

Device Drivers:

Don't build a house on a shaky foundation

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Overview

- Problems
- Nifty Fingerprinting Stuff
- Finding and Exploiting Vulns
- Shellcode Design
- DEMOS!!!!!!



Problems?

- Speed to market is so important.
- Some things don't get tested properly
- New hardware and committee designed protocols are especially susceptible.



Problems (cont...)

- Although what follows is mostly focused on 802.11a/b/g the lessons learned can be applied to lots of things
 - Bluetooth
 - New 802.11 specs
 - Wireless data (EDGE, EV-DO, HSDPA)



802.11

- Why is it so complicated
- Does it have to be
- Can we fix it?
- Consequence's of complexity:
 - Fingerprinting 802.11 implementations
 - Exploiting device drivers



Why so complicated?

- "Fear leads to anger. Anger leads to hate. Hate leads to protocols designed by committee." --warlord (?)



Why so complicated

- Partly to ambitious, partly attempting to deal with legitimate problems.
- -hidden nodes
- -unreliable links
- -other networks on same channel



Can we fix it

- Yes, all it costs is standards compliance.
- Ignore management frames
- Ignore (some?) control frames
- Remove extra's (more on these later),



Why is this interesting?

- Complexity is a hacker's best friend.
- If its not complex theres no room for bugs. No bugs means no fun.
- 802.11 is not lacking in complexity.



Ethernet

- 3 fields: src, dst, type.



802.11

- Version
- Type
- Subtype
- 8 flags.
- 1,2,3 or 4 addresses, variable positions
- Frag num
- Sequence num



Not done yet..

- Positive acknowledgement
- 11 management frames
- 6 control frames
- ..lots of subtypes for each.
- ..various encryption fields (IV, MIC/ICV, etc)



More features!

- Ad-Hoc
- Power savings
- 2 types of MAC (PCF vs DCF)
- .11e QoS
- Geo-locating proposed? WTH does 'media access control' have to do with geo-locating



What do you get when you remove the extras?

Nintendo DS



No Wi-Fi certification

Nowhere near 802.11 compliant

Ignores de-auth/disassociates

Possibly ignores control packets

Works great!

(probably doesn't roam very well)



Fingerprinting 802.11

- Why bother
 - Target exploits
 - WIDS can monitor users' chipset, driver.
 - Possibly refine OS fingerprints



Fingerprinting 802.11

- Why is this cool
 - No other link layer protocol fingerprints that I know of
- Why is this possible?
 - Complexity of the protocol



How far down can you go?

- Chipset families
- Distinct drivers for chipsets
- Different versions of the same driver
- Firmware (?)



