Wireshark Developer and User Conference

Discovering WLAN 802.11n MIMO

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SHARKFEST **‘11**

Stanford University

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Session Agenda

- Design Goals for 802.11n
- IEEE 802.11n physical layer improvements
- IEEE 802.11n MAC layer improvements
- Per-Packet Information Header
- Analyzing 'Bad BAR' and 'Deadlock' problem
- Bandwidth Measurement
- Backwards compatibility to a/b/g
- Future of 802.11n

Design Goals for 802.11n

- IEEE 802.11n is a proposed amendment to the IEEE 802.11-2007 wireless networking standard
- Significantly improve PHY layer transmission rate over previous standards, such as 802.11a and 802.11b/g with ‘High Throughput’ (HT) options
- Increasing the MAC layer transfer rate to achieve a minimum of 100 Mbps data throughput
- Maintain backward compatibility with existing IEEE WLAN legacy solutions (802.11a/b/g)

How the Goals are achieved

A combination of technical functions at PHY and MAC layers are added to the existing 802.11 standard:

- ✓ Increasing the physical transfer rate with new modulation scheme and timing up to 600Mbps
- ✓ New multi-streaming modulation technique using MIMO (multiple input, multiple output antennas)
- ✓ Joining two adjacent channels with Channel bonding
- ✓ Support for frame aggregation A-MPDU & A-MSDU
- ✓ New Block Acknowledgments

PHY layer improvements

- ## Modified OFDM

The number of OFDM data sub-carriers is increased from 48 to 52 which improves the maximum throughput from 54 to 58.5 Mbps

- ## Forward Error Correction

FEC is a system of error control whereby the sender adds redundant data to allow the receiver to detect and correct errors. 3/4 coding rate is improved with 5/6 boosting the link rate from 58.5 to 65 Mbps

PHY layer improvements (cont.)

- Shorter Guard Interval (GI)

The GI between OFDM symbols is reduced from 800ns to 400ns and increases throughput from 65 to 72.2 Mbps

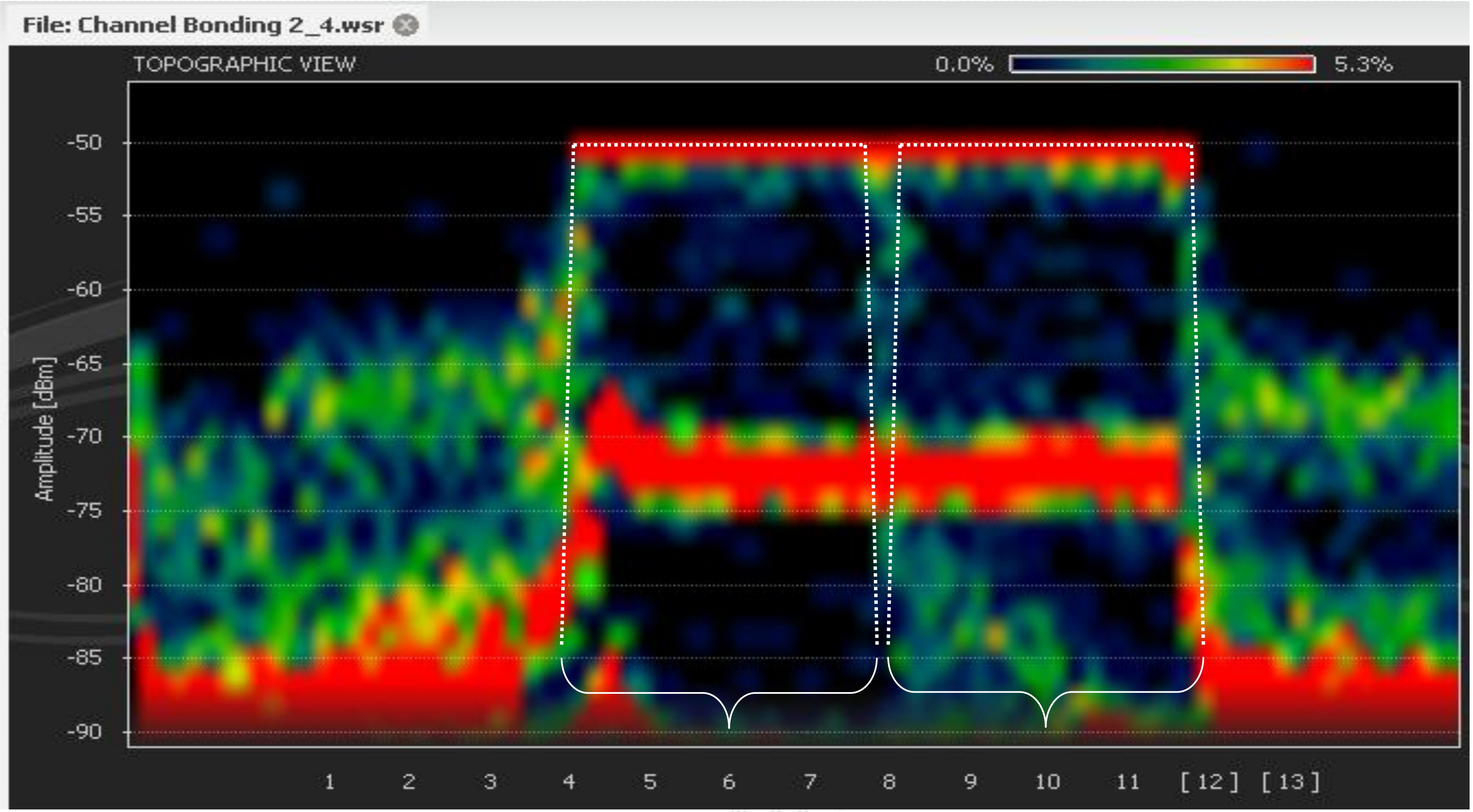
- Channel Bonding

Doubling channel bandwidth from 20 to 40 MHz slightly more than doubles rate from 72.2 to 150 Mbps

- Spatial multiplexing

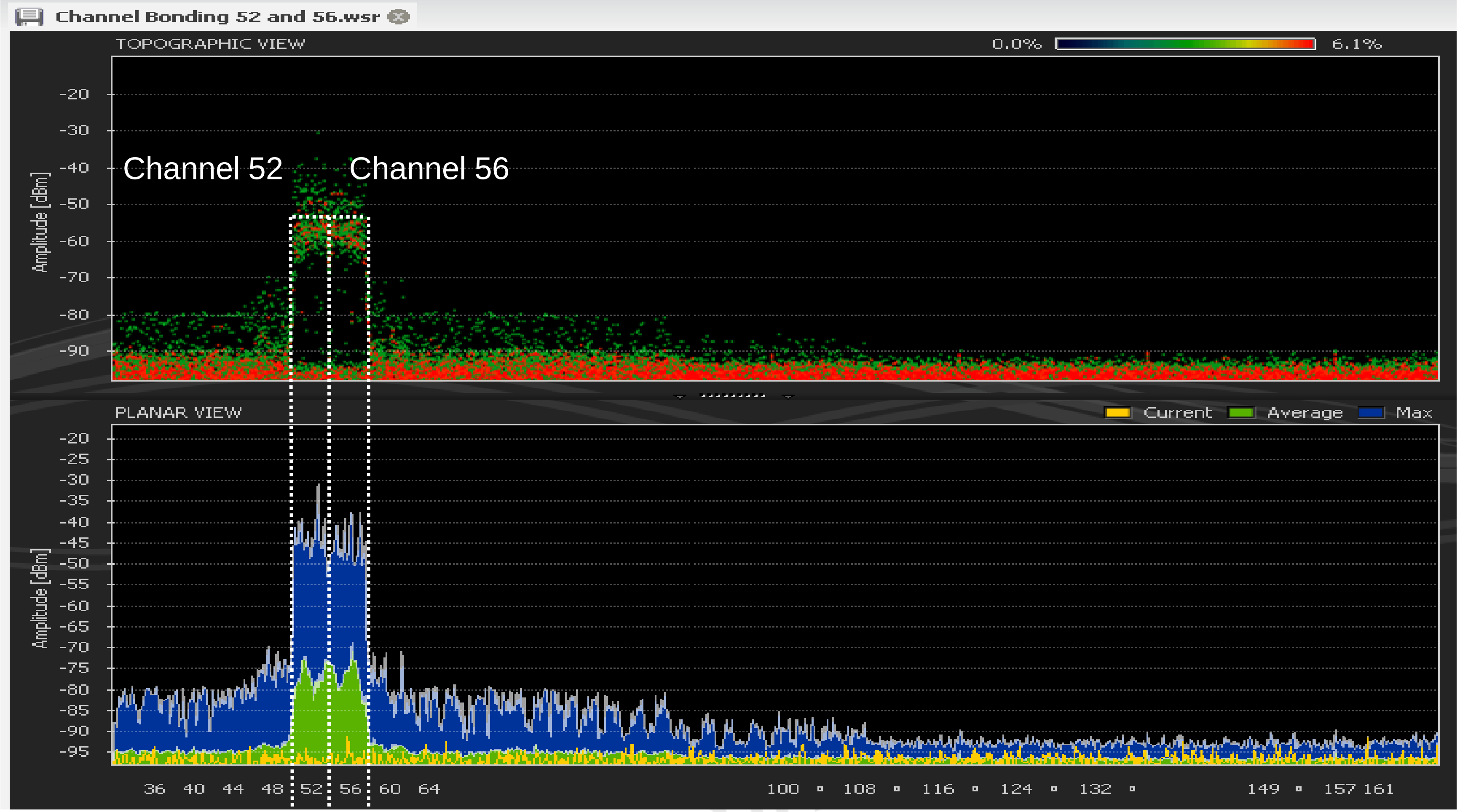
Support of up to four spatial streams (MIMO) increases throughput up to 4 times 150 to 600 Mbps

Channel Bonding (Channel 6 & 10)



Recorded with Wi-Spy® from MetaGeek

Channel Bonding (Channel 52 & 56)

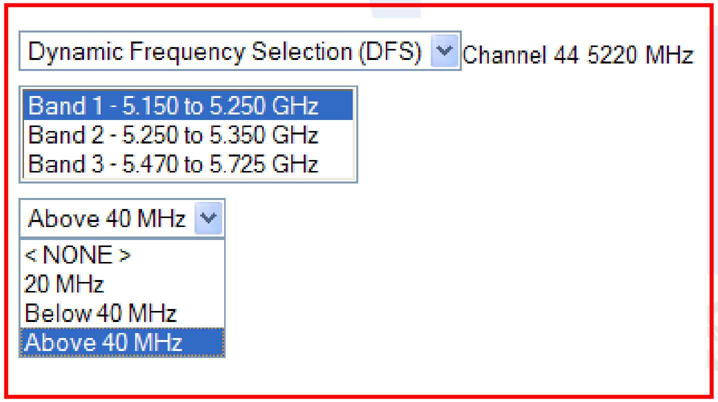


Recorded with Wi-Spy® from MetaGeek

Channel Bonding (configuration)

802.11n supports bundling of two 20 MHz channels

- Select a control channel # and the channel offset
- Both channels must fit inside allowed frequency range
- A-band does not allow to select channel # manually



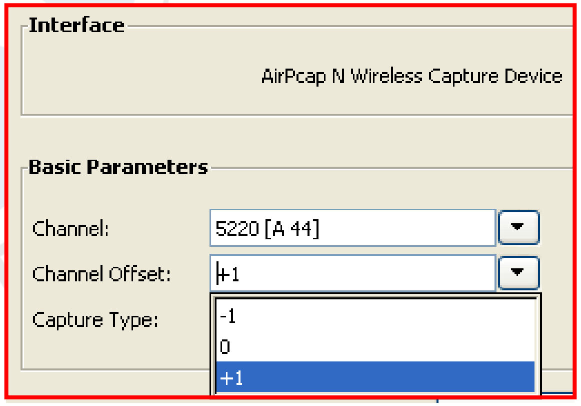
Dynamic Frequency Selection (DFS) Channel 44 5220 MHz

Band 1 - 5.150 to 5.250 GHz
Band 2 - 5.250 to 5.350 GHz
Band 3 - 5.470 to 5.725 GHz

Above 40 MHz

< NONE >
20 MHz
Below 40 MHz
Above 40 MHz

Configuration on Cisco AP1250



Interface

AirPcap N Wireless Capture Device

Basic Parameters

Channel: 5220 [A 44]

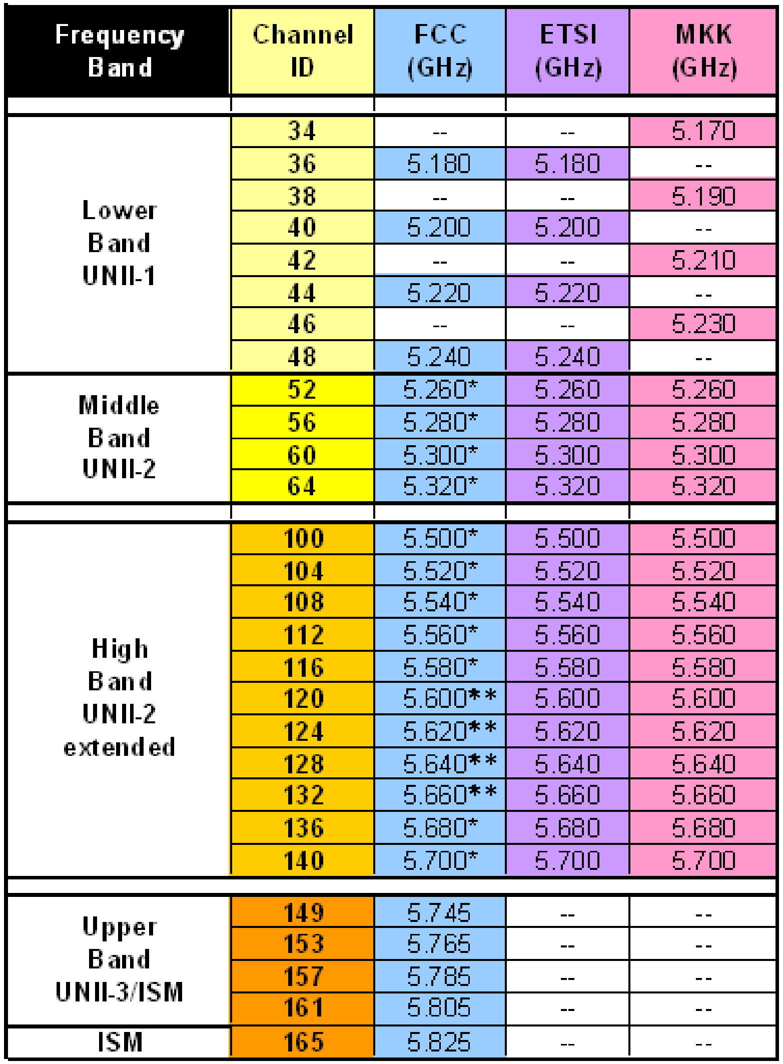
Channel Offset: +1

Capture Type:

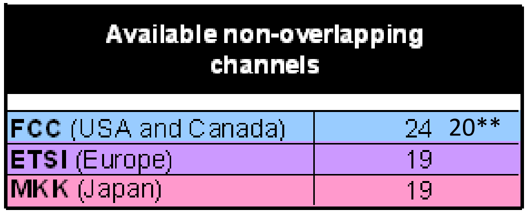
-1
0
+1

Configuration on AirPcap N

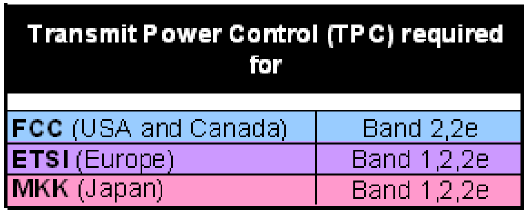
Channel Allocation 5GHz Band



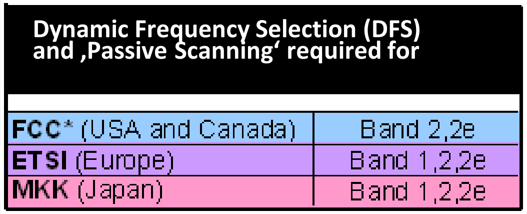
Frequency Band	Channel ID	FCC (GHz)	ETSI (GHz)	MKK (GHz)
Lower Band UNII-1	34	--	--	5.170
	36	5.180	5.180	--
	38	--	--	5.190
	40	5.200	5.200	--
	42	--	--	5.210
	44	5.220	5.220	--
	46	--	--	5.230
	48	5.240	5.240	--
Middle Band UNII-2	52	5.260*	5.260	5.260
	56	5.280*	5.280	5.280
	60	5.300*	5.300	5.300
	64	5.320*	5.320	5.320
High Band UNII-2 extended	100	5.500*	5.500	5.500
	104	5.520*	5.520	5.520
	108	5.540*	5.540	5.540
	112	5.560*	5.560	5.560
	116	5.580*	5.580	5.580
	120	5.600**	5.600	5.600
	124	5.620**	5.620	5.620
	128	5.640**	5.640	5.640
	132	5.660**	5.660	5.660
	136	5.680*	5.680	5.680
	140	5.700*	5.700	5.700
Upper Band UNII-3/ISM	149	5.745	--	--
	153	5.765	--	--
	157	5.785	--	--
	161	5.805	--	--
ISM	165	5.825	--	--



