Networking (from an OS perspective)

David Goff

Congestion and TCP

- Even between trustworthy individuals, TCP can collapse when under severe congestion
  - 3-hop link between LBL and UC Berkley
  - October 1986, throughput dropped from 32Kbps to 40bps
  - Thousandfold drop in bandwidth
- Malicious receivers can take advantage of oversights in TCP to increase their own throughput at the expense of others

Congestion Avoidance and Control

- Van Jacobson
  - Cisco → Parc

Source: http://en.wikipedia.org/wiki/Van_Jacobson

Conservation of Packets Principle

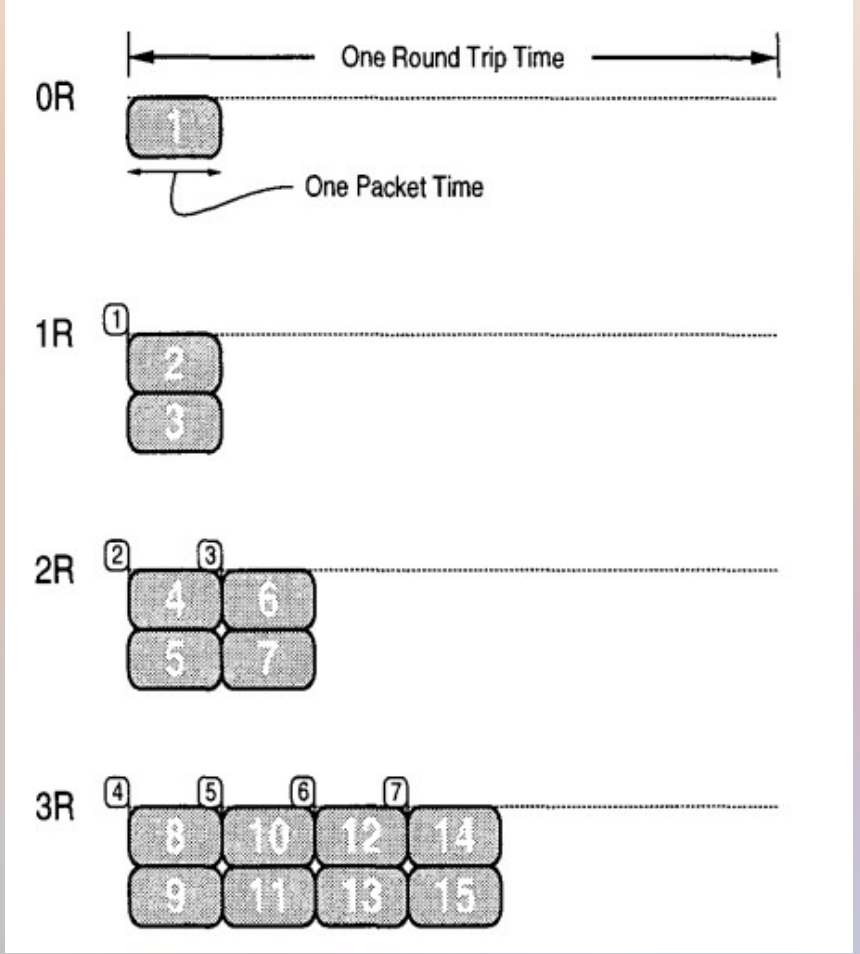
- Packets reach an equilibrium
- Once reached, packets enter and leave the network at the same rate
- So, how do we uphold this principle?
  - Well, what conditions might cause it to be violated?
  - And, how do we prevent these conditions?

Failure Cases for Packet Conservation

- Case I: The connection does not get to equilibrium
- Case II: Sender adds packets faster than they are removed
- Case III: Resource limits within the network path prevent equilibrium from being reached