Specific fingerprints

- RTS/CTS window honouring
- Association Redirection
- Duration analysis

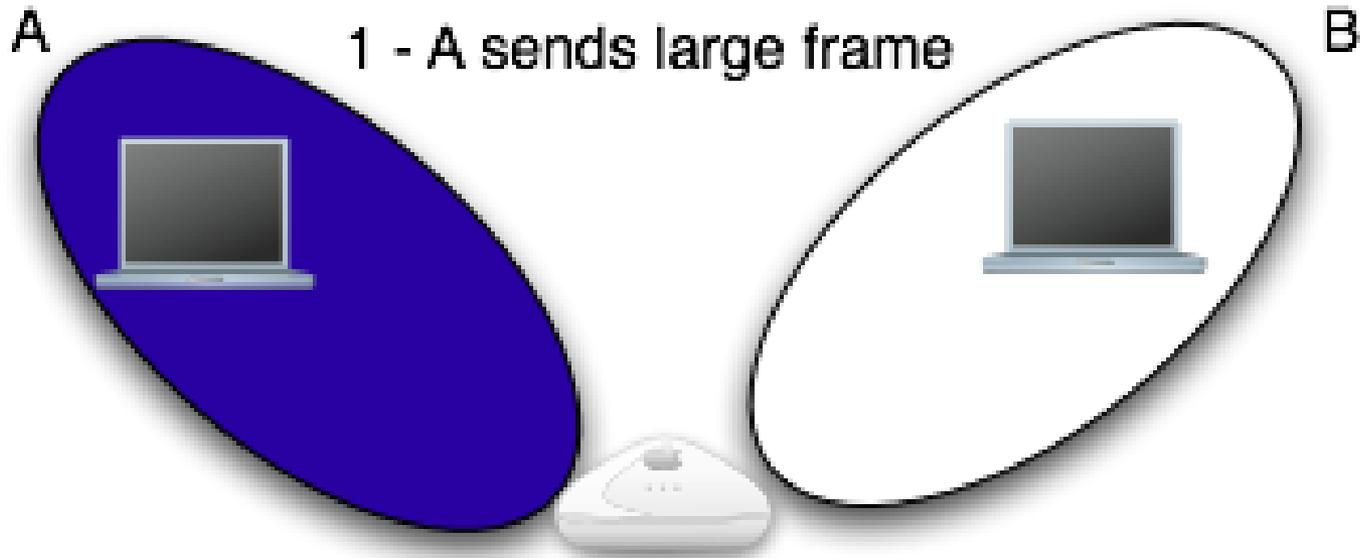


RTS/CTS

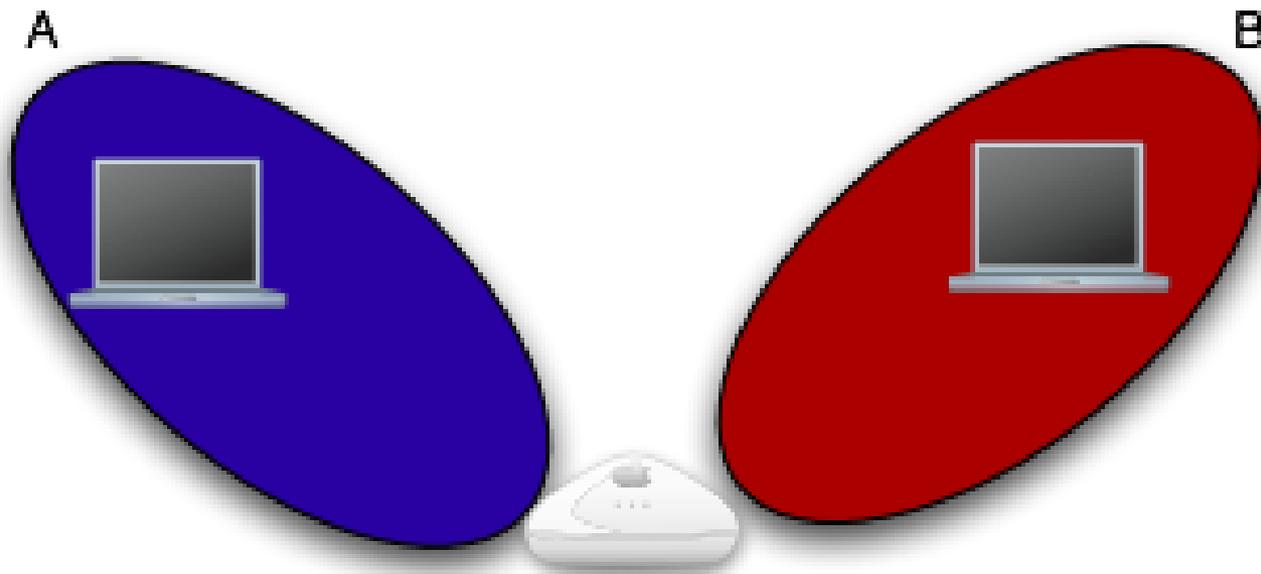
- RTS/CTS packets used to reserve media for large enough packets.



