SharkFest'17 US

TCP Selective Acknowledgement

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SharkFest'17 US • Carnegie Mellon University • June 19-22, 2017

Abstract

- RFC 2018 introduced an optional ACK mechanism called “Selective Acknowledgement” (SACK)
- Understanding how to interpret SACK can help you be more effective and determine effect on overall performance of the application

Agenda

- Relevant RFCs
- TCP ACK Simple Review
- SACK Introduction
- SACK Decodes
- SACK Example Illustration
- Lab Troubleshooting - Visualization Replay
- Wrap-Up

Related RFCs

- RFC 793 – TCP (Original RFC)
- RFC 2018 – TCP Selective ACK Options
- RFC 2883 – An Extension to SACK …

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

ACK Decode Review

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 <u>in order</u> 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 ACK – A TCP Enhancement

- 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

- 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, you may find the root cause is severe out of sequence packets

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
- If you capture on sender you'll see retransmissions and DupACKs
- If you capture on receiver you'll see DupACKs and OOS

Selective ACK Wireshark Decode

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….

Selective ACK Wireshark Decode

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=13765221
41	0.722115	Server	Client	1492				9982	8085 → 43650 [PSH, ACK] Seq=23327 Ack=2171 Win=32044 Len=1426 TSval=13765221
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 TS
43	0.726408	Server	Client	1490				9982	[TCP Fast Retransmission] 8085 → 43650 [ACK] Seq=14771 Ack=2171 Win=32044 Le
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 TS
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 TS
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 TS
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 TS
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 TS

```
▷ Timestamps: TSval 525253240, TSecr 1376522143
▷ No-Operation (NOP)
▷ No-Operation (NOP)
◢ 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]
```