Available non-overlapping channels	
FCC (USA and Canada)	24 20**
ETSI (Europe)	19
MKK (Japan)	19



Transmit Power Control (TPC) required for	
FCC (USA and Canada)	Band 2,2e
ETSI (Europe)	Band 1,2,2e
MKK (Japan)	Band 1,2,2e

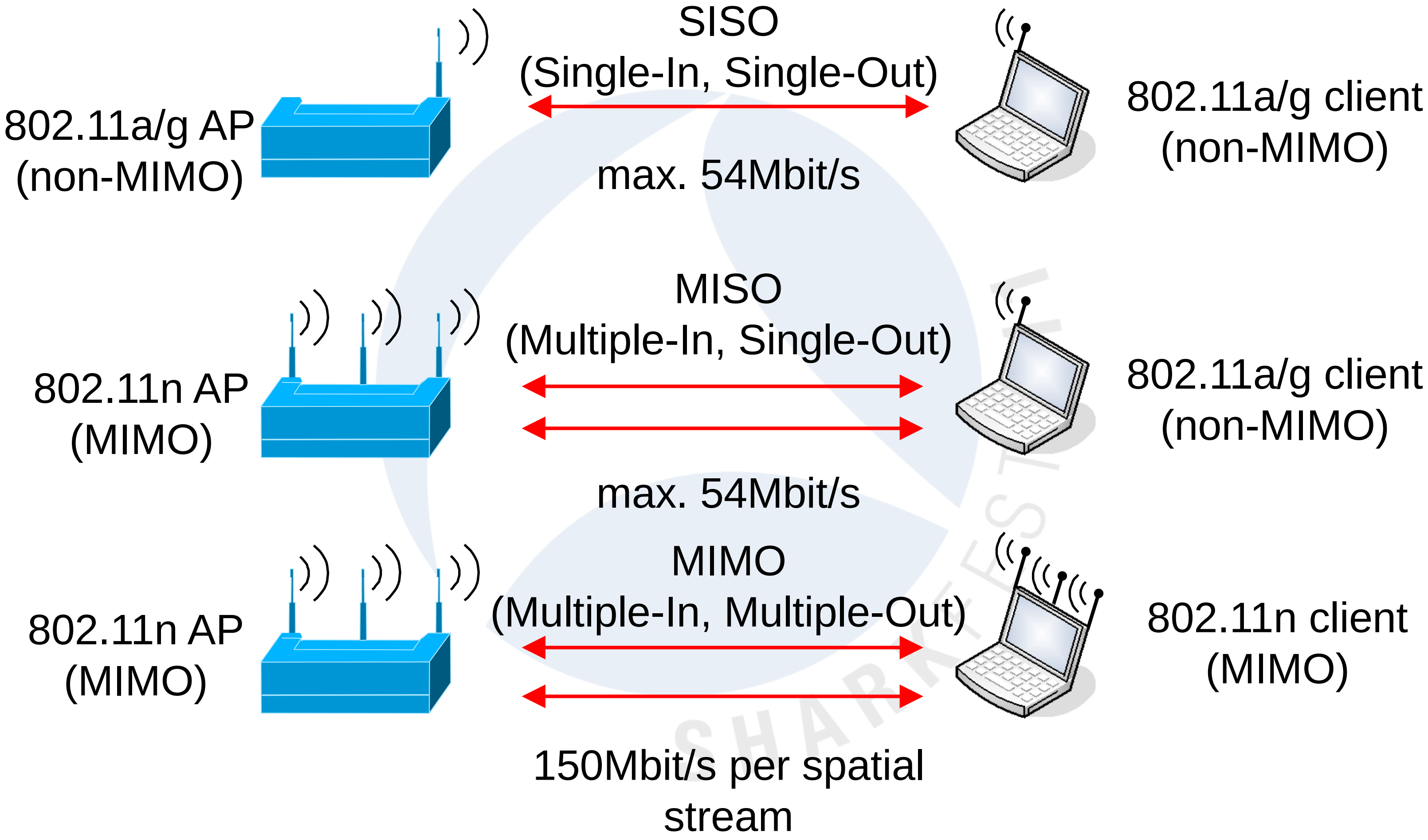


Dynamic Frequency Selection (DFS) and ‚Passive Scanning' required for	
FCC* (USA and Canada)	Band 2,2e
ETSI (Europe)	Band 1,2,2e
MKK (Japan)	Band 1,2,2e

Some channels allowed for inhouse use only

*New stricter DFS2 rules by FCC valid off July 20, 2007
** 4 Channels removed by FCC valid off October 5, 2009

Multi-Streaming Modulation



802.11a/g AP
(non-MIMO)

SISO
(Single-In, Single-Out)

max. 54Mbit/s

802.11a/g client
(non-MIMO)

802.11n AP
(MIMO)

MISO
(Multiple-In, Single-Out)

max. 54Mbit/s

802.11a/g client
(non-MIMO)

802.11n AP
(MIMO)

MIMO
(Multiple-In, Multiple-Out)

150Mbit/s per spatial
stream

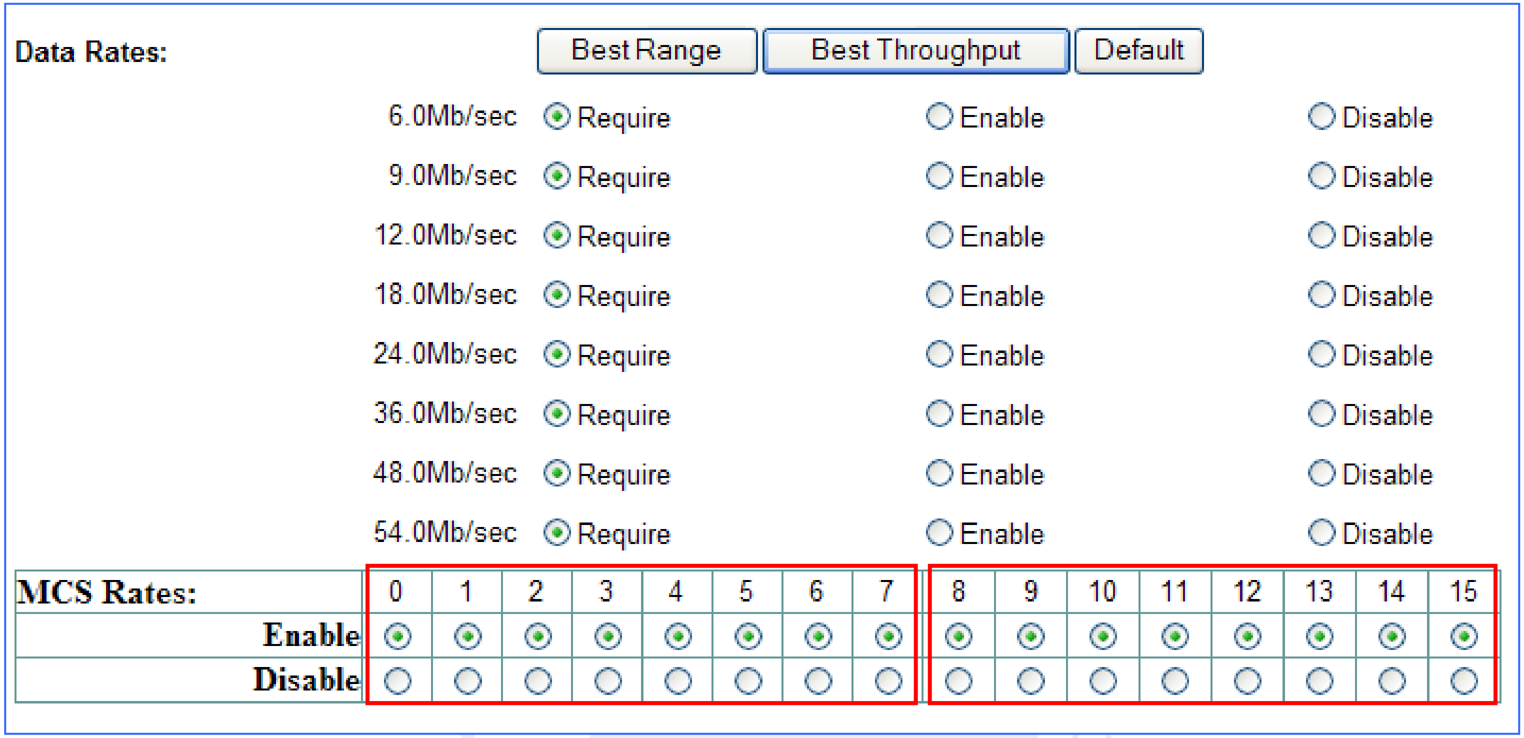
802.11n client
(MIMO)

Modulation Coding Scheme (MCS)

802.11n introduces a new Modulation Coding Scheme

- 802.11 b/g adapts to channel conditions by selecting the highest of 12 possible rates from 1 to 54 Mbps
- The 802.11n standard will allow some 77 possible MCS' - some compulsory, some optional
- MCS selects, based on RF channel conditions, the best combination of 8 data rates, bonded channels, multiple spatial streams, different guard intervals and modulation types

MCS Configuration



Data Rates: [Best Range] [Best Throughput] [Default]

6.0Mb/sec	● Require	○ Enable	○ Disable
9.0Mb/sec	● Require	○ Enable	○ Disable
12.0Mb/sec	● Require	○ Enable	○ Disable
18.0Mb/sec	● Require	○ Enable	○ Disable
24.0Mb/sec	● Require	○ Enable	○ Disable
36.0Mb/sec	● Require	○ Enable	○ Disable
48.0Mb/sec	● Require	○ Enable	○ Disable
54.0Mb/sec	● Require	○ Enable	○ Disable

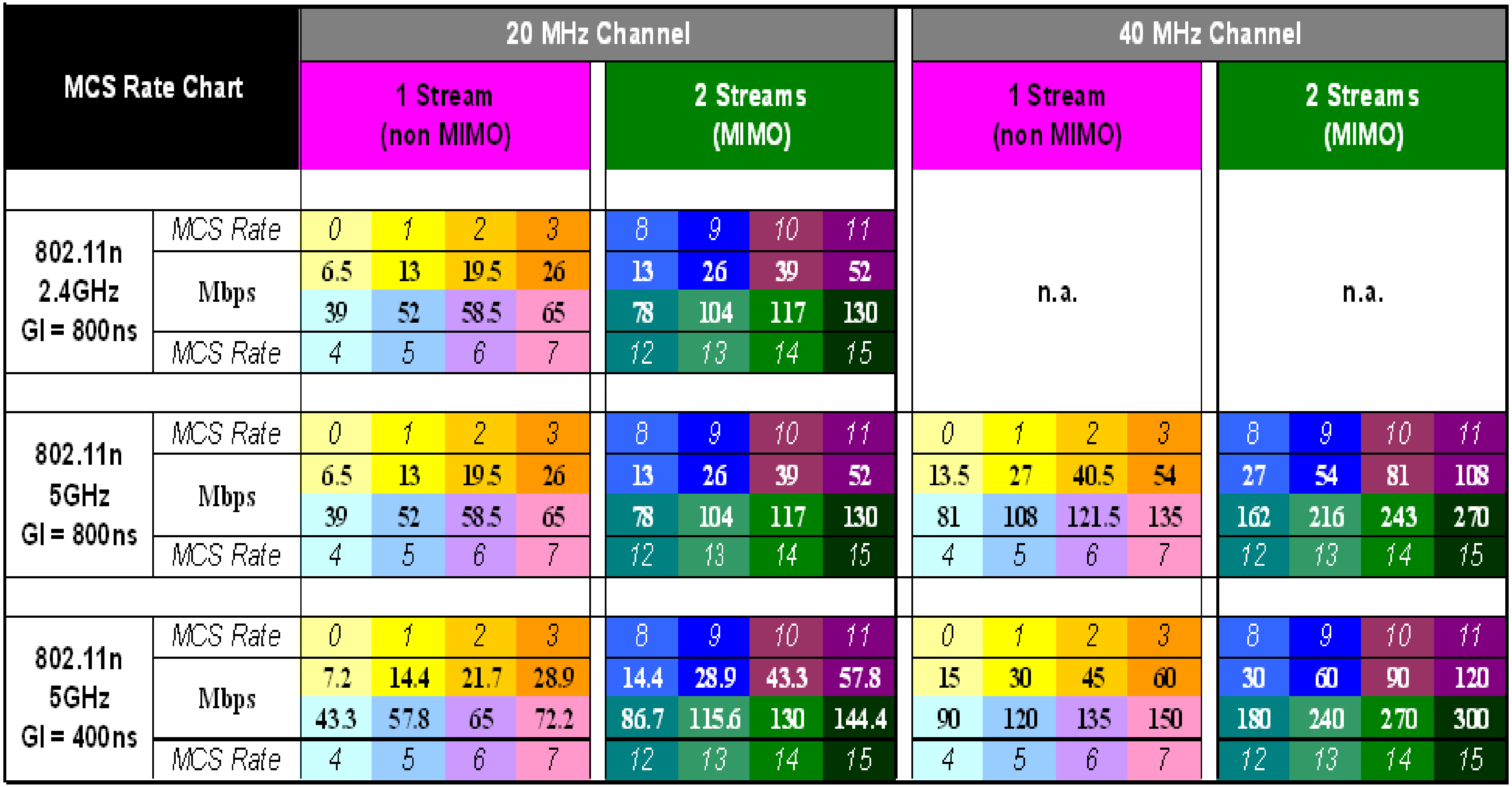
MCS Rates:	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Enable	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
Disable	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○

1 spatial stream

2 spatial streams

Screenshot Cisco AP1250

MCS Rate Chart



MCS Rate Chart		20 MHz Channel								40 MHz Channel							
		1 Stream (non MIMO)				2 Streams (MIMO)				1 Stream (non MIMO)				2 Streams (MIMO)			
802.11n 2.4GHz GI = 800ns	MCS Rate	0	1	2	3	8	9	10	11	n.a.				n.a.			
	Mbps	6.5	13	19.5	26	13	26	39	52								
		39	52	58.5	65	78	104	117	130								
	MCS Rate	4	5	6	7	12	13	14	15								
802.11n 5GHz GI = 800ns	MCS Rate	0	1	2	3	8	9	10	11	0	1	2	3	8	9	10	11
	Mbps	6.5	13	19.5	26	13	26	39	52	13.5	27	40.5	54	27	54	81	108
		39	52	58.5	65	78	104	117	130	81	108	121.5	135	162	216	243	270
	MCS Rate	4	5	6	7	12	13	14	15	4	5	6	7	12	13	14	15
802.11n 5GHz GI = 400ns	MCS Rate	0	1	2	3	8	9	10	11	0	1	2	3	8	9	10	11
	Mbps	7.2	14.4	21.7	28.9	14.4	28.9	43.3	57.8	15	30	45	60	30	60	90	120
		43.3	57.8	65	72.2	86.7	115.6	130	144.4	90	120	135	150	180	240	270	300
	MCS Rate	4	5	6	7	12	13	14	15	4	5	6	7	12	13	14	15

MAC layer improvements

Frame Aggregation Mechanisms

- Aggregate-MAC Service Data Unit (A-MSDU) wraps multiple Ethernet frames in a .11n frame up to 8KB
- Aggregate-MAC Protocol Data Unit (A-MPDU) allows bursting 802.11 frames up to 64KB
- A-MPDU is performed in the software whereas A-MSDU is performed in the hardware

