCP	6 days
Open + Static IP	2 days

Is there a more general solution to the problem ?

Lets look at the Open + Static IP case

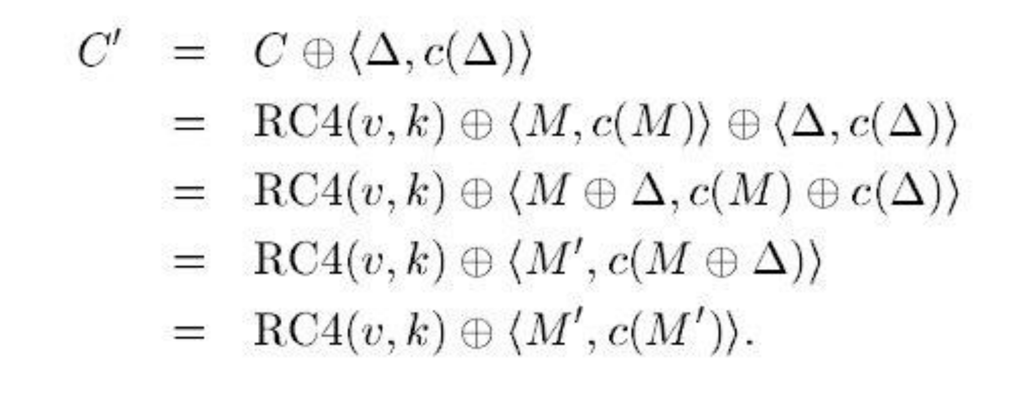
Caffé latte – Open + Static IP



Lets say Client IP is 5.5.5.5

- After Association, the Client sends Gratuitous ARP for 5.5.5.5
- Can we use this ARP packet somehow?

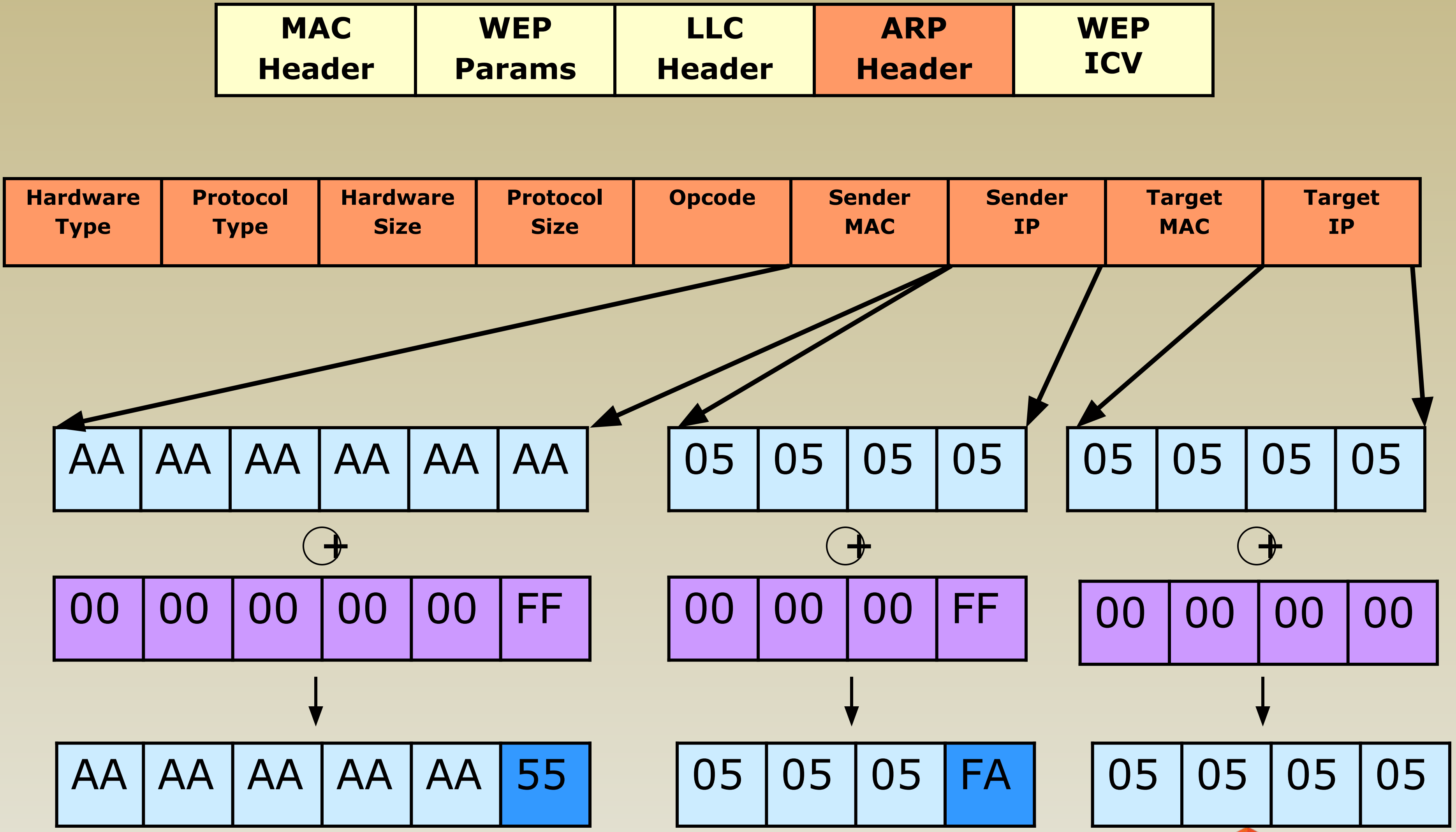
Using flaws in WEP – Message Modification and Message Replay



