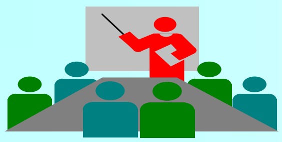
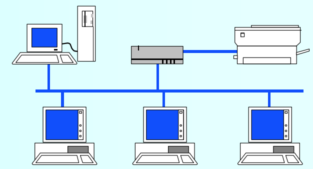




Distributed Systems
600.437
Advanced Networking Protocols
And Overlay Networks

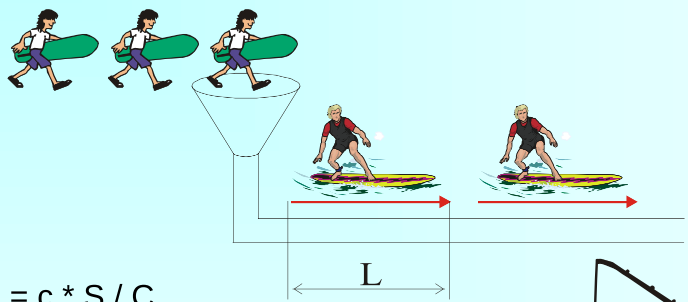
Department of Computer Science

The Johns Hopkins University

Advanced Networking Protocols
And Overlay Networks

Lecture 7

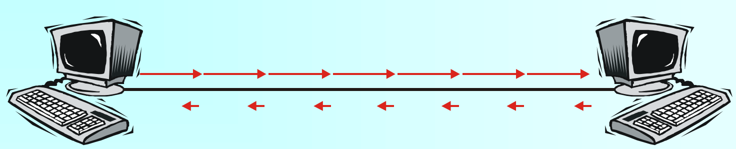
Surfing On The Network Waves



$L = c * S / C$

Where L = length of the packet
S = size of the packet
C = capacity of the network link
c = speed of light (electrons in the wire)

Sliding Window Protocols



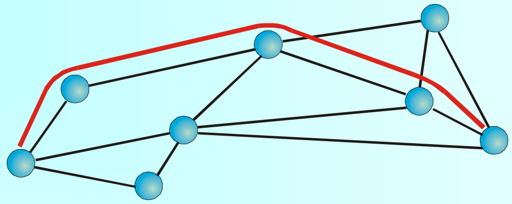
How big should the window size be ? (see exercise 1)

Ideally the window size will "occupy" the entire length of the network

- Maximum throughput (we can not send more than the network capacity)
- Minimum latency (no waiting time)

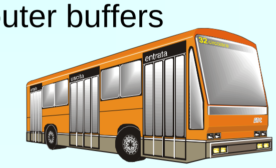
What if there are two senders, sending at the same time ?

Sliding Window Protocols (cont.)



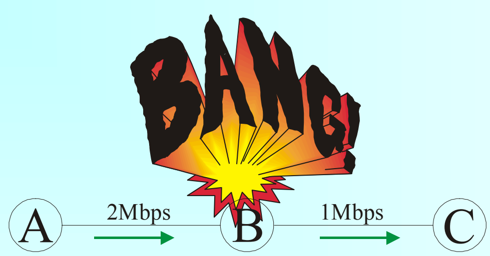
In reality we don't have a link to each destination in the network, but rather a set of different hops and intermediate routers (see traceroute)

If the window size is bigger than optimal, some packets will accumulate in the intermediate router buffers



Still maximum throughput
Increased latency (why ?)

What Is Congestion ?



Packets accumulate in intermediate buffers
Buffers have limited size => at some point packets will be dropped

Low throughput (why ?)
High latency

TCP Congestion Control

Go back n protocol [Jacobson 88]

cwnd – congestion window (dynamic)
ssthresh – slow start threshold

Two phases:

- **slow start** (cwnd < ssthresh)
  Multiplicative **I**ncrease **M**ultiplicative **D**ecrease
  cwnd initialized with 1
  for every ACK received, add **1** to cwnd

- **congestion avoidance** (cwnd > ssthresh)
  Additive **I**ncrease **M**ultiplicative **D**ecrease
  for every ACK received, add **1/cwnd** to cwnd

