

Transport Layer



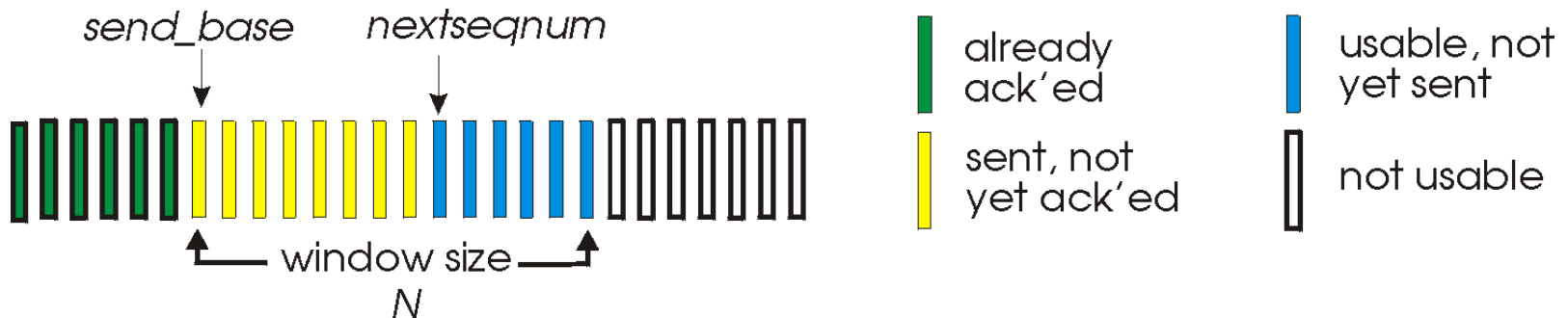
Instructor: C. Pu (Ph.D., Assistant Professor)

Lecture 10

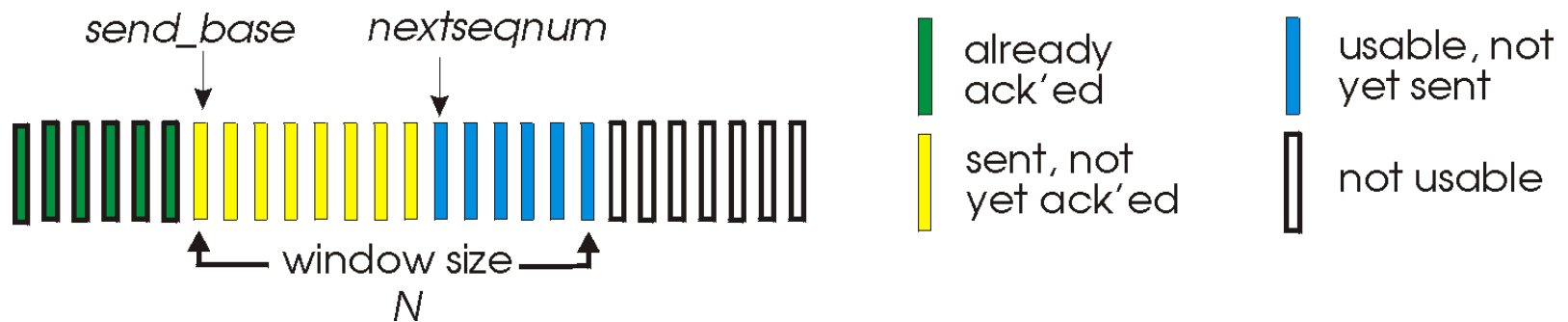
puc@marshall.edu

Go-Back-N

- Sender:
 - allow to transmit *multiple packets without waiting for ACK*
 - constrained to **N** unack'ed packets in the pipeline
- Sender's view of the sequence numbers in GBN



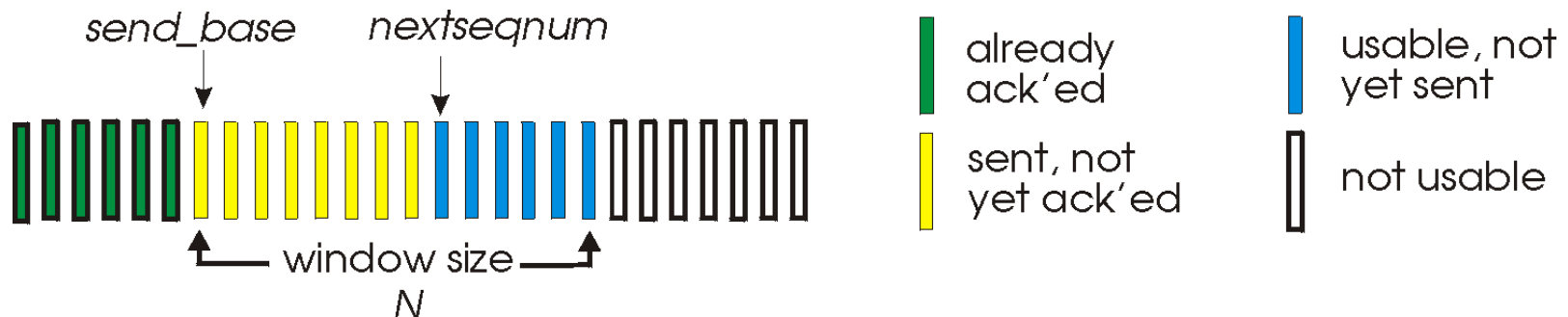
Go-Back-N



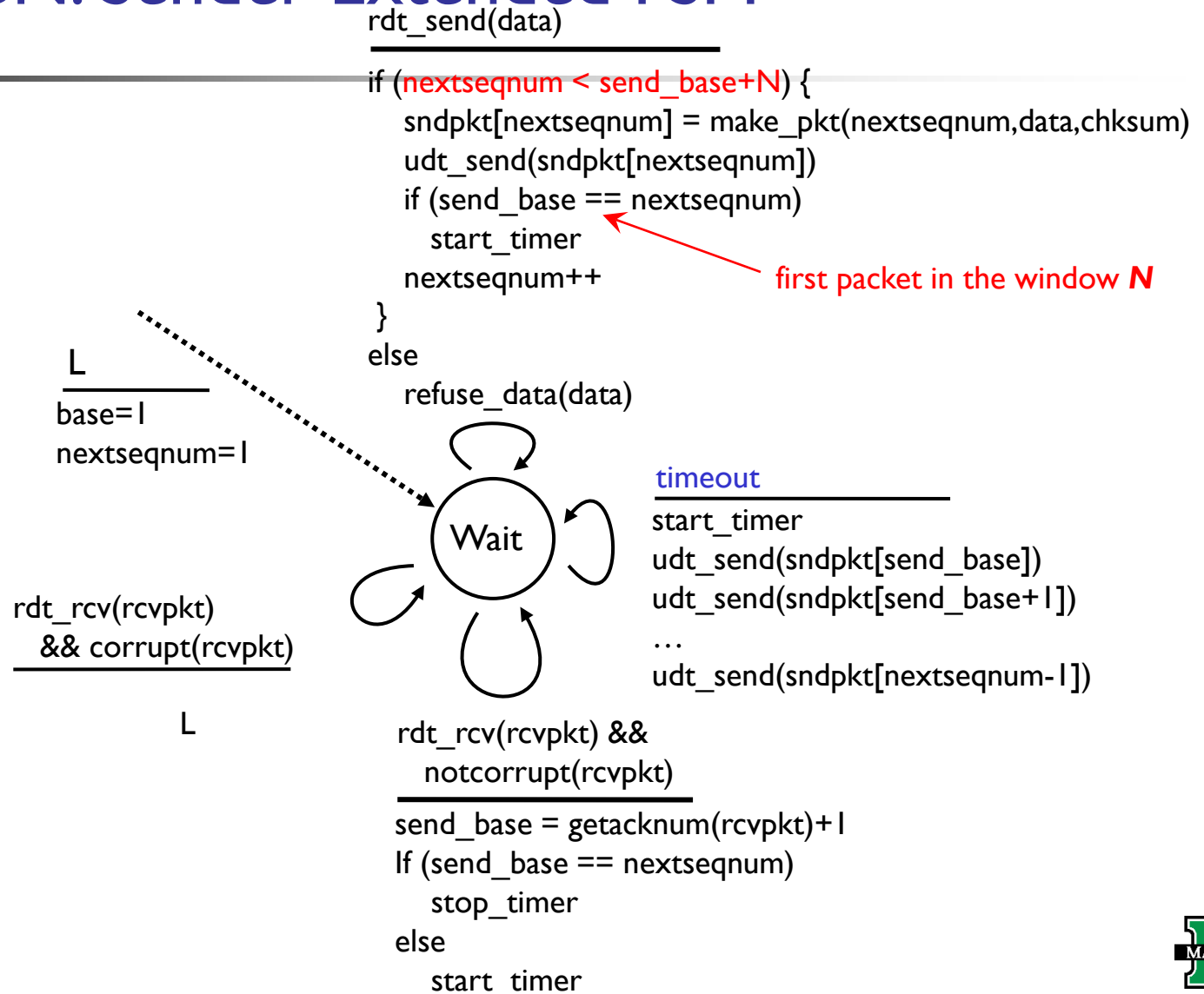
- **send_base**: the seq. number of the **oldest unack'ed packet**
- **nextseqnum**: the **smallest unused seq. number**
- $[0, \text{send_base} - 1]$: packets that have already been **transmitted** and **acked**
- $[\text{send_base}, \text{nextseqnum} - 1]$: packets that have been **sent but not yet acked**
- $[\text{nextseqnum}, \text{send_base} + N - 1]$: packets can be sent immediately