RTS/CTS



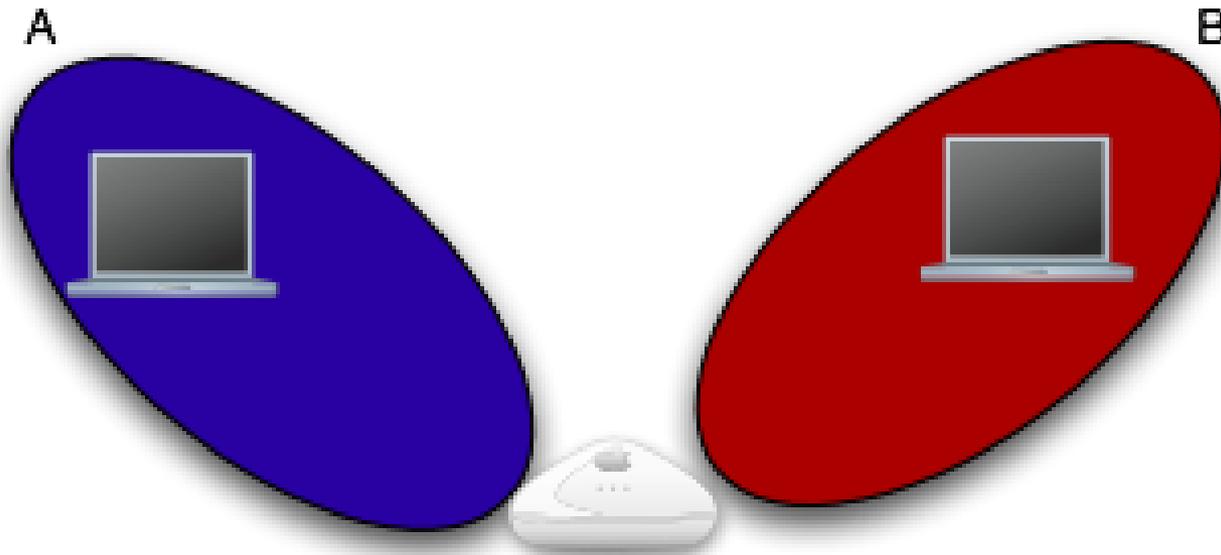
RTS/CTS



2 - halfway through, B transmits



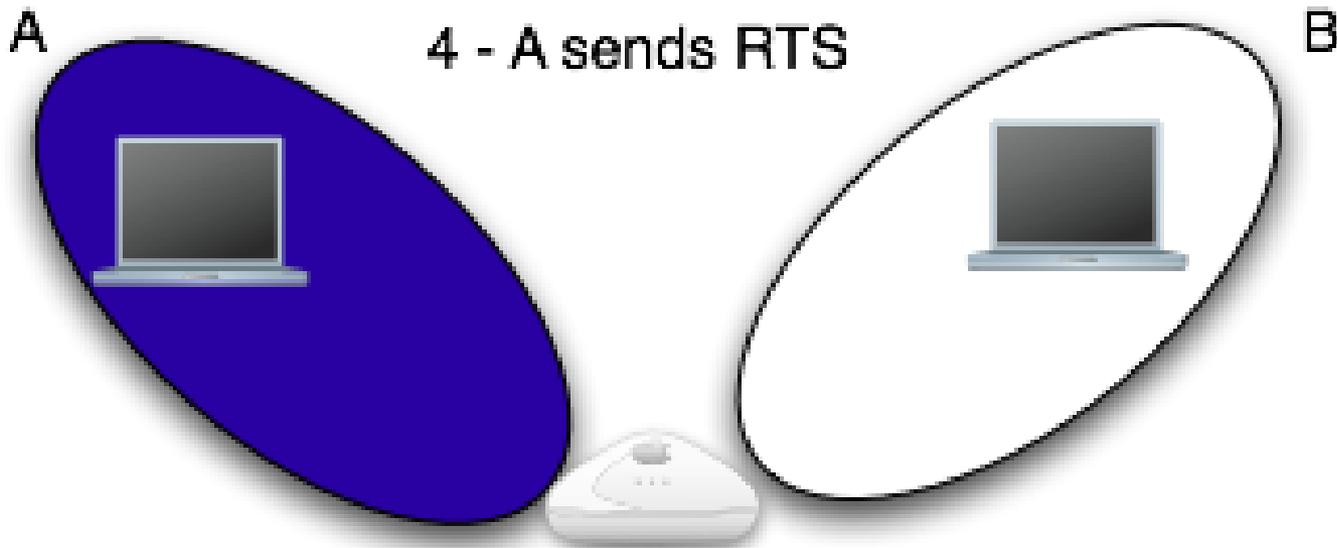
RTS/CTS



Collision!



RTS/CTS



"I need the air for 20000 usec"



RTS/CTS

A

B

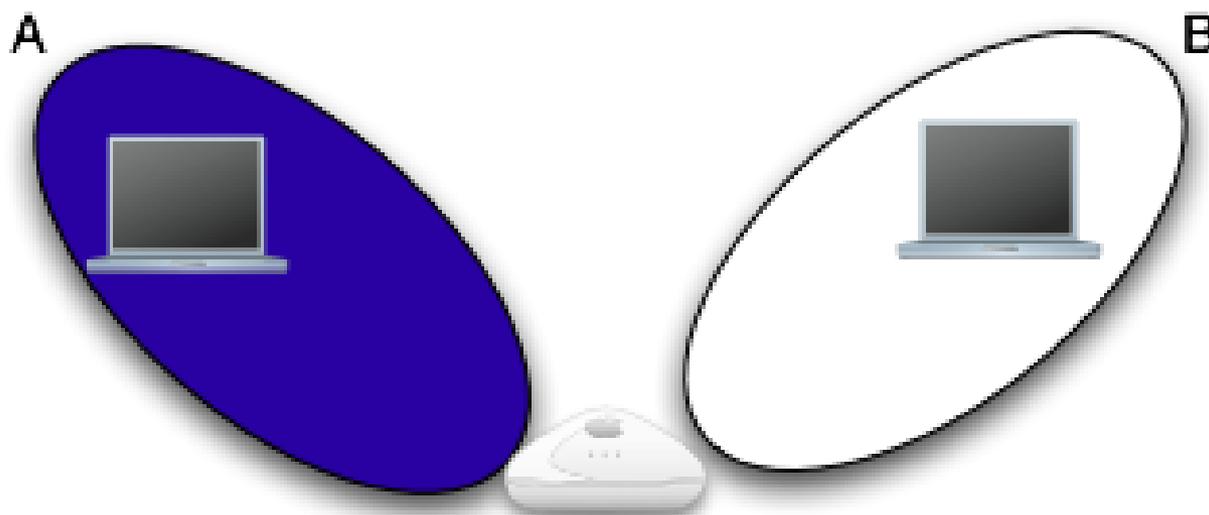


A needs air for 20000 usec.
Everyone shutup!

5 - AP sends CTS



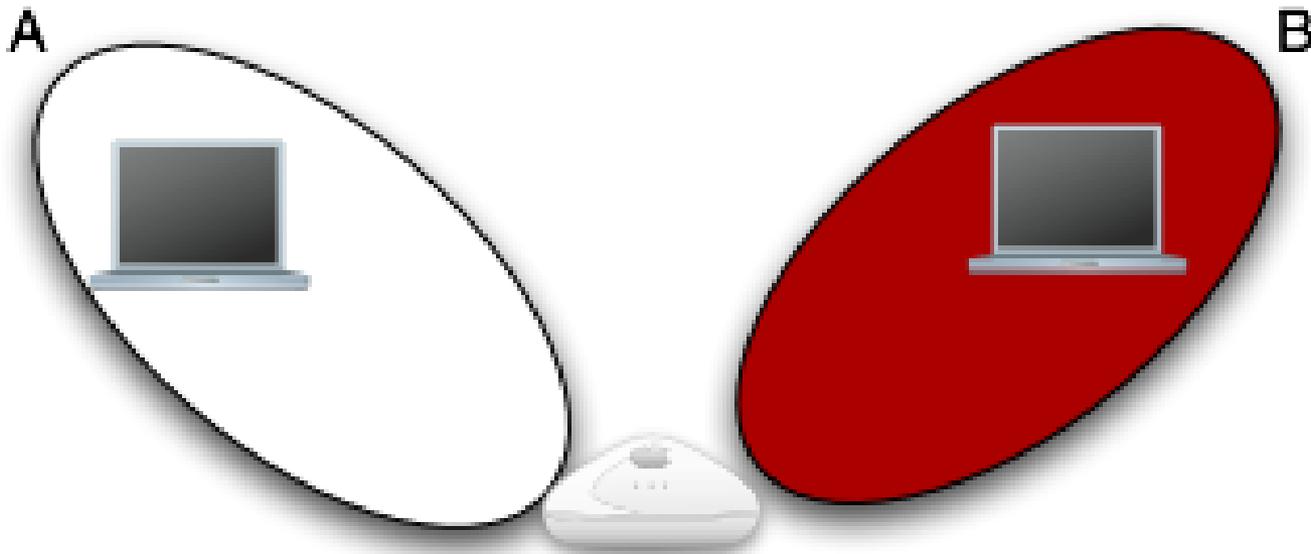
RTS/CTS



6- A sends large frame, B stays quiet
for 20000 usec



RTS/CTS



A finishes, B transmits when he's done



How many implementations use this?

Most?

Nope.

A few?

Nope

None?