$$\begin{aligned} C' &= C \oplus \langle \Delta, c(\Delta) \rangle \\ &= \mathrm{RC4}(v,k) \oplus \langle M, c(M) \rangle \oplus \langle \Delta, c(\Delta) \rangle \\ &= \mathrm{RC4}(v,k) \oplus \langle M \oplus \Delta, c(M) \oplus c(\Delta) \rangle \\ &= \mathrm{RC4}(v,k) \oplus \langle M', c(M \oplus \Delta) \rangle \\ &= \mathrm{RC4}(v,k) \oplus \langle M', c(M') \rangle. \end{aligned}$$

- First mention in “Intercepting Mobile Communication: The Insecurity of 802.11” – Nikita, Ian and David, UC Berkley
- It’s possible to flip bits in a WEP encrypted packet and adjust the ICV to make the packet valid
- This packet can now be replayed back into the air and will be accepted by WEP devices
- Using this technique we can convert a Gratuitous ARP request into an ARP request destined for the Client coming from a different IP address

Applying Bit Flipping to an Encrypted ARP packet



MAC Header	WEP Params	LLC Header	ARP Header	WEP ICV

Hardware Type	Protocol Type	Hardware Size	Protocol Size	Opcode	Sender MAC	Sender IP	Target MAC	Target IP

