



# SharkFest'19 US



## TCP Selective Acknowledgement

...correctly interpreting this field can help  
you be a better performance  
troubleshooter...

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# Your Agenda



- Learn more about TCP SACK and how it relates to Out of Sequence Packet arrival
- Learn more about how OOS impacts application performance
- Learn about the Wireshark display fields that can help you



# My Agenda



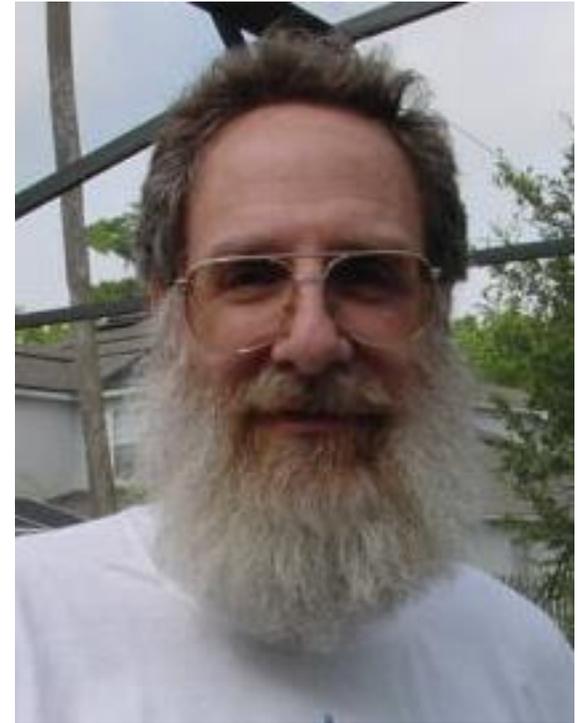
- Relevant RFCs
- Review TCP ACK Basics
- SACK Introduction
- SACK Decode Details
- SACK Example Illustration
- Adventures from the Field - Visualization Replay
- Wrap-Up



# About me?



- Performance Engineering since 1980
- Protocol Analysis since 1991
- Professional Services with OPNET / Riverbed since 2005
- Love the mystery of a complicated performance issue
- Shaved off beard in 2003...





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# Related RFCs



- RFC 793 – TCP (Original RFC – 1981)
- RFC 2018 – TCP Selective ACK Options (1996)
- RFC 2883 – An Extension to SACK ... (2000)



# Review: TCP ACK Behavior



- As long as packets arrive in the expected order, receiver will ACK every other packet (Default Behavior)
- If a packet arrives out of order, the receiver will immediately issue an ACK with a value equal to the SEQ that was expected



# Review: TCP ACK Behavior



- Receiver will continue to ACK every packet until the expected packet is received
- If sender receives 4 ACKs with the same ACK number (aka Triple Duplicate ACK) he will retransmit the missing segment
  - Assumes TCP Fast Retransmit & Recovery (FRR) is available and enabled



# Cumulative ACK (RFC 793)



No.	Time	Source	Destination	Protocol	Length	Info
1	0.000000	172.20.1.1	10.200.50.1	TCP	78	43650 → 8085 [SYN] Seq=0 Win=32850 Len=0 MSS=1436 TSval=525253167 TSecr=0 WS=8 SACK_PERM=1
2	0.000016	10.200.50.1	172.20.1.1	TCP	74	8085 → 43650 [SYN, ACK] Seq=0 Ack=1 Win=28960 Len=0 MSS=1460 SACK_PERM=1 TSval=1376522072 TSecr=525253167 WS=4
3	0.007680	172.20.1.1	10.200.50.1	TCP	66	43650 → 8085 [ACK] Seq=1 Ack=1 Win=263440 Len=0 TSval=525253168 TSecr=1376522072
4	0.008749	172.20.1.1	10.200.50.1	TCP	145	43650 → 8085 [PSH, ACK] Seq=1 Ack=1 Win=263440 Len=79 TSval=525253168 TSecr=1376522072
5	0.008758	10.200.50.1	172.20.1.1	TCP	66	8085 → 43650 [ACK] Seq=1 Ack=80 Win=28960 Len=0 TSval=1376522073 TSecr=525253168
6	0.030798	10.200.50.1	172.20.1.1	TCP	105	8085 → 43650 [PSH, ACK] Seq=1 Ack=80 Win=28960 Len=39 TSval=1376522075 TSecr=525253168
7	0.038758	172.20.1.1	10.200.50.1	TCP	66	43650 → 8085 [ACK] Seq=80 Ack=40 Win=263440 Len=0 TSval=525253171 TSecr=1376522075
8	0.043602	172.20.1.1	10.200.50.1	TCP	290	43650 → 8085 [PSH, ACK] Seq=80 Ack=40 Win=263440 Len=224 TSval=525253172 TSecr=1376522075
9	0.056458	10.200.50.1	172.20.1.1	TCP	2914	8085 → 43650 [ACK] Seq=40 Ack=304 Win=28960 Len=2848 TSval=1376522077 TSecr=525253172
10	0.056607	10.200.50.1	172.20.1.1	TCP	70	8085 → 43650 [PSH, ACK] Seq=2888 Ack=304 Win=28960 Len=4 TSval=1376522077 TSecr=525253172

Frame 7: 66 bytes on wire (528 bits), 66 bytes captured (528 bits)  
Ethernet II, Src: 40:01:d7:63:7c:50 (40:01:d7:63:7c:50), Dst: IntelCor\_bb:d6:1c (00:1e:67:bb:d6:1c)  
Internet Protocol Version 4, Src: 172.20.1.1, Dst: 10.200.50.1  
Transmission Control Protocol, Src Port: 43650, Dst Port: 8085, Seq: 80, Ack: 40, Len: 0

The ACK in the TCP header is called the “**Cumulative ACK**”. The value reflects stream bytes received in order up to the point when the ACK packet was transmitted. Receiver’s TCP declares that all bytes in the stream up to ACK-1 have been received. The next byte of TCP stream expected by the receiver should start with a SEQ equal to this ACK.



# Selective Acknowledgement



- RFC 2018 proposed an enhancement to the TCP ACK mechanism
- Selectively acknowledge segments that have arrived out of order
  - The sender won't have to retransmit those segments if he knows they've been received
  - But, this can't be accomplished with Cumulative ACK field alone, so a new field is needed

# Selective ACK – A TCP Enhancement

- New addition to the TCP Options field of the TCP header
- Up to four (4) contiguous out of order segments/segment ranges can be defined using SACK
  - Only three (3) if the TCP Timestamp option is also being used



# Enabling SACK



- On by default in modern TCP Stacks
- SACK is negotiated at connection start-up
- Decode the TCP Options in SYN and SYN+ACK and you'll see "SACK Permitted"
  - Meaning ... "I will process the SACK field if you send it to me"
- Each side can independently chose



# Intended Benefits



- Better intelligence about packet delivery available to sender
- Positioned to minimize the amount of unnecessary retransmissions
-  Will not necessarily change Congestion Control algorithms
- Any retransmission may still have a negative effect on the Congestion Window and related timers



# Use during packet analysis



- Manually interrogating the SACK fields will give you a perspective of “how bad” is “bad”
- Use “Bytes in Flight” as a guiding metric
- If in-flight data stays high no need to look any further
- If in-flight data constantly dips or hits zero; or you frequently see TCP slow-start, you may find the root cause is severe out of sequence packets



# Do you remember this date?



APRIL 19, 2011



# SKYNET Self-Aware





# Wireshark is SACK Aware



- Wireshark decodes the SACK fields in the TCP Options section of the TCP layer
- SACK Count and Left Edge / Right Edge values can be displayed as columns in the decode summary section





# SACK Wireshark Columns



No.	Time	Source	Destination	Length	TCP SACK Count	TCP SACK Left Edge	TCP SACK Right Edge	Bytes in flight	Info
31	0.711313	Server	Client	1496				5704	8085 → 43650 [PSH, ACK] Seq=13341 Ack=2171 Win=32044 Len=1430 TSval=1376522
32	0.711325	Server	Client	2914				8552	8085 → 43650 [ACK] Seq=14771 Ack=2171 Win=32044 Len=2848 TSval=1376522143 T
33	0.711339	Server	Client	2914				11400	8085 → 43650 [ACK] Seq=17619 Ack=2171 Win=32044 Len=2848 TSval=1376522143 T
34	0.718880	Client	Server	66					43650 → 8085 [ACK] Seq=2171 Ack=10493 Win=263440 Len=0 TSval=525253239 TSec
35	0.718888	Server	Client	74				9982	8085 → 43650 [PSH, ACK] Seq=20467 Ack=2171 Win=32044 Len=8 TSval=1376522144
36	0.719162	Client	Server	66					43650 → 8085 [ACK] Seq=2171 Ack=13341 Win=260592 Len=0 TSval=525253239 TSec
37	0.719441	Client	Server	66					43650 → 8085 [ACK] Seq=2171 Ack=14771 Win=263440 Len=0 TSval=525253239 TSec
38	0.719446	Client	Server	78	1	17619	19043		[TCP Dup ACK 37#1] 43650 → 8085 [ACK] Seq=2171 Ack=14771 Win=263440 Len=0 T
39	0.721344	Server	Client	1492				7130	8085 → 43650 [PSH, ACK] Seq=20475 Ack=2171 Win=32044 Len=1426 TSval=1376522
40	0.721452	Server	Client	1492				8556	8085 → 43650 [PSH, ACK] Seq=21901 Ack=2171 Win=32044 Len=1426 TSval=1376522
41	0.722115	Server	Client	1492				9982	8085 → 43650 [PSH, ACK] Seq=23327 Ack=2171 Win=32044 Len=1426 TSval=1376522
42	0.726388	Client	Server	86	2	20467,17619	20475,19043		[TCP Dup ACK 37#2] 43650 → 8085 [ACK] Seq=2171 Ack=14771 Win=263440 Len=0 T
43	0.726408	Server	Client	1490				9982	[TCP Fast Retransmission] 8085 → 43650 [ACK] Seq=14771 Ack=2171 Win=32044 L

Urgent pointer: 0

Options: (24 bytes), No-Operation (NOP), No-Operation (NOP), Timestamps, No-Operation (NOP), No-Operation (NOP), SACK

▷ No-Operation (NOP)

▷ No-Operation (NOP)

▷ Timestamps: TSval 525253239, TSecr 1376522143

▷ No-Operation (NOP)

▷ No-Operation (NOP)

◀ SACK: 17619-19043

Kind: SACK (5)

Length: 10

left edge = 17619 (relative)

right edge = 19043 (relative)

[TCP SACK Count: 1]

All bytes through 14770r have been received and I'm ready for 14771r. But wait there's more....

I've also received one or more segment(s) out of order: 17619-19042r. What's missing? 14771-17618r



# Example with two blocks OOS

No.	Time	Source	Destination	Length	TCP SACK Count	TCP SACK Left Edge	TCP SACK Right Edge	Bytes in flight	Info
40	0.721452	Server	Client	1492				8556	8085 → 43650 [PSH, ACK] Seq=21901 Ack=2171 Win=32044 Len=1426 TSval=137652214
41	0.722115	Server	Client	1492				9982	8085 → 43650 [PSH, ACK] Seq=23327 Ack=2171 Win=32044 Len=1426 TSval=137652214
42	0.726388	Client	Server	86	2	20467,17619	20475,19043		[TCP Dup ACK 37#2] 43650 → 8085 [ACK] Seq=2171 Ack=14771 Win=263440 Len=0 TSv
43	0.726408	Server	Client	1490				9982	[TCP Fast Retransmission] 8085 → 43650 [ACK] Seq=14771 Ack=2171 Win=32044 Len=
44	0.728899	Client	Server	86	2	20467,17619	21899,19043		[TCP Dup ACK 37#3] 43650 → 8085 [ACK] Seq=2171 Ack=14771 Win=263440 Len=0 TSv
45	0.728910	Client	Server	86	2	20467,17619	21901,19043		[TCP Dup ACK 37#4] 43650 → 8085 [ACK] Seq=2171 Ack=14771 Win=263440 Len=0 TSv
46	0.728915	Server	Client	1490				9982	[TCP Out-Of-Order] 8085 → 43650 [ACK] Seq=16195 Ack=2171 Win=32044 Len=1424
47	0.728920	Server	Client	1490				9982	[TCP Out-Of-Order] 8085 → 43650 [ACK] Seq=19043 Ack=2171 Win=32044 Len=1424
48	0.729045	Client	Server	86	2	20467,17619	23325,19043		[TCP Dup ACK 37#5] 43650 → 8085 [ACK] Seq=2171 Ack=14771 Win=263440 Len=0 TSv
49	0.729054	Server	Client	1490				11406	8085 → 43650 [ACK] Seq=24753 Ack=2171 Win=32044 Len=1424 TSval=1376522145 TS
50	0.729058	Client	Server	86	2	20467,17619	23327,19043		[TCP Dup ACK 37#6] 43650 → 8085 [ACK] Seq=2171 Ack=14771 Win=263440 Len=0 TSv
51	0.729063	Server	Client	1490				12830	8085 → 43650 [ACK] Seq=26177 Ack=2171 Win=32044 Len=1424 TSval=1376522145 TS
52	0.729486	Client	Server	86	2	20467,17619	24751,19043		[TCP Dup ACK 37#7] 43650 → 8085 [ACK] Seq=2171 Ack=14771 Win=263440 Len=0 TSv

▷ Timestamps: TSval 525253240, TSecr 1376522143

▷ No-Operation (NOP)

▷ No-Operation (NOP)

```

4 SACK: 20467-20475 17619-19043
  Kind: SACK (5)
  Length: 18
  left edge = 20467 (relative)
  right edge = 20475 (relative)
  left edge = 17619 (relative)
  right edge = 19043 (relative)
  [TCP SACK Count: 2]

```



# Example with two blocks OOS

```
▲ SACK: 20467-20475 17619-19043  
  Kind: SACK (5)  
  Length: 18  
  left edge = 20467 (relative)  
  right edge = 20475 (relative)  
  left edge = 17619 (relative)  
  right edge = 19043 (relative)  
  [TCP SACK Count: 2]
```



# A Different Wireshark Profile



SACK-Sample-Conn43650 - Copy\_anon.pcapng

File Edit View Go Capture Analyze Statistics Telephony Wireless Tools Help

Apply a display filter ... <Ctrl-/>

No.	Time	Source	Destination	Protocol	Length	SACK Count	Cumm ACK	SACK LE 1	SACK RE 1	SACK LE 2	SACK RE 2	Info
37	0.719441	172.20.1.1	10.200.50.1	TCP	66		14771					43650 → 8085 [A
38	0.719446	172.20.1.1	10.200.50.1	TCP	78	1	14771	17619	19043			[TCP Dup ACK 37
39	0.721344	10.200.50.1	172.20.1.1	TCP	1492		2171					8085 → 43650 [P
40	0.721452	10.200.50.1	172.20.1.1	TCP	1492		2171					8085 → 43650 [P
41	0.722115	10.200.50.1	172.20.1.1	TCP	1492		2171					8085 → 43650 [P
42	0.726388	172.20.1.1	10.200.50.1	TCP	86	2	14771	20467	20475	17619	19043	[TCP Dup ACK 37
43	0.726408	10.200.50.1	172.20.1.1	TCP	1490		2171					[TCP Fast Retra
44	0.728899	172.20.1.1	10.200.50.1	TCP	86	2	14771	20467	21899	17619	19043	[TCP Dup ACK 37
45	0.728910	172.20.1.1	10.200.50.1	TCP	86	2	14771	20467	21901	17619	19043	[TCP Dup ACK 37
46	0.728915	10.200.50.1	172.20.1.1	TCP	1490		2171					[TCP Out-Of-Ord
47	0.728920	10.200.50.1	172.20.1.1	TCP	1490		2171					[TCP Out-Of-Ord



# Edit "Occurrence #"



- Right mouse click on column header
- Select "Edit Column"

Apply a display filter ... <Ctrl-/>

Title: SACK LE 2    Type: Custom    Fields: tcp.options.sack\_le    Occurrence: 2

No.	Time	Source	Destination	Protocol	Length	SACK Count	Cumm ACK	SACK LE 1	SACK RE 1	SA
37	0.719441	172.20.1.1	10.200.50.1	TCP	66		14771			
38	0.719446	172.20.1.1	10.200.50.1	TCP	78	1	14771	17619	19043	
39	0.721344	10.200.50.1	172.20.1.1	TCP	1492		2171			
40	0.721452	10.200.50.1	172.20.1.1	TCP	1492		2171			
41	0.722115	10.200.50.1	172.20.1.1	TCP	1492		2171			
42	0.726388	172.20.1.1	10.200.50.1	TCP	86	2	14771	20467	20475	



# Pop Quiz



- What's one of the best things about Wireshark?
- OK..., besides the Developers?
- Totally flexible columns, views, and profiles!!



# Time for an Illustration...





# SACK Illustration #1



- Sender transmits a burst of 5 packets as follows:
  - Pkt 1 SEQ=11 Len=10
  - Pkt 2 SEQ=21 Len=10
  - Pkt 3 SEQ=31 Len=10
  - Pkt 4 SEQ=41 Len=10
  - Pkt 5 SEQ=51 Len=10



# SACK Illustration #1

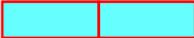


- Due to a network issue, the packets are received in the following order:
  - Pkt 1
  - Pkt 2 ←
  - Pkt 4
  - Pkt 5
  - Pkt 3



# SACK Visualization #1



1<sup>st</sup> two packets arrive 11 - 30  




# SACK Visualization #1



1<sup>st</sup> two packets arrive



Left Edge = 41

Packet 4 arrives



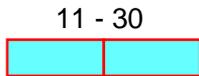
Right Edge = 51



# SACK Visualization #1

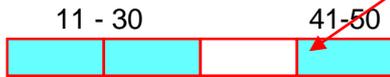


1<sup>st</sup> two packets arrive



Left Edge = 41

Packet 4 arrives



Right Edge = 51

Packet 5 arrives



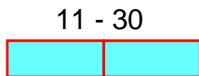
Right Edge = 61



# SACK Visualization #1



1<sup>st</sup> two packets arrive



Left Edge = 41

Packet 4 arrives



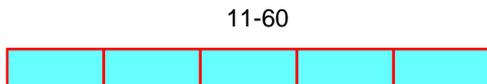
Right Edge = 51

Packet 5 arrives



Right Edge = 61

Packet 3 arrives



All data received up through and including byte 60



# Receiver Side TCP Mechanics





# Receiver's ACK responses



Pkt 1 SEQ=11 Len=10

- Pkt 1 Arrives, receiver starts delayed ACK timer, waits for a 2<sup>nd</sup> packet



# Receiver's ACK responses



Pkt 2 SEQ=21 Len=10

- Pkt 2 Arrives, receiver cancels delayed ACK timer, sends:
  - ACK=31



# Receiver's ACK responses



Pkt 4 SEQ=41 Len=10

- Pkt 4 Arrives..., but wait!, it's out of order...
- receiver issues immediate ACK because...



