CS640: Introduction to Computer Networks

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Lecture 16
TCP – III
Reliability and Implementation Issues

So Far

- Transport protocols and TCP functionality overview
- Principles of reliable data transfer
- TCP segment structure
- Connection management
- Congestion control

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More on Reliability

- TCP provides a "reliable byte stream"
  - "Loss recovery" key to ensuring this abstraction
  - Sender must retransmit lost packets
- Challenges:
  - Congestion related losses
  - Variable packet delays
    - What should the timeout be?
  - Reordering of packets
    - How to tell the difference between a delayed packet and a lost one?

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TCP = Go-Back-N Variant

- Sliding window with cumulative acks
  - Receiver can only return a single "ack" sequence number to the sender.
  - Acknowledges all bytes with a lower sequence number
  - Starting point for retransmission
  - Duplicate acks sent when out-of-order packet received
- ***But***: sender only retransmits a single packet.
  - Only one that it knows is lost
    - Sent after timeout
  - Network is congested → shouldn't overload it
- Choice of timeout interval → crucial

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Round-trip Time Estimation

- Reception success known only after one RTT
  - Wait at least one RTT before retransmitting
- Importance of accurate RTT estimators:
  - Low RTT estimate
    - unneeded retransmissions
  - High RTT estimate
    - poor throughput
- RTT estimator must adapt to change in RTT
  - But not too fast, or too slow!

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Original TCP RTT Estimator

- Round trip times exponentially averaged:
  - New RTT = α (old RTT) + (1 - α) (new sample)
  - Recommended value for α: 0.8 - 0.9
    - 0.875 for most TCP's
- Retransmit timer set to (2 * RTT)
  - Whenever timer expires, RTO exponentially backed-off
- Not good at preventing spurious timeouts
  - Why?

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Jacobson's Retransmission Timeout

- Key observation:
  - At high loads round trip variance is high
- Solution:
  - Base RTO on RTT and deviation
    - RTO = RTT + 4 * rttvar
  - new_rttvar = β * dev + (1- β) old_rttvar
    - Dev = linear deviation
    - Inappropriately named – actually smoothed linear deviation

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AIMD Implementation

- If loss occurs when cwnd = W
  - Network can handle < W segments
  - Set cwnd to 0.5W (multiplicative decrease)
  - Known as "congestion control"
- Upon receiving ACK
  - Increase cwnd by (1 packet)/cwnd
    - What is 1 packet? → 1 MSS worth of bytes
  - After cwnd packets have passed by → approximately increase of 1 MSS
  - Known as "congestion avoidance"
- Implements AIMD

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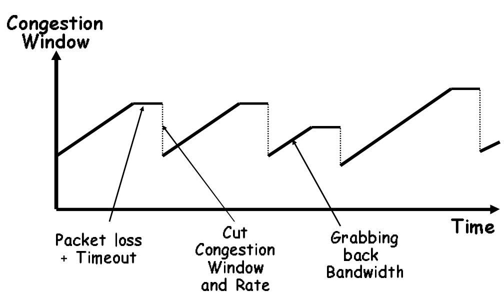
Control/Avoidance Behavior



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Improving Loss Recovery: Fast Retransmit

- Waiting for timeout to retransmit is inefficient
- Are there quicker recovery schemes?
  - Use duplicate acknowledgements as an indication
  - *Fast retransmit*
- What are duplicate acks (dupacks)?
  - Repeated acks for the same sequence
- When can duplicate acks occur?
  - Loss
  - Packet re-ordering
- Assume re-ordering is infrequent and not of large magnitude
  - Use receipt of 3 or more duplicate acks as indication of loss
  - Don't wait for timeout to retransmit packet

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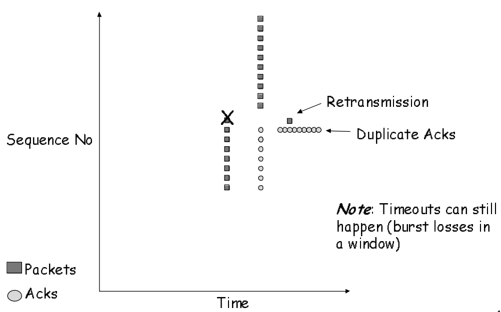
Fast Retransmit



Note: Timeouts can still happen (burst losses in a window)

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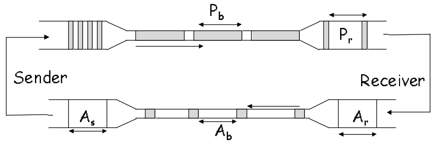
Packet Pacing

- **In steady state, a packet is sent when an ack is received**
  - Data transmission remains smooth, once it is smooth (steady state)
  - "Self-clocking" behavior



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How to Change Window

- When a loss occurs have W packets outstanding
  - A bunch of dupacks arrive
  - Rexmit on 3rd dupack
  - But dupacks keep arriving
  - Must wait for a new ack
- New cwnd = 0.5 * cwnd
  - Send new cwnd packets in a burst
  - Risk losing ack clocking

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Preserving Clocking: Fast Recovery

- Each duplicate ack notifies sender that single packet has cleared network
- When < cwnd packets are outstanding
  - Allow new packets out with each new duplicate acknowledgement
- Behavior
  - Sender is idle for some time – waiting for ½ cwnd worth of dupacks
  - Transmits at original rate after wait
    - Ack clocking rate is same as before loss

