Announcements

- Reading
  - Today: Chapter 5 (5.1-5.2)
- Program #1 Due at 10 PM not 10AM
- Notes on the project have been posted to the web
- Note on CRC example from last time:
  - a generator of degree r has as it's largest term x^r (or r+1 bits) so the example in the notes is fine.

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Simple Link Protocols

- Stop-and-wait
  - Sender

```
while (1) {
        get frame from network layer;
        send frame;
        wait for ack;
}
```

  - Receiver:

```
while (1) {
        recv frame;
        send frame to network layer;
        send ack;
}
```

  - Only one side active (sending) at once
  - Ensures rate matching

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Sliding Window Protocol

- Need to
  - have multiple outstanding packets
  - limit total number of outstanding packets
  - permit re-transmissions to occur
- Sliding Window
  - permit at most N outstanding packets
  - when packet is ACK'd advance window to first non-ACK'd pkt
- Retransmission
  - Go-back N
    - when a packet is lost, restart from that packet
    - provides in-order delivery, but wastes bandwidth
  - Selective Retransmission
    - use timeout to re-sent lost packet
    - use NACK as a **hint** that something was lost

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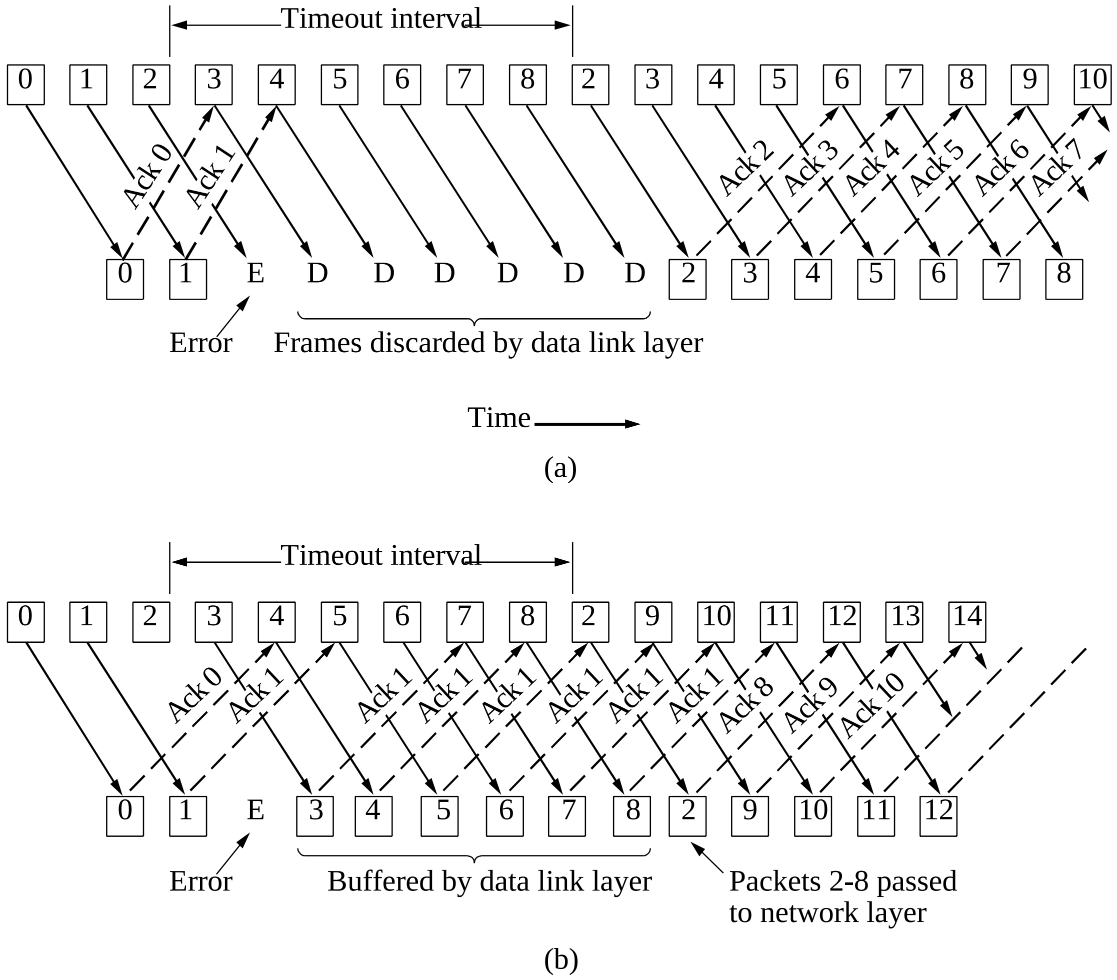
Sliding Window Example



From: *Computer Networks*, 3rd Ed. by Andrew S. Tanenbaum, (c)1996 Prentice Hall.