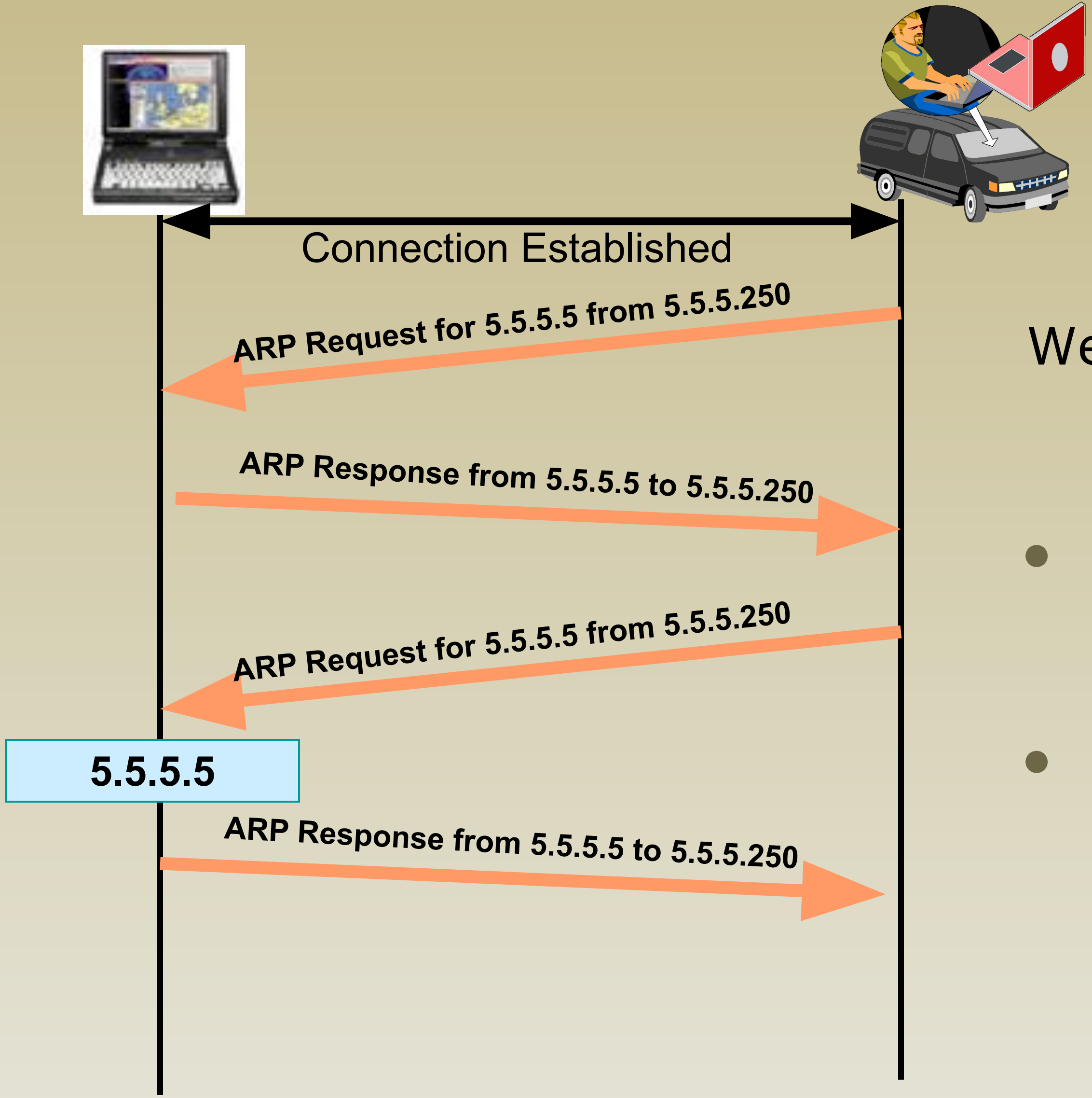
AA	AA	AA	AA	AA	AA
00	00	00	00	00	FF
AA	AA	AA	AA	AA	55

