

WLAN 802.11n MIMO Analysis

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Trace files and coloring rules can be copied from circulating memory stick

Session Agenda

- 🦈 Design Goals for 802.11n
- 🦈 IEEE 802.11n physical layer improvements
- 🦈 IEEE 802.11n MAC layer improvements
- 🦈 Per-Packet Information Header
- 🦈 Analysing '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**

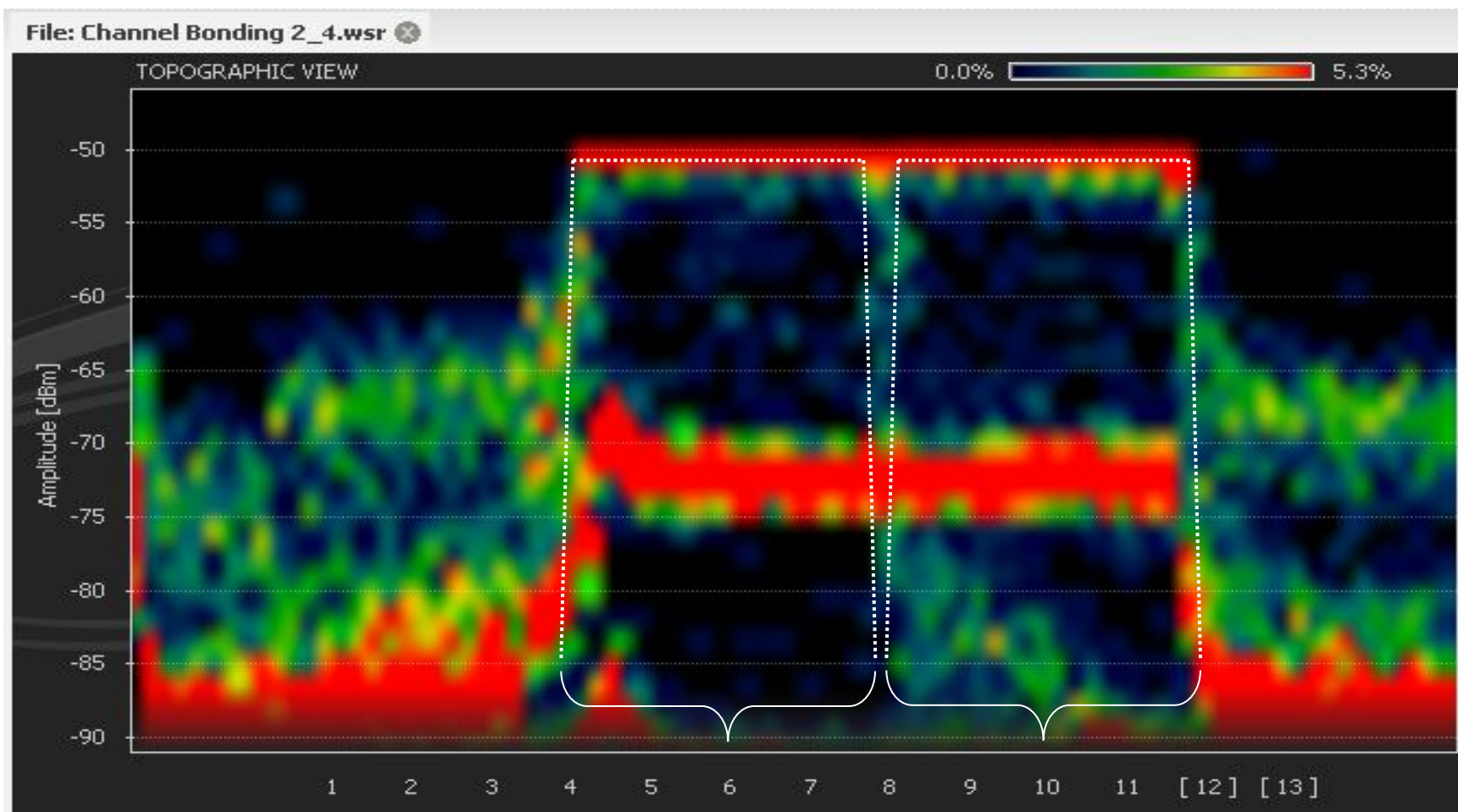
Channel Bonding

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

Spatial multiplexing

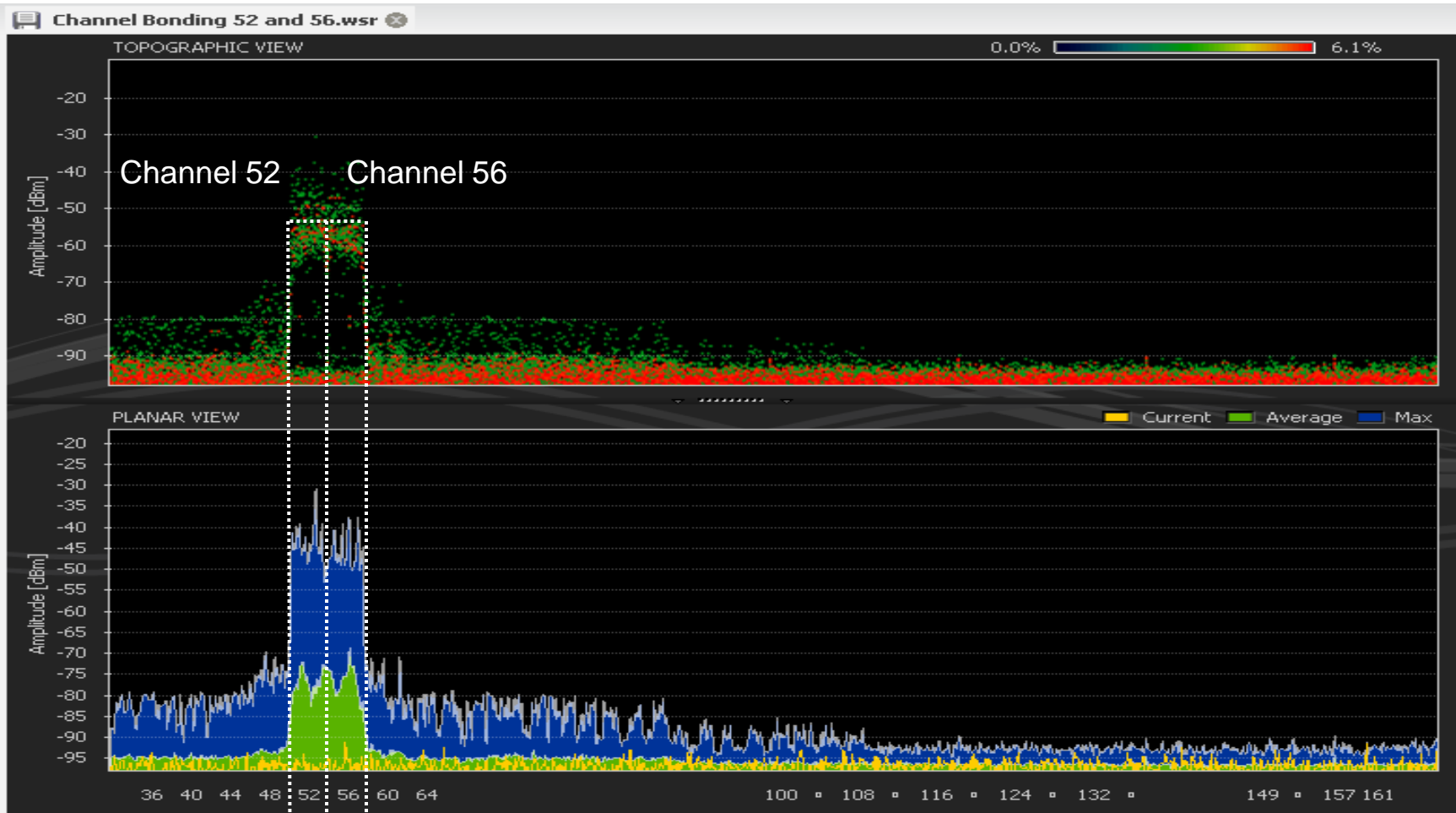
- 🦈 Support of up to four spatial streams (MIMO) increases throughput up to 4 times **150 to 600 Mbps**