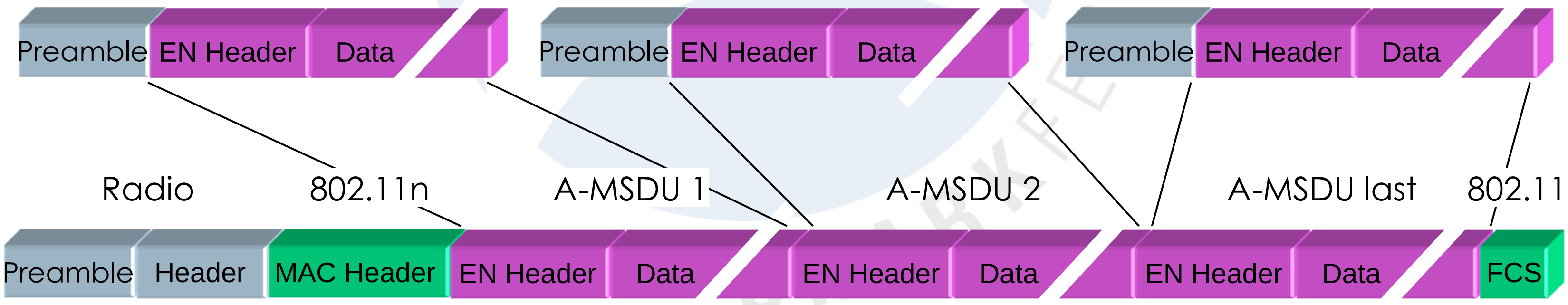
Block Acknowledgement

- Block ACK effectively eliminates the need to initiate a new transfer for every MPDU

MSDU Aggregation

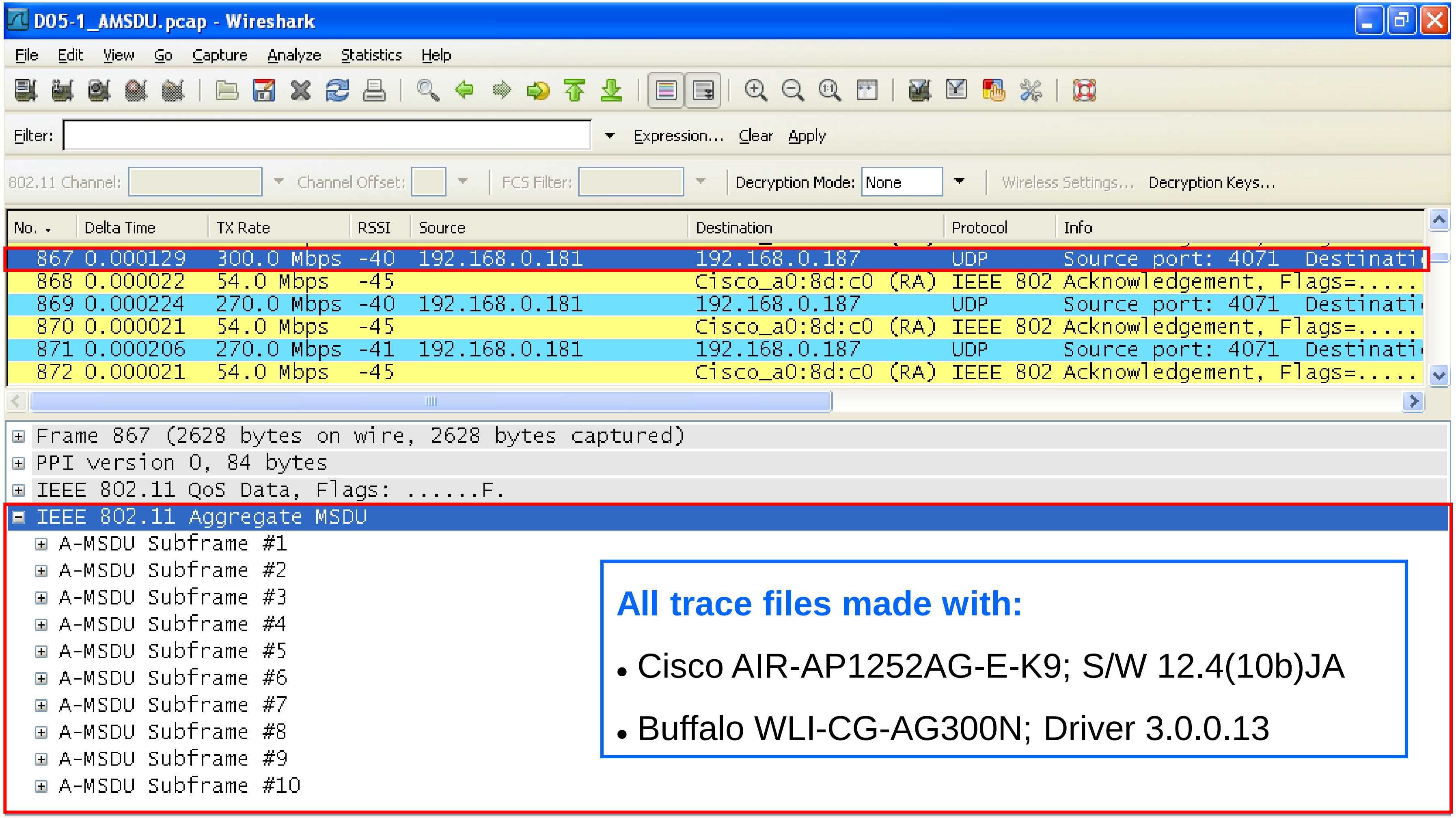
- Multiple Ethernet frames for a common destination are wrapped in a single 802.11 frame
- More efficient than A-MPDU as only one radio- and 802.11 MAC header is applied
- Whole frame must be retransmitted if no acknowledge

Multiple Ethernet Frames



Aggregated MAC Service Data Units

A-MSDU Analysis



Decryption Mode: None

```
No.  Delta Time  TX Rate     RSSI  Source          Destination           Protocol  Info
867 0.000129  300.0 Mbps  -40  192.168.0.181  192.168.0.187         UDP      Source port: 4071  Destinati
868 0.000022  54.0 Mbps   -45                 Cisco_a0:8d:c0 (RA)  IEEE 802 Acknowledgement, Flags=.....
869 0.000224  270.0 Mbps  -40  192.168.0.181  192.168.0.187         UDP      Source port: 4071  Destinati
870 0.000021  54.0 Mbps   -45                 Cisco_a0:8d:c0 (RA)  IEEE 802 Acknowledgement, Flags=.....
871 0.000206  270.0 Mbps  -41  192.168.0.181  192.168.0.187         UDP      Source port: 4071  Destinati
872 0.000021  54.0 Mbps   -45                 Cisco_a0:8d:c0 (RA)  IEEE 802 Acknowledgement, Flags=.....
```

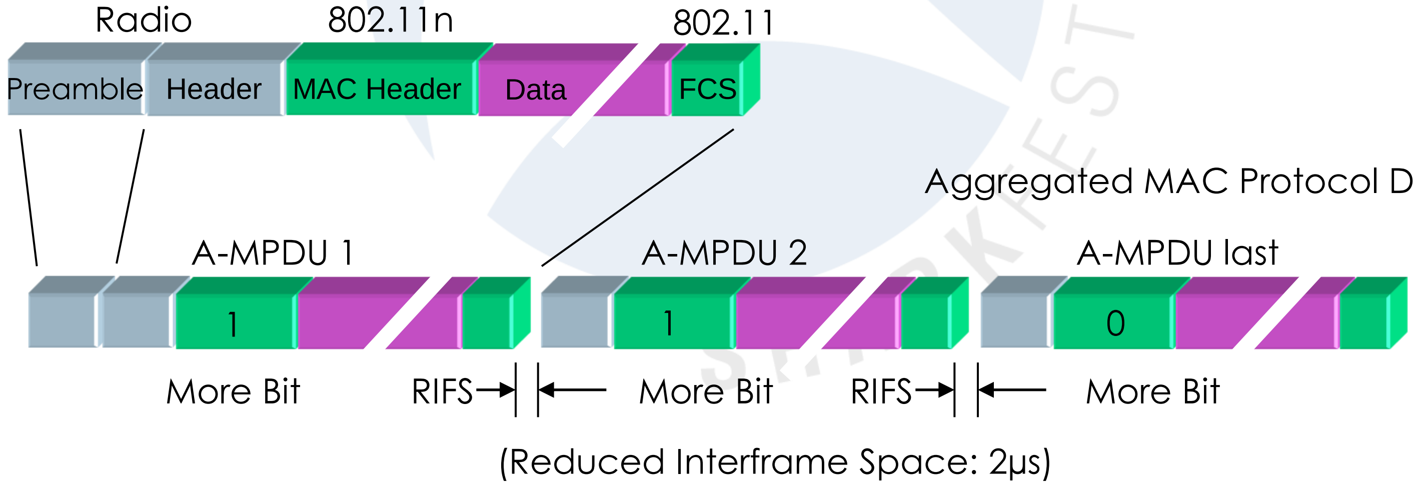
```
⊞ Frame 867 (2628 bytes on wire, 2628 bytes captured)
⊞ PPI version 0, 84 bytes
⊞ IEEE 802.11 QoS Data, Flags: ......F.
⊟ IEEE 802.11 Aggregate MSDU
    ⊞ A-MSDU Subframe #1
    ⊞ A-MSDU Subframe #2
    ⊞ A-MSDU Subframe #3
    ⊞ A-MSDU Subframe #4
    ⊞ A-MSDU Subframe #5
    ⊞ A-MSDU Subframe #6
    ⊞ A-MSDU Subframe #7
    ⊞ A-MSDU Subframe #8
    ⊞ A-MSDU Subframe #9
    ⊞ A-MSDU Subframe #10
```

All trace files made with:

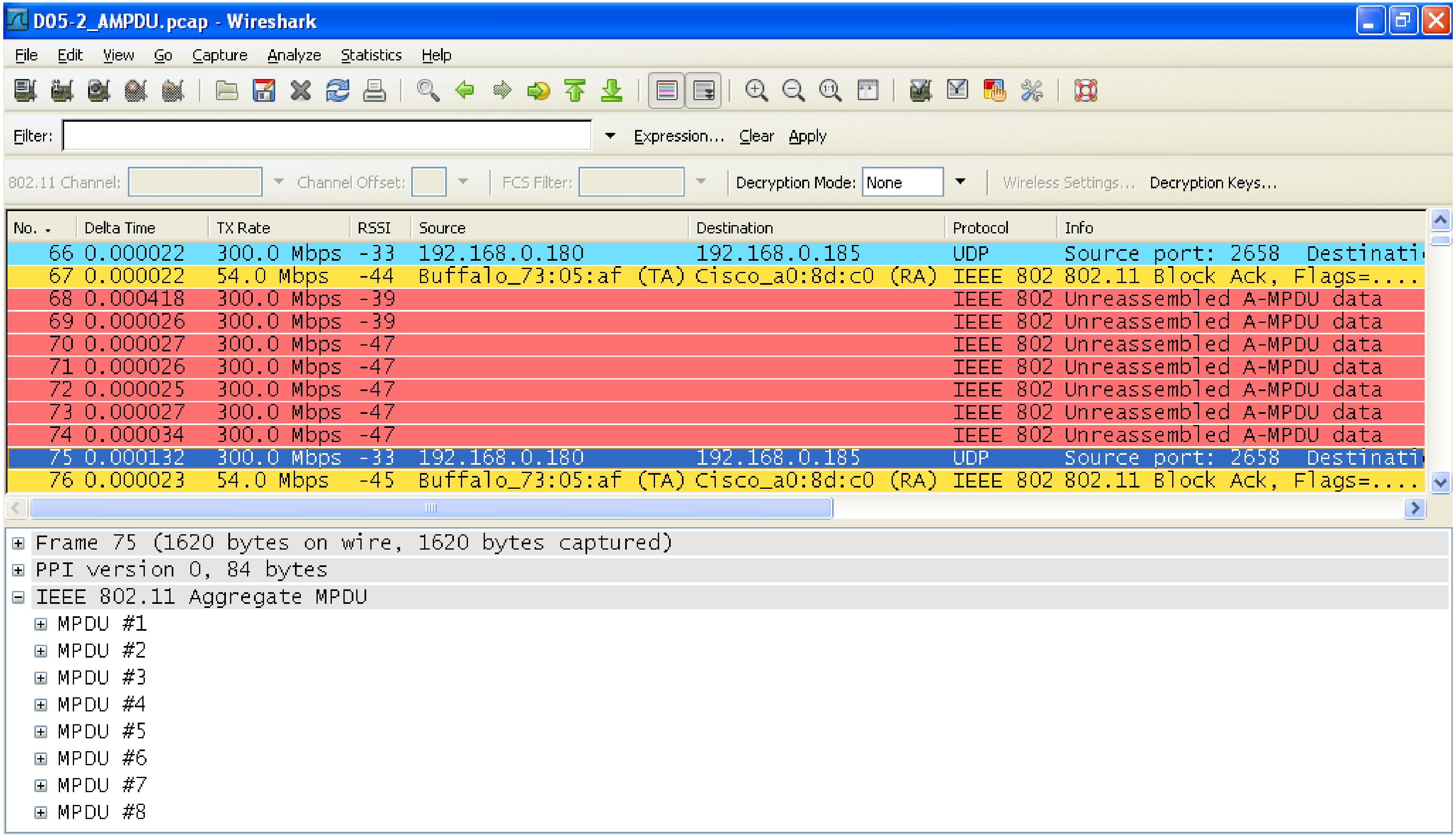
- Cisco AIR-AP1252AG-E-K9; S/W 12.4(10b)JA
- Buffalo WLI-CG-AG300N; Driver 3.0.0.13

MPDU Aggregation

- Multiple Ethernet frames for a common destination are translated to 802.11 format and sent as burst
- Elements of an A-MPDUs burst can be acknowledged individually with one single Block-Acknowledge
- Only not-acknowledged A-MPDUs are retransmitted



A-MPDU Analysis



Decryption Mode: None

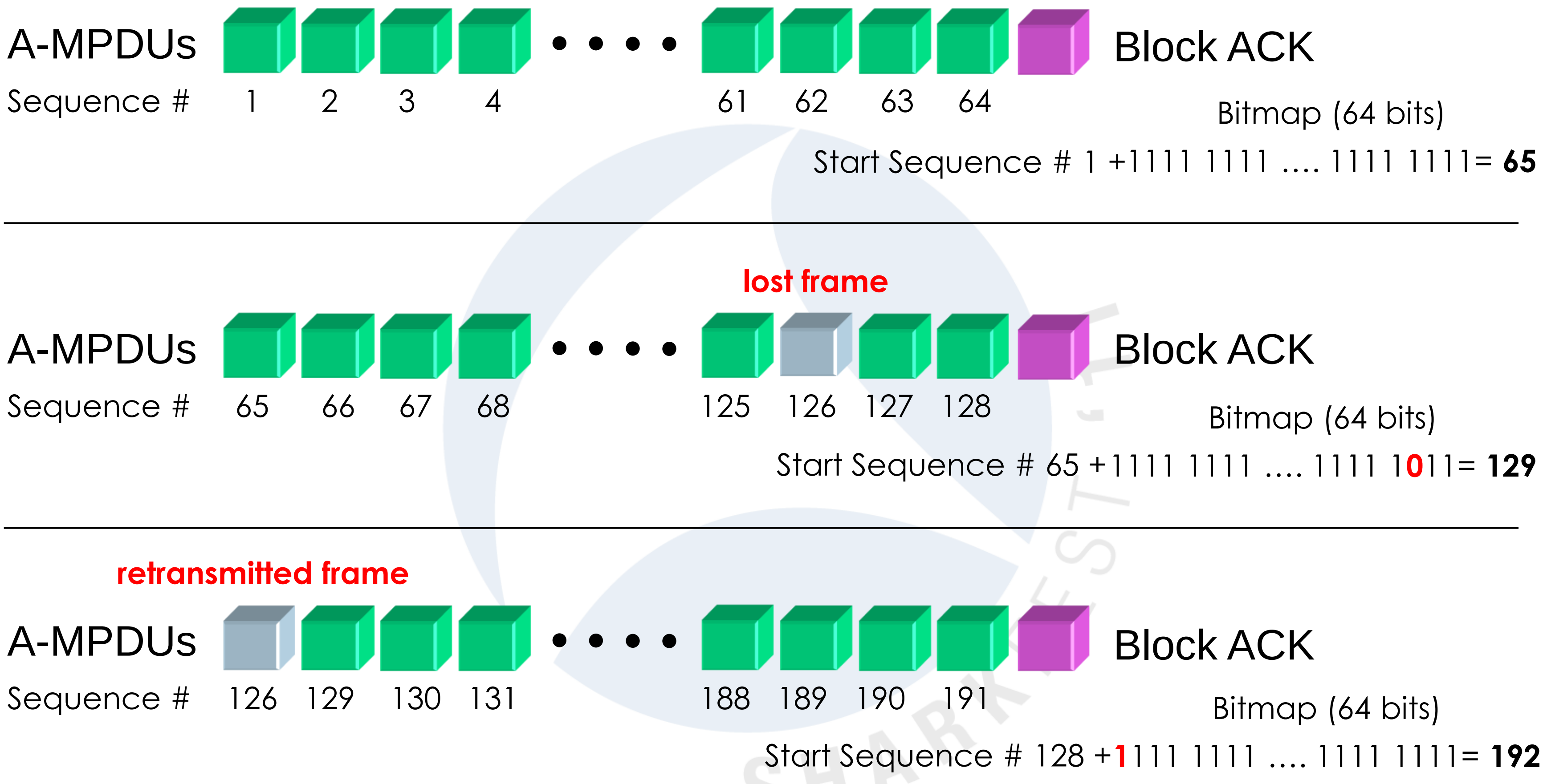
```
No. -  Delta Time  TX Rate     RSSI  Source                  Destination            Protocol  Info
   66 0.000022    300.0 Mbps  -33   192.168.0.180           192.168.0.185          UDP       Source port: 2658  Destinati
   67 0.000022    54.0 Mbps   -44   Buffalo_73:05:af (TA)   Cisco_a0:8d:c0 (RA)    IEEE 802  802.11 Block Ack, Flags=....
   68 0.000418    300.0 Mbps  -39                                                  IEEE 802  Unreassembled A-MPDU data
   69 0.000026    300.0 Mbps  -39                                                  IEEE 802  Unreassembled A-MPDU data
   70 0.000027    300.0 Mbps  -47                                                  IEEE 802  Unreassembled A-MPDU data
   71 0.000026    300.0 Mbps  -47                                                  IEEE 802  Unreassembled A-MPDU data
   72 0.000025    300.0 Mbps  -47                                                  IEEE 802  Unreassembled A-MPDU data
   73 0.000027    300.0 Mbps  -47                                                  IEEE 802  Unreassembled A-MPDU data
   74 0.000034    300.0 Mbps  -47                                                  IEEE 802  Unreassembled A-MPDU data
   75 0.000132    300.0 Mbps  -33   192.168.0.180           192.168.0.185          UDP       Source port: 2658  Destinati
   76 0.000023    54.0 Mbps   -45   Buffalo_73:05:af (TA)   Cisco_a0:8d:c0 (RA)    IEEE 802  802.11 Block Ack, Flags=....
```

```
⊞ Frame 75 (1620 bytes on wire, 1620 bytes captured)
⊞ PPI version 0, 84 bytes
⊟ IEEE 802.11 Aggregate MPDU
   ⊞ MPDU #1
   ⊞ MPDU #2
   ⊞ MPDU #3
   ⊞ MPDU #4
   ⊞ MPDU #5
   ⊞ MPDU #6
   ⊞ MPDU #7
   ⊞ MPDU #8
```

