Read 7.E

Reliability & Flow Control

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Some slides are from lectures by Nick Mckeown, Ion Stoica, Frans Kaashoek, Hari Balakrishnan, and Sam Madden

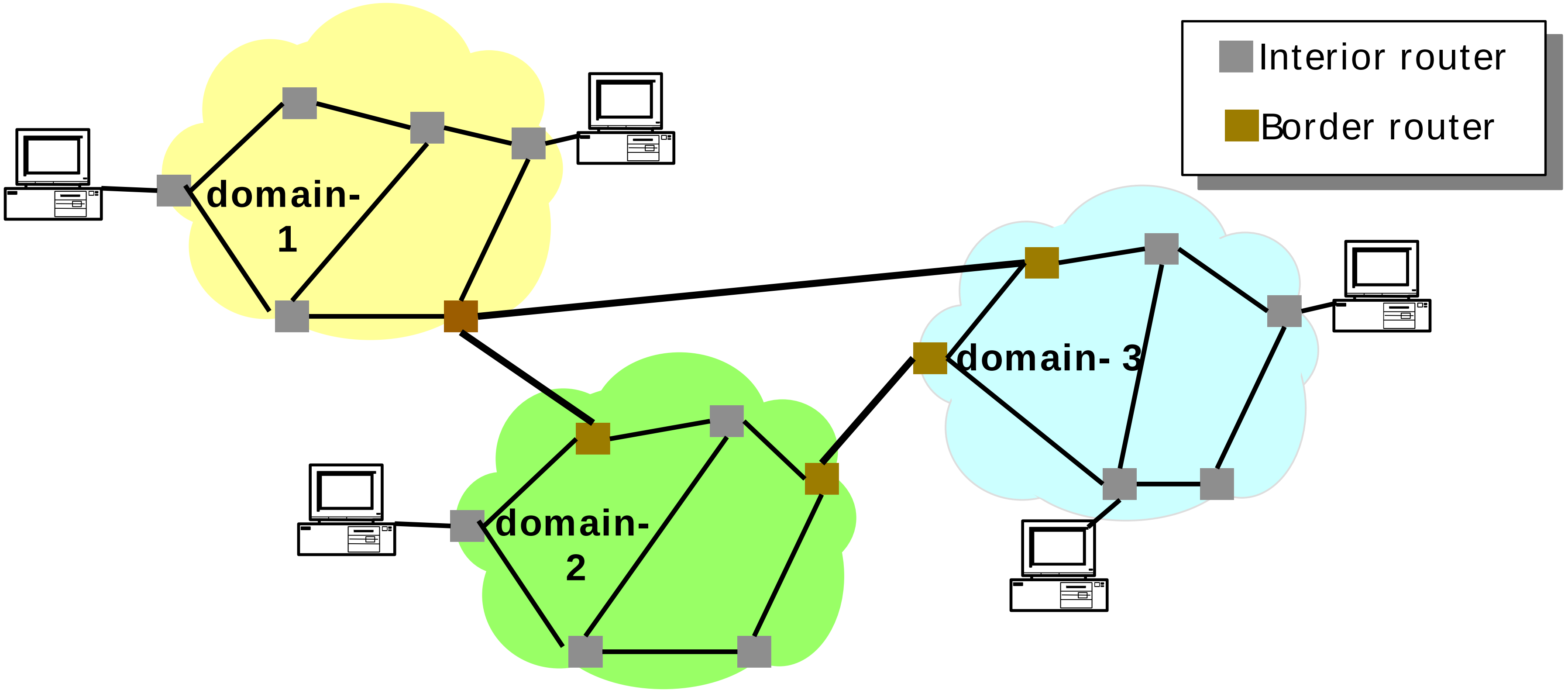
Previous Lecture

How the link layer delivers data over a link

How the network layer performs routing and forwarding

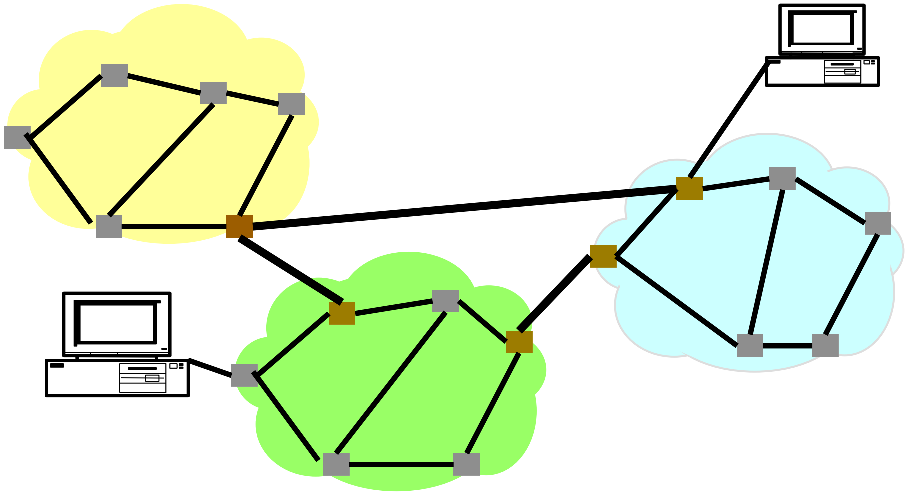
- *Hierarchical Routing and Addressing*

Hierarchical Routing



Internet: collection of domains/networks
Inside a domain: Route over a graph of routers
Between domains: Route over a graph of domains
Address: concatenation of "Domain Id", "Node Id"

Hierarchical Routing



Advantage

- scalable
  - Smaller tables
  - Smaller messages
- Delegation
  - Each domain can run its own routing protocol