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
Middle Band UNII-2	48	5.240	5.240	--
	52	5.260*	5.260	5.260
	56	5.280*	5.280	5.280
	60	5.300*	5.300	5.300
High Band UNII-2 extended	64	5.320*	5.320	5.320
	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
Upper Band UNII-3/ISM	136	5.680*	5.680	5.680
	140	5.700*	5.700	5.700
	149	5.745	--	--
	153	5.765	--	--
ISM	157	5.785	--	--
	161	5.805	--	--
	165	5.825	--	--

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

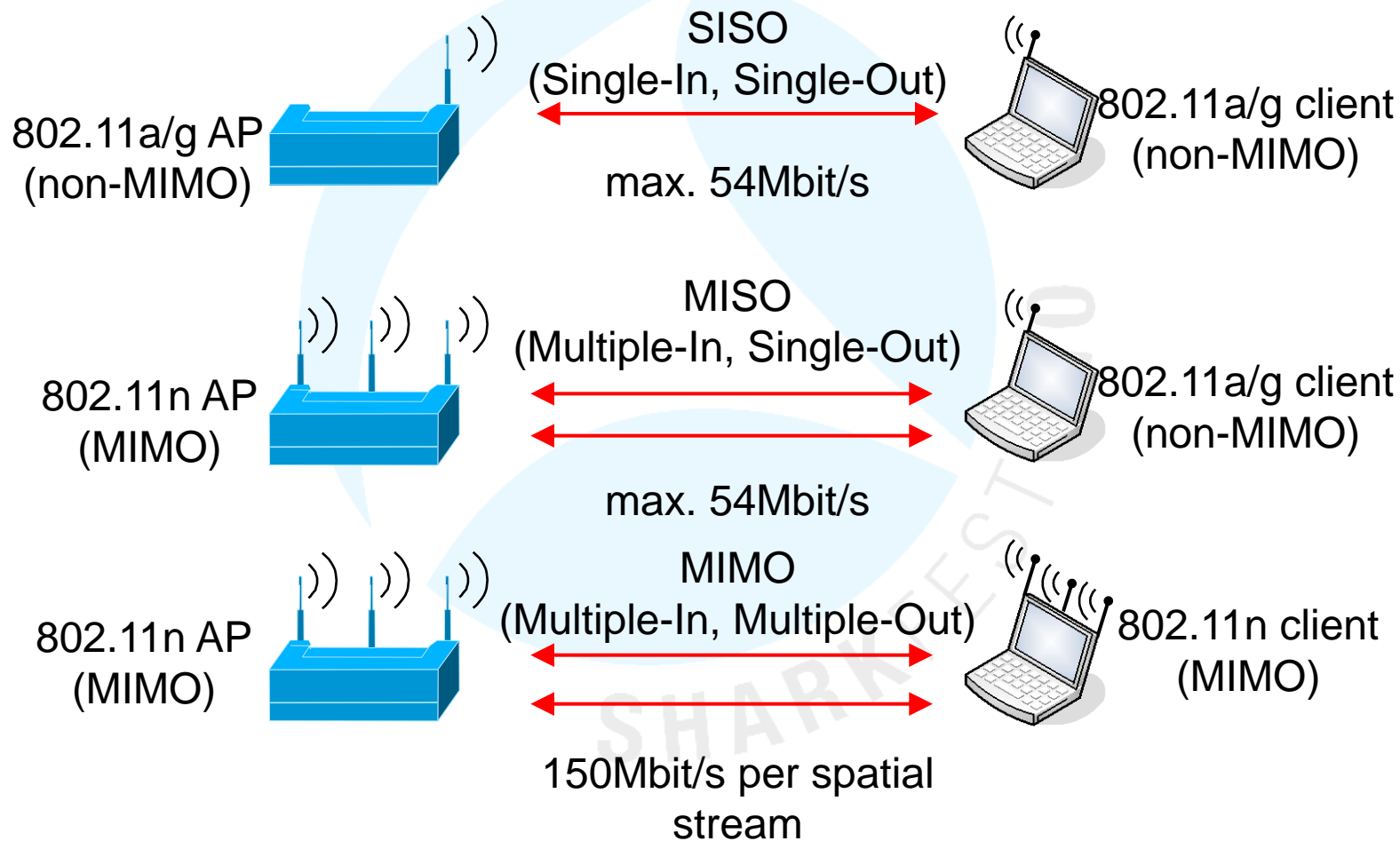
Transmit Power Control (TPC) required for	
FCC (USA and Canada)	Band 2,2e
ETSI (Europe)	Band 1,2,2e
MKK (Japan)	Band 1,2,2e

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

Some channels only allowed for inhouse use

*New stricter FCC DFS2 rules valid off July 20, 2007

Multi-Streaming Modulation



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	<input checked="" type="radio"/> Require	<input type="radio"/> Enable	<input type="radio"/> Disable
9.0Mb/sec	<input checked="" type="radio"/> Require	<input type="radio"/> Enable	<input type="radio"/> Disable
12.0Mb/sec	<input checked="" type="radio"/> Require	<input type="radio"/> Enable	<input type="radio"/> Disable
18.0Mb/sec	<input checked="" type="radio"/> Require	<input type="radio"/> Enable	<input type="radio"/> Disable
24.0Mb/sec	<input checked="" type="radio"/> Require	<input type="radio"/> Enable	<input type="radio"/> Disable
36.0Mb/sec	<input checked="" type="radio"/> Require	<input type="radio"/> Enable	<input type="radio"/> Disable
48.0Mb/sec	<input checked="" type="radio"/> Require	<input type="radio"/> Enable	<input type="radio"/> Disable
54.0Mb/sec	<input checked="" type="radio"/> Require	<input type="radio"/> Enable	<input type="radio"/> Disable

MCS Rates:

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Enable	<input checked="" type="radio"/>	<input checked="" type="radio"/>	<input checked="" type="radio"/>	<input checked="" type="radio"/>	<input checked="" type="radio"/>	<input checked="" type="radio"/>	<input checked="" type="radio"/>	<input checked="" type="radio"/>	<input checked="" type="radio"/>	<input checked="" type="radio"/>	<input checked="" type="radio"/>	<input checked="" type="radio"/>	<input checked="" type="radio"/>	<input checked="" type="radio"/>	<input checked="" type="radio"/>	<input checked="" type="radio"/>
Disable	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>