Block-ACK Mechanism

- Rather than sending an individual acknowledge following each data frame, 802.11n introduces the technique of confirming a burst of up to 64 frames with a single Block ACK (BA) frame
- The Block ACK even contains a bitmap to selectively acknowledge individual frames of a burst (comparable to selective acknowledges of TCP)
- The use of combined acknowledges can be requested by sending a Block ACK Request (BAR)

Block-ACK Mechanism (cont.)



A-MPDUs • • • • Block ACK

Sequence # 1 2 3 4 61 62 63 64

Bitmap (64 bits)

Start Sequence # 1 +1111 1111 .... 1111 1111= **65**

lost frame

A-MPDUs • • • • Block ACK

Sequence # 65 66 67 68 125 126 127 128

Bitmap (64 bits)

Start Sequence # 65 +1111 1111 .... 1111 1011= **129**

retransmitted frame

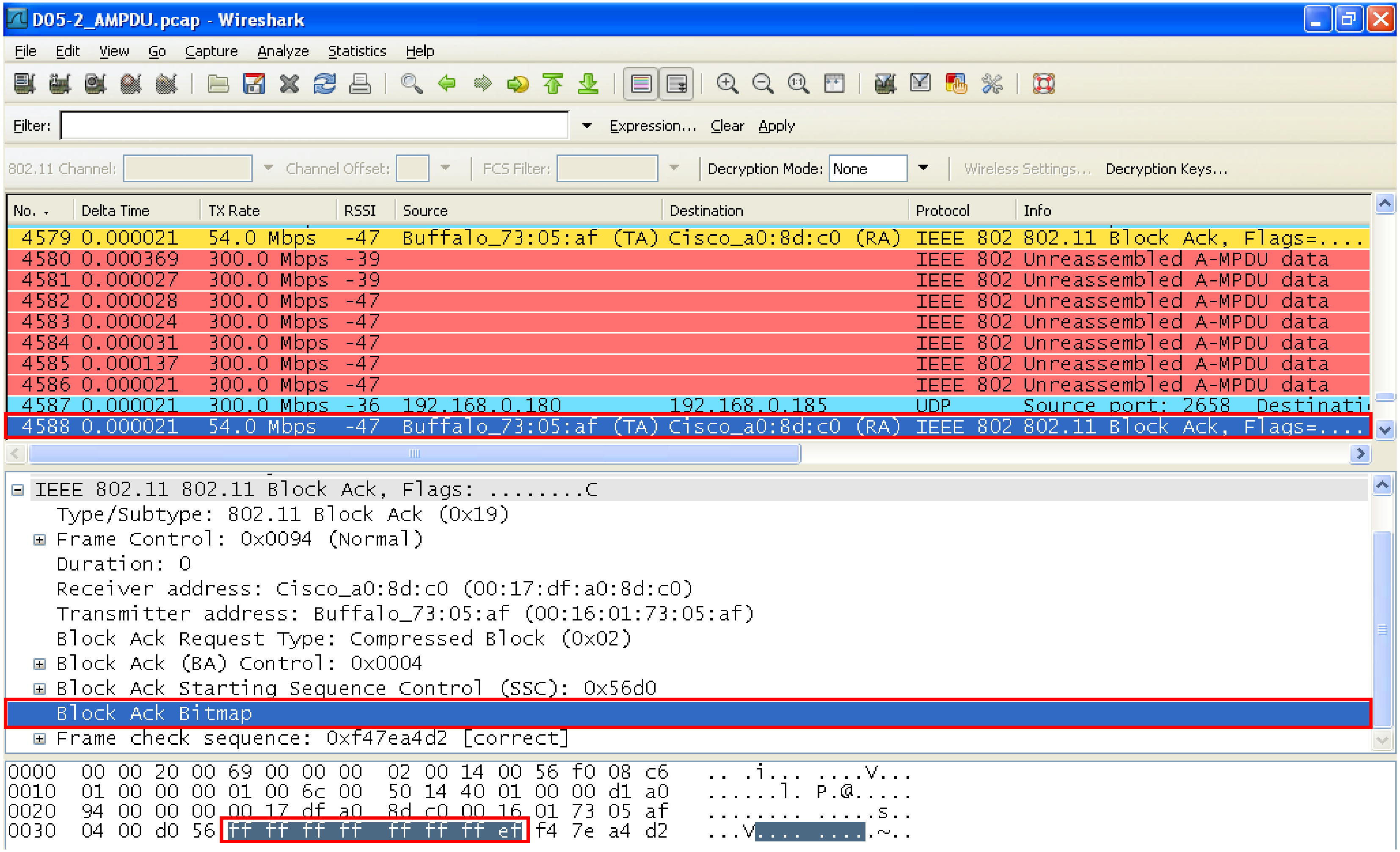
A-MPDUs • • • • Block ACK

Sequence # 126 129 130 131 188 189 190 191

Bitmap (64 bits)

Start Sequence # 128 +1111 1111 .... 1111 1111= **192**

Block-ACK Bitmap Analysis



Decryption Mode: None

```
No. .  Delta Time  TX Rate     RSSI  Source                   Destination             Protocol  Info
4579 0.000021  54.0 Mbps   -47  Buffalo_73:05:af (TA) Cisco_a0:8d:c0 (RA) IEEE 802 802.11 Block Ack, Flags=....
4580 0.000369  300.0 Mbps  -39                                                IEEE 802 Unreassembled A-MPDU data
4581 0.000027  300.0 Mbps  -39                                                IEEE 802 Unreassembled A-MPDU data
4582 0.000028  300.0 Mbps  -47                                                IEEE 802 Unreassembled A-MPDU data
4583 0.000024  300.0 Mbps  -47                                                IEEE 802 Unreassembled A-MPDU data
4584 0.000031  300.0 Mbps  -47                                                IEEE 802 Unreassembled A-MPDU data
4585 0.000137  300.0 Mbps  -47                                                IEEE 802 Unreassembled A-MPDU data
4586 0.000021  300.0 Mbps  -47                                                IEEE 802 Unreassembled A-MPDU data
4587 0.000021  300.0 Mbps  -36  192.168.0.180         192.168.0.185         UDP      Source port: 2658  Destinati
4588 0.000021  54.0 Mbps   -47  Buffalo_73:05:af (TA) Cisco_a0:8d:c0 (RA) IEEE 802 802.11 Block Ack, Flags=....
```

```
⊟ IEEE 802.11 802.11 Block Ack, Flags: ........C
    Type/Subtype: 802.11 Block Ack (0x19)
  ⊞ Frame Control: 0x0094 (Normal)
    Duration: 0
    Receiver address: Cisco_a0:8d:c0 (00:17:df:a0:8d:c0)
    Transmitter address: Buffalo_73:05:af (00:16:01:73:05:af)
    Block Ack Request Type: Compressed Block (0x02)
  ⊞ Block Ack (BA) Control: 0x0004
  ⊞ Block Ack Starting Sequence Control (SSC): 0x56d0
    Block Ack Bitmap
  ⊞ Frame check sequence: 0xf47ea4d2 [correct]
```

```
0000  00 00 20 00 69 00 00 00  02 00 14 00 56 f0 08 c6   .. .i... ....V...
0010  01 00 00 00 01 00 6c 00  50 14 40 01 00 00 d1 a0   ......l. P.@.....
0020  94 00 00 00 00 17 df a0  8d c0 00 16 01 73 05 af   ........ .....s..
0030  04 00 d0 56 ff ff ff ff  ff ff ff ef f4 7e a4 d2   ...V.... .....~..
```

Block-ACK Bitmap Analysis (cont.)

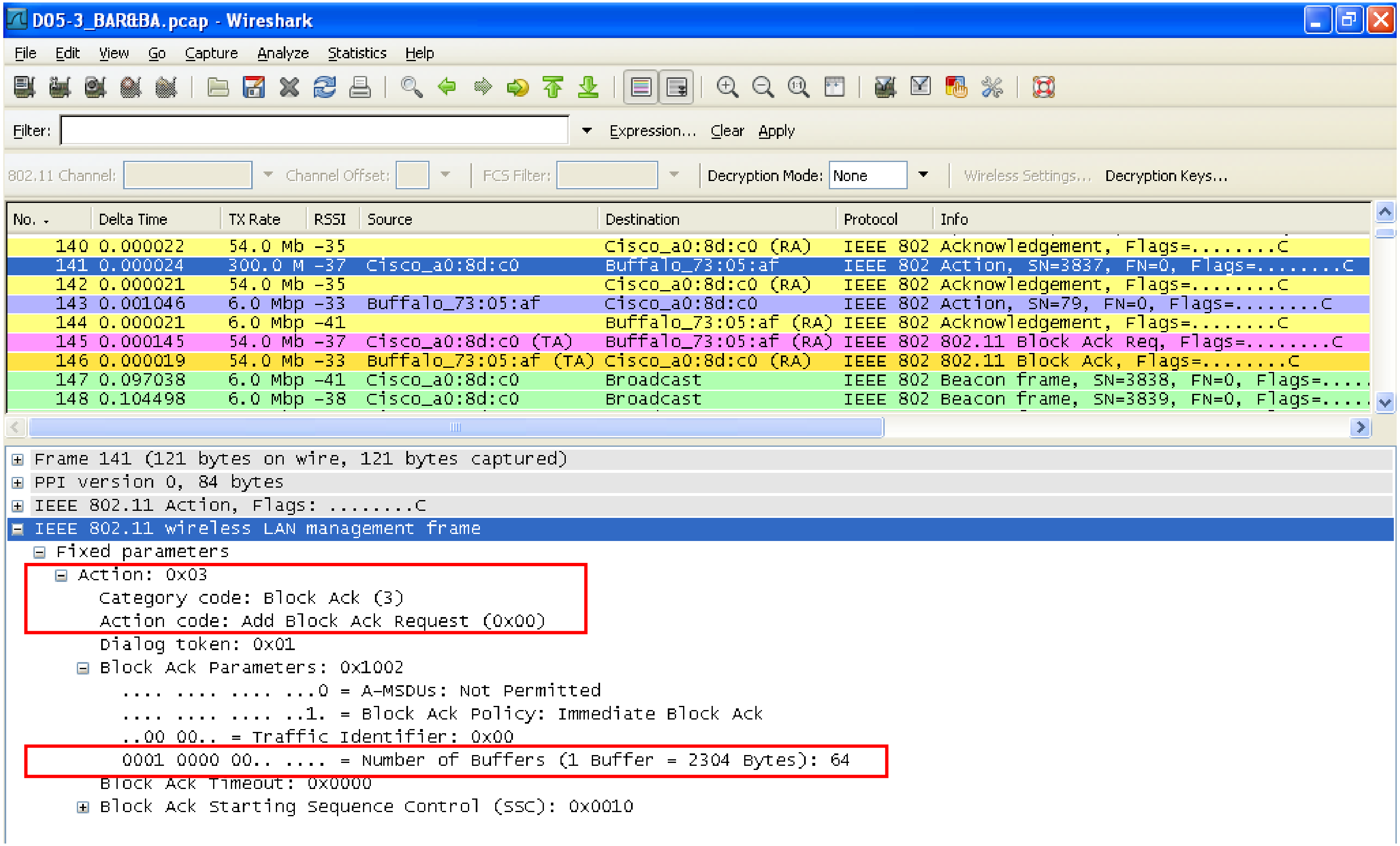
Frame #	Type		Sequence #				Bitmap (64 bits)
4579	Block ACK	🟪	Start Sequence # 1381+ 64 = 1445				**FF FF .... FF FF**
4580	MPDU #1	🟩	1445		1	**F**	
4581	MPDU #2	🟩	1446		1		
4582	MPDU #3	🟩	1447		1		
4583	MPDU #4	🟩	1448		1		
4584	MPDU #5	🟩	**1449**	**lost frame**	0	**E**	
4585	MPDU #6	🟩	1450		1		
4586	MPDU #7	🟩	1451		1		
4587	MPDU #8	🟩	1452		1		
4588	Block ACK	🟪	Start Sequence # 1389 + 64 = 1453				**FF FF .... FF EF**
4589	MPDU #1	⬜	**1449**	**retransmitted**			
4590	MPDU #2	🟩	1453	**frame**			
4591	MPDU #3	🟩	1454				
4592	MPDU #4	🟩	1455				
4593	MPDU #5	🟩	1456				
4594	MPDU #6	🟩	1457				
4595	MPDU #7	🟩	1458				
4596	MPDU #8	🟩	1459				
4597	MPDU #9	🟩	1460				
4598	MPDU #10	🟩	1461				
4599	Block ACK	🟪	Start Sequence # 1398 + 64 = 1462				**FF FF .... FF FF**

Trace file: D05_AMPDU.pcap

Block-ACK negotiation/activation

- The Block-ACK options are negotiated and confirmed with 'Action' frames defined in 802.11e (WLAN QoS)
- ‚Action' frames are used to negotiate other options too
  - Category Code 0 = Spectrum management
  - Category Code 1 = QoS options
  - Category Code 2 = DLS (Direct Link Setup)
  - Category Code 3 = Block Ack
- The use of combined acknowledges can be requested by sending a Block ACK Request (BAR)

Block-ACK negotiation/activation (cont.)



