Wireshark Developer and User Conference

Mobile Application Analysis with Wireshark

June 14, 2011

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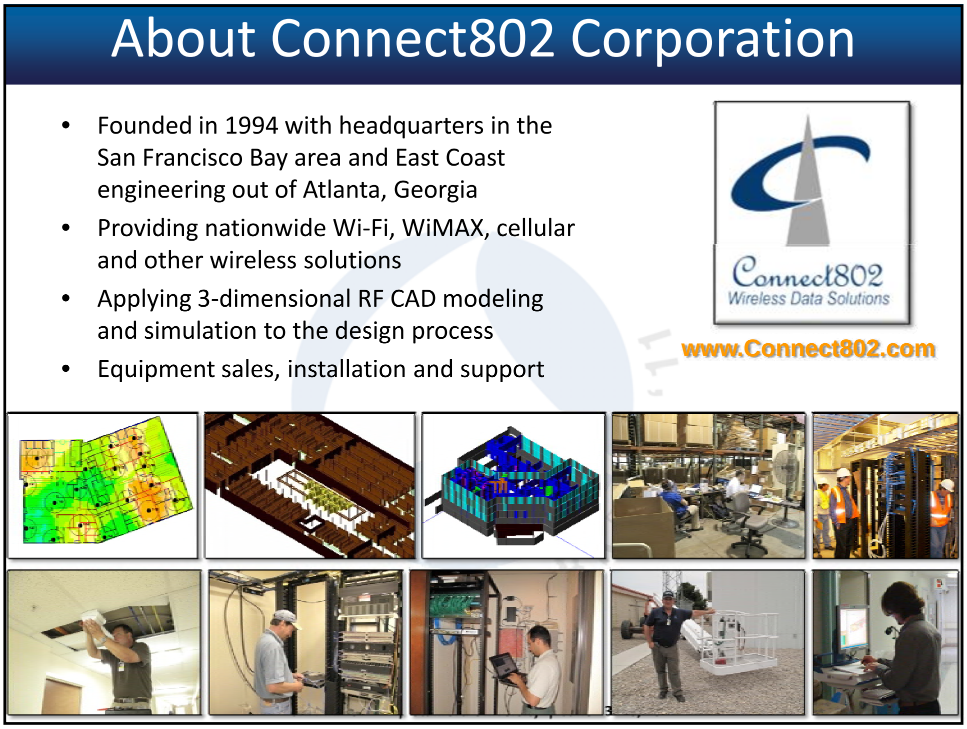
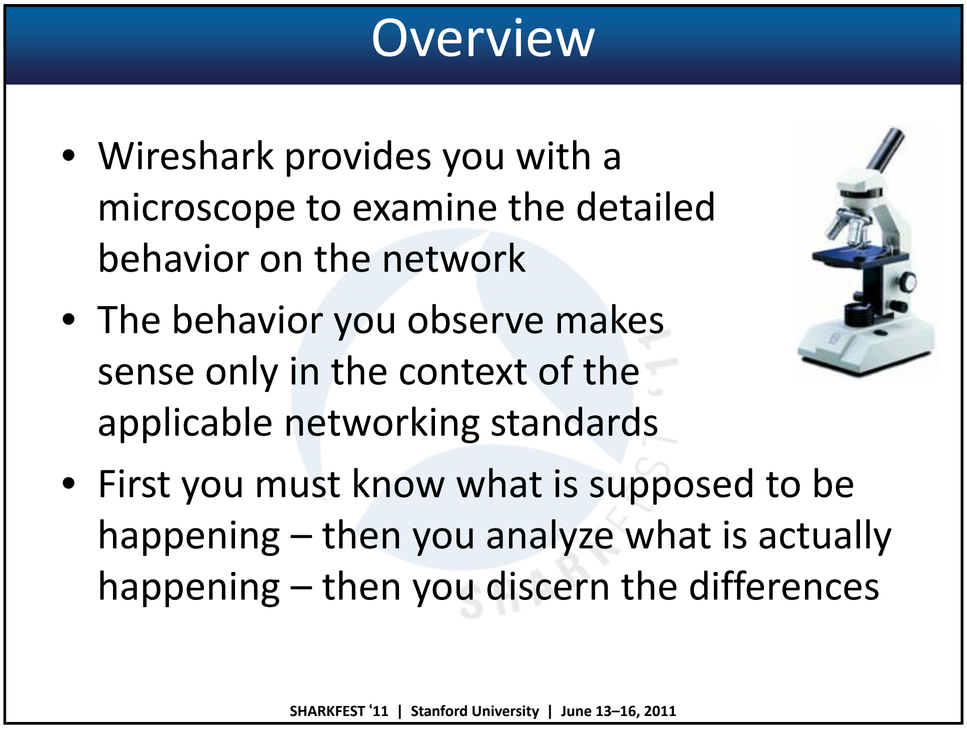


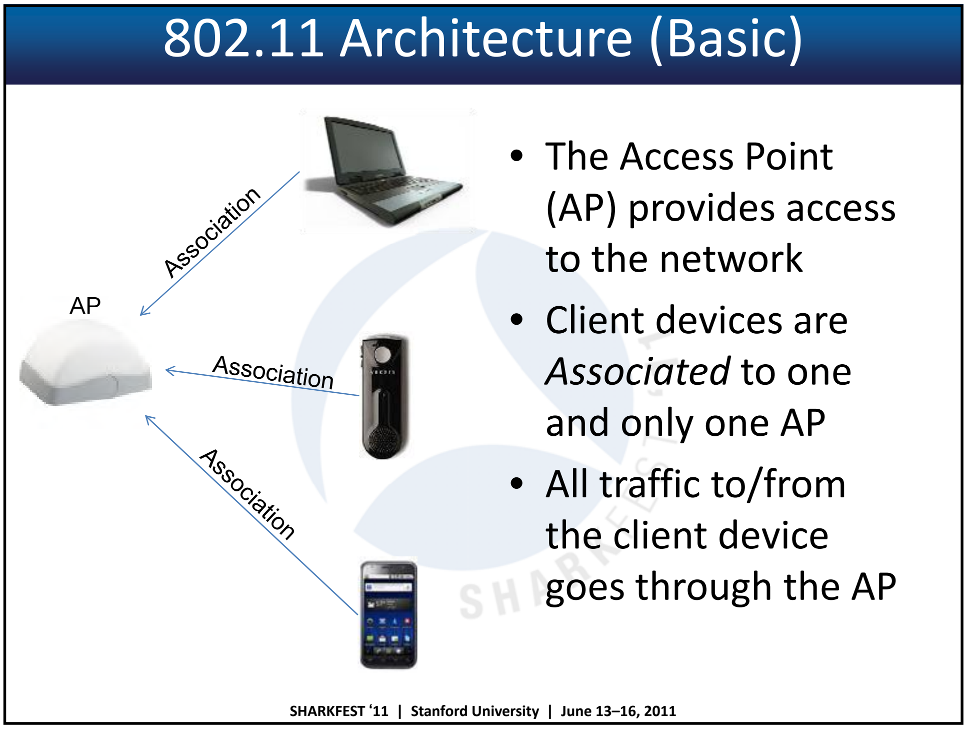
About Connect802 Corporation

- Founded in 1994 with headquarters in the San Francisco Bay area and East Coast engineering out of Atlanta, Georgia
- Providing nationwide Wi-Fi, WiMAX, cellular and other wireless solutions
- Applying 3-dimensional RF CAD modeling and simulation to the design process
- Equipment sales, installation and support



Overview

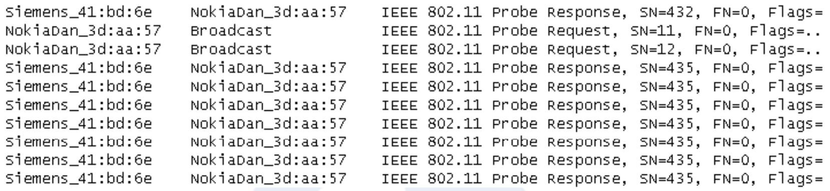
- Wireshark provides you with a microscope to examine the detailed behavior on the network
- The behavior you observe makes sense only in the context of the applicable networking standards
- First you must know what is supposed to be happening – then you analyze what is actually happening – then you discern the differences



802.11 Architecture (Basic)

- The Access Point (AP) provides access to the network
- Client devices are *Associated* to one and only one AP
- All traffic to/from the client device goes through the AP

AP Discovery



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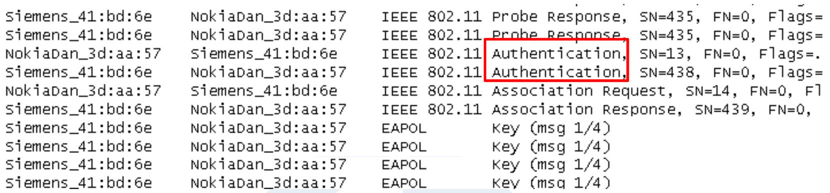
NokiaDan_3d:aa:57   Broadcast            IEEE 802.11 Probe Request, SN=11, FN=0, Flags=..
NokiaDan_3d:aa:57   Broadcast            IEEE 802.11 Probe Request, SN=12, FN=0, Flags=..
Siemens_41:bd:6e    NokiaDan_3d:aa:57    IEEE 802.11 Probe Response, SN=435, FN=0, Flags=
Siemens_41:bd:6e    NokiaDan_3d:aa:57    IEEE 802.11 Probe Response, SN=435, FN=0, Flags=
Siemens_41:bd:6e    NokiaDan_3d:aa:57    IEEE 802.11 Probe Response, SN=435, FN=0, Flags=
Siemens_41:bd:6e    NokiaDan_3d:aa:57    IEEE 802.11 Probe Response, SN=435, FN=0, Flags=
Siemens_41:bd:6e    NokiaDan_3d:aa:57    IEEE 802.11 Probe Response, SN=435, FN=0, Flags=
Siemens_41:bd:6e    NokiaDan_3d:aa:57    IEEE 802.11 Probe Response, SN=435, FN=0, Flags=
Siemens_41:bd:6e    NokiaDan_3d:aa:57    IEEE 802.11 Probe Response, SN=435, FN=0, Flags=
```

- Passive Discovery
  - Client devices listen for *Beacon* frames sent by APs
- Active Discovery
  - Client devices send *Probe Request* frames
  - APs hear the Probe Requests
  - APs respond with *Probe Response* frames

Authentication



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NokiaDan_3d:aa:57   Siemens_41:bd:6e     IEEE 802.11 Authentication, SN=13, FN=0, Flags=.
Siemens_41:bd:6e    NokiaDan_3d:aa:57    IEEE 802.11 Authentication, SN=438, FN=0, Flags=
NokiaDan_3d:aa:57   Siemens_41:bd:6e     IEEE 802.11 Association Request, SN=14, FN=0, Fl
Siemens_41:bd:6e    NokiaDan_3d:aa:57    IEEE 802.11 Association Response, SN=439, FN=0,
Siemens_41:bd:6e    NokiaDan_3d:aa:57    EAPOL       Key (msg 1/4)
Siemens_41:bd:6e    NokiaDan_3d:aa:57    EAPOL       Key (msg 1/4)
Siemens_41:bd:6e    NokiaDan_3d:aa:57    EAPOL       Key (msg 1/4)
Siemens_41:bd:6e    NokiaDan_3d:aa:57    EAPOL       Key (msg 1/4)
```
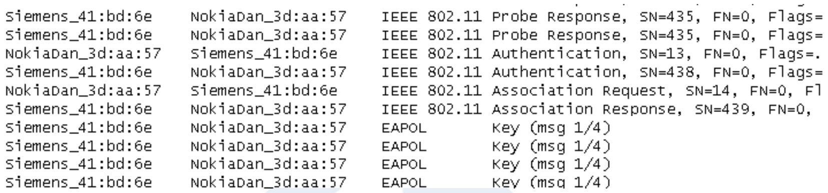

- Authentication between client and AP must succeed before the AP will pass data frames
- 802.11 defines two forms of authentication
  - Open System (always successful—equivalent to no authentication at all)
  - Shared Key (hash-based challenge/response using WEP key as a token)

Association



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NokiaDan_3d:aa:57   Siemens_41:bd:6e     IEEE 802.11 Authentication, SN=13, FN=0, Flags=.
Siemens_41:bd:6e    NokiaDan_3d:aa:57    IEEE 802.11 Authentication, SN=438, FN=0, Flags=
NokiaDan_3d:aa:57   Siemens_41:bd:6e     IEEE 802.11 Association Request, SN=14, FN=0, Fl
Siemens_41:bd:6e    NokiaDan_3d:aa:57    IEEE 802.11 Association Response, SN=439, FN=0,
Siemens_41:bd:6e    NokiaDan_3d:aa:57    EAPOL       Key (msg 1/4)
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Siemens_41:bd:6e    NokiaDan_3d:aa:57    EAPOL       Key (msg 1/4)
Siemens_41:bd:6e    NokiaDan_3d:aa:57    EAPOL       Key (msg 1/4)
```

- Client device decides which AP it wants to associate with
- *Authentication* packets are exchanged
- *Association Request / Response* is exchanged

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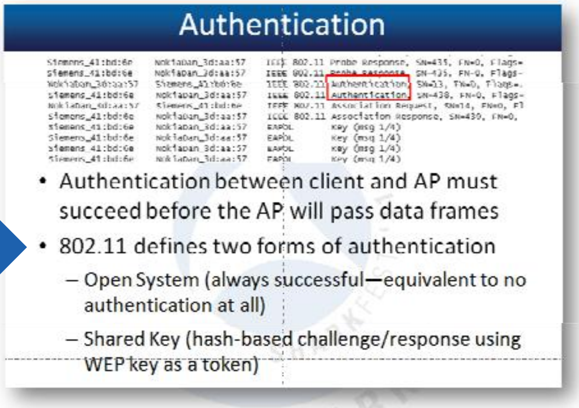
A Conundrum

- Previously, we said that:



Authentication

```
Siemens_41:bd:6e    NokiaDan_3d:aa:57    IEEE 802.11 Probe Response, SN=435, FN=0, Flags=
Siemens_41:bd:6e    NokiaDan_3d:aa:57    IEEE 802.11 Probe Response, SN=435, FN=0, Flags=
NokiaDan_3d:aa:57   Siemens_41:bd:6e     IEEE 802.11 Authentication, SN=13, FN=0, Flags=.
Siemens_41:bd:6e    NokiaDan_3d:aa:57    IEEE 802.11 Authentication, SN=438, FN=0, Flags=
NokiaDan_3d:aa:57   Siemens_41:bd:6e     IEEE 802.11 Association Request, SN=14, FN=0, Fl
Siemens_41:bd:6e    NokiaDan_3d:aa:57    IEEE 802.11 Association Response, SN=439, FN=0,
Siemens_41:bd:6e    NokiaDan_3d:aa:57    EAPOL       Key (msg 1/4)
Siemens_41:bd:6e    NokiaDan_3d:aa:57    EAPOL       Key (msg 1/4)
Siemens_41:bd:6e    NokiaDan_3d:aa:57    EAPOL       Key (msg 1/4)
Siemens_41:bd:6e    NokiaDan_3d:aa:57    EAPOL       Key (msg 1/4)
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- Authentication between client and AP must succeed before the AP will pass data frames
- 802.11 defines two forms of authentication
  - Open System (always successful—equivalent to no authentication at all)
  - Shared Key (hash-based challenge/response using WEP key as a token)

- What about 802.1x (WPA)?