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

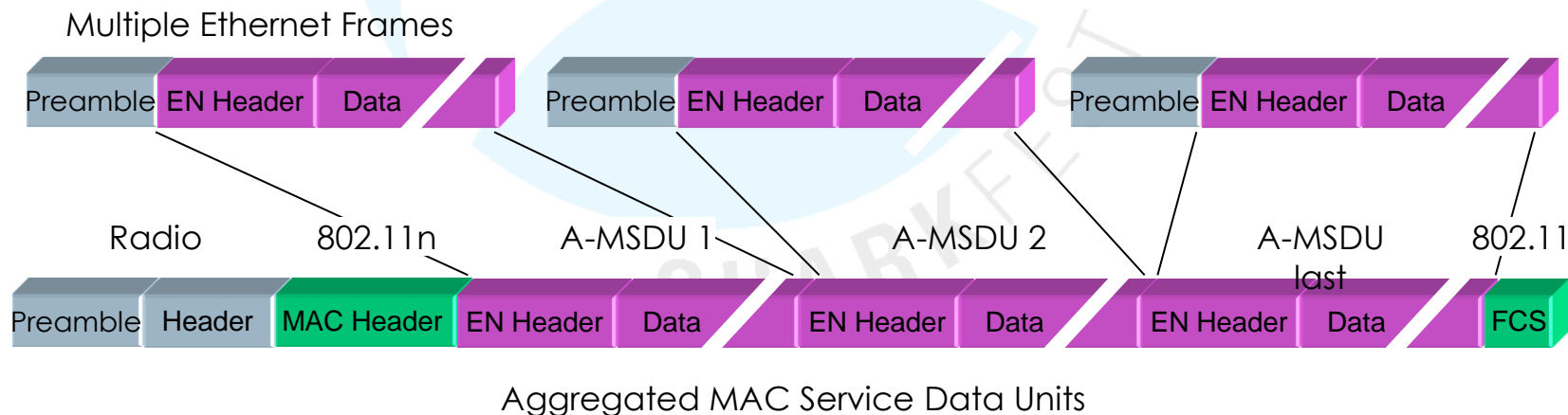
- 🦈 Aggregate-MAC Service Data Unit (A-MSDU) wraps multiple Ethernet frames in a .11n frame up to 8KB
- 🦈 Aggregate-MAC Protocol Data Unit (A-MPDU) allows bursting 802.11 frames up to 64KB
- 🦈 A-MPDU is performed in the software whereas A-MSDU is performed in the hardware

Block Acknowledgement

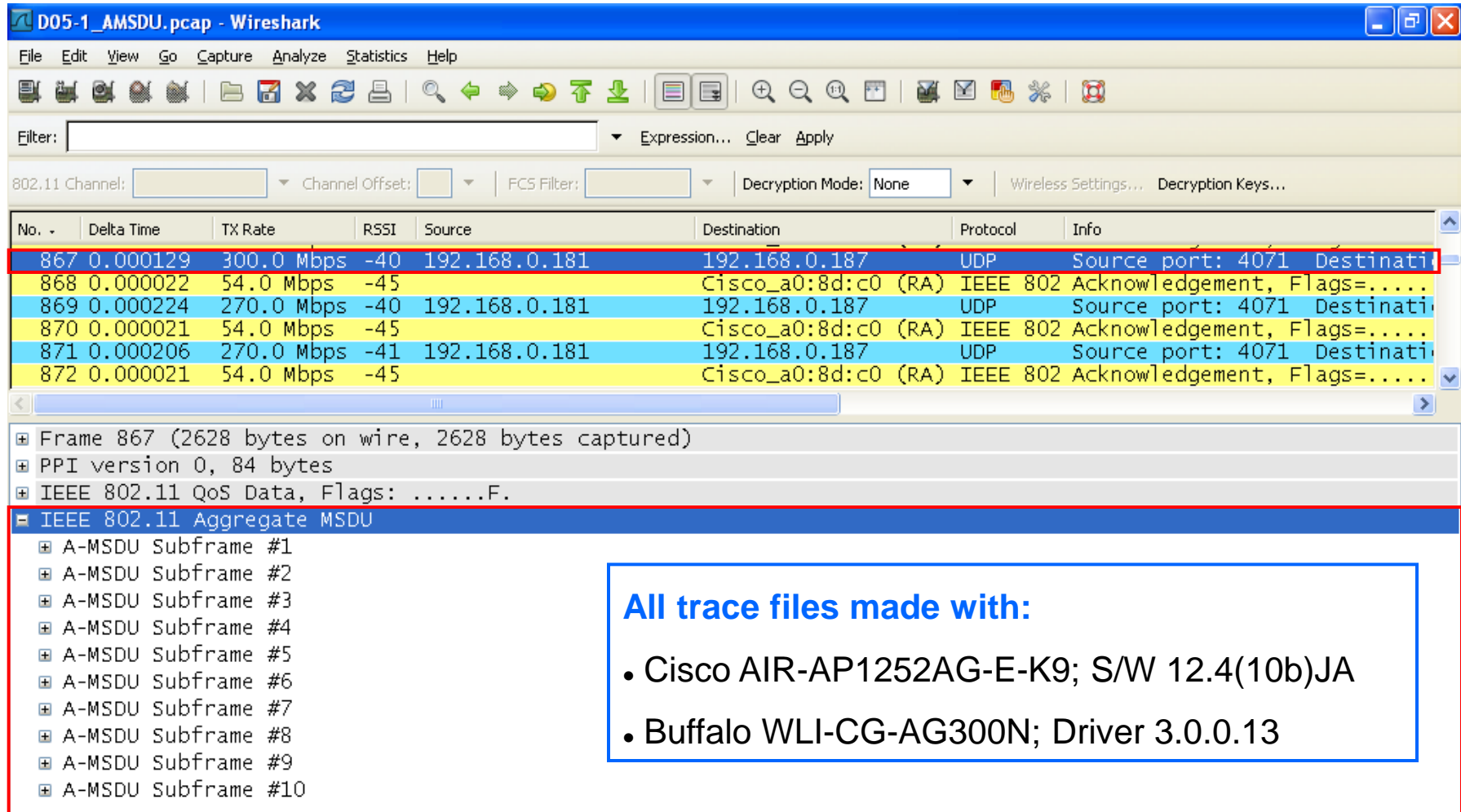
- 🦈 Block ACK effectively eliminates the need to initiate a new transfer for every MPDU

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



A-MSDU Analysis



The image shows a Wireshark capture of IEEE 802.11 frames. The main packet list shows frames 867 through 872. Frame 867 is highlighted in red and is an IEEE 802.11 Aggregate MSDU. The details pane for frame 867 shows the IEEE 802.11 Aggregate MSDU structure, which consists of 10 subframes.