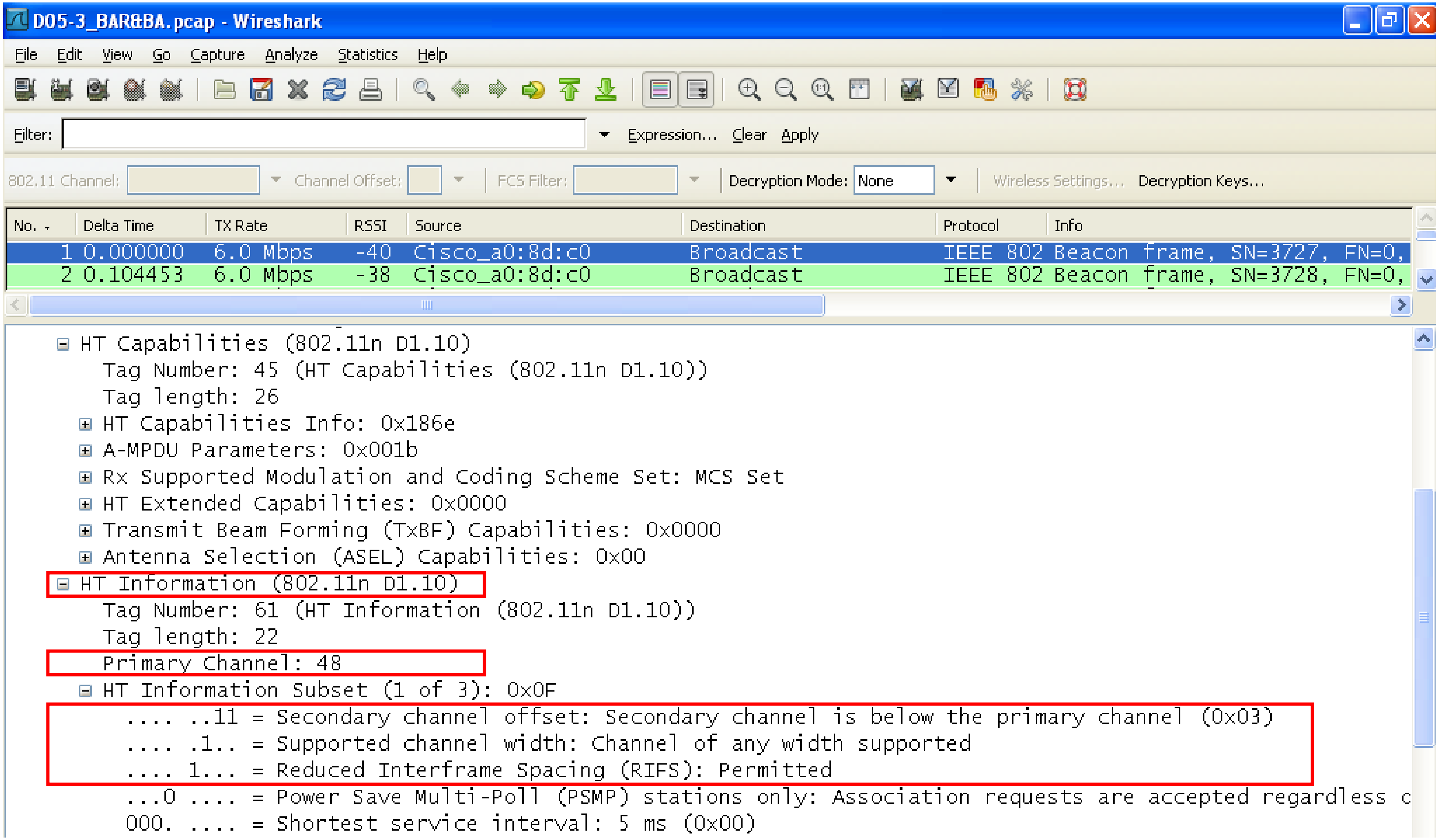
Filter:

802.11 Channel: Channel Offset: FCS Filter: Decryption Mode: None

```
No. -  Delta Time  TX Rate   RSSI  Source                   Destination              Protocol  Info
   140 0.000022    54.0 Mb   -35                            Cisco_a0:8d:c0 (RA)      IEEE 802  Acknowledgement, Flags=........C
   141 0.000024    300.0 M   -37   Cisco_a0:8d:c0           Buffalo_73:05:af         IEEE 802  Action, SN=3837, FN=0, Flags=........C
   142 0.000021    54.0 Mb   -35                            Cisco_a0:8d:c0 (RA)      IEEE 802  Acknowledgement, Flags=........C
   143 0.001046    6.0 Mbp   -33   Buffalo_73:05:af         Cisco_a0:8d:c0           IEEE 802  Action, SN=79, FN=0, Flags=........C
   144 0.000021    6.0 Mbp   -41                            Buffalo_73:05:af (RA)    IEEE 802  Acknowledgement, Flags=........C
   145 0.000145    54.0 Mb   -37   Cisco_a0:8d:c0 (TA)      Buffalo_73:05:af (RA)    IEEE 802  802.11 Block Ack Req, Flags=........C
   146 0.000019    54.0 Mb   -33   Buffalo_73:05:af (TA)    Cisco_a0:8d:c0 (RA)      IEEE 802  802.11 Block Ack, Flags=........C
   147 0.097038    6.0 Mbp   -41   Cisco_a0:8d:c0           Broadcast                IEEE 802  Beacon frame, SN=3838, FN=0, Flags=....
   148 0.104498    6.0 Mbp   -38   Cisco_a0:8d:c0           Broadcast                IEEE 802  Beacon frame, SN=3839, FN=0, Flags=....
```

```
⊞ Frame 141 (121 bytes on wire, 121 bytes captured)
⊞ PPI version 0, 84 bytes
⊞ IEEE 802.11 Action, Flags: ........C
⊟ IEEE 802.11 wireless LAN management frame
  ⊟ Fixed parameters
    ⊟ Action: 0x03
        Category code: Block Ack (3)
        Action code: Add Block Ack Request (0x00)
        Dialog token: 0x01
      ⊟ Block Ack Parameters: 0x1002
          .... .... .... ...0 = A-MSDUs: Not Permitted
          .... .... .... ..1. = Block Ack Policy: Immediate Block Ack
          ..00 00.. = Traffic Identifier: 0x00
          0001 0000 00.. .... = Number of Buffers (1 Buffer = 2304 Bytes): 64
        Block Ack Timeout: 0x0000
      ⊞ Block Ack Starting Sequence Control (SSC): 0x0010
```

New HT Capabilities in Beacon Frame

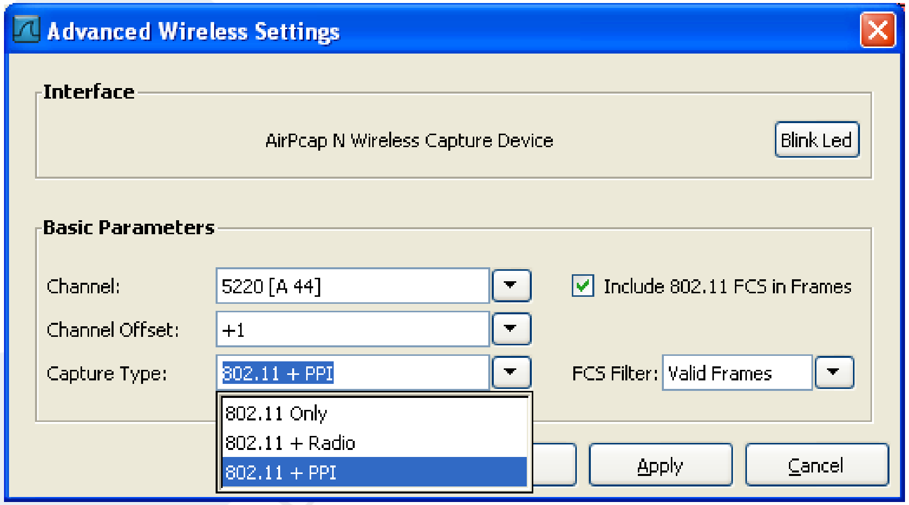


```
No.  Delta Time  TX Rate   RSSI  Source          Destination  Protocol  Info
   1 0.000000    6.0 Mbps  -40   Cisco_a0:8d:c0  Broadcast    IEEE 802  Beacon frame, SN=3727, FN=0,
   2 0.104453    6.0 Mbps  -38   Cisco_a0:8d:c0  Broadcast    IEEE 802  Beacon frame, SN=3728, FN=0,
```

```
⊟ HT Capabilities (802.11n D1.10)
    Tag Number: 45 (HT Capabilities (802.11n D1.10))
    Tag length: 26
  ⊞ HT Capabilities Info: 0x186e
  ⊞ A-MPDU Parameters: 0x001b
  ⊞ Rx Supported Modulation and Coding Scheme Set: MCS Set
  ⊞ HT Extended Capabilities: 0x0000
  ⊞ Transmit Beam Forming (TxBF) Capabilities: 0x0000
  ⊞ Antenna Selection (ASEL) Capabilities: 0x00
⊟ HT Information (802.11n D1.10)
    Tag Number: 61 (HT Information (802.11n D1.10))
    Tag length: 22
    Primary Channel: 48
  ⊟ HT Information Subset (1 of 3): 0x0F
      .... ..11 = Secondary channel offset: Secondary channel is below the primary channel (0x03)
      .... .1.. = Supported channel width: Channel of any width supported
      .... 1... = Reduced Interframe Spacing (RIFS): Permitted
      ...0 .... = Power Save Multi-Poll (PSMP) stations only: Association requests are accepted regardless c
      000. .... = Shortest service interval: 5 ms (0x00)
```

Per-Packet Information Header (PPI)

- New PPI header replaces the radiotap header used in 802.11a/b/g with additional 802.11n radio information
- PPI adds a pseudo-header to each packet and provides Meta data about RF signal strength, timing, options etc.



Advanced Wireless Settings

Interface

AirPcap N Wireless Capture Device

Basic Parameters

Channel: 5220 [A 44]

☑ Include 802.11 FCS in Frames

Channel Offset: +1

Capture Type: 802.11 + PPI

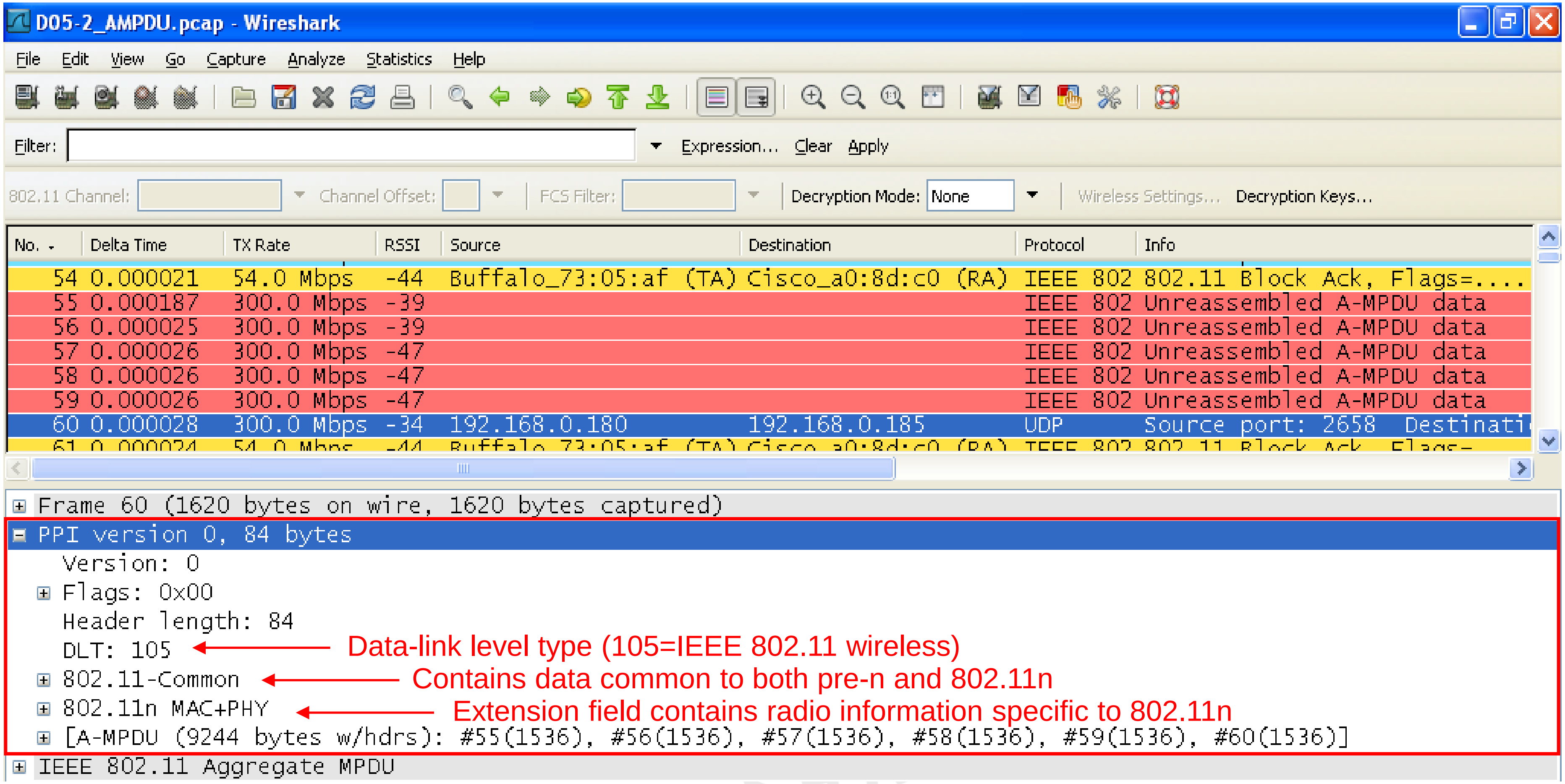
FCS Filter: Valid Frames

References

Radiotap manual: http://netbsd.gw.com/cgi-bin/man-cgi?ieee80211_radiotap+9+NetBSD-current

PPI manual: http://www.cacetech.com/documents/PPI_Header_format_1.0.1.pdf

Per-Packet Information Header (cont.)



```
No.   Delta Time  TX Rate     RSSI  Source                  Destination           Protocol  Info
   54 0.000021   54.0 Mbps   -44   Buffalo_73:05:af (TA) Cisco_a0:8d:c0 (RA)  IEEE 802 802.11 Block Ack, Flags=....
   55 0.000187   300.0 Mbps  -39                                               IEEE 802 Unreassembled A-MPDU data
   56 0.000025   300.0 Mbps  -39                                               IEEE 802 Unreassembled A-MPDU data
   57 0.000026   300.0 Mbps  -47                                               IEEE 802 Unreassembled A-MPDU data
   58 0.000026   300.0 Mbps  -47                                               IEEE 802 Unreassembled A-MPDU data
   59 0.000026   300.0 Mbps  -47                                               IEEE 802 Unreassembled A-MPDU data
   60 0.000028   300.0 Mbps  -34   192.168.0.180           192.168.0.185         UDP       Source port: 2658  Destinati
   61 0.000024   54.0 Mbps   -44   Buffalo_73:05:af (TA) Cisco_a0:8d:c0 (RA)  IEEE 802 802.11 Block Ack, Flags=
```

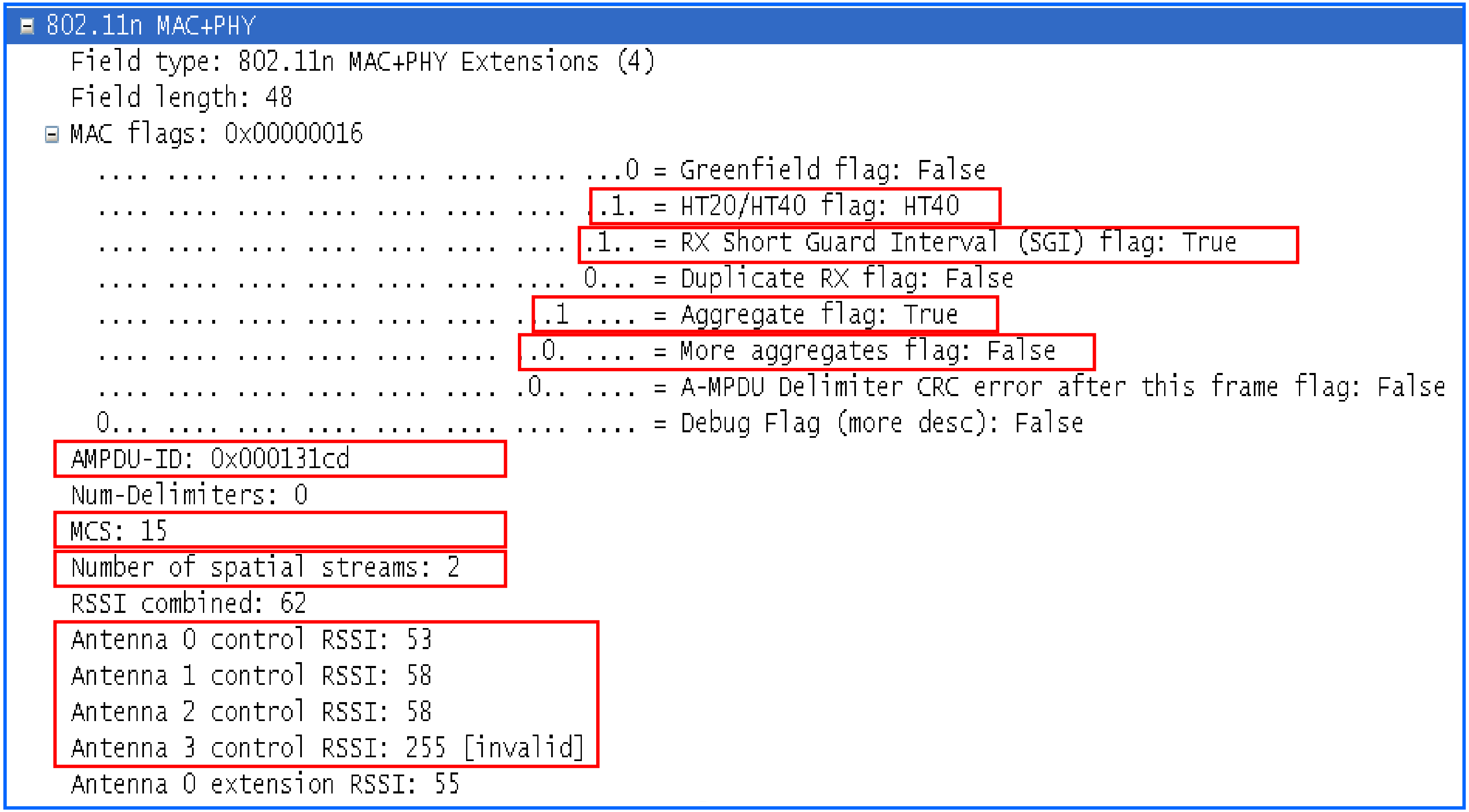
```
⊞ Frame 60 (1620 bytes on wire, 1620 bytes captured)
⊟ PPI version 0, 84 bytes
    Version: 0
  ⊞ Flags: 0x00
    Header length: 84
    DLT: 105
  ⊞ 802.11-Common
  ⊞ 802.11n MAC+PHY
  ⊞ [A-MPDU (9244 bytes w/hdrs): #55(1536), #56(1536), #57(1536), #58(1536), #59(1536), #60(1536)]
⊞ IEEE 802.11 Aggregate MPDU
```