Yes!

(under normal conditions)



RTS/CTS

- If they didn't bother to implement it, they care if other people have?



RTS/CTS

- Though code was written to analyze packet dumps, results were not deterministic enough to be useful.
- Getting such a high resolution clock/timestamp very difficult.



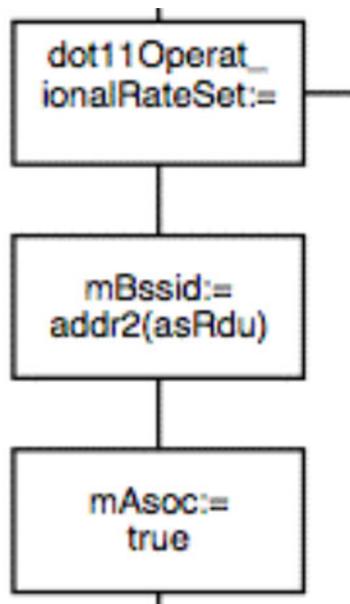
Association Redirection

- Active fingerprinting technique.
- High resolution.
- Mind-numbingly boring to automate.



Association Redirection

- Specified in standard: pg 376



Quick Overview

Important 802.11 fields:

Src, Dst, BSSID



Typical 802.11 Traffic

10.0.0.100
00:11:95:C2:E7:8A



10.0.0.1
BSSID: 00:30:BD:C0:38:9A

10.0.0.222
00:10:C6:6B:07:1D



No. ↓	Time	Source	Destination	Protocol	Info
23	0.253433	10.0.0.100	10.0.0.222	TCP	50300 > 50300
24	0.254762	10.0.0.100	10.0.0.222	TCP	50300 > 50300

▶ Frame 23 (80 bytes on wire, 80 bytes captured)

▼ IEEE 802.11

Type/Subtype: Data (32)

▶ Frame Control: 0x0108 (Normal)

Duration: 258

BSS Id: 00:30:bd:c0:38:9a (BelkinCo_c0:38:9a)

Source address: 00:11:95:c2:e7:8a (AlphaNet_c2:e7:8a)

Destination address: 00:10:c6:6b:07:1d (Usi_6b:07:1d)

Fragment number: 0

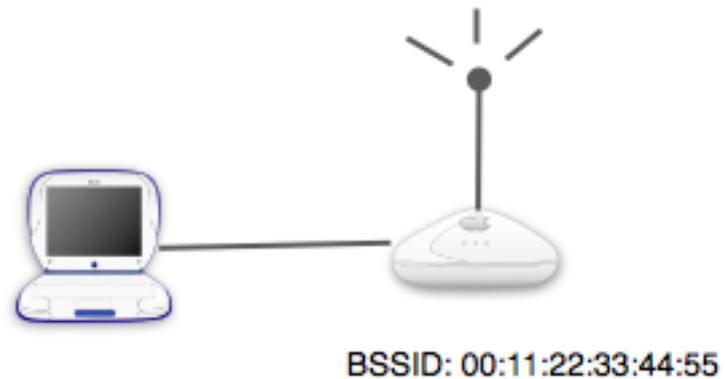
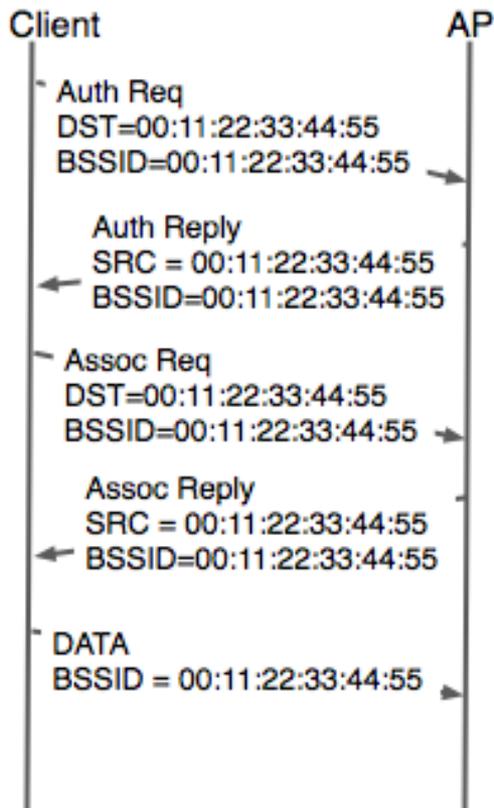
Sequence number: 3368

▶ Logical-Link Control

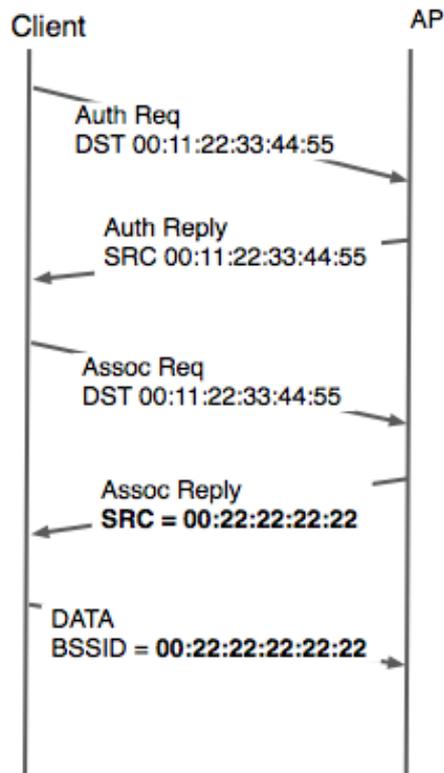
▶ Internet Protocol, Src Addr: 10.0.0.100 (10.0.0.100), Dst Addr: 10.0.0.222 (10.0.0.222)