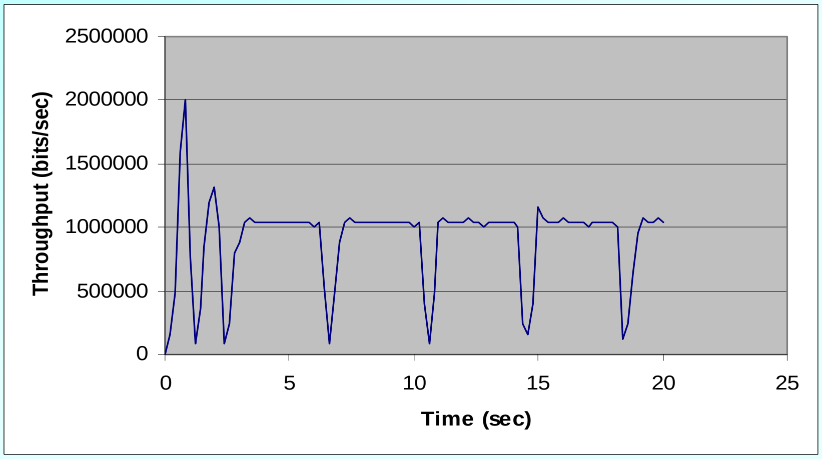
Packet loss: ssthresh = cwnd / 2
cwnd = cwnd / 2

Timeout: ssthresh = cwnd / 2
cwnd = 1

TCP Congestion Control (cont.)

ns2 Demo

TCP throughput



TCP throughput model

[Padhye 98]

Basic idea: $$Throughput = \frac{Window\_size}{Rond\_trip\_time}$$

More accurate: $$T = \frac{s}{R\sqrt{\frac{2p}{3}} + t_{RTO}\left(3\sqrt{\frac{3p}{8}}\right)p\left(1+32p^2\right)}$$

Where:

- T: sending throughput
- s: packet size
- R: round-trip time
- p: loss rate
- t_{RTO}: retransmit timeout

Rate Based Congestion Control

[Floyd 00]

Receiver: computes probability of error and sends feedback to the sender
Sender: computes round-trip time, and adjust rate according to the formula

Advantages:
• smooth, almost no oscillations (as opposed to TCP)
• easy to implement at the sender

Disadvantages:
• difficult to compute p (error rate)
• p averaged => low responsiveness to changes

Flow Control

What if the receiver doesn't read fast enough ?

TCP flow control

• receiver sends to the sender its "advertised window" i.e. the empty slots in its receiving buffer
• sender uses the minimum between congestion window and advertised window

Outline

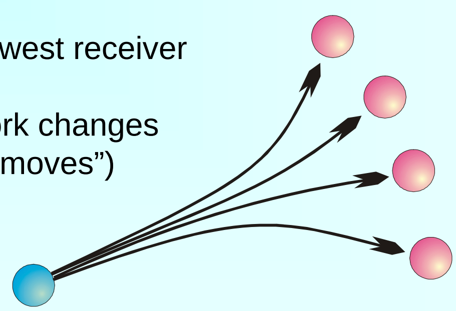
- **Unicast Congestion and Flow control**
  - The choice of a window size
  - TCP congestion control
- **Multicast Congestion Control**
  - PGMCC
- **Overlay Networks**
  - Benefits
  - Low latency reliable unicast
- **Multicast in Overlay Networks**
  - Online flow control for multi-session multicast

Congestion control for multicast

Can we use the TCP protocol for multicast ?

Problems:

- different receivers have different rates
  => send at the slowest receiver speed
- how to choose the slowest receiver
- how to adapt to network changes (the slowest receiver "moves")
- ACK flooding



PGMCC

[Rizzo 00]

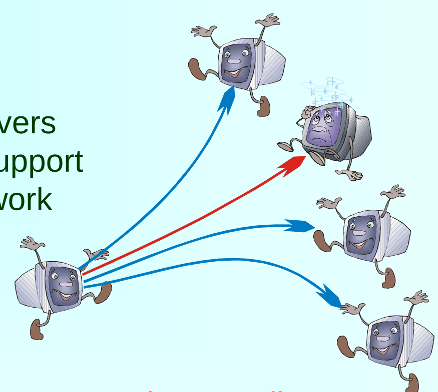
Congestion **C**ontrol based on **PGM** (Pragmatic General Multicast) Reliable Transport Specification

- Each receiver estimates **RTT** and **error rate**
- Receivers send feedback together with **NACK**s
- Based on RTT and error rate, the sender selects the slowest receiver
- Only the slowest receiver acknowledges every packet.
- The rest of them send only **NACK**s
- The sender performs as if it was running **TCP** with the slowest receiver

PGMCC (cont.)