Data-link level type (105=IEEE 802.11 wireless)

Contains data common to both pre-n and 802.11n

Extension field contains radio information specific to 802.11n

Per-Packet Information Header (cont.)



```
⊟ 802.11n MAC+PHY
    Field type: 802.11n MAC+PHY Extensions (4)
    Field length: 48
  ⊟ MAC flags: 0x00000016
      .... .... .... .... .... .... .... ...0 = Greenfield flag: False
      .... .... .... .... .... .... .... ..1. = HT20/HT40 flag: HT40
      .... .... .... .... .... .... .... .1.. = RX Short Guard Interval (SGI) flag: True
      .... .... .... .... .... .... .... 0... = Duplicate RX flag: False
      .... .... .... .... .... .... ...1 .... = Aggregate flag: True
      .... .... .... .... .... .... ..0. .... = More aggregates flag: False
      .... .... .... .... .... .... .0.. .... = A-MPDU Delimiter CRC error after this frame flag: False
      0... .... .... .... .... .... .... .... = Debug Flag (more desc): False
    AMPDU-ID: 0x000131cd
    Num-Delimiters: 0
    MCS: 15
    Number of spatial streams: 2
    RSSI combined: 62
    Antenna 0 control RSSI: 53
    Antenna 1 control RSSI: 58
    Antenna 2 control RSSI: 58
    Antenna 3 control RSSI: 255 [invalid]
    Antenna 0 extension RSSI: 55
```

AirPcap Nx and Wireshark

AirPcap Nx and Wireshark, the perfect combination for:

- Learning about how things are functioning
- Finding out what 802.11n options and capabilities are offered and negotiated in the air
- Verifying vendor specifications (like throughput etc.)
- Investigating compatibility issues between vendors
- Training technical people
- and much more…

Frame Aggregation (config. examples)

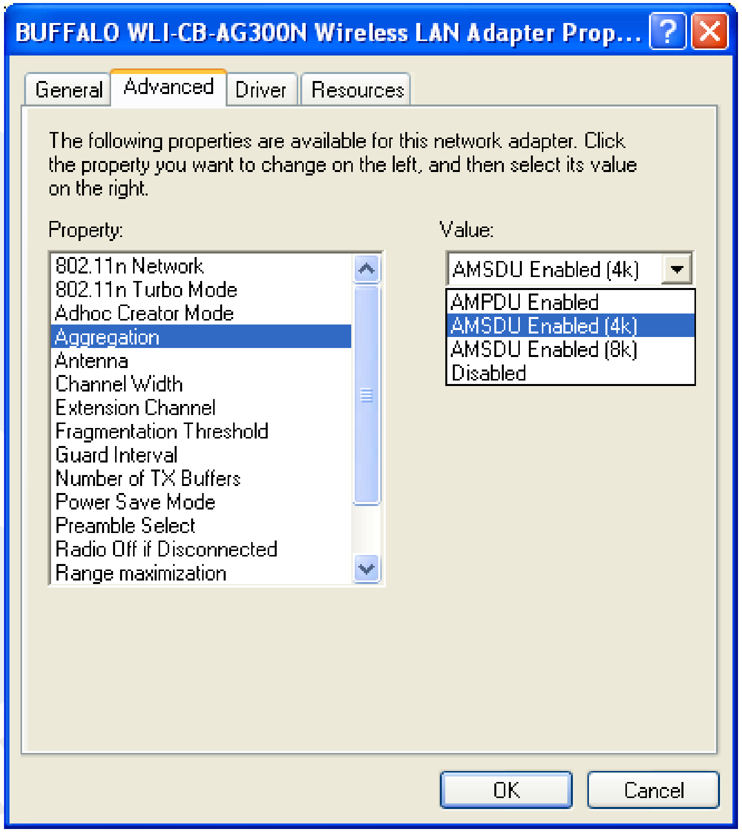
Cisco's 802.11abgn AP1250

By disabling A-MPDU with the 'no' command, the traffic associated with that priority level uses A-MSDU transmission

Command line interface:

```
ap1250(config)#interface dot11Radio 1
ap1250(config-if)#no ampdu transmit priority 0
```

Buffalo's 802.11abgn PC-Card



BUFFALO WLI-CB-AG300N Wireless LAN Adapter Prop...

The following properties are available for this network adapter. Click the property you want to change on the left, and then select its value on the right.

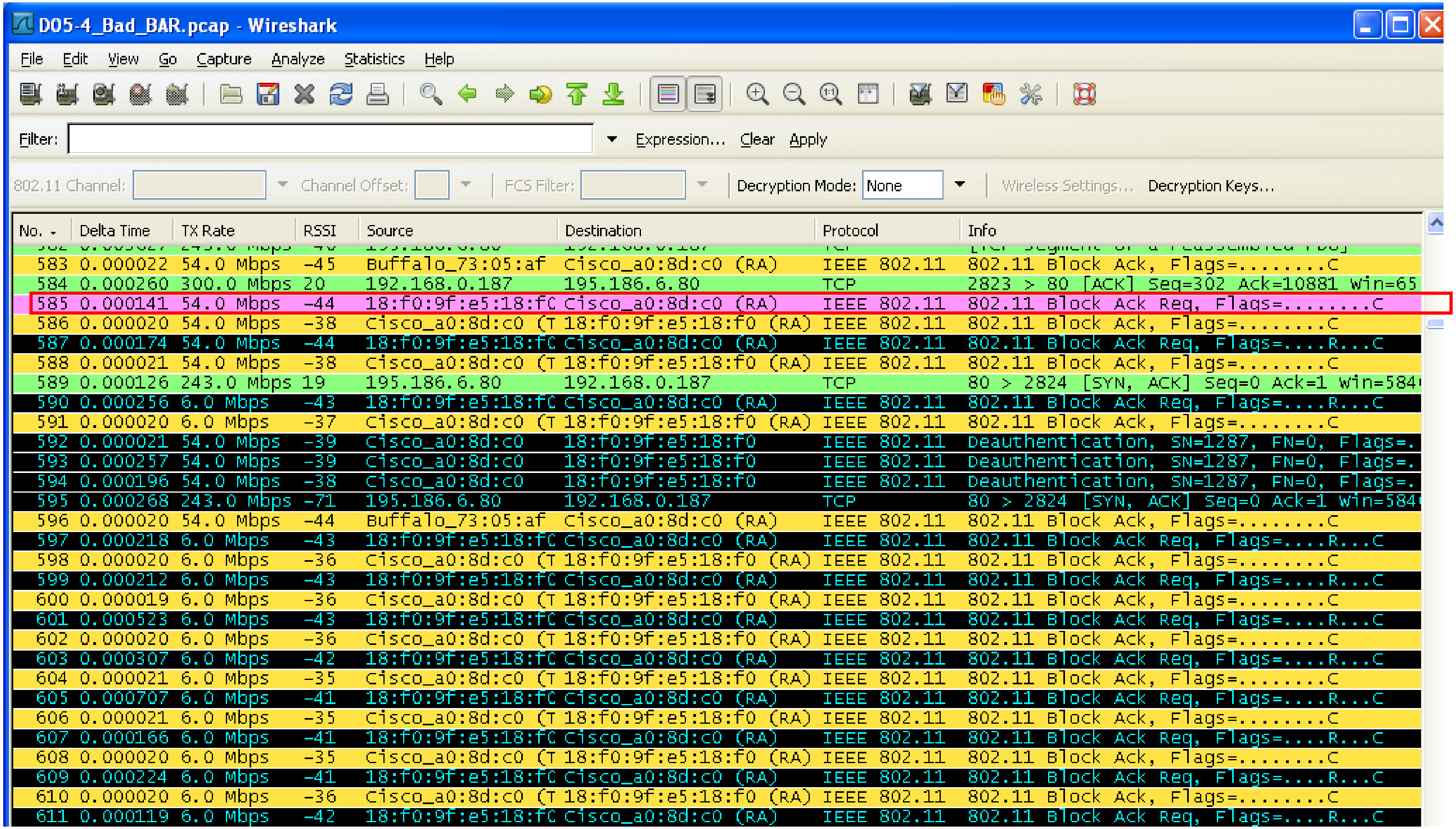
Property:

- 802.11n Network
- 802.11n Turbo Mode
- Adhoc Creator Mode
- Aggregation
- Antenna
- Channel Width
- Extension Channel
- Fragmentation Threshold
- Guard Interval
- Number of TX Buffers
- Power Save Mode
- Preamble Select
- Radio Off if Disconnected
- Range maximization

Value: AMSDU Enabled (4k)

- AMPDU Enabled
- AMSDU Enabled (4k)
- AMSDU Enabled (8k)
- Disabled

Analyzing ‘Bad BAR’ problem

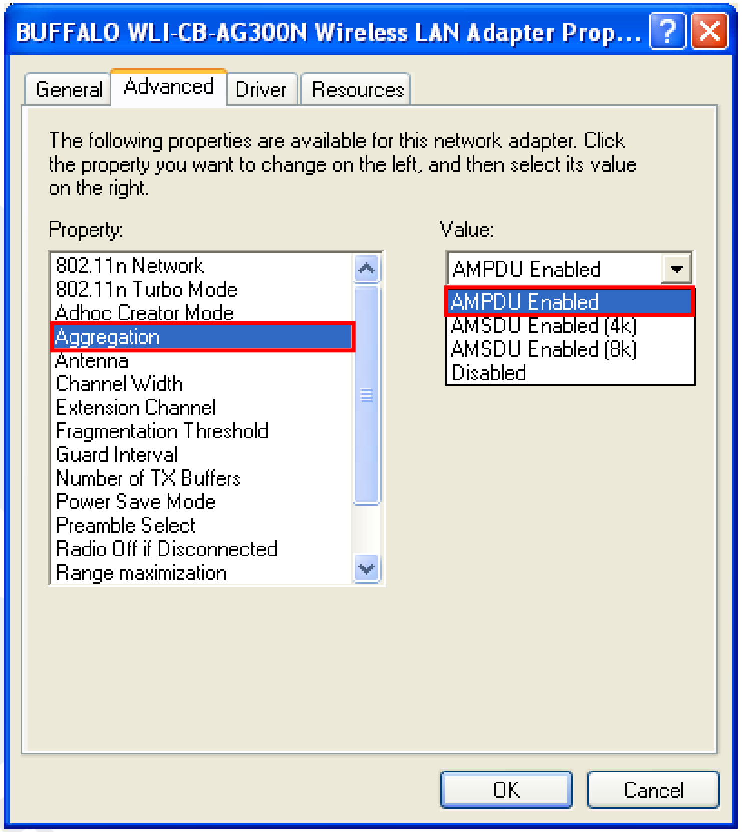


Decryption Mode: None

```
No. - Delta Time TX Rate     RSSI Source            Destination              Protocol     Info
583 0.000022 54.0 Mbps  -45  Buffalo_73:05:af  Cisco_a0:8d:c0 (RA)      IEEE 802.11  802.11 Block Ack, Flags=........C
584 0.000260 300.0 Mbps 20   192.168.0.187     195.186.6.80             TCP          2823 > 80 [ACK] Seq=302 Ack=10881 Win=65
585 0.000141 54.0 Mbps  -44  18:f0:9f:e5:18:fC Cisco_a0:8d:c0 (RA)      IEEE 802.11  802.11 Block Ack Req, Flags=........C
586 0.000020 54.0 Mbps  -38  Cisco_a0:8d:c0 (T 18:f0:9f:e5:18:f0 (RA)  IEEE 802.11  802.11 Block Ack, Flags=........C
587 0.000174 54.0 Mbps  -44  18:f0:9f:e5:18:fC Cisco_a0:8d:c0 (RA)      IEEE 802.11  802.11 Block Ack Req, Flags=....R...C
588 0.000021 54.0 Mbps  -38  Cisco_a0:8d:c0 (T 18:f0:9f:e5:18:f0 (RA)  IEEE 802.11  802.11 Block Ack, Flags=........C
589 0.000126 243.0 Mbps 19   195.186.6.80      192.168.0.187            TCP          80 > 2824 [SYN, ACK] Seq=0 Ack=1 Win=584
590 0.000256 6.0 Mbps   -43  18:f0:9f:e5:18:fC Cisco_a0:8d:c0 (RA)      IEEE 802.11  802.11 Block Ack Req, Flags=....R...C
591 0.000020 6.0 Mbps   -37  Cisco_a0:8d:c0 (T 18:f0:9f:e5:18:f0 (RA)  IEEE 802.11  802.11 Block Ack, Flags=........C
592 0.000021 54.0 Mbps  -39  Cisco_a0:8d:c0    18:f0:9f:e5:18:f0        IEEE 802.11  Deauthentication, SN=1287, FN=0, Flags=.
593 0.000257 54.0 Mbps  -39  Cisco_a0:8d:c0    18:f0:9f:e5:18:f0        IEEE 802.11  Deauthentication, SN=1287, FN=0, Flags=.
594 0.000196 54.0 Mbps  -38  Cisco_a0:8d:c0    18:f0:9f:e5:18:f0        IEEE 802.11  Deauthentication, SN=1287, FN=0, Flags=.
595 0.000268 243.0 Mbps -71  195.186.6.80      192.168.0.187            TCP          80 > 2824 [SYN, ACK] Seq=0 Ack=1 Win=584
596 0.000020 54.0 Mbps  -44  Buffalo_73:05:af  Cisco_a0:8d:c0 (RA)      IEEE 802.11  802.11 Block Ack, Flags=........C
597 0.000218 6.0 Mbps   -43  18:f0:9f:e5:18:fC Cisco_a0:8d:c0 (RA)      IEEE 802.11  802.11 Block Ack Req, Flags=....R...C
598 0.000020 6.0 Mbps   -36  Cisco_a0:8d:c0 (T 18:f0:9f:e5:18:f0 (RA)  IEEE 802.11  802.11 Block Ack, Flags=........C
599 0.000212 6.0 Mbps   -43  18:f0:9f:e5:18:fC Cisco_a0:8d:c0 (RA)      IEEE 802.11  802.11 Block Ack Req, Flags=....R...C
600 0.000019 6.0 Mbps   -36  Cisco_a0:8d:c0 (T 18:f0:9f:e5:18:f0 (RA)  IEEE 802.11  802.11 Block Ack, Flags=........C
601 0.000523 6.0 Mbps   -43  18:f0:9f:e5:18:fC Cisco_a0:8d:c0 (RA)      IEEE 802.11  802.11 Block Ack Req, Flags=....R...C
602 0.000020 6.0 Mbps   -36  Cisco_a0:8d:c0 (T 18:f0:9f:e5:18:f0 (RA)  IEEE 802.11  802.11 Block Ack, Flags=........C
603 0.000307 6.0 Mbps   -42  18:f0:9f:e5:18:fC Cisco_a0:8d:c0 (RA)      IEEE 802.11  802.11 Block Ack Req, Flags=....R...C
604 0.000021 6.0 Mbps   -35  Cisco_a0:8d:c0 (T 18:f0:9f:e5:18:f0 (RA)  IEEE 802.11  802.11 Block Ack, Flags=........C
605 0.000707 6.0 Mbps   -41  18:f0:9f:e5:18:fC Cisco_a0:8d:c0 (RA)      IEEE 802.11  802.11 Block Ack Req, Flags=....R...C
606 0.000021 6.0 Mbps   -35  Cisco_a0:8d:c0 (T 18:f0:9f:e5:18:f0 (RA)  IEEE 802.11  802.11 Block Ack, Flags=........C
607 0.000166 6.0 Mbps   -41  18:f0:9f:e5:18:fC Cisco_a0:8d:c0 (RA)      IEEE 802.11  802.11 Block Ack Req, Flags=....R...C
608 0.000020 6.0 Mbps   -35  Cisco_a0:8d:c0 (T 18:f0:9f:e5:18:f0 (RA)  IEEE 802.11  802.11 Block Ack, Flags=........C
609 0.000224 6.0 Mbps   -41  18:f0:9f:e5:18:fC Cisco_a0:8d:c0 (RA)      IEEE 802.11  802.11 Block Ack Req, Flags=....R...C
610 0.000020 6.0 Mbps   -36  Cisco_a0:8d:c0 (T 18:f0:9f:e5:18:f0 (RA)  IEEE 802.11  802.11 Block Ack, Flags=........C
611 0.000119 6.0 Mbps   -42  18:f0:9f:e5:18:fC Cisco_a0:8d:c0 (RA)      IEEE 802.11  802.11 Block Ack Req, Flags=....R...C
```

Analyzing 'Bad BAR' problem (cont.)

