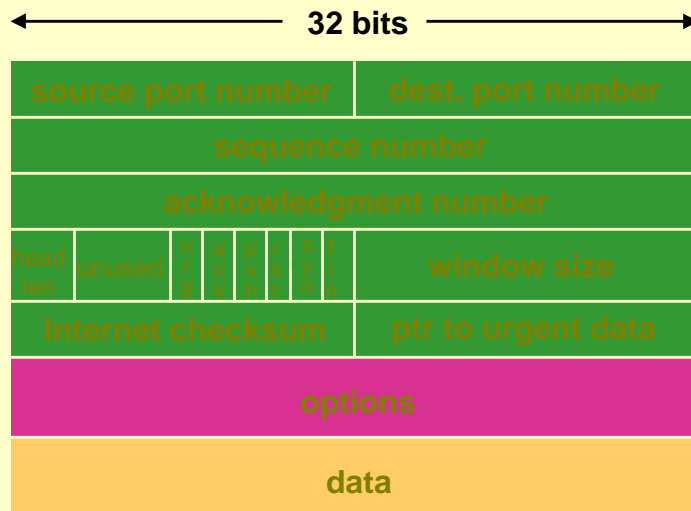


Data Transfer Case Study: TCP

- ❑ Go-back N ARQ
 - ◆ 32-bit sequence # indicates byte number in stream
 - ◆ transfers a byte stream, not fixed size user blocks
 - ◆ full duplex (bi-rectional) data transfer
 - ◆ sends upper level data "at its convenience" (RFC793!), trying to accumulate 512 bytes of data
- ❑ cumulative ACK: ACK(n) ack's all bytes up through n
 - ◆ ACK for received A-to-B data piggybacked on B-to-A data packet
- ❑ Internet checksum: add up data, take 1's complement
 - ◆ covers both header and data

TCP Packet Format



Data Transfer: XTP

- ❑ XTP: Xpress transfer protocol
- ❑ designed for high-speed, high-performance networks
- ❑ 32-bit sequence numbers with transition to 64-bit seq. numbers
- ❑ 32-bit priority field for different priority data
- ❑ user-selectable: reliable or unreliable data transfer
- ❑ Go-Back-N ARQ but receiver can also indicate spans of packets received
 - ◆ sender only retransmits gaps

Data Transfer: XTP

- ❑ checksum:
 - ◆ form of two-dimensional parity
 - ◆ header and data checksummed separately
 - ◆ data checksumming can be disabled
 - ◆ data checksumming at end (send data while computing checksum (need only touch data once))

Flow and Congestion Control

sometimes sender shouldn't send a ready packet:

- receiver not ready (e.g., buffers full)
- react to congestion
 - ◆ many unACK'ed packets may mean long end-end delays, congested networks
 - ◆ network itself may provide sender with congestion indication
- avoid congestion:
 - ◆ sender transmits smoothly to avoid temporary network overloads

Flow and Congestion Control

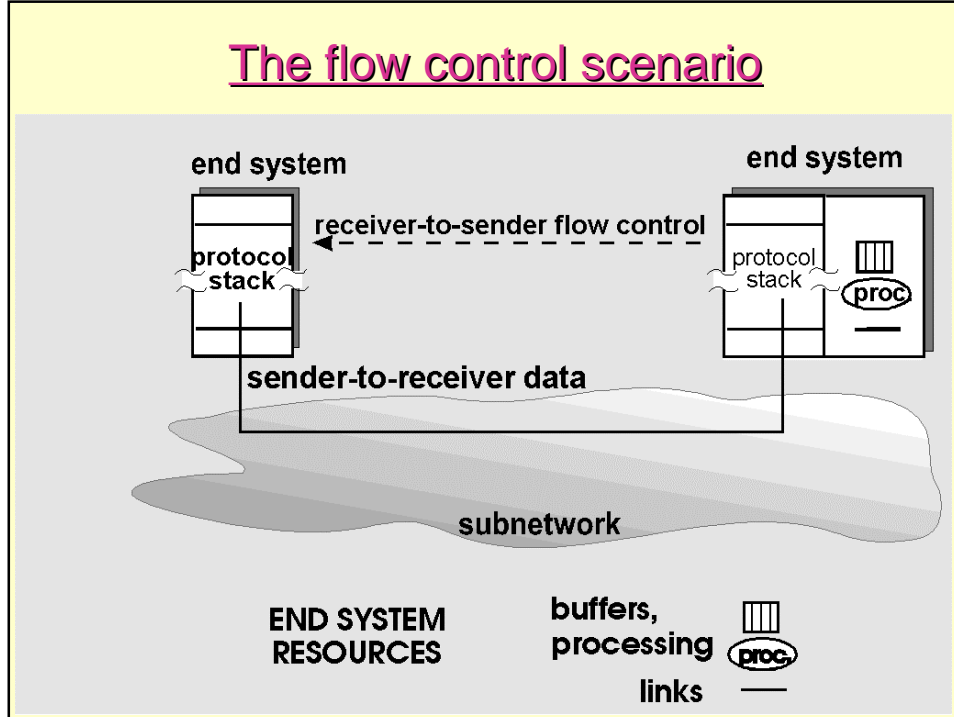
flow control: speed and resource matching of sender and receiver

