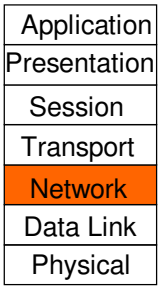
CSE/EE 461 – Lecture 13

Sliding Windows and ARQ

David Wetherall
djw@cs.washington.edu

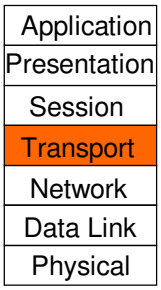
Last Time

- We finished up the Network layer
  - Internetworks (IP)
  - Routing (DV/RIP, LS/OSPF)
  - Scalable addressing/routing (BGP, CIDR)
- It was all about routing: how to provide end-to-end delivery of packets.



This Time

- We begin on the Transport layer



- Focus
  - How do we send information reliably?
- Topics
  - The Transport layer
  - Acknowledgements and retransmissions (ARQ)
  - Sliding windows

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

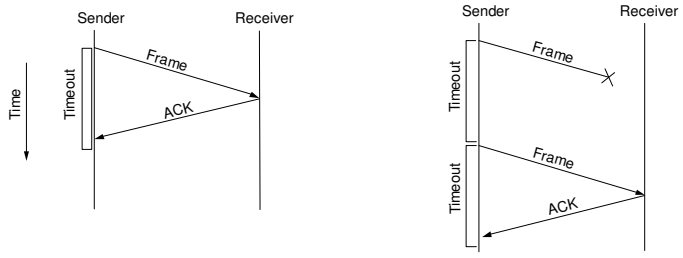
TCP
- Guaranteed delivery
- In-order delivery
- Single delivery
- Arbitrarily long messages
- Synchronization
- Flow control
- Multiple processes

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

Internet Transport Protocols

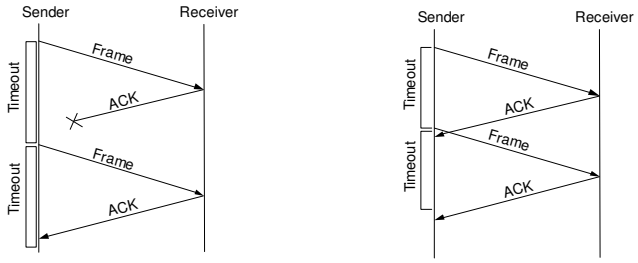
- UDP
  - Datagram abstraction between processes
  - With error detection
- TCP
  - Bytestream abstraction between processes
  - With reliability
  - Plus congestion control (later!)

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

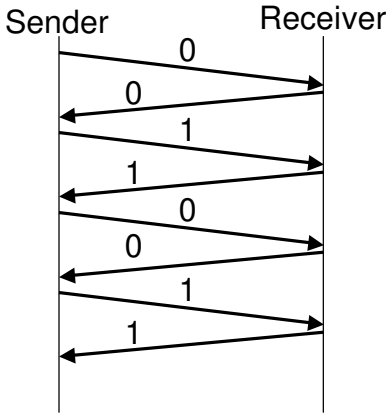
The Need for Sequence Numbers



- In the case of ACK loss (or poor choice of timeout) the receiver can't distinguish this message from the next
  - Need to understand how many packets can be outstanding and number the packets; here, a single bit will do

Stop-and-Wait

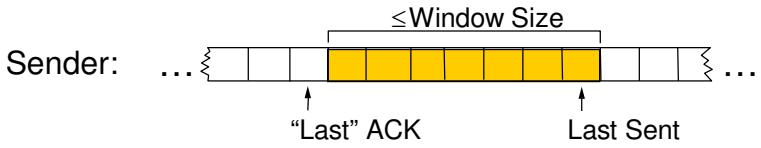
- Only one outstanding packet at a time
- Also called alternating bit protocol



Limitation of Stop-and-Wait

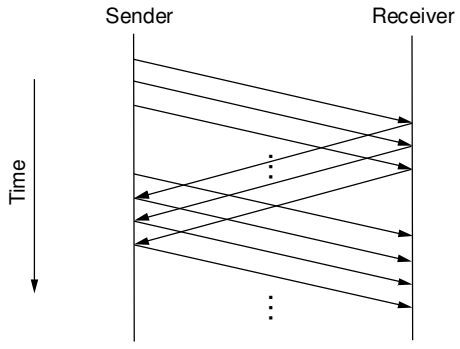
- Lousy performance if wire time << prop. delay
  - How bad? You do the math
- Want to utilize all available bandwidth
  - Need to keep more data "in flight"
  - How much? Remember the bandwidth-delay product?
- Leads to Sliding Window Protocol