- Buffalo WLI-CB-AG300N is using strange SRC MAC address when sending BAR
- Problem occurs only when A-MPDU is activated
- Problem seems to be related to retransmissions
- Possibly a driver issue as A-MPDU is done in soft-ware
- A-MSDU works fine



BUFFALO WLI-CB-AG300N Wireless LAN Adapter Prop...

The following properties are available for this network adapter. Click the property you want to change on the left, and then select its value on the right.

Property:

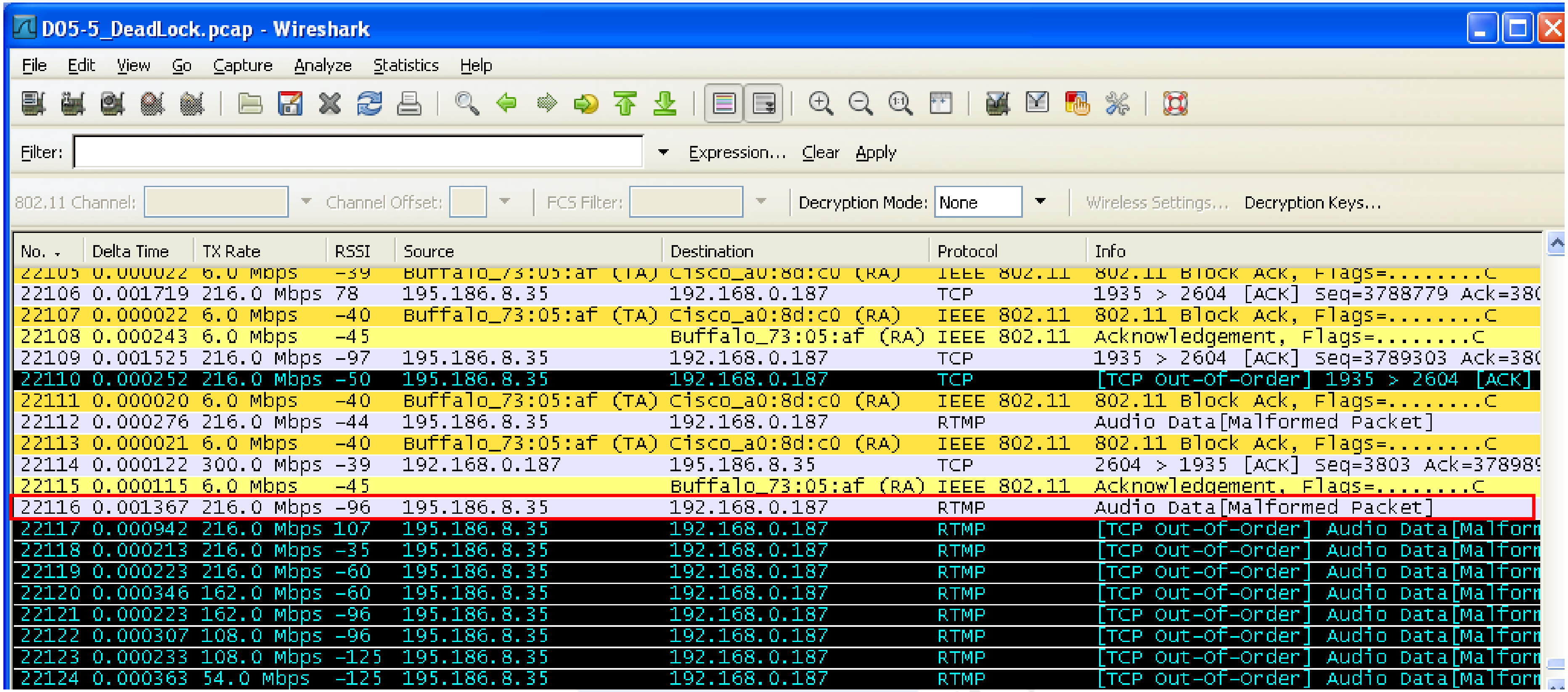
802.11n Network
802.11n Turbo Mode
Adhoc Creator Mode
Aggregation
Antenna
Channel Width
Extension Channel
Fragmentation Threshold
Guard Interval
Number of TX Buffers
Power Save Mode
Preamble Select
Radio Off if Disconnected
Range maximization

Value:

AMPDU Enabled

AMPDU Enabled
AMSDU Enabled (4k)
AMSDU Enabled (8k)
Disabled

Analyzing ‘Deadlock’ problem


D05-5_DeadLock.pcap - Wireshark
File Edit View Go Capture Analyze Statistics Help
Expression... Clear Apply
802.11 Channel:
Channel Offset:
FCS Filter:
Wireless Settings...
Decryption Keys...

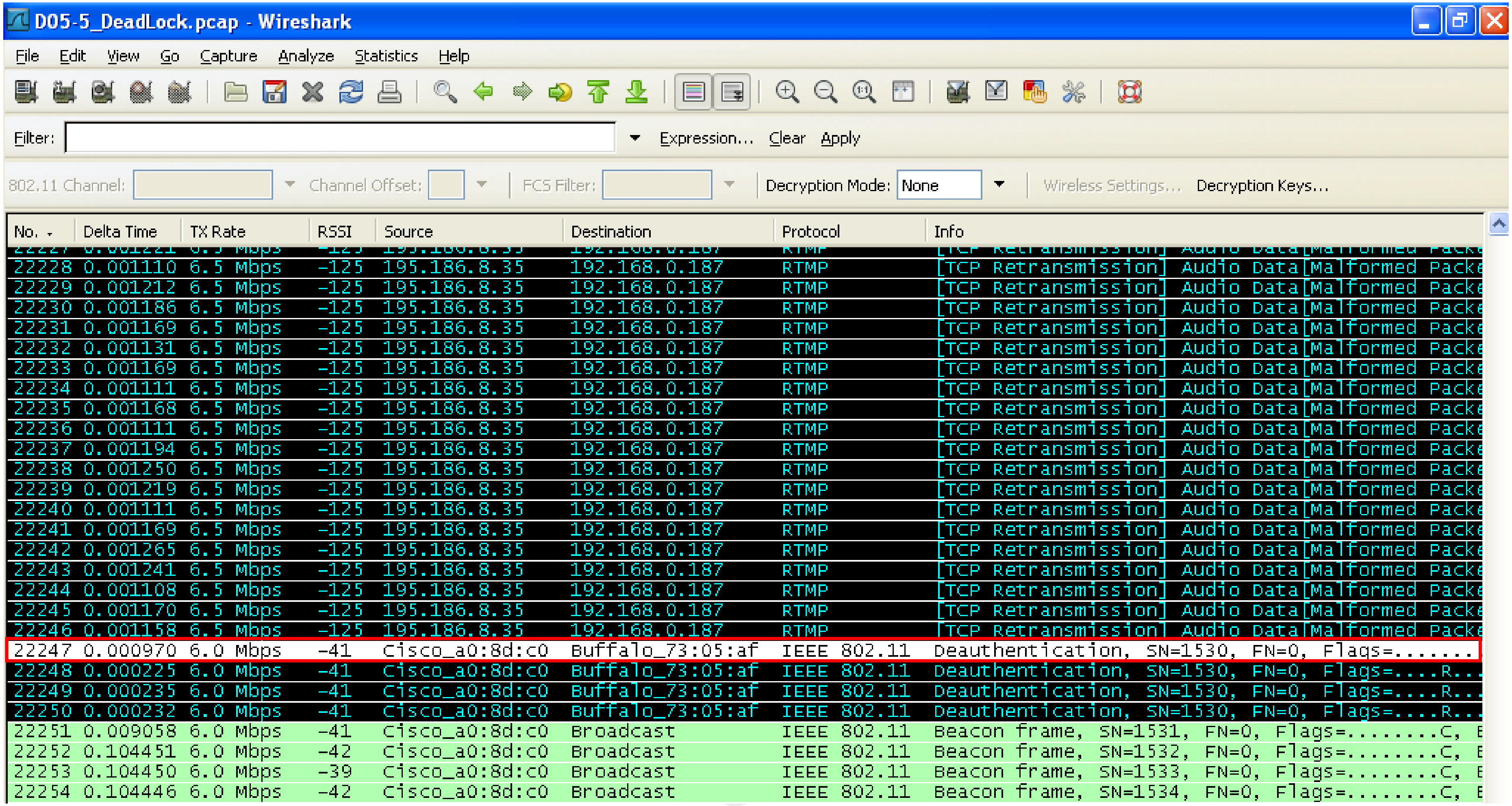
Filter:

Decryption Mode: None

No.	Delta Time	TX Rate	RSSI	Source	Destination	Protocol	Info
22105	0.000022	6.0 Mbps	-39	Buffalo_73:05:af (TA)	Cisco_a0:8d:c0 (RA)	IEEE 802.11	802.11 Block Ack, Flags=........C
22106	0.001719	216.0 Mbps	78	195.186.8.35	192.168.0.187	TCP	1935 > 2604 [ACK] Seq=3788779 Ack=380
22107	0.000022	6.0 Mbps	-40	Buffalo_73:05:af (TA)	Cisco_a0:8d:c0 (RA)	IEEE 802.11	802.11 Block Ack, Flags=........C
22108	0.000243	6.0 Mbps	-45		Buffalo_73:05:af (RA)	IEEE 802.11	Acknowledgement, Flags=........C
22109	0.001525	216.0 Mbps	-97	195.186.8.35	192.168.0.187	TCP	1935 > 2604 [ACK] Seq=3789303 Ack=380
22110	0.000252	216.0 Mbps	-50	195.186.8.35	192.168.0.187	TCP	[TCP Out-Of-Order] 1935 > 2604 [ACK]
22111	0.000020	6.0 Mbps	-40	Buffalo_73:05:af (TA)	Cisco_a0:8d:c0 (RA)	IEEE 802.11	802.11 Block Ack, Flags=........C
22112	0.000276	216.0 Mbps	-44	195.186.8.35	192.168.0.187	RTMP	Audio Data[Malformed Packet]
22113	0.000021	6.0 Mbps	-40	Buffalo_73:05:af (TA)	Cisco_a0:8d:c0 (RA)	IEEE 802.11	802.11 Block Ack, Flags=........C
22114	0.000122	300.0 Mbps	-39	192.168.0.187	195.186.8.35	TCP	2604 > 1935 [ACK] Seq=3803 Ack=378989
22115	0.000115	6.0 Mbps	-45		Buffalo_73:05:af (RA)	IEEE 802.11	Acknowledgement, Flags=........C
22116	0.001367	216.0 Mbps	-96	195.186.8.35	192.168.0.187	RTMP	Audio Data[Malformed Packet]
22117	0.000942	216.0 Mbps	107	195.186.8.35	192.168.0.187	RTMP	[TCP Out-Of-Order] Audio Data[Malforn
22118	0.000213	216.0 Mbps	-35	195.186.8.35	192.168.0.187	RTMP	[TCP Out-Of-Order] Audio Data[Malforn
22119	0.000223	216.0 Mbps	-60	195.186.8.35	192.168.0.187	RTMP	[TCP Out-Of-Order] Audio Data[Malforn
22120	0.000346	162.0 Mbps	-60	195.186.8.35	192.168.0.187	RTMP	[TCP Out-Of-Order] Audio Data[Malforn
22121	0.000223	162.0 Mbps	-96	195.186.8.35	192.168.0.187	RTMP	[TCP Out-Of-Order] Audio Data[Malforn
22122	0.000307	108.0 Mbps	-96	195.186.8.35	192.168.0.187	RTMP	[TCP Out-Of-Order] Audio Data[Malforn
22123	0.000233	108.0 Mbps	-125	195.186.8.35	192.168.0.187	RTMP	[TCP Out-Of-Order] Audio Data[Malforn
22124	0.000363	54.0 Mbps	-125	195.186.8.35	192.168.0.187	RTMP	[TCP Out-Of-Order] Audio Data[Malforn

Problem starts at frame # 22116 which is not acknowledged by receiver

Analyzing ‘Deadlock’ problem (cont.)