- sender should not overwhelm receiver

congestion control: action taken in response to network layer (and below) congestion

- throttling sender is but one solution to congestion

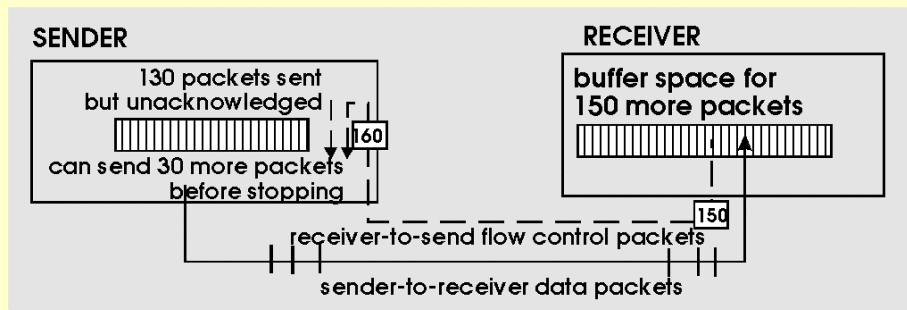
The flow control scenario



Two approaches towards flow control

Explicit flow control

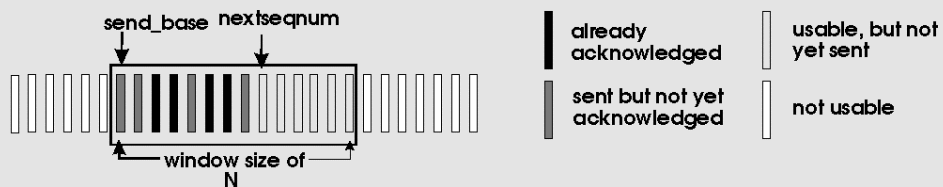
- receiver tells sender how much to send



Explicit flow control (cont)

Useful abstraction: sender maintains sliding window over sequence number, indicating what it can send

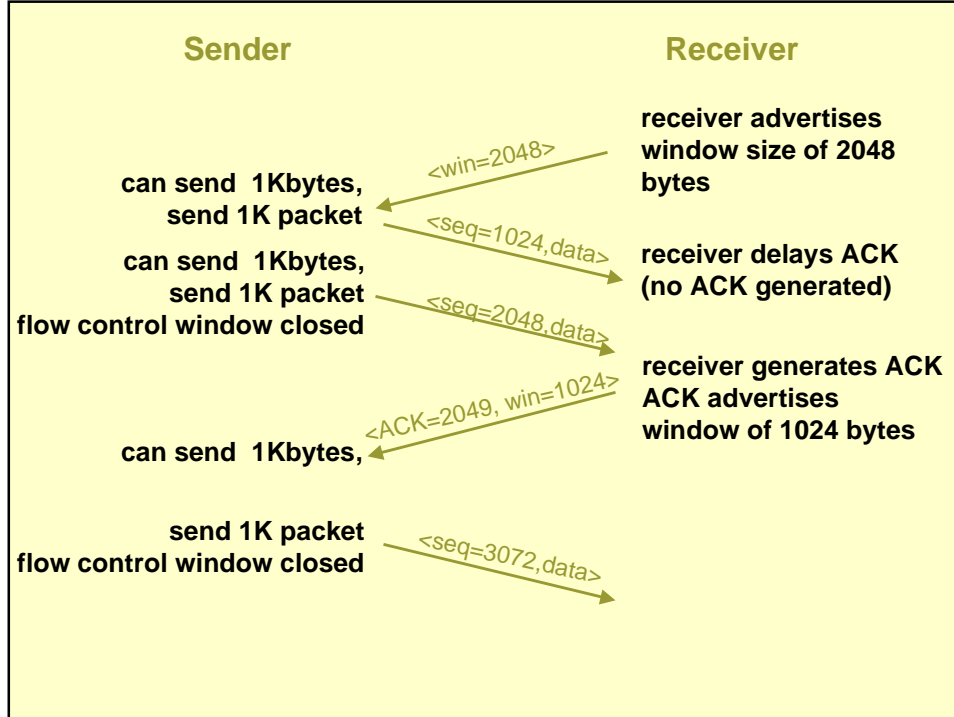
- ❑ done in TCP and TP4
- ❑ congestion (as opposed to flow) control window may further restrict sender