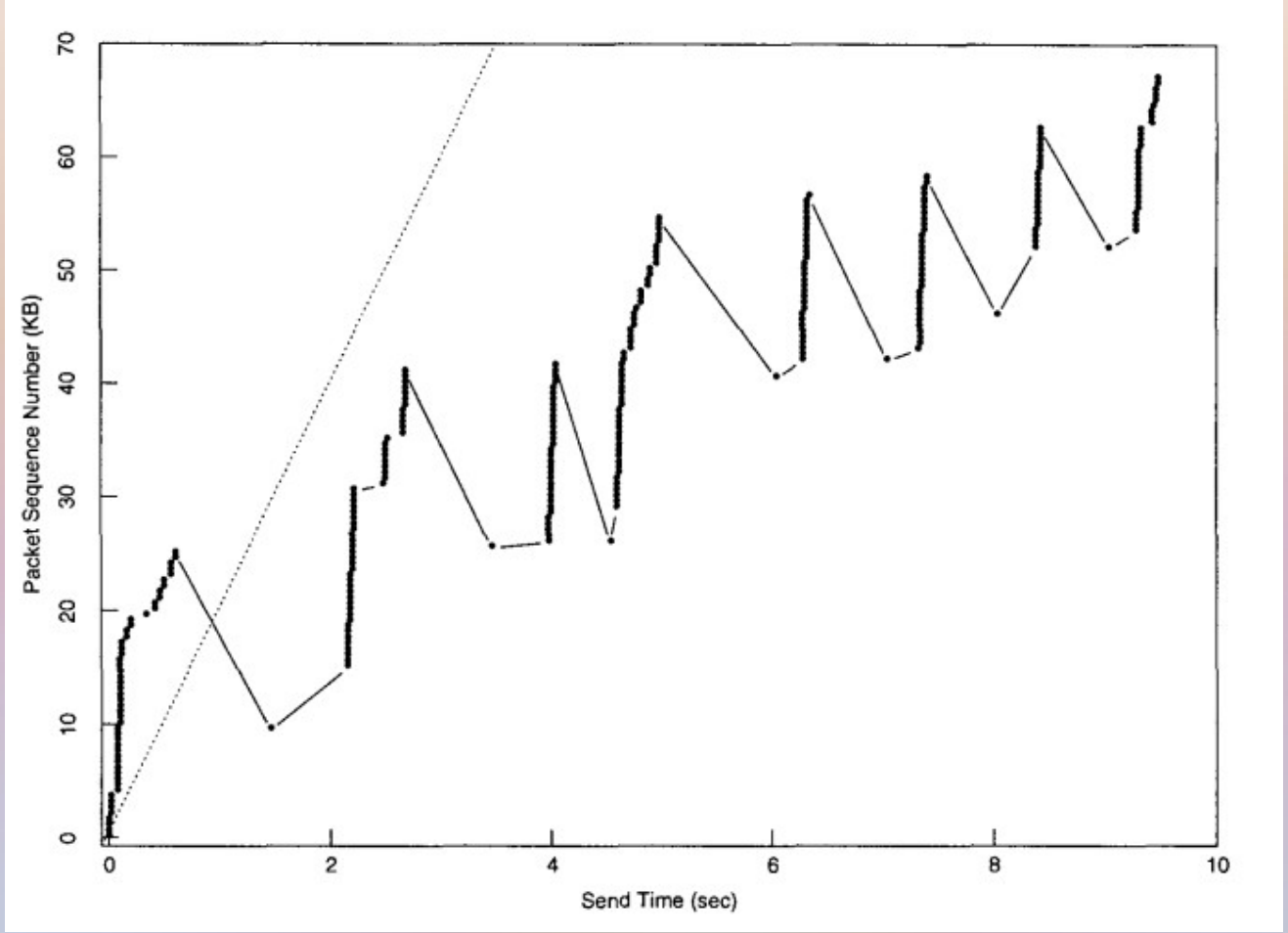
Case I - Getting to Equilibrium

- Slow Start
- Keep a congestion window, *cwnd*
- Start with *cwnd* = 1
- Increase *cwnd* by 1 for each ACK
- Not actually that slow



Congestion Avoidance and Control, Van Jacobson. Appears in Proceedings of ACM SIGCOMM, Vo1ume 18, Number 4, (August 1988).

Startup behavior without Slow Start



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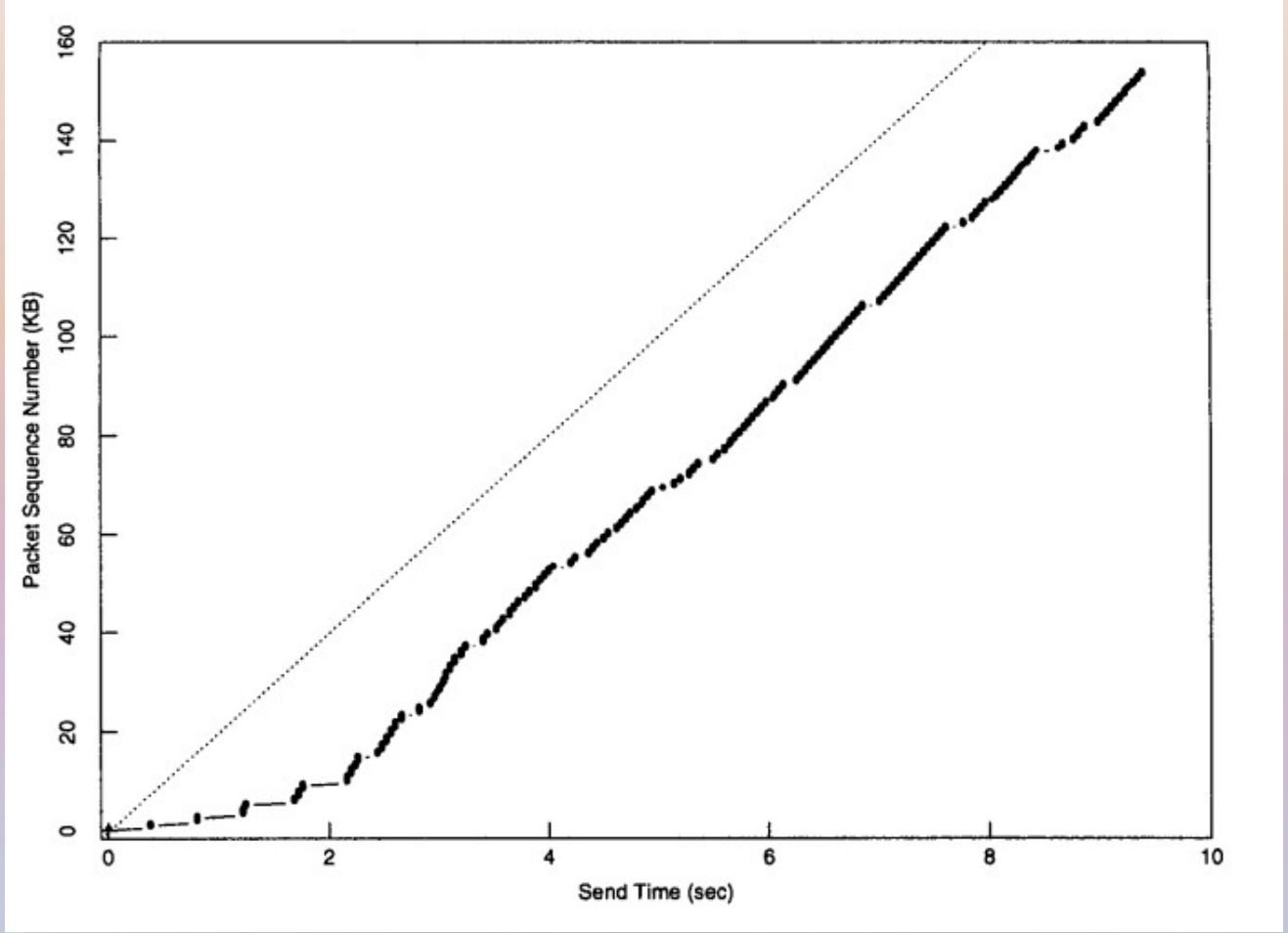
Points of Interest About Previous Graph

- Each dot is a 512 byte data packet
- 20Kbps network
- Almost all packets must be retransmitted
- Data from 54 to 58 Kb is transmitted 5 times
- Only 35% of actual bandwidth is used

