High Speed Risks in 802.11n Networks

Joshua Wright
Aruba Networks
4/17/08 | WIR-301

RSA CONFERENCE 2008

Introduction

- IEEE 802.11n technology introduction
- Availability risks for legacy networks
- Extended range in 802.11n
- 40 MHz monitoring challenges
- Evading WIDS rogue detection systems
- Built-in DoS vulnerability
- Driver flaws

Disruptive Changes to Access Layer

- 802.11n promises to *revolutionize* the deployment of the network access layer
- Many organizations considering 802.11n as a wired replacement for new LAN deployments
  - Cost benefits, application integration benefits
- Represents a viable mechanism for reliability, consistency in connectivity and performance
- Not without its own costs …
- Not without its own risks …

IEEE 802.11n Overview

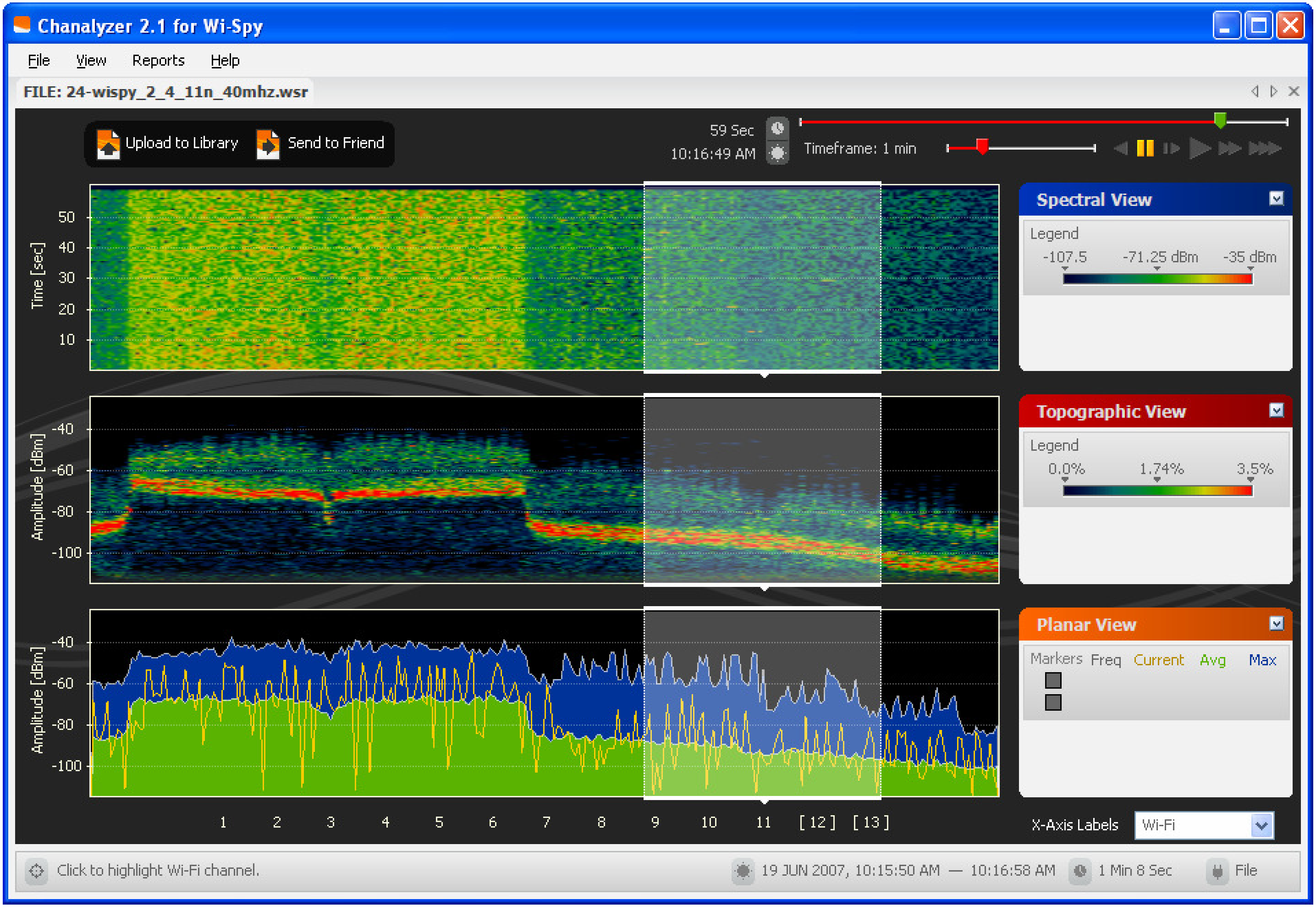
- TGn working group goal to improve PHY and MAC layers for true 100 Mbps performance
- PHY layer features include MIMO, 40 MHz channel availability
- MAC layer features include data aggregation, block acknowledgement
- Currently shipping hardware based on 802.11n D2.0, D4.0 currently in editing process
- Approval tentatively scheduled for 7/2009

New Spectrum Utilization

- 802.11 networks use 22/20 MHz channels
- Channel numbers separated by 5 MHz (mostly)
  - Channel 1 is 2.412 GHz, channel 2 is 2.417 GHz
  - Channel 44 is 5.220 GHz, channel 48 is 5.240 GHz
- Common 2.4 GHz deployments on 1, 6 and 11
- 802.11n can use 20 and 40 MHz channels
  - e.x. Channel 44 and 48 used together for more bandwidth
- Becomes problematic for 2.4 GHz band

2.4 GHz band, 40 MHz channels

- 40 MHz channels works well at 5 GHz
- 40 MHz channels at 2.4 GHz are problematic due to how channels are utilized
  - Channel 1 at 40 MHz utilizes 2.402 GHz - 2.442 GHz
  - Overlaps with channels 1 - 7
  - Leaves only one remaining viable channel
- Coordination effort flawed at 2.4 GHz, 40 MHz channels do not align with channels 1, 6, 11
- WFA requires 40 MHz @ 2.4 GHz off by default