Flow Control in TCP

Receiver explicitly advertises available buffer space to sender:

- ❑ 16-bit "advertised window" specifies number of bytes (starting from ACKnum) receiver willing to receive
- ❑ max window size is 64K
- ❑ recent "scaling" option for larger windows



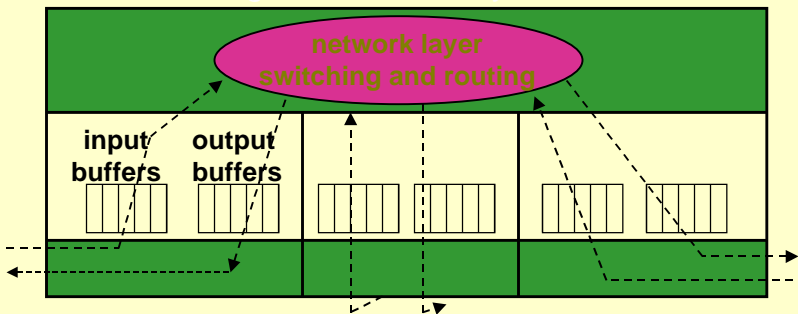
Implicit flow control

- receipt of ACK's triggers more sending
- delayed ACK (for whatever reason) slows down sender
- IBM virtual route pacing:
 - ◆ initially send window of N packets
 - ◆ ACK of first packet in this (and subsequent) windows of N allows sender to send N more
 - ◆ "jumping", non-sliding window
 - ◆ max. number of unACK'ed packets?
 - ◆ decrease in traffic for explicit flow control

Congestion Control

Temporary demand for shared resources (links, processing, buffers) in *network* layer and below may exceed demand:

- ❑ packets buffered until resources available
- ❑ buffers full: packet lost (discarded)
 - ◆ which to discard?
- ❑ lots of buffering: excessive delays



Congestion Control: retransmission effects

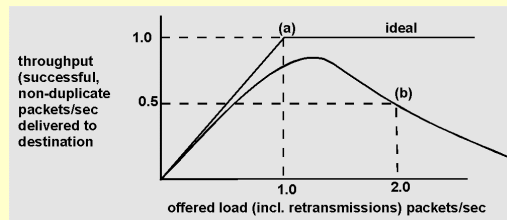
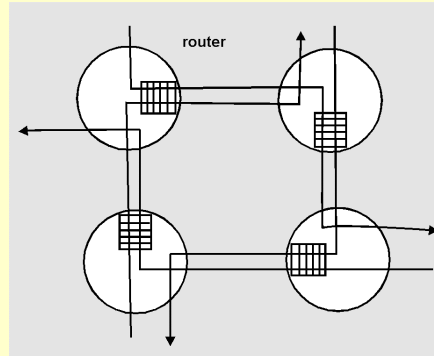
Ideal case:

- ❑ every packet delivered successfully until subnet reaches capacity
- ❑ beyond capacity: deliver packets at capacity rate

In face of loss or long end-end delay, retransmissions can make things worse

- ❑ inject more (not less) traffic into net
- ❑ throwing fuel on fire!

Congestion Control: retransmission effects



Congestion Control (cont)

Realistically:

- as offered load increases, more packets lost, causing more retransmission, causing more traffic, causing more losses, ...
 - ◆ at (b), each original packet sent four times on average
 - ◆ decreasing rate of transmission (e.g., a larger timeout value) **increases** overall throughput

Moral:

- when losses occur: **backoff**, don't aggressively retransmit

However:

- **social versus individual good**: if most back off (and suffer) how to handle greedy sender who does not back off (and benefits)

Three Basic Approaches towards Congestion Control

End-end congestion control

- ❑ sender-observed congestion (e.g., delays, losses) used to control sender
- ❑ closed loop control

Network-indicated congestion control

- ❑ network layer provides feedback to sender

Rate-based control

- ❑ sender behavior fixed (bounded) over time
- ❑ open-loop control

Real-world protocols sometimes mix/combine these