Sliding Window – Sender

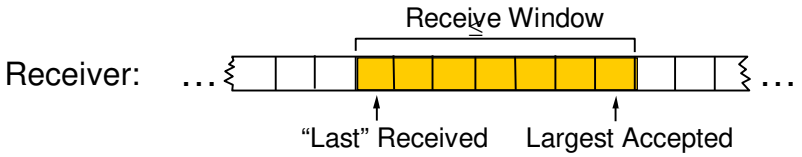


- Window bounds outstanding data
  - Implies need for buffering at sender
- "Last" ACK applies to in-order data
- Sender maintains timers too
  - Go-Back-N: one timer, send all unacknowledged on timeout
  - Selective Repeat: timer per packet, resend as needed

Sliding Window – Timeline



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

Sliding Window Functions

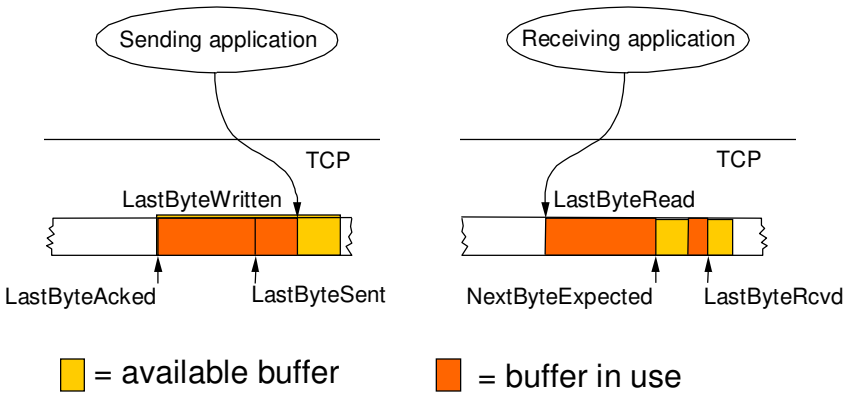
- Sliding window is a mechanism
- It supports multiple functions:

- Reliable delivery
- In-order delivery
- Flow control

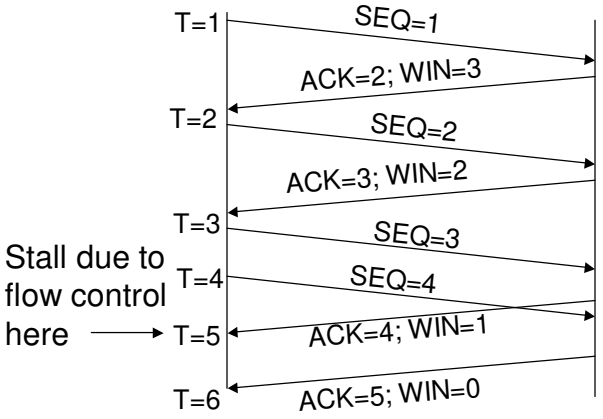
Flow Control

- Sender must transmit data no faster than it can be consumed by the receiver
  - Receiver might be a slow machine
  - App might consume data slowly
- Implement by adjusting the size of the sliding window used at the sender based on receiver feedback about available buffer space
  - This is the purpose of the Advertised Window field

Sender and Receiver Buffering



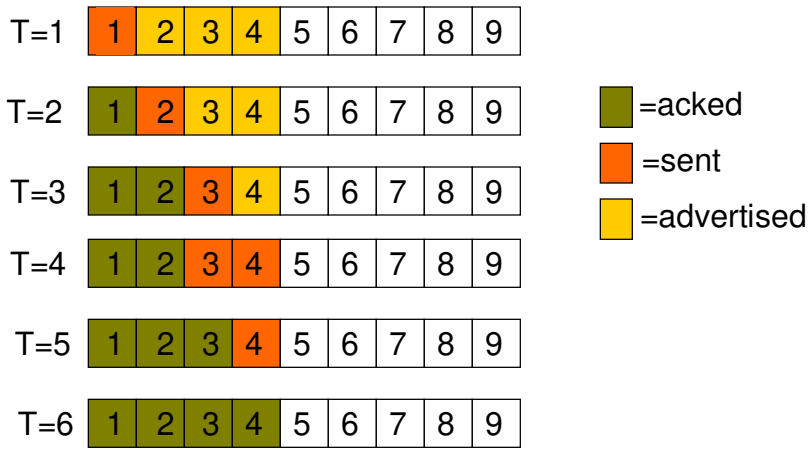
Example – Exchange of Packets



Stall due to flow control here →

Receiver has buffer of size 4 and application doesn't read

Example – Buffer at Sender



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 plus retransmissions