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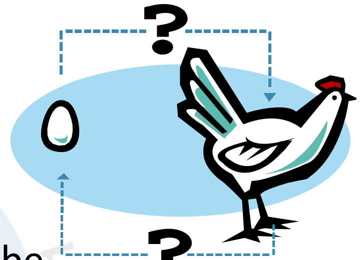
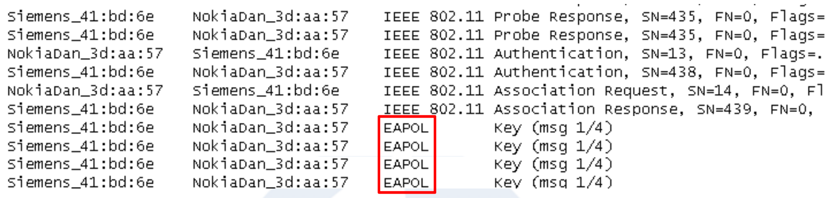
Which Came First…

- 802.1x (WPA) authentication uses the EAPOL protocol
- Only 802.11 packets can be Management or Control frames; EAPOL packets must be sent as Data frames
- Data frames can only be sent after authentication
- But EAPOL is used to accomplish authentication!

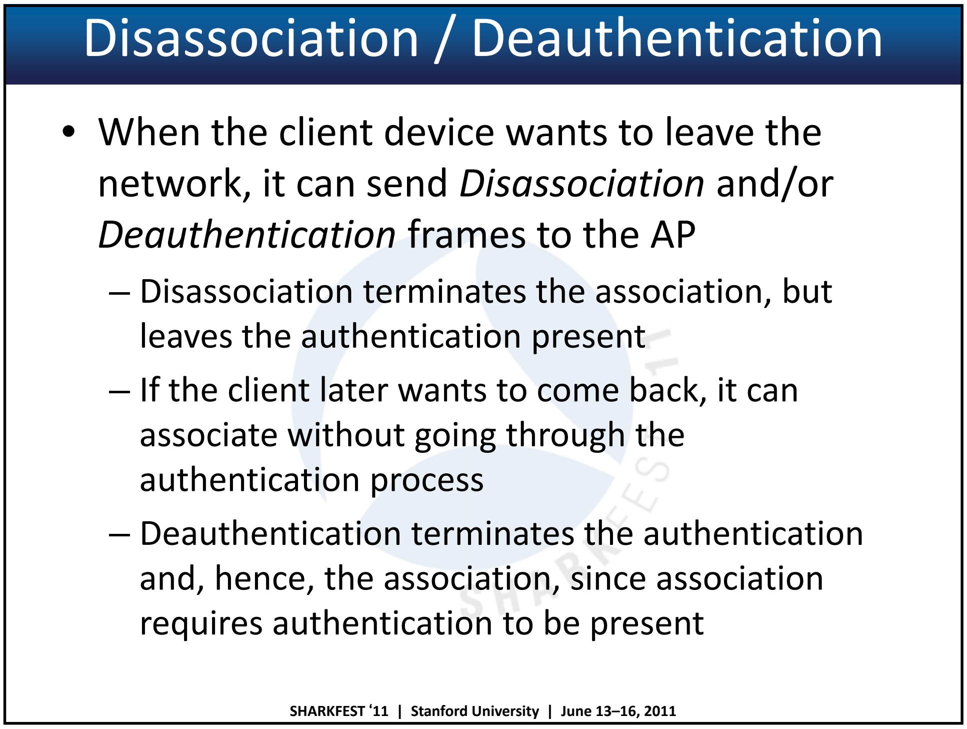


802.1x (WPA) Authentication



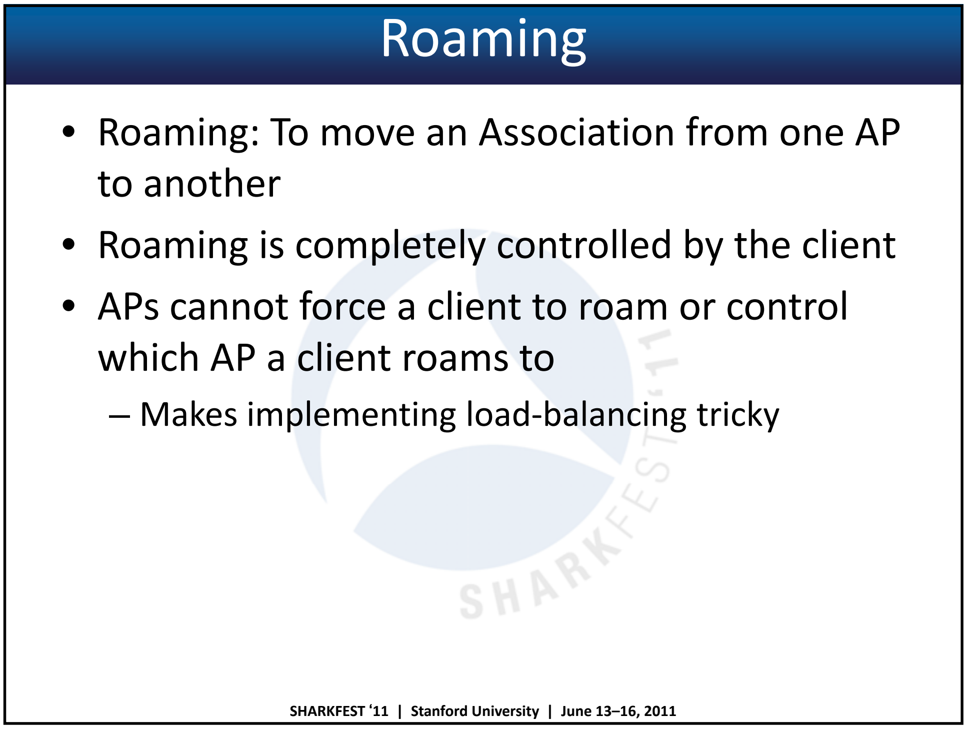
```
Siemens_41:bd:6e    NokiaDan_3d:aa:57   IEEE 802.11 Probe Response, SN=435, FN=0, Flags=
Siemens_41:bd:6e    NokiaDan_3d:aa:57   IEEE 802.11 Probe Response, SN=435, FN=0, Flags=
NokiaDan_3d:aa:57   Siemens_41:bd:6e    IEEE 802.11 Authentication, SN=13, FN=0, Flags=.
Siemens_41:bd:6e    NokiaDan_3d:aa:57   IEEE 802.11 Authentication, SN=438, FN=0, Flags=
NokiaDan_3d:aa:57   Siemens_41:bd:6e    IEEE 802.11 Association Request, SN=14, FN=0, Fl
Siemens_41:bd:6e    NokiaDan_3d:aa:57   IEEE 802.11 Association Response, SN=439, FN=0,
Siemens_41:bd:6e    NokiaDan_3d:aa:57   EAPOL       Key (msg 1/4)
Siemens_41:bd:6e    NokiaDan_3d:aa:57   EAPOL       Key (msg 1/4)
Siemens_41:bd:6e    NokiaDan_3d:aa:57   EAPOL       Key (msg 1/4)
Siemens_41:bd:6e    NokiaDan_3d:aa:57   EAPOL       Key (msg 1/4)
```

- When a client and AP wish to perform WPA authentication, the client uses Open System authentication (which is always successful)
- Once this "authentication" is complete, the client can send Data frames, but…
- The AP only lets the client send EAPOL data frames until WPA authentication is successful



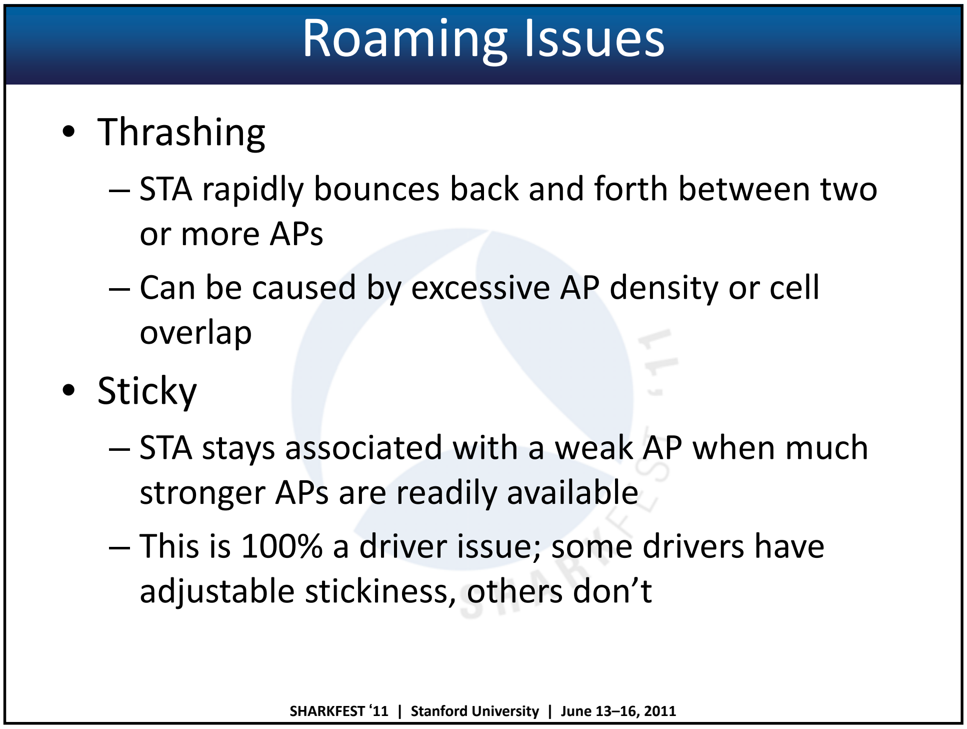
Disassociation / Deauthentication

- When the client device wants to leave the network, it can send *Disassociation* and/or *Deauthentication* frames to the AP
  - Disassociation terminates the association, but leaves the authentication present
  - If the client later wants to come back, it can associate without going through the authentication process
  - Deauthentication terminates the authentication and, hence, the association, since association requires authentication to be present



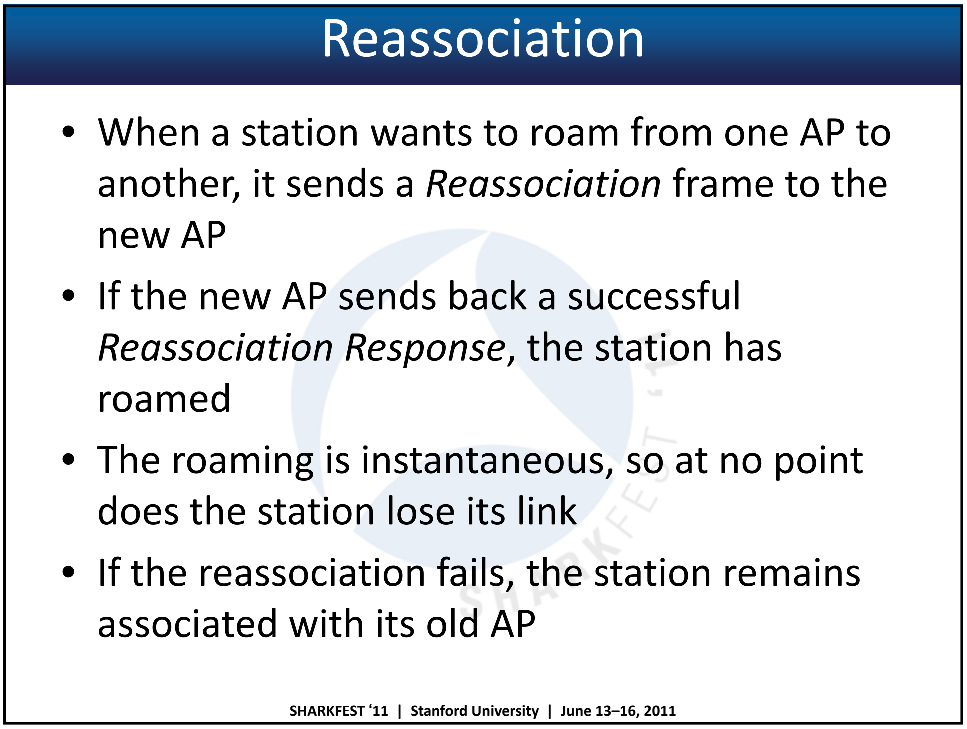
Roaming

- Roaming: To move an Association from one AP to another
- Roaming is completely controlled by the client
- APs cannot force a client to roam or control which AP a client roams to
  - Makes implementing load-balancing tricky



Roaming Issues

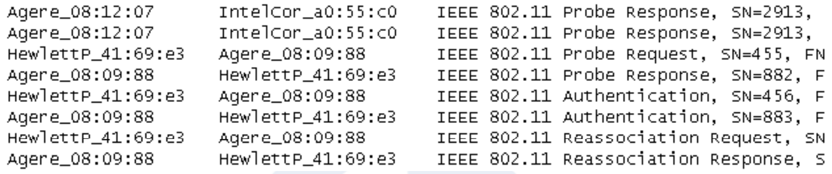
- Thrashing
  - STA rapidly bounces back and forth between two or more APs
  - Can be caused by excessive AP density or cell overlap
- Sticky
  - STA stays associated with a weak AP when much stronger APs are readily available
  - This is 100% a driver issue; some drivers have adjustable stickiness, others don’t



Reassociation

- When a station wants to roam from one AP to another, it sends a *Reassociation* frame to the new AP
- If the new AP sends back a successful *Reassociation Response*, the station has roamed
- The roaming is instantaneous, so at no point does the station lose its link
- If the reassociation fails, the station remains associated with its old AP

Reassociation In Wireshark



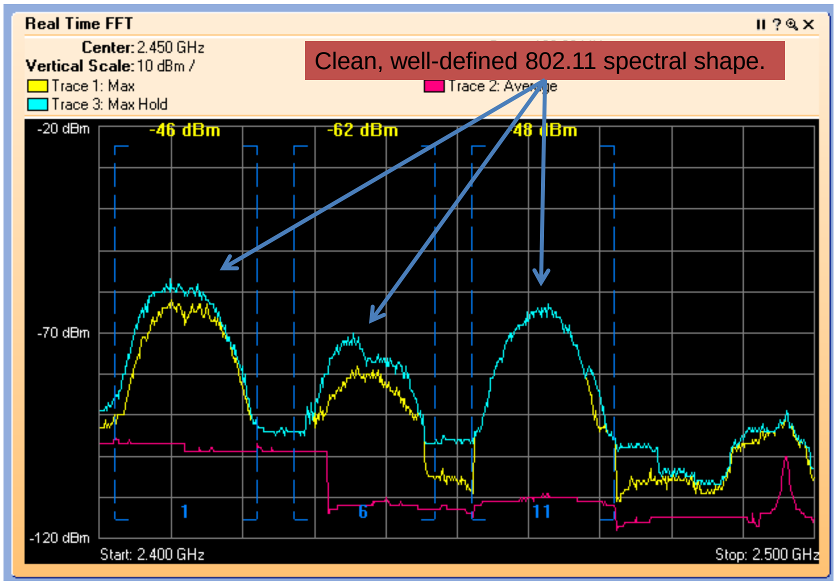
```
Agere_08:12:07      IntelCor_a0:55:c0    IEEE 802.11 Probe Response, SN=2913,
Agere_08:12:07      IntelCor_a0:55:c0    IEEE 802.11 Probe Response, SN=2913,
HewlettP_41:69:e3   Agere_08:09:88       IEEE 802.11 Probe Request, SN=455, FN
Agere_08:09:88      HewlettP_41:69:e3    IEEE 802.11 Probe Response, SN=882, F
HewlettP_41:69:e3   Agere_08:09:88       IEEE 802.11 Authentication, SN=456, F
Agere_08:09:88      HewlettP_41:69:e3    IEEE 802.11 Authentication, SN=883, F
HewlettP_41:69:e3   Agere_08:09:88       IEEE 802.11 Reassociation Request, SN
Agere_08:09:88      HewlettP_41:69:e3    IEEE 802.11 Reassociation Response, S
```

- Probes are used to find potential new APs
  - This usually happens continuously
  - Some devices will only start probing when they want to roam
- Authentication must precede Reassociation
  - Some devices will pre-authenticate with multiple nearby APs to speed up roaming

A Real-World Example

- Customer reported that client devices would go offline periodically
- Incidents were not localized to any particular time or place
- Survey of the environment with spectrum analyzer showed excellent signal strength an no interference (always check for this!)