Go-Back-N

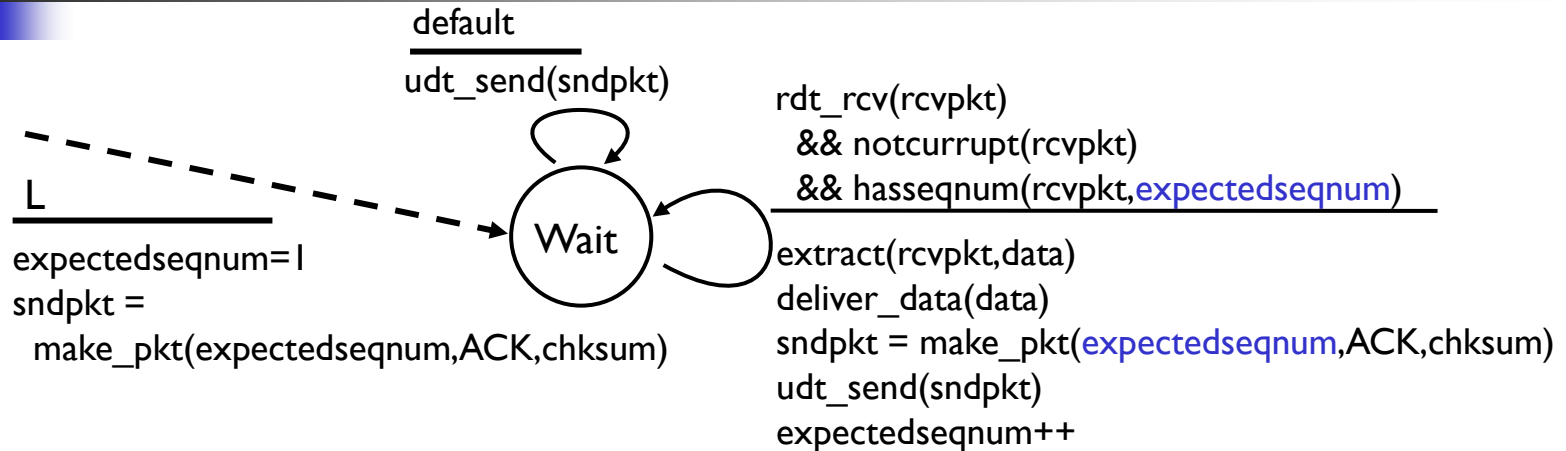
- Sender:
 - allow to transmit *multiple packets without waiting for ACK*
 - constrained to **N** unack'ed packets in the pipeline
 - “window” of up to **N**, consecutive unack'ed pkts allowed
 - seq. number is carried in a fixed-length field in the packet header
 - k-bit seq # in pkt header
 - $[0, 2^k - 1]$
 - e.g., TCP: 32-bits seq #



GBN: Sender Extended FSM



GBN: Receiver Extended FSM



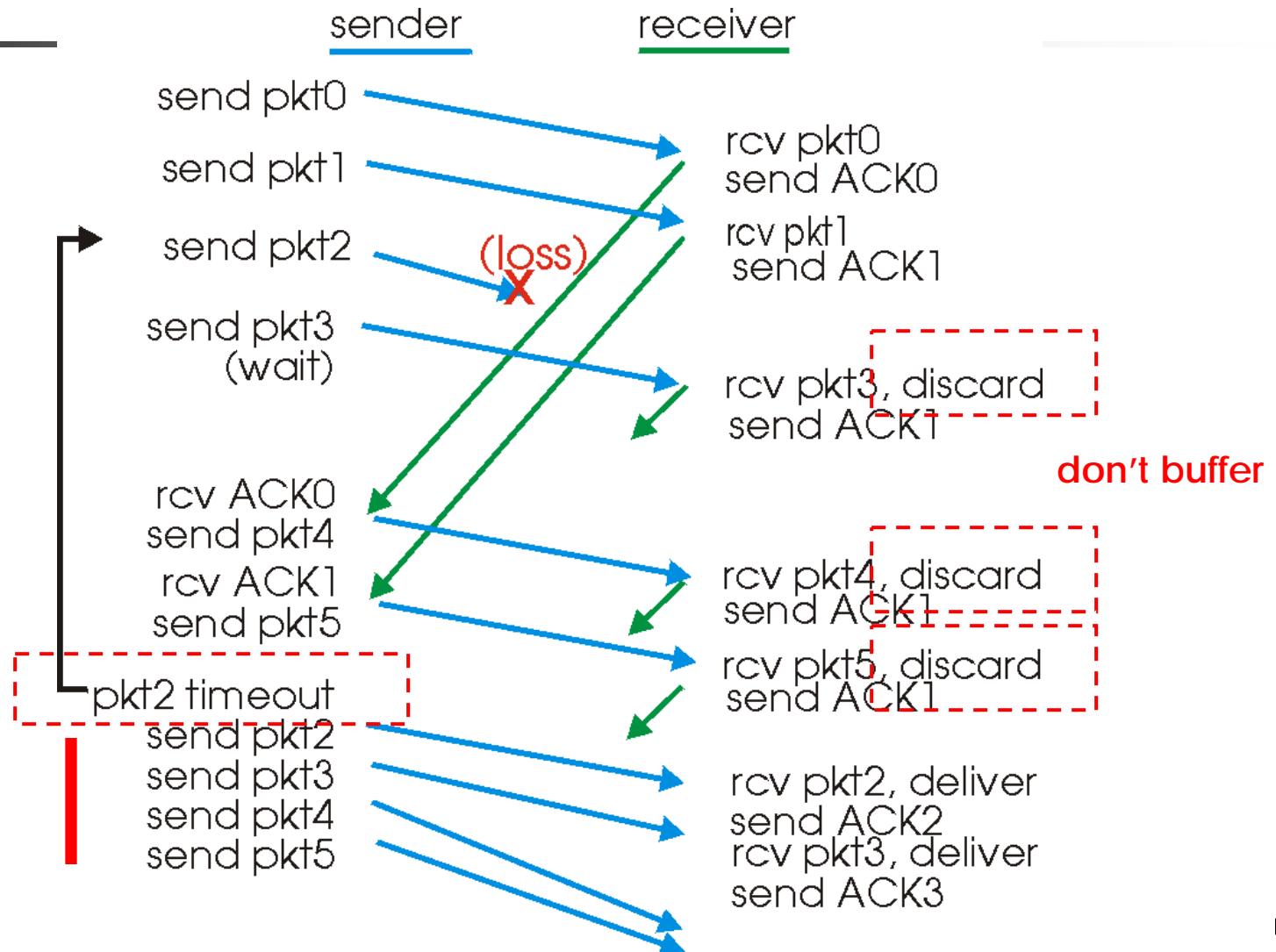
- **ACK(n): ACKs all pkts up to, including seq # n - “cumulative ACK”**
 - may receive duplicate ACKs (see receiver)
- timer for each in-flight pkt
- *timeout(n)*: retransmit pkt **n** and all higher seq # pkts in window
- ACK-only: always send ACK for correctly-received pkt with highest *in-order* seq #
 - may generate duplicate ACKs
 - need only remember **expectedseqnum**



GBN: Receiver Extended FSM (cont.)