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Network Layer

- Responsibility
  - end-to-end delivery of packets to the network
  - selecting routes for the packets to take
    - implies knowledge of the network topology
  - managing utilization of the links
    - provide flow control (across multiple links)
    - spread load among different routes
- Interface Design
  - should be independent of subnet technology
  - hide number, type, and topology of network from upper layers
  - export a common number plan for entire network

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Connection vs. Connectionless

- Two possible designs for network layer
  - connection oriented service (ATM)
    - based on experience of telcos
  - connectionless service (IP)
    - based on packet switching (ARPANET)
- Connectionless
  - transport datagrams from source to destination
    - end-point addresses in every datagram
  - less complex network layer, more complex transport
- Connection oriented
  - also called virtual circuits
  - establish an end-to-end connection with network state
    - can use VCI (global or next hop) in each packet

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Datagram vs. VC Addresses

- Datagrams
  - must include full address in each packet
  - addresses must be unqiue for entire network
    - don’t re-use too often
    - addresses per src/dest pair
- Virtual Circuit
  - globally unique
    - requires allocation scheme to ensure its unique
    - consumes many bits per packet
  - per link
    - requires translation at each switch
    - uses fewer bits (important for small packets like ATM)

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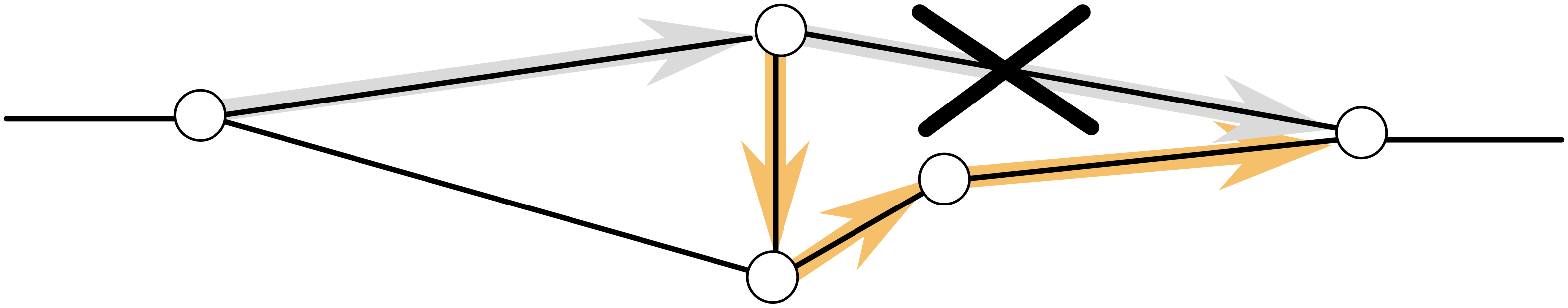
Link Failue in Virtual Circuits



- Re-establish virtual circuit
  - router near failure can patch up link
  - original host/router creates new virtual circuit
- Virtual circuit is dropped
  - transport layer can handle recovery

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Virtual Circuit vs. Datagram

Issue	Datagram	Virtual Circuit
Circuit setup	not needed	necessary
Addresses	full source/dest per packet	next hop vc sufficient
state	no state in network	per connection data at each router
routing	each packet individually	once at VC setup
router/link failure	a few packets may be lost	all VCs through router are terminated
congestion control	difficult	many pre-allocation and policing policies permitted

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Routing: Goals

- Correctness
  - packets get where they are supposed
- Simplicity
  - easy to implement correctly
  - possible to make routing choices fast (or updates easy)
- Robustness
  - failures in the network still permit communication
- Stability
  - small changes in link availability results in a small change in the routing information
- Fairness
  - each host, VC, or datagram has the same chance
- Optimality
  - best possible route
  - best utilization of bandwidth

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