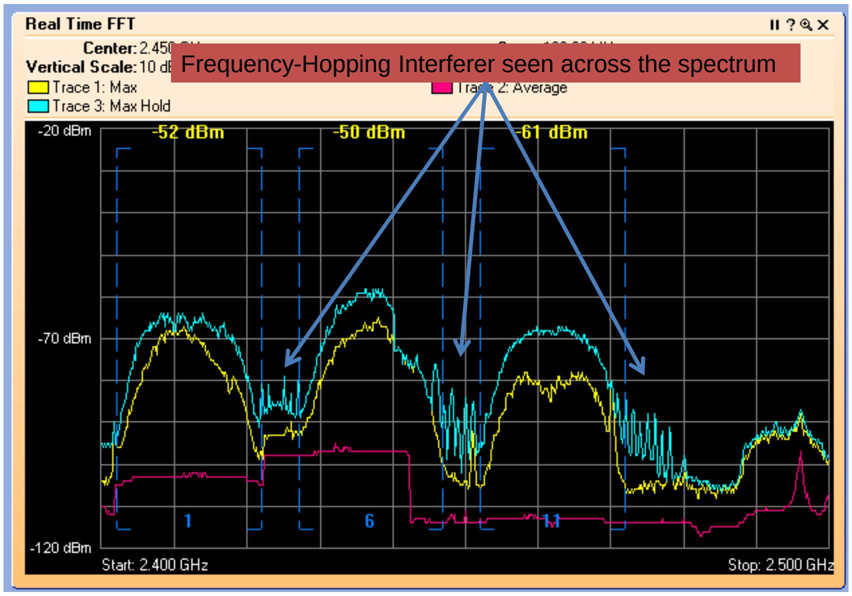
Clean Spectrum



Clean, well-defined 802.11 spectral shape.

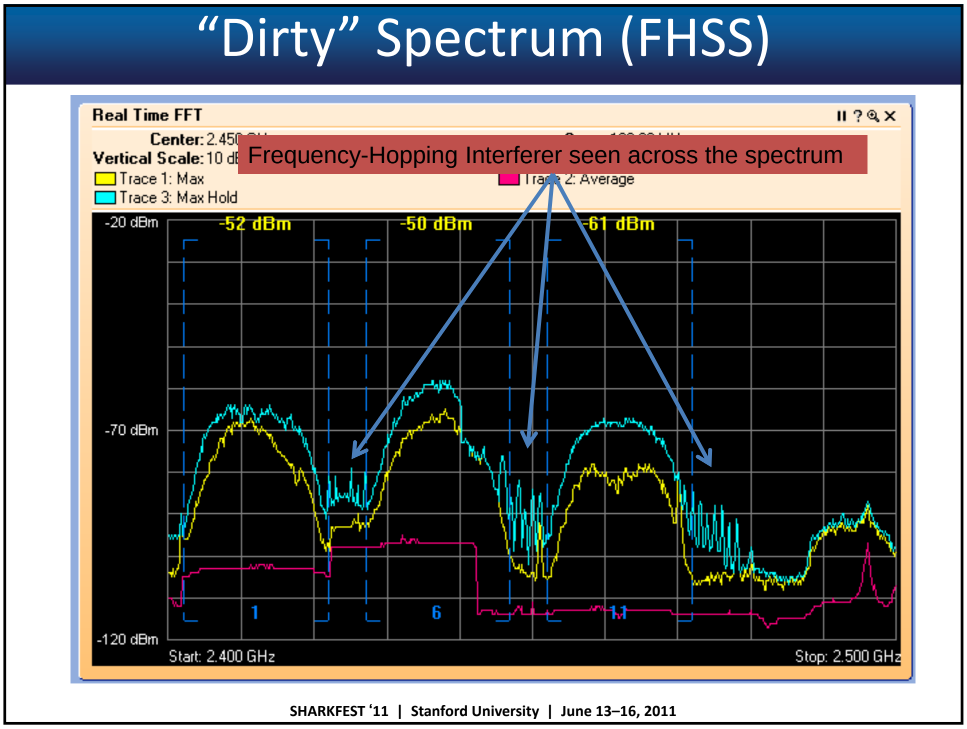
Center: 2.450 GHz
Vertical Scale: 10 dBm /

"Dirty" Spectrum (FHSS)



Frequency-Hopping Interferer seen across the spectrum

Center: 2.450
Vertical Scale: 10 dB



“Dirty” Spectrum (FHSS)

Real Time FFT

Center: 2.450

Vertical Scale: 10 dB

Trace 1: Max

Trace 3: Max Hold

Trace 2: Average

Frequency-Hopping Interferer seen across the spectrum

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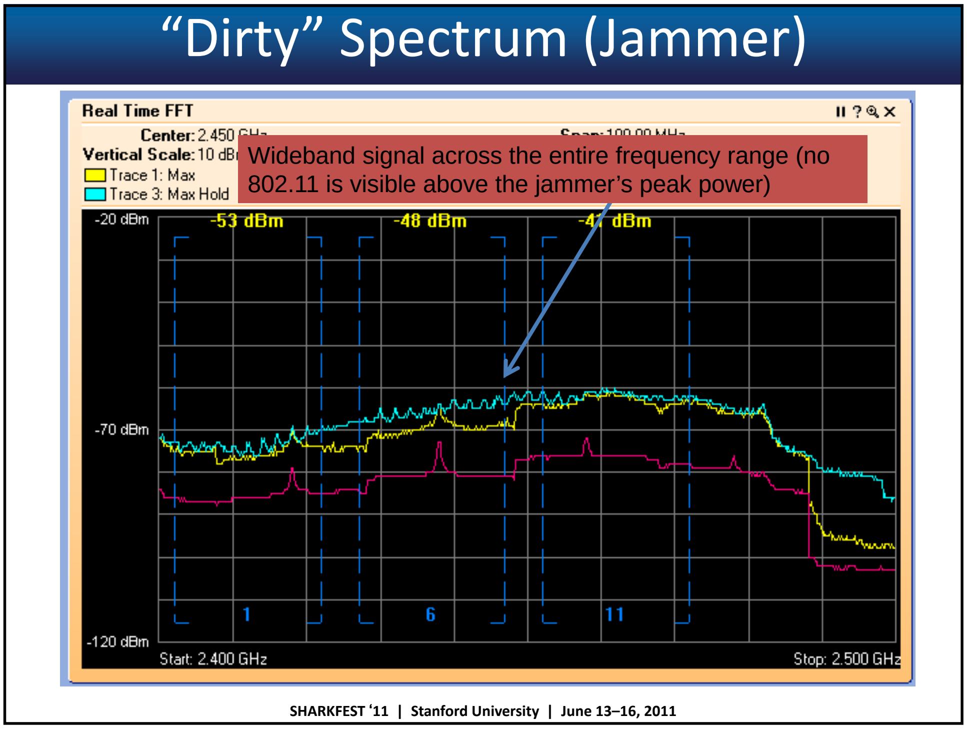

“Dirty” Spectrum (Jammer)

Real Time FFT

Center: 2.450 GHz

Span: 100.00 MHz

Vertical Scale: 10 dB

Trace 1: Max

Trace 3: Max Hold

Wideband signal across the entire frequency range (no 802.11 is visible above the jammer’s peak power)

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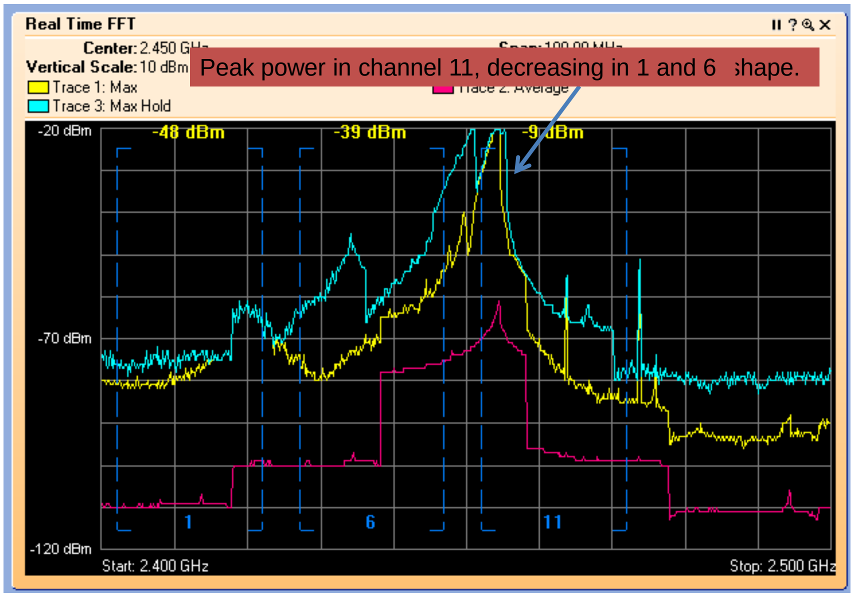
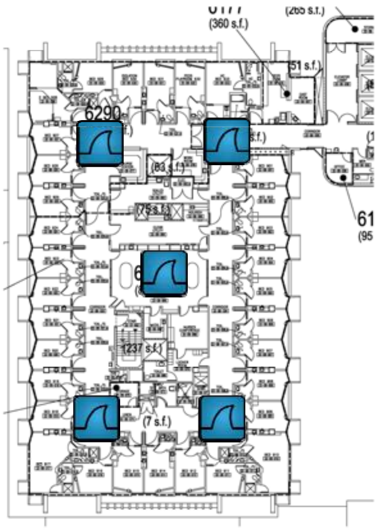
"Dirty" Spectrum (Microwave)



Peak power in channel 11, decreasing in 1 and 6 shape.

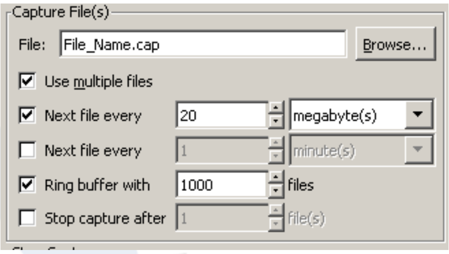
A Distributed Problem

- The problem did not happen in any predictable location
- Multiple Wireshark laptops (with multi-channel adapters) were set up throughout the site so that when the problem happened, we would catch it



Long-Term Capturing

- Incidents were not predictable, therefore Wireshark was set up to capture for a very long time (overnight)
- Wireshark config was as shown to the right



Capture File(s)

File: File_Name.cap

☑ Use multiple files

☑ Next file every 20 megabyte(s)

☐ Next file every 1 minute(s)

☑ Ring buffer with 1000 files

☐ Stop capture after 1 file(s)

Confirm that you have sufficient hard drive space before doing this. 20 meg per file * 1000 files = 20 gig of data total.

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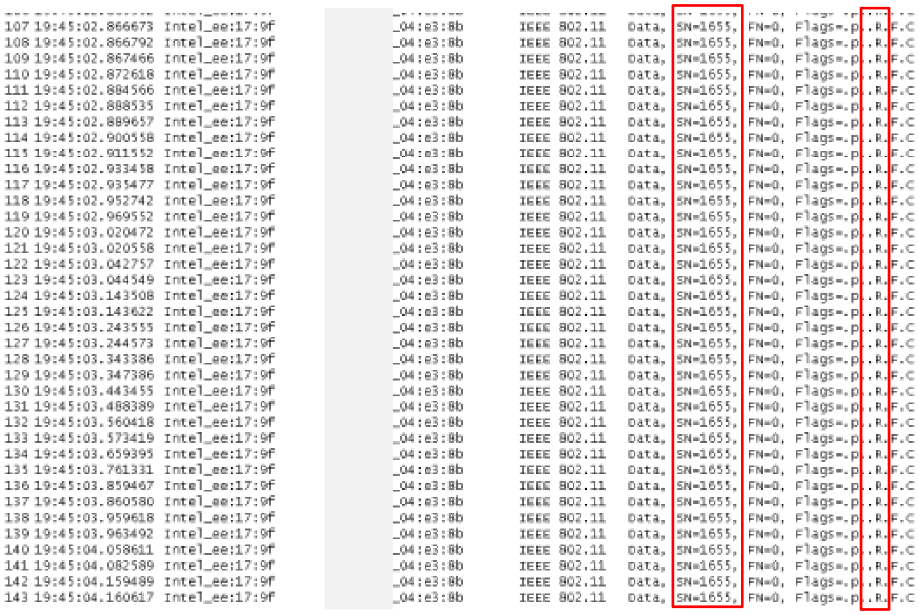
What We Found: Retries



```
107 19:45:02.866673 Intel_ee:17:9f   _04:e3:8b   IEEE 802.11  Data, SN=1655, FN=0, Flags=.p..R.F.C
108 19:45:02.866792 Intel_ee:17:9f   _04:e3:8b   IEEE 802.11  Data, SN=1655, FN=0, Flags=.p..R.F.C
109 19:45:02.867466 Intel_ee:17:9f   _04:e3:8b   IEEE 802.11  Data, SN=1655, FN=0, Flags=.p..R.F.C
110 19:45:02.872618 Intel_ee:17:9f   _04:e3:8b   IEEE 802.11  Data, SN=1655, FN=0, Flags=.p..R.F.C
111 19:45:02.884566 Intel_ee:17:9f   _04:e3:8b   IEEE 802.11  Data, SN=1655, FN=0, Flags=.p..R.F.C
112 19:45:02.888535 Intel_ee:17:9f   _04:e3:8b   IEEE 802.11  Data, SN=1655, FN=0, Flags=.p..R.F.C
113 19:45:02.889657 Intel_ee:17:9f   _04:e3:8b   IEEE 802.11  Data, SN=1655, FN=0, Flags=.p..R.F.C
114 19:45:02.900558 Intel_ee:17:9f   _04:e3:8b   IEEE 802.11  Data, SN=1655, FN=0, Flags=.p..R.F.C
115 19:45:02.911552 Intel_ee:17:9f   _04:e3:8b   IEEE 802.11  Data, SN=1655, FN=0, Flags=.p..R.F.C
116 19:45:02.933458 Intel_ee:17:9f   _04:e3:8b   IEEE 802.11  Data, SN=1655, FN=0, Flags=.p..R.F.C
117 19:45:02.935477 Intel_ee:17:9f   _04:e3:8b   IEEE 802.11  Data, SN=1655, FN=0, Flags=.p..R.F.C
118 19:45:02.952742 Intel_ee:17:9f   _04:e3:8b   IEEE 802.11  Data, SN=1655, FN=0, Flags=.p..R.F.C
119 19:45:02.969552 Intel_ee:17:9f   _04:e3:8b   IEEE 802.11  Data, SN=1655, FN=0, Flags=.p..R.F.C
120 19:45:03.020472 Intel_ee:17:9f   _04:e3:8b   IEEE 802.11  Data, SN=1655, FN=0, Flags=.p..R.F.C
121 19:45:03.020558 Intel_ee:17:9f   _04:e3:8b   IEEE 802.11  Data, SN=1655, FN=0, Flags=.p..R.F.C
122 19:45:03.042757 Intel_ee:17:9f   _04:e3:8b   IEEE 802.11  Data, SN=1655, FN=0, Flags=.p..R.F.C
123 19:45:03.044549 Intel_ee:17:9f   _04:e3:8b   IEEE 802.11  Data, SN=1655, FN=0, Flags=.p..R.F.C
124 19:45:03.143508 Intel_ee:17:9f   _04:e3:8b   IEEE 802.11  Data, SN=1655, FN=0, Flags=.p..R.F.C
125 19:45:03.143622 Intel_ee:17:9f   _04:e3:8b   IEEE 802.11  Data, SN=1655, FN=0, Flags=.p..R.F.C
126 19:45:03.243555 Intel_ee:17:9f   _04:e3:8b   IEEE 802.11  Data, SN=1655, FN=0, Flags=.p..R.F.C
127 19:45:03.244573 Intel_ee:17:9f   _04:e3:8b   IEEE 802.11  Data, SN=1655, FN=0, Flags=.p..R.F.C
128 19:45:03.343386 Intel_ee:17:9f   _04:e3:8b   IEEE 802.11  Data, SN=1655, FN=0, Flags=.p..R.F.C
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131 19:45:03.488389 Intel_ee:17:9f   _04:e3:8b   IEEE 802.11  Data, SN=1655, FN=0, Flags=.p..R.F.C
132 19:45:03.560418 Intel_ee:17:9f   _04:e3:8b   IEEE 802.11  Data, SN=1655, FN=0, Flags=.p..R.F.C
133 19:45:03.573419 Intel_ee:17:9f   _04:e3:8b   IEEE 802.11  Data, SN=1655, FN=0, Flags=.p..R.F.C
134 19:45:03.659395 Intel_ee:17:9f   _04:e3:8b   IEEE 802.11  Data, SN=1655, FN=0, Flags=.p..R.F.C
135 19:45:03.761331 Intel_ee:17:9f   _04:e3:8b   IEEE 802.11  Data, SN=1655, FN=0, Flags=.p..R.F.C
136 19:45:03.859467 Intel_ee:17:9f   _04:e3:8b   IEEE 802.11  Data, SN=1655, FN=0, Flags=.p..R.F.C
137 19:45:03.860580 Intel_ee:17:9f   _04:e3:8b   IEEE 802.11  Data, SN=1655, FN=0, Flags=.p..R.F.C
138 19:45:03.959618 Intel_ee:17:9f   _04:e3:8b   IEEE 802.11  Data, SN=1655, FN=0, Flags=.p..R.F.C
139 19:45:03.963492 Intel_ee:17:9f   _04:e3:8b   IEEE 802.11  Data, SN=1655, FN=0, Flags=.p..R.F.C
140 19:45:04.058611 Intel_ee:17:9f   _04:e3:8b   IEEE 802.11  Data, SN=1655, FN=0, Flags=.p..R.F.C
141 19:45:04.082589 Intel_ee:17:9f   _04:e3:8b   IEEE 802.11  Data, SN=1655, FN=0, Flags=.p..R.F.C
142 19:45:04.159489 Intel_ee:17:9f   _04:e3:8b   IEEE 802.11  Data, SN=1655, FN=0, Flags=.p..R.F.C
143 19:45:04.160617 Intel_ee:17:9f   _04:e3:8b   IEEE 802.11  Data, SN=1655, FN=0, Flags=.p..R.F.C
```