# Receiver's ACK responses



Pkt 4 SEQ=41 Len=10

- ...the packet we just received is out of order
- Here's the ACK and SACK info...
  - ACK=31 SACK=41-51



# Receiver's ACK responses



Pkt 5 SEQ=51 Len=10

- Pkt 5 Arrives but it's also out of order, receiver issues another immediate ACK because packet is not the expected segment (i.e. it's OOO)
  - ACK=31 SACK=41-61
- \*\*\* Note: at this point TCP stack is holding up to 2 packets in the receive buffer \*\*\*



# Receiver's ACK responses



- Pkt 3 Arrives, receiver issues:
  - ACK=61



# Receiver's ACK responses



- Pkt 3 Arrives, receiver issues:
  - ACK=61
  
- Order is restored to the Force...





# Another Example, Slightly More Complicated



- Sender transmits a burst of 6 packets as follows:
  - Pkt 1 SEQ=11 Len=10
  - Pkt 2 SEQ=21 Len=10
  - Pkt 3 SEQ=31 Len=10
  - Pkt 4 SEQ=41 Len=10
  - Pkt 5 SEQ=51 Len=10
  - Pkt 6 SEQ=61 Len=10



# Another Example, Slightly More Complicated



- Due to a network problem, the packets are received in the following order:

- Pkt 1
- Pkt 3 ←
- Pkt 6 ←
- Pkt 4 ←
- Pkt 5 ←
- Pkt 2 ←





# SACK Visualization #2



Packet 1 arrives

11 - 20



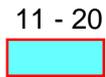
Start Delayed ACK Timer...



# SACK Visualization #2



Packet 1 arrives



Start Delayed ACK Timer...

Packet 3 arrives



ACK=21 SACK=31-41



# SACK Visualization #2



Packet 1 arrives

11 - 20



Start Delayed ACK Timer...

Packet 3 arrives

11 - 20

31-40



ACK=21 SACK=31-41

Packet 6 arrives

11 - 20

31-40

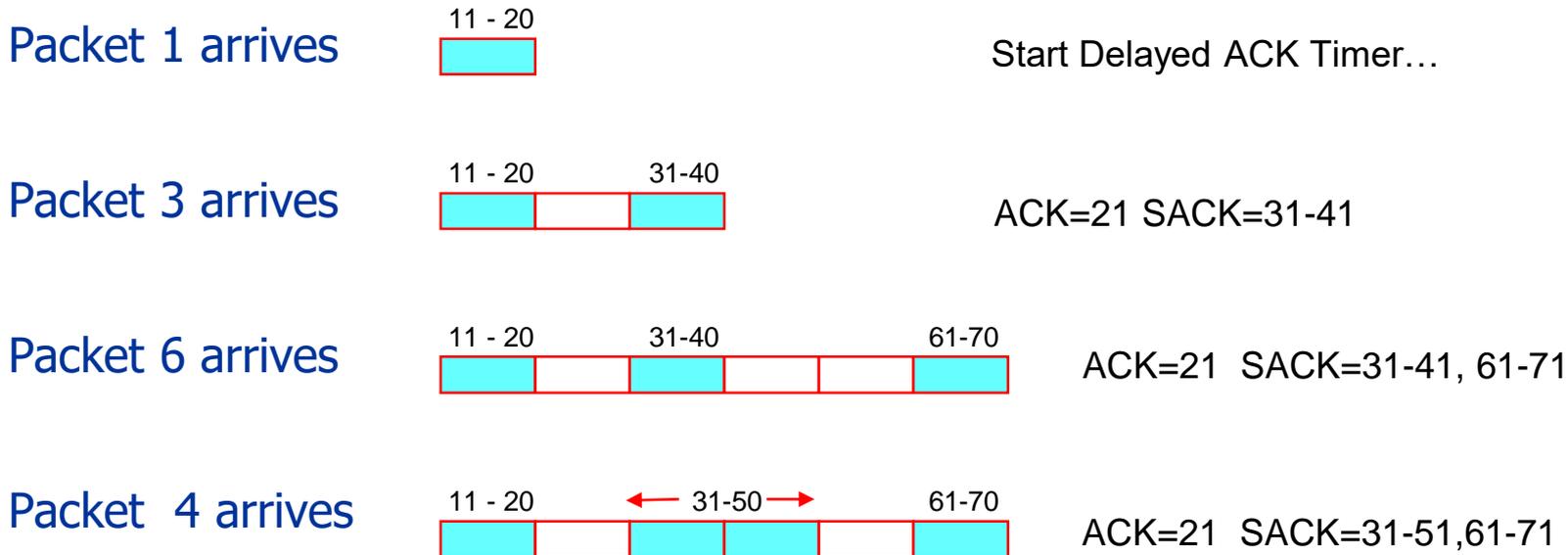
61-70



ACK=21 SACK=31-41, 61-71

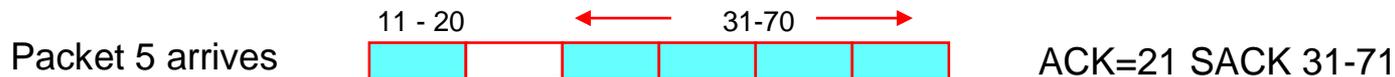


# SACK Visualization #2



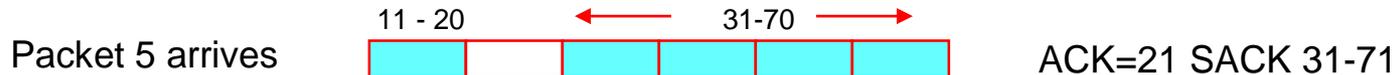


# SACK Visualization #2





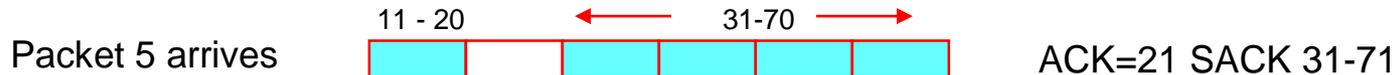
# Pop Quiz



How many packets  
are in sender's  
retransmit queue?



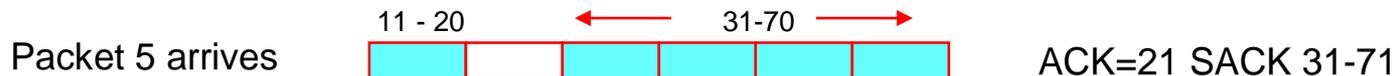
# Pop Quiz



How many packets  
are in receiver's  
queue?



# SACK Visualization #2





# Questions / Discussions





# Firewall Effects



- Some firewalls will randomize the starting TCP SYN sequence number when new connections are created
- The receiver only knows the randomized version of the sequence numbers generated by the Firewall



# Firewall Effects



- When receiver creates ACKs with SACK values, the SACK sequence numbers will not match the sequence numbers in the TCP header known by the sender
  - Firewall will always restore the original sequence numbers in the TCP header only
  - ...but no guarantees for translating the SACK field
  - This generally makes the SACK field unusable for the sender



# Example of Firewall SEQ



- SACK sequence numbers bare no resemblance to the SEQ or ACK in the TCP header

```
103574
  ETH  Ethernet II, Src: Cisco_9b:58:00 (00:1a:30:9b:58:00), Dst: SunMicro_9d:78:ee (00:14:4f:9d:78:ee)
  IP   Internet Protocol, Src: 10.144.21.19 (10.144.21.19), Dst: 10.10.81.21 (10.10.81.21) ID=21991
  TCP  D=49242 S=1526 ACK=1472937932 SEQ=1369621428 LEN=0 WIN=151
      Source port: pdap-np (1526)
      Destination port: 49242 (49242)
      Sequence number: 1369621428
      Acknowledgement number: 1472937932
      Header length: 32 bytes
      Flags: 0x10 (ACK)
          0... .. = Congestion Window Reduced (CWR): Not set
          .0.. .. = ECN-Echo: Not set
          ..0. .... = Urgent: Not set
          ...1 .... = Acknowledgment: Set
          .... 0... = Push: Not set
          .... .0.. = Reset: Not set
          .... ..0. = Syn: Not set
          .... ...0 = Fin: Not set
      Window size: 151
      Checksum: 0xca1b [correct]
          [Good Checksum: True]
          [Bad Checksum: False]
      Options: (12 bytes)
          NOP
          NOP
          SACK: 3215007281-3215008661
              left edge = 3215007281
              right edge = 3215008661
```



# Example of Firewall SEQ



- Zoom in from previous slide

```
→ 103574
... ETH      Ethernet II, Src: Cisco_9b:58:00 (00:1a:30:9b:58:00), Dst: SunMicro_9
... IP       Internet Protocol, Src: 10.144.21.19 (10.144.21.19), Dst: 10.10.81.21
... TCP      D=49242 S=1526 ACK=1472937932 SEQ=1369621428 LEN=0 WIN=151
```

```
SACK: 3215007281-3215008661
      left edge = 3215007281
      right edge = 3215008661
```



# Adventures from the Field



#sf19us • UC Berkeley • June 8-13



# Adventures from the Field



- Next we're going to look at actual results from a troubleshooting engagement involving crazy high levels out of sequence packets
- Not just high levels of OOS, but *crazy* high...



# Scenario



- Pre-migration Performance Testing in Lab
- APP: Virtual host provisioning and spin-up assessment
- Performance so bad, unable to “green-light” the migration



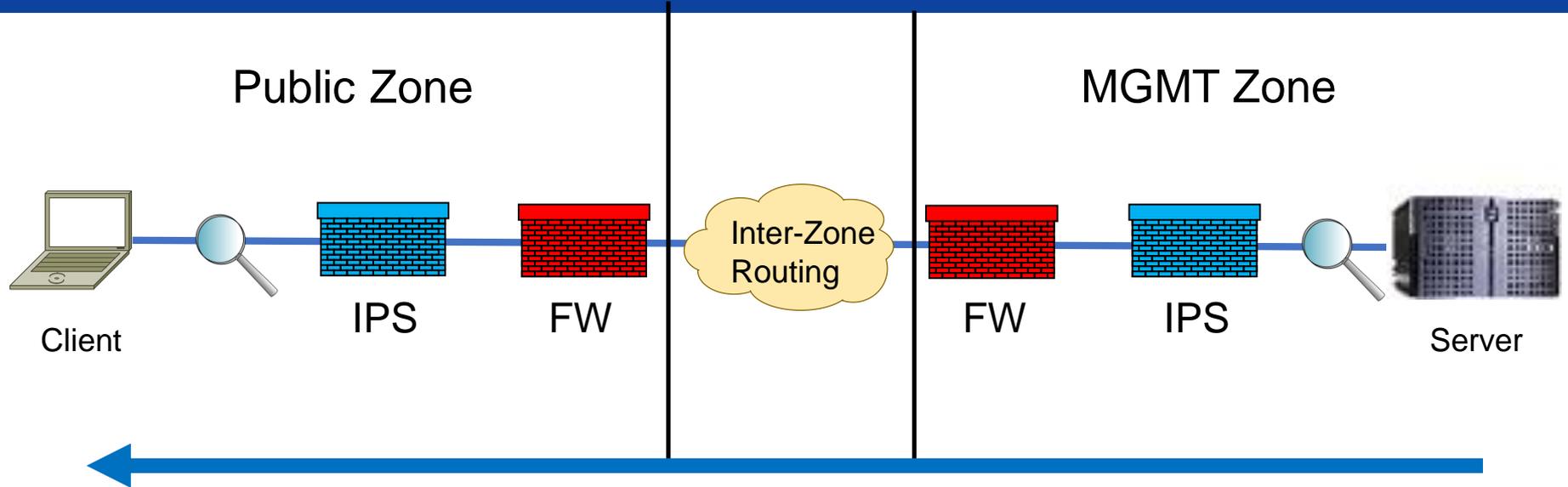
# Non-Technical Issues



- Finger pointing to the extreme...
- ...each vendor (3) is sure they are innocent and that it was the other vendor's issue
- Challenge: Help Customer figure out why throughput is so low, and help identify the vendor causing the problem



# Lab Configuration



Traffic: Client Downloading OS Configuration Build Details from Server  
1 Gbps Links with no other active traffic



Wireshark Capture Sources



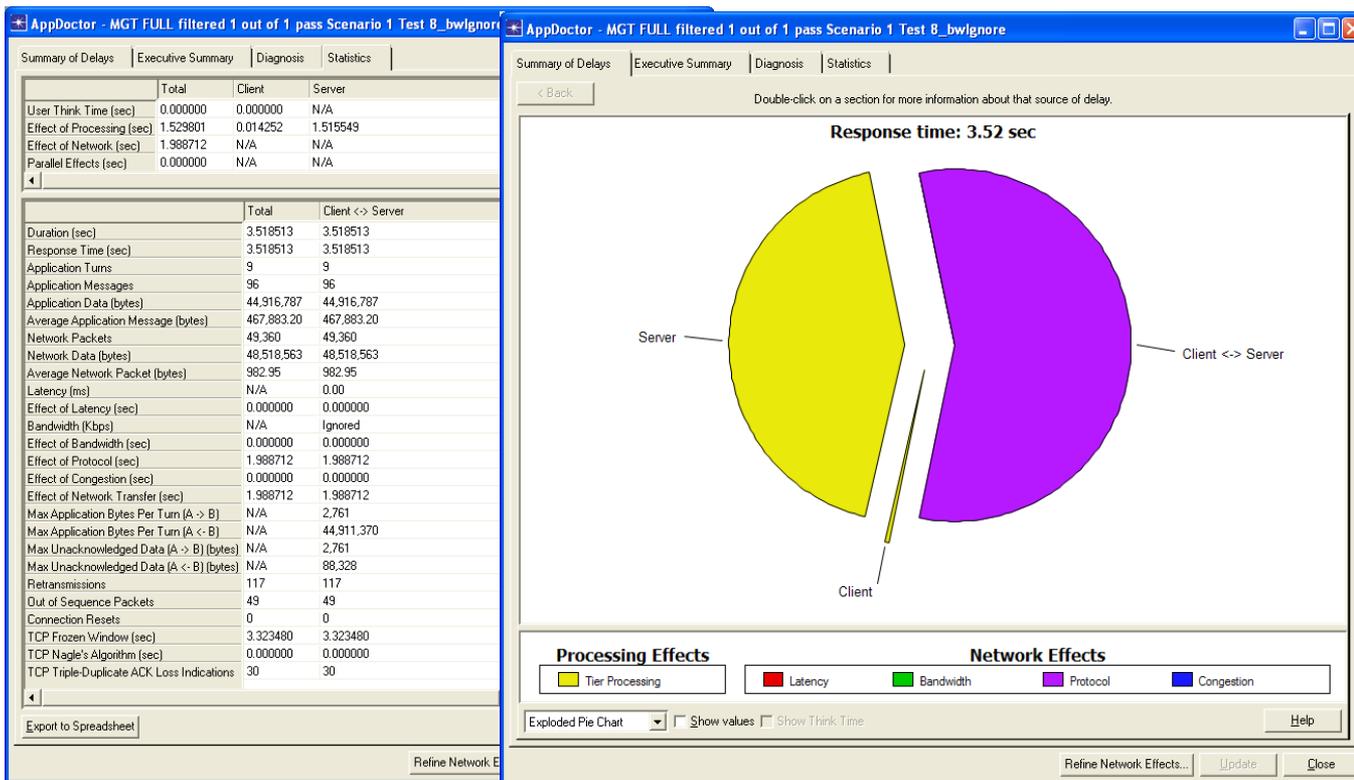
# Advanced Analytics & Viz



- Let's take a quick look at a visualization of the performance issue, before we deep dive into the packets



# Summary of Delays





# Summary of Delays



	Total	Client	Server
User Think Time (sec)	0.000000	0.000000	N/A
Effect of Processing (sec)	1.529801	0.014252	1.515549
Effect of Network (sec)	1.988712	N/A	N/A
Parallel Effects (sec)	0.000000	N/A	N/A

	Total	Client <-> Server
Duration (sec)	3.518513	3.518513
Response Time (sec)	3.518513	3.518513
Application Turns	9	9
Application Messages	96	96
Application Data (bytes)	44,916,787	44,916,787
Average Application Message (bytes)	467,883.20	467,883.20
Network Packets	49,360	49,360
Network Data (bytes)	48,518,563	48,518,563
Average Network Packet (bytes)	982.95	982.95
Latency (ms)	N/A	0.00
Effect of Latency (sec)	0.000000	0.000000
Bandwidth (Kbps)	N/A	Ignored
Effect of Bandwidth (sec)	0.000000	0.000000
Effect of Protocol (sec)	1.988712	1.988712
Effect of Congestion (sec)	0.000000	0.000000
Effect of Network Transfer (sec)	1.988712	1.988712
Max Application Bytes Per Turn (A -> B)	N/A	2,761
Max Application Bytes Per Turn (A <- B)	N/A	44,911,370
Max Unacknowledged Data (A -> B) (bytes)	N/A	2,761
Max Unacknowledged Data (A <- B) (bytes)	N/A	88,328
Retransmissions	117	117
Out of Sequence Packets	49	49
Connection Resets	0	0
TCP Frozen Window (sec)	3.323480	3.323480
TCP Nagle's Algorithm (sec)	0.000000	0.000000
TCP Triple-Duplicate ACK Loss Indications	30	30

Response time: 3.52 sec

Processing Effects: Tier Processing (yellow)

Network Effects: Latency (red), Bandwidth (green), Protocol (purple), Congestion (blue)