Chanalyzer 2.1 for Wi-Spy
File View Reports Help
FILE: 24-wispy_2_4_11n_40mhz.wsr
Upload to Library
Send to Friend
59 Sec
10:16:49 AM
Timeframe: 1 min
Time [sec]
50
40
30
20
10
Amplitude [dBm]
-40
-60
-80
-100
Spectral View
Legend
-107.5
-71.25 dBm
-35 dBm
Topographic View
Legend
0.0%
1.74%
3.5%
Planar View
Markers Freq Current Avg Max
1 2 3 4 5 6 7 8 9 10 11 [12] [13]
X-Axis Labels
Wi-Fi
Click to highlight Wi-Fi channel.
19 JUN 2007, 10:15:50 AM — 10:16:58 AM
1 Min 8 Sec
File

Range Extensions in 802.11n

- SISO transmitters suffer from multipath propagation, reduces effective transmit distance
- MIMO transmitters leverage multipath to transmit multiple signals simultaneously
- Effectively increases range of 802.11n networks
- Legacy client support requires traditional site-survey planning

MIMO planning should expect 1.5x to 4x the range of SISO networks


Weybosset St
Abbott Park Pl
Abbott Park Pl
Abbott Park Pl
Standard 802.11a/g deployment range estimate

MIMO upgrade using existing AP locations

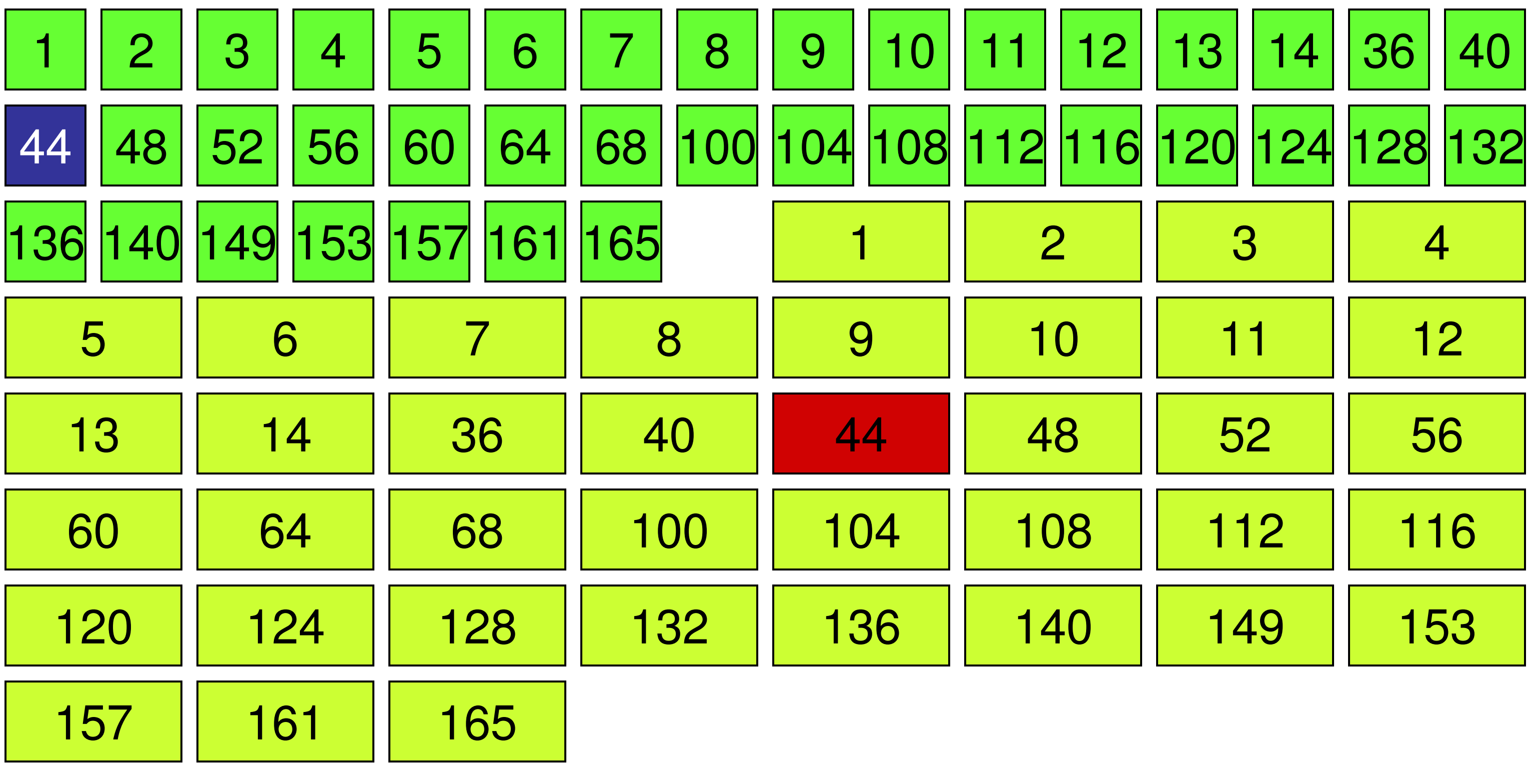
WIDS Channel Monitoring

- Overlay WIDS systems utilize channel hopping to monitor all frequencies
  - Necessary to identify attacks on channels not utilized
- With more channel availability, WIDS sensor spends less time on each channel
- If sensor spends 1/10th second on each channel, attack has to last for ~4 seconds to be detected