SACK Illustration #1

- Sender transmits 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

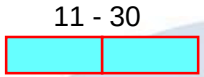
SACK Illustration #1

- Sender transmits 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

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

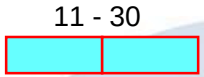
SACK Visualization #1

1st two packets arrive



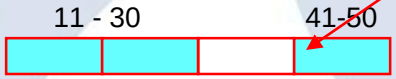
SACK Visualization #1

1st two packets arrive



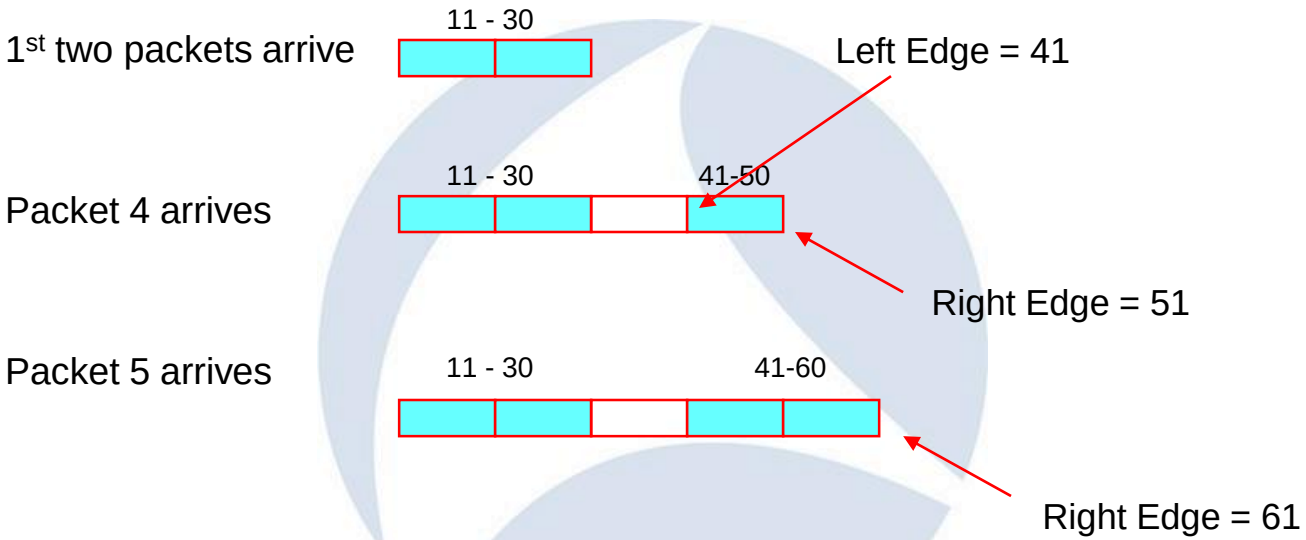
Left Edge = 41

Packet 4 arrives



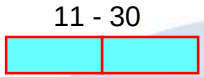
Right Edge = 51

SACK Visualization #1



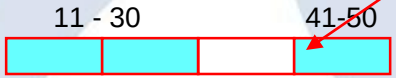
SACK Visualization #1

1st two packets arrive



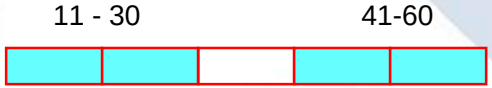
Left Edge = 41

Packet 4 arrives



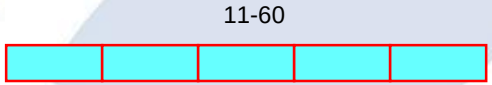
Right Edge = 51

Packet 5 arrives



Right Edge = 61

Packet 3 arrives



All data received up through and including byte 60

Receiver's ACK responses

Pkt 1 SEQ=11 Len=10
Pkt 2 SEQ=21 Len=10

- Pkt 1 Arrives, receiver starts delayed ACK timer, waits for a 2nd packet
- 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 it's out of order, receiver issues immediate ACK because packet is out of order
  - ACK=31 SACK=41-51

Pkt 5 SEQ=51 Len=10

- Pkt 5 Arrives but it's also out of order, receiver issues immediate ACK because packet is out of order
  - 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

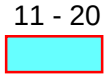
Another Example, Slightly More Complicated

Sender transmits 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

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

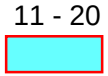
Packet 1 arrives



Start Delayed ACK Timer…

SACK Visualization #2

Packet 1 arrives



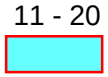
Start Delayed ACK Timer…

Packet 3 arrives

ACK=21 SACK=31-41

SACK Visualization #2

Packet 1 arrives

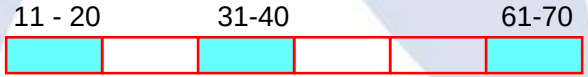


Start Delayed ACK Timer…

Packet 3 arrives

ACK=21 SACK=31-41

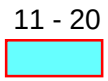
Packet 6 arrives



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

SACK Visualization #2

Packet 1 arrives

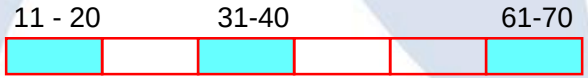


Start Delayed ACK Timer…

Packet 3 arrives

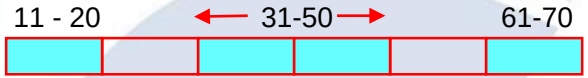
ACK=21 SACK=31-41

Packet 6 arrives



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

Packet 4 arrives



ACK=21 SACK=31-51,61-71

SACK Visualization #2

Packet 5 arrives

ACK=21 SACK 31-71

SACK Visualization #2

Packet 5 arrives

ACK=21 SACK 31-71

How many packets are in sender's retransmit queue?

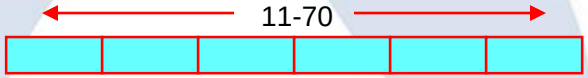
How many packets are in receiver's queue?