48.5 MB Xfer

117 x Retrans

49 x OOS

20 x 3ACKs



# Review: Bytes in Flight



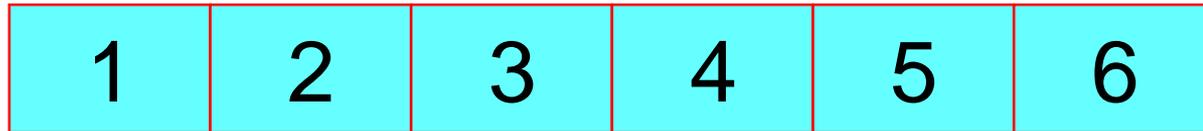
- What does this metric tell us?
- Answer: the amount of stream bytes that are outstanding on the network before sender receives an ACK for the left most edge of the current burst
- Usually reflects the sender's Congestion Window



# Left Edge Example



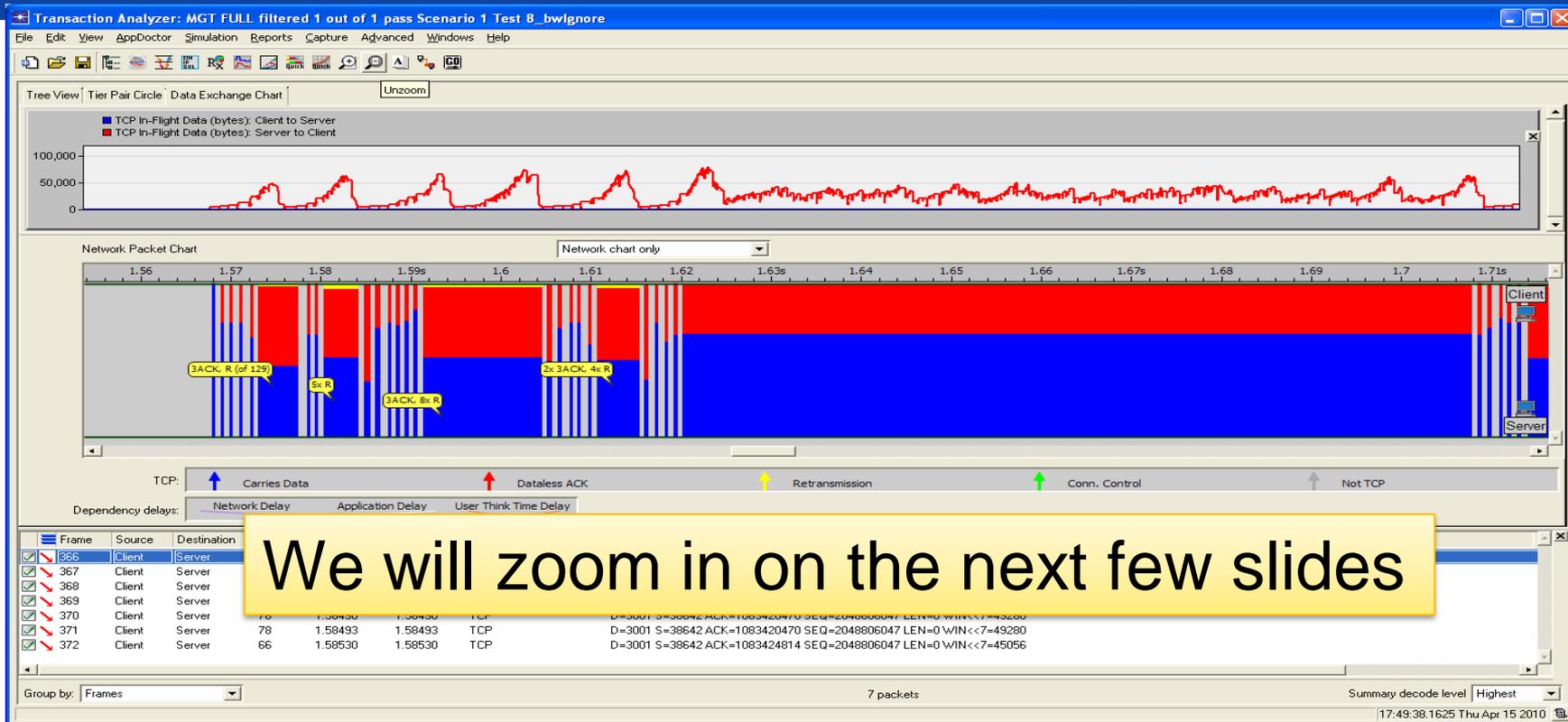
Burst of six packets

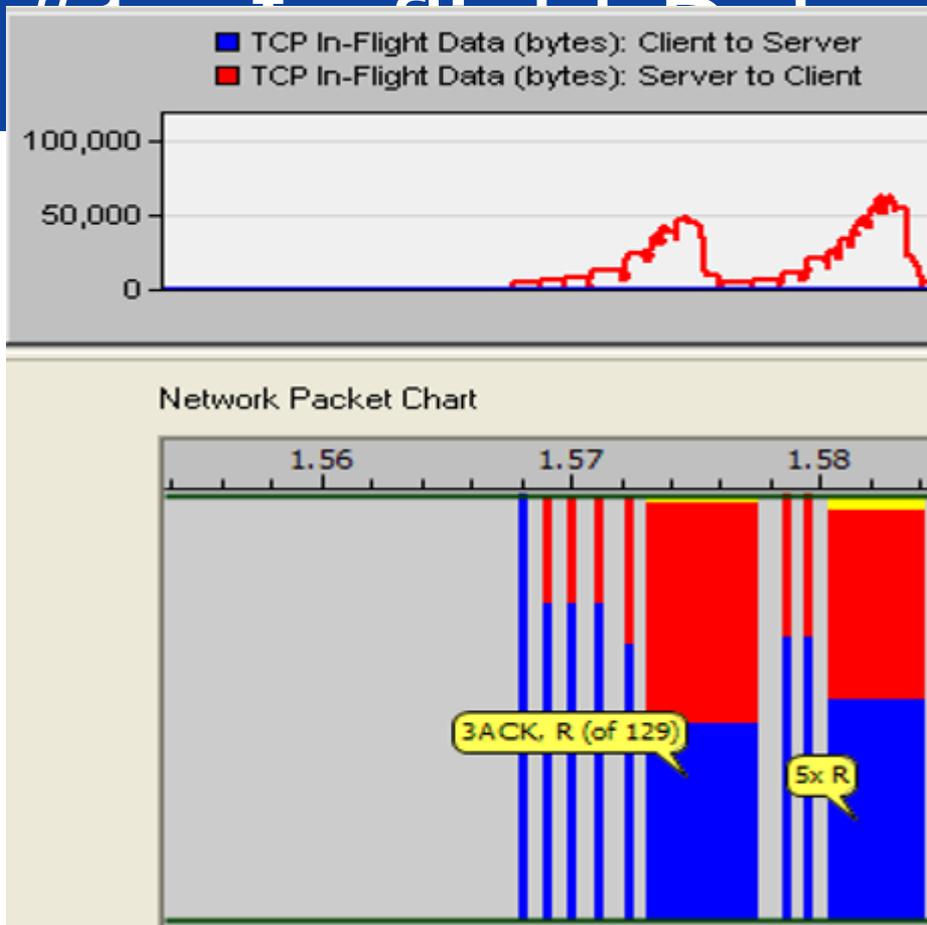


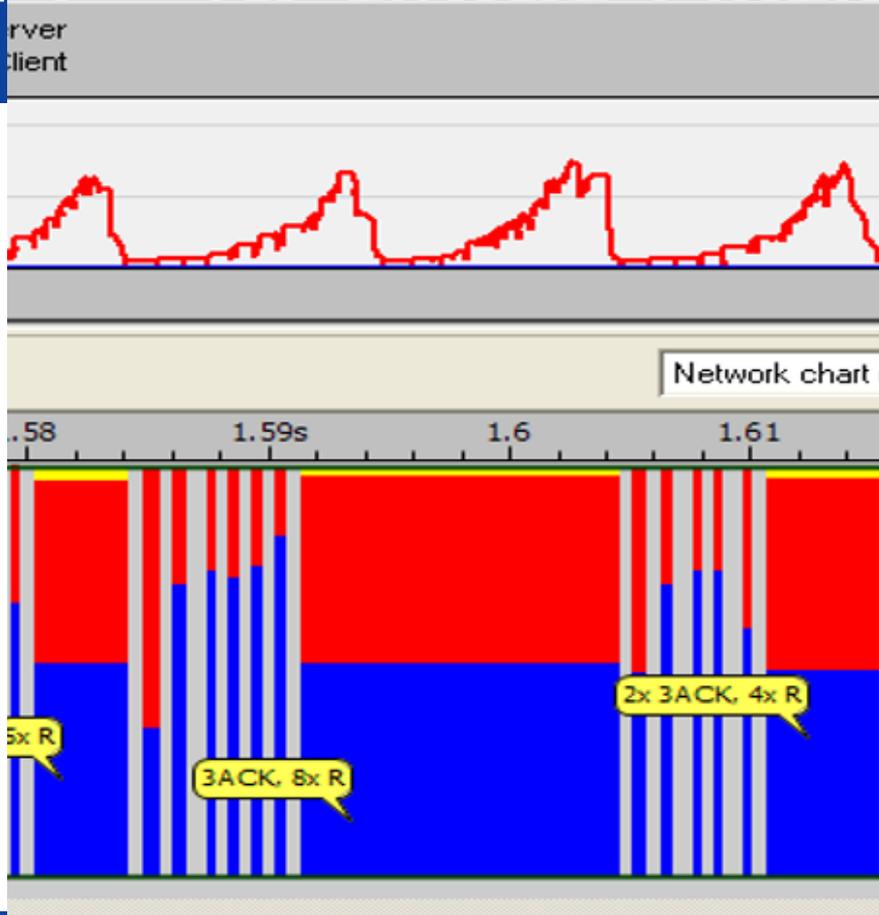
Left edge



# In-flight Data Analysis

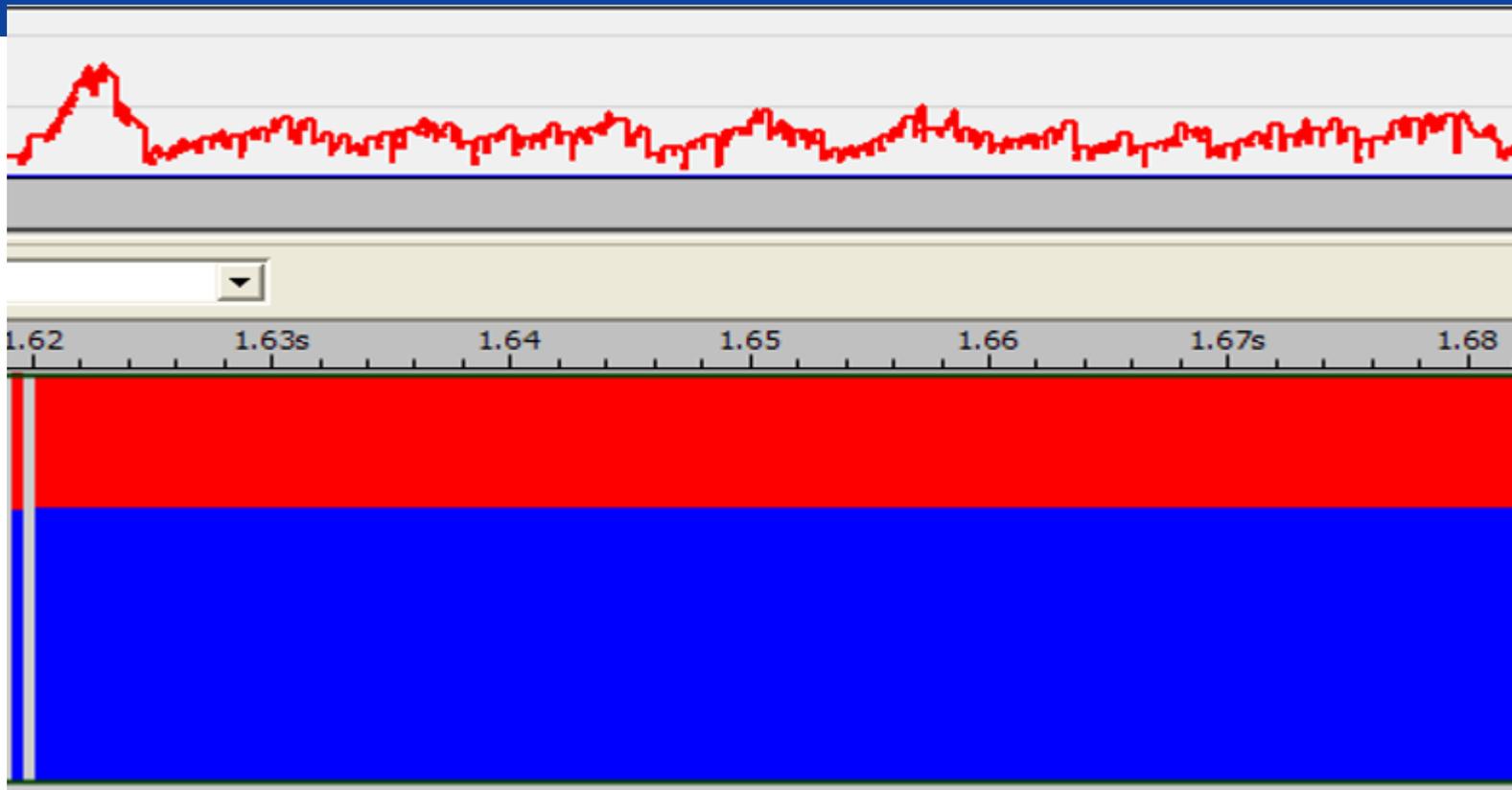








# Zoom #3 - In-flight Data Analysis





# Questions / Discussion





# OOS Visualization + SACK Analysis



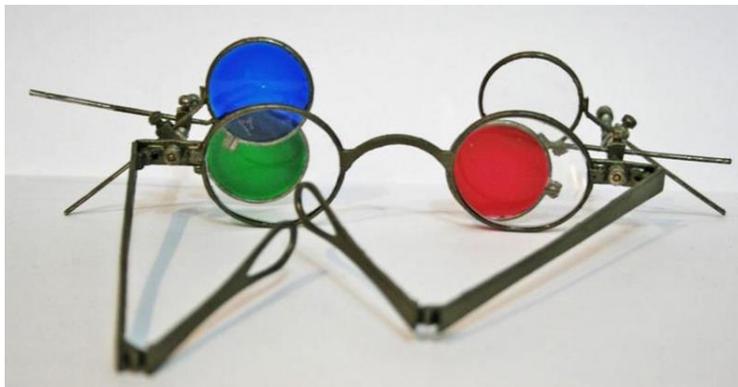
- The following section uses time lapse photography to step you through a 19 packet burst chosen at random
- The number, and *nature*, of out of sequence packets is crazy high and it's a nice example to illustrate how to interpret the SACK field



# Impact on Performance



- It's also a great example of how OOS can impact performance & interpreting "how bad is bad" with SACK





# ACK Packets Corresponding to a Packet Burst



- These are the ACKs from the client

✓	↘	2721	Client	Server	78	1.68016	1.68016	TCP	D=3001 S=38642 ACK=1085576095 SEQ=2048806047 LEN=0 WIN<<7=44416
✓	↘	2722	Client	Server	86	1.68021	1.68021	TCP	D=3001 S=38642 ACK=1085576095 SEQ=2048806047 LEN=0 WIN<<7=44416
✓	↘	2723	Client	Server	86	1.68031	1.68031	TCP	D=3001 S=38642 ACK=1085577543 SEQ=2048806047 LEN=0 WIN<<7=42880
✓	↘	2724	Client	Server	86	1.68034	1.68034	TCP	D=3001 S=38642 ACK=1085577543 SEQ=2048806047 LEN=0 WIN<<7=42880
✓	↘	2725	Client	Server	86	1.68036	1.68036	TCP	D=3001 S=38642 ACK=1085577543 SEQ=2048806047 LEN=0 WIN<<7=42880
✓	↘	2726	Client	Server	78	1.68040	1.68040	TCP	D=3001 S=38642 ACK=1085581887 SEQ=2048806047 LEN=0 WIN<<7=38528
✓	↘	2727	Client	Server	86	1.68041	1.68041	TCP	D=3001 S=38642 ACK=1085581887 SEQ=2048806047 LEN=0 WIN<<7=38528
✓	↘	2728	Client	Server	94	1.68044	1.68044	TCP	D=3001 S=38642 ACK=1085581887 SEQ=2048806047 LEN=0 WIN<<7=38528
✓	↘	2729	Client	Server	94	1.68047	1.68047	TCP	D=3001 S=38642 ACK=1085583335 SEQ=2048806047 LEN=0 WIN<<7=37120
✓	↘	2730	Client	Server	94	1.68049	1.68049	TCP	D=3001 S=38642 ACK=1085583335 SEQ=2048806047 LEN=0 WIN<<7=37120
✓	↘	2731	Client	Server	94	1.68051	1.68051	TCP	D=3001 S=38642 ACK=1085583335 SEQ=2048806047 LEN=0 WIN<<7=37120
✓	↘	2732	Client	Server	94	1.68054	1.68054	TCP	D=3001 S=38642 ACK=1085583335 SEQ=2048806047 LEN=0 WIN<<7=37120
✓	↘	2733	Client	Server	94	1.68056	1.68056	TCP	D=3001 S=38642 ACK=1085583335 SEQ=2048806047 LEN=0 WIN<<7=37120
✓	↘	2734	Client	Server	86	1.68059	1.68059	TCP	D=3001 S=38642 ACK=1085583335 SEQ=2048806047 LEN=0 WIN<<7=37120
✓	↘	2735	Client	Server	78	1.68064	1.68064	TCP	D=3001 S=38642 ACK=1085592023 SEQ=2048806047 LEN=0 WIN<<7=28416
✓	↘	2736	Client	Server	78	1.68064	1.68064	TCP	D=3001 S=38642 ACK=1085592023 SEQ=2048806047 LEN=0 WIN<<7=28416
✓	↘	2737	Client	Server	78	1.68067	1.68067	TCP	D=3001 S=38642 ACK=1085593471 SEQ=2048806047 LEN=0 WIN<<7=27008
✓	↘	2738	Client	Server	78	1.68069	1.68069	TCP	D=3001 S=38642 ACK=1085593471 SEQ=2048806047 LEN=0 WIN<<7=27008
✓	↘	2739	Client	Server	66	1.68083	1.68083	TCP	D=3001 S=38642 ACK=1085605055 SEQ=2048806047 LEN=0 WIN<<7=17280