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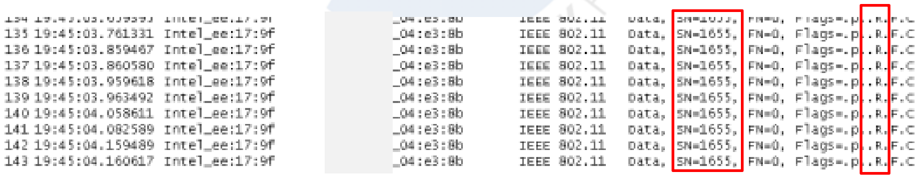
802.11 Reliability

- 802.11 Data must be acknowledged by the recipient
- If an ACK is not received, the source station retransmits
- Note the Retry bit and the repeated Sequence Number in the packets below



```
134 19:45:03.659593 Intel_ee:17:9f                  _04:e3:8b        IEEE 802.11   Data, SN=1655, FN=0, Flags=.p..R.F.C
135 19:45:03.761331 Intel_ee:17:9f                  _04:e3:8b        IEEE 802.11   Data, SN=1655, FN=0, Flags=.p..R.F.C
136 19:45:03.859467 Intel_ee:17:9f                  _04:e3:8b        IEEE 802.11   Data, SN=1655, FN=0, Flags=.p..R.F.C
137 19:45:03.860580 Intel_ee:17:9f                  _04:e3:8b        IEEE 802.11   Data, SN=1655, FN=0, Flags=.p..R.F.C
138 19:45:03.959618 Intel_ee:17:9f                  _04:e3:8b        IEEE 802.11   Data, SN=1655, FN=0, Flags=.p..R.F.C
139 19:45:03.963492 Intel_ee:17:9f                  _04:e3:8b        IEEE 802.11   Data, SN=1655, FN=0, Flags=.p..R.F.C
140 19:45:04.058611 Intel_ee:17:9f                  _04:e3:8b        IEEE 802.11   Data, SN=1655, FN=0, Flags=.p..R.F.C
141 19:45:04.082589 Intel_ee:17:9f                  _04:e3:8b        IEEE 802.11   Data, SN=1655, FN=0, Flags=.p..R.F.C
142 19:45:04.159489 Intel_ee:17:9f                  _04:e3:8b        IEEE 802.11   Data, SN=1655, FN=0, Flags=.p..R.F.C
143 19:45:04.160617 Intel_ee:17:9f                  _04:e3:8b        IEEE 802.11   Data, SN=1655, FN=0, Flags=.p..R.F.C
```

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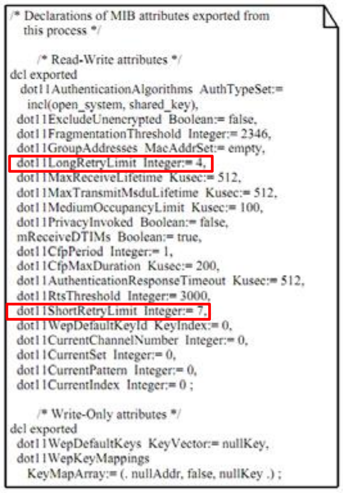
How Many Retries?

- We see over 60 retries from the AP
- 802.11 defines two Retry thresholds, which default to 7 and 4
- This can be overridden by the administrator
- This is a good example of why this defaults to a LOW number!



```
/* Declarations of MIB attributes exported from
   this process */

      /* Read-Write attributes */
dcl exported
   dot11AuthenticationAlgorithms  AuthTypeSet:=
     incl(open_system, shared_key),
  dot11ExcludeUnencrypted  Boolean:= false,
  dot11FragmentationThreshold  Integer:= 2346,
  dot11GroupAddresses  MacAddrSet:= empty,
  dot11LongRetryLimit  Integer:= 4,
  dot11MaxReceiveLifetime  Kusec:= 512,
  dot11MaxTransmitMsduLifetime  Kusec:= 512,
  dot11MediumOccupancyLimit  Kusec:= 100,
  dot11PrivacyInvoked  Boolean:= false,
  mReceiveDTIMs  Boolean:= true,
  dot11CfpPeriod  Integer:= 1,
  dot11CfpMaxDuration  Kusec:= 200,
  dot11AuthenticationResponseTimeout  Kusec:= 512,
  dot11RtsThreshold  Integer:= 3000,
  dot11ShortRetryLimit  Integer:= 7,
  dot11WepDefaultKeyId  KeyIndex:= 0,
  dot11CurrentChannelNumber  Integer:= 0,
  dot11CurrentSet  Integer:= 0,
  dot11CurrentPattern  Integer:= 0,
  dot11CurrentIndex  Integer:= 0 ;

      /* Write-Only attributes */
dcl exported
  dot11WepDefaultKeys  KeyVector:= nullKey,
  dot11WepKeyMappings
    KeyMapArray:= (. nullAddr, false, nullKey .) ;
```

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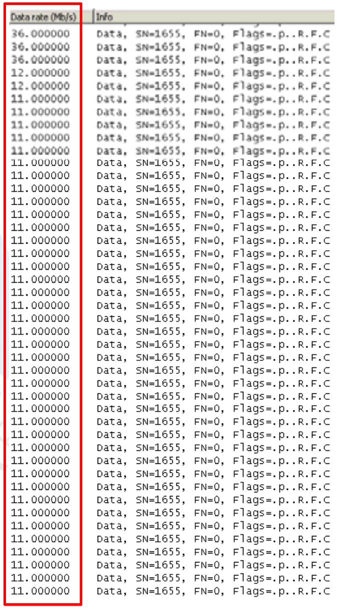
Dynamic Rate Shifting

- When retries occur, a station will decrease the data rate used to increase the packet's resistance to corruption
- This is known as Dynamic Rate Shifting (DRS)



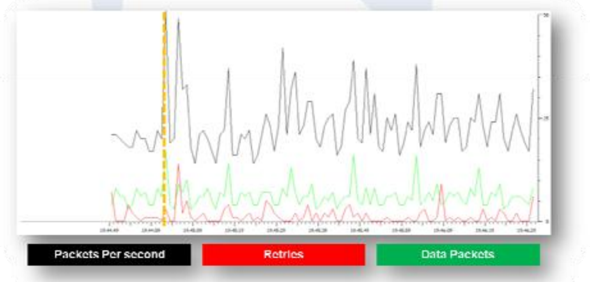
```
Data rate (Mb/s)  Info
36.000000    Data, SN=1655, FN=0, Flags=.p..R.F.C
36.000000    Data, SN=1655, FN=0, Flags=.p..R.F.C
36.000000    Data, SN=1655, FN=0, Flags=.p..R.F.C
12.000000    Data, SN=1655, FN=0, Flags=.p..R.F.C
12.000000    Data, SN=1655, FN=0, Flags=.p..R.F.C
11.000000    Data, SN=1655, FN=0, Flags=.p..R.F.C
11.000000    Data, SN=1655, FN=0, Flags=.p..R.F.C
11.000000    Data, SN=1655, FN=0, Flags=.p..R.F.C
11.000000    Data, SN=1655, FN=0, Flags=.p..R.F.C
11.000000    Data, SN=1655, FN=0, Flags=.p..R.F.C
11.000000    Data, SN=1655, FN=0, Flags=.p..R.F.C
11.000000    Data, SN=1655, FN=0, Flags=.p..R.F.C
11.000000    Data, SN=1655, FN=0, Flags=.p..R.F.C
11.000000    Data, SN=1655, FN=0, Flags=.p..R.F.C
11.000000    Data, SN=1655, FN=0, Flags=.p..R.F.C
11.000000    Data, SN=1655, FN=0, Flags=.p..R.F.C
11.000000    Data, SN=1655, FN=0, Flags=.p..R.F.C
11.000000    Data, SN=1655, FN=0, Flags=.p..R.F.C
11.000000    Data, SN=1655, FN=0, Flags=.p..R.F.C
11.000000    Data, SN=1655, FN=0, Flags=.p..R.F.C
11.000000    Data, SN=1655, FN=0, Flags=.p..R.F.C
11.000000    Data, SN=1655, FN=0, Flags=.p..R.F.C
11.000000    Data, SN=1655, FN=0, Flags=.p..R.F.C
11.000000    Data, SN=1655, FN=0, Flags=.p..R.F.C
11.000000    Data, SN=1655, FN=0, Flags=.p..R.F.C
11.000000    Data, SN=1655, FN=0, Flags=.p..R.F.C
11.000000    Data, SN=1655, FN=0, Flags=.p..R.F.C
11.000000    Data, SN=1655, FN=0, Flags=.p..R.F.C
11.000000    Data, SN=1655, FN=0, Flags=.p..R.F.C
11.000000    Data, SN=1655, FN=0, Flags=.p..R.F.C
11.000000    Data, SN=1655, FN=0, Flags=.p..R.F.C
11.000000    Data, SN=1655, FN=0, Flags=.p..R.F.C
11.000000    Data, SN=1655, FN=0, Flags=.p..R.F.C
11.000000    Data, SN=1655, FN=0, Flags=.p..R.F.C
11.000000    Data, SN=1655, FN=0, Flags=.p..R.F.C
11.000000    Data, SN=1655, FN=0, Flags=.p..R.F.C
11.000000    Data, SN=1655, FN=0, Flags=.p..R.F.C
11.000000    Data, SN=1655, FN=0, Flags=.p..R.F.C
11.000000    Data, SN=1655, FN=0, Flags=.p..R.F.C
11.000000    Data, SN=1655, FN=0, Flags=.p..R.F.C
11.000000    Data, SN=1655, FN=0, Flags=.p..R.F.C
11.000000    Data, SN=1655, FN=0, Flags=.p..R.F.C
11.000000    Data, SN=1655, FN=0, Flags=.p..R.F.C
11.000000    Data, SN=1655, FN=0, Flags=.p..R.F.C
```

What's Happening: Retries

- Packets from the AP to the STA are being retransmitted
- Four possibilities:
  - STA did not get the data frame, hence no ACK
  - STA got the data but did not send an ACK
  - STA sent an ACK, but it didn't get to the AP
  - ACK got to the AP, and the AP incorrectly retransmitted anyway

Is It The AP or the STA?

- Graph below is filtered on only traffic going to/from the AP in question and not the STA in question
- Orange line indicates the anomalous event
- Does anything seem to change before/after?

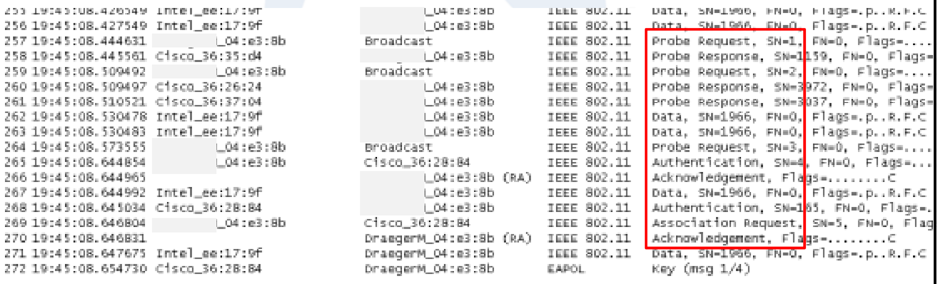


It's the Station

- AP's behavior is consistent before/after the anomalous event
  - Data (green line) continues to flow
  - No increase in retries to stations other than the one in question
- What could cause this behavior?
  - STA is receiving data frames and not sending ACKs, in violation of 802.11 standard (unlikely)
  - STA is not receiving data frames for some reason (more likely)

What We Found: Association

- After a short time, STA is seen associating to a different AP
- Most likely scenario: STA went offline (hence, retries from the AP) then came back