Startup Behavior with Slow Start



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Points of Interest about Previous Graph

- Same parameters as previous experiment
- Notice how the window size doubles in each burst
- No bandwidth wasted on retransmits
- Over time, effective bandwidth approaches ideal bandwidth

Case II – Round Trip Time

- Need to know RTT to know when to add next packet
- Importance of estimating σ_R
- Old method
  - $R = \alpha R + (1 - \alpha)M$
  - $rto = \beta R$
  - $\beta = 2$
  - Only works for loads of 30%

Case III - Congestion Avoidance

- Sender needs a way to detect network congestion
- Sender must reduce load when congestion is detected
- Packet loss is almost always due to congestion

Response to Congestion

- L_i = load during time interval i
- N = load at some sampling time
- $L_i = N + \gamma L_{i-1}$

- On congestion, $W_i = dW_{i-1}$ $(d < 1)$

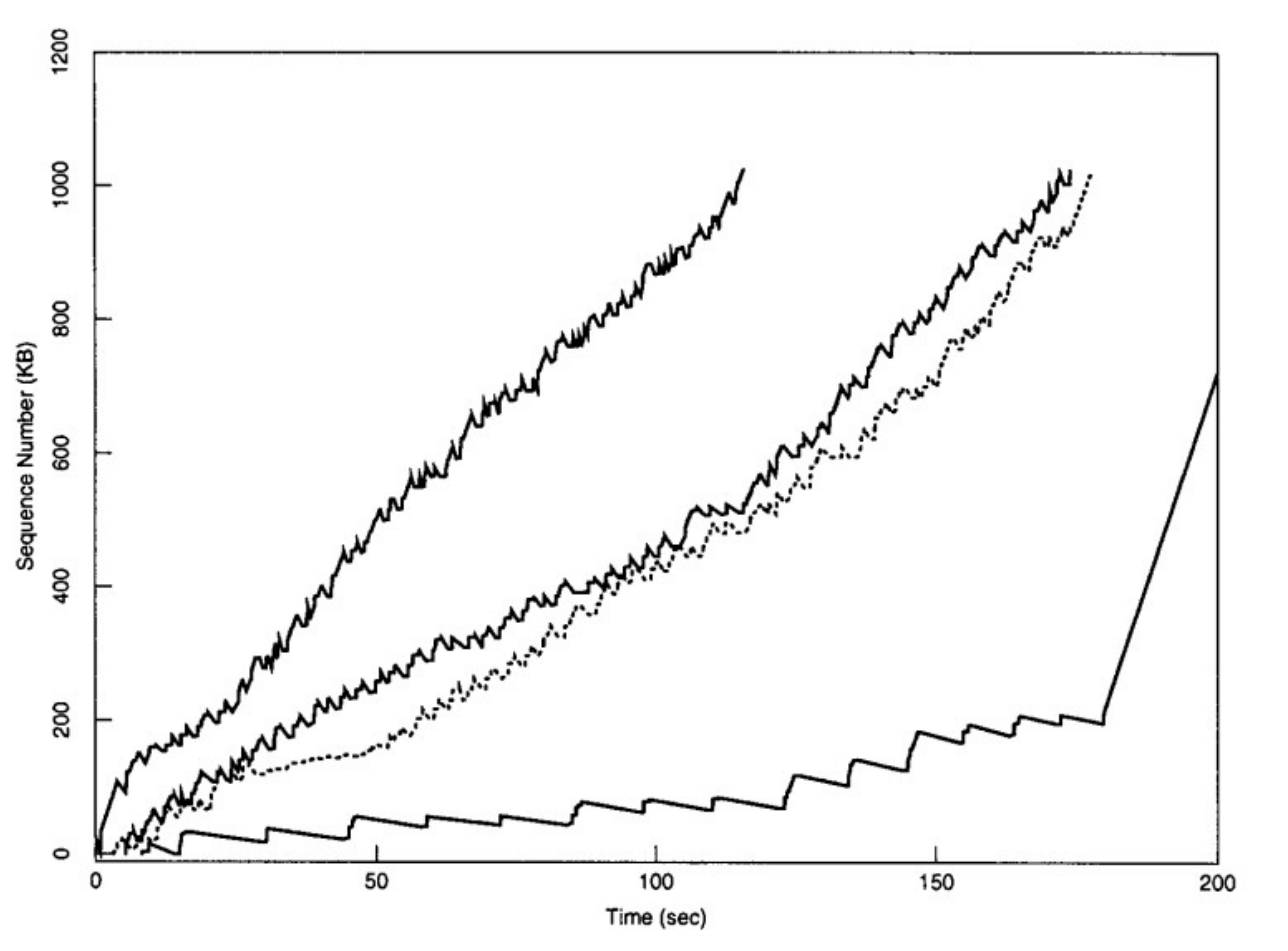
What about On No Congestion?

- Bad solution: $W_i = bW_{i-1}$ $(1 < b < 1/d)$
- Overestimating is much worse than underestimating
- Need small increases in W_i

Final Congestion Control Algorithm

- On timeout, cut *cwnd* in half (multiplicative decrease)
- On each ACK received for new data, increase *cwnd* by 1/*cwnd* (additive increase)
- On sending, send the minimum of *cwnd* and the recipient's advertised *cwnd*