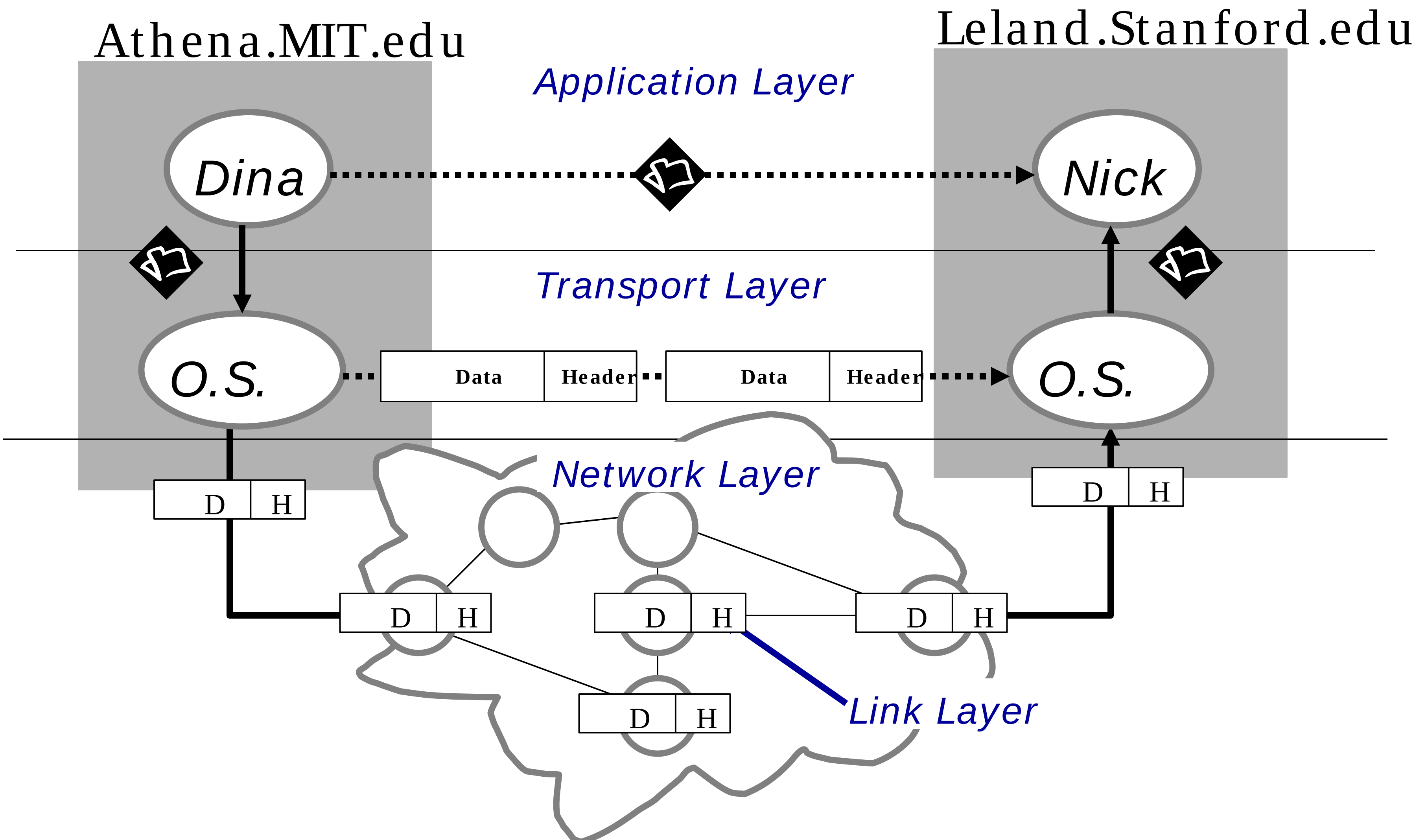
Disadvantage

- Mobility is difficult
  - Address depends on geographic location
- Sup-optimal paths
  - E.g., in the figure, the shortest path between the two machines should traverse the yellow domain. But hierarchical routing goes directly between the green and blue domains, then finds the local destination   path traverses more routers.