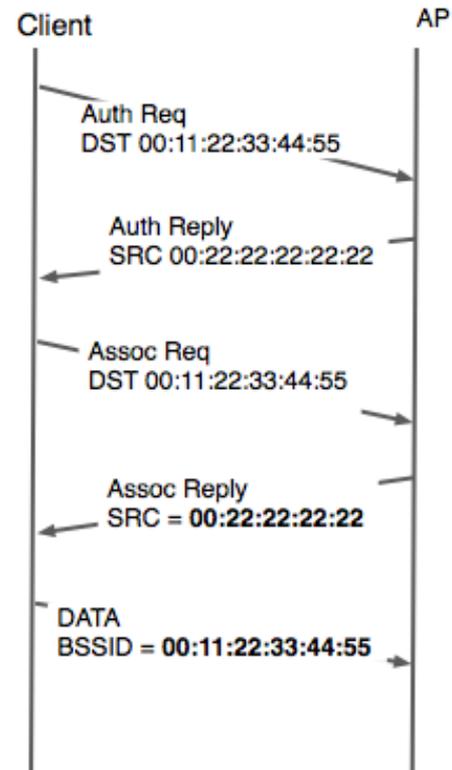
Normal 802.11 Association



Association Redirection



Successful



Unsuccessful



id-num	image	MAC/Model/Chipset	driver-id	SRC
1		00:12:17:79:1C:B0 Atheros AR5212	ar5211.sys	IGN_ASSOC_REPLY 1 2 3
2		00:20:A6:4C:D9:4A Atheros AR5212	ntpr11ag.sys	IGN_ASSOC_REPLY 1 2 3
3		00:20:A6:4B:DD:85 Atheros AR5211	(ntpr11ag.sys)	IGN_ASSOC_REPLY 1 2 3
4		00:20:A6:51:EC:09 Atheros AR5212	(ntpr11ag.sys)	IGN_ASSOC_REPLY 1 2 3
5		00:0A:95:F3:2F:AB Broadcom BCM4318	AppleAirport2-bcm4318	DEAUTH_FLOOD_NULL 1 2 3
6		00:14:a5:06:8F:E6 BCM-4306	BCMWL5.sys	DEAUTH_FLOOD_NULL 1 2 3
7		00:0E:35:E9:C9:5B Intel PRO/Wireless 2200BG	w29n51.sys	DUAL_NACK_DATA 1 2 3
8		00:13:46:E3:B4:2C Ralink RA2570	rt2500usb.sys	IGN_ASSOC_REPLY 1 2 3
9		00:04:E2:80:2C:21 Prism 2.5	smc2532w.sys	DEAUTH_TYPE_1 1 2 3
10		00:14:A4:2A:9E:58 BCM4318	bcmwl5.sys	DEAUTH_FLOOD_NULL 1 2 3



So what weird things happen?

- Cards de-auth flood null address (broadcom)
- Cards think they are on both networks? (centrino)
- Other less dramatic hijinks.



Deauth-Flood example auth-reply

No. ↓	Time	Source	Destination	Protocol	Info
40	1.315883	AppleCom_f3:2f:ab	Cimsys_33:44:55	IEEE 802.11	Authentication
41	1.316220		AppleCom_f3:2f:ab (R)	IEEE 802.11	Acknowledgement
42	1.317122	Cimsys_33:44:55	AppleCom_f3:2f:ab	IEEE 802.11	Authentication
43	1.317466		Cimsys_33:44:55 (RA)	IEEE 802.11	Acknowledgement
44	1.318342	AppleCom_f3:2f:ab	Cimsys_33:44:55	IEEE 802.11	Association Request, SSID: "dojooffoo"
45	1.318679		AppleCom_f3:2f:ab (R)	IEEE 802.11	Acknowledgement
46	1.319333	00:22:22:22:22:22	AppleCom_f3:2f:ab	IEEE 802.11	Association Response
47	1.319599		00:22:22:22:22:22 (R)	IEEE 802.11	Acknowledgement
48	1.319996	AppleCom_f3:2f:ab	00:22:22:22:22:22	IEEE 802.11	Deauthentication
49	1.321020	AppleCom_f3:2f:ab	00:22:22:22:22:22	IEEE 802.11	Deauthentication

▷ Frame 42 (30 bytes on wire, 30 bytes captured)

▽ IEEE 802.11

Type/Subtype: Authentication (11)

▷ Frame Control: 0x00B0 (Normal)

Duration: 314

Destination address: 00:0a:95:f3:2f:ab (AppleCom_f3:2f:ab)

Source address: 00:11:22:33:44:55 (Cimsys_33:44:55)

BSS Id: 00:11:22:33:44:55 (Cimsys_33:44:55)

Fragment number: 0

Sequence number: 108



Deauth-Flood example

assoc-request

No. -	Time	Source	Destination	Protocol	Info
40	1.315883	AppleCom_f3:2f:ab	Cimsys_33:44:55	IEEE 802.11	Authentication
41	1.316220		AppleCom_f3:2f:ab (R)	IEEE 802.11	Acknowledgement
42	1.317122	Cimsys_33:44:55	AppleCom_f3:2f:ab	IEEE 802.11	Authentication
43	1.317466		Cimsys_33:44:55 (RA)	IEEE 802.11	Acknowledgement
44	1.318342	AppleCom_f3:2f:ab	Cimsys_33:44:55	IEEE 802.11	Association Request, SSID: "dojooffoo"
45	1.318679		AppleCom_f3:2f:ab (R)	IEEE 802.11	Acknowledgement
46	1.319333	00:22:22:22:22:22	AppleCom_f3:2f:ab	IEEE 802.11	Association Response
47	1.319599		00:22:22:22:22:22 (R)	IEEE 802.11	Acknowledgement
48	1.319996	AppleCom_f3:2f:ab	00:22:22:22:22:22	IEEE 802.11	Deauthentication
49	1.321020	AppleCom_f3:2f:ab	00:22:22:22:22:22	IEEE 802.11	Deauthentication

