Last time

How can we detect & correct corrupted data?

- Hamming distance
- Methods of error detection & correction: Parity, checksum, CRC
- Error detection at many layers

This time

How can we cope with lost and corrupted messages?

1. ARQ
2. Model of a Link
3. Sliding window

Example: Two Generals
Automatic Repeat Request (ARQ)

• Receiver sends acknowledgment (ACK)
• Sender retransmits after a timeout if no ACK

The Need for Sequence Numbers

• The receiver doesn’t know this is the same message:
  -
  -

The Need for Sequence Numbers

• Sender doesn’t know

Stop-and-Wait

• Only one outstanding message at a time
• Also called alternating bit protocol
Limitation of Stop-and-Wait

- Lousy performance if
- Want to keep more data “in flight”
  - How much?

Message Latency

- How long does it take to send a message?

  ![Diagram of message latency with variables: Message M, Delay D, Rate R]

  - Two terms:
    - Propagation delay =
    - Transmission delay =

  - Later we will see queuing delay …

2. Intermezzo: Model of a Link

- Abstract model is typically all we will need
- Other parameters that are important:
  - The kind and frequency of errors
  - Whether the media is broadcast or not

Message Latency examples

- Dialup with a modem:
  - \( D = 10 \text{ ms} \), \( R = 56 \text{ Kbps} \), \( M = 1000 \text{ bytes} \)
  - Latency =

- Cross-country with T3 (45Mbps) line:
  - \( D = 50 \text{ ms} \), \( R = 45 \text{ Mbps} \), \( M = 1000 \text{ bytes} \)
  - Latency =
Terminology

- Latency is typically one way delay
- The round trip time (RTT) is twice one way delay
  - Measure of
- An important metric is the bandwidth-delay product
  - Measure of

Limitation of Stop-and-Wait, redux

- Stop & wait has lousy performance if
  - How bad? You do the math
- Want to utilize all available bandwidth
  - Leads to Sliding Window Protocol

3. Sliding Window

- Window bounds outstanding data
  - Implies need for
- “Last” ACK applies to in-order data
- Sender maintains timers
  - Go-Back-N: one timer, send all unacknowledged on timeout
  - Selective Repeat: timer per packet, resend as needed
Sliding Window – Receiver

- Receiver buffers too:
  - data may arrive
  - or
- Receiver ACK choices:
  - Individual, Cumulative (TCP), Selective (newer TCP), Negative

Sliding Window Functions

- Reliable delivery
- In-order delivery
- Flow control

Flow Control

- Sender must transmit data no faster than it can be consumed by the receiver
- Adjust the size of the sliding window used at the sender based on receiver feedback about available buffer space

Sender and Receiver Buffering

- Available buffer
- Buffer in use
Example – Exchange of Packets

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

Example – Buffer at Sender

Key Concepts

• Model of a link is specified by propagation delay $D$ and rate $R$
• Basic reliability is provided by ARQ mechanisms
  – Stop-and-Wait through Sliding Window plus retransmissions
• Next time: How can we estimate the retransmission timeout?