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 Destination port: 4071
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 Destination port: 4071
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 Destination port: 4071
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)

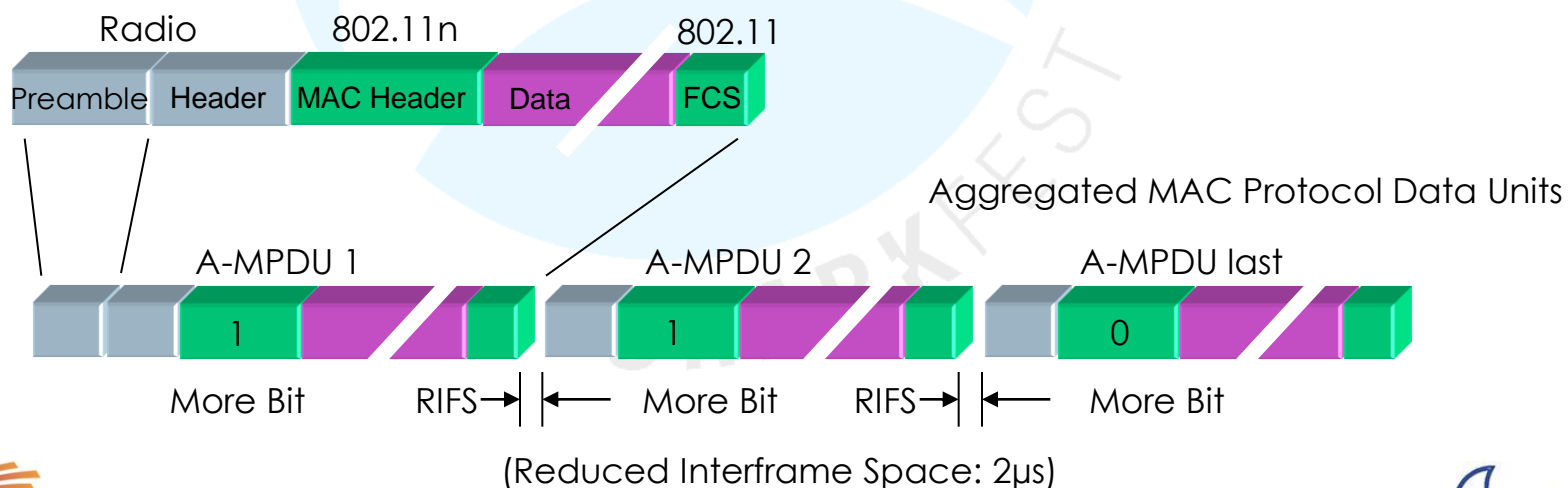
- PPI version 0, 84 bytes
- IEEE 802.11 QoS Data, Flags:F.
- IEEE 802.11 Aggregate MSDU
 - A-MSDU Subframe #1
 - A-MSDU Subframe #2
 - A-MSDU Subframe #3
 - A-MSDU Subframe #4
 - A-MSDU Subframe #5
 - A-MSDU Subframe #6
 - A-MSDU Subframe #7
 - A-MSDU Subframe #8
 - A-MSDU Subframe #9
 - A-MSDU Subframe #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

D05-2_AMPDU.pcap - Wireshark

Filter: Expression... Clear Apply

802.11 Channel: Channel Offset: FCS Filter: Decryption Mode: None Wireless Settings... Decryption Keys...

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=...

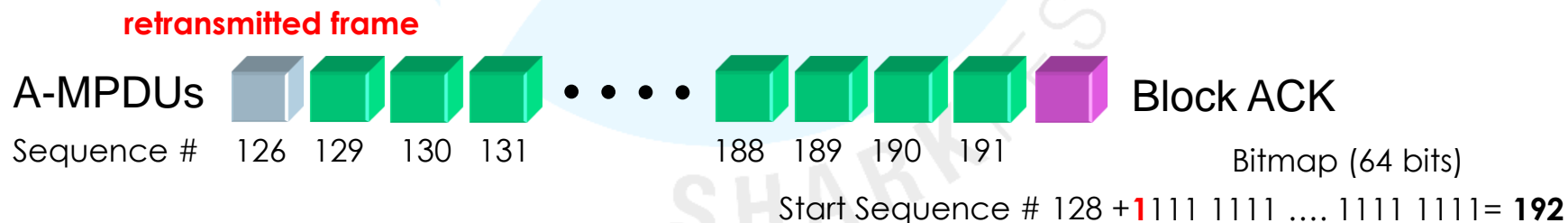
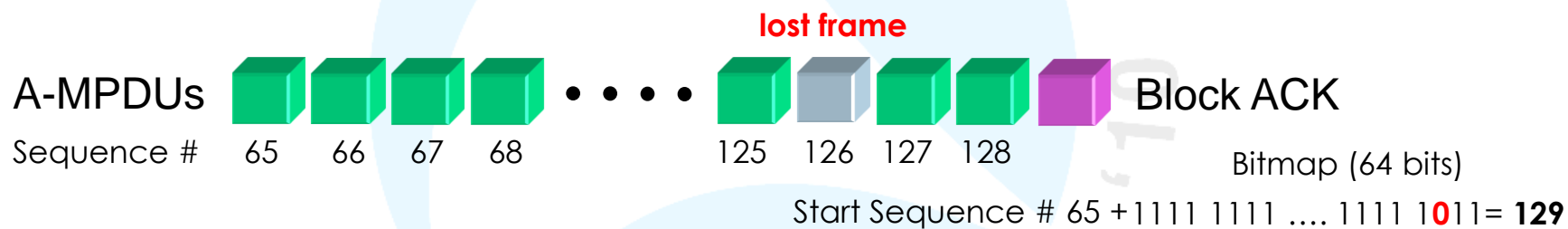
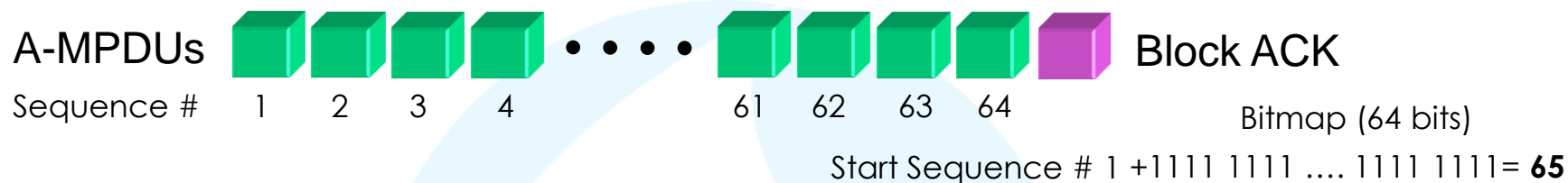
Frame 75 (1620 bytes on wire, 1620 bytes captured)

- 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.)



Block-ACK Bitmap Analysis

D05-2_AMPDU.pcap - Wireshark

Filter: Expression... Clear Apply

802.11 Channel: Channel Offset: FCS Filter: Decryption Mode: None Wireless Settings... Decryption Keys...

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 Destination...
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 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
4581	MPDU #2	1446	1
4582	MPDU #3	1447	1
4583	MPDU #4	1448	1
4584	MPDU #5	1449 lost frame	0
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 frame	
4590	MPDU #2	1453	
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.)