- ▼ IEEE 802.11
 - Type/Subtype: Association Request (0)
 - ▶ Frame Control: 0x0000 (Normal)
 - Duration: 314
 - Destination address: 00:11:22:33:44:55 (Cimsys_33:44:55)
 - Source address: 00:0a:95:f3:2f:ab (AppleCom_f3:2f:ab)
 - BSS Id: 00:11:22:33:44:55 (Cimsys_33:44:55)
 - Fragment number: 0
 - Sequence number: 46
- ▶ IEEE 802.11 wireless LAN management frame



Deauth-Flood example assoc-reply

No. ↓	Time	Source	Destination	Protocol	Info
40	1.315883	AppleCom_f3:2f:ab	Cimsys_33:44:55	IEEE 802.11	Authentication
41	1.316220		AppleCom_f3:2f:ab (R)	IEEE 802.11	Acknowledgement
42	1.317122	Cimsys_33:44:55	AppleCom_f3:2f:ab	IEEE 802.11	Authentication
43	1.317466		Cimsys_33:44:55 (RA)	IEEE 802.11	Acknowledgement
44	1.318342	AppleCom_f3:2f:ab	Cimsys_33:44:55	IEEE 802.11	Association Request, SSID: "dojooffoo"
45	1.318679		AppleCom_f3:2f:ab (R)	IEEE 802.11	Acknowledgement
46	1.319333	00:22:22:22:22:22	AppleCom_f3:2f:ab	IEEE 802.11	Association Response
47	1.319599		00:22:22:22:22:22 (R)	IEEE 802.11	Acknowledgement
48	1.319996	AppleCom_f3:2f:ab	00:22:22:22:22:22	IEEE 802.11	Deauthentication
49	1.321020	AppleCom_f3:2f:ab	00:22:22:22:22:22	IEEE 802.11	Deauthentication

IEEE 802.11

Type/Subtype: Association Response (1)

▶ Frame Control: 0x0010 (Normal)

Duration: 258

Destination address: 00:0a:95:f3:2f:ab (AppleCom_f3:2f:ab)

Source address: 00:22:22:22:22:22 (00:22:22:22:22:22)

BSS Id: 00:11:22:33:44:55 (Cimsys_33:44:55)

Fragment number: 0

Sequence number: 109

▶ IEEE 802.11 wireless LAN management frame



Deauth-Flood starts

No.	Time	Source	Destination	Protocol	Info
40	1.315883	AppleCom_f3:2f:ab	Cimsys_33:44:55	IEEE 802.11	Authentication
41	1.316220		AppleCom_f3:2f:ab (Receiver)	IEEE 802.11	Acknowledgement
42	1.317122	Cimsys_33:44:55	AppleCom_f3:2f:ab	IEEE 802.11	Authentication
43	1.317466		Cimsys_33:44:55 (Receiver)	IEEE 802.11	Acknowledgement
44	1.318342	AppleCom_f3:2f:ab	Cimsys_33:44:55	IEEE 802.11	Association Request, SSID: "dojooffoo"
45	1.318679		AppleCom_f3:2f:ab (Receiver)	IEEE 802.11	Acknowledgement
46	1.319333	00:22:22:22:22:22	AppleCom_f3:2f:ab	IEEE 802.11	Association Response
47	1.319599		00:22:22:22:22:22 (Receiver)	IEEE 802.11	Acknowledgement
48	1.319996	AppleCom_f3:2f:ab	00:22:22:22:22:22	IEEE 802.11	Deauthentication
49	1.321020	AppleCom_f3:2f:ab	00:22:22:22:22:22	IEEE 802.11	Deauthentication

IEEE 802.11

Type/Subtype: Deauthentication (12)

▶ Frame Control: 0x00C0 (Normal)

Duration: 314

Destination address: 00:22:22:22:22:22 (00:22:22:22:22:22)

Source address: 00:0a:95:f3:2f:ab (AppleCom_f3:2f:ab)

BSS Id: 00:00:00:00:00:00 (00:00:00_00:00:00)

Fragment number: 0

Sequence number: 47

▶ IEEE 802.11 wireless LAN management frame



Association Redirection redux

- If 1 weird standards quirk is good 3 must be better!
 - Instead of just source mangle as many things as possible: src, bssid, both



Table2 here



Association Redir redux

- If 3 standards quirks work OK, why not 9?
- Two more tables



Tables 3 and 4 here



Association Redirection summary

- very possible to remotely version chipset
- can't really distinguish different drivers
- - active technique, requires you to transmit packets.



Duration analysis

- Totally passive
- Very accurate
- Easy to automate
- Only basic statistical techniques used.



What is a duration?

No. ↓	Time	HW-src	HW-dst	Protocol	Info
1	21:07:18.620	00:0a:95:f3:2f:ab	ff:ff:ff:ff:ff:ff	IEEE 8	Data
2	21:07:21.388	00:0a:95:f3:2f:ab	ff:ff:ff:ff:ff:ff	IEEE 8	Data
3	21:07:23.428	00:0a:95:f3:2f:ab	ff:ff:ff:ff:ff:ff	IEEE 8	Data
4	21:07:23.429	00:0a:95:f3:2f:ab	ff:ff:ff:ff:ff:ff	IEEE 8	Data

▶ Frame 3 (68 bytes on wire, 68 bytes captured)

▼ IEEE 802.11

Type/Subtype: Data (32)

▶ Frame Control: 0x4108 (Normal)

Duration: 258

BSS Id: 00:30:bd:c0:38:9a (00:30:bd:c0:38:9a)

Source address: 00:0a:95:f3:2f:ab (00:0a:95:f3:2f:ab)

Destination address: ff:ff:ff:ff:ff:ff (ff:ff:ff:ff:ff:ff)

Fragment number: 0

Sequence number: 1286

▶ WFP parameters



What influences duration values.

