TCP Congestion Avoidance

Joshua Gancher

November 10, 2016

A little history

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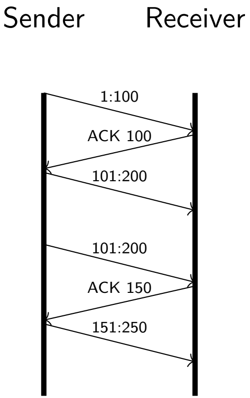
- 1961: Leonard Kleinrock – queueing theory $\Longrightarrow$ packet switching
- 1964: Dartmouth Time Sharing System
- 1969: Beginning of ARPANET – UCLA, SRI, UCSB, Utah
  - Initially over NCP

"We typed the L and we asked on the phone, "Do you see the L?"
"Yes, we see the L," came the response.
"We typed the O, and we asked, "Do you see the O."
"Yes, we see the O."
"Then we typed the G, and the system crashed...
Yet a revolution had begun..."

Kleinrock, at UCLA

TCP in One Slide



$(wsize = 100; \text{rate} = wsize/RTT)$

- 1974: RFC 675
  - (coined the term Internet)

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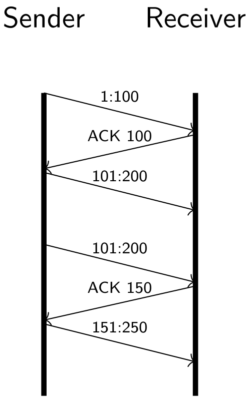

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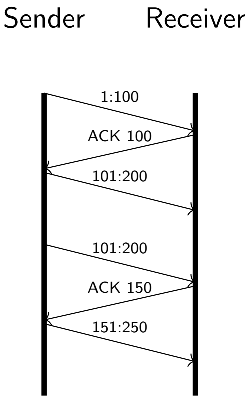

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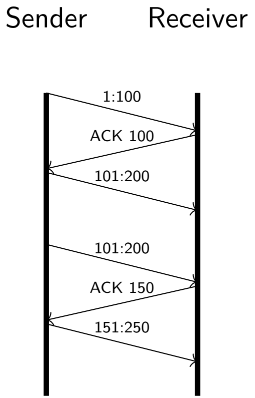

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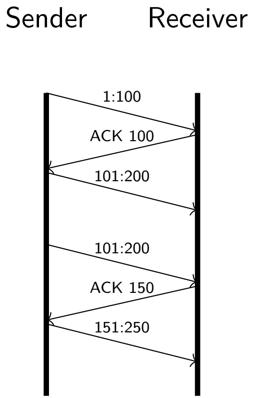

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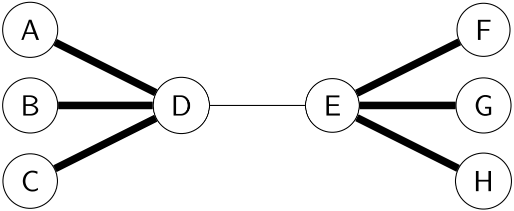
- All data carries a sequence number
- Receiver sends back cumulative acknowledgement (ACKs)
  - If no ACK, retransmit from last ACK
- Receiver advertises window size in header

TCP Sending Behavior

Repeat:

1. Send packet
2. Wait for ack
3. If no ack within timeout, retransmit until acknowledged

Bottleneck Buffers



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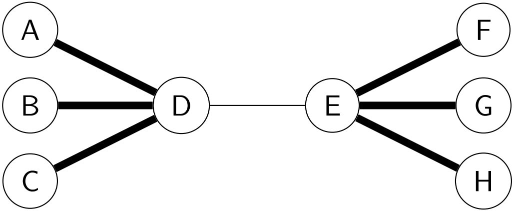

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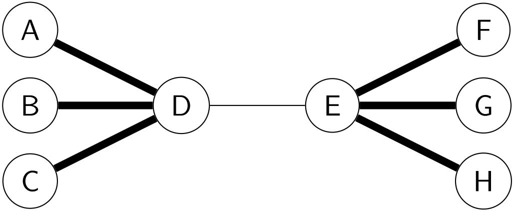