# ACK Packets Corresponding to a Packet Burst



- Each ACK corresponds to one (or more) of the 19 payload packets in our random sample
- We'll use these ACKs to determine the arrival order for the 19 packets



# Before we start... a quick Pop Quiz:



1. Why are there so many ACKs, I thought receiver is supposed to ACK of every other packet?

✓	↘	2721	Client	Server	78	1.68016	1.68016	TCP	D=3001 S=38642 ACK=1085576095 SEQ=2048806047 LEN=0 WIN<<7=44416
✓	↘	2722	Client	Server	86	1.68021	1.68021	TCP	D=3001 S=38642 ACK=1085576095 SEQ=2048806047 LEN=0 WIN<<7=44416
✓	↘	2723	Client	Server	86	1.68031	1.68031	TCP	D=3001 S=38642 ACK=1085577543 SEQ=2048806047 LEN=0 WIN<<7=42880
✓	↘	2724	Client	Server	86	1.68034	1.68034	TCP	D=3001 S=38642 ACK=1085577543 SEQ=2048806047 LEN=0 WIN<<7=42880
✓	↘	2725	Client	Server	86	1.68036	1.68036	TCP	D=3001 S=38642 ACK=1085577543 SEQ=2048806047 LEN=0 WIN<<7=42880
✓	↘	2726	Client	Server	78	1.68040	1.68040	TCP	D=3001 S=38642 ACK=1085581887 SEQ=2048806047 LEN=0 WIN<<7=38528
✓	↘	2727	Client	Server	86	1.68041	1.68041	TCP	D=3001 S=38642 ACK=1085581887 SEQ=2048806047 LEN=0 WIN<<7=38528
✓	↘	2728	Client	Server	94	1.68044	1.68044	TCP	D=3001 S=38642 ACK=1085581887 SEQ=2048806047 LEN=0 WIN<<7=38528
✓	↘	2729	Client	Server	94	1.68047	1.68047	TCP	D=3001 S=38642 ACK=1085583335 SEQ=2048806047 LEN=0 WIN<<7=37120
✓	↘	2730	Client	Server	94	1.68049	1.68049	TCP	D=3001 S=38642 ACK=1085583335 SEQ=2048806047 LEN=0 WIN<<7=37120
✓	↘	2731	Client	Server	94	1.68051	1.68051	TCP	D=3001 S=38642 ACK=1085583335 SEQ=2048806047 LEN=0 WIN<<7=37120
✓	↘	2732	Client	Server	94	1.68054	1.68054	TCP	D=3001 S=38642 ACK=1085583335 SEQ=2048806047 LEN=0 WIN<<7=37120
✓	↘	2733	Client	Server	94	1.68056	1.68056	TCP	D=3001 S=38642 ACK=1085583335 SEQ=2048806047 LEN=0 WIN<<7=37120
✓	↘	2734	Client	Server	86	1.68059	1.68059	TCP	D=3001 S=38642 ACK=1085583335 SEQ=2048806047 LEN=0 WIN<<7=37120
✓	↘	2735	Client	Server	78	1.68064	1.68064	TCP	D=3001 S=38642 ACK=1085592023 SEQ=2048806047 LEN=0 WIN<<7=28416
✓	↘	2736	Client	Server	78	1.68064	1.68064	TCP	D=3001 S=38642 ACK=1085592023 SEQ=2048806047 LEN=0 WIN<<7=28416
✓	↘	2737	Client	Server	78	1.68067	1.68067	TCP	D=3001 S=38642 ACK=1085593471 SEQ=2048806047 LEN=0 WIN<<7=27008
✓	↘	2738	Client	Server	78	1.68069	1.68069	TCP	D=3001 S=38642 ACK=1085593471 SEQ=2048806047 LEN=0 WIN<<7=27008
✓	↘	2739	Client	Server	66	1.68083	1.68083	TCP	D=3001 S=38642 ACK=1085605055 SEQ=2048806047 LEN=0 WIN<<7=17280



## 2. Why does the ACK packet size change between 66, 78, 86, and 94?

✓	↘	2721	Client	Server	78	1.68016	1.68016	TCP	D=3001 S=38642 ACK=1085576095 SEQ=2048806047 LEN=0 WIN<<7=44416
✓	↘	2722	Client	Server	86	1.68021	1.68021	TCP	D=3001 S=38642 ACK=1085576095 SEQ=2048806047 LEN=0 WIN<<7=44416
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✓	↘	2724	Client	Server	86	1.68034	1.68034	TCP	D=3001 S=38642 ACK=1085577543 SEQ=2048806047 LEN=0 WIN<<7=42880
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✓	↘	2726	Client	Server	78	1.68040	1.68040	TCP	D=3001 S=38642 ACK=1085581887 SEQ=2048806047 LEN=0 WIN<<7=38528
✓	↘	2727	Client	Server	86	1.68041	1.68041	TCP	D=3001 S=38642 ACK=1085581887 SEQ=2048806047 LEN=0 WIN<<7=38528
✓	↘	2728	Client	Server	94	1.68044	1.68044	TCP	D=3001 S=38642 ACK=1085581887 SEQ=2048806047 LEN=0 WIN<<7=38528
✓	↘	2729	Client	Server	94	1.68047	1.68047	TCP	D=3001 S=38642 ACK=1085583335 SEQ=2048806047 LEN=0 WIN<<7=37120
✓	↘	2730	Client	Server	94	1.68049	1.68049	TCP	D=3001 S=38642 ACK=1085583335 SEQ=2048806047 LEN=0 WIN<<7=37120
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✓	↘	2732	Client	Server	94	1.68054	1.68054	TCP	D=3001 S=38642 ACK=1085583335 SEQ=2048806047 LEN=0 WIN<<7=37120
✓	↘	2733	Client	Server	94	1.68056	1.68056	TCP	D=3001 S=38642 ACK=1085583335 SEQ=2048806047 LEN=0 WIN<<7=37120
✓	↘	2734	Client	Server	86	1.68059	1.68059	TCP	D=3001 S=38642 ACK=1085583335 SEQ=2048806047 LEN=0 WIN<<7=37120
✓	↘	2735	Client	Server	78	1.68064	1.68064	TCP	D=3001 S=38642 ACK=1085592023 SEQ=2048806047 LEN=0 WIN<<7=28416
✓	↘	2736	Client	Server	78	1.68064	1.68064	TCP	D=3001 S=38642 ACK=1085592023 SEQ=2048806047 LEN=0 WIN<<7=28416
✓	↘	2737	Client	Server	78	1.68067	1.68067	TCP	D=3001 S=38642 ACK=1085593471 SEQ=2048806047 LEN=0 WIN<<7=27008
✓	↘	2738	Client	Server	78	1.68069	1.68069	TCP	D=3001 S=38642 ACK=1085593471 SEQ=2048806047 LEN=0 WIN<<7=27008
✓	↘	2739	Client	Server	66	1.68083	1.68083	TCP	D=3001 S=38642 ACK=1085605055 SEQ=2048806047 LEN=0 WIN<<7=17280



### 3. Why is the receive window continuing to shrink?

✓	↘	2721	Client	Server	78	1.68016	1.68016	TCP	D=3001 S=38642 ACK=1085576095 SEQ=2048806047 LEN=0	WIN<<7=44416
✓	↘	2722	Client	Server	86	1.68021	1.68021	TCP	D=3001 S=38642 ACK=1085576095 SEQ=2048806047 LEN=0	WIN<<7=44416
✓	↘	2723	Client	Server	86	1.68031	1.68031	TCP	D=3001 S=38642 ACK=1085577543 SEQ=2048806047 LEN=0	WIN<<7=42880
✓	↘	2724	Client	Server	86	1.68034	1.68034	TCP	D=3001 S=38642 ACK=1085577543 SEQ=2048806047 LEN=0	WIN<<7=42880
✓	↘	2725	Client	Server	86	1.68036	1.68036	TCP	D=3001 S=38642 ACK=1085577543 SEQ=2048806047 LEN=0	WIN<<7=42880
✓	↘	2726	Client	Server	78	1.68040	1.68040	TCP	D=3001 S=38642 ACK=1085581887 SEQ=2048806047 LEN=0	WIN<<7=38528
✓	↘	2727	Client	Server	86	1.68041	1.68041	TCP	D=3001 S=38642 ACK=1085581887 SEQ=2048806047 LEN=0	WIN<<7=38528
✓	↘	2728	Client	Server	94	1.68044	1.68044	TCP	D=3001 S=38642 ACK=1085581887 SEQ=2048806047 LEN=0	WIN<<7=38528
✓	↘	2729	Client	Server	94	1.68047	1.68047	TCP	D=3001 S=38642 ACK=1085583335 SEQ=2048806047 LEN=0	WIN<<7=37120
✓	↘	2730	Client	Server	94	1.68049	1.68049	TCP	D=3001 S=38642 ACK=1085583335 SEQ=2048806047 LEN=0	WIN<<7=37120
✓	↘	2731	Client	Server	94	1.68051	1.68051	TCP	D=3001 S=38642 ACK=1085583335 SEQ=2048806047 LEN=0	WIN<<7=37120
✓	↘	2732	Client	Server	94	1.68054	1.68054	TCP	D=3001 S=38642 ACK=1085583335 SEQ=2048806047 LEN=0	WIN<<7=37120
✓	↘	2733	Client	Server	94	1.68056	1.68056	TCP	D=3001 S=38642 ACK=1085583335 SEQ=2048806047 LEN=0	WIN<<7=37120
✓	↘	2734	Client	Server	86	1.68059	1.68059	TCP	D=3001 S=38642 ACK=1085583335 SEQ=2048806047 LEN=0	WIN<<7=37120
✓	↘	2735	Client	Server	78	1.68064	1.68064	TCP	D=3001 S=38642 ACK=1085592023 SEQ=2048806047 LEN=0	WIN<<7=28416
✓	↘	2736	Client	Server	78	1.68064	1.68064	TCP	D=3001 S=38642 ACK=1085592023 SEQ=2048806047 LEN=0	WIN<<7=28416
✓	↘	2737	Client	Server	78	1.68067	1.68067	TCP	D=3001 S=38642 ACK=1085593471 SEQ=2048806047 LEN=0	WIN<<7=27008
✓	↘	2738	Client	Server	78	1.68069	1.68069	TCP	D=3001 S=38642 ACK=1085593471 SEQ=2048806047 LEN=0	WIN<<7=27008
✓	↘	2739	Client	Server	66	1.68083	1.68083	TCP	D=3001 S=38642 ACK=1085605055 SEQ=2048806047 LEN=0	WIN<<7=17280



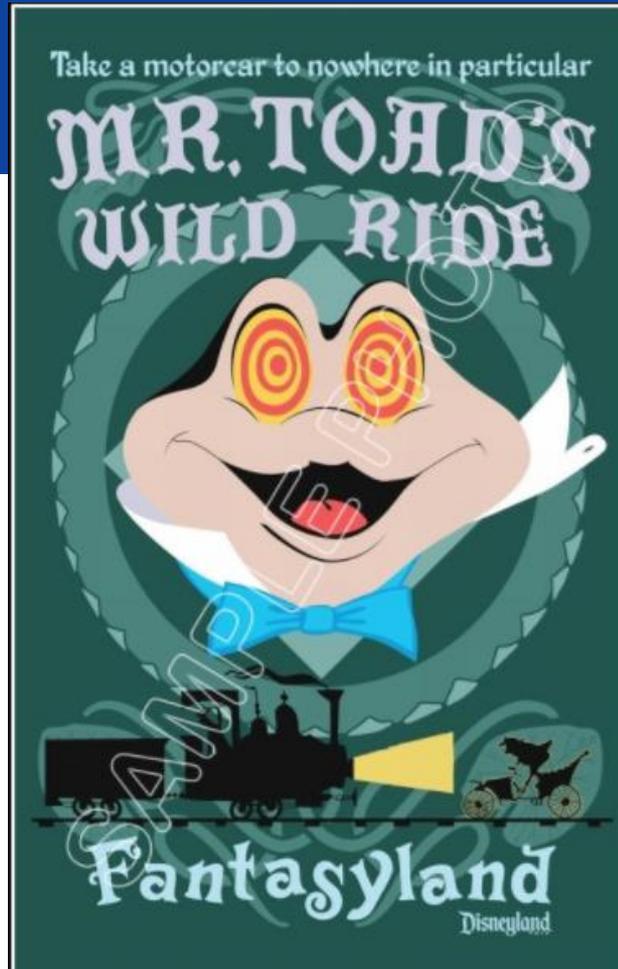
## 4. Why do we see so many duplicate ACKs?

✓	↘	2721	Client	Server	78	1.68016	1.68016	TCP	D=3001 S=38642 ACK=1085576095 SEQ=2048806047 LEN=0 WIN<<7=44416
✓	↘	2722	Client	Server	86	1.68021	1.68021	TCP	D=3001 S=38642 ACK=1085576095 SEQ=2048806047 LEN=0 WIN<<7=44416
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✓	↘	2724	Client	Server	86	1.68034	1.68034	TCP	D=3001 S=38642 ACK=1085577543 EQ=2048806047 LEN=0 WIN<<7=42880
✓	↘	2725	Client	Server	86	1.68036	1.68036	TCP	D=3001 S=38642 ACK=1085577543 EQ=2048806047 LEN=0 WIN<<7=42880
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✓	↘	2727	Client	Server	86	1.68041	1.68041	TCP	D=3001 S=38642 ACK=1085581887 SEQ=2048806047 LEN=0 WIN<<7=38528
✓	↘	2728	Client	Server	94	1.68044	1.68044	TCP	D=3001 S=38642 ACK=1085581887 SEQ=2048806047 LEN=0 WIN<<7=38528
✓	↘	2729	Client	Server	94	1.68047	1.68047	TCP	D=3001 S=38642 ACK=1085583335 EQ=2048806047 LEN=0 WIN<<7=37120
✓	↘	2730	Client	Server	94	1.68049	1.68049	TCP	D=3001 S=38642 ACK=1085583335 EQ=2048806047 LEN=0 WIN<<7=37120
✓	↘	2731	Client	Server	94	1.68051	1.68051	TCP	D=3001 S=38642 ACK=1085583335 EQ=2048806047 LEN=0 WIN<<7=37120
✓	↘	2732	Client	Server	94	1.68054	1.68054	TCP	D=3001 S=38642 ACK=1085583335 EQ=2048806047 LEN=0 WIN<<7=37120
✓	↘	2733	Client	Server	94	1.68056	1.68056	TCP	D=3001 S=38642 ACK=1085583335 EQ=2048806047 LEN=0 WIN<<7=37120
✓	↘	2734	Client	Server	86	1.68059	1.68059	TCP	D=3001 S=38642 ACK=1085583335 EQ=2048806047 LEN=0 WIN<<7=37120
✓	↘	2735	Client	Server	78	1.68064	1.68064	TCP	D=3001 S=38642 ACK=1085592023 SEQ=2048806047 LEN=0 WIN<<7=28416
✓	↘	2736	Client	Server	78	1.68064	1.68064	TCP	D=3001 S=38642 ACK=1085592023 SEQ=2048806047 LEN=0 WIN<<7=28416
✓	↘	2737	Client	Server	78	1.68067	1.68067	TCP	D=3001 S=38642 ACK=1085593471 SEQ=2048806047 LEN=0 WIN<<7=27008
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# Questions / Comments







# Pre-Departure Orientation



- 19 Slide Journey
- The top portion of the slide shows you which packet in the burst has been received
- The bottom portion shows you the ACK and SACK values extracted from the corresponding ACK packets
- Each slide represents a new packet being received and the state of all previously received packets



# Orientation



Pub Frame	Mgmt Frame	IP ID	SEQ #	Last Byte	Len	Next Seq #
2,703	2,692	33,044	1,085,576,095	1,085,577,542	1,448	1,085,577,543
2,706	2,693	33,046	1,085,577,543	1,085,578,990	1,448	1,085,578,991
2,701	2,694	33,048	1,085,578,991	1,085,580,438	1,448	1,085,580,439
2,705	2,695	33,050	1,085,580,439	1,085,581,886	1,448	1,085,581,887
2,709	2,696	33,052	1,085,581,887	1,085,583,334	1,448	1,085,583,335
2,715	2,697	33,054	1,085,583,335	1,085,584,782	1,448	1,085,584,783
2,708	2,698	33,056	1,085,584,783	1,085,586,230	1,448	1,085,586,231
2,714	2,699	33,058	1,085,586,231	1,085,587,678	1,448	1,085,587,679
2,702	2,700	33,060	1,085,587,679	1,085,589,126	1,448	1,085,589,127
2,704	2,701	33,062	1,085,589,127	1,085,590,574	1,448	1,085,590,575
2,711	2,702	33,064	1,085,590,575	1,085,592,022	1,448	1,085,592,023
2,717	2,703	33,066	1,085,592,023	1,085,593,470	1,448	1,085,593,471
2,719	2,704	33,068	1,085,593,471	1,085,594,918	1,448	1,085,594,919
2,716	2,705	33,070	1,085,594,919	1,085,596,366	1,448	1,085,596,367
2,707	2,706	33,072	1,085,596,367	1,085,597,814	1,448	1,085,597,815
2,710	2,707	33,074	1,085,597,815	1,085,599,262	1,448	1,085,599,263
2,712	2,708	33,076	1,085,599,263	1,085,600,710	1,448	1,085,600,711
2,713	2,709	33,078	1,085,600,711	1,085,602,158	1,448	1,085,602,159
2,718	2,710	33,080	1,085,602,159	1,085,603,606	1,448	1,085,603,607