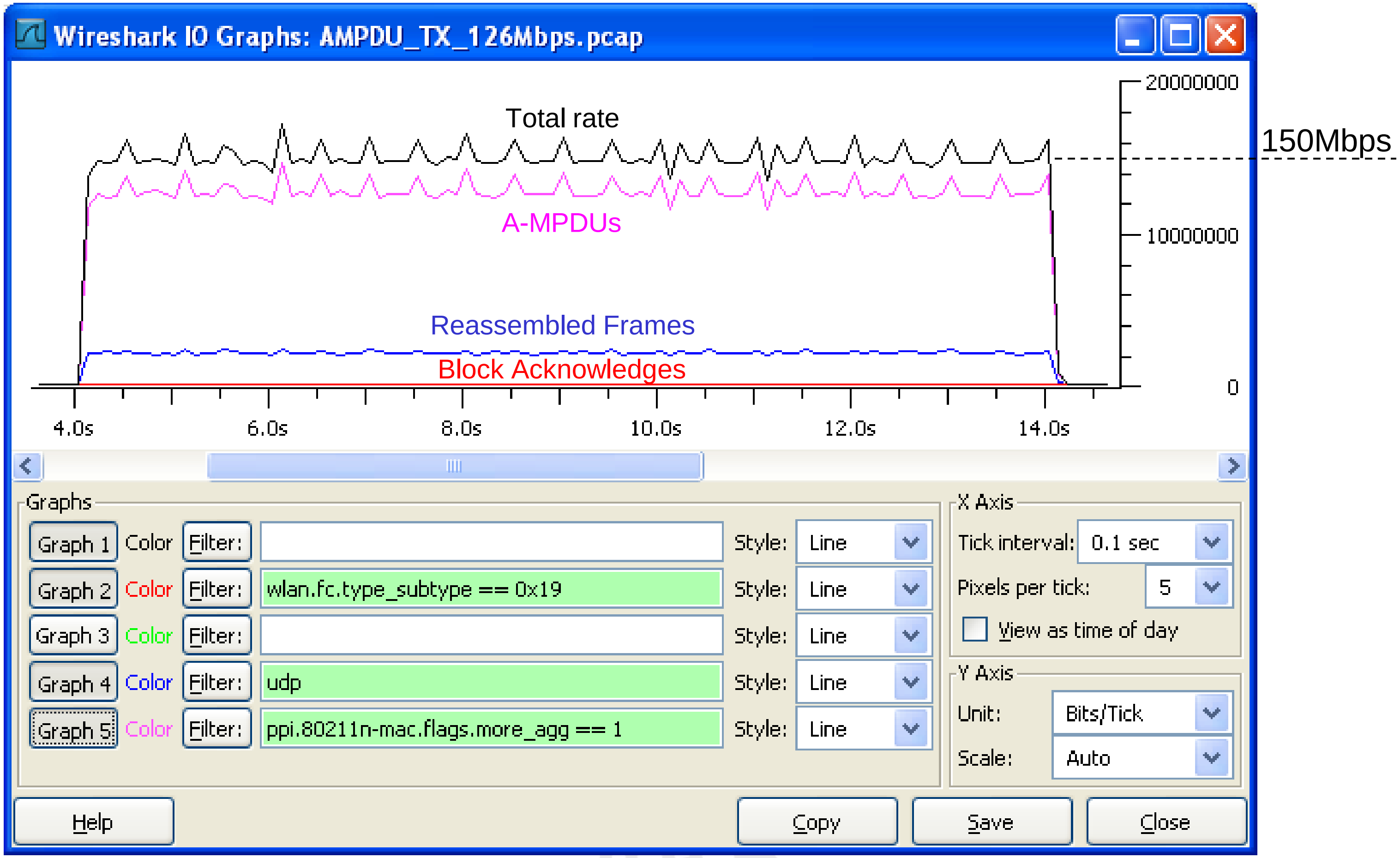


No.	Delta Time	TX Rate	RSSI	Source	Destination	Protocol	Info
22227	0.001221	6.5 Mbps	-125	195.186.8.35	192.168.0.187	RTMP	[TCP Retransmission] Audio Data[Malformed Packe
22228	0.001110	6.5 Mbps	-125	195.186.8.35	192.168.0.187	RTMP	[TCP Retransmission] Audio Data[Malformed Packe
22229	0.001212	6.5 Mbps	-125	195.186.8.35	192.168.0.187	RTMP	[TCP Retransmission] Audio Data[Malformed Packe
22230	0.001186	6.5 Mbps	-125	195.186.8.35	192.168.0.187	RTMP	[TCP Retransmission] Audio Data[Malformed Packe
22231	0.001169	6.5 Mbps	-125	195.186.8.35	192.168.0.187	RTMP	[TCP Retransmission] Audio Data[Malformed Packe
22232	0.001131	6.5 Mbps	-125	195.186.8.35	192.168.0.187	RTMP	[TCP Retransmission] Audio Data[Malformed Packe
22233	0.001169	6.5 Mbps	-125	195.186.8.35	192.168.0.187	RTMP	[TCP Retransmission] Audio Data[Malformed Packe
22234	0.001111	6.5 Mbps	-125	195.186.8.35	192.168.0.187	RTMP	[TCP Retransmission] Audio Data[Malformed Packe
22235	0.001168	6.5 Mbps	-125	195.186.8.35	192.168.0.187	RTMP	[TCP Retransmission] Audio Data[Malformed Packe
22236	0.001111	6.5 Mbps	-125	195.186.8.35	192.168.0.187	RTMP	[TCP Retransmission] Audio Data[Malformed Packe
22237	0.001194	6.5 Mbps	-125	195.186.8.35	192.168.0.187	RTMP	[TCP Retransmission] Audio Data[Malformed Packe
22238	0.001250	6.5 Mbps	-125	195.186.8.35	192.168.0.187	RTMP	[TCP Retransmission] Audio Data[Malformed Packe
22239	0.001219	6.5 Mbps	-125	195.186.8.35	192.168.0.187	RTMP	[TCP Retransmission] Audio Data[Malformed Packe
22240	0.001111	6.5 Mbps	-125	195.186.8.35	192.168.0.187	RTMP	[TCP Retransmission] Audio Data[Malformed Packe
22241	0.001169	6.5 Mbps	-125	195.186.8.35	192.168.0.187	RTMP	[TCP Retransmission] Audio Data[Malformed Packe
22242	0.001265	6.5 Mbps	-125	195.186.8.35	192.168.0.187	RTMP	[TCP Retransmission] Audio Data[Malformed Packe
22243	0.001241	6.5 Mbps	-125	195.186.8.35	192.168.0.187	RTMP	[TCP Retransmission] Audio Data[Malformed Packe
22244	0.001108	6.5 Mbps	-125	195.186.8.35	192.168.0.187	RTMP	[TCP Retransmission] Audio Data[Malformed Packe
22245	0.001170	6.5 Mbps	-125	195.186.8.35	192.168.0.187	RTMP	[TCP Retransmission] Audio Data[Malformed Packe
22246	0.001158	6.5 Mbps	-125	195.186.8.35	192.168.0.187	RTMP	[TCP Retransmission] Audio Data[Malformed Packe
22247	0.000970	6.0 Mbps	-41	Cisco_a0:8d:c0	Buffalo_73:05:af	IEEE 802.11	Deauthentication, SN=1530, FN=0, Flags=........
22248	0.000225	6.0 Mbps	-41	Cisco_a0:8d:c0	Buffalo_73:05:af	IEEE 802.11	Deauthentication, SN=1530, FN=0, Flags=....R...
22249	0.000235	6.0 Mbps	-41	Cisco_a0:8d:c0	Buffalo_73:05:af	IEEE 802.11	Deauthentication, SN=1530, FN=0, Flags=....R...
22250	0.000232	6.0 Mbps	-41	Cisco_a0:8d:c0	Buffalo_73:05:af	IEEE 802.11	Deauthentication, SN=1530, FN=0, Flags=....R...
22251	0.009058	6.0 Mbps	-41	Cisco_a0:8d:c0	Broadcast	IEEE 802.11	Beacon frame, SN=1531, FN=0, Flags=........C, B
22252	0.104451	6.0 Mbps	-42	Cisco_a0:8d:c0	Broadcast	IEEE 802.11	Beacon frame, SN=1532, FN=0, Flags=........C, B
22253	0.104450	6.0 Mbps	-39	Cisco_a0:8d:c0	Broadcast	IEEE 802.11	Beacon frame, SN=1533, FN=0, Flags=........C, B
22254	0.104446	6.0 Mbps	-42	Cisco_a0:8d:c0	Broadcast	IEEE 802.11	Beacon frame, SN=1534, FN=0, Flags=........C, B

Analyzing ‘Deadlock’ problem (cont.)

- Access point retransmits frame 128 times up to frame # 22246 (value of Max. Data Retries counter)
- As the mobile station does not acknowledge, access point sends ‘Deauthentication’ in frame # 22247 and removes station from association list
- As mobile station does not acknowledge again, access point retransmits in frames # 22248 to 22250
- Mobile station does not acknowledge, assumes to be still associated with access point and keeps sending frames (# 22298, 22315 etc.) → Deadlock situation

Bandwidth Measurement



Graphs

Graph 1	Color	Filter:		Style:	Line
Graph 2	Color	Filter:	wlan.fc.type_subtype == 0x19	Style:	Line
Graph 3	Color	Filter:		Style:	Line
Graph 4	Color	Filter:	udp	Style:	Line
Graph 5	Color	Filter:	ppi.80211n-mac.flags.more_agg == 1	Style:	Line

X Axis

Tick interval: 0.1 sec

Pixels per tick: 5

□ View as time of day

Y Axis

Unit: Bits/Tick

Scale: Auto

UDP bandwidth measurement with **IPerf** indicates throughput of 126Mbps

Backwards compatibility to a/b/g

Mbps	Coding	Modulation	Description	
1 2	Barker Barker	DBPSK	**802.11** **DSSS (Clause 15)** with ‚Long Preamble‘	
5.5 11	CCK CCK	DQPSK	**802.11b** **HR/DSSS (Clause 18)** with ‚Short Preamble‘	
6, 9 12, 18 24, 36 48, 54	OFDM OFDM OFDM OFDM	BPSK QPSK 16-QAM 64-QAM	**802.11g** **Extended Rate PHY** **(ERP)**	**802.11a**
7.2-72.2 14.4-144.4	OFDM OFDM	MCS 0-7 MCS 8-15	1 Stream 2 Streams **802.11n** **High Troughput (HT)** **Extensions**	

2.4 GHz

5 GHz

CCK = Complementary Code Keying
DBPSK = Differential Binary Phase-Shift Keying
DQPSK = Differential Quadrature Phase-Shift Keying
OFDM = Orthogonal Frequency Division Multiplexing

BPSK = Binary Phase-Shift Keying
QPSK = Quadrature Phase-Shift Keying
QAM = Quadrature Amplitude Modul.
MCS = Modulation Coding Scheme

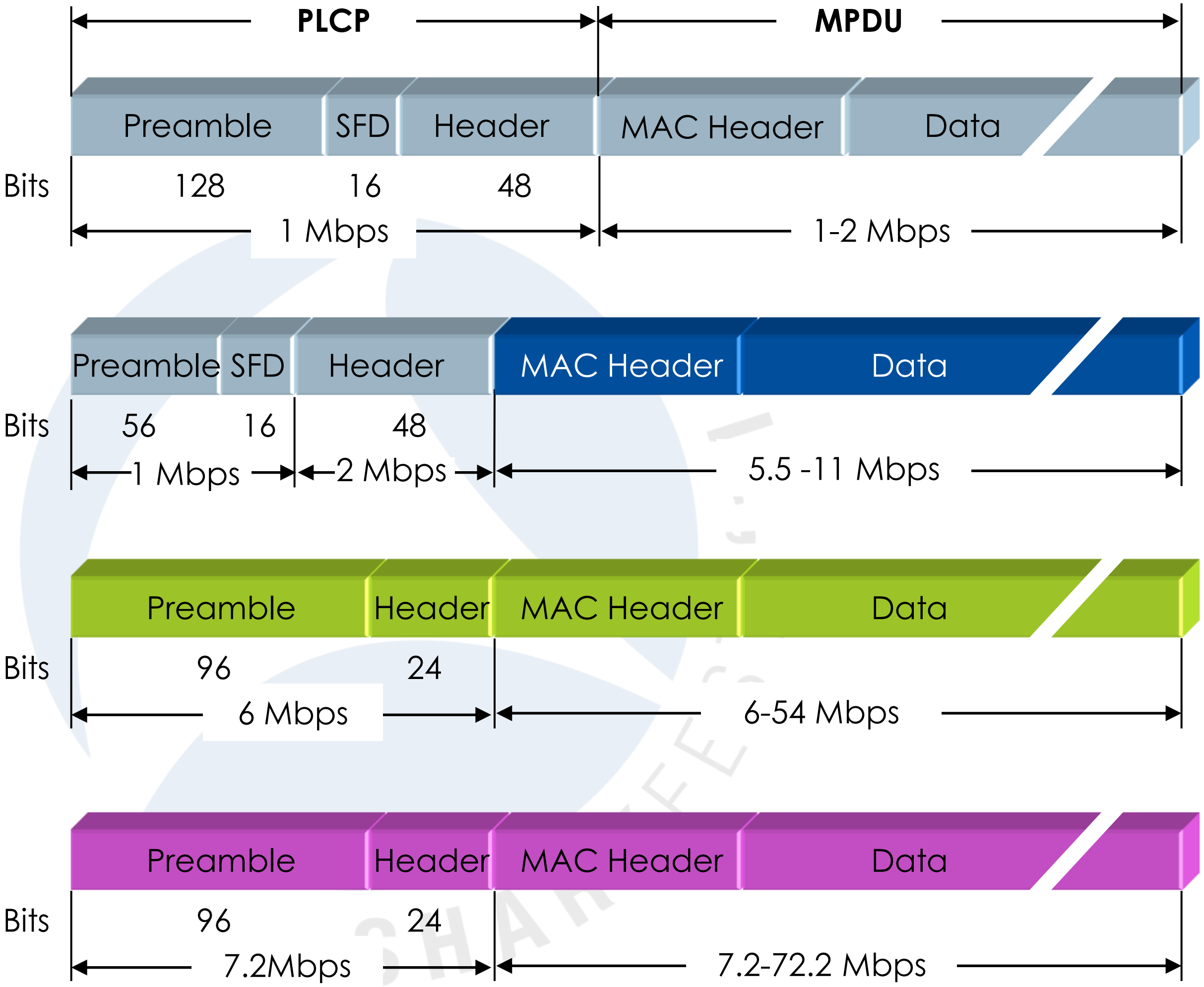
Backwards compatibility to a/b/g (cont.)

802.11 DSSS with
‚Long Preamble‘
Barker Code

802.11b HR/DSSS with
‚Short Preamble‘
Barker / **CCK**

802.11g (ERP)
Extended Rate PHY
OFDM

802.11n (HT)
High Throughput
extended OFDM

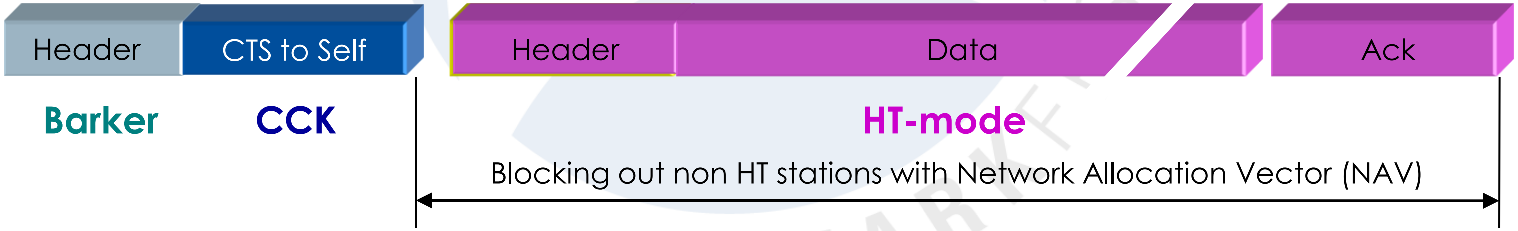


PLCP = Physical Layer Convergence Protocol
MPDU = MAC Layer Protocol Data Unit (decodiert by Wireshark)

Backwards compatibility to a/b/g (cont.)

- 802.11n supports three compatibility modes
  - Legacy mode
  - Mixed mode
  - Greenfield mode
- Legacy mode

802.11n to b/g compatibility with Clear-to-send to self

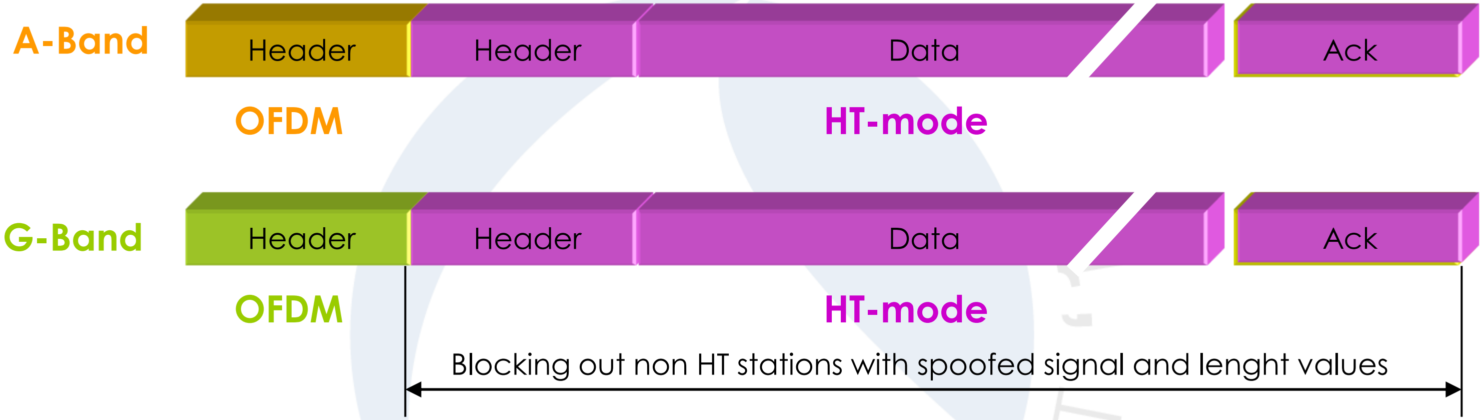


Header
CTS to Self
Header
Data
Ack
Barker
CCK
HT-mode
Blocking out non HT stations with Network Allocation Vector (NAV)

Backwards compatibility to a/b/g (cont.)

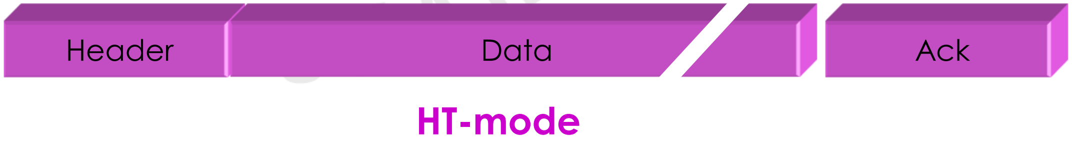
Mixed mode

802.11n to a/g compatibility with Legacy header



Greenfield mode

No backwards compatibility to a/b/g



Future of 802.11n

- Standard has been ratified September 2009 after years of discussions. (IEEE 802.11n-2009)
- Standard is based on 802.11n Draft 2 specifications with two streams, all other functions are optional.
- Interoperability remains a question mark for pre-N products
- New products supporting technical features like:
  - Up to four spatial streams
  - Transmit Beamforming
  - Direct Link Setup … and many more

Thanks for visiting

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