4 TCP Instances, No Congestion Avoidance



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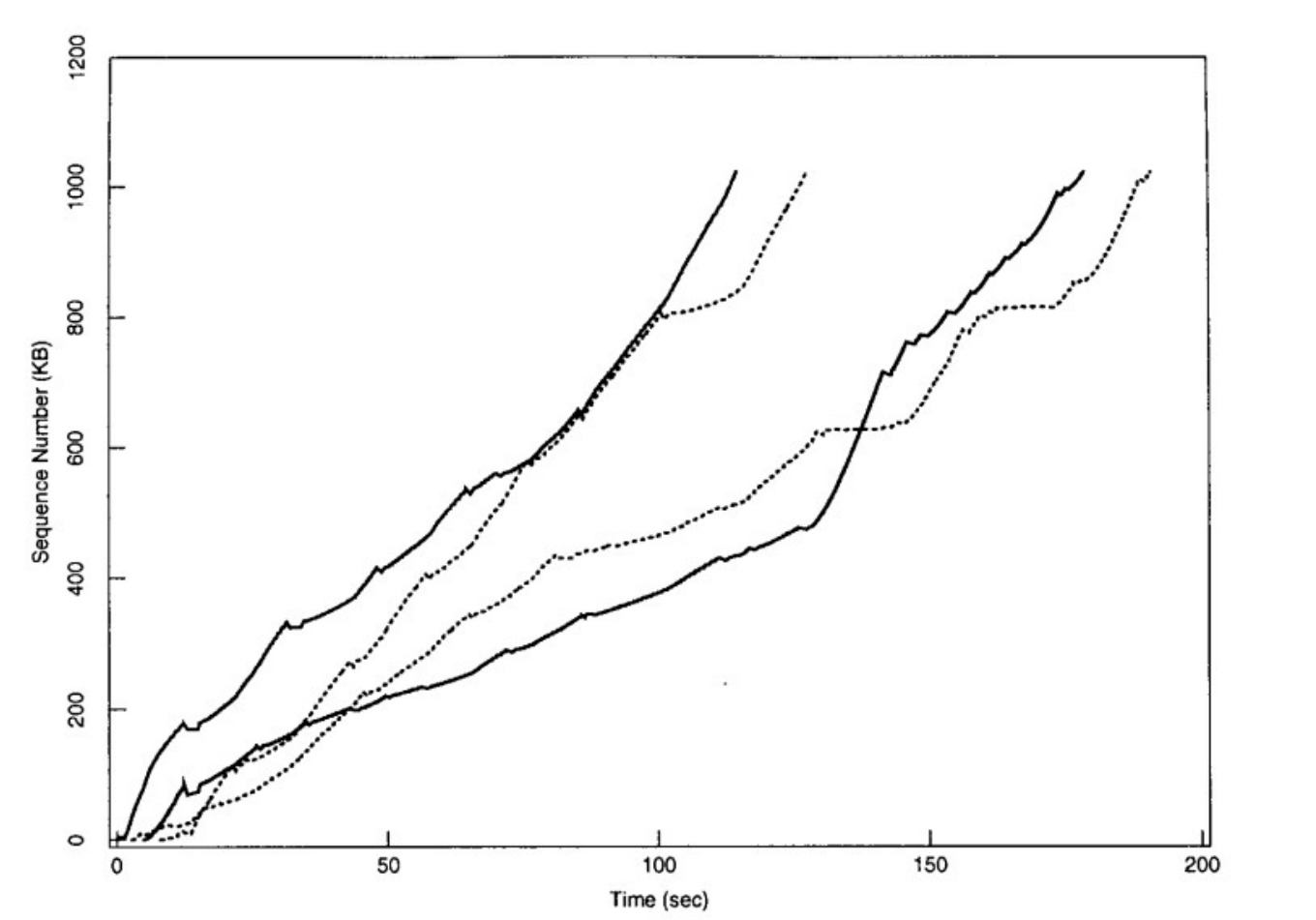
4 TCP instances, Congestion Avoidance



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Next Steps: Congestion Control at Gateways

- Algorithms at the endpoints of communication cannot ensure fairness
- Only gateways have enough information
- No need to modify endpoint code
- Early detection is important

Changes to TCP

- round-trip-time variance estimation
- exponential retransmit timer backoff
- slow-start
- more aggressive receiver ack policy
- dynamic window sizing on congestion
- Karn's clamped retransmit backoff (not described)
- fast retransmit (not described)

Takeaways

- TCP can scale
- Needs
  - Slow start
  - Exponential backoff
  - Slow probe for additional bandwidth

So...

- Now that TCP is congestion avoidant..
- ...Let's try to break it...

TCP Congestion Control with a Misbehaving Receiver

- Stefan Savage
  - University of Washington → University of California
- Neal Cardwell
  - University of California → University of Washington
- David Wetherall
  - University of Washington
- Tom Anderson
  - University of Washington → MySpace