# Orientation

Pub Frame	Mgmt Frame	IP ID	SEQ #	Last Byte	Len	Next Seq #
2,703	2,692	33,044	1,085,576,095	1,085,577,542	1,448	1,085,577,543
2,706	2,693	33,046	1,085,577,543	1,085,578,990	1,448	1,085,578,991
2,701	2,694	33,048	1,085,578,991	1,085,580,438	1,448	1,085,580,439
2,705	2,695	33,050	1,085,580,439	1,085,581,886	1,448	1,085,581,887
2,709	2,696	33,052	1,085,581,887	1,085,583,334	1,448	1,085,583,335
2,715	2,697	33,054	1,085,583,335	1,085,584,783	1,448	1,085,584,784
2,708	2,698	33,056	1,085,584,783	1,085,586,231	1,448	1,085,586,232
2,714	2,699	33,058	1,085,586,231	1,085,587,679	1,448	1,085,587,680
2,702	2,700	33,060	1,085,587,679	1,085,589,127	1,448	1,085,589,128
2,704	2,701	33,062	1,085,589,127	1,085,590,575	1,448	1,085,590,576
2,711	2,702	33,064	1,085,590,575	1,085,592,023	1,448	1,085,592,024
2,717	2,703	33,066	1,085,592,023	1,085,593,471	1,448	1,085,593,472
2,719	2,704	33,068	1,085,593,471	1,085,594,918	1,448	1,085,594,919
2,716	2,705	33,070	1,085,594,919	1,085,596,366	1,448	1,085,596,367
2,707	2,706	33,072	1,085,596,367	1,085,597,814	1,448	1,085,597,815
2,710	2,707	33,074	1,085,597,815	1,085,599,262	1,448	1,085,599,263
2,712	2,708	33,076	1,085,599,263	1,085,600,710	1,448	1,085,600,711
2,713	2,709	33,078	1,085,600,711	1,085,602,158	1,448	1,085,602,159
2,718	2,710	33,080	1,085,602,159	1,085,603,606	1,448	1,085,603,607

This is the frame order as seen in the Public capture (closest to Receiver)



# Orient...

This is the frame order as seen in the Mgmt capture – traffic in transit to Public (closest to Sender)

Pub Frame	Mgmt Frame	IP ID	SEQ #	Len	Next Seq #
2,703	2,692	33,044	1,085,576,095	1,448	1,085,577,543
2,706	2,693	33,046	1,085,577,543	1,448	1,085,578,991
2,701	2,694	33,048	1,085,578,991	1,448	1,085,580,439
2,705	2,695	33,050	1,085,580,439	1,448	1,085,581,887
2,709	2,696	33,052	1,085,581,887	1,448	1,085,583,335
2,715	2,697	33,054	1,085,583,335	1,448	1,085,584,783
2,708	2,698	33,056	1,085,584,783	1,448	1,085,586,231
2,714	2,699	33,058	1,085,586,231	1,448	1,085,587,679
2,702	2,700	33,060	1,085,587,679	1,448	1,085,589,127
2,704	2,701	33,062	1,085,589,127	1,448	1,085,590,575
2,711	2,702	33,064	1,085,590,575	1,448	1,085,592,023
2,717	2,703	33,066	1,085,592,023	1,448	1,085,593,471
2,719	2,704	33,068	1,085,593,471	1,448	1,085,594,919
2,716	2,705	33,070	1,085,594,919	1,448	1,085,596,367
2,707	2,706	33,072	1,085,596,367	1,448	1,085,597,815
2,710	2,707	33,074	1,085,597,815	1,448	1,085,599,263
2,712	2,708	33,076	1,085,599,263	1,448	1,085,600,711
2,713	2,709	33,078	1,085,600,711	1,448	1,085,602,159
2,718	2,710	33,080	1,085,602,159	1,448	1,085,603,607

This is the frame order as seen in the Public capture (closest to Receiver)



# Orient...

This is the frame order as seen in the Mgmt capture – traffic in transit to Public (closest to Sender)

Pub Frame	Mgmt Frame	IP ID	SEQ #	...	Len	Next Seq #
2,703	2,692	33,044	1,085,576,095	1,085,577,542	1,448	1,085,577,543
2,706	2,693	33,046	1,085,577,543	1,085,578,990	1,448	1,085,578,991
2,701	2,694	33,048	1,085,578,991	1,085,580,438	1,448	1,085,580,439
2,705	2,695	33,050	1,085,580,439	1,085,581,886	1,448	1,085,581,887
2,709	2,696	33,052	1,085,581,887	1,085,583,334	1,448	1,085,583,335
2,715	2,697	33,054	1,085,583,335	1,085,584,783	1,448	1,085,584,784
2,708	2,698	33,056	1,085,584,783	1,085,586,231	1,448	1,085,586,232
		33,058	1,085,586,231	1,085,587,679	1,448	1,085,587,680
		33,060	1,085,587,679	1,085,589,127	1,448	1,085,589,128
		33,062	1,085,589,127	1,085,590,575	1,448	1,085,590,576
		33,064	1,085,590,575	1,085,592,023	1,448	1,085,592,024
2,717	2,703	33,066	1,085,592,023	1,085,593,471	1,448	1,085,593,472
2,719	2,704	33,068	1,085,593,471	1,085,594,918	1,448	1,085,594,919
2,716	2,705	33,070	1,085,594,919	1,085,596,366	1,448	1,085,596,367
2,707	2,706	33,072	1,085,596,367	1,085,597,814	1,448	1,085,597,815
2,710	2,707	33,074	1,085,597,815	1,085,599,262	1,448	1,085,599,263
2,712	2,708	33,076	1,085,599,263	1,085,600,710	1,448	1,085,600,711
2,713	2,709	33,078	1,085,600,711	1,085,602,158	1,448	1,085,602,159
2,718	2,710	33,080	1,085,602,159	1,085,603,606	1,448	1,085,603,607

Packet Just Received Bracketed in Red

This is the frame order as seen in the Public capture (closest to Receiver)



# Orient...

This is the frame order as seen in the Mgmt capture – traffic in transit to Public (closest to Sender)

Pub Frame	Mgmt Frame	IP ID	SEQ #	...	Len	Next Seq #
2,703	2,692	33,044	1,085,576,095	1,085,577,542	1,448	1,085,577,543
2,706	2,693	33,046	1,085,577,543	1,085,578,990	1,448	1,085,578,991
2,701	2,694	33,048	1,085,578,991	1,085,580,438	1,448	1,085,580,439
2,705	2,695	33,050	1,085,580,439	1,085,581,886	1,448	1,085,581,887
2,709	2,696	33,052	1,085,581,887	1,085,583,334	1,448	1,085,583,335
2,715	2,697	33,054	1,085,583,335	1,085,584,782	1,448	1,085,584,783
2,708	2,698	33,056	1,085,584,783	1,085,586,231	1,448	1,085,586,231
		33,058	1,085,586,231	1,085,587,679	1,448	1,085,587,679
		33,060	1,085,587,679	1,085,589,127	1,448	1,085,589,127
		33,062	1,085,589,127	1,085,590,575	1,448	1,085,590,575
		33,064	1,085,590,575	1,085,592,023	1,448	1,085,592,023
2,717	2,703	33,066	1,085,592,023	1,085,593,471	1,448	1,085,593,471
2,719	2,704	33,068	1,085,593,471	1,085,594,918	1,448	1,085,594,918
2,716	2,705	33,070	1,085,594,918	1,085,596,366	1,448	1,085,596,366
2,707	2,706	33,072	1,085,596,367	1,085,597,814	1,448	1,085,597,814
2,710	2,707	33,074	1,085,597,815	1,085,599,262	1,448	1,085,599,262
2,712	2,708	33,076	1,085,599,263	1,085,600,710	1,448	1,085,600,710
2,713	2,709	33,078	1,085,600,711	1,085,602,158	1,448	1,085,602,158
2,718	2,710	33,080	1,085,602,159	1,085,603,606	1,448	1,085,603,606

Packet Just Received Bracketed in Red

This is the frame order as seen in the Public capture (closest to Receiver)

Frames previously received bracketed in Green



# ACK Details for each packet received

Pub Frame	Mgmt Frame	IP ID	SEQ #	Last Byte	Len	Next Seq #
2,703	2,692	33,044	1,085,576,095	1,085,577,542	1,448	1,085,577,543
2,706	2,693	33,046	1,085,577,543	1,085,578,990	1,448	1,085,578,991
2,701	2,694	33,048	1,085,578,991	1,085,580,438	1,448	1,085,580,439
2,705	2,695	33,050	1,085,580,439	1,085,581,886	1,448	1,085,581,887
2,709	2,696	33,052	1,085,581,887	1,085,583,334	1,448	1,085,583,335
2,715	2,697	33,054	1,085,583,335	1,085,584,782	1,448	1,085,584,783
2,708	2,698	33,056	1,085,584,783	1,085,586,230	1,448	1,085,586,231
2,714	2,699	33,058	1,085,586,231	1,085,587,678	1,448	1,085,587,679
2,702	2,700	33,060	1,085,587,679	1,085,589,126	1,448	1,085,589,127
2,704	2,701	33,062	1,085,589,127	1,085,590,574	1,448	1,085,590,575
2,711	2,702	33,064	1,085,590,575	1,085,592,022	1,448	1,085,592,023
2,717	2,703	33,066	1,085,592,023	1,085,593,470	1,448	1,085,593,471
2,719	2,704	33,068	1,085,593,471	1,085,594,918	1,448	1,085,594,919
			1,085,594,919	1,085,596,366	1,448	1,085,596,367
			1,085,596,367	1,085,597,814	1,448	1,085,597,815
			1,085,597,815	1,085,599,262	1,448	1,085,599,263
			1,085,599,263	1,085,600,710	1,448	1,085,600,711
2,713	2,709	33,078	1,085,600,711	1,085,602,158	1,448	1,085,602,159
2,718	2,710	33,080	1,085,602,159	1,085,603,606	1,448	1,085,603,607

This is the TCP Header from ACK Packet's Decode Summary

TCP D=3001 S=38642 ACK=1085576095 SEQ=2048806047 LEN=0 WIN<<7=44416

SACK: 1085578991-1085580439  
left edge = 1085578991  
right edge = 1085580439



# ACK Details for each packet received

Pub Frame	Mgmt Frame	IP ID	SEQ #	Last Byte	Len	Next Seq #
2,703	2,692	33,044	1,085,576,095	1,085,577,542	1,448	1,085,577,543
2,706	2,693	33,046	1,085,577,543	1,085,578,990	1,448	1,085,578,991
2,701	2,694	33,048	1,085,578,991	1,085,580,438	1,448	1,085,580,439
2,705	2,695	33,050	1,085,580,439	1,085,581,886	1,448	1,085,581,887
2,709	2,696	33,052	1,085,581,887	1,085,583,334	1,448	1,085,583,335
2,715	2,697	33,054	1,085,583,335	1,085,584,782	1,448	1,085,584,783
2,708	2,698	33,056	1,085,584,783	1,085,586,230	1,448	1,085,586,231
2,714	2,699	33,058	1,085,586,231	1,085,587,678	1,448	1,085,587,679
2,702	2,700	33,060	1,085,587,679	1,085,589,126	1,448	1,085,589,127
2,704	2,701	33,062	1,085,589,127	1,085,590,574	1,448	1,085,590,575
2,711	2,702	33,064	1,085,590,575	1,085,592,022	1,448	1,085,592,023
2,717	2,703	33,066	1,085,592,023	1,085,593,470	1,448	1,085,593,471
2,719	2,704	33,068	1,085,593,471	1,085,594,918	1,448	1,085,594,919
			1,085,594,919	1,085,596,366	1,448	1,085,596,367
			1,085,596,367	1,085,597,814	1,448	1,085,597,815
			1,085,597,815	1,085,599,262	1,448	1,085,599,263
			1,085,599,263	1,085,600,710	1,448	1,085,600,711
2,713	2,709	33,078	1,085,600,711	1,085,602,158	1,448	1,085,602,159
2,718	2,710	33,080	1,085,602,159	1,085,603,606	1,448	1,085,603,607

This is the TCP Header from ACK Packet's Decode Summary

TCP D=3001 S=38642 ACK=1085576095 SEQ=2048806047 LEN=0 WIN<<7=44416

SACK: 1085578991-1085580439  
left edge = 1085578991  
right edge = 1085580439

This is the value of the SACK from TCP Options Field



# Ready to start our Wild Ride....?



- Fasten your seat belt..
- Focus on the Cumulative ACK values and the SACK values as each packet is received..
- Double check your understanding, ask if what you're seeing tracks with our earlier study of SACK
- Prior to the start of this sequence, receiver had signaled that he's ready to receive the stream starting at byte:

1,085,576,095





# 1<sup>st</sup> Packet Received

Pub Frame	Mgmt Frame	IP ID	SEQ #	Last Byte	Len	Next Seq #
2,703	2,692	33,044	1,085,576,095	1,085,577,542	1,448	1,085,577,543
2,706	2,693	33,046	1,085,577,543	1,085,578,990	1,448	1,085,578,991
2,701	2,694	33,048	1,085,578,991	1,085,580,438	1,448	1,085,580,439
2,705	2,695	33,050	1,085,580,439	1,085,581,886	1,448	1,085,581,887
2,709	2,696	33,052	1,085,581,887	1,085,583,334	1,448	1,085,583,335
2,715	2,697	33,054	1,085,583,335	1,085,584,782	1,448	1,085,584,783
2,708	2,698	33,056	1,085,584,783	1,085,586,230	1,448	1,085,586,231
2,714	2,699	33,058	1,085,586,231	1,085,587,678	1,448	1,085,587,679
2,702	2,700	33,060	1,085,587,679	1,085,589,126	1,448	1,085,589,127
2,704	2,701	33,062	1,085,589,127	1,085,590,574	1,448	1,085,590,575
2,711	2,702	33,064	1,085,590,575	1,085,592,022	1,448	1,085,592,023
2,717	2,703	33,066	1,085,592,023	1,085,593,470	1,448	1,085,593,471
2,719	2,704	33,068	1,085,593,471	1,085,594,918	1,448	1,085,594,919
2,716	2,705	33,070	1,085,594,919	1,085,596,366	1,448	1,085,596,367
2,707	2,706	33,072	1,085,596,367	1,085,597,814	1,448	1,085,597,815
2,710	2,707	33,074	1,085,597,815	1,085,599,262	1,448	1,085,599,263
2,712	2,708	33,076	1,085,599,263	1,085,600,710	1,448	1,085,600,711
2,713	2,709	33,078	1,085,600,711	1,085,602,158	1,448	1,085,602,159
2,718	2,710	33,080	1,085,602,159	1,085,603,606	1,448	1,085,603,607

After receipt of the above packet (in Red), the receiver issued the following ACK

```
TCP D=3001 S=38642 ACK=1085576095 SEQ=2048806047 LEN=0 WIN<<7=44416
```

```
SACK: 1085578991-1085580439  
left edge = 1085578991  
right edge = 1085580439
```



## 2<sup>nd</sup> Packet Received

Pub Frame	Mgmt Frame	IP ID	SEQ #	Last Byte	Len	Next Seq #
2,703	2,692	33,044	1,085,576,095	1,085,577,542	1,448	1,085,577,543
2,706	2,693	33,046	1,085,577,543	1,085,578,990	1,448	1,085,578,991
2,701	2,694	33,048	1,085,578,991	1,085,580,438	1,448	1,085,580,439
2,705	2,695	33,050	1,085,580,439	1,085,581,886	1,448	1,085,581,887
2,709	2,696	33,052	1,085,581,887	1,085,583,334	1,448	1,085,583,335
2,715	2,697	33,054	1,085,583,335	1,085,584,782	1,448	1,085,584,783
2,708	2,698	33,056	1,085,584,783	1,085,586,230	1,448	1,085,586,231
2,714	2,699	33,058	1,085,586,231	1,085,587,678	1,448	1,085,587,679
2,702	2,700	33,060	1,085,587,679	1,085,589,126	1,448	1,085,589,127
2,704	2,701	33,062	1,085,589,127	1,085,590,574	1,448	1,085,590,575
2,711	2,702	33,064	1,085,590,575	1,085,592,022	1,448	1,085,592,023
2,717	2,703	33,066	1,085,592,023	1,085,593,470	1,448	1,085,593,471
2,719	2,704	33,068	1,085,593,471	1,085,594,918	1,448	1,085,594,919
2,716	2,705	33,070	1,085,594,919	1,085,596,366	1,448	1,085,596,367
2,707	2,706	33,072	1,085,596,367	1,085,597,814	1,448	1,085,597,815
2,710	2,707	33,074	1,085,597,815	1,085,599,262	1,448	1,085,599,263
2,712	2,708	33,076	1,085,599,263	1,085,600,710	1,448	1,085,600,711
2,713	2,709	33,078	1,085,600,711	1,085,602,158	1,448	1,085,602,159
2,718	2,710	33,080	1,085,602,159	1,085,603,606	1,448	1,085,603,607

After receipt of the above packet (in Red), the receiver issued the following ACK

```
IP      Internet Protocol, Src: 10.128.194.191 (10.128.194.191), Dst: 10.153.2.25 (10.153.2.25) ID=64741
TCP    D=3001 S=38642 ACK=1085576095 SEQ=2048806047 LEN=0 WIN<<7=44416
```

```
SACK: 1085587679-1085589127 1085578991-1085580439
      left edge = 1085587679
      right edge = 1085589127
      left edge = 1085578991
      right edge = 1085580439
```



# 3<sup>rd</sup> Packet Received

Pub Frame	Mgmt Frame	IP ID	SEQ #	Last Byte	Len	Next Seq #
2,703	2,692	33,044	1,085,576,095	1,085,577,542	1,448	1,085,577,543
2,706	2,693	33,046	1,085,577,543	1,085,578,990	1,448	1,085,578,991
2,701	2,694	33,048	1,085,578,991	1,085,580,438	1,448	1,085,580,439
2,705	2,695	33,050	1,085,580,439	1,085,581,886	1,448	1,085,581,887
2,709	2,696	33,052	1,085,581,887	1,085,583,334	1,448	1,085,583,335
2,715	2,697	33,054	1,085,583,335	1,085,584,782	1,448	1,085,584,783
2,708	2,698	33,056	1,085,584,783	1,085,586,230	1,448	1,085,586,231
2,714	2,699	33,058	1,085,586,231	1,085,587,678	1,448	1,085,587,679
2,702	2,700	33,060	1,085,587,679	1,085,589,126	1,448	1,085,589,127
2,704	2,701	33,062	1,085,589,127	1,085,590,574	1,448	1,085,590,575
2,711	2,702	33,064	1,085,590,575	1,085,592,022	1,448	1,085,592,023
2,717	2,703	33,066	1,085,592,023	1,085,593,470	1,448	1,085,593,471
2,719	2,704	33,068	1,085,593,471	1,085,594,918	1,448	1,085,594,919
2,716	2,705	33,070	1,085,594,919	1,085,596,366	1,448	1,085,596,367
2,707	2,706	33,072	1,085,596,367	1,085,597,814	1,448	1,085,597,815
2,710	2,707	33,074	1,085,597,815	1,085,599,262	1,448	1,085,599,263
2,712	2,708	33,076	1,085,599,263	1,085,600,710	1,448	1,085,600,711
2,713	2,709	33,078	1,085,600,711	1,085,602,158	1,448	1,085,602,159
2,718	2,710	33,080	1,085,602,159	1,085,603,606	1,448	1,085,603,607