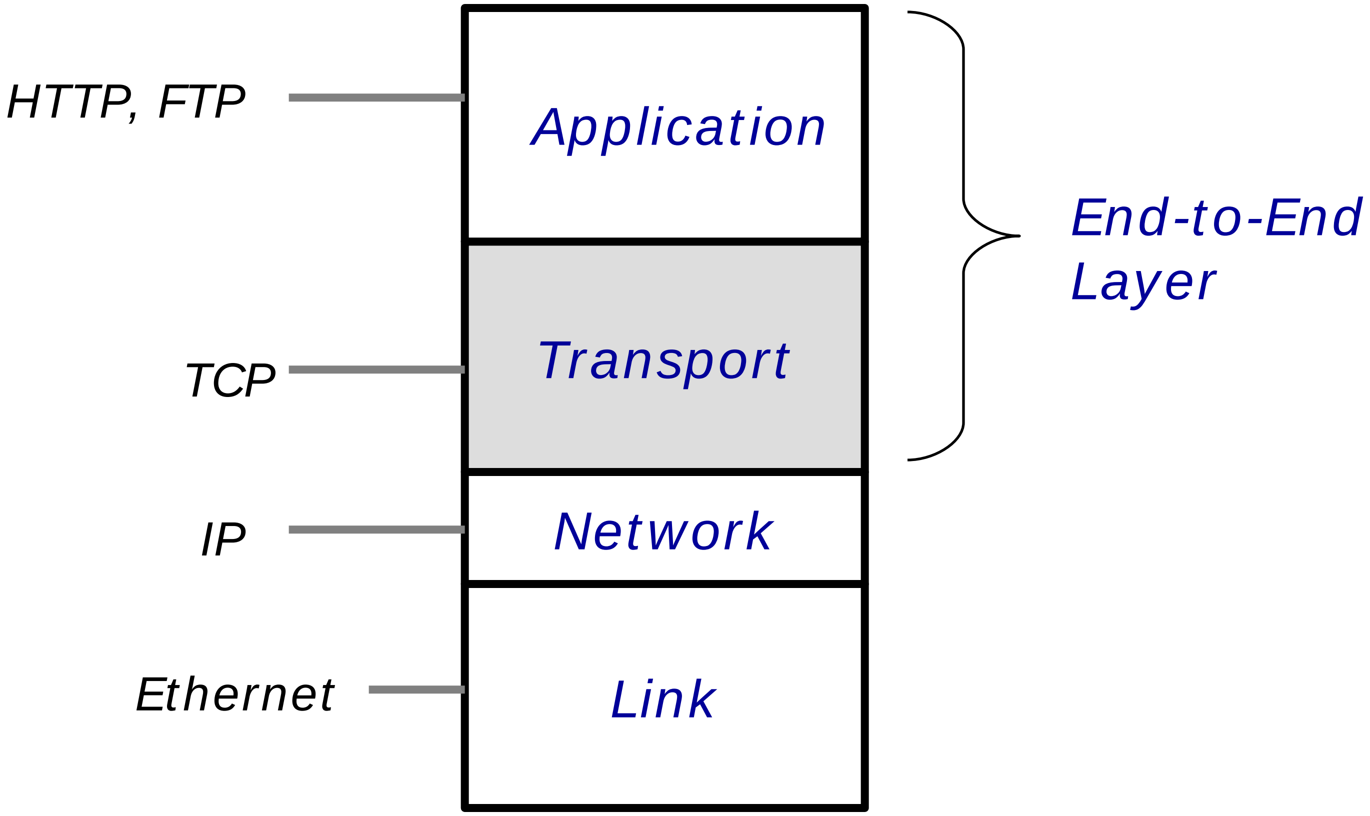
This Lecture

- Transport Layer
  - Reliable data transmission
  - Flow Control
  - Multiplexing

Review of the Transport Layer



Layering



The 4-layer Internet model

Transport Layer

- Network layer provides best-effort service
  - Loss, delay, jitter, duplicates, reordering, …
  - Not convenient for applications
- Transport layer builds on the best effort service to provide applications with a convenient environment