- out-of-order pkt:
 - packet n is expected, but packet $n+1$ arrives
 - discard (don't buffer) -> **no receiver buffering!** why?
 - based on GBN, the sender transmit the packet
 - adv?
 - simplicity of receiver buffering
 - disadv?
 - throwing away a correctly received packet
 - subsequent retransmission of that packet might be lost or garbled
 - even more retransmission would be required

GBN in Action





Selective Repeat

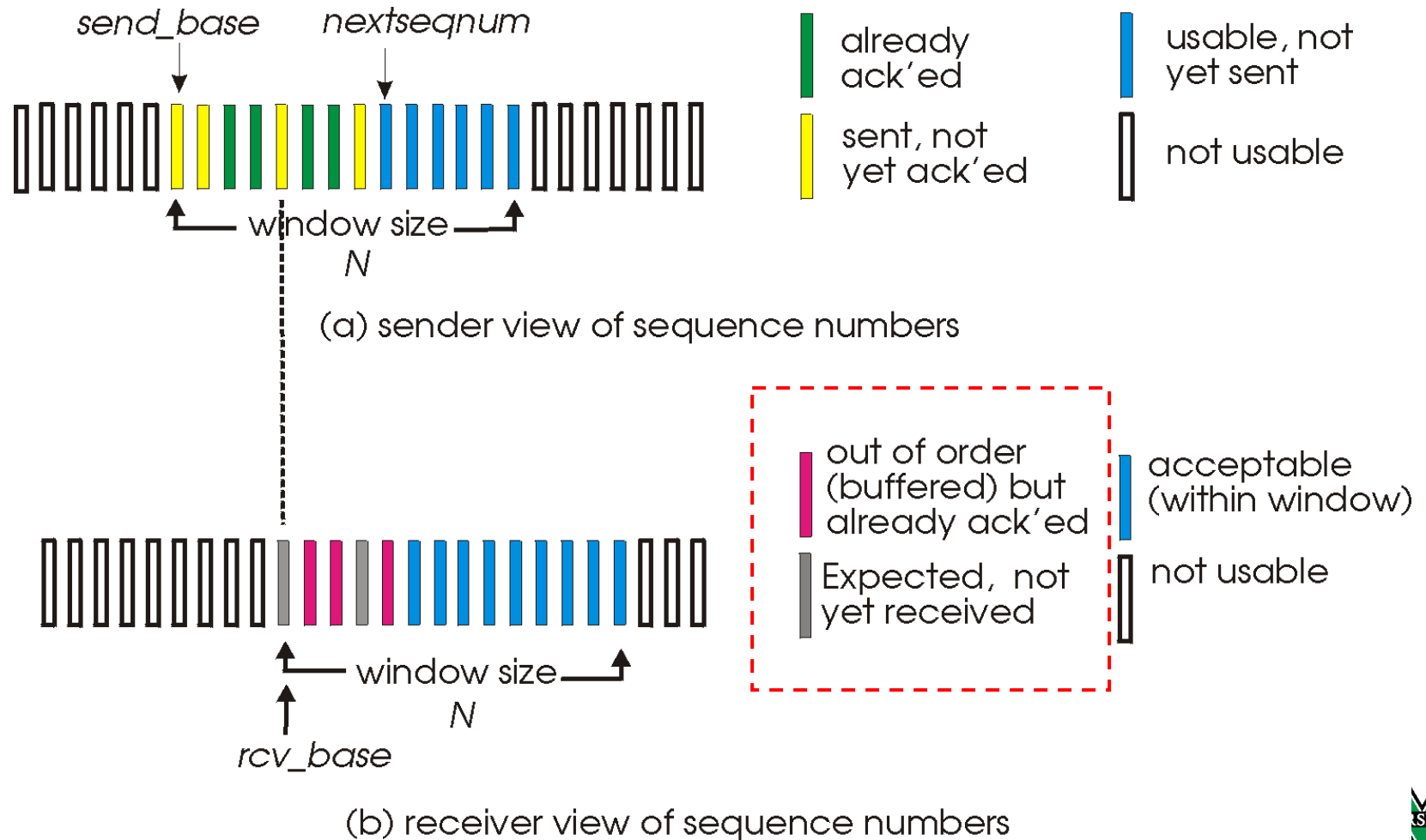
- In GBN protocol,
 - allow the sender to potentially “fill the pipeline”
 - avoiding the channel utilization problem
 - → suffer from **performance problem**, e.g. many packets in the pipeline, but **a single packet error**?
 - **retransmit a large number of packets (many unnecessarily)**



Selective Repeat (cont.)

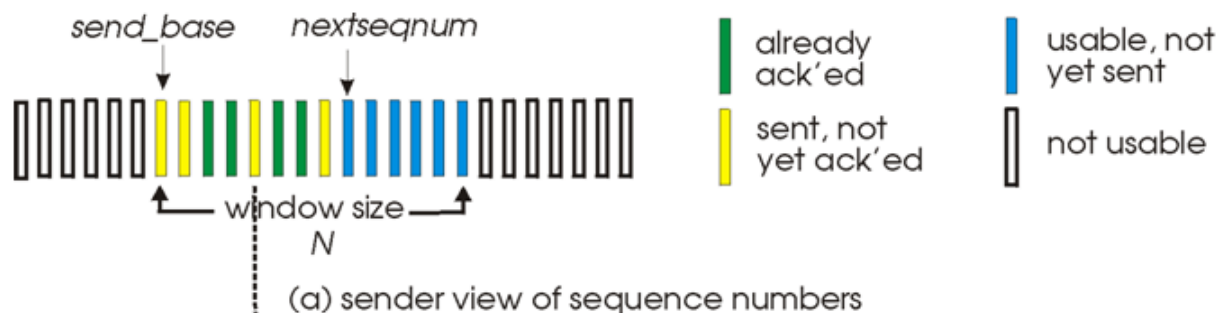
- selective-repeat protocol *avoids unnecessary retransmissions* by having the sender retransmit only those packets that it suspects were received in error at the receiver
- receiver *individually acknowledges all correctly received pkts*, whether or not they are in order
 - *buffers pkts*, as needed, for eventual in-order delivery to upper layer
- sender only resends pkts for which ACK not received
 - sender timer for each unACKed pkt
- sender window:
 - N consecutive seq #'s
 - again limits seq #'s of sent, unACKed pkts

Selective Repeat: Sender, Receiver Windows



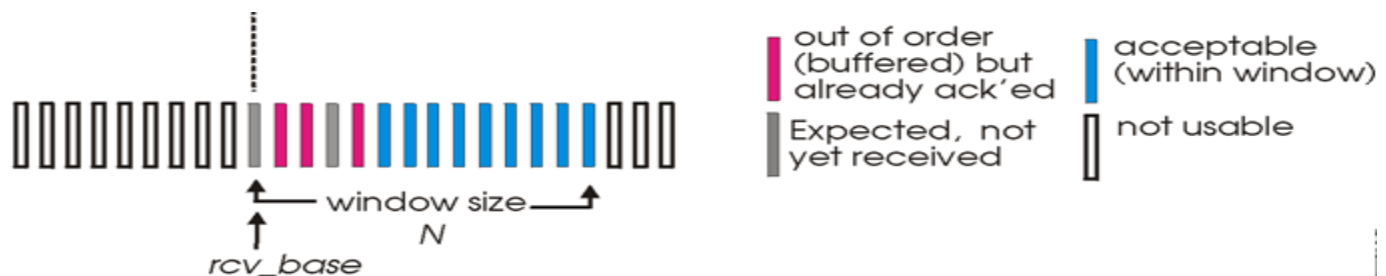
Selective Repeat (cont.)