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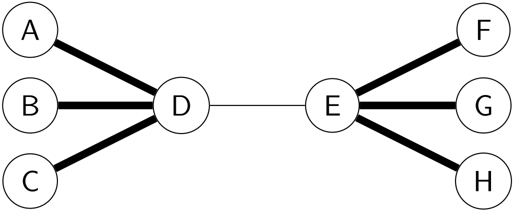

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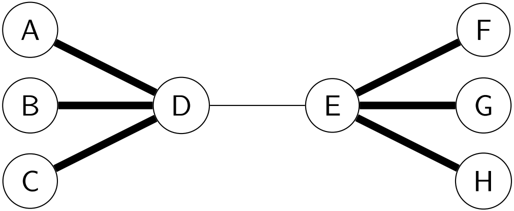

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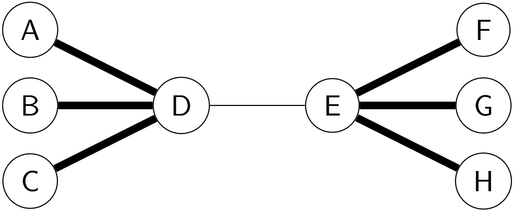

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What if timeout range is smaller than transmit time?

Congestion Collapse

1986: NSFNET dropped from 32 Kb/s to 40 b/s

> *[Hosts] will begin to introduce more and more copies of the same datagrams into the net. The network is now in serious trouble... Hosts are sending each packet several times, and eventually some copy of each packet arrives at its destination. This is congestion collapse. – RFC 896*

Optimistic Case / Worst Case

- Low demand on network
- No major bottleneck
- Little packet loss

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$\Downarrow$

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Optimistic Case / Worst Case

Optimistic Case	Worst Case
▶ Low demand on network ▶ No major bottleneck ▶ Little packet loss	▶ High demand on network ▶ Bottleneck ▶ High packet loss
⇓	⇓
▶ Low load stable state ▶ Low round trip time	▶ High load stable state ▶ High round trip time

Congestion Avoidance and Control

Van Jacobson*

University of California
Lawrence Berkeley Laboratory
Berkeley, CA 94720
van@helios.ee.lbl.gov

- From Berkeley; now at UCLA
- Major contributions to TCP/IP
- Member of the Internet Hall of Fame

Conservation of Packets

Conservation

Under stable conditions, new packets enter the stream only when old packets leave.

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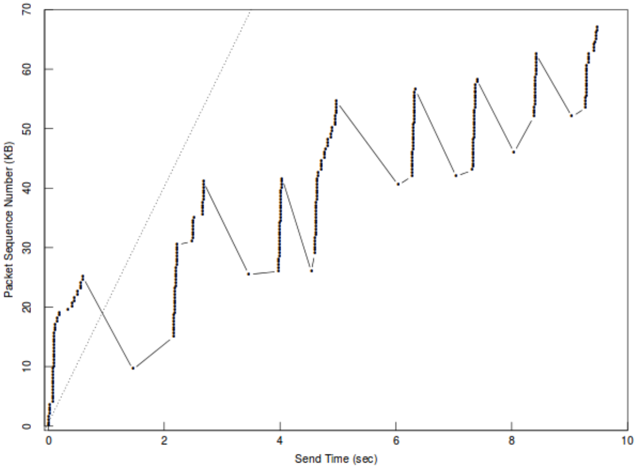
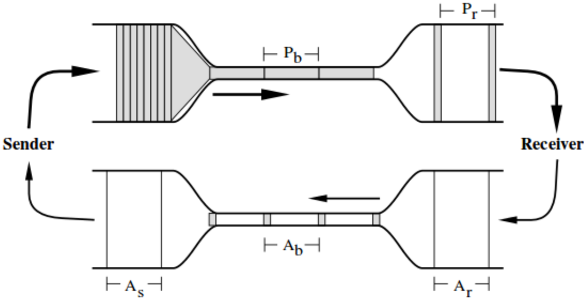
- A new packet enters before an old packet is received
- In-transit packet loss