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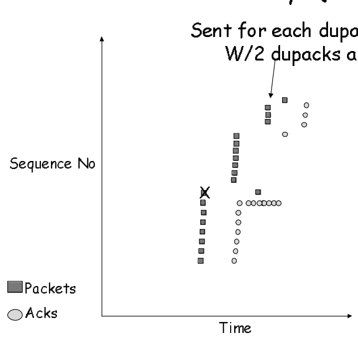
Fast Recovery (Reno)



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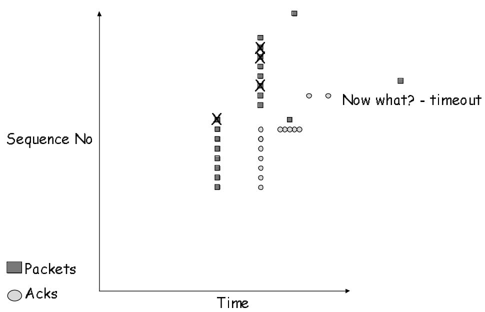
Timeouts can still happen!



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Reaching Steady State

- Doing AIMD is fine in steady state…
  - But how to get to steady state?
- How does TCP know what is a good initial rate to start with?
- Quick initial phase to help get up to speed
  - Called "slow" start (!!)

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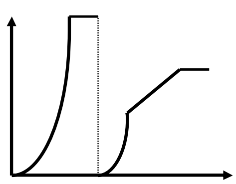
Slow Start

- Slow start
  - Initialize cwnd = 1
  - Upon receipt of every ack, cwnd = cwnd + 1
- Implications
  - Window actually increases to W in RTT * $\log_2(W)$
  - Can overshoot window and cause packet loss



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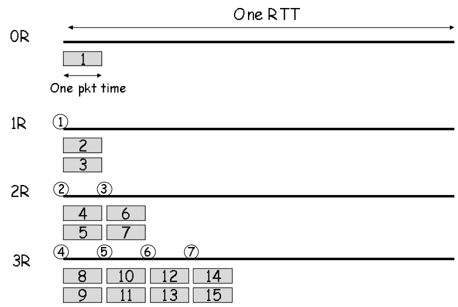
Slow Start Example



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Return to Slow Start

- If too many packets are lost self clocking is lost as well
  - Need to implement slow-start and congestion avoidance together
- When timeout occurs set ssthresh to 0.5w
  - If cwnd < ssthresh, use slow start
  - Else use congestion avoidance

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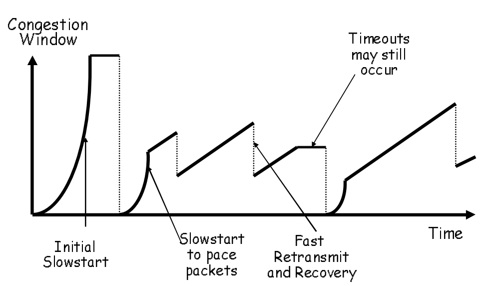
The Whole TCP “Saw Tooth”



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TCP Performance

- Can TCP saturate a link?
- Congestion control
  - Increase utilization until… link becomes congested
  - React by decreasing window by 50%
  - Window is proportional to rate * RTT
- Doesn't this mean that the network oscillates between 50 and 100% utilization?
  - Average utilization = 75%??
  - No…this is *not* right!

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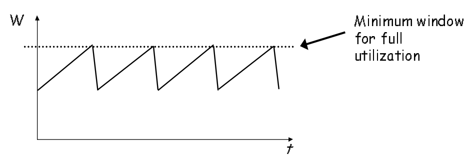
Unbuffered Link



- The router can't fully utilize the link
  - If the window is too small, link is not full
  - If the link is full, next window increase causes drop
  - With no buffer TCP achieves 75% utilization

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TCP Performance

- In the real world, router queues play important role
  - Window is proportional to rate * RTT
    - But, RTT changes as well as the window
  - Window to fill links = propagation RTT * bottleneck bandwidth
    - Role of Buffers → If window is larger, packets sit in queue on bottleneck link

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TCP Performance

- In the real world, router queues play important role
  - Role of Buffers → If window is larger, packets sit in queue on bottleneck link
- If we have a large router queue → can get 100% utilization
  - But, router queues can cause large delays
- How big does the queue need to be?
  - Windows vary from W → W/2
    - To make sure that link is always full
      W/2 > RTT * BW
    - W = RTT * BW + Qsize
      → Qsize > RTT * BW
  - Ensures 100% utilization
  - Delay?
    - Varies between RTT and 2 * RTT
    - Queuing between 0 and RTT

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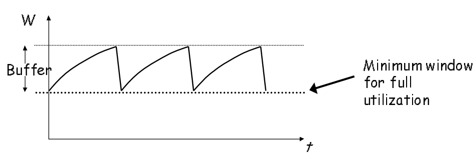
Buffered Link



- With sufficient buffering we achieve full link utilization
  - The window is always above the "critical" threshold
  - Buffer absorbs changes in window size
    - Buffer Size = Height of TCP Sawtooth
    - Minimum buffer size needed is 2T*C
  - This is the origin of the rule-of-thumb

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TCP Summary

- General loss recovery
  - Stop and wait
  - Selective repeat
- TCP sliding window flow control
- TCP state machine
- TCP loss recovery
  - Timeout-based
    - RTT estimation
  - Fast retransmit, recovery

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TCP Summary

- Congestion collapse
  - Definition & causes
- Congestion control
  - Why AIMD?
  - Slow start & congestion avoidance modes
  - ACK clocking
  - Packet conservation
- TCP performance modeling
  - How does TCP fully utilize a link?
    - Role of router buffers

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Next Class

- Naming and the DNS

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