- Sender:
 - data received from above :
 - if next available seq # in window, send pkt
 - timeout(n):
 - resend pkt n, restart timer
 - ACK(n) in [send_base, send_base+N-1]:
 - mark pkt n as received
 - If the packet's sequence# == send_base
 - advance the window base to the **unacked packet with the smallest** sequence #



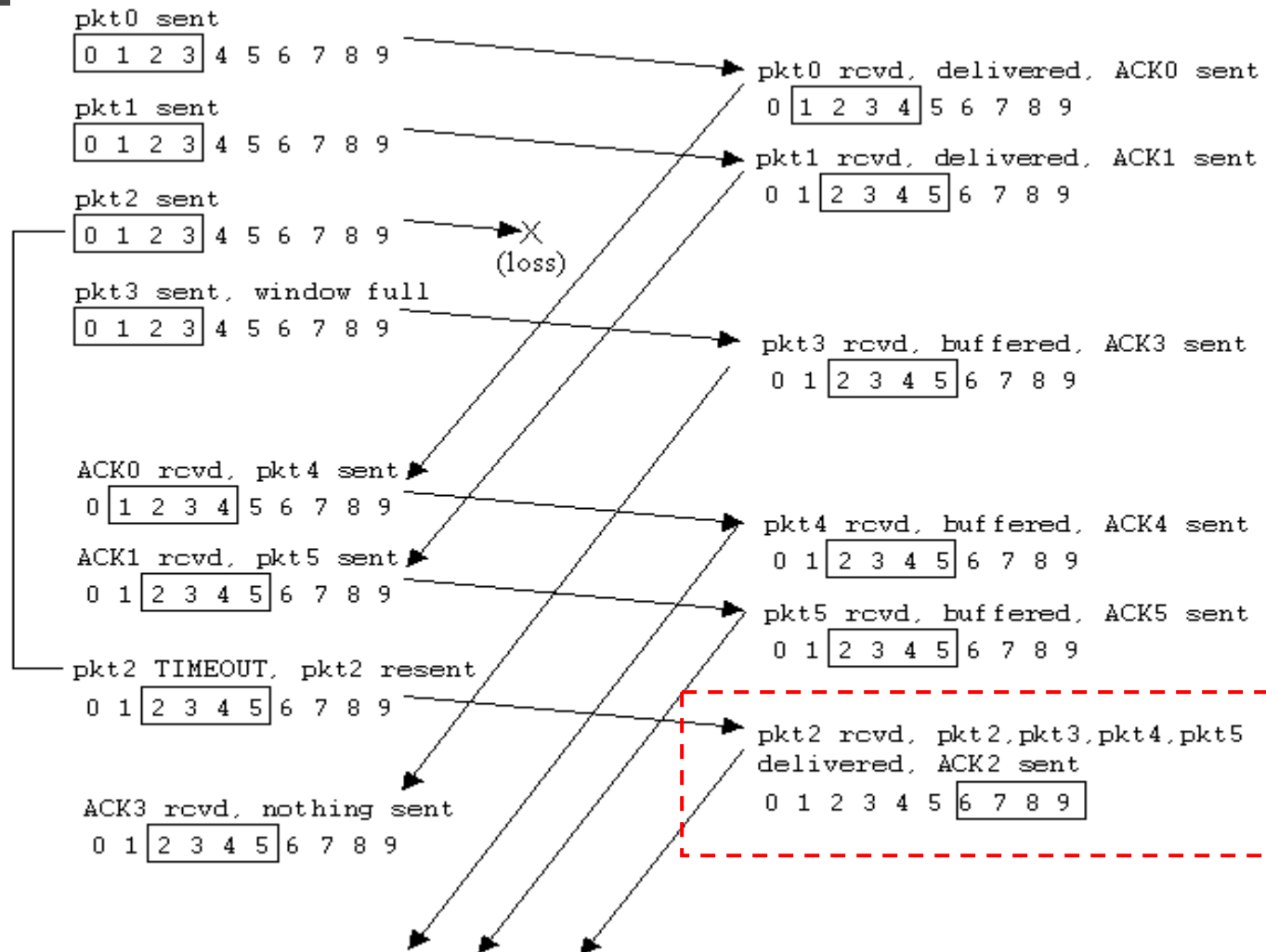
Selective Repeat (cont.)

- Receiver:
 - pkt n in $[rcv_base, rcv_base+N-1]$
 - send $ACK(n)$
 - out-of-order: buffering
 - in-order: deliver (also deliver buffered, in-order pkts), advance window to next not-yet-received pkt
 - pkt n in $[rcv_base-N, rcv_base-1]$
 - $ACK(n)$
 - although, the receiver has previously acknowledged
 - otherwise: ignore the packet



(b) receiver view of sequence numbers

Selective repeat in Action





Pipelined Protocols: Summary

Go-back-N:

- sender can have up to N unack'ed packets in pipeline
- receiver only sends *cumulative ack*
 - doesn't ack packet if there's a gap
- sender has timer for oldest unack'ed packet
 - when timer expires, retransmit *all* unack'ed packets

Selective Repeat:

- sender can have up to N unack'ed packets in pipeline
- receiver sends *individual ack* for each packet
- sender maintains timer for each unack'ed packet
 - when timer expires, retransmit *only* that unack'ed packet



TCP: Overview

RFCs: 793, 1122, 1323, 2018, 2581

- TCP is said to be **connection-oriented**
 - before one application process can begin to send data to another
 - the two processes must first “*handshake*” with each other
 - send some preliminary segments to each other to establish the parameters of the ensuing data transfer
 - both sides of the connection will initialize many TCP state variables associated with the TCP connection



TCP: Overview

RFCs: 793, 1122, 1323, 2018, 2581

- The TCP “**connection**” is not an end-to-end TDM or FDM circuit as in a circuits switched network
 - the connection state resides entirely in the two end systems
 - because the TCP protocol runs only in the end systems and not in the intermediate network elements (routers and link-layer switches)
 - the intermediate network elements do not maintain TCP connection state



TCP: Overview

RFCs: 793, 1122, 1323, 2018, 2581

- A TCP connection provides a *full-duplex service*
 - if there is a TCP connection between Process A on one host and Process B on another host
 - then application layer data can flow from Process A to Process B at the same time as application layer data flows from Process B to Process A
- A TCP connection is always *point-to-point*:
 - one sender and one receiver
- *multicasting*
 - the transfer of data from one sender to many receivers in a single send operation
 - not possible with TCP