05	05	05	05
00	00	00	FF
05	05	05	FA

05	05	05	05
00	00	00	00
05	05	05	05

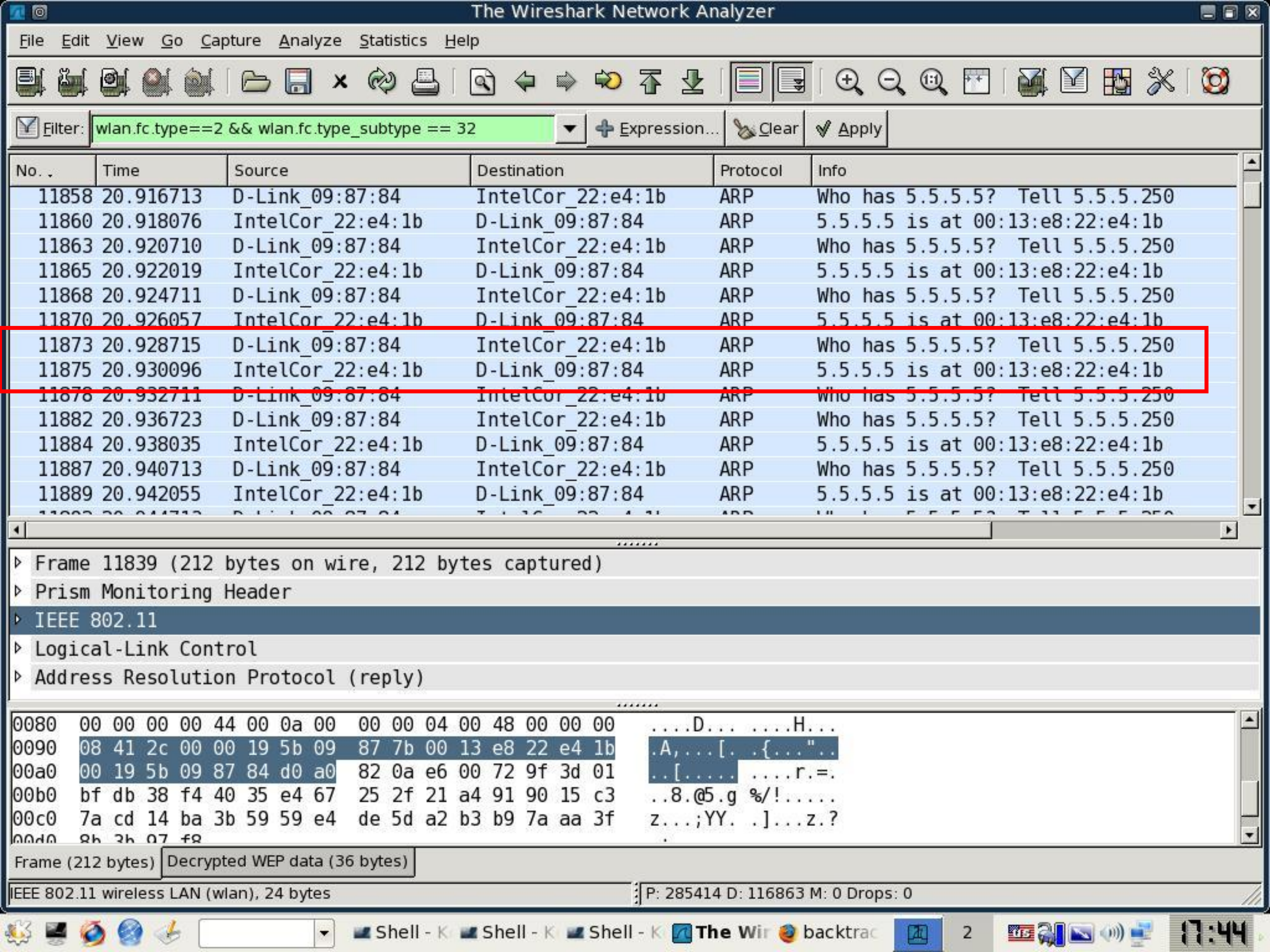
5.5.5.250

Caffe latte – Open + Static IP (2)


Connection Established
ARP Request for 5.5.5.5 from 5.5.5.250
ARP Response from 5.5.5.5 to 5.5.5.250
ARP Request for 5.5.5.5 from 5.5.5.250
5.5.5.5
ARP Response from 5.5.5.5 to 5.5.5.250

We send this bit flipped ARP packet to the Client

- We don’t really care what the bit flipped IP was ☺
- Collect the ARP responses and fire up Aircrack-ng ☺



Filter: wlan.fc.type==2 && wlan.fc.type_subtype == 32

```
No. .  Time       Source              Destination         Protocol  Info
11858  20.916713  D-Link_09:87:84     IntelCor_22:e4:1b   ARP       Who has 5.5.5.5?  Tell 5.5.5.250
11860  20.918076  IntelCor_22:e4:1b   D-Link_09:87:84     ARP       5.5.5.5 is at 00:13:e8:22:e4:1b
11863  20.920710  D-Link_09:87:84     IntelCor_22:e4:1b   ARP       Who has 5.5.5.5?  Tell 5.5.5.250
11865  20.922019  IntelCor_22:e4:1b   D-Link_09:87:84     ARP       5.5.5.5 is at 00:13:e8:22:e4:1b
11868  20.924711  D-Link_09:87:84     IntelCor_22:e4:1b   ARP       Who has 5.5.5.5?  Tell 5.5.5.250
11870  20.926057  IntelCor_22:e4:1b   D-Link_09:87:84     ARP       5.5.5.5 is at 00:13:e8:22:e4:1b
11873  20.928715  D-Link_09:87:84     IntelCor_22:e4:1b   ARP       Who has 5.5.5.5?  Tell 5.5.5.250
11875  20.930096  IntelCor_22:e4:1b   D-Link_09:87:84     ARP       5.5.5.5 is at 00:13:e8:22:e4:1b
11878  20.932711  D-Link_09:87:84     IntelCor_22:e4:1b   ARP       Who has 5.5.5.5?  Tell 5.5.5.250
11882  20.936723  D-Link_09:87:84     IntelCor_22:e4:1b   ARP       Who has 5.5.5.5?  Tell 5.5.5.250
11884  20.938035  IntelCor_22:e4:1b   D-Link_09:87:84     ARP       5.5.5.5 is at 00:13:e8:22:e4:1b
11887  20.940713  D-Link_09:87:84     IntelCor_22:e4:1b   ARP       Who has 5.5.5.5?  Tell 5.5.5.250
11889  20.942055  IntelCor_22:e4:1b   D-Link_09:87:84     ARP       5.5.5.5 is at 00:13:e8:22:e4:1b
```

```
▷ Frame 11839 (212 bytes on wire, 212 bytes captured)
▷ Prism Monitoring Header
▷ IEEE 802.11
▷ Logical-Link Control
▷ Address Resolution Protocol (reply)
```