  - Reliability:
    - at least once
    - at most once
  - Performance:
    - flow and congestion control
  - Ordering
  - Data integrity (checksum)
  - Timeliness (remove jitter)
- Also transport provides multiplexing between multiple applications

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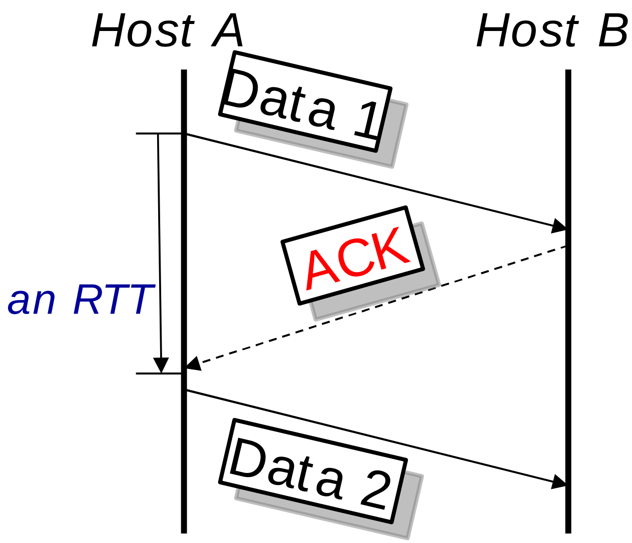
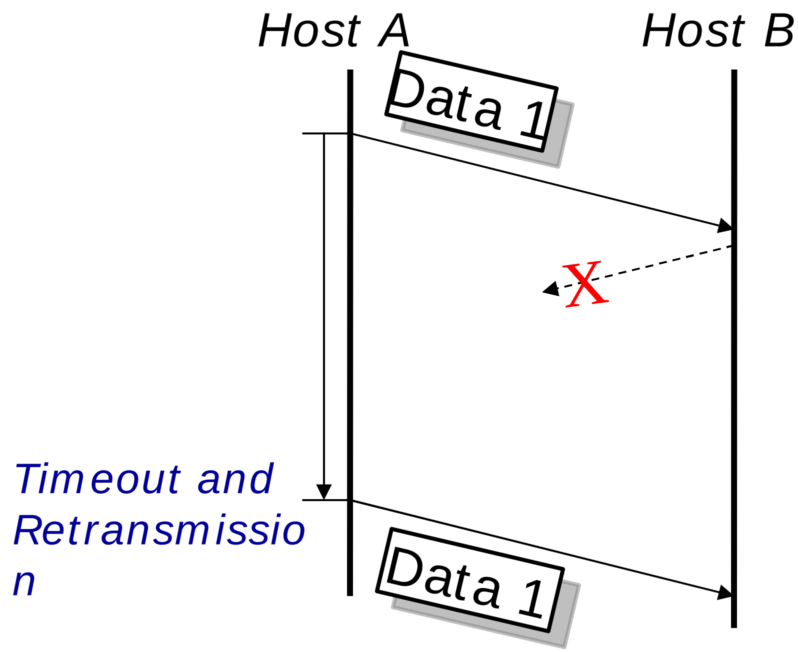
At Least Once