TCP: How a TCP Connection is Established

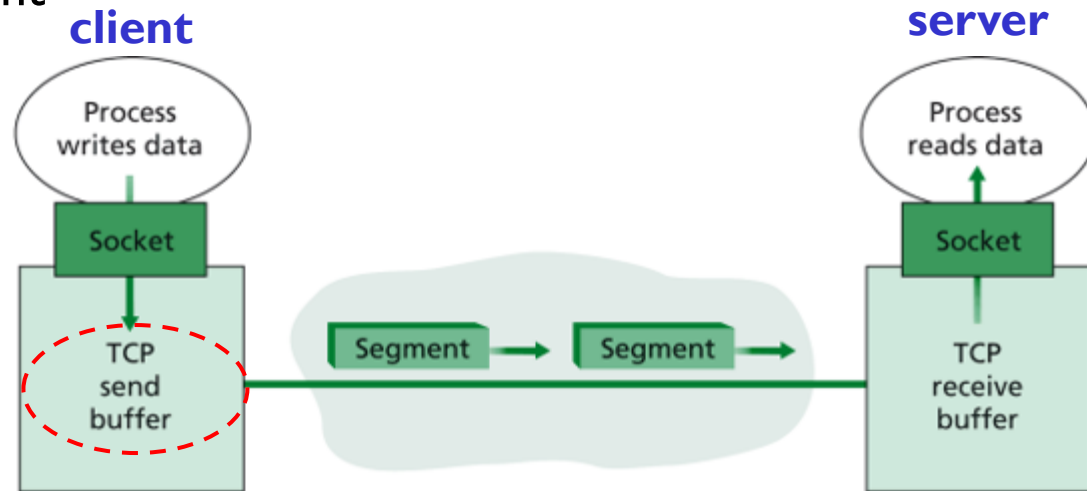
- suppose a process running in one host wants to initiate a connection with another process in another host
 - *client process*
 - *the process that is initiating the connection*
 - *server process*
 - *the other process*
 - **three-way handshake**
 1. *the client first sends a special TCP segment*
 2. *the server responds with a second special TCP segment*
 3. *the client responds again with a third special segment*
 - the first two segments carry no payload
 - the third of these segments may carry a payload

TCP: How a TCP Connection is Established

- Once a TCP connection is established, the two application processes can send data to each other
 - the client process passes a stream of data through the socket
 - once the data passes through the door, the data is in the hands of TCP running in the client

send buffer:

- set aside during initial 3-way handshake
- grab chunks of data from send buffer and pass the data to the network layer
- **maximum segment size (MSS)**: the maximum amount of data that can be grabbed and placed in a segment
 - MSS is typically set by first determining the length of the largest link-layer frame that can be sent by the sending host



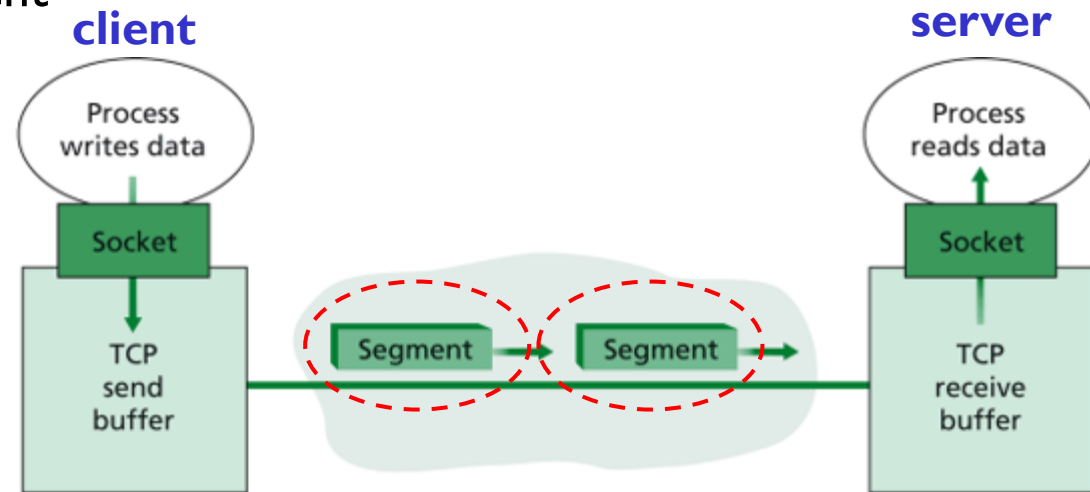
TCP send and receive buffers

TCP: How a TCP Connection is Established

- Once a TCP connection is established, the two application processes can send data to each other
 - the client process passes a stream of data through the socket
 - once the data passes through the door, the data is in the hands of TCP running in the client

segment:

- TCP pairs each chunk of client data with a TCP header, thereby forming TCP segments



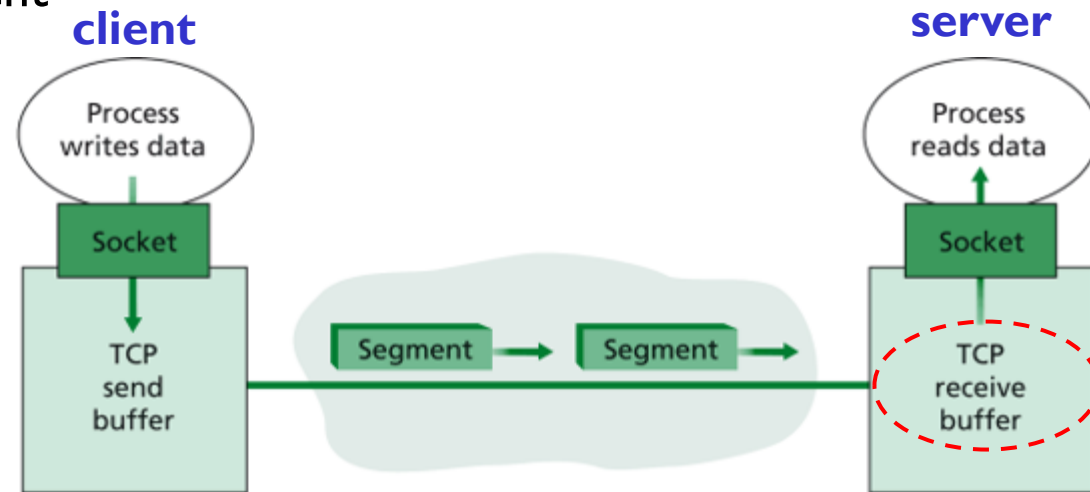
TCP send and receive buffers

TCP: How a TCP Connection is Established

- Once a TCP connection is established, the two application processes can send data to each other
 - the client process passes a stream of data through the socket
 - once the data passes through the door, the data is in the hands of TCP running in the client

receiver buffer:

- when TCP receives a segment at the other end, the segment's data is placed in the TCP connection's receive buffer
- app. reads the stream of data from buffer

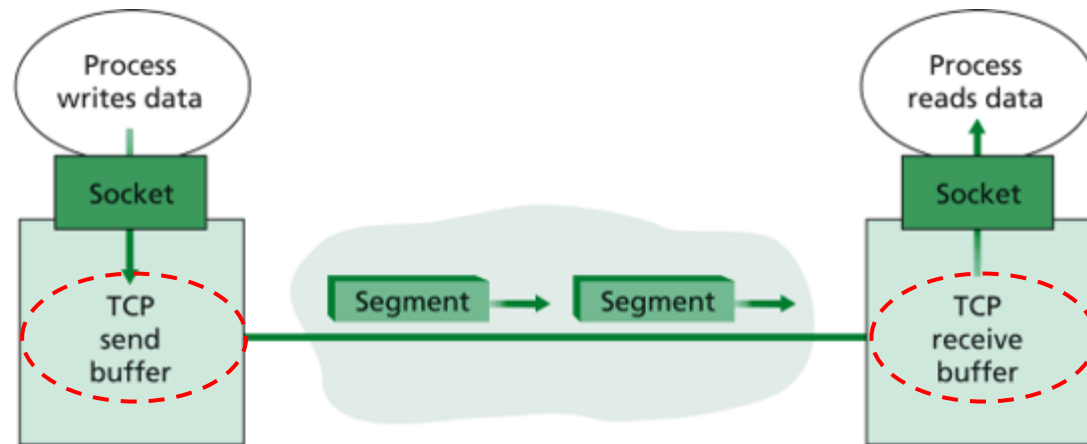


TCP send and receive buffers

TCP: How a TCP Connection is Established

- Once a TCP connection is established, the two application processes can send data to each other
 - the client process passes a stream of data through the socket
 - once the data passes through the door, the data is in the hands of TCP running in the client