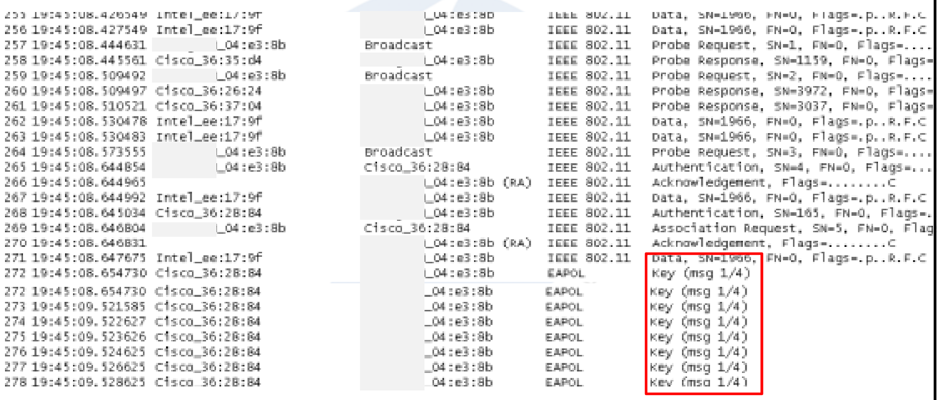
```
255 19:45:08.426549 Intel_ee:17:9f             _04:e3:8b            IEEE 802.11  Data, SN=1966, FN=0, Flags=.p..R.F.C
256 19:45:08.427549 Intel_ee:17:9f             _04:e3:8b            IEEE 802.11  Data, SN=1966, FN=0, Flags=.p..R.F.C
257 19:45:08.444631            _04:e3:8b   Broadcast                IEEE 802.11  Probe Request, SN=1, FN=0, Flags=....
258 19:45:08.445561 Cisco_36:35:d4             _04:e3:8b            IEEE 802.11  Probe Response, SN=1159, FN=0, Flags=
259 19:45:08.509492            _04:e3:8b   Broadcast                IEEE 802.11  Probe Request, SN=2, FN=0, Flags=....
260 19:45:08.509497 Cisco_36:26:24             _04:e3:8b            IEEE 802.11  Probe Response, SN=3972, FN=0, Flags=
261 19:45:08.510521 Cisco_36:37:04             _04:e3:8b            IEEE 802.11  Probe Response, SN=3037, FN=0, Flags=
262 19:45:08.530478 Intel_ee:17:9f             _04:e3:8b            IEEE 802.11  Data, SN=1966, FN=0, Flags=.p..R.F.C
263 19:45:08.530483 Intel_ee:17:9f             _04:e3:8b            IEEE 802.11  Data, SN=1966, FN=0, Flags=.p..R.F.C
264 19:45:08.573555            _04:e3:8b   Broadcast                IEEE 802.11  Probe Request, SN=3, FN=0, Flags=....
265 19:45:08.644854            _04:e3:8b   Cisco_36:28:84           IEEE 802.11  Authentication, SN=4, FN=0, Flags=...
266 19:45:08.644965                                _04:e3:8b (RA)       IEEE 802.11  Acknowledgement, Flags=........C
267 19:45:08.644992 Intel_ee:17:9f             _04:e3:8b            IEEE 802.11  Data, SN=1966, FN=0, Flags=.p..R.F.C
268 19:45:08.645034 Cisco_36:28:84             _04:e3:8b            IEEE 802.11  Authentication, SN=165, FN=0, Flags=.
269 19:45:08.646804            _04:e3:8b   Cisco_36:28:84           IEEE 802.11  Association Request, SN=5, FN=0, Flag
270 19:45:08.646831                        DraegerM_04:e3:8b (RA)   IEEE 802.11  Acknowledgement, Flags=........C
271 19:45:08.647675 Intel_ee:17:9f         DraegerM_04:e3:8b        IEEE 802.11  Data, SN=1966, FN=0, Flags=.p..R.F.C
272 19:45:08.654730 Cisco_36:28:84         DraegerM_04:e3:8b        EAPOL        Key (msg 1/4)
```

“Optional”?

- 802.11 does not require Disassociate or Deauthenticate frames when a station goes offline
  - – What if a station had its battery pulled or suddenly went out of range?
  - – 802.11 must allow for situations where the station unexpectedly goes offline
- If STA doesn’t send Disassociate or Deauthenticate, this scenario can arise
  - – AP doesn’t know the STA is gone!

What We Found: More Retries!

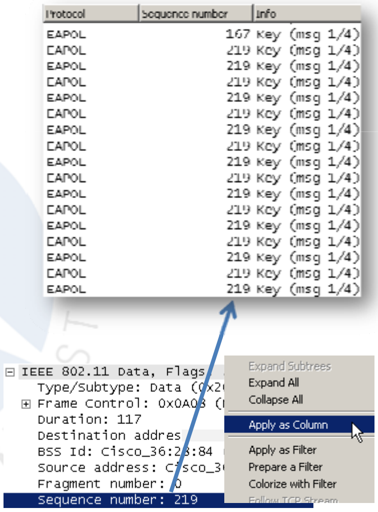
- The Association is interrupted during WPA authentication



```
255 19:45:08.426549 Intel_ee:17:9f              _04:e3:8b      IEEE 802.11  Data, SN=1966, FN=0, Flags=.p..R.F.C
256 19:45:08.427549 Intel_ee:17:9f              _04:e3:8b      IEEE 802.11  Data, SN=1966, FN=0, Flags=.p..R.F.C
257 19:45:08.444631          _04:e3:8b   Broadcast             IEEE 802.11  Probe Request, SN=1, FN=0, Flags=....
258 19:45:08.445561 Cisco_36:35:d4              _04:e3:8b      IEEE 802.11  Probe Response, SN=1159, FN=0, Flags=
259 19:45:08.509492          _04:e3:8b   Broadcast             IEEE 802.11  Probe Request, SN=2, FN=0, Flags=....
260 19:45:08.509497 Cisco_36:26:24              _04:e3:8b      IEEE 802.11  Probe Response, SN=3972, FN=0, Flags=
261 19:45:08.510521 Cisco_36:37:04              _04:e3:8b      IEEE 802.11  Probe Response, SN=3037, FN=0, Flags=
262 19:45:08.530478 Intel_ee:17:9f              _04:e3:8b      IEEE 802.11  Data, SN=1966, FN=0, Flags=.p..R.F.C
263 19:45:08.530483 Intel_ee:17:9f              _04:e3:8b      IEEE 802.11  Data, SN=1966, FN=0, Flags=.p..R.F.C
264 19:45:08.573555          _04:e3:8b   Broadcast             IEEE 802.11  Probe Request, SN=3, FN=0, Flags=....
265 19:45:08.644854          _04:e3:8b   Cisco_36:28:84        IEEE 802.11  Authentication, SN=4, FN=0, Flags=...
266 19:45:08.644965                             _04:e3:8b (RA) IEEE 802.11  Acknowledgement, Flags=........C
267 19:45:08.644992 Intel_ee:17:9f              _04:e3:8b      IEEE 802.11  Data, SN=1966, FN=0, Flags=.p..R.F.C
268 19:45:08.645034 Cisco_36:28:84              _04:e3:8b      IEEE 802.11  Authentication, SN=165, FN=0, Flags=.
269 19:45:08.646804          _04:e3:8b   Cisco_36:28:84        IEEE 802.11  Association Request, SN=5, FN=0, Flag
270 19:45:08.646831                             _04:e3:8b (RA) IEEE 802.11  Acknowledgement, Flags=........C
271 19:45:08.647675 Intel_ee:17:9f              _04:e3:8b      IEEE 802.11  Data, SN=1966, FN=0, Flags=.p..R.F.C
272 19:45:08.654730 Cisco_36:28:84              _04:e3:8b      EAPOL        Key (msg 1/4)
272 19:45:08.654730 Cisco_36:28:84              _04:e3:8b      EAPOL        Key (msg 1/4)
273 19:45:09.521585 Cisco_36:28:84              _04:e3:8b      EAPOL        Key (msg 1/4)
274 19:45:09.522627 Cisco_36:28:84              _04:e3:8b      EAPOL        Key (msg 1/4)
275 19:45:09.523626 Cisco_36:28:84              _04:e3:8b      EAPOL        Key (msg 1/4)
276 19:45:09.524625 Cisco_36:28:84              _04:e3:8b      EAPOL        Key (msg 1/4)
277 19:45:09.526625 Cisco_36:28:84              _04:e3:8b      EAPOL        Key (msg 1/4)
278 19:45:09.528625 Cisco_36:28:84              _04:e3:8b      EAPOL        Key (msg 1/4)
```

Retry Analysis

- When analyzing repeated packets, examine sequence numbers at various layers of the OSI model to determine where the retransmission is coming from
  - – Repeated 802.11 sequence number indicates wireless ACK was not received

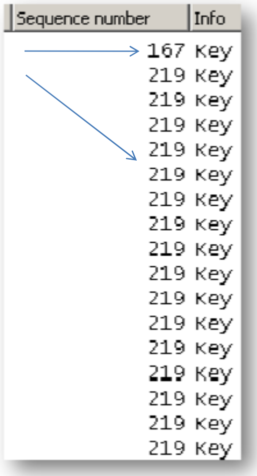


```
Protocol   Sequence number  Info
EAPOL                   167 Key (msg 1/4)
EAPOL                   219 Key (msg 1/4)
EAPOL                   219 Key (msg 1/4)
EAPOL                   219 Key (msg 1/4)
EAPOL                   219 Key (msg 1/4)
EAPOL                   219 Key (msg 1/4)
EAPOL                   219 Key (msg 1/4)
EAPOL                   219 Key (msg 1/4)
EAPOL                   219 Key (msg 1/4)
EAPOL                   219 Key (msg 1/4)
EAPOL                   219 Key (msg 1/4)
EAPOL                   219 Key (msg 1/4)
EAPOL                   219 Key (msg 1/4)
EAPOL                   219 Key (msg 1/4)
EAPOL                   219 Key (msg 1/4)
EAPOL                   219 Key (msg 1/4)
EAPOL                   219 Key (msg 1/4)
```

```
⊟ IEEE 802.11 Data, Flags
    Type/Subtype: Data (0x2
  ⊞ Frame Control: 0x0A08 (
    Duration: 117
    Destination addres
    BSS Id: Cisco_36:28:84
    Source address: Cisco_3
    Fragment number: 0
    Sequence number: 219
```

Retry Analysis

- 1st Packet has SEQ 167
- 2nd and subsequent packets have SEQ 219
- 1st Packet must have been ACK'ed by the STA
- STA failed to send the appropriate EAPOL response
- AP's operating system timed out and tried again



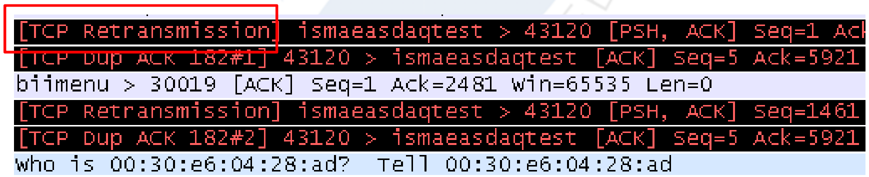
```
Sequence number Info
            167 Key
            219 Key
            219 Key
            219 Key
            219 Key
            219 Key
            219 Key
            219 Key
            219 Key
            219 Key
            219 Key
            219 Key
            219 Key
            219 Key
            219 Key
            219 Key
            219 Key
```

Retry Analysis

- This same process can be applied going up the layers of the OSI model
  - 802.11 retries indicate no ACK from recipient
    - Noise/interference corrupting packet
      - Remove the source of interference
      - Shield the source of interference
      - Move to a different channel than the interference
    - Insufficient signal strength/client is out of range
      - Assess network design to determine if AP placement is correct
      - Assess AP output power (dynamic power setting sometimes turns output power down too low)

Retry Analysis

- This same process can be applied going up the layers of the OSI model
  - TCP retransmissions with 802.11 retries on the same packet indicate extreme interference
    - Normally, 802.11 retries would get the data through before TCP timed out
    - If TCP is timing out, the wireless network must be nearly totally congested



```
[TCP Retransmission] ismaeasdaqtest > 43120 [PSH, ACK] Seq=1 Ack
[TCP Dup ACK 182#1] 43120 > ismaeasdaqtest [ACK] Seq=5 Ack=5921
biimenu > 30019 [ACK] Seq=1 Ack=2481 Win=65535 Len=0
[TCP Retransmission] ismaeasdaqtest > 43120 [PSH, ACK] Seq=1461
[TCP Dup ACK 182#2] 43120 > ismaeasdaqtest [ACK] Seq=5 Ack=5921
Who is 00:30:e6:04:28:ad?  Tell 00:30:e6:04:28:ad
```

Retry Analysis

- This same process can be applied going up the layers of the OSI model
  - TCP retransmissions without 802.11 retries on the same packet usually indicates corruption or congestion on the wired network
    - Corruption is rare in today's wired networks
    - Congestion (possibly due to QoS rules?) is more likely
  - The lack of 802.11 retries indicates that the packet got from the wireless station to the AP successfully

Retry Analysis

- This same process can be applied going up the layers of the OSI model
  - Repeated packets or packet sequences without either TCP or 802.11 retransmissions indicate an app or user is the cause
  - App with server polling interval too low
  - Very impatient user!

