1 # EECS 122, Lecture 21

Today's Topics:

Congestion Control Metrics

TCP Congestion Control

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2 # Evaluation Criteria

- Effectiveness
  - want to fully utilize links in network, but filling all queues increases end-to-end delay
  - how to measure throughput/delay tradeoff?
- Fairness
  - how do multiple flows share a common network?
  - if we assume fair means equal, how to measure if a set of flows are receiving equal treatment?

3 # Effectiveness

- Throughput/delay tradeoff
  - with stat muxing (and a *work-conserving* service discipline), outgoing link is always fully utilized if any packet present
  - want to avoid empty queues, but larger queues mean larger delays
- Network power:
  - Power = (Throughput) / (Delay)
  - $0 < \alpha < 1$

4 # Network Power

5 **Jain's Fairness Index**

- A definition for fairness:
  - 0 <= f() <= 1, given flow throughputs *x*
  - locally equal partitioning of bandwidth achieves index of 1. If only k of n flows receive equal bw (and others get none), index is k/n
  - what about different-length flows? (p.401)

6 **Properties of the Index**

- population size independence
- scale and metric independent
- bounded on [0..1]
- continuous

7 **Allocation between A & B**

8 **Congestion Control with TCP**

- Congestion control added to TCP in late 80s as a result of congestion collapse problem
- Idea:
  - host figures out how many packets it can safely inject into network
  - each received indicates 1 (or possibly more) packets have been removed from network, allowing host to inject another
  - self-clocking property ensures stability

9 **Challenges for TCP**

- How to determine how many packets to inject into network?
  - Too many: overrun buffers
  - too few: underutilization of link
- Additional problems:

- available bandwidth changes over time as new connections start and terminate

10 Congestion Window Maintenance

- TCP maintains a *congestion window* (cwnd), based on packets
- Sender's window limited to MIN(receiver's window, cwnd)
- Maintenance policy:
  - on congestion signal, multiplicative decrease
  - on success, additive increase
- Additive increase/multiplicative decrease produces stability [CJ 89]

11 Window Increase/Decrease

- TCP Congestion Avoidance:
  - use packet loss as indicator of congestion
  - on loss, divide cwnd by 2
  - on successful ACK, increase cwnd by 1/cwnd
- Results in window growth of 1 packet for each window's worth of ACKs [linear]

12 TCP Congestion Avoidance

13 TCP Congestion Avoidance

14 Congestion Avoidance

- TCP Congestion Avoidance makes sense when the connection is operating near capacity (in steady-state)
- What about when a connection starts up, or there has been a long pause (where the state of the

world may have changed)?

- Need a way to get to equilibrium … next time …