IP Internet Protocol, Src: 10.128.194.191 (10.128.194.191), Dst: 10.153.2.25 (10.153.2.25) ID=64742  
 TCP D=3001 S=38642 ACK=1085577543 SEQ=2048806047 LEN=0 WIN<<7=42880

SACK: 1085587679-1085589127 1085578991-1085580439  
 left edge = 1085587679  
 right edge = 1085589127  
 left edge = 1085578991  
 right edge = 1085580439

Notice the cumulative ACK has increased to a value of 1085577543

SACK Field has not changed



# 4<sup>th</sup> Packet Received

Pub Frame	Mgmt Frame	IP ID	SEQ #	Last Byte	Len	Next Seq #
2,703	2,692	33,044	1,085,576,095	1,085,577,542	1,448	1,085,577,543
2,706	2,693	33,046	1,085,577,543	1,085,578,990	1,448	1,085,578,991
2,701	2,694	33,048	1,085,578,991	1,085,580,438	1,448	1,085,580,439
2,705	2,695	33,050	1,085,580,439	1,085,581,886	1,448	1,085,581,887
2,709	2,696	33,052	1,085,581,887	1,085,583,334	1,448	1,085,583,335
2,715	2,697	33,054	1,085,583,335	1,085,584,782	1,448	1,085,584,783
2,708	2,698	33,056	1,085,584,783	1,085,586,230	1,448	1,085,586,231
2,714	2,699	33,058	1,085,586,231	1,085,587,678	1,448	1,085,587,679
2,702	2,700	33,060	1,085,587,679	1,085,589,126	1,448	1,085,589,127
2,704	2,701	33,062	1,085,589,127	1,085,590,574	1,448	1,085,590,575
2,711	2,702	33,064	1,085,590,575	1,085,592,022	1,448	1,085,592,023
2,717	2,703	33,066	1,085,592,023	1,085,593,470	1,448	1,085,593,471
2,719	2,704	33,068	1,085,593,471	1,085,594,918	1,448	1,085,594,919
2,716	2,705	33,070	1,085,594,919	1,085,596,366	1,448	1,085,596,367
2,707	2,706	33,072	1,085,596,367	1,085,597,814	1,448	1,085,597,815
2,710	2,707	33,074	1,085,597,815	1,085,599,262	1,448	1,085,599,263
2,712	2,708	33,076	1,085,599,263	1,085,600,710	1,448	1,085,600,711
2,713	2,709	33,078	1,085,600,711	1,085,602,158	1,448	1,085,602,159
2,718	2,710	33,080	1,085,602,159	1,085,603,606	1,448	1,085,603,607

IP Internet Protocol, Src: 10.128.194.191 (10.128.194.191), Dst: 10.153.2.25 (10.153.2.25) ID=64743  
 TCP D=3001 S=38642 ACK=1085577543 SEQ=2048806047 LEN=0 WIN<<7=42880

SACK: 1085587679-1085590575 1085578991-1085580439

left edge = 1085587679  
 right edge = 1085590575  
 left edge = 1085578991  
 right edge = 1085580439

← Right edge changed



# 5<sup>th</sup> Packet Received

Pub Frame	Mgmt Frame	IP ID	SEQ #	Column1	Len	Next Seq #
2,703	2,692	33,044	1,085,576,095	1,085,577,542	1,448	1,085,577,543
2,706	2,693	33,046	1,085,577,543	1,085,578,990	1,448	1,085,578,991
2,701	2,694	33,048	1,085,578,991	1,085,580,438	1,448	1,085,580,439
2,705	2,695	33,050	1,085,580,439	1,085,581,886	1,448	1,085,581,887
2,709	2,696	33,052	1,085,581,887	1,085,583,334	1,448	1,085,583,335
2,715	2,697	33,054	1,085,583,335	1,085,584,782	1,448	1,085,584,783
2,708	2,698	33,056	1,085,584,783	1,085,586,230	1,448	1,085,586,231
2,714	2,699	33,058	1,085,586,231	1,085,587,678	1,448	1,085,587,679
2,702	2,700	33,060	1,085,587,679	1,085,589,126	1,448	1,085,589,127
2,704	2,701	33,062	1,085,589,127	1,085,590,574	1,448	1,085,590,575
2,711	2,702	33,064	1,085,590,575	1,085,592,022	1,448	1,085,592,023
2,717	2,703	33,066	1,085,592,023	1,085,593,470	1,448	1,085,593,471
2,719	2,704	33,068	1,085,593,471	1,085,594,918	1,448	1,085,594,919
2,716	2,705	33,070	1,085,594,919	1,085,596,366	1,448	1,085,596,367
2,707	2,706	33,072	1,085,596,367	1,085,597,814	1,448	1,085,597,815
2,710	2,707	33,074	1,085,597,815	1,085,599,262	1,448	1,085,599,263
2,712	2,708	33,076	1,085,599,263	1,085,600,710	1,448	1,085,600,711
2,713	2,709	33,078	1,085,600,711	1,085,602,158	1,448	1,085,602,159
2,718	2,710	33,080	1,085,602,159	1,085,603,606	1,448	1,085,603,607

IP Internet Protocol, Src: 10.128.194.191 (10.128.194.191), Dst: 10.153.2.25 (10.153.2.25) ID=64744  
TCP D=3001 S=38642 ACK=1085577543 SEQ=2048806047 LEN=0 WIN<<7=42880

SACK: 1085578991-1085581887 1085587679-1085590575  
left edge = 1085578991  
right edge = 1085581887  
left edge = 1085587679  
right edge = 1085590575



# Packet #6

Pub Frame	Mgmt Frame	IP ID	SEQ #	Column1	Len	Next Seq #
2,703	2,692	33,044	1,085,576,095	1,085,577,542	1,448	1,085,577,543
2,706	2,693	33,046	1,085,577,543	1,085,578,990	1,448	1,085,578,991
2,701	2,694	33,048	1,085,578,991	1,085,580,438	1,448	1,085,580,439
2,705	2,695	33,050	1,085,580,439	1,085,581,886	1,448	1,085,581,887
2,709	2,696	33,052	1,085,581,887	1,085,583,334	1,448	1,085,583,335
2,715	2,697	33,054	1,085,583,335	1,085,584,782	1,448	1,085,584,783
2,708	2,698	33,056	1,085,584,783	1,085,586,230	1,448	1,085,586,231
2,714	2,699	33,058	1,085,586,231	1,085,587,678	1,448	1,085,587,679
2,702	2,700	33,060	1,085,587,679	1,085,589,126	1,448	1,085,589,127
2,704	2,701	33,062	1,085,589,127	1,085,590,574	1,448	1,085,590,575
2,711	2,702	33,064	1,085,590,575	1,085,592,022	1,448	1,085,592,023
2,717	2,703	33,066	1,085,592,023	1,085,593,470	1,448	1,085,593,471
2,719	2,704	33,068	1,085,593,471	1,085,594,918	1,448	1,085,594,919
2,716	2,705	33,070	1,085,594,919	1,085,596,366	1,448	1,085,596,367
2,707	2,706	33,072	1,085,596,367	1,085,597,814	1,448	1,085,597,815
2,710	2,707	33,074	1,085,597,815	1,085,599,262	1,448	1,085,599,263
2,712	2,708	33,076	1,085,599,263	1,085,600,710	1,448	1,085,600,711
2,713	2,709	33,078	1,085,600,711	1,085,602,158	1,448	1,085,602,159
2,718	2,710	33,080	1,085,602,159	1,085,603,606	1,448	1,085,603,607

IP Internet Protocol, Src: 10.128.194.191 (10.128.194.191), Dst: 10.153.2.25 (10.153.2.25) ID=64745  
TCP D=3001 S=38642 ACK=1085581887 SEQ=2048806047 LEN=0 WIN<<7=38528

SACK: 1085587679-1085590575  
left edge = 1085587679  
right edge = 1085590575



# Packet #7

Pub Frame	Mgmt Frame	IP ID	SEQ #	Column1	Len	Next Seq #
2,703	2,692	33,044	1,085,576,095	1,085,577,542	1,448	1,085,577,543
2,706	2,693	33,046	1,085,577,543	1,085,578,990	1,448	1,085,578,991
2,701	2,694	33,048	1,085,578,991	1,085,580,438	1,448	1,085,580,439
2,705	2,695	33,050	1,085,580,439	1,085,581,886	1,448	1,085,581,887
2,709	2,696	33,052	1,085,581,887	1,085,583,334	1,448	1,085,583,335
2,715	2,697	33,054	1,085,583,335	1,085,584,782	1,448	1,085,584,783
2,708	2,698	33,056	1,085,584,783	1,085,586,230	1,448	1,085,586,231
2,714	2,699	33,058	1,085,586,231	1,085,587,678	1,448	1,085,587,679
2,702	2,700	33,060	1,085,587,679	1,085,589,126	1,448	1,085,589,127
2,704	2,701	33,062	1,085,589,127	1,085,590,574	1,448	1,085,590,575
2,711	2,702	33,064	1,085,590,575	1,085,592,022	1,448	1,085,592,023
2,717	2,703	33,066	1,085,592,023	1,085,593,470	1,448	1,085,593,471
2,719	2,704	33,068	1,085,593,471	1,085,594,918	1,448	1,085,594,919
2,716	2,705	33,070	1,085,594,919	1,085,596,366	1,448	1,085,596,367
2,707	2,706	33,072	1,085,596,367	1,085,597,814	1,448	1,085,597,815
2,710	2,707	33,074	1,085,597,815	1,085,599,262	1,448	1,085,599,263
2,712	2,708	33,076	1,085,599,263	1,085,600,710	1,448	1,085,600,711
2,713	2,709	33,078	1,085,600,711	1,085,602,158	1,448	1,085,602,159
2,718	2,710	33,080	1,085,602,159	1,085,603,606	1,448	1,085,603,607

IP Internet Protocol, Src: 10.128.194.191 (10.128.194.191), Dst: 10.153.2.25 (10.153.2.25) ID=64746  
TCP D=3001 S=38642 ACK=1085581887 SEQ=2048806047 LEN=0 WIN<<7=38528

SACK: 1085596367-1085597815 1085587679-1085590575  
left edge = 1085596367  
right edge = 1085597815  
left edge = 1085587679  
right edge = 1085590575



# Packet #8

Pub Frame	Mgmt Frame	IP ID	SEQ #	Column1	Len	Next Seq #
2,703	2,692	33,044	1,085,576,095	1,085,577,542	1,448	1,085,577,543
2,706	2,693	33,046	1,085,577,543	1,085,578,990	1,448	1,085,578,991
2,701	2,694	33,048	1,085,578,991	1,085,580,438	1,448	1,085,580,439
2,705	2,695	33,050	1,085,580,439	1,085,581,886	1,448	1,085,581,887
2,709	2,696	33,052	1,085,581,887	1,085,583,334	1,448	1,085,583,335
2,715	2,697	33,054	1,085,583,335	1,085,584,782	1,448	1,085,584,783
2,708	2,698	33,056	1,085,584,783	1,085,586,230	1,448	1,085,586,231
2,714	2,699	33,058	1,085,586,231	1,085,587,678	1,448	1,085,587,679
2,702	2,700	33,060	1,085,587,679	1,085,589,126	1,448	1,085,589,127
2,704	2,701	33,062	1,085,589,127	1,085,590,574	1,448	1,085,590,575
2,711	2,702	33,064	1,085,590,575	1,085,592,022	1,448	1,085,592,023
2,717	2,703	33,066	1,085,592,023	1,085,593,470	1,448	1,085,593,471
2,719	2,704	33,068	1,085,593,471	1,085,594,918	1,448	1,085,594,919
2,716	2,705	33,070	1,085,594,919	1,085,596,366	1,448	1,085,596,367
2,707	2,706	33,072	1,085,596,367	1,085,597,814	1,448	1,085,597,815
2,710	2,707	33,074	1,085,597,815	1,085,599,262	1,448	1,085,599,263
2,712	2,708	33,076	1,085,599,263	1,085,600,710	1,448	1,085,600,711
2,713	2,709	33,078	1,085,600,711	1,085,602,158	1,448	1,085,602,159
2,718	2,710	33,080	1,085,602,159	1,085,603,606	1,448	1,085,603,607

IP Internet Protocol, Src: 10.128.194.191 (10.128.194.191), Dst: 10.153.2.25 (10.153.2.25) ID=64747  
 TCP D=3001 S=38642 ACK=1085581887 SEQ=2048806047 LEN=0 WIN<<7=38528

SACK: 1085584783-1085586231 1085596367-1085597815 1085587679-1085590575  
 left edge = 1085584783  
 right edge = 1085586231  
 left edge = 1085596367  
 right edge = 1085597815  
 left edge = 1085587679  
 right edge = 1085590575

SACK now represents three groups of stream bytes



# Packet #9

Pub Frame	Mgmt Frame	IP ID	SEQ #	Column1	Len	Next Seq #
2,703	2,692	33,044	1,085,576,095	1,085,577,542	1,448	1,085,577,543
2,706	2,693	33,046	1,085,577,543	1,085,578,990	1,448	1,085,578,991
2,701	2,694	33,048	1,085,578,991	1,085,580,438	1,448	1,085,580,439
2,705	2,695	33,050	1,085,580,439	1,085,581,886	1,448	1,085,581,887
2,709	2,696	33,052	1,085,581,887	1,085,583,334	1,448	1,085,583,335
2,715	2,697	33,054	1,085,583,335	1,085,584,782	1,448	1,085,584,783
2,708	2,698	33,056	1,085,584,783	1,085,586,230	1,448	1,085,586,231
2,714	2,699	33,058	1,085,586,231	1,085,587,678	1,448	1,085,587,679
2,702	2,700	33,060	1,085,587,679	1,085,589,126	1,448	1,085,589,127
2,704	2,701	33,062	1,085,589,127	1,085,590,574	1,448	1,085,590,575
2,711	2,702	33,064	1,085,590,575	1,085,592,022	1,448	1,085,592,023
2,717	2,703	33,066	1,085,592,023	1,085,593,470	1,448	1,085,593,471
2,719	2,704	33,068	1,085,593,471	1,085,594,918	1,448	1,085,594,919
2,716	2,705	33,070	1,085,594,919	1,085,596,366	1,448	1,085,596,367
2,707	2,706	33,072	1,085,596,367	1,085,597,814	1,448	1,085,597,815
2,710	2,707	33,074	1,085,597,815	1,085,599,262	1,448	1,085,599,263
2,712	2,708	33,076	1,085,599,263	1,085,600,710	1,448	1,085,600,711
2,713	2,709	33,078	1,085,600,711	1,085,602,158	1,448	1,085,602,159
2,718	2,710	33,080	1,085,602,159	1,085,603,606	1,448	1,085,603,607

IP Internet Protocol, Src: 10.128.194.191 (10.128.194.191), Dst: 10.153.2.25 (10.153.2.25) ID=64748

TCP D=3001 S=38642 ACK=1085583335 SEQ=2048806047 LEN=0 WIN<<7=37120

SACK: 1085584783-1085586231 1085596367-1085597815 1085587679-1085590575

left edge = 1085584783  
right edge = 1085586231  
left edge = 1085596367  
right edge = 1085597815  
left edge = 1085587679  
right edge = 1085590575



# Packet #10

Pub Frame	Mgmt Frame	IP ID	SEQ #	Column1	Len	Next Seq #
2,703	2,692	33,044	1,085,576,095	1,085,577,542	1,448	1,085,577,543
2,706	2,693	33,046	1,085,577,543	1,085,578,990	1,448	1,085,578,991
2,701	2,694	33,048	1,085,578,991	1,085,580,438	1,448	1,085,580,439
2,705	2,695	33,050	1,085,580,439	1,085,581,886	1,448	1,085,581,887
2,709	2,696	33,052	1,085,581,887	1,085,583,334	1,448	1,085,583,335
2,715	2,697	33,054	1,085,583,335	1,085,584,782	1,448	1,085,584,783
2,708	2,698	33,056	1,085,584,783	1,085,586,230	1,448	1,085,586,231
2,714	2,699	33,058	1,085,586,231	1,085,587,678	1,448	1,085,587,679
2,702	2,700	33,060	1,085,587,679	1,085,589,126	1,448	1,085,589,127
2,704	2,701	33,062	1,085,589,127	1,085,590,574	1,448	1,085,590,575
2,711	2,702	33,064	1,085,590,575	1,085,592,022	1,448	1,085,592,023
2,717	2,703	33,066	1,085,592,023	1,085,593,470	1,448	1,085,593,471
2,719	2,704	33,068	1,085,593,471	1,085,594,918	1,448	1,085,594,919
2,716	2,705	33,070	1,085,594,919	1,085,596,366	1,448	1,085,596,367
2,707	2,706	33,072	1,085,596,367	1,085,597,814	1,448	1,085,597,815
2,710	2,707	33,074	1,085,597,815	1,085,599,262	1,448	1,085,599,263
2,712	2,708	33,076	1,085,599,263	1,085,600,710	1,448	1,085,600,711
2,713	2,709	33,078	1,085,600,711	1,085,602,158	1,448	1,085,602,159
2,718	2,710	33,080	1,085,602,159	1,085,603,606	1,448	1,085,603,607

IP Internet Protocol, Src: 10.128.194.191 (10.128.194.191), Dst: 10.153.2.25 (10.153.2.25) ID=64749  
 TCP D=3001 S=38642 ACK=1085583335 SEQ=2048806047 LEN=0 WIN<<7=37120

SACK: 1085596367-1085599263 1085584783-1085586231 1085587679-1085590575  
 left edge = 1085596367  
 right edge = 1085599263 ←  
 left edge = 1085584783  
 right edge = 1085586231  
 left edge = 1085587679  
 right edge = 1085590575