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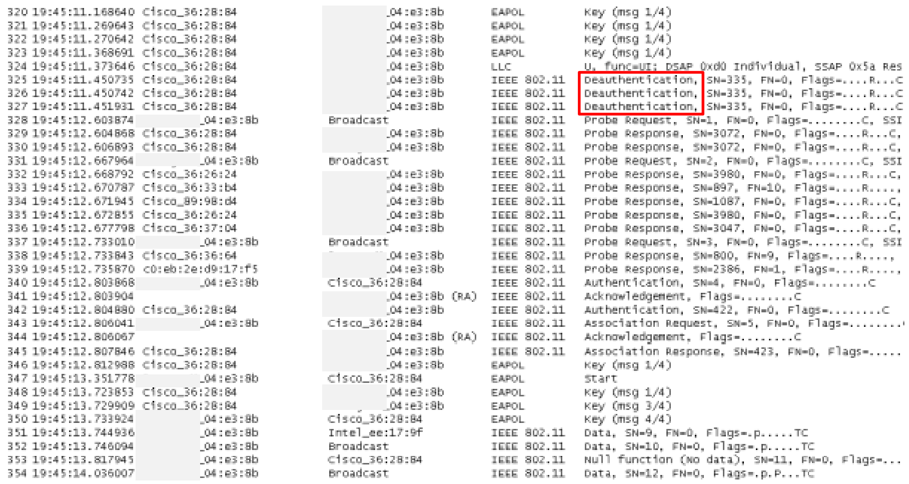
What We Found: Deauthenticate



```
320 19:45:11.168640 Cisco_36:28:84          [redacted]_04:e3:8b       EAPOL         Key (msg 1/4)
321 19:45:11.269643 Cisco_36:28:84          [redacted]_04:e3:8b       EAPOL         Key (msg 1/4)
322 19:45:11.270642 Cisco_36:28:84          [redacted]_04:e3:8b       EAPOL         Key (msg 1/4)
323 19:45:11.368691 Cisco_36:28:84          [redacted]_04:e3:8b       EAPOL         Key (msg 1/4)
324 19:45:11.373646 Cisco_36:28:84          [redacted]_04:e3:8b       LLC           U, func=UI; DSAP 0xd0 Individual, SSAP 0x5a Res
325 19:45:11.450735 Cisco_36:28:84          [redacted]_04:e3:8b       IEEE 802.11   Deauthentication, SN=335, FN=0, Flags=....R...C
326 19:45:11.450742 Cisco_36:28:84          [redacted]_04:e3:8b       IEEE 802.11   Deauthentication, SN=335, FN=0, Flags=....R...C
327 19:45:11.451931 Cisco_36:28:84          [redacted]_04:e3:8b       IEEE 802.11   Deauthentication, SN=335, FN=0, Flags=....R...C
328 19:45:12.603874 [redacted]_04:e3:8b     Broadcast                 IEEE 802.11   Probe Request, SN=1, FN=0, Flags=........C, SSI
329 19:45:12.604868 Cisco_36:28:84          [redacted]_04:e3:8b       IEEE 802.11   Probe Response, SN=3072, FN=0, Flags=....R...C,
330 19:45:12.606893 Cisco_36:28:84          [redacted]_04:e3:8b       IEEE 802.11   Probe Response, SN=3072, FN=0, Flags=....R...C,
331 19:45:12.667964 [redacted]_04:e3:8b     Broadcast                 IEEE 802.11   Probe Request, SN=2, FN=0, Flags=........C, SSI
332 19:45:12.668792 Cisco_36:26:24          [redacted]_04:e3:8b       IEEE 802.11   Probe Response, SN=3980, FN=0, Flags=....R...C,
333 19:45:12.670787 Cisco_36:33:b4          [redacted]_04:e3:8b       IEEE 802.11   Probe Response, SN=897, FN=10, Flags=....R....,
334 19:45:12.671945 Cisco_89:98:d4          [redacted]_04:e3:8b       IEEE 802.11   Probe Response, SN=1087, FN=0, Flags=....R...C,
335 19:45:12.672855 Cisco_36:26:24          [redacted]_04:e3:8b       IEEE 802.11   Probe Response, SN=3980, FN=0, Flags=....R...C,
336 19:45:12.677798 Cisco_36:37:04          [redacted]_04:e3:8b       IEEE 802.11   Probe Response, SN=3047, FN=0, Flags=....R...C,
337 19:45:12.733010 [redacted]_04:e3:8b     Broadcast                 IEEE 802.11   Probe Request, SN=3, FN=0, Flags=........C, SSI
338 19:45:12.733843 Cisco_36:36:64          [redacted]_04:e3:8b       IEEE 802.11   Probe Response, SN=800, FN=9, Flags=....R....,
339 19:45:12.735870 c0:eb:2e:d9:17:f5       [redacted]_04:e3:8b       IEEE 802.11   Probe Response, SN=2386, FN=1, Flags=....R....,
340 19:45:12.803868 [redacted]_04:e3:8b     Cisco_36:28:84            IEEE 802.11   Authentication, SN=4, FN=0, Flags=........C
341 19:45:12.803904                         [redacted]_04:e3:8b (RA)  IEEE 802.11   Acknowledgement, Flags=........C
342 19:45:12.804880 Cisco_36:28:84          [redacted]_04:e3:8b       IEEE 802.11   Authentication, SN=422, FN=0, Flags=........C
343 19:45:12.806041 [redacted]_04:e3:8b     Cisco_36:28:84            IEEE 802.11   Association Request, SN=5, FN=0, Flags=........'
344 19:45:12.806067                         [redacted]_04:e3:8b (RA)  IEEE 802.11   Acknowledgement, Flags=........C
345 19:45:12.807846 Cisco_36:28:84          [redacted]_04:e3:8b       IEEE 802.11   Association Response, SN=423, FN=0, Flags=.....
346 19:45:12.812988 Cisco_36:28:84          [redacted]_04:e3:8b       EAPOL         Key (msg 1/4)
347 19:45:13.351778 [redacted]_04:e3:8b     Cisco_36:28:84            EAPOL         Start
348 19:45:13.723853 Cisco_36:28:84          [redacted]_04:e3:8b       EAPOL         Key (msg 1/4)
349 19:45:13.729909 Cisco_36:28:84          [redacted]_04:e3:8b       EAPOL         Key (msg 3/4)
350 19:45:13.733924 [redacted]_04:e3:8b     Cisco_36:28:84            EAPOL         Key (msg 4/4)
351 19:45:13.744936 [redacted]_04:e3:8b     Intel_ee:17:9f            IEEE 802.11   Data, SN=9, FN=0, Flags=.p.....TC
352 19:45:13.746094 [redacted]_04:e3:8b     Broadcast                 IEEE 802.11   Data, SN=10, FN=0, Flags=.p.....TC
353 19:45:13.817945 [redacted]_04:e3:8b     Cisco_36:28:84            IEEE 802.11   Null function (No data), SN=11, FN=0, Flags=...
354 19:45:14.036007 [redacted]_04:e3:8b     Broadcast                 IEEE 802.11   Data, SN=12, FN=0, Flags=.p.P...TC
```

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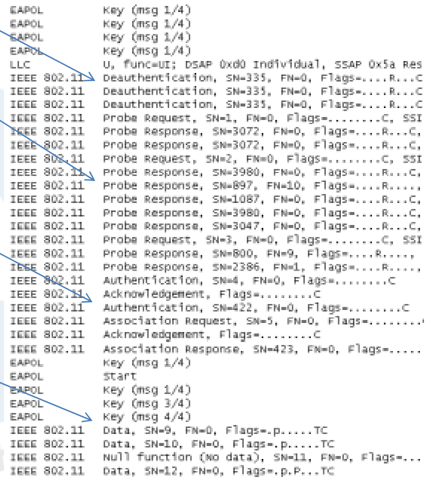
What We Found: Deauthenticate

AP finally times out on the absent STA. Sends Deauth just to make sure the STA knows the transaction is off.

Oh look! There's the STA again, trying to find an AP to associate to!

STA begins association again.

This time it succeeds and data begins to flow.

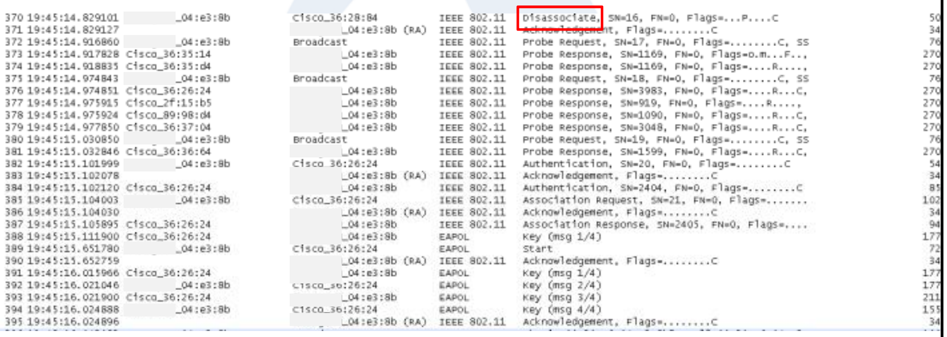


```
EAPOL          Key (msg 1/4)
EAPOL          Key (msg 1/4)
EAPOL          Key (msg 1/4)
EAPOL          Key (msg 1/4)
LLC            U, func=UI; DSAP 0xd0 Individual, SSAP 0x5a Res
IEEE 802.11    Deauthentication, SN=335, FN=0, Flags=....R...C
IEEE 802.11    Deauthentication, SN=335, FN=0, Flags=....R...C
IEEE 802.11    Deauthentication, SN=335, FN=0, Flags=....R...C
IEEE 802.11    Probe Request, SN=1, FN=0, Flags=........C, SSI
IEEE 802.11    Probe Response, SN=3072, FN=0, Flags=....R...C,
IEEE 802.11    Probe Response, SN=3072, FN=0, Flags=....R...C,
IEEE 802.11    Probe Request, SN=2, FN=0, Flags=........C, SSI
IEEE 802.11    Probe Response, SN=3980, FN=0, Flags=....R...C,
IEEE 802.11    Probe Response, SN=897, FN=10, Flags=....R....,
IEEE 802.11    Probe Response, SN=1087, FN=0, Flags=....R...C,
IEEE 802.11    Probe Response, SN=3980, FN=0, Flags=....R...C,
IEEE 802.11    Probe Response, SN=3047, FN=0, Flags=....R...C,
IEEE 802.11    Probe Request, SN=3, FN=0, Flags=........C, SSI
IEEE 802.11    Probe Response, SN=800, FN=9, Flags=....R....,
IEEE 802.11    Probe Response, SN=2386, FN=1, Flags=....R....,
IEEE 802.11    Authentication, SN=4, FN=0, Flags=........C
IEEE 802.11    Acknowledgement, Flags=........C
IEEE 802.11    Authentication, SN=422, FN=0, Flags=........C
IEEE 802.11    Association Request, SN=5, FN=0, Flags=........
IEEE 802.11    Acknowledgement, Flags=........C
IEEE 802.11    Association Response, SN=423, FN=0, Flags=.....
EAPOL          Key (msg 1/4)
EAPOL          Start
EAPOL          Key (msg 1/4)
EAPOL          Key (msg 3/4)
EAPOL          Key (msg 4/4)
IEEE 802.11    Data, SN=9, FN=0, Flags=.p.....TC
IEEE 802.11    Data, SN=10, FN=0, Flags=.p.....TC
IEEE 802.11    Null function (No data), SN=11, FN=0, Flags=...
IEEE 802.11    Data, SN=12, FN=0, Flags=.p.P...TC
```

… And they all lived happily ever after?

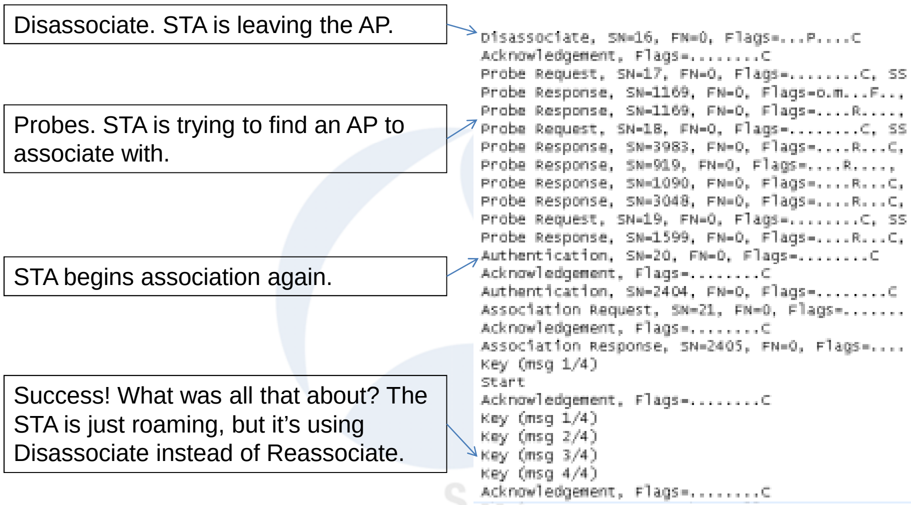
What We Found: Disassociate

- After some time, the station disassociates
  - Is it going offline (correctly this time?)
  - What happens next?



```
370 19:45:14.829101          _04:e3:8b          Cisco_36:28:84          IEEE 802.11  Disassociate, SN=16, FN=0, Flags=...P....C           50
371 19:45:14.829127                                      _04:e3:8b (RA)  IEEE 802.11  Acknowledgement, Flags=........C                   34
372 19:45:14.916860          _04:e3:8b          Broadcast               IEEE 802.11  Probe Request, SN=17, FN=0, Flags=........C, SS     76
373 19:45:14.917828 Cisco_36:35:14                       _04:e3:8b      IEEE 802.11  Probe Response, SN=1169, FN=0, Flags=o.m...F..,     270
374 19:45:14.918835 Cisco_36:35:d4                       _04:e3:8b      IEEE 802.11  Probe Response, SN=1169, FN=0, Flags=....R....,     270
375 19:45:14.974843          _04:e3:8b          Broadcast               IEEE 802.11  Probe Request, SN=18, FN=0, Flags=........C, SS     76
376 19:45:14.974851 Cisco_36:26:24                       _04:e3:8b      IEEE 802.11  Probe Response, SN=3983, FN=0, Flags=....R...C,     270
377 19:45:14.975915 Cisco_2f:15:b5                       _04:e3:8b      IEEE 802.11  Probe Response, SN=919, FN=0, Flags=....R....,      270
378 19:45:14.975924 Cisco_89:98:d4                       _04:e3:8b      IEEE 802.11  Probe Response, SN=1090, FN=0, Flags=....R...C,     270
379 19:45:14.977850 Cisco_36:37:04                       _04:e3:8b      IEEE 802.11  Probe Response, SN=3048, FN=0, Flags=....R...C,     270
380 19:45:15.030850          _04:e3:8b          Broadcast               IEEE 802.11  Probe Request, SN=19, FN=0, Flags=........C, SS     76
381 19:45:15.032846 Cisco_36:36:64                       _04:e3:8b      IEEE 802.11  Probe Response, SN=1599, FN=0, Flags=....R...C,     270
382 19:45:15.101999          _04:e3:8b          Cisco 36:26:24          IEEE 802.11  Authentication, SN=20, FN=0, Flags=........C        54
383 19:45:15.102078                                      _04:e3:8b (RA)  IEEE 802.11  Acknowledgement, Flags=........C                   34
384 19:45:15.102120 Cisco_36:26:24                       _04:e3:8b      IEEE 802.11  Authentication, SN=2404, FN=0, Flags=........C      85
385 19:45:15.104003          _04:e3:8b          Cisco_36:26:24          IEEE 802.11  Association Request, SN=21, FN=0, Flags=.......     102
386 19:45:15.104030                                      _04:e3:8b (RA)  IEEE 802.11  Acknowledgement, Flags=........C                   34
387 19:45:15.105895 Cisco_36:26:24                       _04:e3:8b      IEEE 802.11  Association Response, SN=2405, FN=0, Flags=....     94
388 19:45:15.111900 Cisco_36:26:24                       _04:e3:8b      EAPOL        Key (msg 1/4)                                       177
389 19:45:15.651780          _04:e3:8b          Cisco_36:26:24          EAPOL        Start                                               72
390 19:45:15.652759                                      _04:e3:8b (RA)  IEEE 802.11  Acknowledgement, Flags=........C                   34
391 19:45:16.015966 Cisco_36:26:24                       _04:e3:8b      EAPOL        Key (msg 1/4)                                       177
392 19:45:16.021046          _04:e3:8b          Cisco_36:26:24          EAPOL        Key (msg 2/4)                                       177
393 19:45:16.021900 Cisco_36:26:24                       _04:e3:8b      EAPOL        Key (msg 3/4)                                       211
394 19:45:16.024888          _04:e3:8b          Cisco_36:26:24          EAPOL        Key (msg 4/4)                                       155
395 19:45:16.024896                                      _04:e3:8b (RA)  IEEE 802.11  Acknowledgement, Flags=........C                   34
```

What We Found: Disassociate



Disassociate. STA is leaving the AP.

Probes. STA is trying to find an AP to associate with.

STA begins association again.

Success! What was all that about? The STA is just roaming, but it's using Disassociate instead of Reassociate.

```
Disassociate, SN=16, FN=0, Flags=...P....C
Acknowledgement, Flags=........C
Probe Request, SN=17, FN=0, Flags=........C, SS
Probe Response, SN=1169, FN=0, Flags=o.m...F..,
Probe Response, SN=1169, FN=0, Flags=....R....,
Probe Request, SN=18, FN=0, Flags=........C, SS
Probe Response, SN=3983, FN=0, Flags=....R...C,
Probe Response, SN=919, FN=0, Flags=....R....,
Probe Response, SN=1090, FN=0, Flags=....R...C,
Probe Response, SN=3048, FN=0, Flags=....R...C,
Probe Request, SN=19, FN=0, Flags=........C, SS
Probe Response, SN=1599, FN=0, Flags=....R...C,
Authentication, SN=20, FN=0, Flags=........C
Acknowledgement, Flags=........C
Authentication, SN=2404, FN=0, Flags=........C
Association Request, SN=21, FN=0, Flags=.......
Acknowledgement, Flags=........C
Association Response, SN=2405, FN=0, Flags=....
Key (msg 1/4)
Start
Acknowledgement, Flags=........C
Key (msg 1/4)
Key (msg 2/4)
Key (msg 3/4)
Key (msg 4/4)
Acknowledgement, Flags=........C
```

What Do We Know?

- Station sometimes drops offline without sending a Disassociate or Deauthenticate frame, causing the AP to retransmit packets 50-70 times before giving up
- Station uses Disassociate frame when roaming, resulting in loss of connectivity until roaming succeeds
- Who is at fault here? AP? STA? Network?

