Read 7.E

Reliability & Flow Control

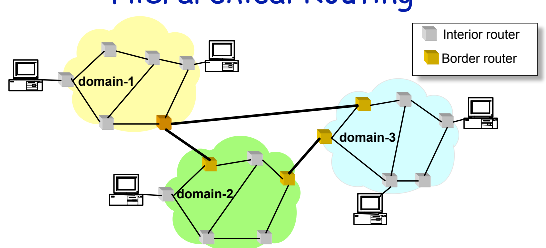
Prof. Dina Katabi

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

Previous Lecture

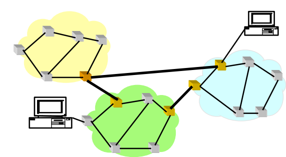
- How the link layer delivers data over a link
- How the network layer performs routing and forwarding
  - Hierarchical Routing and Addressing

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



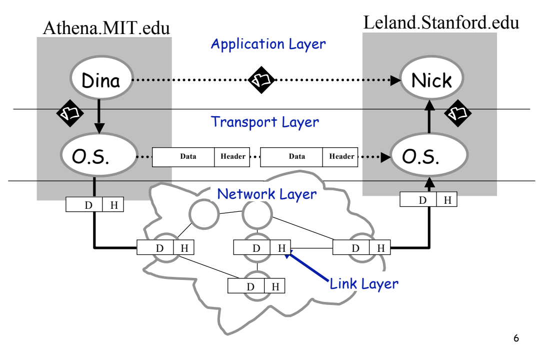
Advantage
- scalable
  - Smaller tables
  - Smaller messages
- Delegation
  - Each domain can run its own routing protocol

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.

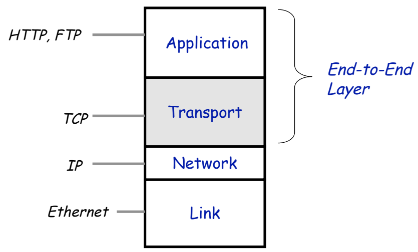
This Lecture

- 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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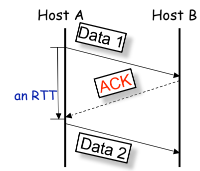
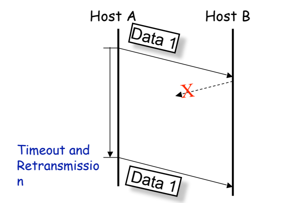
At Least Once

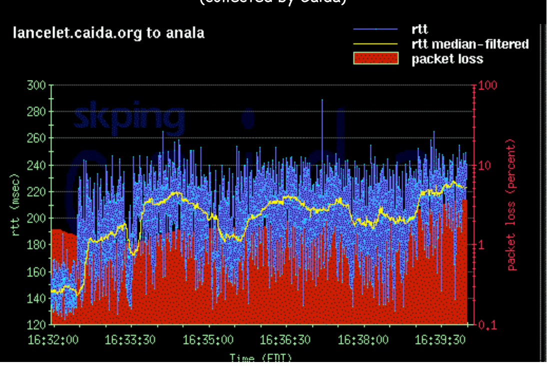




- Sender persistently sends until it receives an ack
- How long should the timeout be?
  - Fixed is bad. RTT changes depending on congestion
    - Pick a values that's too big and it will wait too long to retransmit a packet,
    - Pick a value too small, and it will unnecessarily retransmit packets.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

RTT Measurements

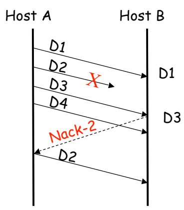
(collected by Caida)



Adaptive Timeout

- Samples S_1, S_2, S_3, ..
- Algorithm
  - EstimatedRTT = T_0
  - EstimatedRTT = α S + (1- α) EstimatedRTT
  - where $0 \le \alpha \le 1$
- 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

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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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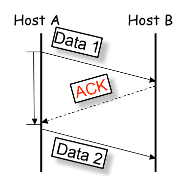
How fast should the sender sends?



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

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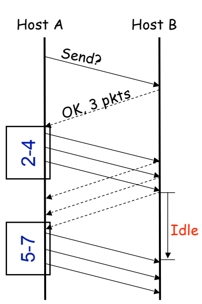
Send a window of packets



- 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

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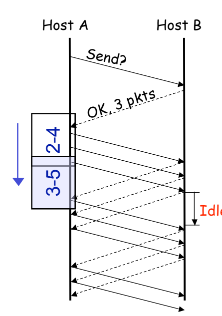
Sliding Window



- Senders advances the window whenever it receives an ack → sliding window
- But what is the right value for the window?

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The Right Window Size

- Note that
  - if W/RTT < Bottleneck Capacity → under utilization
  - If W/RTT > Bottleneck Capacity → Large queues

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Multiplexing by Transport

Multiple applications run on the same machine but use different ports