Advantages:

- Fair with TCP
- Scalable with # of receivers
- Does not need router support
- Adapts very fast to network changes



Potential problems:

- Gives the same preference to senders sending to different number of receivers
- Scalable with # of groups ?

Congestion Control Summary

• Congestion occurs when the incoming traffic is **higher** than the capacity of the network – intermediate buffers drop packets

• Senders **slow down** by adjusting their sending rate

• All the participants should slow down **equally** in order to share the network resources fairly

• Single rate reliable multicast should send at the rate of the **slowest receiver**

Outline

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- **Multicast in Overlay Networks**
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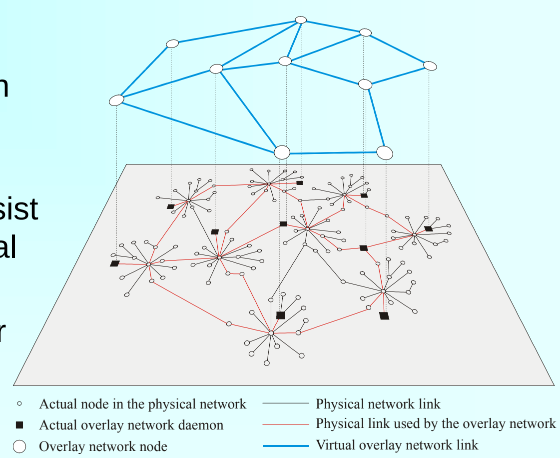
The Internet is great !

- It's everywhere
  - at school, at work, at home, etc.
- We expect it to be everywhere
  - It is part of our culture
  - a basic, globally available service
- It becomes like electricity
  - Usually a plug in the wall… sometimes not even that…
- Overlay networks open the door for new protocols that
  - can provide additional services to the application
  - have potential to improve network performance

Overlay Networks

- Virtual network of application-level routers working on top of a physical network.
- Overlay links consist of multiple physical links.
- No need for router support



Overlay Networks – Benefits

- Overlay networks are **small**
  - Optimized algorithms based on more available information
- Added value
  - New services (e.g. reliable multicast).
  - Better service (e.g. resilient routing).
- Experimentation and deployment flexibility
  - Hard to experiment with new protocols directly on the Internet
  - Difficult to change existing standards (e.g. 802.11b)
  - When is the last time electricity changed ?

Overlay Networks - Drawbacks

- Processing overhead
  - Another level of indirection
  - Overlay routers usually run on standard computers
  - Processing is often done in the user space
  - OS scheduling is not instantaneous
  - Additional level of encapsulation
- **Latency** overhead
  - Overlay networks do not always map the Internet topology. Overlay paths are usually **longer** than the direct Internet path

Overlay network Systems

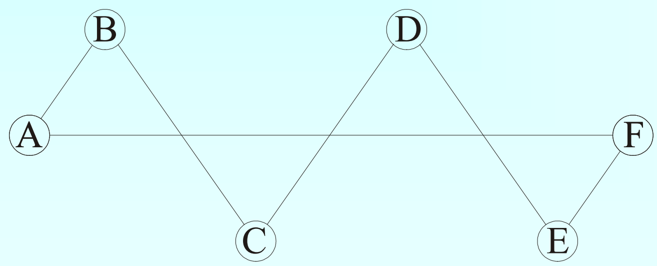
- Overlay networks
  - XBone – overlays using IP in IP tunneling [TH98]
  - RON – resilient routing using alternate routes [ABKM01]
  - Yoid – content distribution network [Fran00]
- Reliable multicast
  - SRM – uses randomized timeouts for sending retransmission requests and retransmissions [FJL+97]
  - TRAM – localizes recoveries using repair trees [CKP+02]
  - PRM – uses randomized forwarding and triggered nacks to improve the delivery ratio in multicast [BLB+03]
- Group communication
  - Spread – scalable wide area support using an overlay network approach [ADS00]

Spines - An Overlay Network Research Platform

- **Spines** builds an overlay router (daemon) platform on top of UDP – a regular user level application
- **A research platform** – researchers can build their own protocols within its framework, experimenting with routing, flow control, congestion control, etc. at application level
- "Almost" transparent API
  - API similar to the socket interface
- **A deployable platform**.
  - Improving performance over the Internet.
  - Enabling new services.
- Open source (www.spines.org)