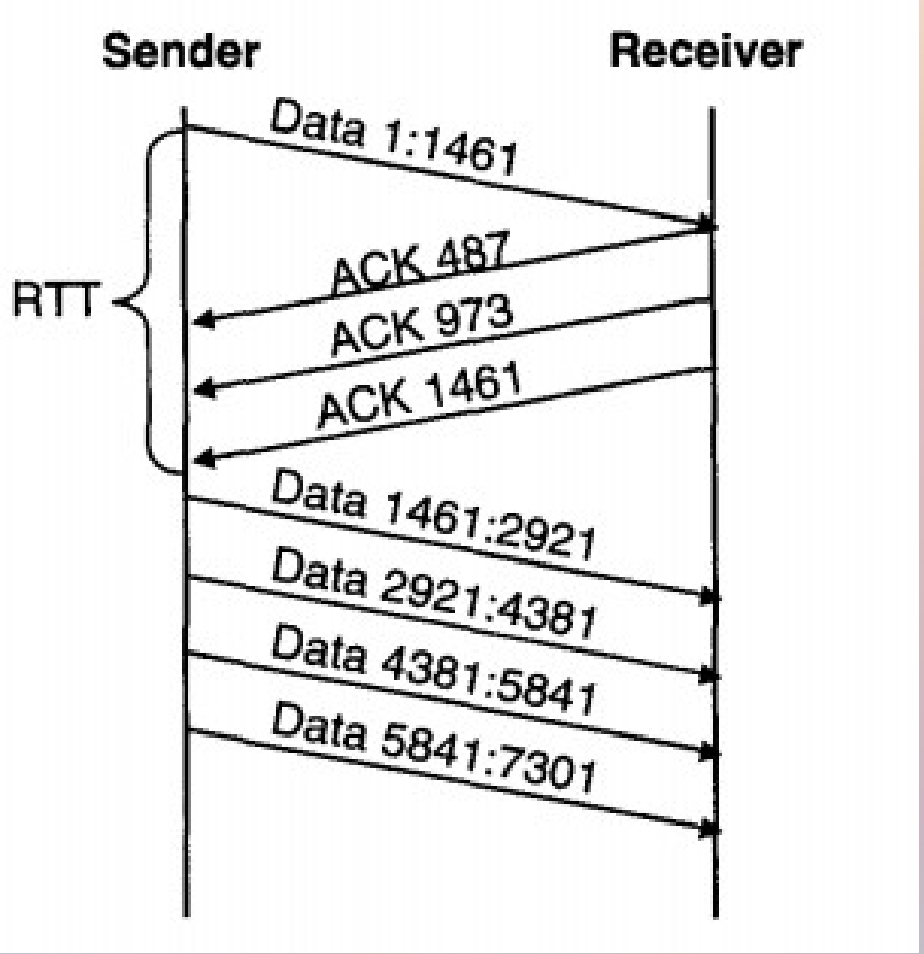
Problem: TCP Receiver is Trusted

- Receivers outnumber Senders
- *Receivers* have the motive and the means to break *Sender* congestion control
- This allows receivers to steal bandwidth from each other
- Tested 3 Attacks
  - ACK Division
  - DupACK Spoof
  - Optimistic ACKing

Attack 1: ACK Division

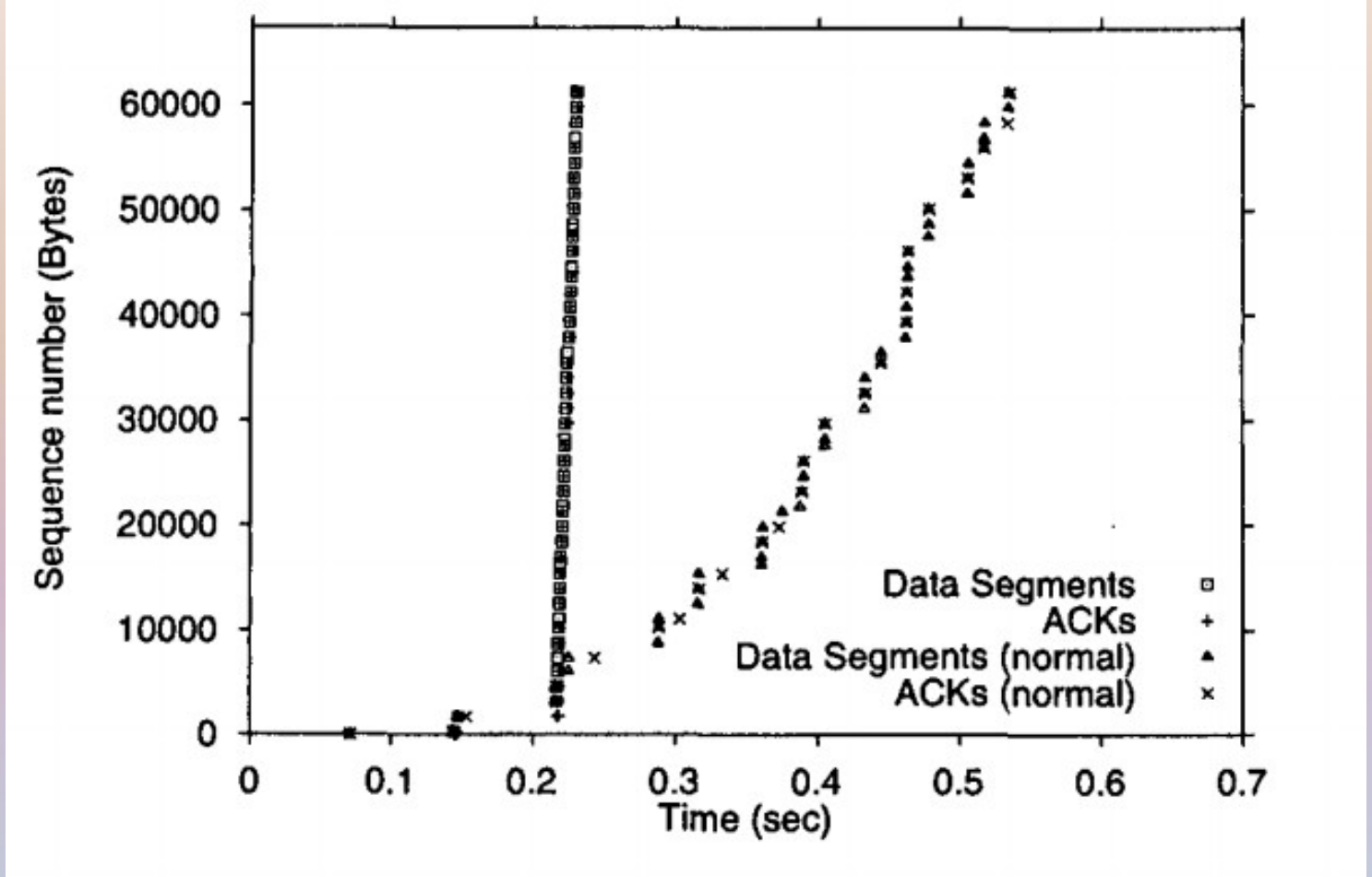
- TCP Specification:
  - During slow start, TCP increments cwin by at most SMSS bytes for each ACK received that acknowledges new data
- Attack:
  - On receiving a data segment, divide into M pieces and ACK each one.
  - cwin of the sender will increase by M * SMSS instead of SMSS