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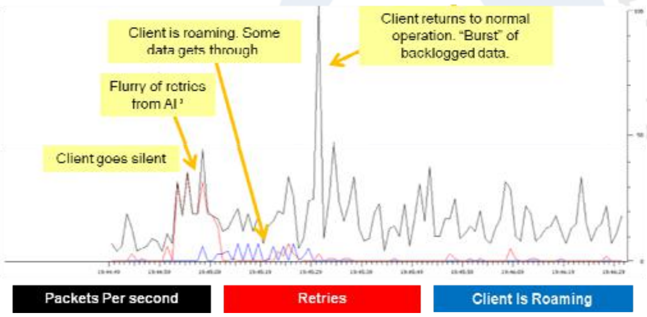
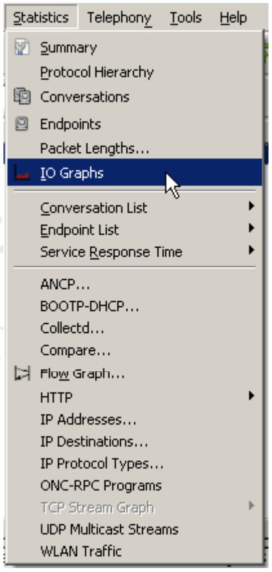
Analysis With I/O Graphs

- When combined with filters, Wireshark's I/O graphs can help with visualization of a network issue





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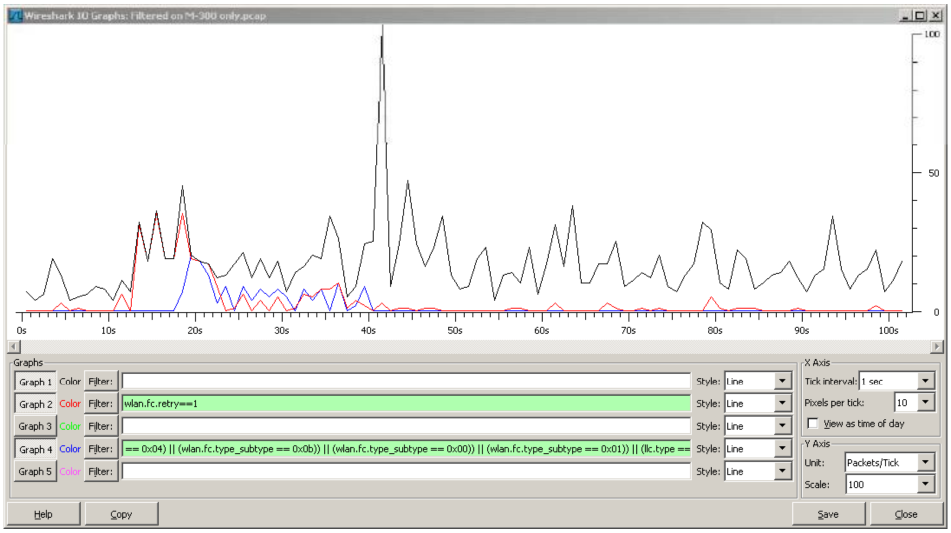
Analysis With I/O Graphs



Wireshark IO Graphs: Filtered on M-300 only.pcap

Graphs

- Graph 1 Color Filter: Style: Line
- Graph 2 Color Filter: wlan.fc.retry==1 Style: Line
- Graph 3 Color Filter: Style: Line
- Graph 4 Color Filter: == 0x04) || (wlan.fc.type_subtype == 0x0b)) || (wlan.fc.type_subtype == 0x00)) || (wlan.fc.type_subtype == 0x01)) || (llc.type == Style: Line
- Graph 5 Color Filter: Style: Line

X Axis

- Tick interval: 1 sec
- Pixels per tick: 10
- ☐ View as time of day

Y Axis

- Unit: Packets/Tick
- Scale: 100

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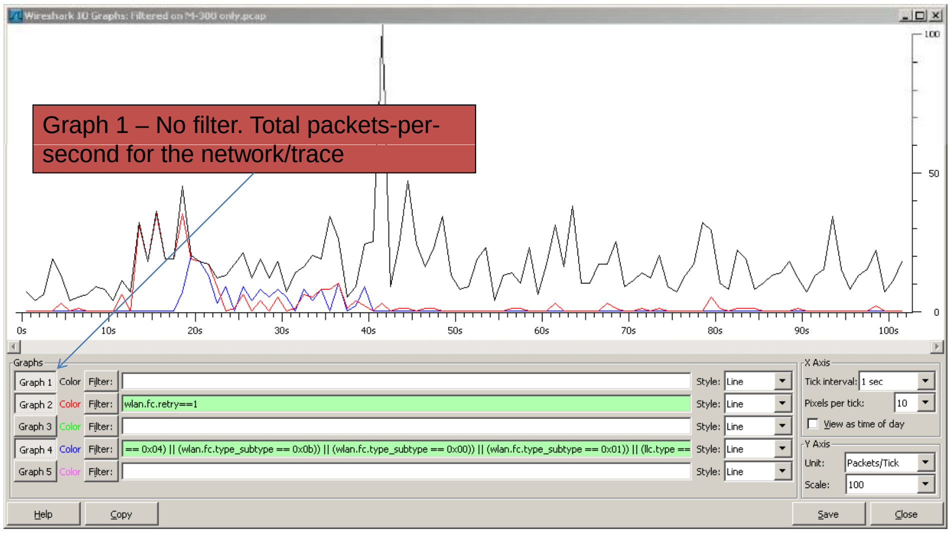
Analysis With I/O Graphs



Graph 1 – No filter. Total packets-per-second for the network/trace

Wireshark IO Graphs: Filtered on M-300 only.pcap

Graphs

- Graph 1 Color Filter: Style: Line
- Graph 2 Color Filter: wlan.fc.retry==1 Style: Line
- Graph 3 Color Filter: Style: Line
- Graph 4 Color Filter: == 0x04) || (wlan.fc.type_subtype == 0x0b)) || (wlan.fc.type_subtype == 0x00)) || (wlan.fc.type_subtype == 0x01)) || (llc.type == Style: Line
- Graph 5 Color Filter: Style: Line

X Axis

- Tick interval: 1 sec
- Pixels per tick: 10
- ☐ View as time of day

Y Axis

- Unit: Packets/Tick
- Scale: 100

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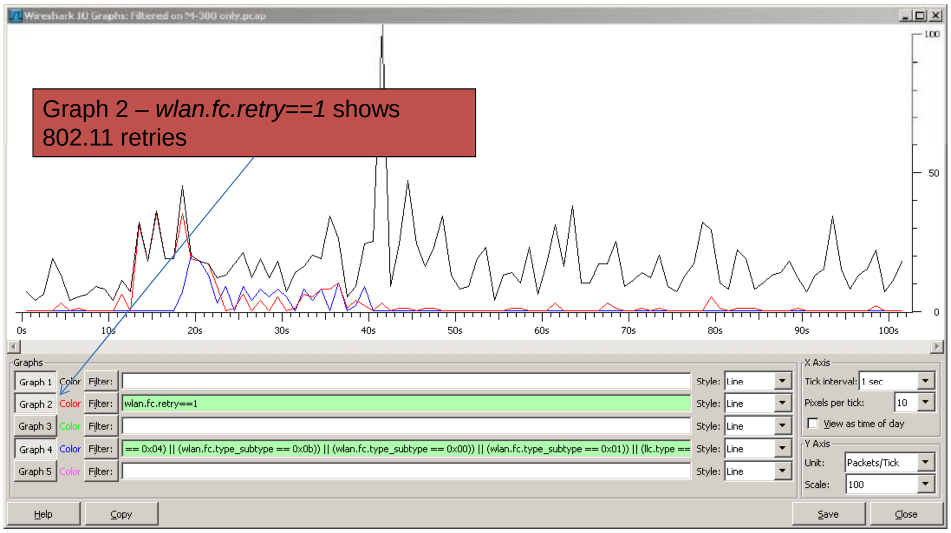
Analysis With I/O Graphs



Wireshark IO Graphs: Filtered on M-300 only.pcap

Graph 2 – *wlan.fc.retry==1* shows 802.11 retries

Graph 1 Color Filter: Style: Line

Graph 2 Color Filter: wlan.fc.retry==1 Style: Line

Graph 3 Color Filter: Style: Line

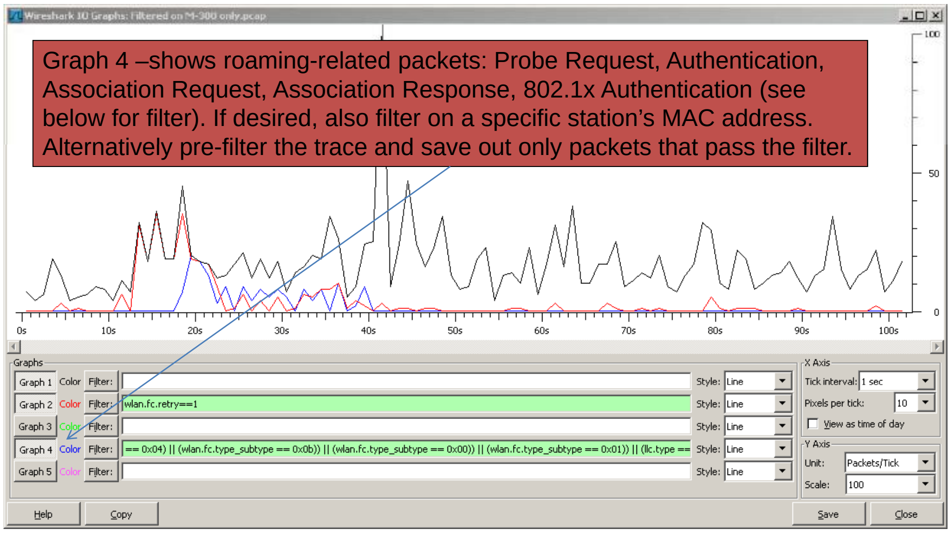
Graph 4 Color Filter: == 0x04) || (wlan.fc.type_subtype == 0x0b)) || (wlan.fc.type_subtype == 0x00)) || (wlan.fc.type_subtype == 0x01)) || (llc.type == Style: Line

Graph 5 Color Filter: Style: Line

X Axis: Tick interval: 1 sec; Pixels per tick: 10; □ View as time of day

Y Axis: Unit: Packets/Tick; Scale: 100

Analysis With I/O Graphs



Wireshark IO Graphs: Filtered on M-300 only.pcap

Graph 4 –shows roaming-related packets: Probe Request, Authentication, Association Request, Association Response, 802.1x Authentication (see below for filter). If desired, also filter on a specific station's MAC address. Alternatively pre-filter the trace and save out only packets that pass the filter.

Graph 1 Color Filter: Style: Line

Graph 2 Color Filter: wlan.fc.retry==1 Style: Line

Graph 3 Color Filter: Style: Line

Graph 4 Color Filter: == 0x04) || (wlan.fc.type_subtype == 0x0b)) || (wlan.fc.type_subtype == 0x00)) || (wlan.fc.type_subtype == 0x01)) || (llc.type == Style: Line

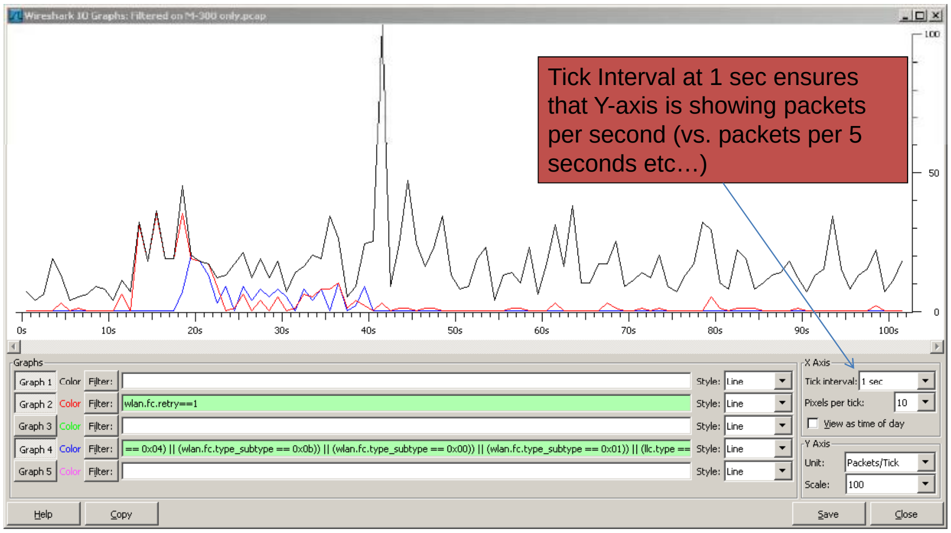
Graph 5 Color Filter: Style: Line

X Axis: Tick interval: 1 sec; Pixels per tick: 10; □ View as time of day

Y Axis: Unit: Packets/Tick; Scale: 100

wlan.fc.type_subtype == 0x04 || wlan.fc.type_subtype == 0x0b || wlan.fc.type_subtype == 0x00 || wlan.fc.type_subtype == 0x01 || llc.type == 0x888e

Analysis With I/O Graphs



Tick Interval at 1 sec ensures that Y-axis is showing packets per second (vs. packets per 5 seconds etc…)

Graphs

- Graph 1 Color Filter: Style: Line
- Graph 2 Color Filter: wlan.fc.retry==1 Style: Line
- Graph 3 Color Filter: Style: Line
- Graph 4 Color Filter: == 0x04) || (wlan.fc.type_subtype == 0x0b)) || (wlan.fc.type_subtype == 0x00)) || (wlan.fc.type_subtype == 0x01)) || (llc.type == Style: Line
- Graph 5 Color Filter: Style: Line

X Axis

Tick interval: 1 sec

Pixels per tick: 10

☐ View as time of day

Y Axis

Unit: Packets/Tick

Scale: 100

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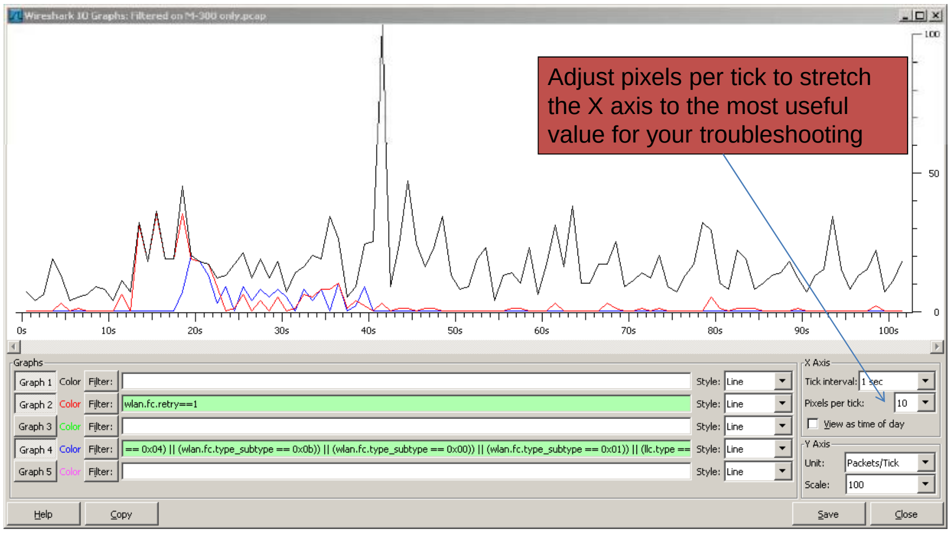
Analysis With I/O Graphs



Adjust pixels per tick to stretch the X axis to the most useful value for your troubleshooting

Graphs

- Graph 1 Color Filter: Style: Line
- Graph 2 Color Filter: wlan.fc.retry==1 Style: Line
- Graph 3 Color Filter: Style: Line
- Graph 4 Color Filter: == 0x04) || (wlan.fc.type_subtype == 0x0b)) || (wlan.fc.type_subtype == 0x00)) || (wlan.fc.type_subtype == 0x01)) || (llc.type == Style: Line
- Graph 5 Color Filter: Style: Line

X Axis

Tick interval: 1 sec

Pixels per tick: 10

☐ View as time of day

Y Axis

Unit: Packets/Tick

Scale: 100

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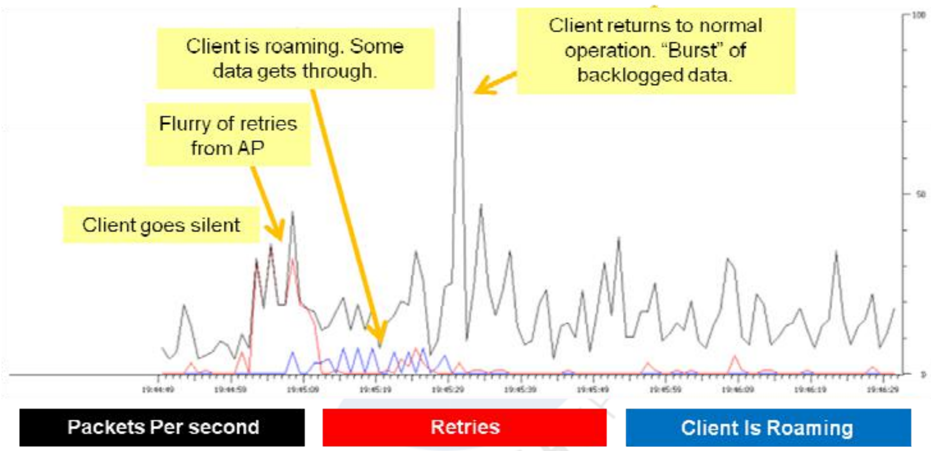
A Visual Guide



Client is roaming. Some data gets through.