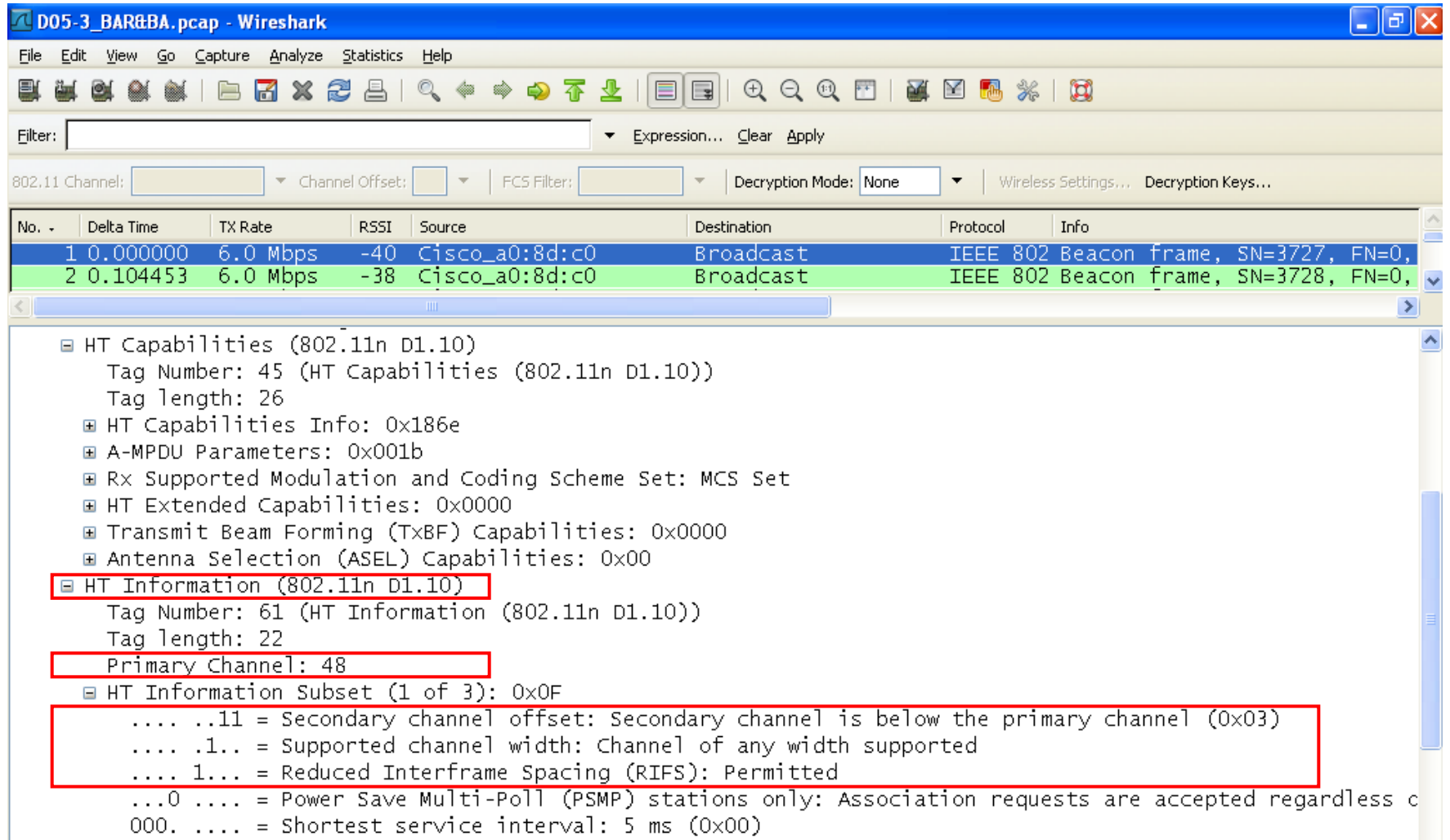
The image shows a Wireshark capture of IEEE 802.11 wireless LAN management frames. The main pane displays a list of frames with the following details:

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=.....

The packet details pane for frame 141 shows the following structure:

- Frame 141 (121 bytes on wire, 121 bytes captured)
- PPI version 0, 84 bytes
- IEEE 802.11 Action, Flags:
- 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
 - = A-MSDUs: Not Permitted
 - = 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

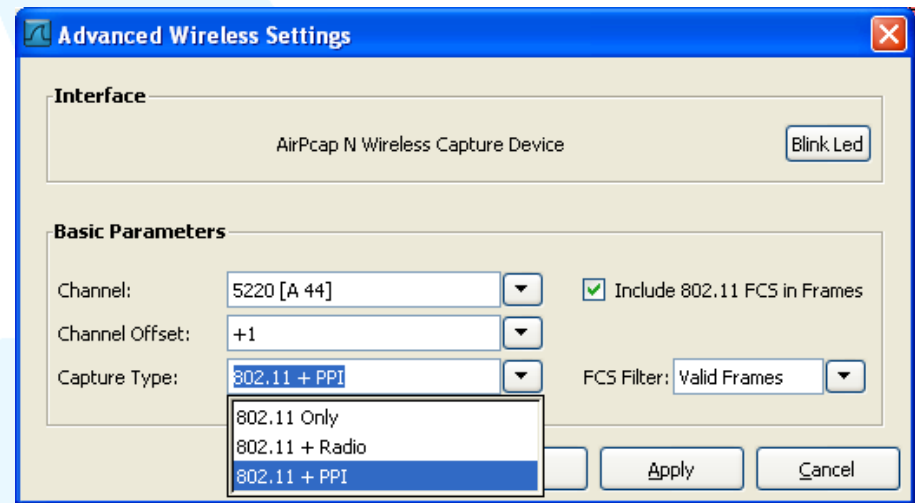


The screenshot shows the Wireshark interface with a packet list and packet details pane. The packet list shows two IEEE 802.11n beacon frames. The details pane for the second frame shows the HT Information (802.11n D1.10) section, which is highlighted with a red box. The HT Information section includes the following fields:

- 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) (highlighted with a red box)
 - Tag Number: 61 (HT Information (802.11n D1.10))
 - Tag length: 22
 - Primary Channel: 48 (highlighted with a red box)
 - 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.



References

- Radiotap manual: http://netbsd.gw.com/cgi-bin/man-cgi?ieee80211_radiotap+9+NetBSD-current
- PPI manual: http://www.cacotech.com/documents/PPI_Header_format_1.0.1.pdf

Per-Packet Information Header (cont.)

The image shows the Wireshark interface with a packet capture file named 'D05-2_AMPDU.pcap'. The main display area shows a list of packets. Packet 60 is selected and expanded to show its Per-Packet Information (PPI) header. The PPI header is highlighted with a red border and contains the following fields:

- Version: 0
- Flags: 0x00
- Header length: 84
- DLT: 105 ← Data-link level type (105=IEEE 802.11 wireless)
- 802.11-Common ← Contains data common to both pre-n and 802.11n
- 802.11n MAC+PHY ← Extension field contains radio information specific to 802.11n
- [A-MPDU (9244 bytes w/hdrs): #55(1536), #56(1536), #57(1536), #58(1536), #59(1536), #60(1536)]
- IEEE 802.11 Aggregate MPDU

The packet list table below shows the context of the captured packets:

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 Destination...
61	0.000024	54.0 Mbps	-44	Buffalo_73:05:af (TA)	Cisco_a0:8d:c0 (RA)	IEEE 802	802.11 Block Ack, Flags=...