SACK Visualization #2

Packet 5 arrives

ACK=21 SACK 31-71

Packet 2 arrives



ACK=71

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 Cumulative ACK sequence numbers in the TCP header seen 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 Randomization

- 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 Randomization

- 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
```

From the Field: Troubleshooting Engagement

- Next we're going to look at actual results from a troubleshooting engagement involving crazy high levels out of sequence packets

From the Field: Troubleshooting Engagement

- Test lab setup
- Traffic downloaded from an Image Server in a "MGMT" security zone - to a client host in the "PUBLIC" security zone

- All traffic is internal to the data center with high end network gear and 10G links
- Throughput should be scream'n, right?
- Sadly, it's awful – should we upgrade to 40G?

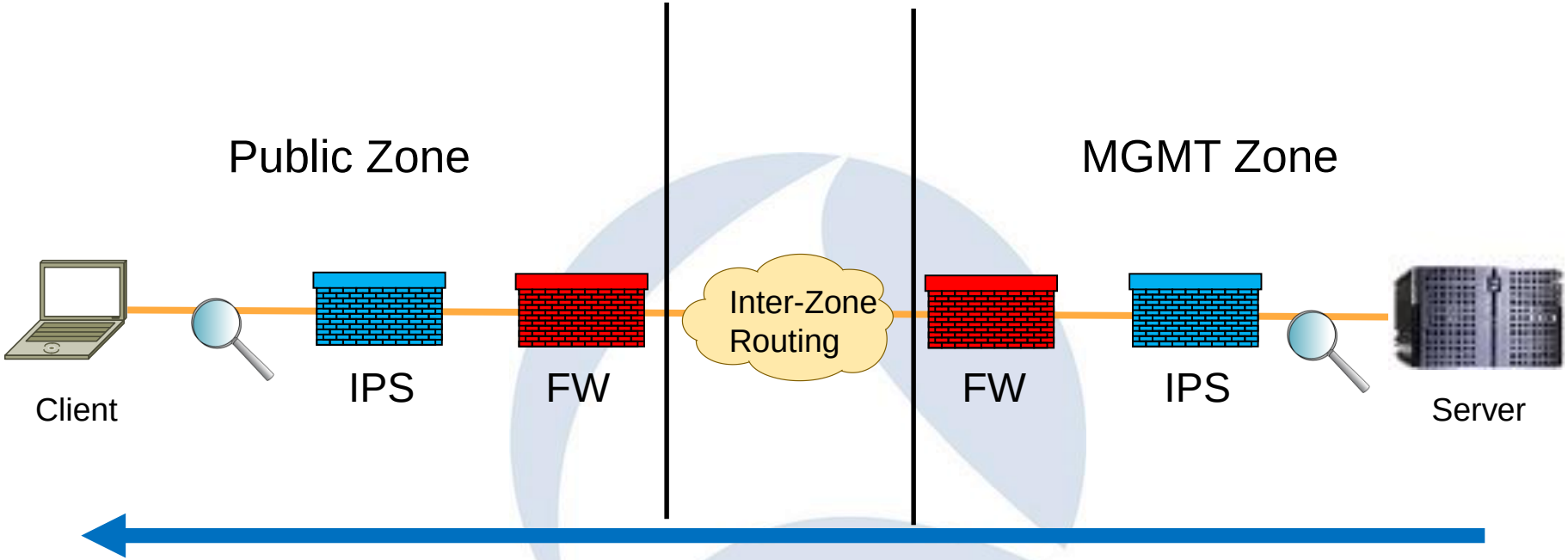
Lab Configuration

- Network gear between Image Server and Client

- There are two firewalls…
- … two IPS…
- … and one router

- Two capture points: before “MGMT” IPS and after “PUBLIC” IPS

Lab Configuration Abstract



Client Downloading Configuration Build Details from Server

Packet Capture Source

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: Need to figure out why throughput is so low, and help identify the vendor causing the problem

Packet Captures

- Wireshark host captures
- Laptops each getting a SPAN feed
- One on “internal” side of the IPS in the MGMT Zone
- One on “internal” side of the IPS in the Public Zone

Summary of Delays

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

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 E

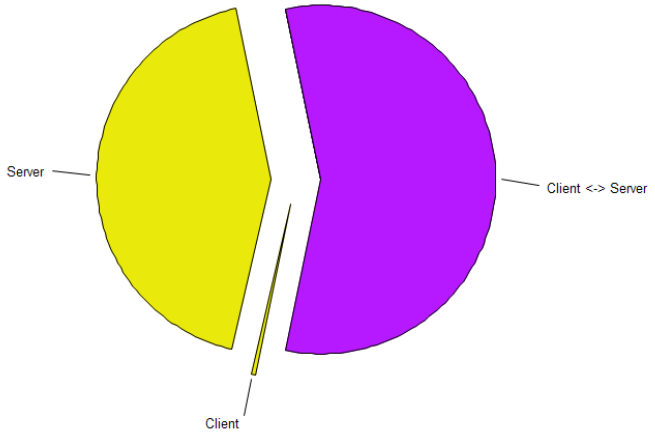
AppDoctor - MGT FULL filtered 1 out of 1 pass Scenario 1 Test 8_bwIgnore

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