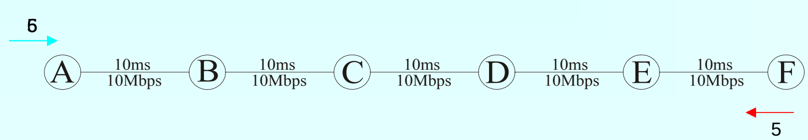
Reliability in overlay networks

- Usually done by running TCP end to end
  - Best for the Internet (very scalable)
  - Only the end nodes are involved in the communication
  - Uses the most direct path
- But when applied to overlay networks…
  - The path is not direct anymore **(and it is longer !)**
  - Multiple nodes process the packets



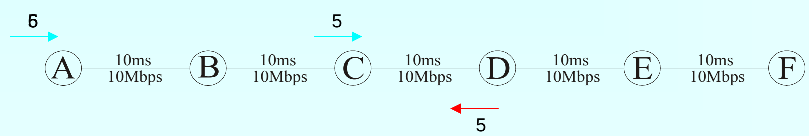
End-to-end reliability

- 50 milliseconds network, five hops
  - 50 milliseconds to tell the sender about the loss
  - 50 milliseconds to resend the packet
- At least 100 milliseconds to recover a packet
  - Can we do better ?



Hop-by-hop reliability

- 50 millisecond network, five hops
  - 10 ms to tell C the sender about the loss
  - 10 ms to get the packet back from C
- Only 20 milliseconds to recover a packet
  - Lost packet sent twice only on link C-D
  - Where was packet 6 during recovery of 5 ?



The latency impact of the lost packet

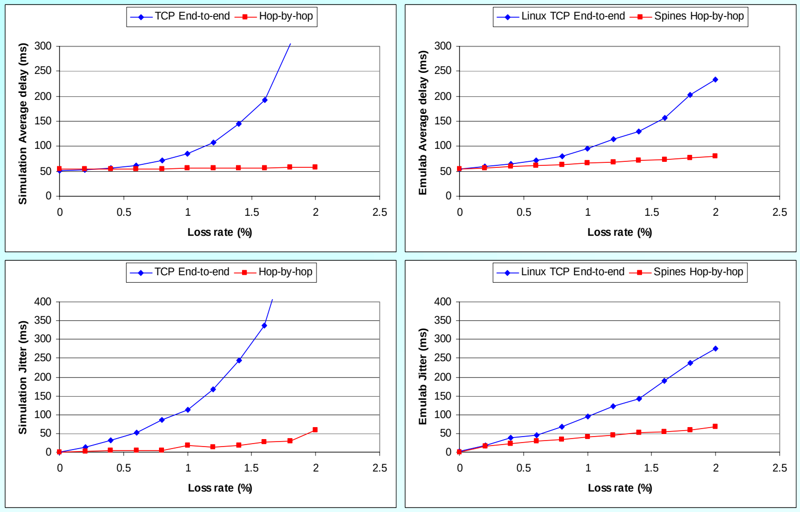
- During the recovery period, a window size of messages are on their way
  - Recovery takes at least one roundtrip time
  - All the packets in a window are buffered at the receiver as they are not FIFO ordered
- TCP shrinks the congestion window
  - New packets generated by the application are not even sent, as they are buffered at the sender
- Number of delayed packets is **much bigger** than number of lost packets

Average Latency and Jitter

Simulation | Spines on Emulab

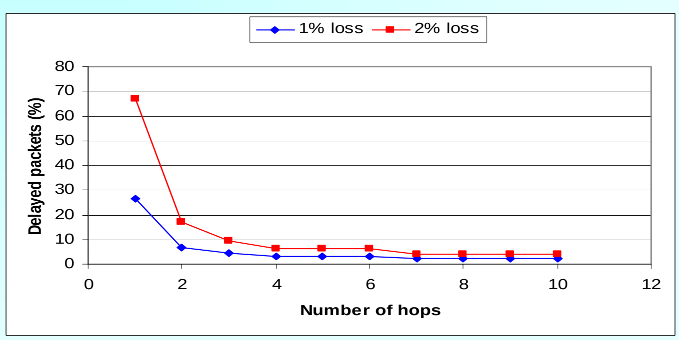
Latency

Jitter



500 Kbps Stream

How Many Nodes Do We Need ?