- Rate (.11b, .11g)
- Short slot time (g only)
- Short pre amble



Example atheros fingerprint

Well behaved atheros card:

CTS: 0

pwrmgmt: 1

frag: 0

order: 0

```
<0 0>   Duration( (314) )           //assoc request
<0 4>   Duration( (0) (314) )       //probe request
<0 11>  Duration( (314) )           //authentication
<2 0>   Duration( (162) (0) )       //data
<2 4>   Duration( (162) )           //null function data
```



Example prism fingerprint

poorly behaved prism card:

CTS: 0

pwrmgmt: 1

frag: 0

order: 0

<0 0> Duration((258)) //assoc req

<0 4> Duration((0)) //probe req

<0 11> Duration((53389)) //auth

<0 12> Duration((258) (314)) //de-auth

<2 0> Duration((213) (0) (223)) //data

<2 4> Duration((37554)) //null-func



Simple example

- Duration match 2 prints here

<pre>../duration-print-matcher -a 00:12:17:79:1C:B0 -p ./pcaps/1-3- lexie.pcap -f ./prints/1.prnt ./prints/9.prnt</pre>	<pre>../duration-print-matcher -a 00:04:E2:80:2C:21 -p ./pcaps/9-3- lexie.pcap -f ./prints/1.prnt ./prints/9.prnt</pre>
<pre>Score: ID 29800.00 1 //atheros card 13000.00 9 //prism card</pre>	<pre>Score: ID 50600.00 9 //prism card 13000.00 1 //atheros card</pre>



Simple example cont.

```
../duration-print-matcher -a  
00:12:17:79:1C:B0 -p ./pcaps/1-3-  
lexie.pcap -f ./prints/*.prnt
```

Score:	ID	
24802.86	2	//Atheros
23785.00	1	//Atheros
23785.00	3	//Atheros
23785.00	4	//Atheros
19645.71	7	//centrino
17610.00	10	//broadcom
16110.00	6	//broadcom
13327.86	13	//aironet 350
12880.00	12	//Ninteno DS
12310.00	5	//broadcom
10077.86	9	//prism
9060.00	8	//ralink
8577.86	11	//PSP

```
../duration-print-matcher -a  
00:04:E2:80:2C:21 -p ./pcaps/9-3-  
lexie.pcap -f ./prints/*.prnt
```

Score:	ID	
172256.43	9	//prism
21138.57	10	//broadcom
18982.62	11	//PSP
17738.57	5	//broadcom
11774.29	2	//atheros
10417.14	7	//centrino
10161.19	13	//aironet 350
10138.57	6	//broadcom
10077.86	4	//atheros
10077.86	3	//atheros
10077.86	1	//atheros
9060.00	8	//ralink
5280.00	12	//Nintendo DS



Real life example (centrino)

```
../duration-print-matcher -a 00:0E:35:E9:C9:5B -p  
./pcaps/7-2-mixed--wrt54g.pcap -f ./prints/*.pr n t
```

Score:	ID	
58404.88	7	//centrino
44365.05	13	//aironet 350
38781.71	9	//prism2.5
37394.32	6	//broadcom 4306
32883.61	4	//atheros ar5212
32883.61	2	//atheros ar5212
31553.30	5	//broadcom (apple)
26508.61	1	//atheros 5212
24100.27	10	//broadcom bcm4318
22051.56	3	//atheros ar5212
19526.16	11	//PSP
14103.69	8	//Ralink RA2570
12248.00	12	//Nintendo DS



Unknown Ralink example

```
tcpdump -i rausb0 -s 0 -w unknown.pcap
```

```
../duration-print-matcher -a 00:13:D4:6F:13:A9 -  
p ./unknown.pcap -f ./prints/*.prnt
```

Score	ID	
84719.08	8	//Ralink
14103.69	4	//atheros
14103.69	2	//atheros
14103.69	10	//broadcom
14103.69	1	//atheros
13319.08	7	//centrino
12603.69	6	//broadcom
11819.08	5	//broadcom
9396.00	9	//prism
9396.00	3	//atheros
7896.00	13	//aironet
7896.00	11	//PSP
5448.00	12	//Nintendo DS



So how's it work?

--MagicStats Duration summary--

Total number of unique durations: 12

Total volume: 95

dur	times_seen	prob	weight
0,	25,	0.2632,	3.8000
117,	8,	0.0842,	11.8750
127,	2,	0.0211,	47.5000
152,	1,	0.0105,	95.0000
162,	15,	0.1579,	6.3333
213,	5,	0.0526,	19.0000
223,	1,	0.0105,	95.0000
248,	2,	0.0211,	47.5000
258,	6,	0.0632,	15.8333
314,	28,	0.2947,	3.3929
37554,	1,	0.0105,	95.0000
53389,	1,	0.0105,	95.0000

Atheros print

CTS: 0

pwrmgmt: 1

frag: 0

order: 0

<0 0> Duration((314))

<0 4> Duration((0) (314))

<0 11> Duration((314))

<2 0> Duration((162) (0))

<2 4> Duration((162))



So how's it work?

- Compute fingerprint across input pcap.
- Fuzzily compare it to all known fingerprints.
 - For every matching duration in comparison print, add points proportional to weight for that duration.
 - Bonus points for matching type, subtype, and duration all at once.



Fuzzy compare

- For every matching duration in comparison print, add points proportional to weight for that duration.
- Bonus points for matching type, subtype, and duration all at once.