Processing Effects: Tier Processing

Network Effects: Latency, Bandwidth, Protocol, Congestion

Exploded Pie Chart | Show values | Show Think Time | Help

Refine Network Effects... | Update | Close

In-flight Data Analysis

Transaction Analyzer: MGT FULL filtered 1 out of 1 pass Scenario 1 Test 8_bwIgnore

File Edit View AppDoctor Simulation Reports Capture Advanced Windows Help

Tree View | Tier Pair Circle | Data Exchange Chart | Unzoom

TCP In-Flight Data (bytes): Client to Server
TCP In-Flight Data (bytes): Server to Client

100,000
50,000
0

Network Packet Chart — Network chart only

1.56 1.57 1.58 1.59s 1.6 1.61 1.62 1.63s 1.64 1.65 1.66 1.67s 1.68 1.69 1.7 1.71s

3ACK, R (of 129) | 5x R | 3ACK, 8x R | 2x 3ACK, 4x R | Client | Server

TCP: Carries Data | Dataless ACK | Retransmission | Conn. Control | Not TCP

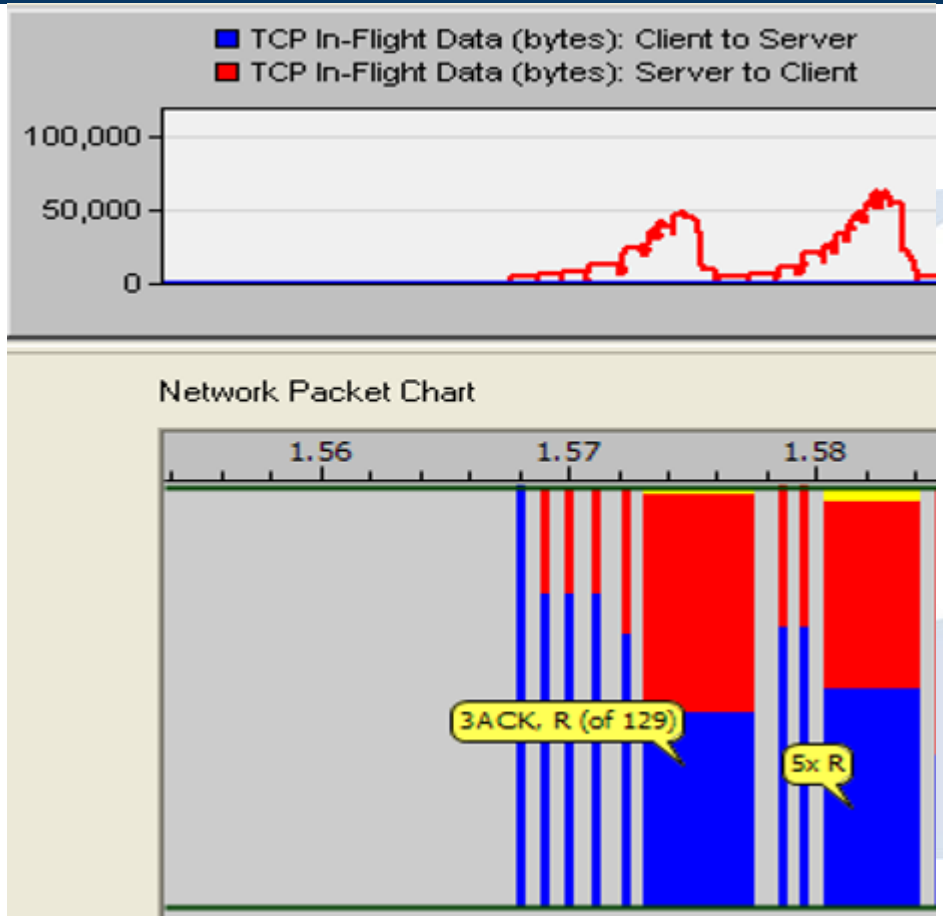
Dependency delays: Network Delay | Application Delay | User Think Time Delay

Frame	Source	Destination	Size	Send Time	Recv Time	Decode	Labels	Decode Summary
366	Client	Server	66	1.58475	1.58475	TCP		D=3001 S=38642 ACK=1083420470 SEQ=2048806047 LEN=0 WIN<<7=49280
367	Client	Server	78	1.58481	1.58481	TCP		D=3001 S=38642 ACK=1083420470 SEQ=2048806047 LEN=0 WIN<<7=49280
368	Client	Server	78	1.58483	1.58483	TCP		D=3001 S=38642 ACK=1083420470 SEQ=2048806047 LEN=0 WIN<<7=49280
369	Client	Server	78	1.58488	1.58488	TCP		D=3001 S=38642 ACK=1083420470 SEQ=2048806047 LEN=0 WIN<<7=49280
370	Client	Server	78	1.58490	1.58490	TCP		D=3001 S=38642 ACK=1083420470 SEQ=2048806047 LEN=0 WIN<<7=49280
371	Client	Server	78	1.58493	1.58493	TCP		D=3001 S=38642 ACK=1083420470 SEQ=2048806047 LEN=0 WIN<<7=49280
372	Client	Server	66	1.58530	1.58530	TCP		D=3001 S=38642 ACK=1083424814 SEQ=2048806047 LEN=0 WIN<<7=45056

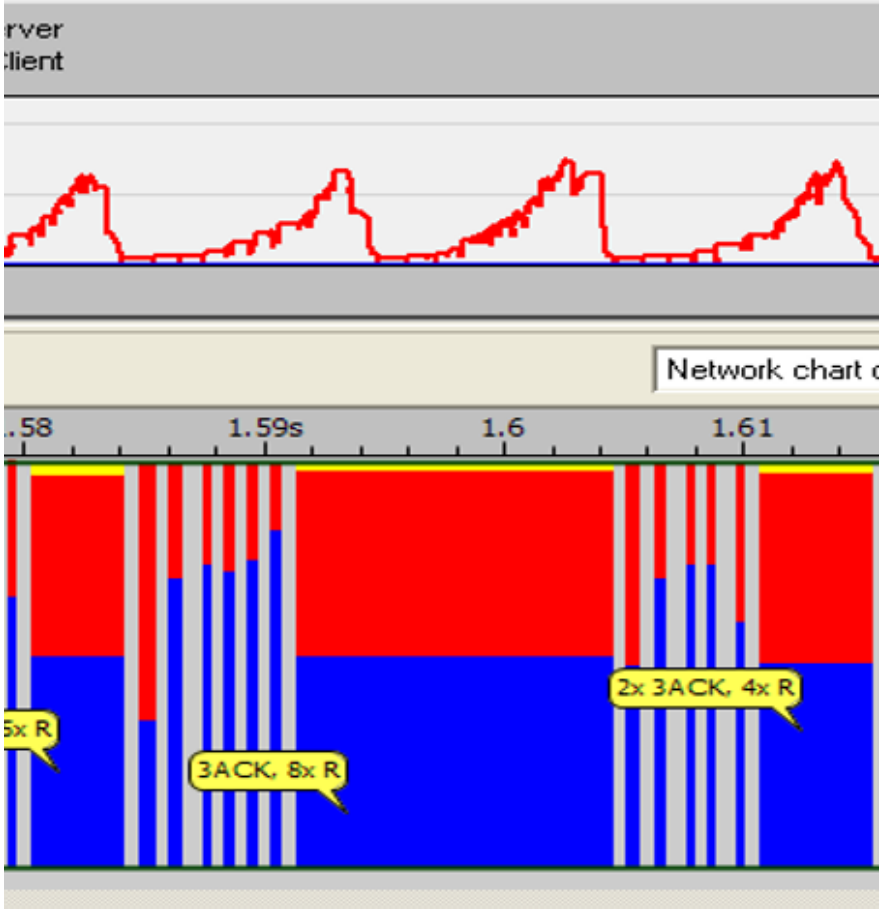
Group by: Frames — 7 packets — Summary decode level: Highest

17:49:38.1625 Thu Apr 15 2010

Zoom #1 - In-flight Data Analysis