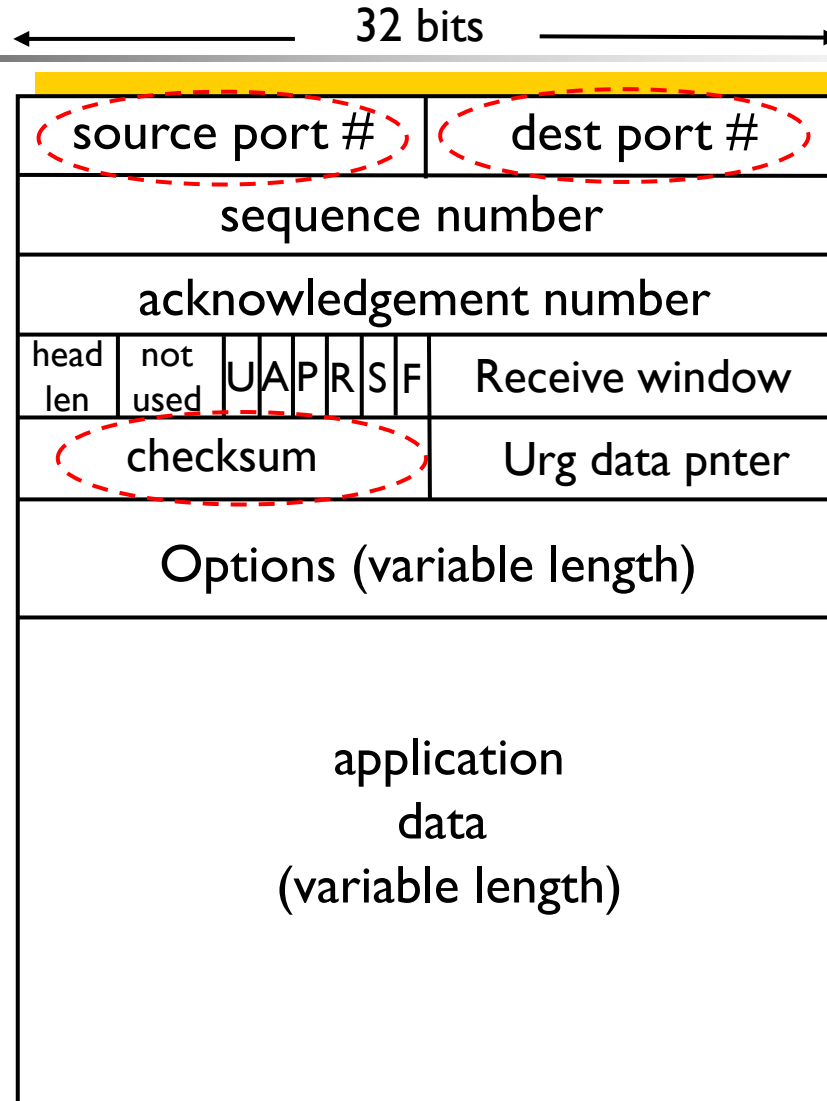
- each side of the connection has its own send buffer and its own receive buffer



