

CSE/EE 461 – Lecture 10

David Wetherall
djw@cs.washington.edu

Last Time

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

Application
Presentation
Session
Transport
Network
Data Link
Physical

djw // CSE/EE 461, Winter 2000

L10.2

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)

Application
Presentation
Session
Transport
Network
Data Link
Physical

djw // CSE/EE 461, Winter 2000

L10.3

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

djw // CSE/EE 461, Winter 2000

L10.4

Example – Common Properties

- | | |
|-----------------------------|------------------------|
| TCP | IP |
| • Guaranteed delivery | • Lost packets |
| • In-order delivery | • Reordered packets |
| • Single delivery | • Duplicate packets |
| • Arbitrarily long messages | • Limited size packets |
| • Synchronization | |
| • Flow control | |
| • Multiple processes | |

djw // CSE/EE 461, Winter 2000

L10.5

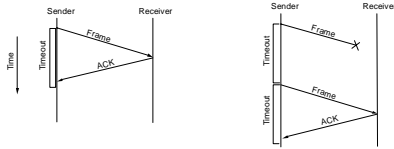
Internet Transport Protocols

- UDP
 - Datagram abstraction between processes
 - With error detection
- TCP
 - Bytestream abstraction between processes
 - With reliability
 - Plus congestion control (later!)

djw // CSE/EE 461, Winter 2000

L10.6

Automatic Repeat Request (ARQ)

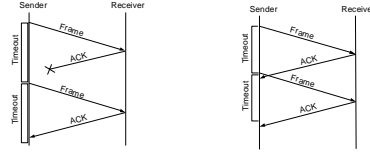


- Packets can be corrupted or lost. How do we add reliability?
- Acknowledgments (ACKs) and retransmissions after a timeout
- ARQ is generic name for protocols based on this strategy

djw // CSE/EE 461, Winter 2000

L10.7

The Need for Sequence Numbers



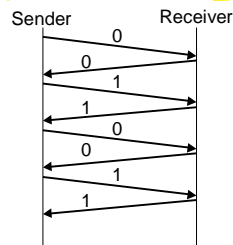
- In the case of ACK loss (or poor choice of timeout) the receiver can't distinguish this message from the next
 - Number packets; here, a single bit will do

djw // CSE/EE 461, Winter 2000

L10.8

Stop-and-Wait

- Only one outstanding packet at a time
- Also called alternating bit protocol



djw // CSE/EE 461, Winter 2000

L10.9

Limitation of Stop-and-Wait

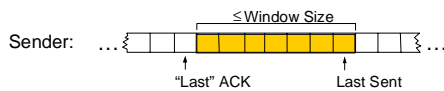


- Lousy performance if wire time \ll prop. delay
 - How bad? You do the math
- Want to utilize all available bandwidth
 - Need to keep more data "in flight"
 - How much? Bandwidth-delay product
- Leads to Sliding Window Protocol

djw // CSE/EE 461, Winter 2000

L10.10

Sliding Window – Sender

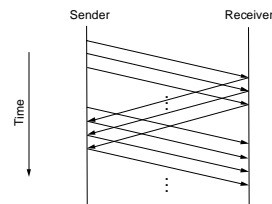


- Window bounds outstanding data
 - Implies need for buffering at sender
- "Last" ACK applies to in-order data
- Sender maintains timers too
 - Go-Back-N: one timer, send all unacknowledged on timeout
 - Selective Repeat: timer per packet, resend as needed

djw // CSE/EE 461, Winter 2000

L10.11

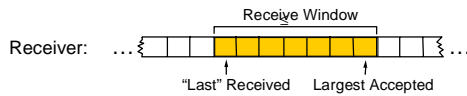
Sliding Window – Timeline



djw // CSE/EE 461, Winter 2000

L10.12

Sliding Window – Receiver



- 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

djw // CSE/EE 461, Winter 2000

L10.13

Sliding Window Functions

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

djw // CSE/EE 461, Winter 2000

L10.14

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?

djw // CSE/EE 461, Winter 2000

L10.15

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

djw // CSE/EE 461, Winter 2000

L10.16

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

djw // CSE/EE 461, Winter 2000

L10.17