# Packet #11

Pub Frame	Mgmt Frame	IP ID	SEQ #	Column1	Len	Next Seq #
2,703	2,692	33,044	1,085,576,095	1,085,577,542	1,448	1,085,577,543
2,706	2,693	33,046	1,085,577,543	1,085,578,990	1,448	1,085,578,991
2,701	2,694	33,048	1,085,578,991	1,085,580,438	1,448	1,085,580,439
2,705	2,695	33,050	1,085,580,439	1,085,581,886	1,448	1,085,581,887
2,709	2,696	33,052	1,085,581,887	1,085,583,334	1,448	1,085,583,335
2,715	2,697	33,054	1,085,583,335	1,085,584,782	1,448	1,085,584,783
2,708	2,698	33,056	1,085,584,783	1,085,586,230	1,448	1,085,586,231
2,714	2,699	33,058	1,085,586,231	1,085,587,678	1,448	1,085,587,679
2,702	2,700	33,060	1,085,587,679	1,085,589,126	1,448	1,085,589,127
2,704	2,701	33,062	1,085,589,127	1,085,590,574	1,448	1,085,590,575
2,711	2,702	33,064	1,085,590,575	1,085,592,022	1,448	1,085,592,023
2,717	2,703	33,066	1,085,592,023	1,085,593,470	1,448	1,085,593,471
2,719	2,704	33,068	1,085,593,471	1,085,594,918	1,448	1,085,594,919
2,716	2,705	33,070	1,085,594,919	1,085,596,366	1,448	1,085,596,367
2,707	2,706	33,072	1,085,596,367	1,085,597,814	1,448	1,085,597,815
2,710	2,707	33,074	1,085,597,815	1,085,599,262	1,448	1,085,599,263
2,712	2,708	33,076	1,085,599,263	1,085,600,710	1,448	1,085,600,711
2,713	2,709	33,078	1,085,600,711	1,085,602,158	1,448	1,085,602,159
2,718	2,710	33,080	1,085,602,159	1,085,603,606	1,448	1,085,603,607

IP Internet Protocol, Src: 10.128.194.191 (10.128.194.191), Dst: 10.153.2.25 (10.153.2.25) ID=64750  
 TCP D=3001 S=38642 ACK=1085583335 SEQ=2048806047 LEN=0 WIN<<7=37120

SACK: 1085587679-1085592023 1085596367-1085599263 1085584783-1085586231  
 left edge = 1085587679  
 right edge = 1085592023 ←  
 left edge = 1085596367  
 right edge = 1085599263  
 left edge = 1085584783  
 right edge = 1085586231



# Packets #12 + 13

Pub Frame	Mgmt Frame	IP ID	SEQ #	Column1	Len	Next Seq #
2,703	2,692	33,044	1,085,576,095	1,085,577,542	1,448	1,085,577,543
2,706	2,693	33,046	1,085,577,543	1,085,578,990	1,448	1,085,578,991
2,701	2,694	33,048	1,085,578,991	1,085,580,438	1,448	1,085,580,439
2,705	2,695	33,050	1,085,580,439	1,085,581,886	1,448	1,085,581,887
2,709	2,696	33,052	1,085,581,887	1,085,583,334	1,448	1,085,583,335
2,715	2,697	33,054	1,085,583,335	1,085,584,782	1,448	1,085,584,783
2,708	2,698	33,056	1,085,584,783	1,085,586,230	1,448	1,085,586,231
2,714	2,699	33,058	1,085,586,231	1,085,587,678	1,448	1,085,587,679
2,702	2,700	33,060	1,085,587,679	1,085,589,126	1,448	1,085,589,127
2,704	2,701	33,062	1,085,589,127	1,085,590,574	1,448	1,085,590,575
2,711	2,702	33,064	1,085,590,575	1,085,592,022	1,448	1,085,592,023
2,717	2,703	33,066	1,085,592,023	1,085,593,470	1,448	1,085,593,471
2,719	2,704	33,068	1,085,593,471	1,085,594,918	1,448	1,085,594,919
2,716	2,705	33,070	1,085,594,919	1,085,596,366	1,448	1,085,596,367
2,707	2,706	33,072	1,085,596,367	1,085,597,814	1,448	1,085,597,815
2,710	2,707	33,074	1,085,597,815	1,085,599,262	1,448	1,085,599,263
2,712	2,708	33,076	1,085,599,263	1,085,600,710	1,448	1,085,600,711
2,713	2,709	33,078	1,085,600,711	1,085,602,158	1,448	1,085,602,159
2,718	2,710	33,080	1,085,602,159	1,085,603,606	1,448	1,085,603,607

IP Internet Protocol, Src: 10.128.194.191 (10.128.194.191), Dst: 10.153.2.25 (10.153.2.25) ID=64752  
 TCP D=3001 S=38642 ACK=1085583335 SEQ=2048806047 LEN=0 WIN<<7=37120

SACK: 1085596367-1085602159 1085587679-1085592023 1085584783-1085586231  
 left edge = 1085596367  
 right edge = 1085602159 ←  
 left edge = 1085587679  
 right edge = 1085592023  
 left edge = 1085584783  
 right edge = 1085586231



# Packet #14

Pub Frame	Mgmt Frame	IP ID	SEQ #	Column1	Len	Next Seq #
2,703	2,692	33,044	1,085,576,095	1,085,577,542	1,448	1,085,577,543
2,706	2,693	33,046	1,085,577,543	1,085,578,990	1,448	1,085,578,991
2,701	2,694	33,048	1,085,578,991	1,085,580,438	1,448	1,085,580,439
2,705	2,695	33,050	1,085,580,439	1,085,581,886	1,448	1,085,581,887
2,709	2,696	33,052	1,085,581,887	1,085,583,334	1,448	1,085,583,335
2,715	2,697	33,054	1,085,583,335	1,085,584,782	1,448	1,085,584,783
2,708	2,698	33,056	1,085,584,783	1,085,586,230	1,448	1,085,586,231
2,714	2,699	33,058	1,085,586,231	1,085,587,678	1,448	1,085,587,679
2,702	2,700	33,060	1,085,587,679	1,085,589,126	1,448	1,085,589,127
2,704	2,701	33,062	1,085,589,127	1,085,590,574	1,448	1,085,590,575
2,711	2,702	33,064	1,085,590,575	1,085,592,022	1,448	1,085,592,023
2,717	2,703	33,066	1,085,592,023	1,085,593,470	1,448	1,085,593,471
2,719	2,704	33,068	1,085,593,471	1,085,594,918	1,448	1,085,594,919
2,716	2,705	33,070	1,085,594,919	1,085,596,366	1,448	1,085,596,367
2,707	2,706	33,072	1,085,596,367	1,085,597,814	1,448	1,085,597,815
2,710	2,707	33,074	1,085,597,815	1,085,599,262	1,448	1,085,599,263
2,712	2,708	33,076	1,085,599,263	1,085,600,710	1,448	1,085,600,711
2,713	2,709	33,078	1,085,600,711	1,085,602,158	1,448	1,085,602,159
2,718	2,710	33,080	1,085,602,159	1,085,603,606	1,448	1,085,603,607

IP Internet Protocol, Src: 10.128.194.191 (10.128.194.191), Dst: 10.153.2.25 (10.153.2.25) ID=64753  
 TCP D=3001 S=38642 ACK=1085583335 SEQ=2048806047 LEN=0 WIN<<7=37120

SACK: 1085584783-1085592023 1085596367-1085602159  
 left edge = 1085584783  
 right edge = 1085592023  
 left edge = 1085596367  
 right edge = 1085602159

Notice that two of the dis-contiguous blocks are now contiguous; so we go from 3 blocks down to 2 blocks



# Packet #15

Pub Frame	Mgmt Frame	IP ID	SEQ #	Column1	Len	Next Seq #
2,703	2,692	33,044	1,085,576,095	1,085,577,542	1,448	1,085,577,543
2,706	2,693	33,046	1,085,577,543	1,085,578,990	1,448	1,085,578,991
2,701	2,694	33,048	1,085,578,991	1,085,580,438	1,448	1,085,580,439
2,705	2,695	33,050	1,085,580,439	1,085,581,886	1,448	1,085,581,887
2,709	2,696	33,052	1,085,581,887	1,085,583,334	1,448	1,085,583,335
2,715	2,697	33,054	1,085,583,335	1,085,584,782	1,448	1,085,584,783
2,708	2,698	33,056	1,085,584,783	1,085,586,230	1,448	1,085,586,231
2,714	2,699	33,058	1,085,586,231	1,085,587,678	1,448	1,085,587,679
2,702	2,700	33,060	1,085,587,679	1,085,589,126	1,448	1,085,589,127
2,704	2,701	33,062	1,085,589,127	1,085,590,574	1,448	1,085,590,575
2,711	2,702	33,064	1,085,590,575	1,085,592,022	1,448	1,085,592,023
2,717	2,703	33,066	1,085,592,023	1,085,593,470	1,448	1,085,593,471
2,719	2,704	33,068	1,085,593,471	1,085,594,918	1,448	1,085,594,919
2,716	2,705	33,070	1,085,594,919	1,085,596,366	1,448	1,085,596,367
2,707	2,706	33,072	1,085,596,367	1,085,597,814	1,448	1,085,597,815
2,710	2,707	33,074	1,085,597,815	1,085,599,262	1,448	1,085,599,263
2,712	2,708	33,076	1,085,599,263	1,085,600,710	1,448	1,085,600,711
2,713	2,709	33,078	1,085,600,711	1,085,602,158	1,448	1,085,602,159
2,718	2,710	33,080	1,085,602,159	1,085,603,606	1,448	1,085,603,607

IP Internet Protocol, Src: 10.128.194.191 [10.128.194.191], Dst: 10.153.2.25 [10.153.2.25] ID=64754  
 TCP D=3001 S=38642 ACK=1085592023 SEQ=2048806047 LEN=0 WIN<<7=28416

SACK: 1085596367-1085602159  
 left edge = 1085596367  
 right edge = 1085602159

Notice the cumulative ACK has increased to a value of 1085592023 and we're down to just one dis-contiguous block



# Packet #16

Pub Frame	Mgmt Frame	IP ID	SEQ #	Column1	Len	Next Seq #
2,703	2,692	33,044	1,085,576,095	1,085,577,542	1,448	1,085,577,543
2,706	2,693	33,046	1,085,577,543	1,085,578,990	1,448	1,085,578,991
2,701	2,694	33,048	1,085,578,991	1,085,580,438	1,448	1,085,580,439
2,705	2,695	33,050	1,085,580,439	1,085,581,886	1,448	1,085,581,887
2,709	2,696	33,052	1,085,581,887	1,085,583,334	1,448	1,085,583,335
2,715	2,697	33,054	1,085,583,335	1,085,584,782	1,448	1,085,584,783
2,708	2,698	33,056	1,085,584,783	1,085,586,230	1,448	1,085,586,231
2,714	2,699	33,058	1,085,586,231	1,085,587,678	1,448	1,085,587,679
2,702	2,700	33,060	1,085,587,679	1,085,589,126	1,448	1,085,589,127
2,704	2,701	33,062	1,085,589,127	1,085,590,574	1,448	1,085,590,575
2,711	2,702	33,064	1,085,590,575	1,085,592,022	1,448	1,085,592,023
2,717	2,703	33,066	1,085,592,023	1,085,593,470	1,448	1,085,593,471
2,719	2,704	33,068	1,085,593,471	1,085,594,918	1,448	1,085,594,919
2,716	2,705	33,070	1,085,594,919	1,085,596,366	1,448	1,085,596,367
2,707	2,706	33,072	1,085,596,367	1,085,597,814	1,448	1,085,597,815
2,710	2,707	33,074	1,085,597,815	1,085,599,262	1,448	1,085,599,263
2,712	2,708	33,076	1,085,599,263	1,085,600,710	1,448	1,085,600,711
2,713	2,709	33,078	1,085,600,711	1,085,602,158	1,448	1,085,602,159
2,718	2,710	33,080	1,085,602,159	1,085,603,606	1,448	1,085,603,607

IP Internet Protocol, Src: 10.128.194.191 (10.128.194.191), Dst: 10.153.2.25 (10.153.2.25) ID=64755  
 TCP D=3001 S=38642 ACK=1085592023 SEQ=2048806047 LEN=0 WIN<<7=28416

SACK: 1085594919-1085602159  
 left edge = 1085594919  
 right edge = 1085602159



Left edge updated to reflect packet #16



# Packet #17

Pub Frame	Mgmt Frame	IP ID	SEQ #	Column1	Len	Next Seq #
2,703	2,692	33,044	1,085,576,095	1,085,577,542	1,448	1,085,577,543
2,706	2,693	33,046	1,085,577,543	1,085,578,990	1,448	1,085,578,991
2,701	2,694	33,048	1,085,578,991	1,085,580,438	1,448	1,085,580,439
2,705	2,695	33,050	1,085,580,439	1,085,581,886	1,448	1,085,581,887
2,709	2,696	33,052	1,085,581,887	1,085,583,334	1,448	1,085,583,335
2,715	2,697	33,054	1,085,583,335	1,085,584,782	1,448	1,085,584,783
2,708	2,698	33,056	1,085,584,783	1,085,586,230	1,448	1,085,586,231
2,714	2,699	33,058	1,085,586,231	1,085,587,678	1,448	1,085,587,679
2,702	2,700	33,060	1,085,587,679	1,085,589,126	1,448	1,085,589,127
2,704	2,701	33,062	1,085,589,127	1,085,590,574	1,448	1,085,590,575
2,711	2,702	33,064	1,085,590,575	1,085,592,022	1,448	1,085,592,023
2,717	2,703	33,066	1,085,592,023	1,085,593,470	1,448	1,085,593,471
2,719	2,704	33,068	1,085,593,471	1,085,594,918	1,448	1,085,594,919
2,716	2,705	33,070	1,085,594,919	1,085,596,366	1,448	1,085,596,367
2,707	2,706	33,072	1,085,596,367	1,085,597,814	1,448	1,085,597,815
2,710	2,707	33,074	1,085,597,815	1,085,599,262	1,448	1,085,599,263
2,712	2,708	33,076	1,085,599,263	1,085,600,710	1,448	1,085,600,711
2,713	2,709	33,078	1,085,600,711	1,085,602,158	1,448	1,085,602,159
2,718	2,710	33,080	1,085,602,159	1,085,603,606	1,448	1,085,603,607

IP Internet Protocol, Src: 10.128.194.191 (10.128.194.191), Dst: 10.153.2.25 (10.153.2.25) ID=64756  
 TCP D=3001 S=38642 ACK=1085593471 SEQ=2048806047 LEN=0 WIN<<7=27008

SACK: 1085594919-1085602159  
 left edge = 1085594919  
 right edge = 1085602159

Cumulative ACK is updated to reflect receipt of #17  
 No change to SACK fields



# Packet #18

Pub Frame	Mgmt Frame	IP ID	SEQ #	Column1	Len	Next Seq #
2,703	2,692	33,044	1,085,576,095	1,085,577,542	1,448	1,085,577,543
2,706	2,693	33,046	1,085,577,543	1,085,578,990	1,448	1,085,578,991
2,701	2,694	33,048	1,085,578,991	1,085,580,438	1,448	1,085,580,439
2,705	2,695	33,050	1,085,580,439	1,085,581,886	1,448	1,085,581,887
2,709	2,696	33,052	1,085,581,887	1,085,583,334	1,448	1,085,583,335
2,715	2,697	33,054	1,085,583,335	1,085,584,782	1,448	1,085,584,783
2,708	2,698	33,056	1,085,584,783	1,085,586,230	1,448	1,085,586,231
2,714	2,699	33,058	1,085,586,231	1,085,587,678	1,448	1,085,587,679
2,702	2,700	33,060	1,085,587,679	1,085,589,126	1,448	1,085,589,127
2,704	2,701	33,062	1,085,589,127	1,085,590,574	1,448	1,085,590,575
2,711	2,702	33,064	1,085,590,575	1,085,592,022	1,448	1,085,592,023
2,717	2,703	33,066	1,085,592,023	1,085,593,470	1,448	1,085,593,471
2,719	2,704	33,068	1,085,593,471	1,085,594,918	1,448	1,085,594,919
2,716	2,705	33,070	1,085,594,919	1,085,596,366	1,448	1,085,596,367
2,707	2,706	33,072	1,085,596,367	1,085,597,814	1,448	1,085,597,815
2,710	2,707	33,074	1,085,597,815	1,085,599,262	1,448	1,085,599,263
2,712	2,708	33,076	1,085,599,263	1,085,600,710	1,448	1,085,600,711
2,713	2,709	33,078	1,085,600,711	1,085,602,158	1,448	1,085,602,159
2,718	2,710	33,080	1,085,602,159	1,085,603,606	1,448	1,085,603,607

IP Internet Protocol, Src: 10.128.194.191 (10.128.194.191), Dst: 10.153.2.25 (10.153.2.25) ID=64757  
 TCP D=3001 S=38642 ACK=1085593471 SEQ=2048806047 LEN=0 WIN<<7=27008

SACK: 1085594919-1085603607  
 left edge = 1085594919  
 right edge = 1085603607



Right edge updated to reflect packet #18



# Packet #19

Pub Frame	Mgmt Frame	IP ID	SEQ #	Column1	Len	Next Seq #
2,703	2,692	33,044	1,085,576,095	1,085,577,542	1,448	1,085,577,543
2,706	2,693	33,046	1,085,577,543	1,085,578,990	1,448	1,085,578,991
2,701	2,694	33,048	1,085,578,991	1,085,580,438	1,448	1,085,580,439
2,705	2,695	33,050	1,085,580,439	1,085,581,886	1,448	1,085,581,887
2,709	2,696	33,052	1,085,581,887	1,085,583,334	1,448	1,085,583,335
2,715	2,697	33,054	1,085,583,335	1,085,584,782	1,448	1,085,584,783
2,708	2,698	33,056	1,085,584,783	1,085,586,230	1,448	1,085,586,231
2,714	2,699	33,058	1,085,586,231	1,085,587,678	1,448	1,085,587,679
2,702	2,700	33,060	1,085,587,679	1,085,589,126	1,448	1,085,589,127
2,704	2,701	33,062	1,085,589,127	1,085,590,574	1,448	1,085,590,575
2,711	2,702	33,064	1,085,590,575	1,085,592,022	1,448	1,085,592,023
2,717	2,703	33,066	1,085,592,023	1,085,593,470	1,448	1,085,593,471
2,719	2,704	33,068	1,085,593,471	1,085,594,918	1,448	1,085,594,919
2,716	2,705	33,070	1,085,594,919	1,085,596,366	1,448	1,085,596,367
2,707	2,706	33,072	1,085,596,367	1,085,597,814	1,448	1,085,597,815
2,710	2,707	33,074	1,085,597,815	1,085,599,262	1,448	1,085,599,263
2,712	2,708	33,076	1,085,599,263	1,085,600,710	1,448	1,085,600,711
2,713	2,709	33,078	1,085,600,711	1,085,602,158	1,448	1,085,602,159
2,718	2,710	33,080	1,085,602,159	1,085,603,606	1,448	1,085,603,607

IP Internet Protocol, Src: 10.128.194.191 (10.128.194.191), Dst: 10.153.2.25 (10.153.2.25) ID=64758  
TCP D=3001 S=38642 ACK=1085605055 SEQ=2048806047 LEN=0 WIN<<7=17280

New cumulative ACK reflects receipt of all 19 packets  
(Plus, packet 20 not shown in the list....)