Stability

Problem 1: Stability



Self-Clocking TCP



Slow Start

Congestion Windows

```
Initialize: cwnd := 1
On ack: cwnd++
On packet loss: set cwnd := 1
On send: send min(cwnd, receiver's window size)
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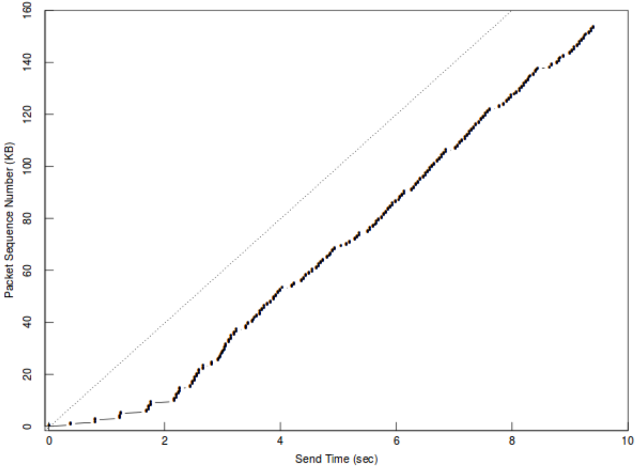
- Exponential acceleration to receiver's window size ($R \log W$ time to reach window size of W)
- Reset back to 1 on failure (will be amended)

Execution with Slow Start



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- Each ACK: $RTT := \alpha \cdot RTT + (1 - \alpha) \cdot M$
  - Where $\alpha \approx 0.9$

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- Each ACK: $RTT := \alpha \cdot RTT + (1 - \alpha) \cdot M$
  - Where $\alpha \approx 0.9$
- Set timeout to $\beta \cdot RTT$
  - Where $\beta \approx 2$

Round-Trip Time Estimation

Figure 5: Performance of an RFC793 retransmit timer

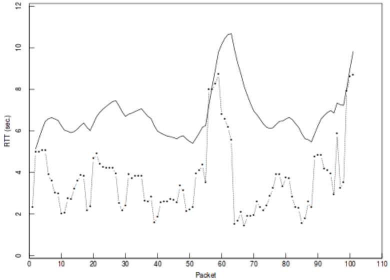
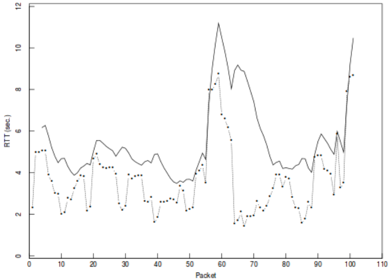


Figure 6: Performance of a Mean+Variance retransmit timer



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- Low load: average buffer length $\approx$ constant
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Queueing theory:

- Low load: average buffer length ≈ constant
- Congestive load: average buffer length ≈ exponential growth

Jacobson's insight:

- Use timeouts to determine congestion
- No congestion: log growth
- Congestion: exponential decay

New Congestion Window Algorithm