1	2	3	4	5	6	7	8	9	10	11	12	13	14	36	40
44	48	52	56	60	64	68	100	104	108	112	116	120	124	128	132
136	140	149	153	157	161	165									

40 MHz WIDS Monitoring

- Each channel must be monitored at 20 and 40 MHz
- Attack has to last for ~8 seconds to be detected



Evading WIDS Systems

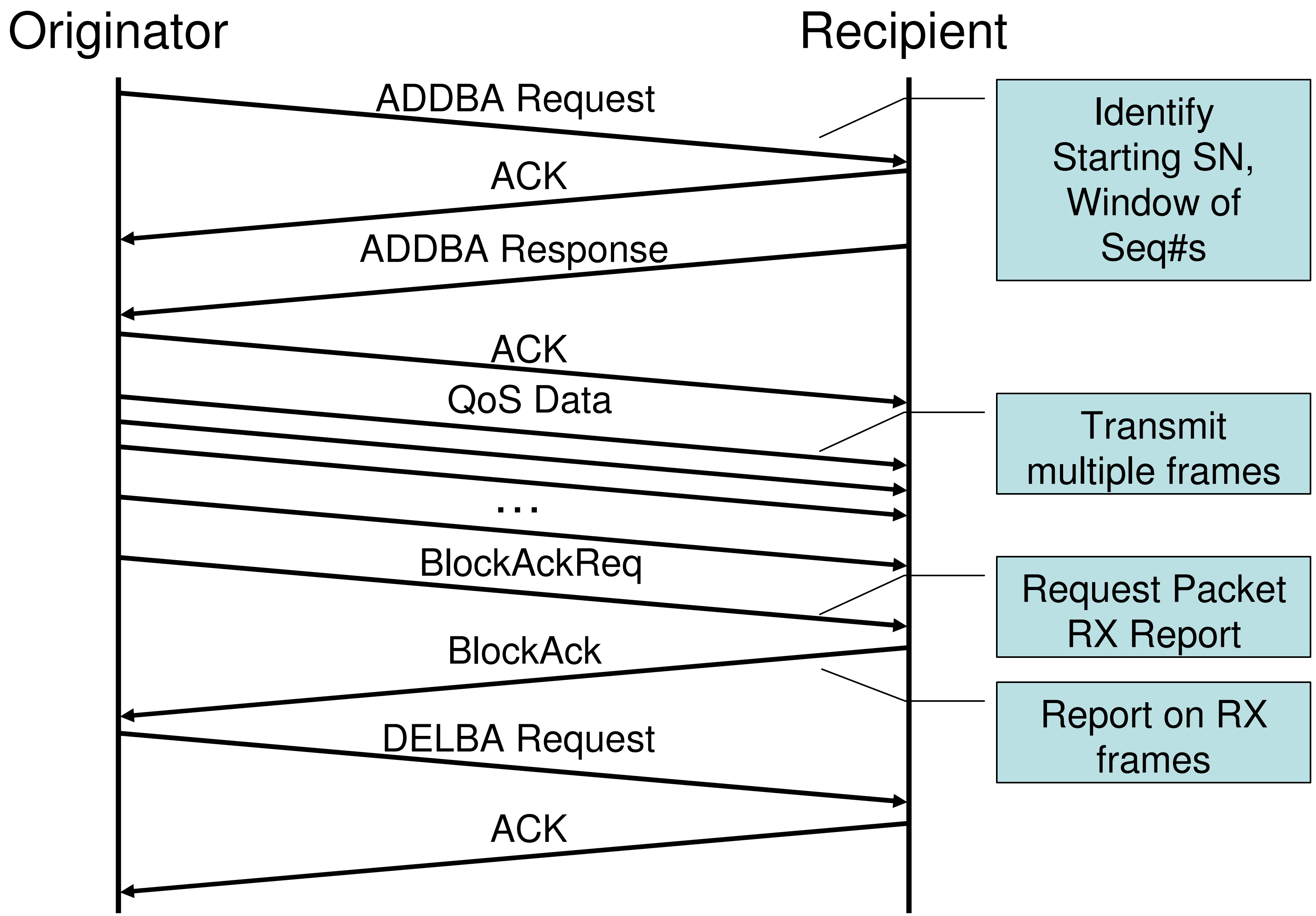
- High Throughput (HT) mixed mode designed to be backward-compatible with existing chips
  - Performance degradation similar to 802.11b/802.11g
- Maximum 802.11n performance achieved through HT greenfield format
  - Not backward compatible with existing cards
- Legacy 802.11a/b/g WIDS systems unable to decode greenfield mode data

Evading Rogue Detection Mechanisms

- Rogue: unauthorized AP on your network
  - Essentially "Ethernet jack in your parking lot"
- WIDS systems significant value-add is identification and IPS against rogue APs
- Greenfield rogue devices can be used to evade existing WIDS analysis systems
  - Cannot be detected by WIDS without 802.11n card
  - Allows "attacker" to evade policy and enforcement mechanisms

Built-In DoS Vulnerability

- Positive acknowledgement of all data frames
- Real-time applications may not need positive acknowledgement
- Block ACK introduced in 802.11e, enhanced in 802.11n D3.0
  - Receiver positively or negatively acknowledge multiple frames within a negotiated window
  - 802.11 sequence numbers used for identification
- Enhanced in 802.11n for frame aggregation