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 is 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

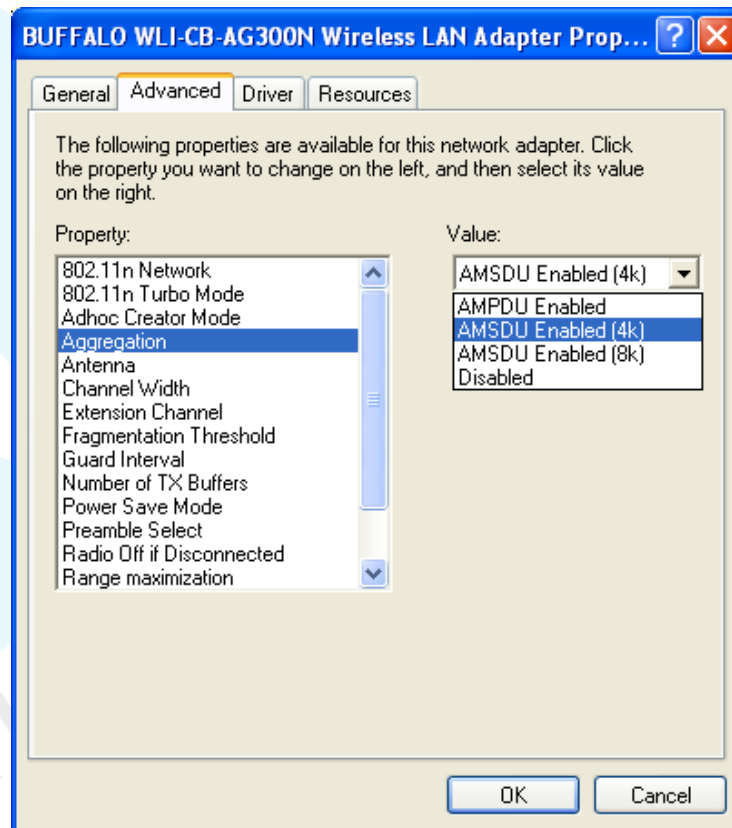


By disabling **A-MPDU** with the 'no' command, the traffic associated with that priority level uses **A-MSDU** transmission

Command line interface:

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

Buffalo's 802.11abgn PC-Card



Analysing 'Bad BAR' problem

D05-4_Bad_BAR.pcap - Wireshark

File Edit View Go Capture Analyze Statistics Help

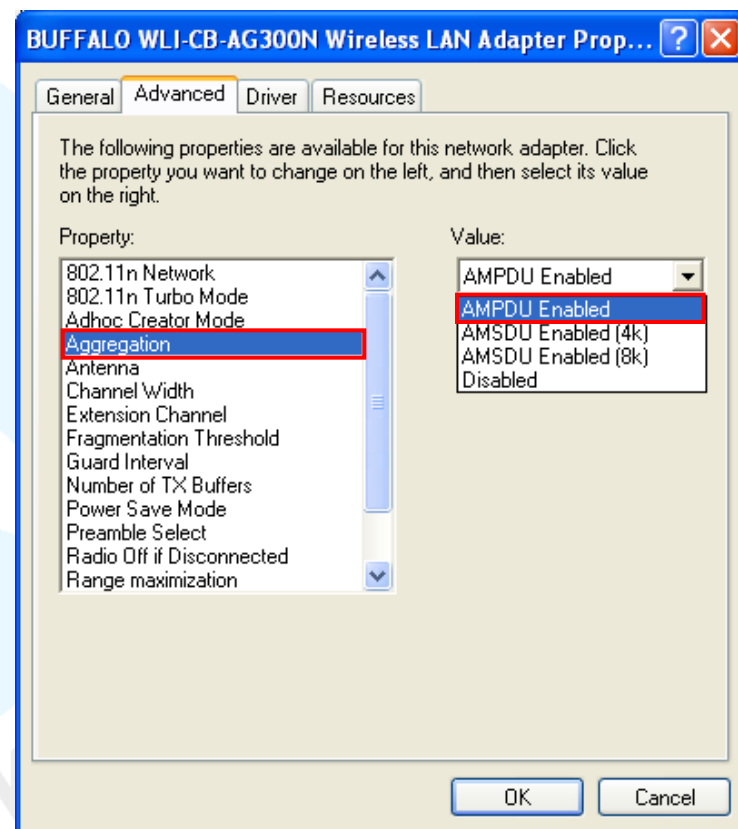
Filter: Expression... Clear Apply

802.11 Channel: Channel Offset: FCS Filter: Decryption Mode: None Wireless Settings... Decryption Keys...

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:f0	Cisco_a0:8d:c0 (RA)	IEEE 802.11	802.11 Block Ack Reg, 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:f0	Cisco_a0:8d:c0 (RA)	IEEE 802.11	802.11 Block Ack Reg, 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:f0	Cisco_a0:8d:c0 (RA)	IEEE 802.11	802.11 Block Ack Reg, 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:f0	Cisco_a0:8d:c0 (RA)	IEEE 802.11	802.11 Block Ack Reg, 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:f0	Cisco_a0:8d:c0 (RA)	IEEE 802.11	802.11 Block Ack Reg, 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:f0	Cisco_a0:8d:c0 (RA)	IEEE 802.11	802.11 Block Ack Reg, 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:f0	Cisco_a0:8d:c0 (RA)	IEEE 802.11	802.11 Block Ack Reg, 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:f0	Cisco_a0:8d:c0 (RA)	IEEE 802.11	802.11 Block Ack Reg, 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:f0	Cisco_a0:8d:c0 (RA)	IEEE 802.11	802.11 Block Ack Reg, 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:f0	Cisco_a0:8d:c0 (RA)	IEEE 802.11	802.11 Block Ack Reg, 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:f0	Cisco_a0:8d:c0 (RA)	IEEE 802.11	802.11 Block Ack Reg, Flags=...R...C

Analysing '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 software
- 🐡 A-MSDU works fine