Client returns to normal operation. "Burst" of backlogged data.

Flurry of retries from AP

Client goes silent

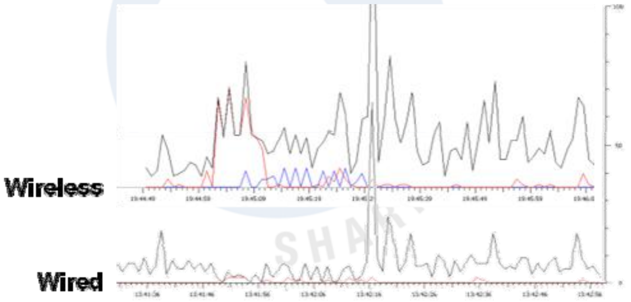
Packets Per second

Retries

Client Is Roaming

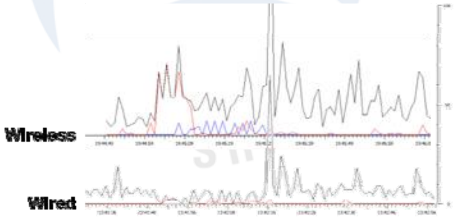
Using I/O Graphs To Compare

- These two graphs compare the wireless and the wired side of the same conversation
- Red lines indicate retries (wireless) or TCP retransmissions (wired)



Using I/O Graphs To Compare

- These two graphs compare the wireless and the wired side of the same conversation
  - Wireshark was capturing on both sides and timestamps were cross-correlated
- Red lines indicate retries (wireless) or TCP retransmissions (wired)



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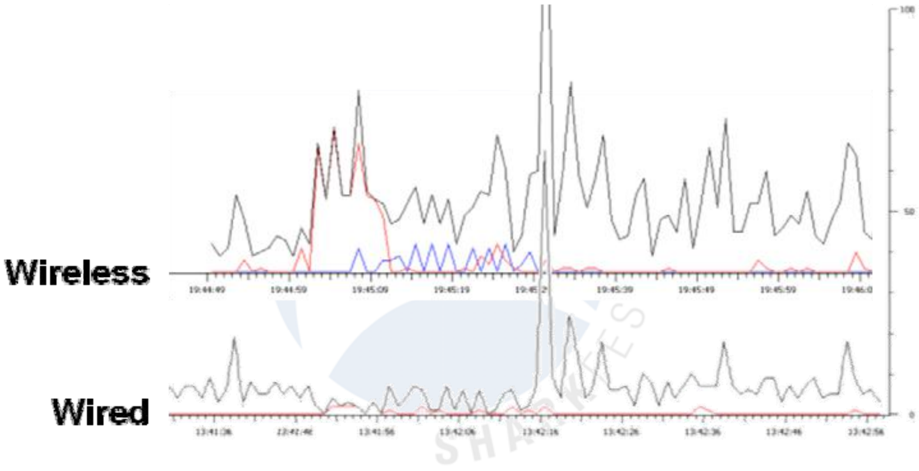
Using I/O Graphs To Compare



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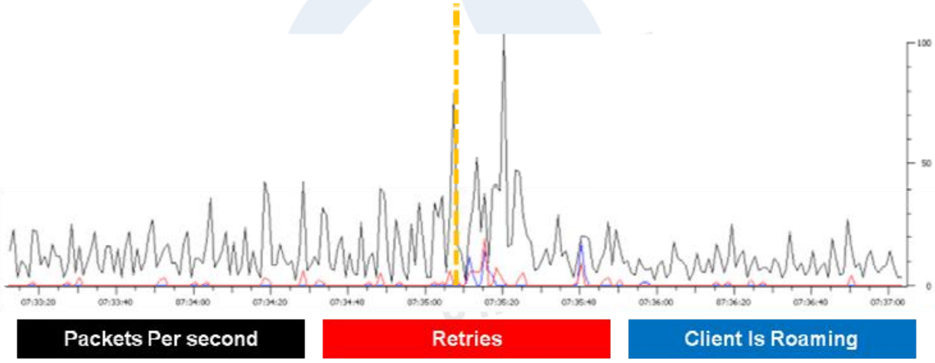
Clock Synchronization

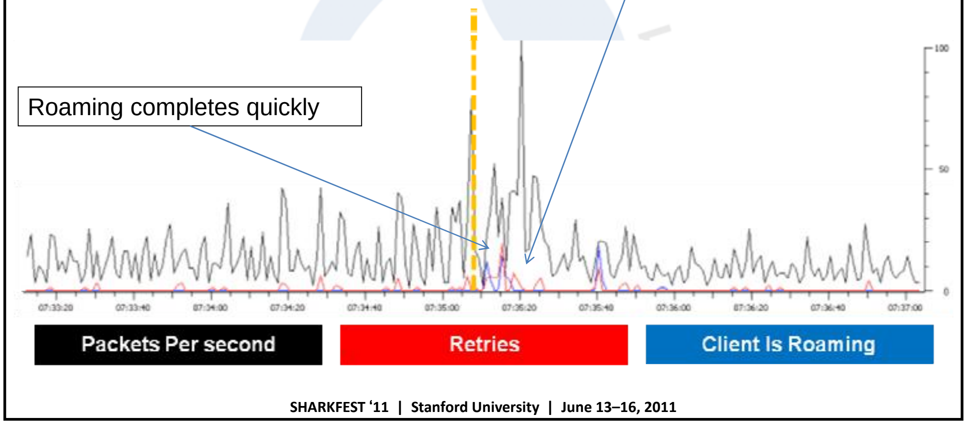
- When analyzing roaming, it is sometimes necessary to compare traces taken from different laptops
- Clocks on the laptops are seldom perfectly synchronized, so comparing the traces can be difficult
- Record time offset of each laptop relative to a “master” clock like a cell phone or one laptop
- Calculate delta between each laptop and each other laptop to allow trace comparison

“Normal” Roaming

- Same device, slightly different behavior
- Just based on the graph, how does this compare?



“Normal” Roaming

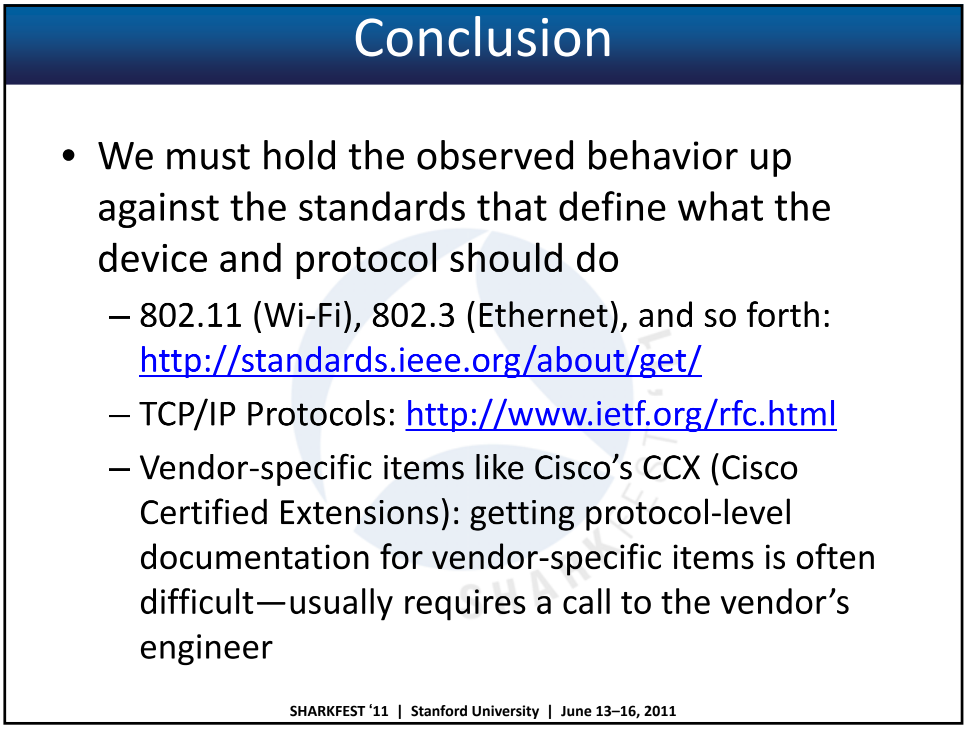


No flurry of retries. STA did go “radio silent” before roaming

Roaming completes quickly

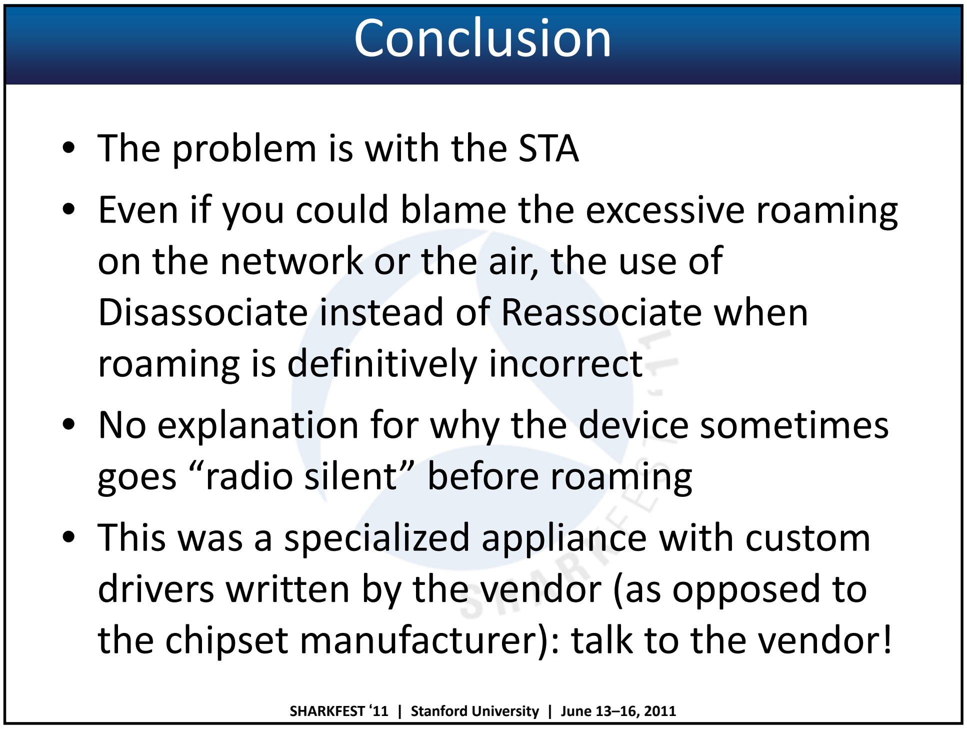
Conclusion

“When you have eliminated the impossible, whatever remains, *however improbable*, must be the truth.”—*Sir Arthur Conan Doyle*



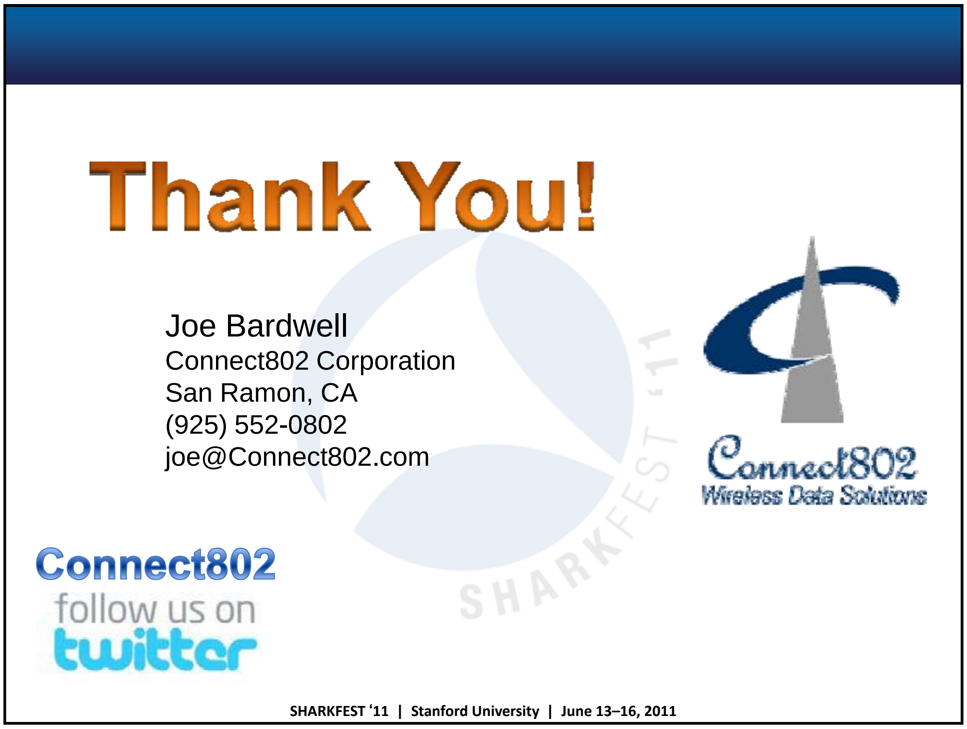
Conclusion

- We must hold the observed behavior up against the standards that define what the device and protocol should do
  - 802.11 (Wi-Fi), 802.3 (Ethernet), and so forth: http://standards.ieee.org/about/get/
  - TCP/IP Protocols: http://www.ietf.org/rfc.html
  - Vendor-specific items like Cisco’s CCX (Cisco Certified Extensions): getting protocol-level documentation for vendor-specific items is often difficult—usually requires a call to the vendor’s engineer



Conclusion

- The problem is with the STA
- Even if you could blame the excessive roaming on the network or the air, the use of Disassociate instead of Reassociate when roaming is definitively incorrect
- No explanation for why the device sometimes goes “radio silent” before roaming
- This was a specialized appliance with custom drivers written by the vendor (as opposed to the chipset manufacturer): talk to the vendor!



Thank You!

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