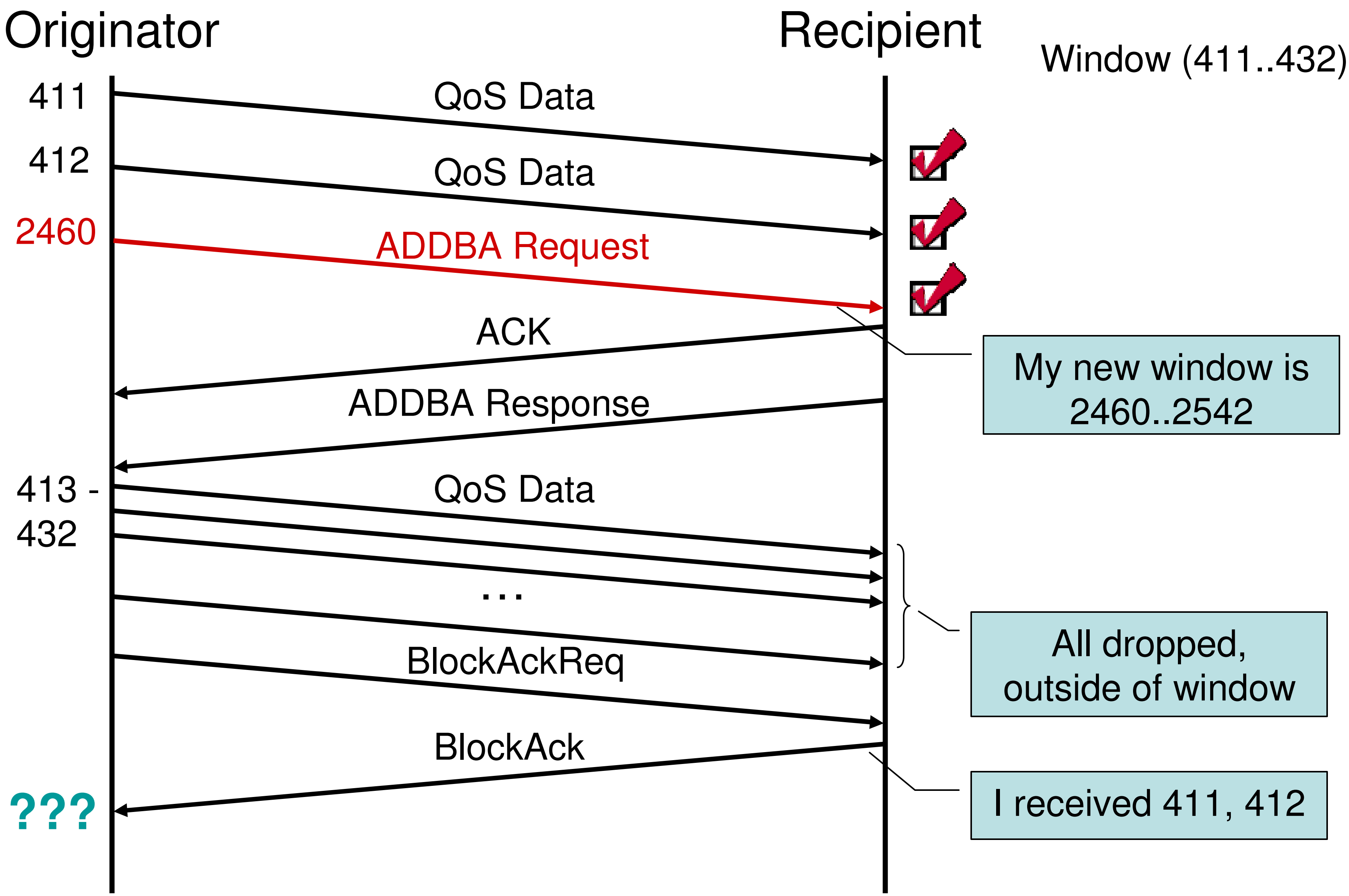

Originator
Recipient
ADDBA Request
ACK
ADDBA Response
ACK
QoS Data
…
BlockAckReq
BlockAck
DELBA Request
ACK
Identify Starting SN, Window of Seq#s
Transmit multiple frames
Request Packet RX Report
Report on RX frames

Block Acknowledgement Handling

- ADDBA Request, transmitter specifies start and end of sequence numbers receiver should expect
  - WinStart_B is the next expected sequence number
  - WinSize_B is the block size of sequence numbers
  - WinEnd_B = (WinStart_B + WinSize_B) - 1
- Receiver accepts frames within the window
  - WinStart_B <= SN <= WinEnd_B
  - Frames outside of window are dropped, cannot be acknowledged with block ACK

Vulnerability in Block ACK Handling

- Recipient receives or drops frames according to WinStart_B and WinEnd_B values
- Attacker can impersonate ADDBA frames
  - Control frame, no security applied
- Artificially modifying WinStart_B and WinEnd_B causes all other frames to be dropped
- BlockAckReq "status report" will indicate multiple frames missed



Originator
Recipient
Window (411..432)
411
QoS Data
412
QoS Data
2460
ADDBA Request
ACK
My new window is 2460..2542
ADDBA Response
413 - 432
QoS Data
...
BlockAckReq
All dropped, outside of window
BlockAck
I received 411, 412
???

802.11n Block ACK DoS Vulnerability

- All traffic is discarded until the new window is reached
- Transmitting station gets TX report, knows that frames were not received
  - Could be retransmitted, if buffered
  - Defeats the purpose of block acknowledgement
  - Impact will be implementation-dependent
- Attacker can repeat with new ADDBA messages to keep moving valid window
- No plans to address in 802.11n
- Sometimes DoS vulnerabilities are considered acceptable

Driver Flaws

- Next-generation attack vehicle for 802.11 networks
- Attackers recognize strength of WPA/WPA2 with AES-CCMP and EAP/TLS or PEAP/TTLS
- Attackers migrating to exploiting client vulnerabilities
  - Crafting malformed frames that trigger software vulnerabilities on a target machine
  - Executed with few packets, full compromise of target

Discovery: 802.11 Protocol Fuzzing

- Protocol fuzzing sends malformed input to test for programming flaws, bugs
- Identified flaws often turn into buffer/heap overflow vulnerabilities
- Flaws exploited by attackers at layer 2
- Little protection from firewalls at layer 3
- Recent public attention at hacker conferences, academic publications, commercial tools