50ms network divided evenly by x hops

Delayed packets: packets that arrived after more than (50+10)ms

Multicast Using Overlay Networks

One to many

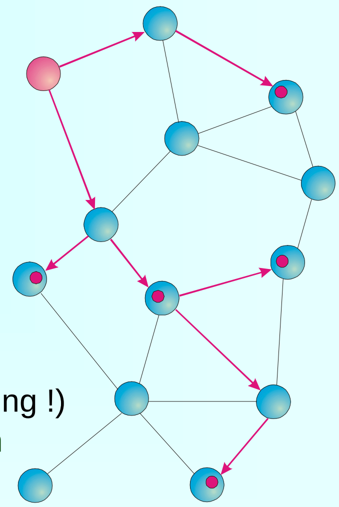
- used for broadcasting data

Many to many (more interesting)

- used in conferencing

Multi group, multi sender (amazing !)

- used in group communication



Multi-group Multi-sender Multicast in Overlay Networks

- Each node chooses its own (different) multicast tree
- Big number of (open) groups
- Big number of clients connected to each of the overlay nodes
- Each client can join any number of groups and send simultaneously to any number / combination of groups
- Flow control required !!!

Flow Control for Multi-group Multi-sender Multicast

[AADS 02]

End-to-end window

- Requires a window per sender per receiver per group
- Control traffic dependent on number of participants and groups
- Not dependent on number of intermediate links

Link-state

- Each sender is aware about the state of the overlay links that it uses, and adjusts its rate accordingly
- Control traffic dependent on number of links in the overlay network
- Not dependent on number of participants or groups

Online Cost-Benefit Flow Control

Summary:

- Each link is associated with a **cost** based on current resource utilization
- Each application stream is associated with application **benefit** for sending its messages
- Benefit is given to each application periodically
- Goal: maximize the **benefit of all applications** (number of messages sent on the network)
- **Online** decision of accepting/forwarding each packet
- **Competitive ratio** is the ratio between benefits achieved by the **Offline** and **Online** algorithms

Resource - Cost Function

- Opportunity cost = benefit lost by *high benefit* connections as a result of consuming the resource by a *lower benefit* connection

- $C(u_l) = \alpha \cdot \gamma^{u_l}$
  has a $\Omega(\log \gamma)$ on competitive ratio
  (*Awerbuch, Azar, Potkin, 1993*)

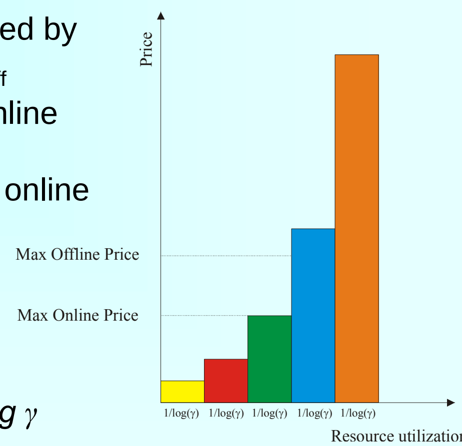
u_l = utilization of link l
α = minimum benefit
β = maximum benefit
$\gamma = \beta / \alpha$

- Achievable if every *1/log* γ fraction of the utilized resource necessitates doubling the price

An Online Auction Example

- The maximum bid accepted by the offline algorithm is P_{off}
- If P_{off} is rejected by the online algorithm, at least *1/log* γ resource was sold by the online for at least ½ P_{off}
- Offline – Online < P_{off}

- It follows that
  Offline/Online < *1 + 2 * log* γ



Choosing The Resource

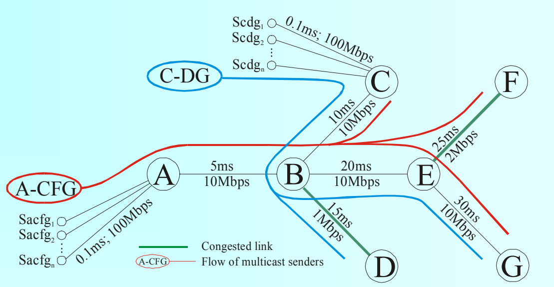
Potential resource: Link available bandwidth