Attack 1: ACK Division



TCP congestion control with a misbehaving receiver

Attack 1: ACK Division



TCP congestion control with a misbehaving receiver

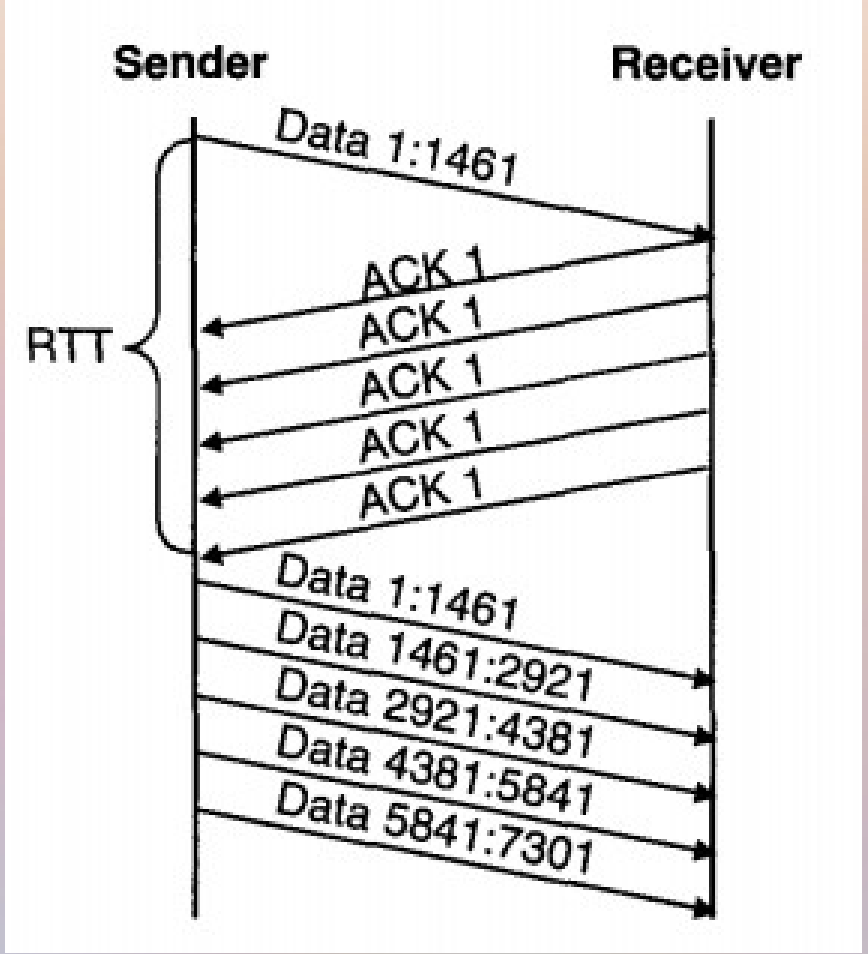
Solution – ACK division

- Problem caused by ambiguity in ACK interpretation
  - TCP error-control allows specific byte offsets to be ACKed
  - Congestion control expects ACKs to cover entire segments
- Solution: pick one of these and stick to it
- Backwards compatible: only sender protocol needs modification

Attack 2: DupACK Spoof

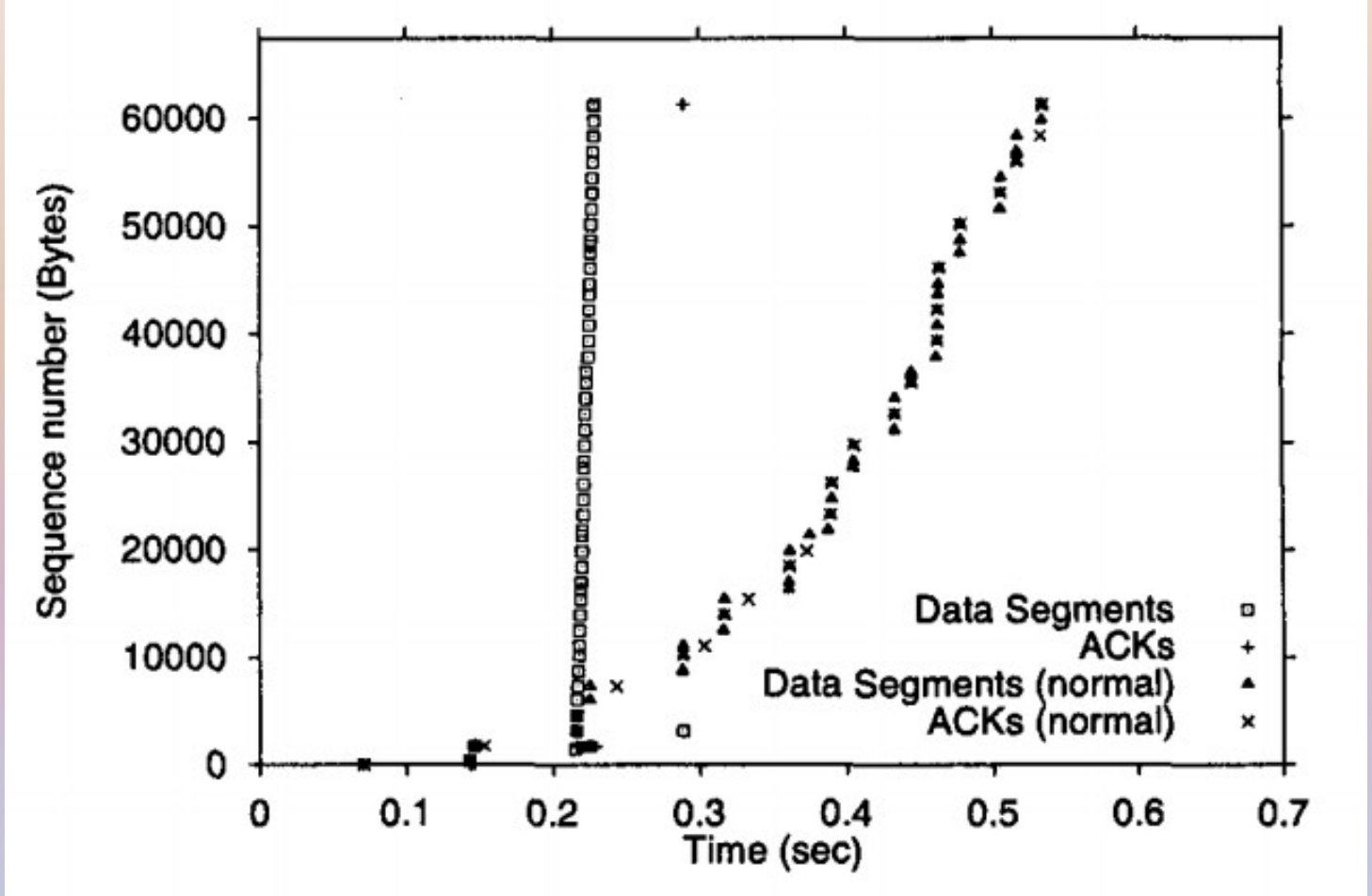
- TCP specification, on receiving a duplicate ACK
  - Set cwnd to ssthresh plus 3*SMSS
  - Increment cwnd by SMSS for each additional duplicate
- Justification: supposed to mean that packets left the network
- Attack:
  - Upon receiving a data segment, the receiver sends a long stream of acknowledgments for the last sequence number received