SSID Information Element

"The length of the SSID information field is between 0 and 32 octets. A 0 length information field indicates the broadcast SSID." IEEE 802.11-1999 p 55

Bytes	1	1	0 - 32
	Element ID	Length	SSID

No.	Time	Source	Dest	Protocol	Info
51	1.207784	00:0f:66:e3:e4:03	ff:ff:ff:ff:ff:ff	Beacon	Beacon frame,SN=3672
52	1.250975	00:0f:66:e3:e4:03	ff:ff:ff:ff:ff:ff	Beacon	Beacon frame,SN=3709

```
▷ Frame 52 (339 bytes on wire, 339 bytes captured)
▷ IEEE 802.11
▽ IEEE 802.11 wireless LAN management frame
  ▷ Fixed parameters (12 bytes)
  ▽ Tagged parameters (303 bytes)
    ▽ SSID parameter set: "AAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAA
        Tag Number: 0 (SSID parameter set)
        Tag length: 255
        Tag interpretation [truncated]: AAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAA
    ▷ Supported Rates: 1.0(B) 2.0(B) 5.5(B) 11.0(B)
    ▷ DS Parameter set: Current Channel: 11
```

Python and Scapy Fuzzing

```
#!/usr/bin/python
import sys
from scapy import *
target = "00:09:5B:64:6F:23"
ap = "00:40:96:01:02:03"
conf.iface = "wlan0"
basep = Dot11(
        proto=0, type=0, subtype=5,             # Probe response frame
        addr1=target, addr2=ap, addr3=ap,       # sent to target from AP
        FCfield=0, SC=0, ID=0)                  # other fields set to 0
basep /= Dot11ProbeResp(
        timestamp = random.getrandbits(64),     # Random BSS timestamp
        beacon_interval = socket.ntohs(0x64),   # byte-swap BI, ~.10 sec
        cap = socket.ntohs(0x31))               # AP/WEP/Short Preamble
ssid = "fuzzproberesp"
basep /= Dot11Elt(ID=0, len=len(ssid), info=ssid)
basep /= Dot11Elt(ID=3, len=1, info="\x01")
while 1:
        tmpp = basep
        tmpp /= fuzz(Dot11Elt(ID=1))
        # Send a packet every 1/10th of a second, 20 times
        sendp(p, count=20, inter=.1)
```

Metasploit 3.1 Framework Fuzzer

- Exploit framework written in Ruby
- Includes over 250 exploits, 118 payloads and auxiliary utilities
- Designed for Linux or Windows systems
- Integrates exploits with payloads for various compromise methods
  - Adduser payload: Creates a new administrative user
  - VNC Inject payload: Starts a VNC process on target
  - Metaterpreter: Enhanced remote shell access on target
- Auxiliary utilities include fuzzing tools