TCP send and receive buffers

TCP segment: header fields and a data field

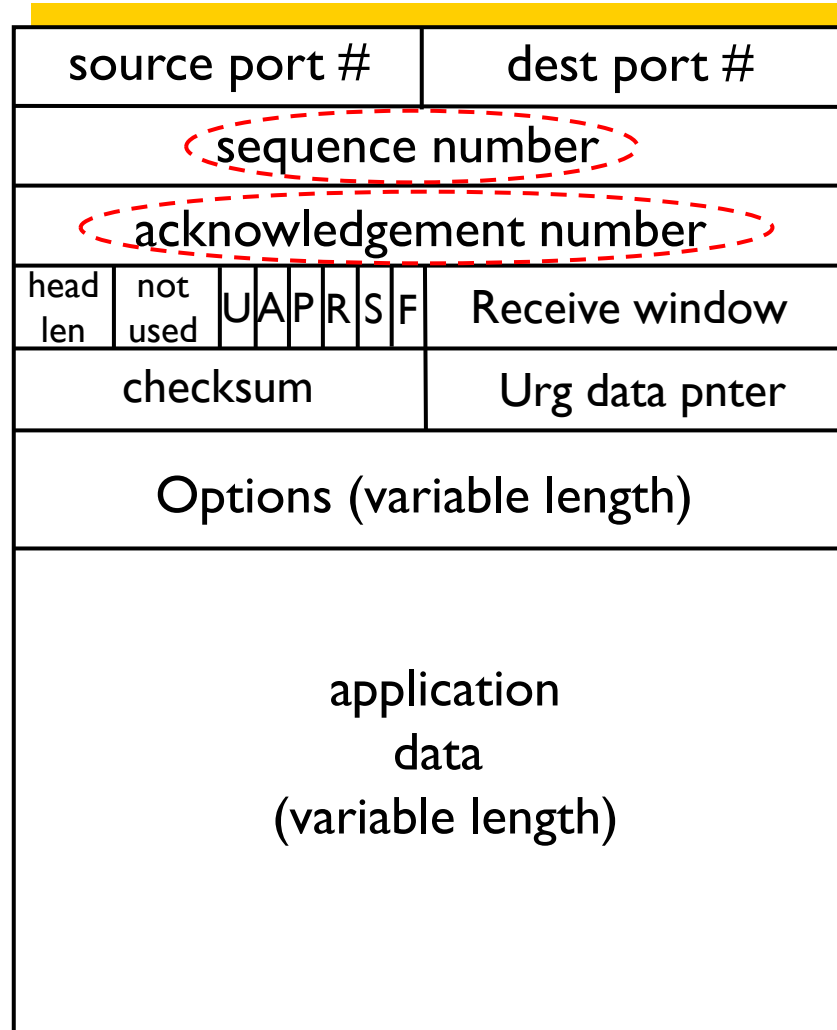
TCP Segment Structure



TCP segment: header fields and a data field

TCP Segment Structure

← 32 bits →

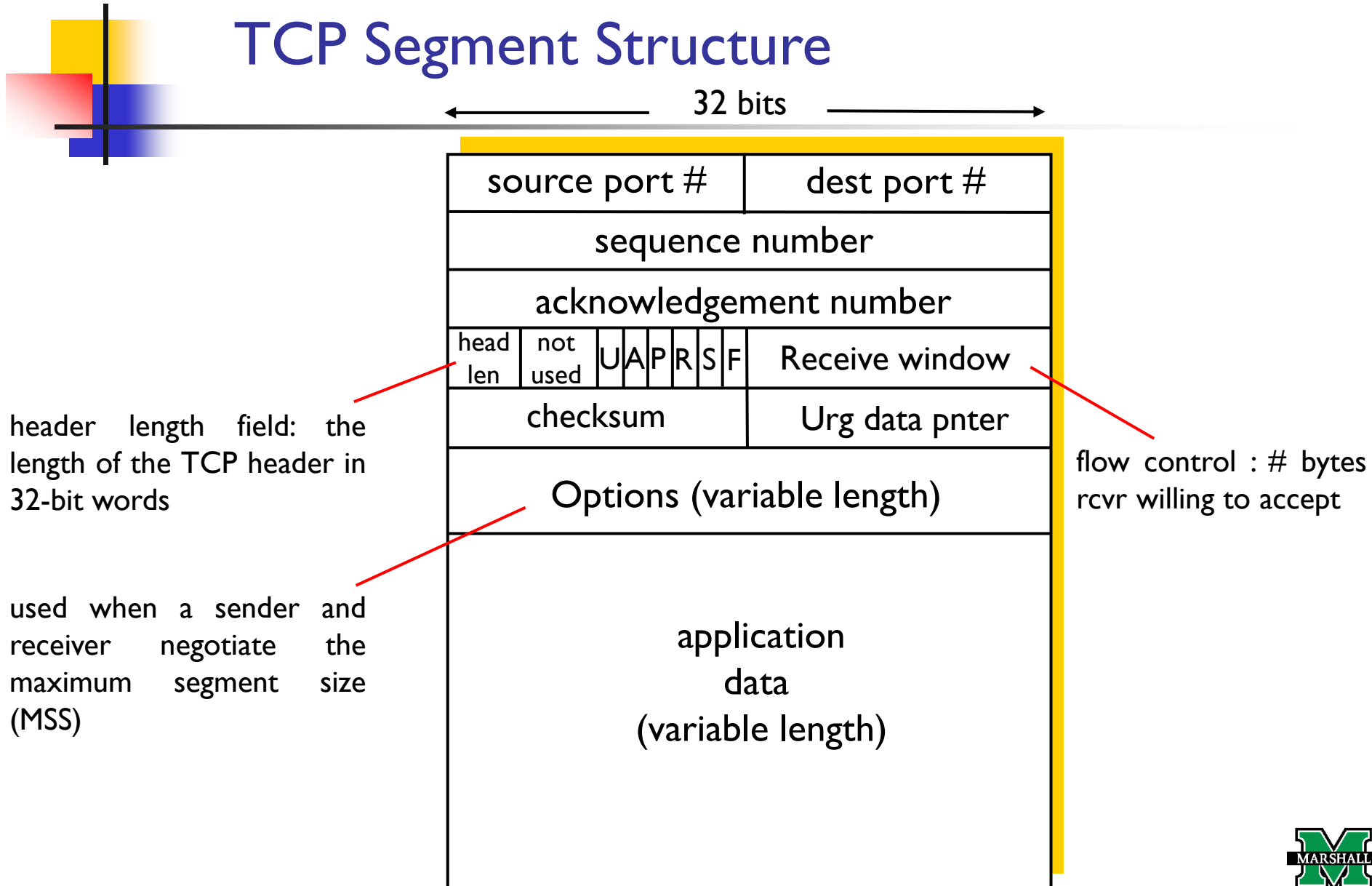


32-bit sequence number
field

32-bit acknowledgment
number field

TCP segment: header fields and a data field

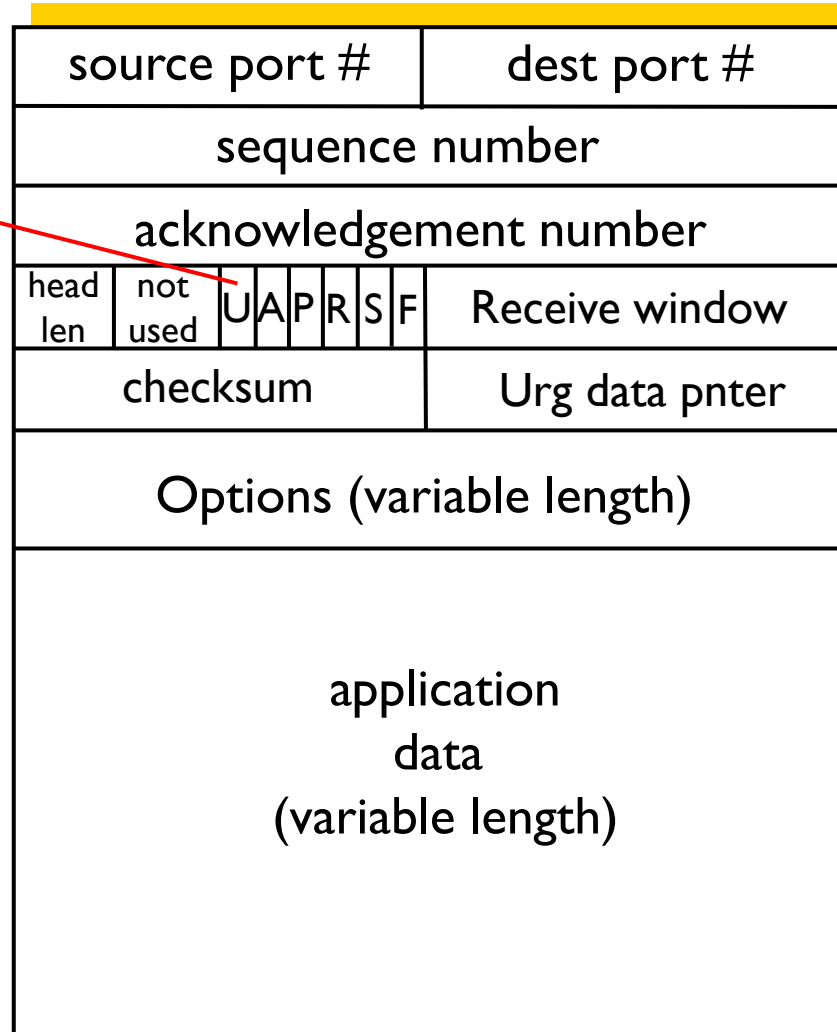
TCP Segment Structure



TCP segment: header fields and a data field

TCP Segment Structure

← 32 bits →

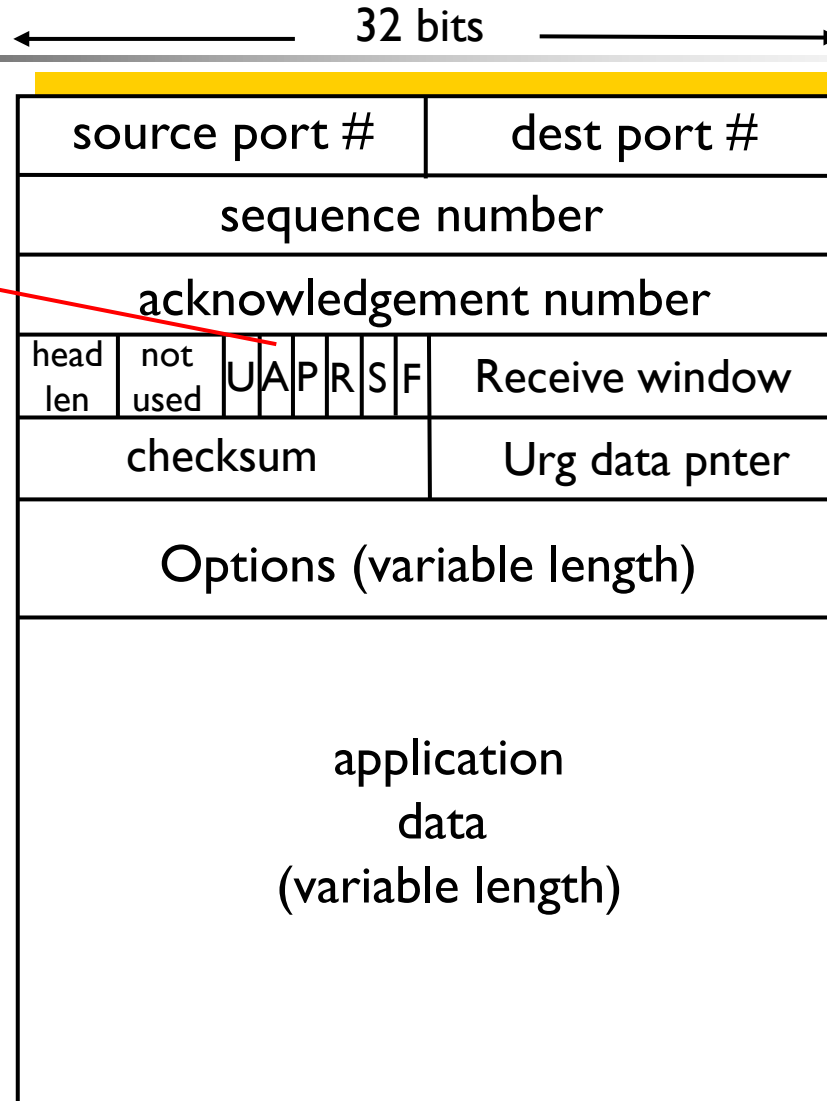


URG: urgent data
(generally not used)