Attack 2: DupACK Spoof



TCP congestion control with a misbehaving receiver

Attack 2: DupACK Spoof



TCP congestion control with a misbehaving receiver

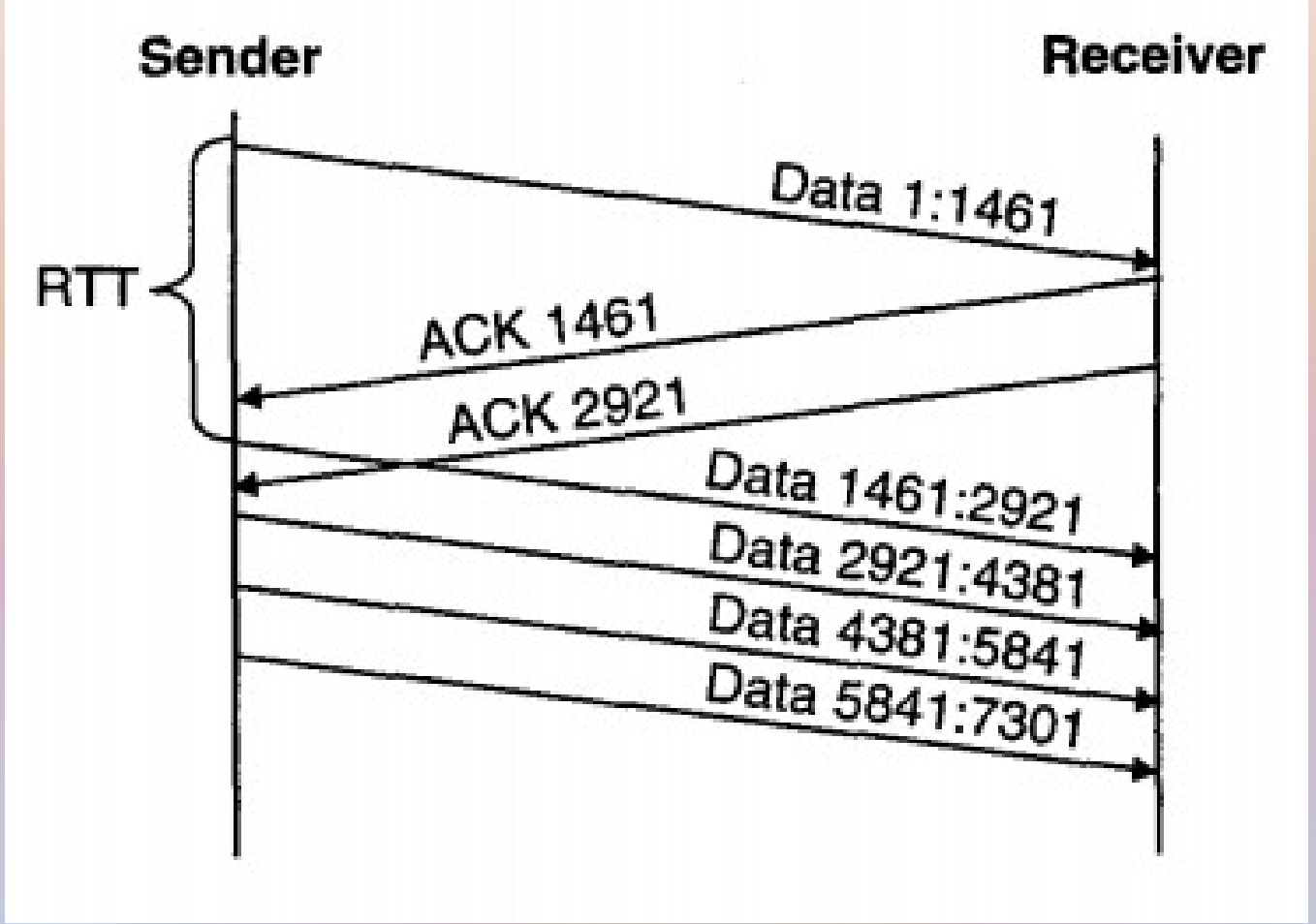
Solution – DupACK Spoof

- Need to identify the data segment that lead to the duplicate ACK
- Only way to do this is to add new TCP fields: nonce and nonce reply
- The nonce field in a data packet is a random number
- The nonce reply field is supposed to send back the same number
- Unfortunately, not backwards compatible