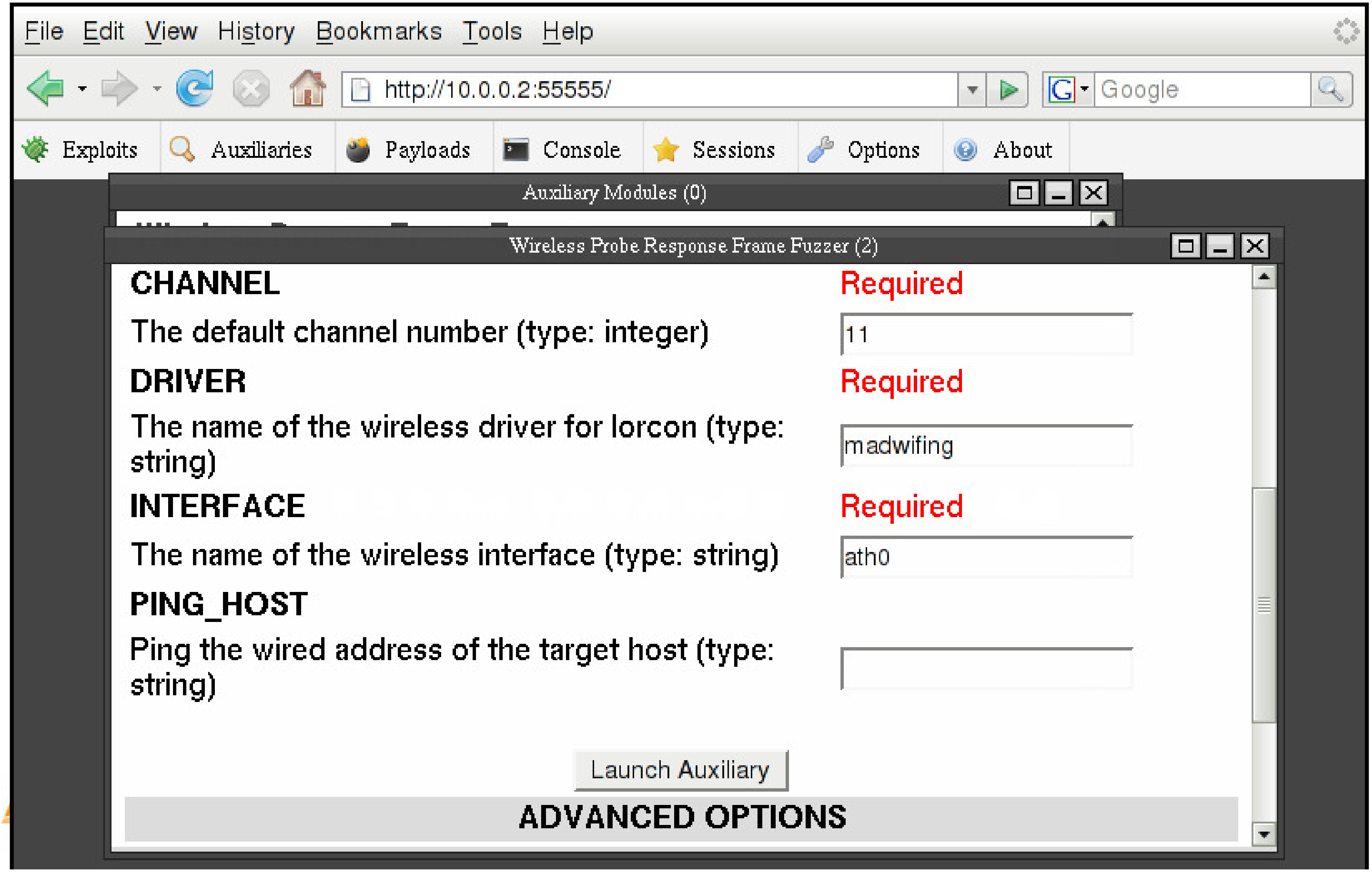
Metasploit Probe Response Fuzzing

File Edit View Terminal Go Help

```
       =[ msf v3.2-release
+ -- --=[ 269 exploits - 118 payloads
+ -- --=[ 17 encoders - 6 nops
       =[ 48 aux

msf > use auxiliary/dos/wireless/fuzz_proberesp
msf auxiliary(fuzz_proberesp) > set ADDR_DST 00:13:ce:55:98:ef
ADDR_DST => 00:13:ce:55:98:ef
msf auxiliary(fuzz_proberesp) > set PING_HOST 10.0.0.2
PING_HOST => 10.0.0.2
msf auxiliary(fuzz_proberesp) > exploit
[*] Sending corrupt frames...
```

Metasploit Probe Response Fuzzing GUI



Driver Disassembly for Bug Hunting

IDA View-A

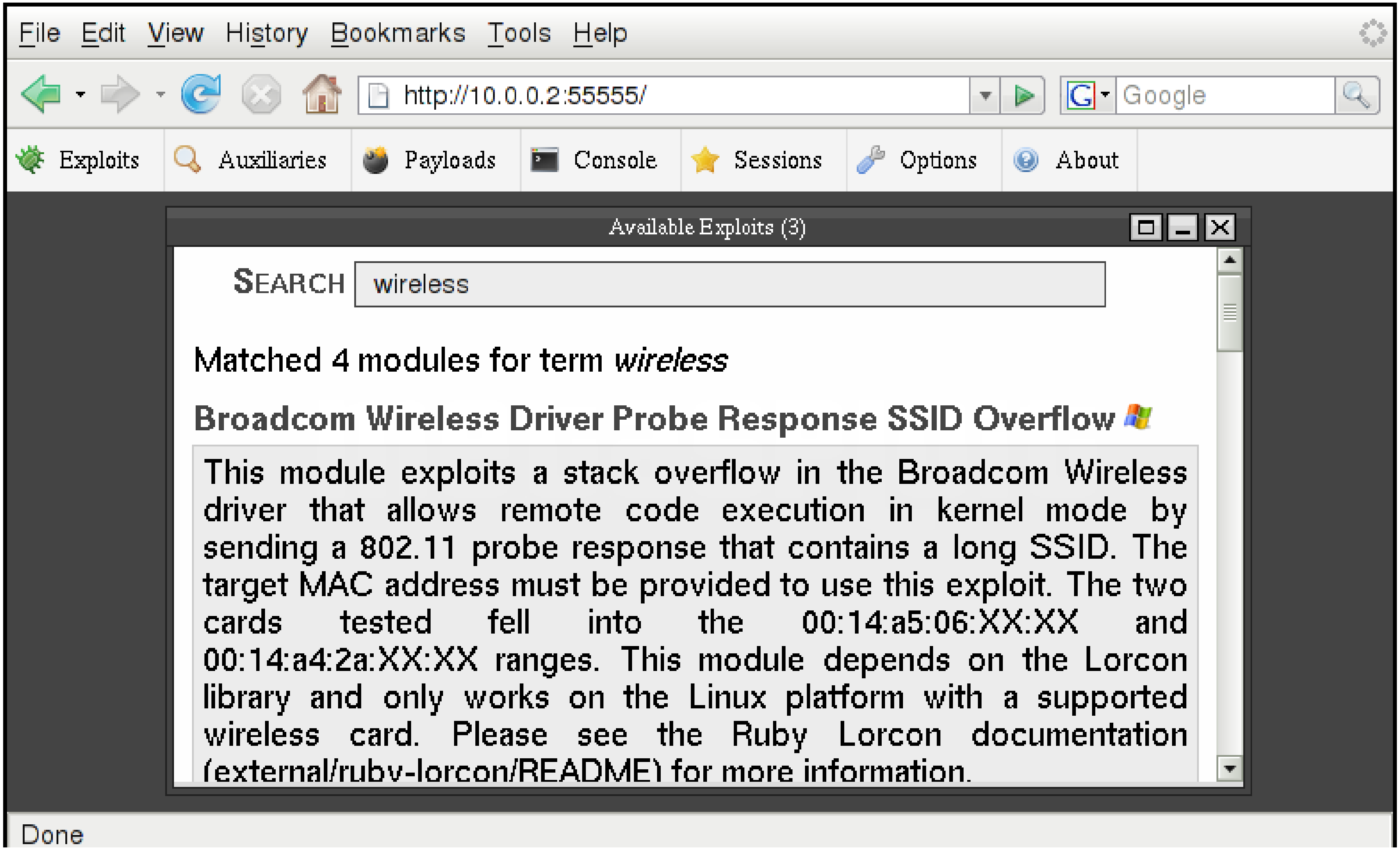
```
ext:0001D314
ext:0001D314 loc_1D314:                                    ; CODE XREF: sub_1D206+108↑j
ext:0001D314                 mov     al, [eax+edi+0FCBCh]
ext:0001D31B                 mov     [ebx+45h], al
ext:0001D31E                 movzx   ax, byte ptr [esi+9]
ext:0001D323                 movzx   cx, byte ptr [esi+8]
ext:0001D328                 push    0
ext:0001D32A                 push    [ebp+var_C]
ext:0001D32D                 push    [ebp+var_10]
ext:0001D330                 shl     eax, 8
ext:0001D333                 add     eax, ecx
ext:0001D335                 mov     [ebx+2Ah], ax
ext:0001D339                 call    sub_318D0
ext:0001D33E                 test    eax, eax
ext:0001D340                 jz      loc_1D2AE
ext:0001D346                 mov     cl, [eax+1]       ; SSID IE offset + 1 = length byte?
ext:0001D349                 mov     [ebx+6], cl
ext:0001D34C                 movzx   ecx, cl           ; Length of data to copy
ext:0001D34F                 lea     esi, [eax+2]      ; Data to be copied
ext:0001D352                 mov     eax, ecx          ; Save the length for later
ext:0001D354                 shr     ecx, 2            ; divide ecx by 4, DWORD size
ext:0001D357                 lea     edi, [ebx+7]      ; Destination location on the stack
ext:0001D35A                 rep movsd                 ; memcpy
ext:0001D35C                 mov     ecx, eax
ext:0001D35E                 and     ecx, 3
ext:0001D361                 rep movsb
ext:0001D363                 mov     esi, [ebp+var_C]
```