TCP segment: header fields and a data field

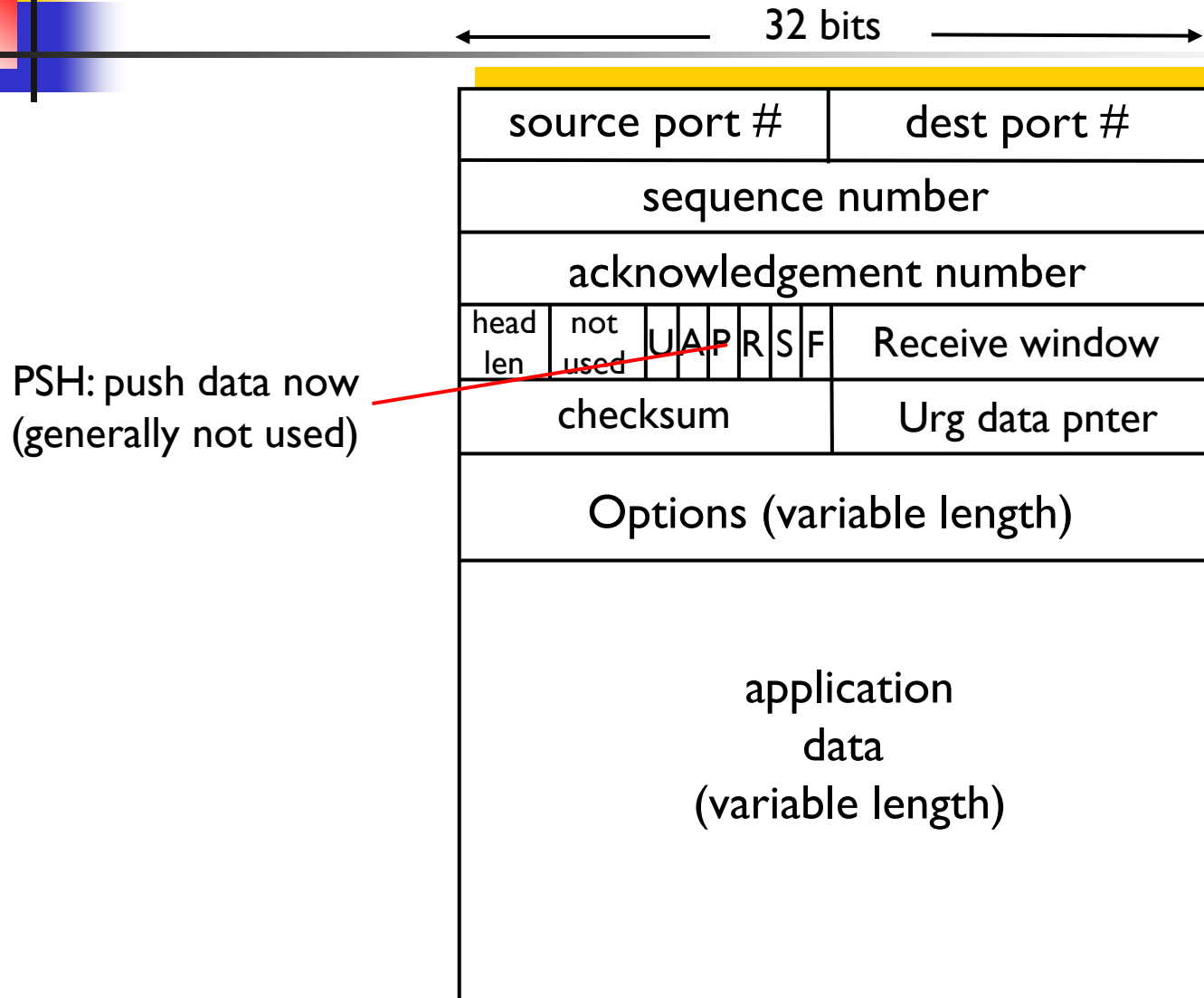
TCP Segment Structure

ACK bit: indicate that the value carried in the acknowledgment field is valid;



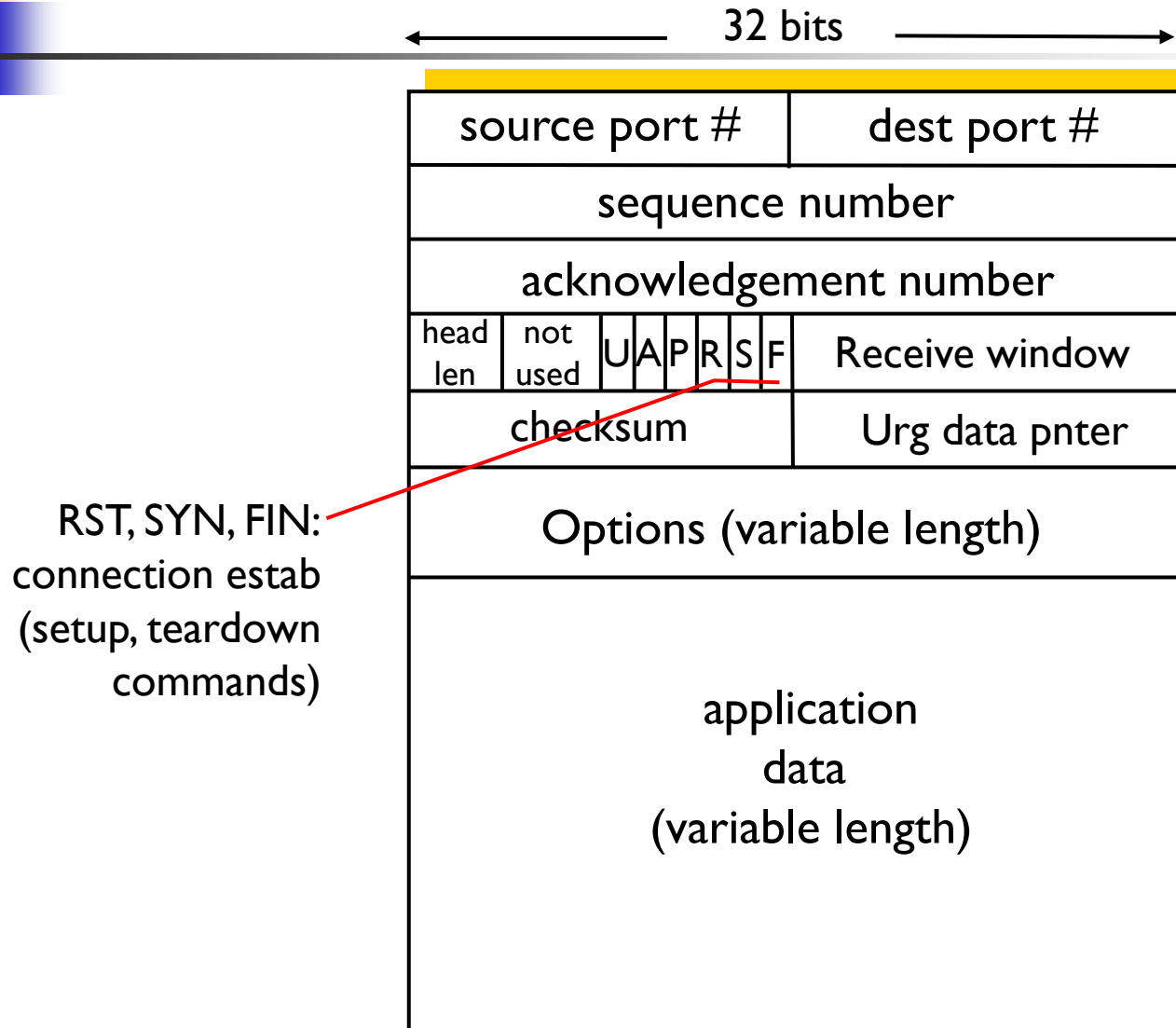
TCP segment: header fields and a data field

TCP Segment Structure



TCP segment: header fields and a data field

TCP Segment Structure



TCP segment: header fields and a data field

TCP Segment Structure