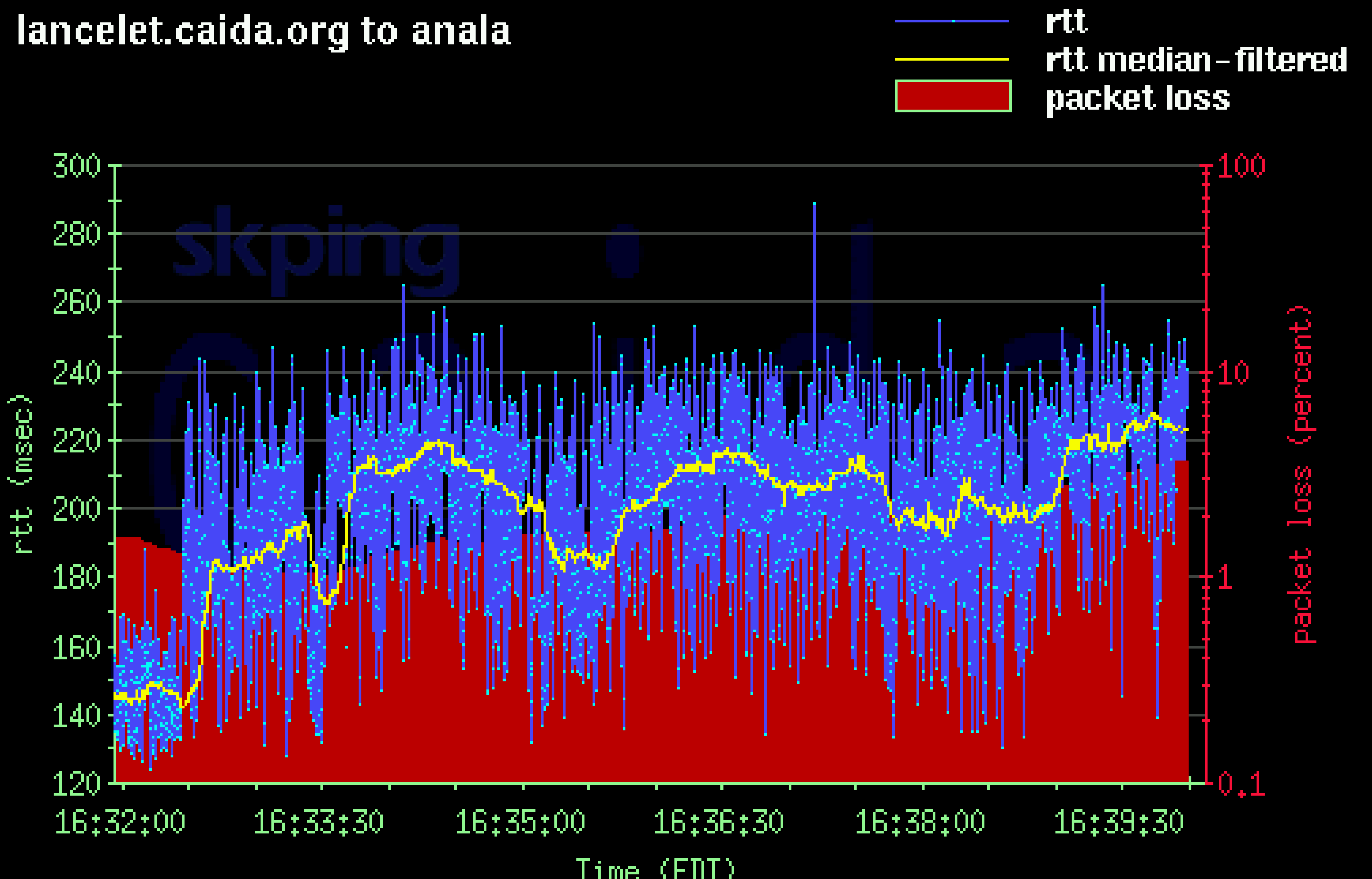




- Sender persistently sends until it receives an ack
- How long should the timeout be?
  - Fixed is bad. RTT changes depending on congestion
    - Pick a values that's too big and it will wait too long to retransmit a packet,
    - Pick a value too small, and it will unnecessarily retransmit packets.
  - Adapt the estimate of RTT adaptive timeout

RTT Measurements

(collected by Caida)



Adaptive Timeout

Samples S_1, S_2, S_3, ..