Analysing 'Deadlock' problem

D05-5_DeadLock.pcap - Wireshark

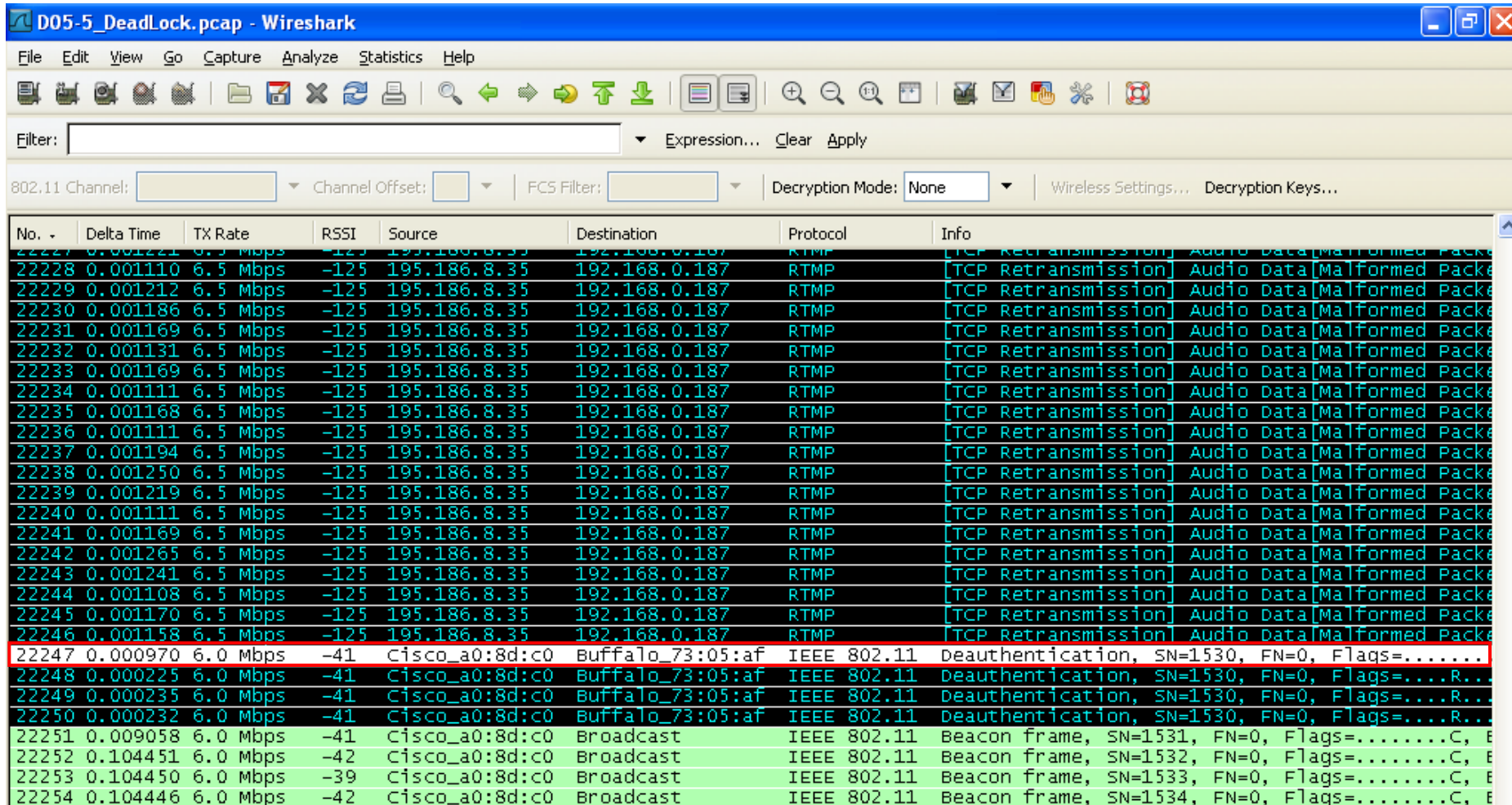
Filter: Expression... Clear Apply

802.11 Channel: Channel Offset: FCS Filter: Decryption Mode: None Wireless Settings... Decryption Keys...

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	195.186.8.35	192.168.0.187	TCP	1935 > 2604 [ACK] Seq=3789303 Ack=380
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	Buffalo_73:05:af (TA)	Cisco_a0:8d:c0 (RA)	IEEE 802.11	802.11 Block Ack, Flags=.....C
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 (TA)	Cisco_a0:8d:c0 (RA)	IEEE 802.11	802.11 Block Ack, 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[Malform
22118	0.000213	216.0 Mbps	-35	195.186.8.35	192.168.0.187	RTMP	[TCP out-of-order] Audio Data[Malform
22119	0.000223	216.0 Mbps	-60	195.186.8.35	192.168.0.187	RTMP	[TCP out-of-order] Audio Data[Malform
22120	0.000346	162.0 Mbps	-60	195.186.8.35	192.168.0.187	RTMP	[TCP out-of-order] Audio Data[Malform
22121	0.000223	162.0 Mbps	-96	195.186.8.35	192.168.0.187	RTMP	[TCP out-of-order] Audio Data[Malform
22122	0.000307	108.0 Mbps	-96	195.186.8.35	192.168.0.187	RTMP	[TCP out-of-order] Audio Data[Malform
22123	0.000233	108.0 Mbps	-125	195.186.8.35	192.168.0.187	RTMP	[TCP out-of-order] Audio Data[Malform
22124	0.000363	54.0 Mbps	-125	195.186.8.35	192.168.0.187	RTMP	[TCP out-of-order] Audio Data[Malform

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

Analysing 'Deadlock' problem (cont.)

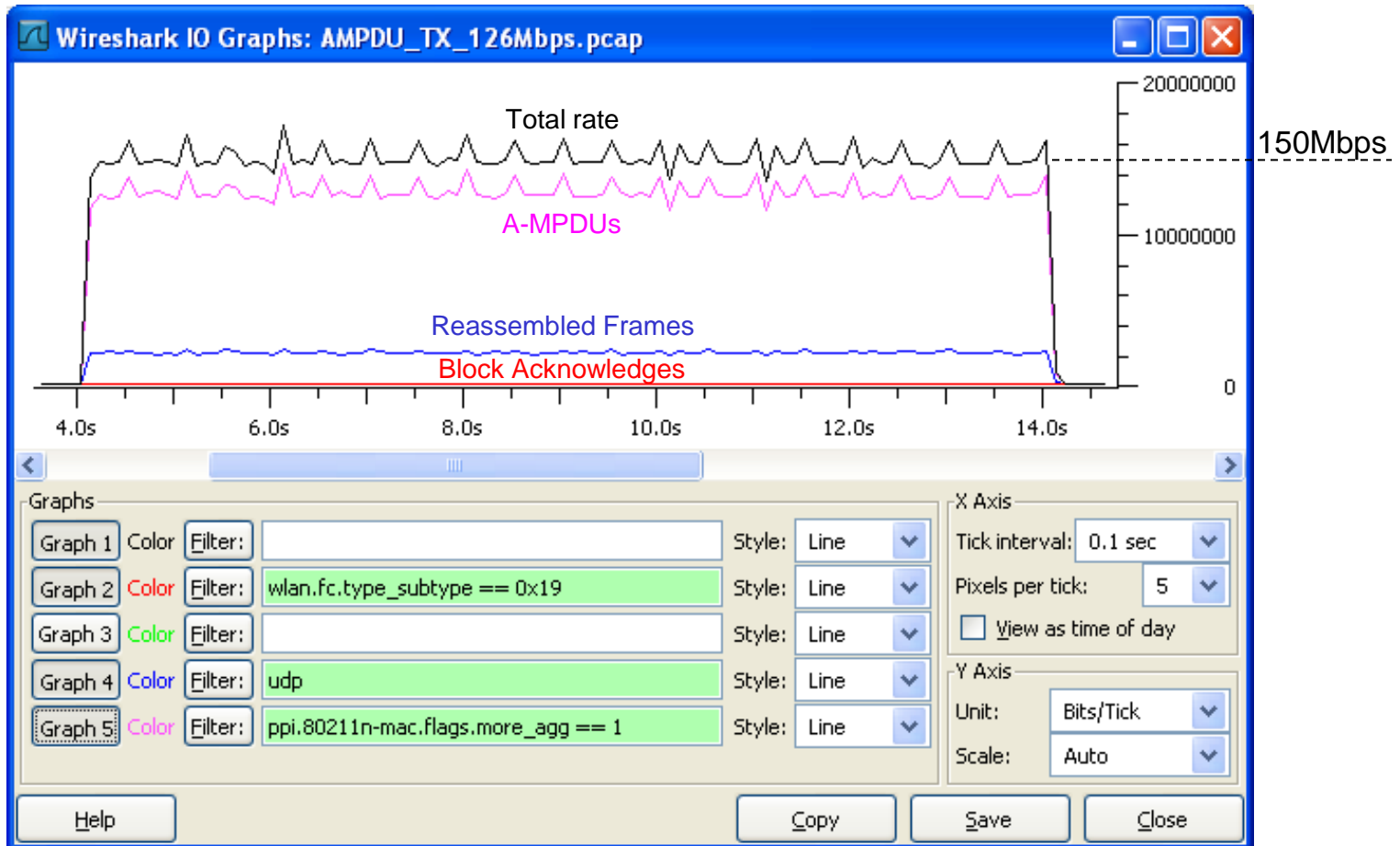


No.	Delta Time	TX Rate	RSSI	Source	Destination	Protocol	Info
22227	0.001221	6.5 Mbps	-125	195.186.8.35	192.168.0.187	RTMP	[TCP Retransmission] Audio Data [Malformed Packe
22228	0.001110	6.5 Mbps	-125	195.186.8.35	192.168.0.187	RTMP	[TCP Retransmission] Audio Data [Malformed Packe
22229	0.001212	6.5 Mbps	-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, E
22252	0.104451	6.0 Mbps	-42	Cisco_a0:8d:c0	Broadcast	IEEE 802.11	Beacon frame, SN=1532, FN=0, Flags=.....C, E
22253	0.104450	6.0 Mbps	-39	Cisco_a0:8d:c0	Broadcast	IEEE 802.11	Beacon frame, SN=1533, FN=0, Flags=.....C, E
22254	0.104446	6.0 Mbps	-42	Cisco_a0:8d:c0	Broadcast	IEEE 802.11	Beacon frame, SN=1534, FN=0, Flags=.....C, E