0000D354 | 0001D354: sub_1D206+14E

Exploiting Driver Bugs

- IEEE 802.11 fuzzing has uncovered driver bugs, attacker opportunities
- Drivers run in ring0, compromise reveals full access to host by the attacker
- Driver vulnerabilities are often not mitigated with encryption or authentication
  - Applicable regardless of WPA, WPA2, EAP/TLS, etc.
- Few organizations upgrade drivers as part of a patch management process
  - Systems remain vulnerable for an extended duration

Metasploit - Exploiting Driver Flaws



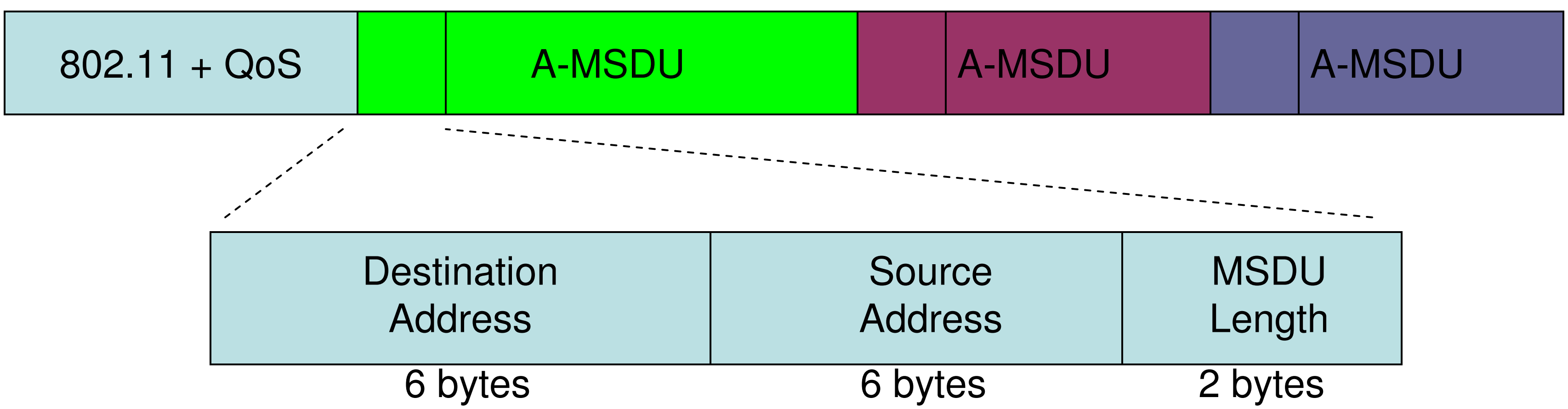
Drivers and 802.11n Networks

- New complexities in 802.11n require new drivers to be written
  - New frame types, information elements, frame aggregation mechanisms, QoS parameters, etc.
  - Complexity is an attacker's friend
- Manufacturers in a frenzy of delivering 802.11n
  - Often, security wanes when product deadlines approach

802.11n represents new opportunities to exploit implementation flaws in drivers

802.11n Aggregate MSDU Delivery

- One of two mechanisms for aggregating traffic
- Multiple frames for any destination are aggregated into a single payload
  - AP or STA de-aggregates packets and processes data



Potential A-MSDU Handling Example

```
handle_amsdu(uint8_t *packet, int framelen) {
    int offset = 0;
    struct amsdu_header *amsduhdr;

    while (framelen != 0) {
        amsduhdr = (packet+offset);
        if (memcmp(amsduhdr->destaddr, MY_MAC, 6)) {
            process_amsdu(amsduhdr+AMSDUHDR_LEN);
        }
        framelen -= amsduhdr->length;
        offset += amsduhdr->length;
    }
}
```

Attacker controls "length" in A-MSDU field, can influence framelen to become negative

New Metasploit Fuzzer - A-MSDU

- New fuzzer adds ability to fuzz test A-MSDU payloads
- Sends one initial payload, with following random MSDU length and payload

```
       =[ msf v3.2-release
+ -- --=[ 269 exploits - 118 payloads
+ -- --=[ 17 encoders - 6 nops
       =[ 48 aux

msf > use auxiliary/dos/wireless/fuzz_amsdu
msf auxiliary(fuzz_amsdu) > set ADDR_DST 00:1d:7e:03:28:bb
ADDR_DST => 00:1d:7e:03:28:bb
msf auxiliary(fuzz_amsdu) > set ADDR_SRC 00:19:5b:4e:29:b1
ADDR_SRC => 00:19:5b:4e:29:b1
msf auxiliary(fuzz_amsdu) >  set PING_HOST 10.0.0.2
PING_HOST => 10.0.0.2
msf auxiliary(fuzz_amsdu) > exploit
[*] Sending corrupt frames...
```