# After packet 19

Pub Frame	Mgmt Frame	IP ID	SEQ #	Column1	Len	Next Seq #
2,703	2,692	33,044	1,085,576,095	1,085,577,542	1,448	1,085,577,543
2,706	2,693	33,046	1,085,577,543	1,085,578,990	1,448	1,085,578,991
2,701	2,694	33,048	1,085,578,991	1,085,580,438	1,448	1,085,580,439
2,705	2,695	33,050	1,085,580,439	1,085,581,886	1,448	1,085,581,887
2,709	2,696	33,052	1,085,581,887	1,085,583,334	1,448	1,085,583,335
2,715	2,697	33,054	1,085,583,335	1,085,584,782	1,448	1,085,584,783
2,708	2,698	33,056	1,085,584,783	1,085,586,230	1,448	1,085,586,231
2,714	2,699	33,058	1,085,586,231	1,085,587,678	1,448	1,085,587,679
2,702	2,700	33,060	1,085,587,679	1,085,589,126	1,448	1,085,589,127
2,704	2,701	33,062	1,085,589,127	1,085,590,574	1,448	1,085,590,575
2,711	2,702	33,064	1,085,590,575	1,085,592,022	1,448	1,085,592,023
2,717	2,703	33,066	1,085,592,023	1,085,593,470	1,448	1,085,593,471
2,719	2,704	33,068	1,085,593,471	1,085,594,918	1,448	1,085,594,919
2,716	2,705	33,070	1,085,594,919	1,085,596,366	1,448	1,085,596,367
2,707	2,706	33,072	1,085,596,367	1,085,597,814	1,448	1,085,597,815
2,710	2,707	33,074	1,085,597,815	1,085,599,262	1,448	1,085,599,263
2,712	2,708	33,076	1,085,599,263	1,085,600,710	1,448	1,085,600,711
2,713	2,709	33,078	1,085,600,711	1,085,602,158	1,448	1,085,602,159
2,718	2,710	33,080	1,085,602,159	1,085,603,606	1,448	1,085,603,607

It's been a long, strange journey, but all data has finally been received



# Buffer Mgmt Issues?



- FIFO?
- LIFO?
- UFO?
- IFFY?



# Questions / Comments





# Outcome from this Study



- Client was very pleased that we could help them understand the full extent of the OOS problem
  - Showed that packets are not “just a little out of sequence” but significantly out of sequence
  - Definitely impacted sender’s ability to maintain a large congestion window
  - Client re-evaluated plans to deploy more IPS devices



# Outcome from this Study



- Client shared results with their IPS vendor which triggered a major investigation into stream and buffer management in the IPS



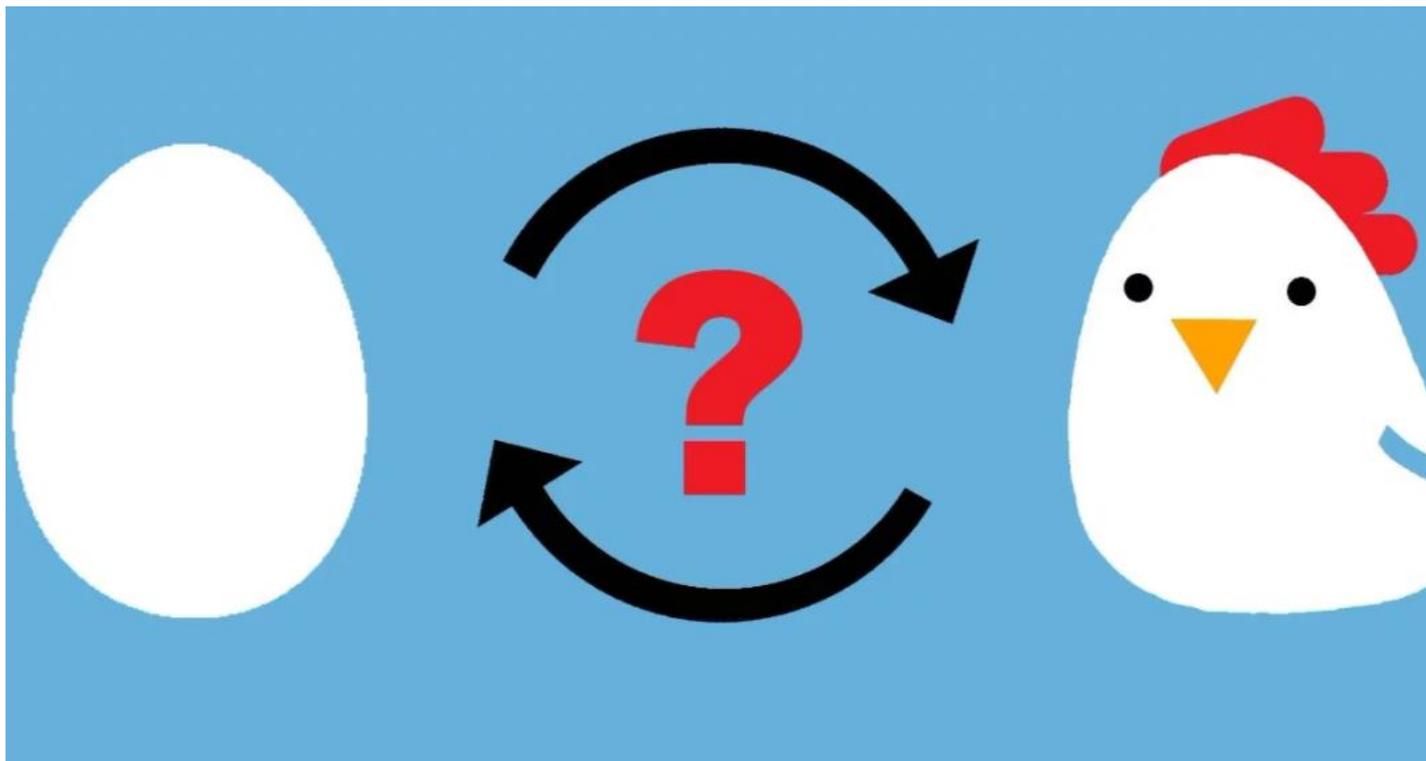
# Outcome from this Study



- A few months later we tested a new model of IPS in Client's lab
- Some improvement but still a problem even at low throughput levels



# Cause and Effect





# Review: Effect of the OOS on the sender

- Potential Throughput Killer: Will likely trigger TCP congestion window reduction if he has to retransmit
- Dependent on the OS and patch level of the sender...and possibly the NIC driver (maybe)
- The RFC for SACK has a lot of “should”s and “may”s.
  - The implementer is allowed a lot flexibility in how they handle the SACK information provided by the receiver



# Effect of the SACK field on the sender



- Consider: should the sender retransmit just one missing segment, or if he can see from the SACK that lot's of different packets are missing should he retransmit all of them
- Also, sender has to maintain all packets in the retransmit queue until they've been ACK'd, possible stress on memory



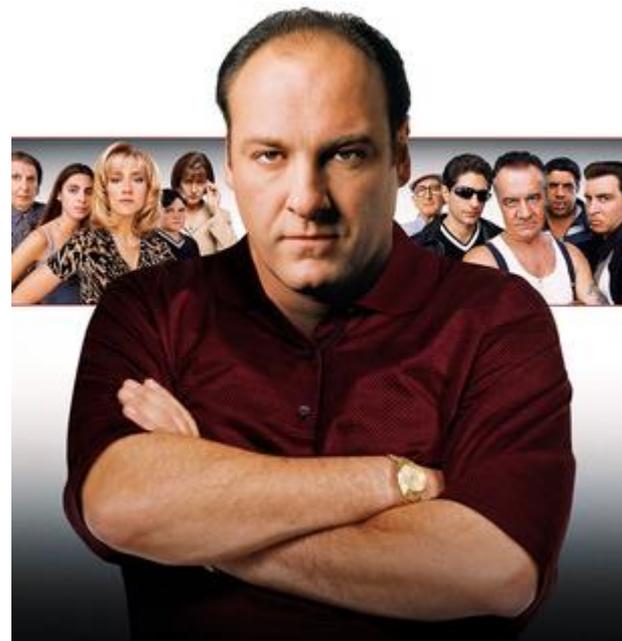
# Impact on Receiver



- He has to buffer all out of sequence packets
- Can not deliver any discontinuous stream bytes to the app until all missing packets are received
- Will generate more ACKs – one for each OOS packet received
- What happens if there are lots of gaps?
  - Remember SACK can only record up to 4 gaps (3 if timestamp option is also being used)



# SACK is not a Promise





# Effect of out of sequence arrivals on the receiver



- Receiver is allowed to “reneg” if he runs out of buffer space

## 8. Data Receiver Reneging

Note that the data receiver is permitted to discard data in its queue that has not been acknowledged to the data sender, even if the data has already been reported in a SACK option. Such discarding of SACKed packets is discouraged, but may be used if the receiver runs out of buffer space.



# Effect on Sender's NIC



- What if TSO is enabled?
- What if TCP Chimney is enabled (Windows)?
- Who is managing the retransmit queue...the TCP Stack on the OS or the NIC?
- I pose these questions because they might be important...
- The specific NIC brand, driver version, and firmware version may impact answers to the above..



# Effect on Sender's ESX Host NIC



- What if TSO is enabled on the Physical NIC?
- Who is managing the retransmit queue...the TCP Stack on ESX, NIC, OS or the vNIC?
- The specific NIC brand, driver version, and firmware version may impact answers to the above..



# Ready to Wrap?



- Let's look at a few reminders...



# Reminders



- You can quickly determine presence of SACK in Wireshark using a display filter!
- “tcp.options.sack.count”
- You can easily add SACK related columns to Wireshark GUI



# SACK Wireshark Columns



No.	Time	Source	Destination	Length	TCP SACK Count	TCP SACK Left Edge	TCP SACK Right Edge	Bytes in flight	Info
31	0.711313	Server	Client	1496				5704	8085 → 43650 [PSH, ACK] Seq=13341 Ack=2171 Win=32044 Len=1430 TSval=1376522
32	0.711325	Server	Client	2914				8552	8085 → 43650 [ACK] Seq=14771 Ack=2171 Win=32044 Len=2848 TSval=1376522143 T
33	0.711339	Server	Client	2914				11400	8085 → 43650 [ACK] Seq=17619 Ack=2171 Win=32044 Len=2848 TSval=1376522143 T
34	0.718880	Client	Server	66				43650	→ 8085 [ACK] Seq=2171 Ack=10493 Win=263440 Len=0 TSval=525253239 TSec
35	0.718888	Server	Client	74				9982	8085 → 43650 [PSH, ACK] Seq=20467 Ack=2171 Win=32044 Len=8 TSval=1376522144
36	0.719162	Client	Server	66				43650	→ 8085 [ACK] Seq=2171 Ack=13341 Win=260592 Len=0 TSval=525253239 TSec
37	0.719441	Client	Server	66				43650	→ 8085 [ACK] Seq=2171 Ack=14771 Win=263440 Len=0 TSval=525253239 TSec
38	0.719446	Client	Server	78	1	17619	19043		[TCP Dup ACK 37#1] 43650 → 8085 [ACK] Seq=2171 Ack=14771 Win=263440 Len=0 T
39	0.721344	Server	Client	1492				7130	8085 → 43650 [PSH, ACK] Seq=20475 Ack=2171 Win=32044 Len=1426 TSval=1376522
40	0.721452	Server	Client	1492				8556	8085 → 43650 [PSH, ACK] Seq=21901 Ack=2171 Win=32044 Len=1426 TSval=1376522
41	0.722115	Server	Client	1492				9982	8085 → 43650 [PSH, ACK] Seq=23327 Ack=2171 Win=32044 Len=1426 TSval=1376522
42	0.726388	Client	Server	86	2	20467,17619	20475,19043		[TCP Dup ACK 37#2] 43650 → 8085 [ACK] Seq=2171 Ack=14771 Win=263440 Len=0 T
43	0.726408	Server	Client	1490				9982	[TCP Fast Retransmission] 8085 → 43650 [ACK] Seq=14771 Ack=2171 Win=32044 L

Urgent pointer: 0

Options: (24 bytes), No-Operation (NOP), No-Operation (NOP), Timestamps, No-Operation (NOP), No-Operation (NOP), SACK

▷ No-Operation (NOP)

▷ No-Operation (NOP)

▷ Timestamps: TSval 525253239, TSecr 1376522143

▷ No-Operation (NOP)

▷ No-Operation (NOP)

◀ SACK: 17619-19043

Kind: SACK (5)

Length: 10

left edge = 17619 (relative)

right edge = 19043 (relative)

[TCP SACK Count: 1]

All bytes through 14770r have been received and I'm ready for 14771r. But wait there's more....



# Power of Profiles



SACK-Sample-Conn43650 - Copy\_anon.pcapng

File Edit View Go Capture Analyze Statistics Telephony Wireless Tools Help

Apply a display filter ... <Ctrl-/>

No.	Time	Source	Destination	Protocol	Length	SACK Count	Cumm ACK	SACK LE 1	SACK RE 1	SACK LE 2	SACK RE 2	Info
37	0.719441	172.20.1.1	10.200.50.1	TCP	66		14771					43650 → 8085 [A
38	0.719446	172.20.1.1	10.200.50.1	TCP	78	1	14771	17619	19043			[TCP Dup ACK 37
39	0.721344	10.200.50.1	172.20.1.1	TCP	1492		2171					8085 → 43650 [P
40	0.721452	10.200.50.1	172.20.1.1	TCP	1492		2171					8085 → 43650 [P
41	0.722115	10.200.50.1	172.20.1.1	TCP	1492		2171					8085 → 43650 [P
42	0.726388	172.20.1.1	10.200.50.1	TCP	86	2	14771	20467	20475	17619	19043	[TCP Dup ACK 37
43	0.726408	10.200.50.1	172.20.1.1	TCP	1490		2171					[TCP Fast Retra
44	0.728899	172.20.1.1	10.200.50.1	TCP	86	2	14771	20467	21899	17619	19043	[TCP Dup ACK 37
45	0.728910	172.20.1.1	10.200.50.1	TCP	86	2	14771	20467	21901	17619	19043	[TCP Dup ACK 37
46	0.728915	10.200.50.1	172.20.1.1	TCP	1490		2171					[TCP Out-Of-Ord
47	0.728920	10.200.50.1	172.20.1.1	TCP	1490		2171					[TCP Out-Of-Ord



# Reminders



- Firewall sequence number randomization can render SACK unusable by the sending host
  - Result = no benefit from SACK



# Closing Remarks



- Focus on “Bytes in Flight” Data
  - If you see the congestion window constantly closing or reduced by half, then you need to figure out why
  - Interpreting SACK might help complete the picture
- It’s easy to get lost drilling in to SACK fields...
- It’s prudent to interpret some of them and make a high level assessment as to the extent of OOS packets
  - To interpret them you have to understand the RFC and expected behavior



# Closing Remarks



- If you have a lot of SACKs with 3 or 4 gaps declared, then OOS is “high” / “pervasive”
- If you have a few SACKs with only 1 gap each, then OOS may be less of a contributing factor



# Supplemental Analytics Help



AppDoctor - MGT FULL filtered 1 out of 1 pass Scenario 1 Test 8\_bwlgnore

Summary of Delays | Executive Summary | Diagnosis | Statistics

	Total	Client	Server
User Think Time (sec)	0.000000	0.000000	N/A
Effect of Processing (sec)	1.529801	0.014252	1.515549
Effect of Network (sec)	1.988712	N/A	N/A
Parallel Effects (sec)	0.000000	N/A	N/A

	Total	Client <-> Server
Duration (sec)	3.518513	3.518513
Response Time (sec)	3.518513	3.518513
Application Turns	9	9
Application Messages	96	96
Application Data (bytes)	44,916,787	44,916,787
Average Application Message (bytes)	467,883.20	467,883.20
Network Packets	49,360	49,360
Network Data (bytes)	48,518,563	48,518,563
Average Network Packet (bytes)	982.95	982.95
Latency (ms)	N/A	0.00
Effect of Latency (sec)	0.000000	0.000000
Bandwidth (Kbps)	N/A	Ignored
Effect of Bandwidth (sec)	0.000000	0.000000
Effect of Protocol (sec)	1.988712	1.988712
Effect of Congestion (sec)	0.000000	0.000000
Effect of Network Transfer (sec)	1.988712	1.988712
Max Application Bytes Per Turn (A -> B)	N/A	2,761
Max Application Bytes Per Turn (A <- B)	N/A	44,911,370
Max Unacknowledged Data (A -> B) (bytes)	N/A	2,761
Max Unacknowledged Data (A <- B) (bytes)	N/A	88,328
Retransmissions	117	117
Out of Sequence Packets	49	49
Connection Resets	0	0
TCP Frozen Window (sec)	3.323480	3.323480
TCP Nagle's Algorithm (sec)	0.000000	0.000000
TCP Triple-Duplicate ACK Loss Indications	30	30

Export to Spreadsheet

Refine Network Effects...

AppDoctor - MGT FULL filtered 1 out of 1 pass Scenario 1 Test 8\_bwlgnore

Summary of Delays | Executive Summary | Diagnosis | Statistics

< Back

Double-click on a section for more information about that source of delay.

**Response time: 3.52 sec**

Server

Client <-> Server

Client

**Processing Effects**

- Tier Processing

**Network Effects**

- Latency
- Bandwidth
- Protocol
- Congestion

Exploded Pie Chart  Show values  Show Think Time

Refine Network Effects... Update Close