Analysing '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



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

Backwards compatibility to a/b/g



Present situation

Mbps	Coding	Description
1	Barker Code	802.11 DSSS (Clause 15) with ,Long Preamble'
2	Barker Code	
5.5	CCK	802.11b HR/DSSS (Clause 18) with ,Short Preamble'
11	CCK	
6	OFDM	802.11g Extended Rate PHY (ERP) new Frame Format
9	OFDM	
12	OFDM	
18	OFDM	
24	OFDM	
36	OFDM	
48	OFDM	
54	OFDM	

802.11a

CCK = Complementary Code Keying

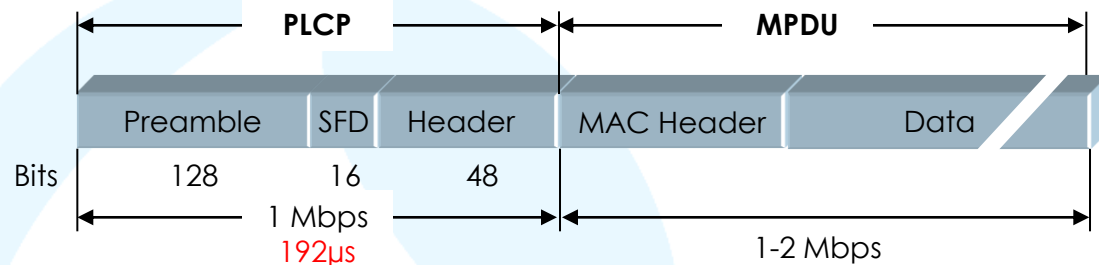
OFDM = Orthogonal Frequency Division Multiplexing

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

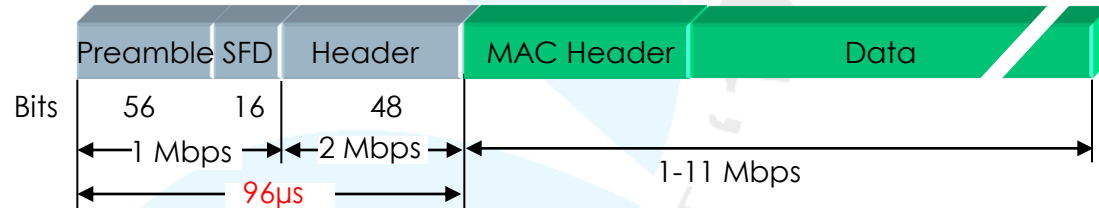


Present situation

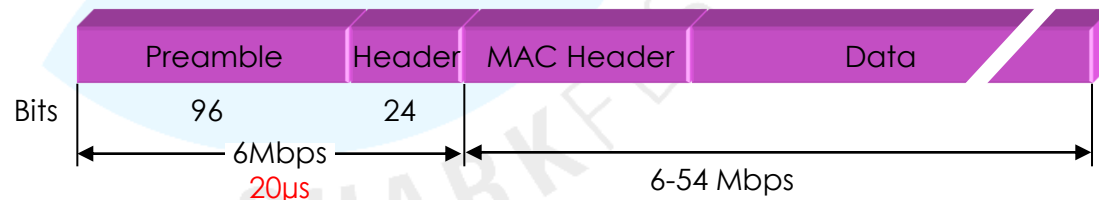
802.11 DSSS with
,Long Preamble'
Barker Code



802.11b HR/DSSS with
,Short Preamble'
Barker / CCK



802.11g (ERP)
Extended Rate PHY
new Frame Format
OFDM



PLCP = Physical Layer Convergence Protocol

MPDU = MAC Layer Protocol Data Unit (decoded by Wireshark)

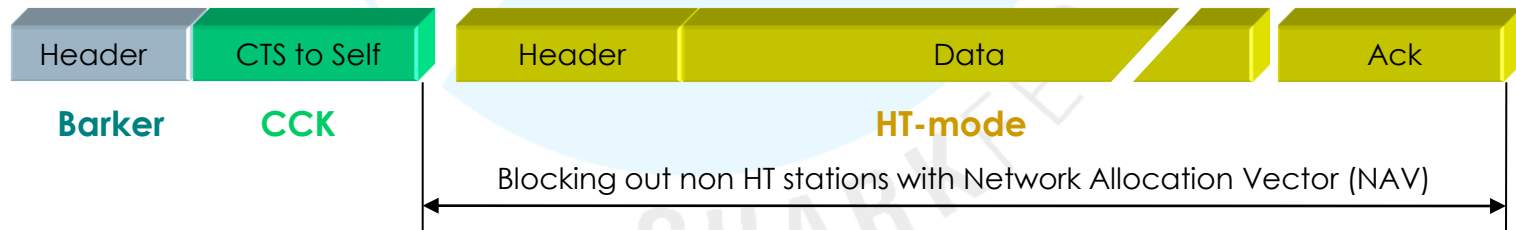
Backwards compatibility to a/b/g (cont.)

🦈 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

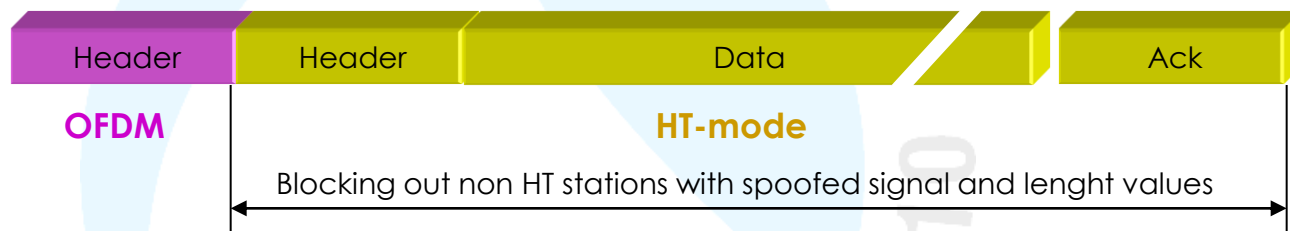


Backwards compatibility to a/b/g (cont.)



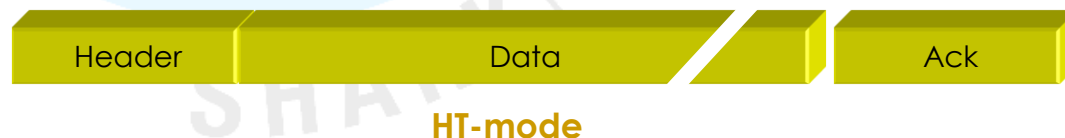
Mixed mode

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 🦈

Thank you for your attention



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