TCP Sliding Windows, Flow Control, and Congestion Control

Lecture material taken from
"Computer Networks *A Systems Approach*", Third Ed.,Peterson and Davie,
Morgan Kaufmann, 2003.

Sliding Windows

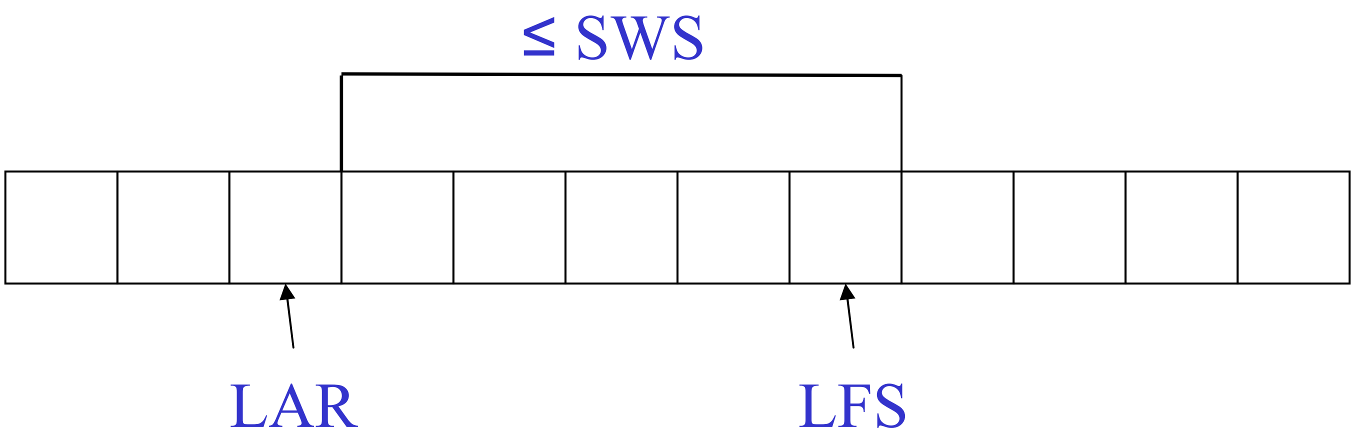
- Normally a data link layer concept.
- Our interest is understanding the TCP mechanism at the transport layer.
- Each frame is assigned a sequence number: SeqNum.
- The sender maintains three variables: send window size (SWS), last ACK received (LAR), and last Frame sent (LFS).

Sender Variables

- SWS :: the upper bound on the number of outstanding frames (not ACKed) the sender can transmit.
- LAR :: the sequence number of the last ACK received.
- LFS :: the sequence number of the last frame sent.

Sender Invariant

$$LFS - LAR \leq SWS$$



Sender Window

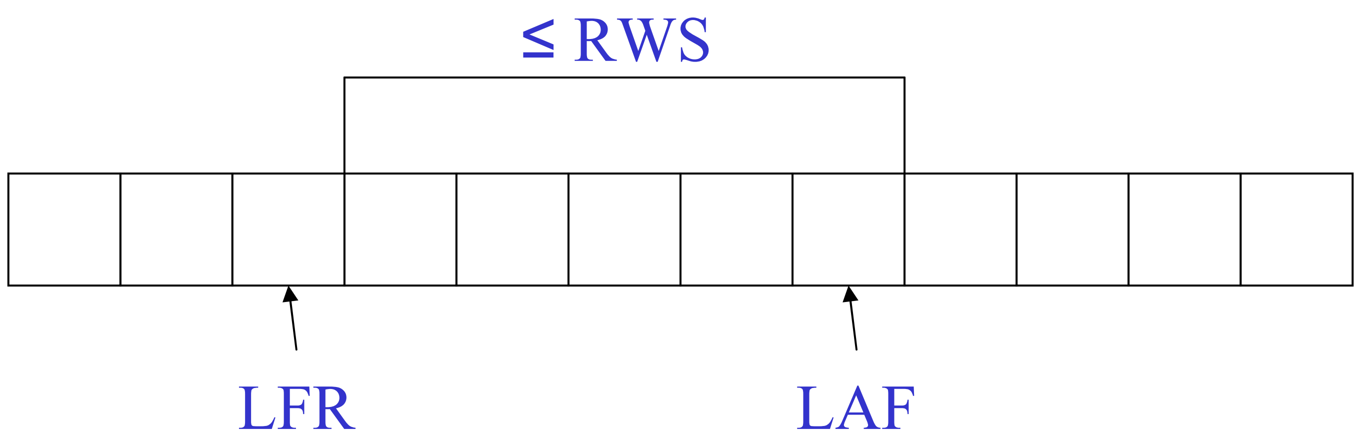
- An arriving ACK ➔ LAR moves right 1
  ➔ sender can send one more frame.
- Associate a *timer* with each frame the sender transmits.
- Sender retransmits the frame if the timer *times out.*
- Sender buffer :: up to SWS frames.