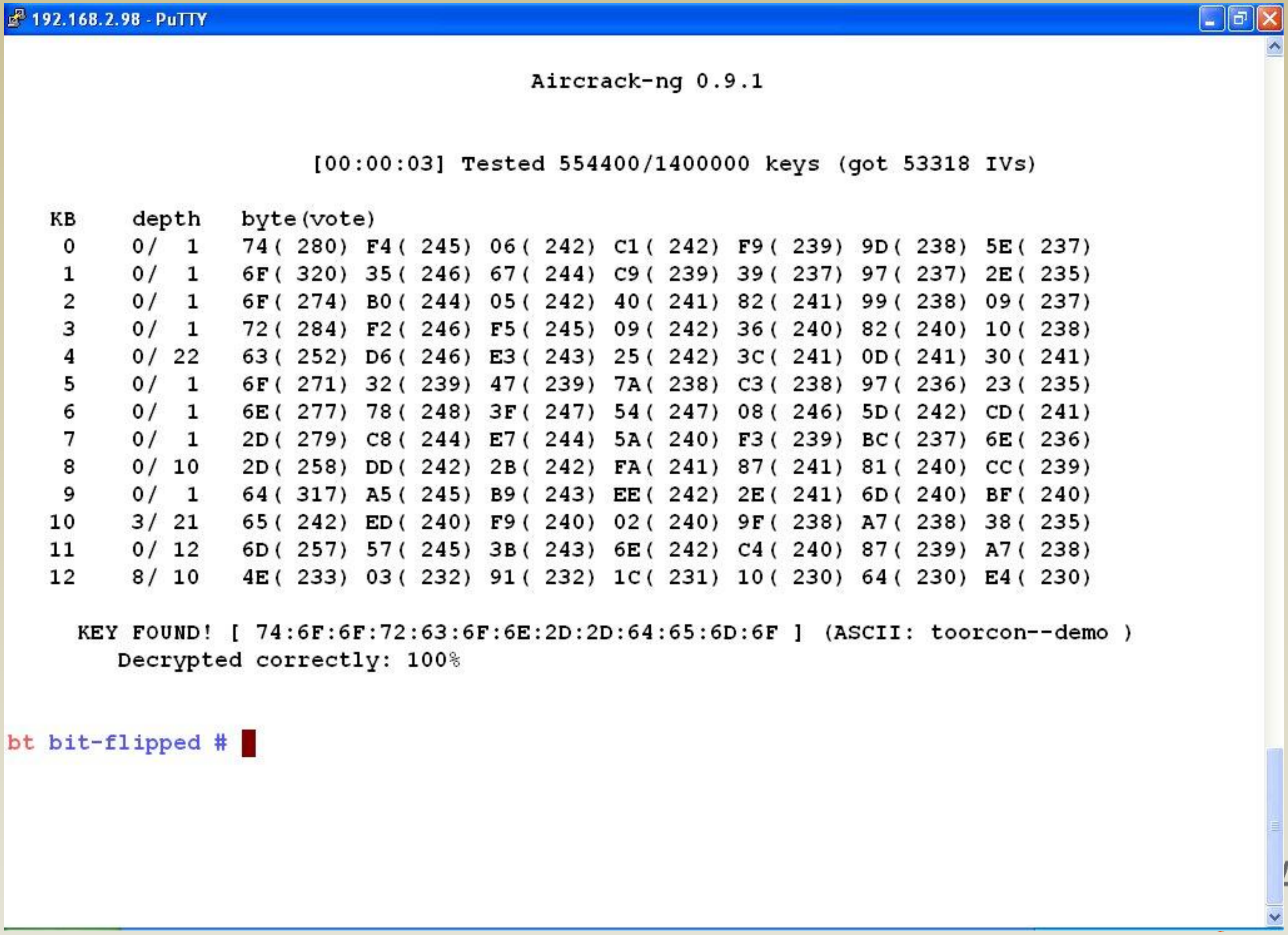
```
0080  00 00 00 00 44 00 0a 00  00 00 04 00 48 00 00 00   ....D... ....H...
0090  08 41 2c 00 00 19 5b 09  87 7b 00 13 e8 22 e4 1b   .A,...[. .{..."..
00a0  00 19 5b 09 87 84 d0 a0  82 0a e6 00 72 9f 3d 01   ..[..... ....r.=.
00b0  bf db 38 f4 40 35 e4 67  25 2f 21 a4 91 90 15 c3   ..8.@5.g %/!.....
00c0  7a cd 14 ba 3b 59 59 e4  de 5d a2 b3 b9 7a aa 3f   z...;YY. .]...z.?
00d0  8b 3b 97 f8
```