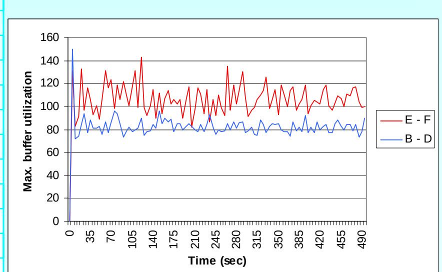
- Intuitively, this is the **resource** we try to control
- Dynamic, as a result of congestion control
- At the mercy of the external traffic
- Difficult to measure (usually requires some flooding)

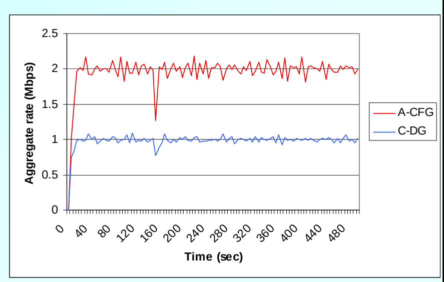
Potential resource: Link buffer

- Immediate indication of congestion
- Easy to control as a resource owned by the overlay network
- Easy to measure (locally available information)
- Extremely dynamic

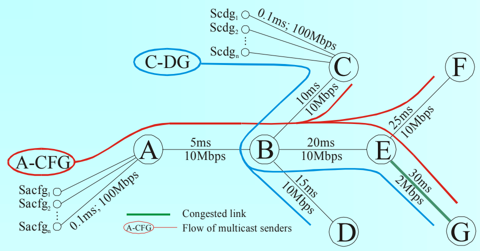
Simulation: Resource Utilization

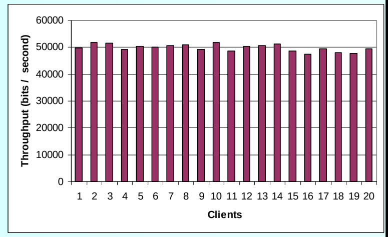


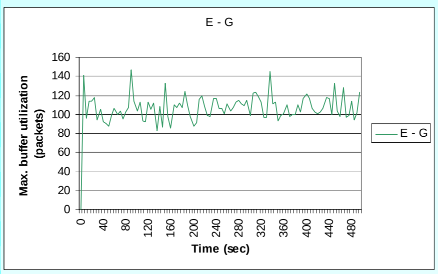


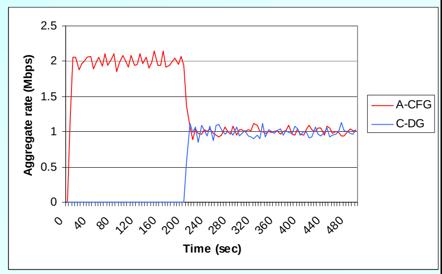


Simulation: Resource Sharing

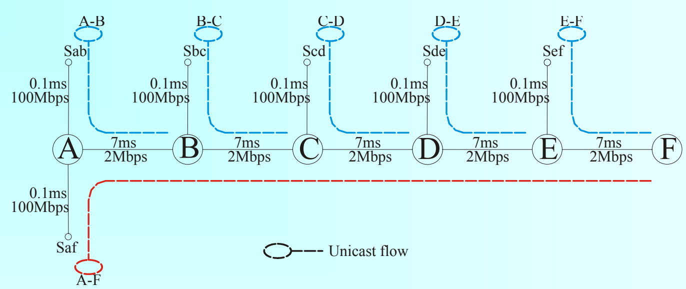


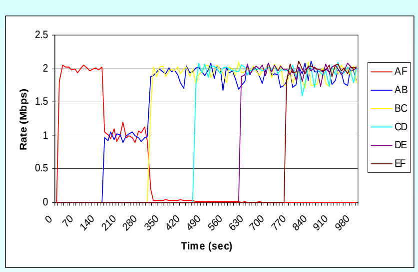


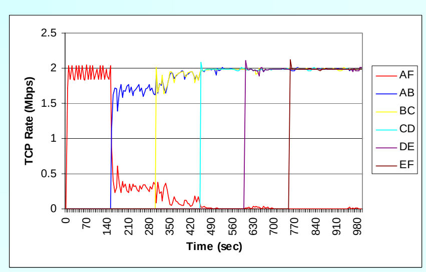




Simulation: Additive Cost In A Chain







Internet Results