```
On timeout: ssthresh := cur window size / 2
            cwnd := 1
On ack: if cwnd < ssthresh, cwnd++ // slow start
        else, cwnd += 1/cwnd // exploratory growth
```

Congestion Avoidance

Figure 8: Multiple, simultaneous TCPs with no congestion avoidance

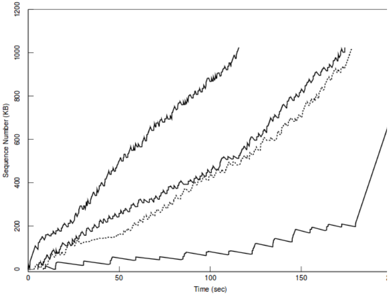
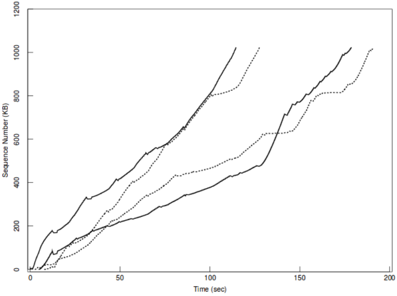


Figure 9: Multiple, simultaneous TCPs with congestion avoidance



Biggest lesson learned:

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- Analytic methods $\Longrightarrow$ tiny codebase which does a whole lot

TCP Congestion Control with a Misbehaving Receiver

Stefan Savage, Neal Cardwell, David Wetherall, and Tom Anderson
Department of Computer Science and Engineering
University of Washington, Seattle

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TCP Congestion Control with a Misbehaving Receiver

- Van Jacobson paper assumes coordination
- Attacks: Malicious receivers can encourage unfriendliness
- Modifications to disable such attacks

Attack 1: ACK Division

ACK Granularity

During slow start, acks assumed to be in units of segments

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- Send many acks for each segment received

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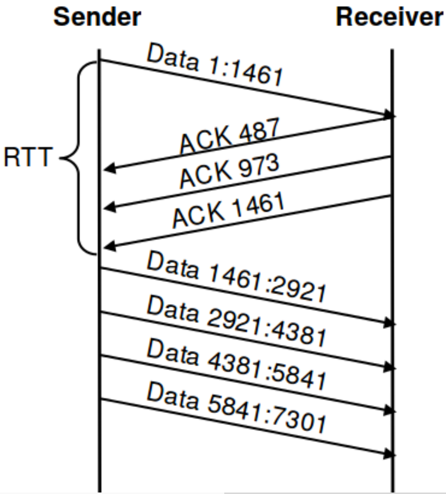
ACK Granularity

During slow start, acks assumed to be in units of segments

Attack:

- Send many acks for each segment received
- Causes congestion window to increase many times

Attack 1: ACK Division