Attack 3: Optimistic ACKing

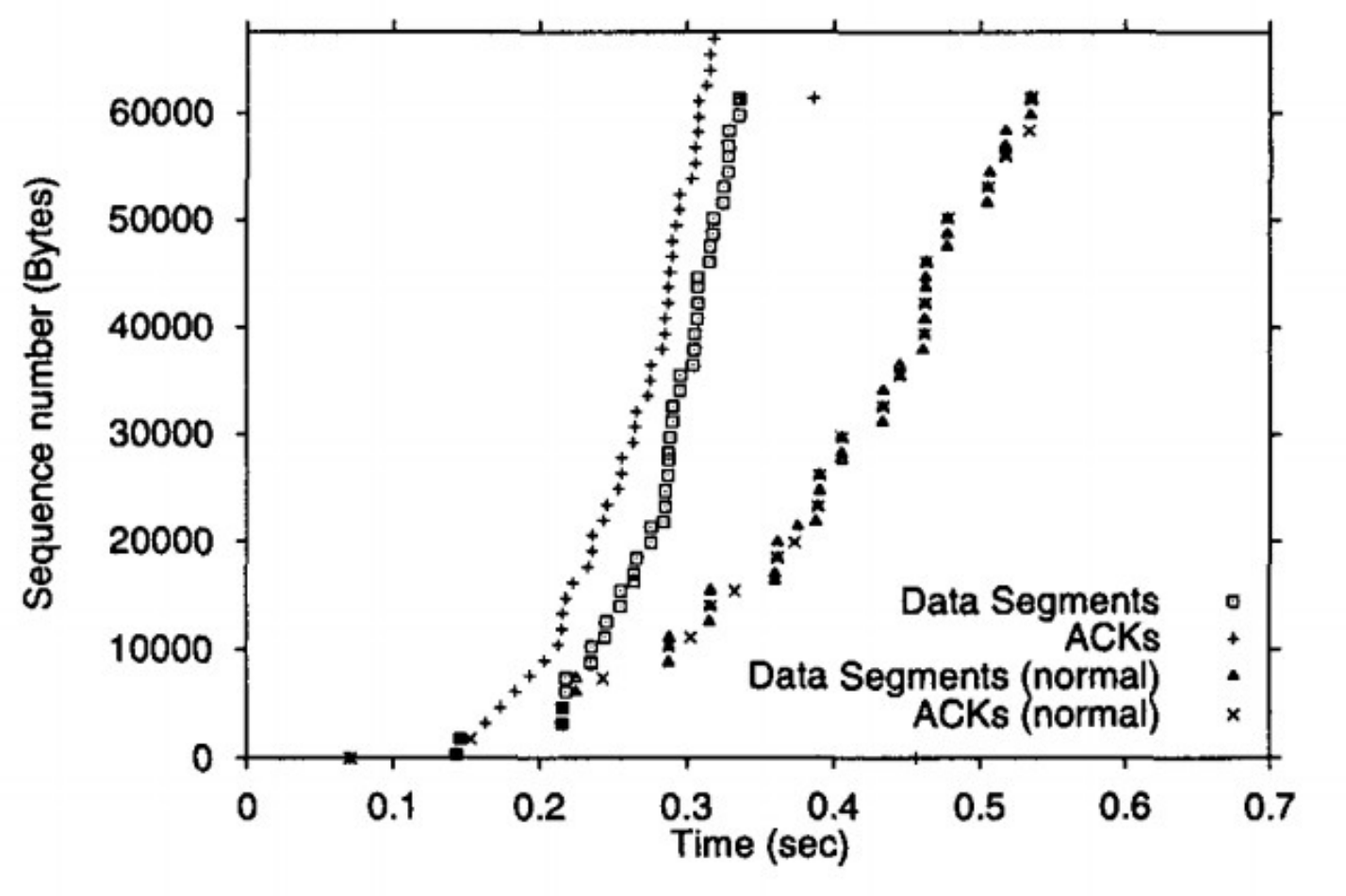
- TCP assumes that the time between message and its ACK is at least the round trip time of the network
- Attack:
  - Upon receiving a data packet, send a stream of ACKs in anticipation of future data packets
- Breaks end-to-end semantics

Attack 3: Optimistic ACKing



TCP congestion control with a misbehaving receiver

Attack 3: Optimistic ACKing

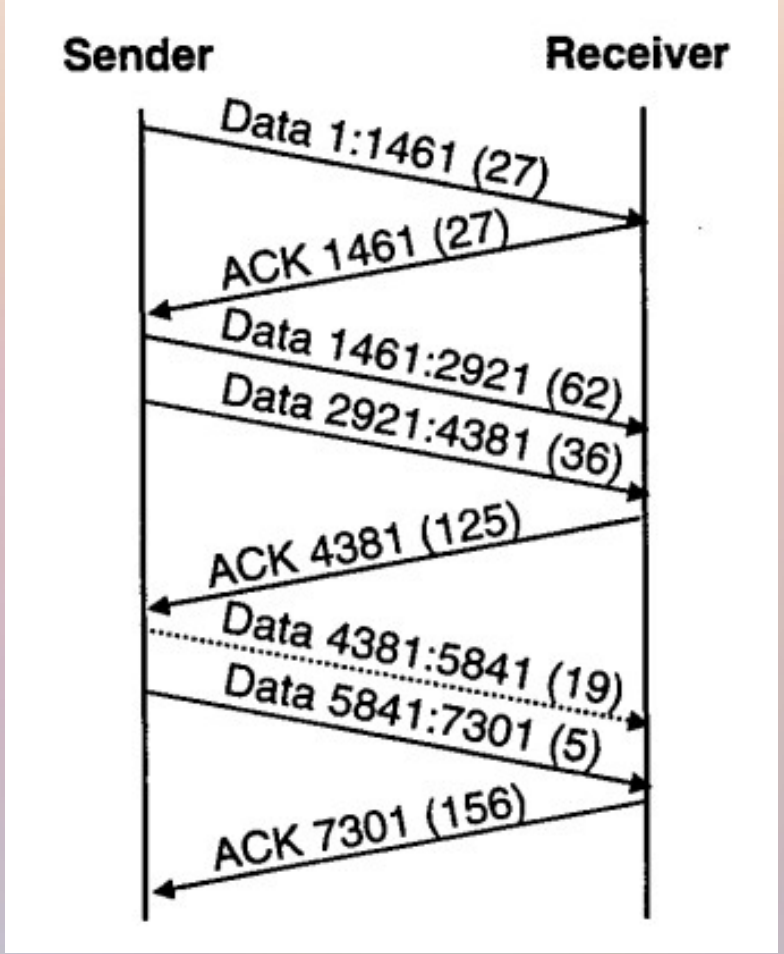


TCP congestion control with a misbehaving receiver

Solution – Optimistic ACKing

- Only possible because ACKs do not contain proof about which data segment they represent
- Also solvable by adding a nonce
- TCP is cumulative, so a cumulative nonce should be used

Cumulative Nonce



TCP congestion control with a misbehaving receiver

Takeaways

- TCP should not require that both parties be trusted
- Most systems vulnerable to attacks
- Simple fixes can prevent many kinds of attacks

Questions?