Also tracks a few other flags

Flag	value	ratio	prob	weight
CTS:	1	0/12	0.0000	inf
CTS:	0	12/12	1.0000	1.0000
PwrMgmt:	1	8/12	0.6667	1.5000
PwrMgmt:	0	4/12	0.3333	3.0000
frag:	1	0/12	0.0000	inf
frag:	0	12/12	1.0000	1.0000
order:	1	0/12	0.0000	inf
order:	0	12/12	1.0000	1.0000



how accurate is it?

- When run across my own set of training data, the following results apply:
- B-only (0x0021 flags, lexie)
 - 26 times better than random
- mixed-BG (0x0401/0x0001 flags)
 - 18 times better than random



Finding and exploiting vulns in
drivers.



Ways to find bugs?

- Static auditing
- Fuzzing



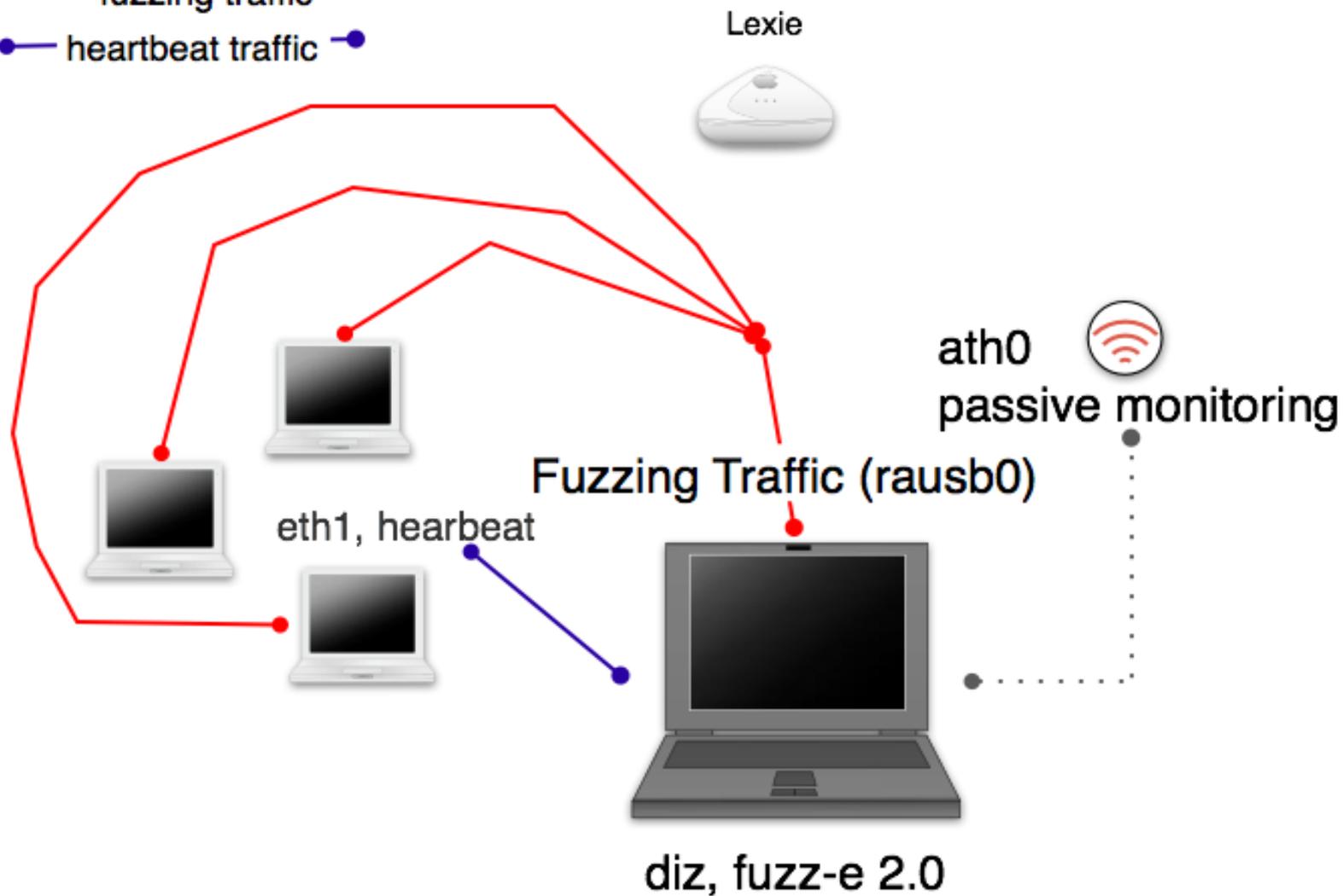
Things to think about

- Fuzzing can be frustrating
 - A bug could be triggered by something 8 packet chains ago
 - Hard to track down in ring0



● fuzzing traffic ●

● heartbeat traffic ●



fuzz-e

```
( johnycsh@diz:fuzz-e )$ ./fuzz-e -R -A -P ath0 -n 500  
-r rt2570 -i rausb0 -c 11 -D ./dest-addys.txt -w  
u20000  
-s 00:07:0E:B9:74:BB -b 00:07:0E:B9:74:BB -E log.txt
```

-R	random delays
-A	autonomous mode (don't stop)
-P	passive interface to sniff on
-n 500	send 500 packets per cycle
-r rt2570	driver to inject with
-i rausb0	inject on rausb0
-c 11	set channel to 11
-D dest-addys	specify list of victims
-w u20000	wait 200000 usecs (max)
-s	source address of packets
-b	bssid of packets
-E	log events to log.txt



Shellcode

- Most often a direct return shell is not possible.
- Bots or other malicious shellcode have to be designed.



DEMOS

(there are a few)

