Last Time

- We finished up the Network layer
  - Internetworks (IP)
  - Routing (DV/RIP, LS/OSPF)
  - Scalable addressing/routing (BGP, CIDR)
  - Routers

This Time

- We begin on the Transport layer
- Focus: How do we send information reliably?
- Topics:
  - The Transport layer
  - Acknowledgements and retransmissions (ARQ)
  - End-to-End argument (E2E)

The Transport Layer

- Builds on the services of the Network layer
- Communication between processes running on hosts
  - Naming/Addressing
- Stronger guarantees of message delivery
  - Reliability

Example – Common Properties

TCP
- Guaranteed delivery
- In-order delivery
- Single delivery
- Arbitrarily long messages
- Synchronization
- Flow control
- Multiple processes

IP
- Lost packets
- Reordered packets
- Duplicate packets
- Limited size packets

Internet Transport Protocols

- UDP
  - Datagram abstraction between processes
  - With error detection
- TCP
  - Bytestream abstraction between processes
  - With reliability
  - Plus congestion control (later!)
Packets can be corrupted or lost. How do we add reliability?

Acknowledgments (ACKs) and retransmissions after a timeout

ARQ is a generic name for protocols based on this strategy.

In the case of ACK loss (or poor choice of timeout) the receiver cannot distinguish this message from the next.

Number packets; here, a single bit will do.

Only one outstanding packet at a time

Also called alternating bit protocol

Lousy performance if wire time << prop. delay

How bad? You do the math

Want to utilize all available bandwidth

How much? Bandwidth-delay product

Leads to Sliding Window Protocol

Window bounds outstanding data

Implies need for buffering at sender

"Last" ACK applies to in-order data

Sender maintains timers too:

Go-Back-N: one timer, send all unacknowledged on timeout

Selective Repeat: timer per packet, resend as needed

Sliding Window – Sender

Sliding Window – Timeline
Receiver buffers too:
- data may arrive out-of-order
- or faster than can be consumed (flow control)

Receiver ACK choices:
- Individual, Cumulative (TCP), Selective (newer TCP), Negative

Sliding window is a mechanism
It supports multiple functions:
- Reliable delivery
- In-order delivery
- Flow control

Which layer provides Reliability?

- We’ve been talking about the Transport layer but ...
- ARQ is used by some link layers
  - Acknowledgements in 802.11
- Error detection/correction codes boost reliability
  - Ethernet CRC, IP header checksum, etc.
- Where is the “right” place in the protocol stack?

End-to-End Argument

- Key design principle applied in the Internet
- Reliability is needed end-to-end and can’t be replaced by lower layer mechanisms. So put it end-to-end; use lower mechanisms to improve performance as needed.
- TCP provides reliable delivery
  - Checksums packet data as well
- Lower layers keep their residual error rate is low
  - CRC enough for Ethernet; wireless links more problematic

Key Concepts

- Transport layer allows processes to communicate with stronger guarantees, e.g., reliability
- Basic reliability is provided by ARQ mechanisms
  - Stop-and-Wait through Sliding Window
- End-to-End principle guides placement of functions
- Coming Next: Connections and Congestion Control
- Read Keshav 12.4 and Ch 13, esp. 13.4