Target

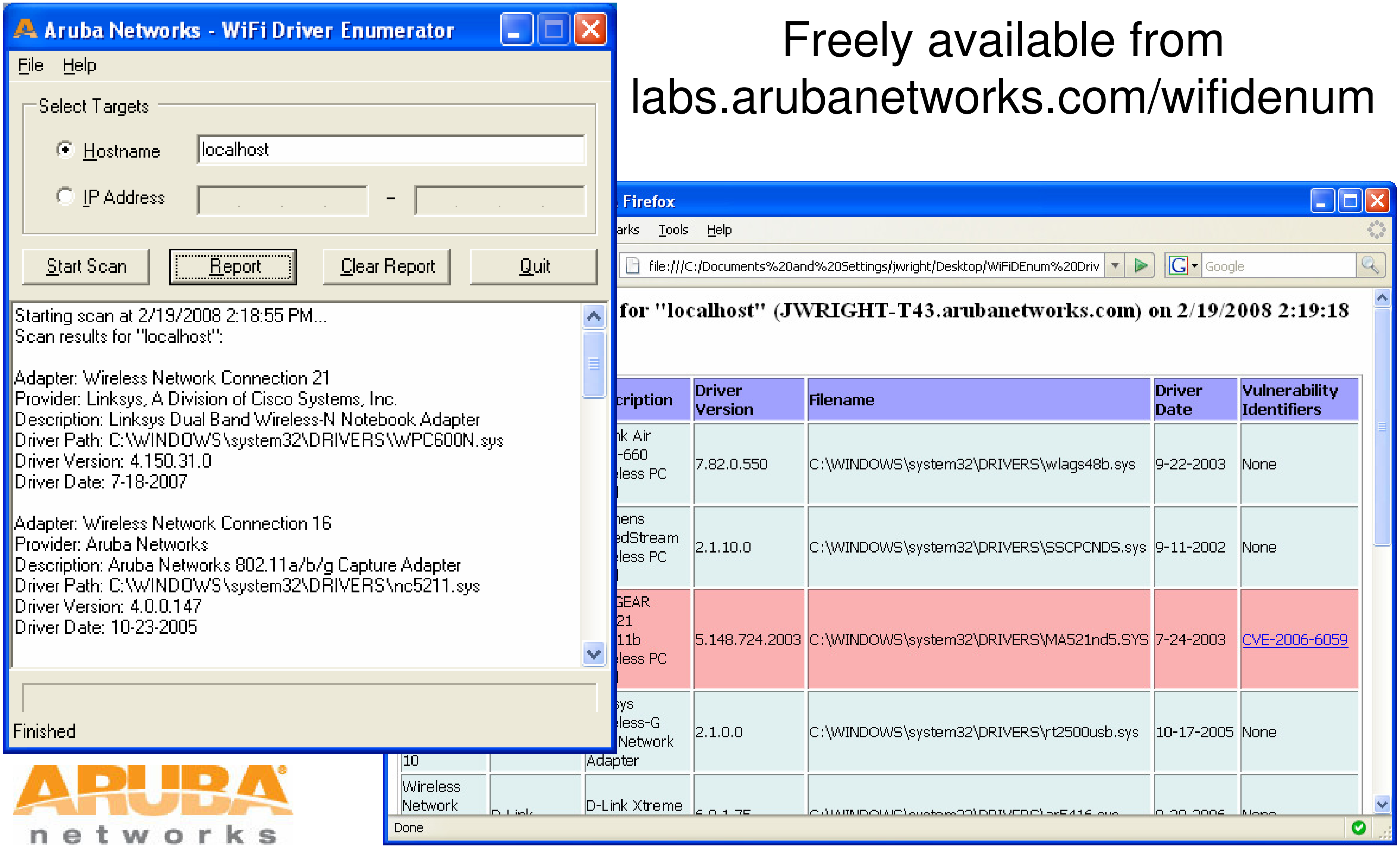
Spoofed AP

Mitigating Driver Flaws

- Ensure vendors are maintaining driver versions and responding to vulnerability reports
  - Monitor vendor website for driver updates
- Monitoring public wireless vulnerability reports
- Perform your own fuzzing tests
  - Write your own tools, leverage existing free and commercial tools
- Auditing your environment for driver vulnerabilities
- WiFiDEnum - Wireless Driver Enumerator

WiFiDEnum

Freely available from
labs.arubanetworks.com/wifidenum



ARUBA networks

802.11n Risk Mitigation

- Careful deployment planning required
  - Always leverage WPA/WPA2 with strong EAP types for protected authentication
- Discuss with vendor WIDS strategies for channel monitoring, GF detection/mitigation
- No protection against DoS vulnerabilities (including 802.11w and MFP)
- Carefully monitor workstations for driver threats
- Consider in-house and commercial testing

Summary

- 802.11n promises to significantly enhance WLAN
- New application and cost savings opportunities
- Consistency in performance and reliability a huge win for organizations
- Improved bandwidth rivals or exceeds many existing LAN deployments
- Not without risks that can expose organizations
- Careful planning, vendor communication required for successful deployments

Questions? Thank you!

- Your Speaker:

Joshua Wright
Senior Security Researcher
Aruba Networks
jwright@arubanetworks.com
Office/Mobile: 401-524-2911

Knowledge helps us all to defend our networks

ARUBA networks