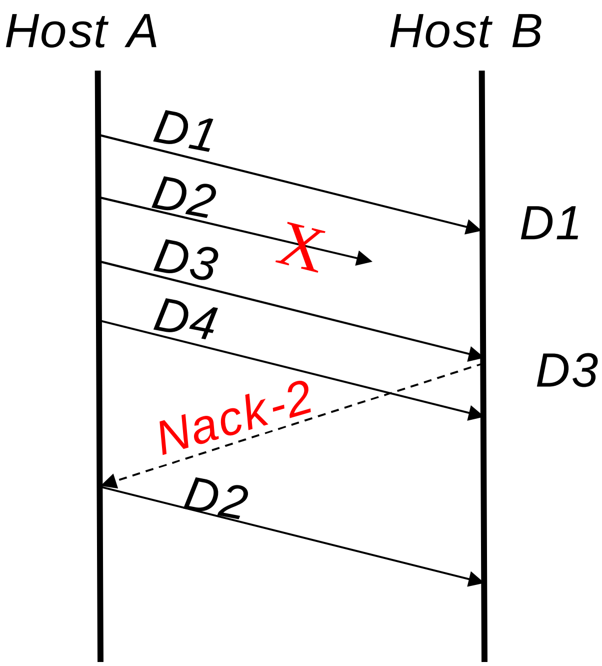
Algorithm

- *EstimatedRTT = T_0*
- *EstimatedRTT = α S + (1- α) EstimatedRTT*
- *where $0 \leq \alpha \leq 1$*

What values should one pick for α and T_0?

- *Adaptive timeout is also hard*

Different Approach: NACK



- Minimize reliance on timer
- Add sequence numbers to packets
- Send a Nack when the receiver finds a hole in the sequence numbers
- Difficulties
  - Reordering
  - Cannot eliminate acks, because we need to ack the last packet

At Most Once

Suppress duplicates

Packets must have ids to allow the receiver to distinguish a duplicate from a new packet

Receiver should keep track of which packet ids have been delivered to applications

To simplify tracking, senders pick monotonically increasing packet ids, i.e., sequence numbers

Receiver delivers packets to application in order. It keeps track of the largest id delivered so far

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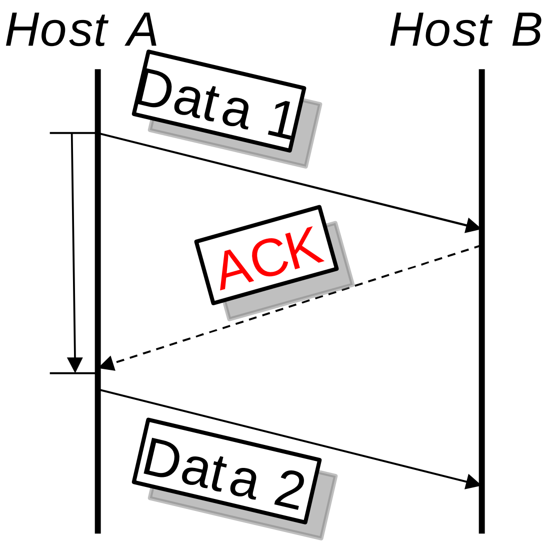
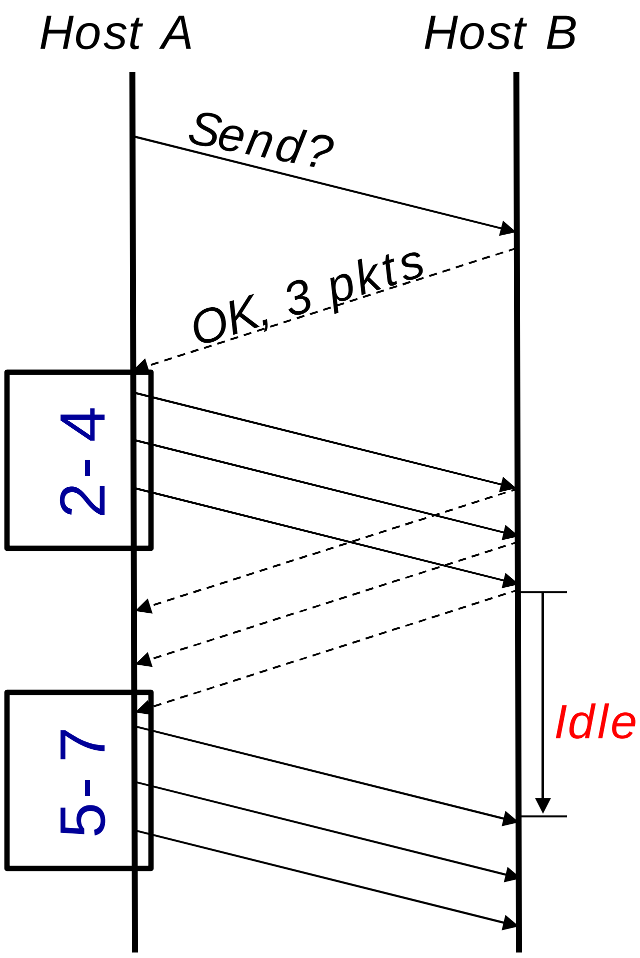
How fast should the sender sends?