Frame (212 bytes) | Decrypted WEP data (36 bytes)

IEEE 802.11 wireless LAN (wlan), 24 bytes | P: 285414 D: 116863 M: 0 Drops: 0

Caffé latte – Open + Static IP (3)

- Once we have around 60,000 ARP Response packets: ☺️ ☺️ ☺️



```
                              Aircrack-ng 0.9.1


                 [00:00:03] Tested 554400/1400000 keys (got 53318 IVs)

   KB    depth   byte(vote)
    0    0/  1   74( 280) F4( 245) 06( 242) C1( 242) F9( 239) 9D( 238) 5E( 237)
    1    0/  1   6F( 320) 35( 246) 67( 244) C9( 239) 39( 237) 97( 237) 2E( 235)
    2    0/  1   6F( 274) B0( 244) 05( 242) 40( 241) 82( 241) 99( 238) 09( 237)
    3    0/  1   72( 284) F2( 246) F5( 245) 09( 242) 36( 240) 82( 240) 10( 238)
    4    0/ 22   63( 252) D6( 246) E3( 243) 25( 242) 3C( 241) 0D( 241) 30( 241)
    5    0/  1   6F( 271) 32( 239) 47( 239) 7A( 238) C3( 238) 97( 236) 23( 235)
    6    0/  1   6E( 277) 78( 248) 3F( 247) 54( 247) 08( 246) 5D( 242) CD( 241)
    7    0/  1   2D( 279) C8( 244) E7( 244) 5A( 240) F3( 239) BC( 237) 6E( 236)
    8    0/ 10   2D( 258) DD( 242) 2B( 242) FA( 241) 87( 241) 81( 240) CC( 239)
    9    0/  1   64( 317) A5( 245) B9( 243) EE( 242) 2E( 241) 6D( 240) BF( 240)
   10    3/ 21   65( 242) ED( 240) F9( 240) 02( 240) 9F( 238) A7( 238) 38( 235)
   11    0/ 12   6D( 257) 57( 245) 3B( 243) 6E( 242) C4( 240) 87( 239) A7( 238)
   12    8/ 10   4E( 233) 03( 232) 91( 232) 1C( 231) 10( 230) 64( 230) E4( 230)

     KEY FOUND! [ 74:6F:6F:72:63:6F:6E:2D:2D:64:65:6D:6F ] (ASCII: toorcon--demo )
        Decrypted correctly: 100%


bt bit-flipped #
```

Caffé Latte for Open + Static IP - Analysis

- Capturing an ARP packet and bit flipping it: ~1 msec ☺
- ARP Request/Response Flood: 4-5 minutes (to get around 80,000 packets)
- Key cracking with Aircrack-ng: ~1 minute

Bit Flipping works for all the cases

Network Configuration	**Approximate Cracking time**
Shared + DHCP	~ 6 minutes
Shared + Static IP	~ 6 minutes
Open + DHCP	~ 6 minutes
Open + Static IP	~ 6 minutes

Implications of Caffé Latte

Risk is higher than previously perceived:

- WEP keys can now be cracked remotely, putting your enterprise at risk
- WEP Honey-pots are now possible

Few hours before our talk we came to know that a tool WEPOff had taken a stab at attacking isolated clients using a different technique (fragmentation) and only for a limited set of network configurations (DHCP). Also due to the nature of the fragmentation attack, it has to send 9 times the number of packets.

http://www.darknet.org.uk/2007/01/wep0ff-wireless-wep-key-cracker-tool/

Advisory

- Yet another reason to upgrade to WPA/WPA2

- Road warriors need to be careful even more now:
  - Exercise caution when using public hotspots
  - Upgrade your wireless drivers regularly
  - Switch off wireless when not in use
  - …
  - …

  Too many best practices to remember!

  Use a freely available wireless security agent on your laptop

- If you are using legacy WEP, do not build your enterprise defenses assuming the WEP key cannot be broken

Questions?

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