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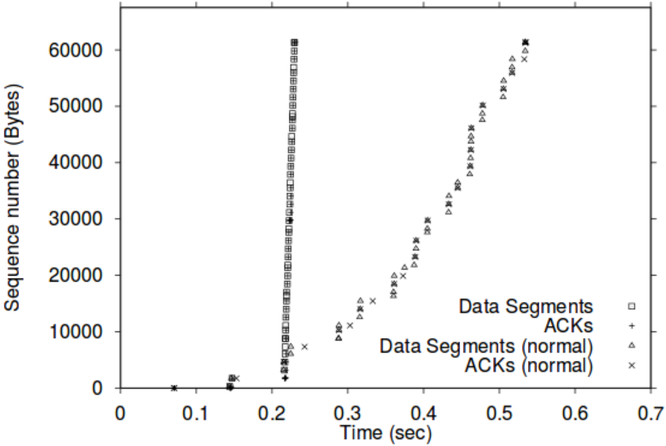

Attack 1: ACK Division

Solution:

- Require unambiguous ACK granularity

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Solution:

- Require unambiguous ACK granularity
- Either byte-level or segment-level

Attack 2: Duplicate ACKs

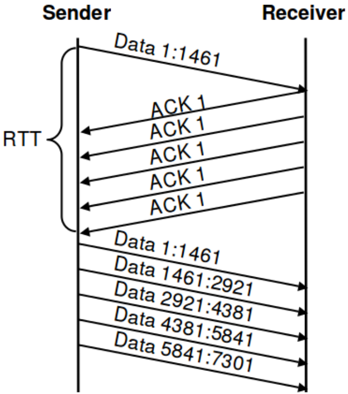
Duplicate ACKs

Duplicate ACKs interpreted as duplicate packets leaving the network; each ACK increases cwnd

Attack:

- Flood connection with duplicate ACKs

Attack 2: Duplicate ACKs



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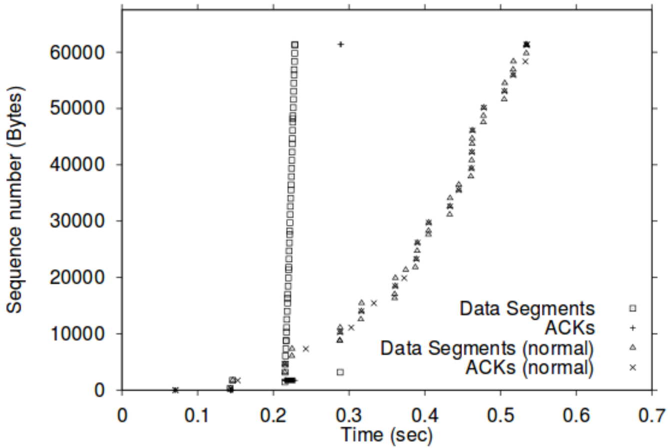


Attack 2: Duplicate ACKs

Solution:

- Attach nonces to retransmitted data

Attack 3: Optimistic ACKing

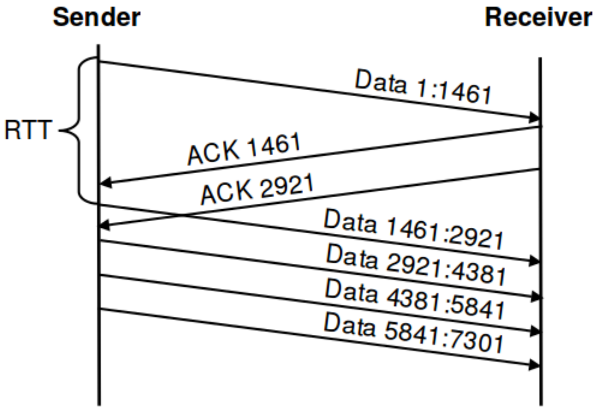
Optimistic ACKs

ACKs can be sent before data is received, obtaining artificially low RTT

Attack:

- Send ACKs before data is received
- Time so that ACK received just after data is sent

Attack 3: Optimistic ACKing



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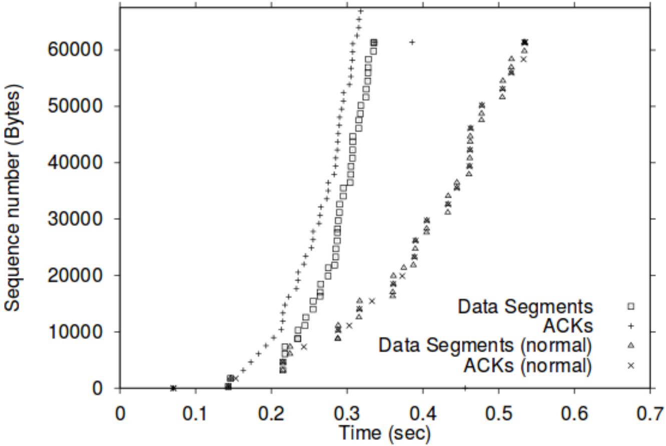
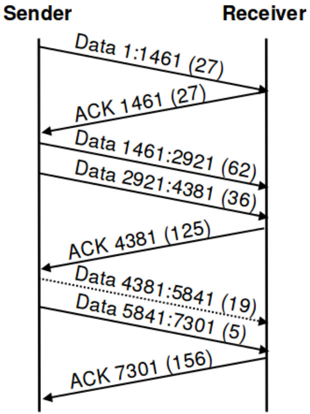


Attack 3: Optimistic ACKing

Solution:

- Use cumulative nonces to enforce causality



	ACK Division	DupACK Spoofing	Optimistic Acks
Solaris 2.6	Y	Y	Y
Linux 2.0	Y	Y (**N**)	Y
Linux 2.2	**N**	Y	Y
Windows NT4/95	Y	**N**	Y
FreeBSD 3.0	Y	Y	Y
DIGITAL Unix 4.0	Y	Y	Y
IRIX 6.x	Y	Y	Y
HP-UX 10.20	Y	Y	Y
AIX 4.2	Y	Y	Y

Lesson learned:

- Must assume malicious behavior in wide area networks!!
- More important now than ever