Zoom #2 - 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 of out of sequence packets is crazy high and it’s a nice example to illustrate how to interpret the SACK field

ACK Packets Corresponding to a Packet Burst

These are the ACKs from the client
Each ACK corresponds to one of the 19 packets in the burst shown above
We'll use these ACKs to determine the arrival order for the 19 packets

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

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

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?
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
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

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

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

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 #	[illegible]	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

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

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

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,		
2,708	2,698	33,056	1,085,584,783	1,085,586,		
2,714	2,699	33,058	1,085,586,231	1,085,587,		
2,702	2,700	33,060	1,085,587,679	1,085,589,		
2,704	2,701	33,062	1,085,589,127	1,085,590,		
2,711	2,702	33,064	1,085,590,575	1,085,592,		
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

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,		
2,708	2,698	33,056	1,085,584,783	1,085,586,		
		33,058	1,085,586,231	1,085,587,		
		33,060	1,085,587,679	1,085,589,		
		33,062	1,085,589,127	1,085,590,		
		33,064	1,085,590,575	1,085,592,		
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

Packet Just Received Bracketed in Red

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

Orientation

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,		
2,708	2,698	33,056	1,085,584,783	1,085,586,		
		33,058	1,085,586,231	1,085,587,		
		33,060	1,085,587,679	1,085,589,		
		33,062	1,085,589,127	1,085,590,		
		33,064	1,085,590,575	1,085,592,		
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

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
[illegible]	[illegible]	[illegible]	1,085,594,919	1,085,596,366	1,448	1,085,596,367
[illegible]	[illegible]	[illegible]	1,085,596,367	1,085,597,814	1,448	1,085,597,815
[illegible]	[illegible]	[illegible]	1,085,597,815	1,085,599,262	1,448	1,085,599,263
[illegible]	[illegible]	[illegible]	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
[illegible]	[illegible]	[illegible]	1,085,594,919	1,085,596,366	1,448	1,085,596,367
[illegible]	[illegible]	[illegible]	1,085,596,367	1,085,597,814	1,448	1,085,597,815
[illegible]	[illegible]	[illegible]	1,085,597,815	1,085,599,262	1,448	1,085,599,263
[illegible]	[illegible]	[illegible]	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….?

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 makes sense..

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

1st 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
```

2nd 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
```

3rd 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

4th 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

5th 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 segment groups

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

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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

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

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

Effect of out of sequence arrivals on the 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)

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?
- 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..

Reminder

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

End of Session

- Thank you for your attendance and participation