- Waiting for acks is too slow
- Throughput is one packet/RTT
  - Say packet is 500B
  - RTT 100ms
    - Throughput = 40Kb/s, Awful!
- Overlap pkt transmission

Send a window of packets



Assume the receiver is the bottleneck

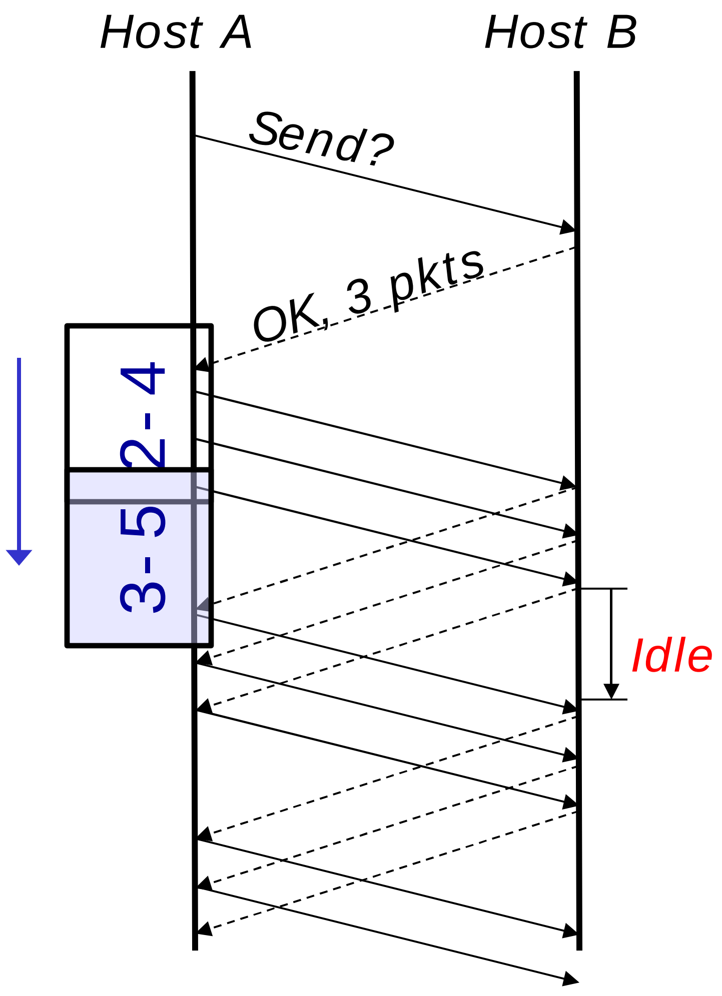
- Maybe because the receiver is a slow machine

Receiver needs to tell the sender when and how much it can send

The window advances once all previous packets are acked

too slow

Sliding Window



Senders advances the window whenever it receives an ack
sliding window

But what is the right value for the window?

The Right Window Size

Note that

if W/RTT < Bottleneck Capacity   under utilization

If W/RTT > Bottleneck Capacity   Large queues

This Lecture

Transport Layer

- *Reliable data transmission*
- *Flow Control*
- *Multiplexing*

Multiplexing by Transport

Multiple applications run on the same machine but use different ports