Receiver Variables

- Receiver window size (RWS) :: the upper bound on the number of out-of-order frames the receiver is willing to accept.
- Largest acceptable frame (LAF) :: the sequence number of the largest acceptable frame.
- Last frame received (LFR) :: the sequence number of the last frame received.

Receiver Invariant

$$LAF - LFR \leq RWS$$



Receiver Window

When a frame arrives with SeqNum:

If (SeqNum ≤ LFR or SeqNum > LAF)

*the frame is **discarded** because it is outside the window.*

If (LFR < SeqNum ≤ LAF)

*the frame is **accepted**.*

Receiver ACK Decisions

SeqNumToAck :: largest sequence number **not yet ACKed** such that all frames ≤ SeqNumToAck have been received.

- Receiver ACKs receipt of SeqNumToAck

  and sets

  LFR = SeqNumToAck

  LAF = LFR + RWS

SeqNumToAck is adjusted appropriately!

Generic ACK Choices

1. ACK sequence number indicates the *last frame successfully received.*

- OR -

2. ACK sequence number indicates the *next frame the receiver expects to receive.*

Both of these can be strictly *<u>individual</u>* *ACKs or represent* *<u>cumulative</u>* *ACKing.*

Cumulative ACKing is the most common technique.

Generic Responses to a lost packet or frame

1. Use a duplicate ACK.

2. Use a selective ACK [SACK].

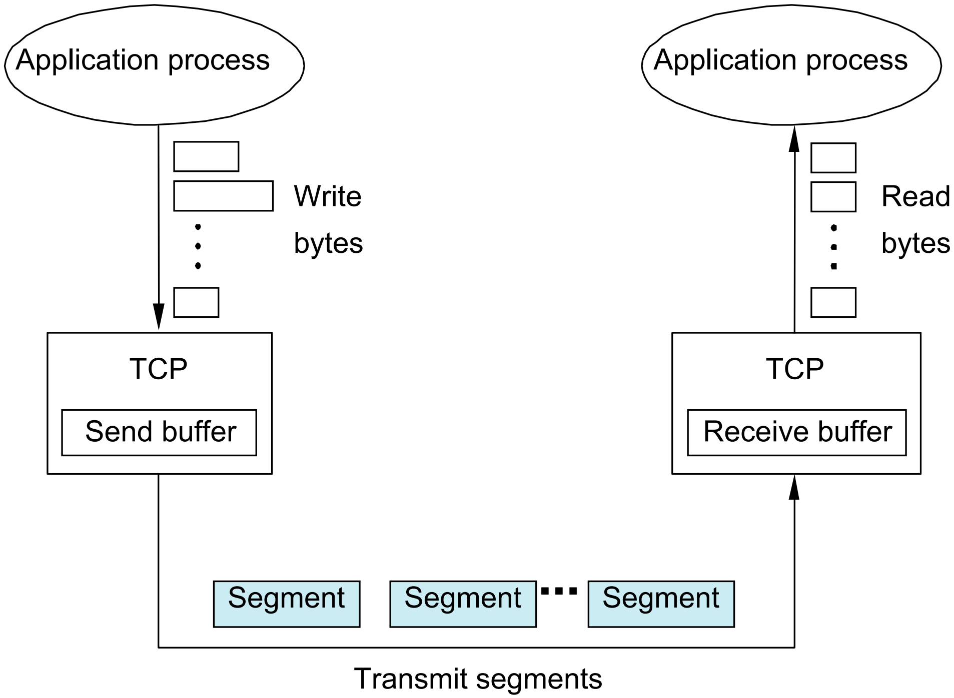
3. Use a negative ACK [NACK] .

TCP Sliding Windows

* *In practice, the TCP implementation switches from packet pointers to byte pointers.*

- Guarantees reliable delivery of data.
- Ensures data delivered in order.
- Enforces flow control between sender and receiver.
- The idea is: the sender does not overrun the receiver's buffer.

Figure 5.3
TCP Managing a Byte Stream



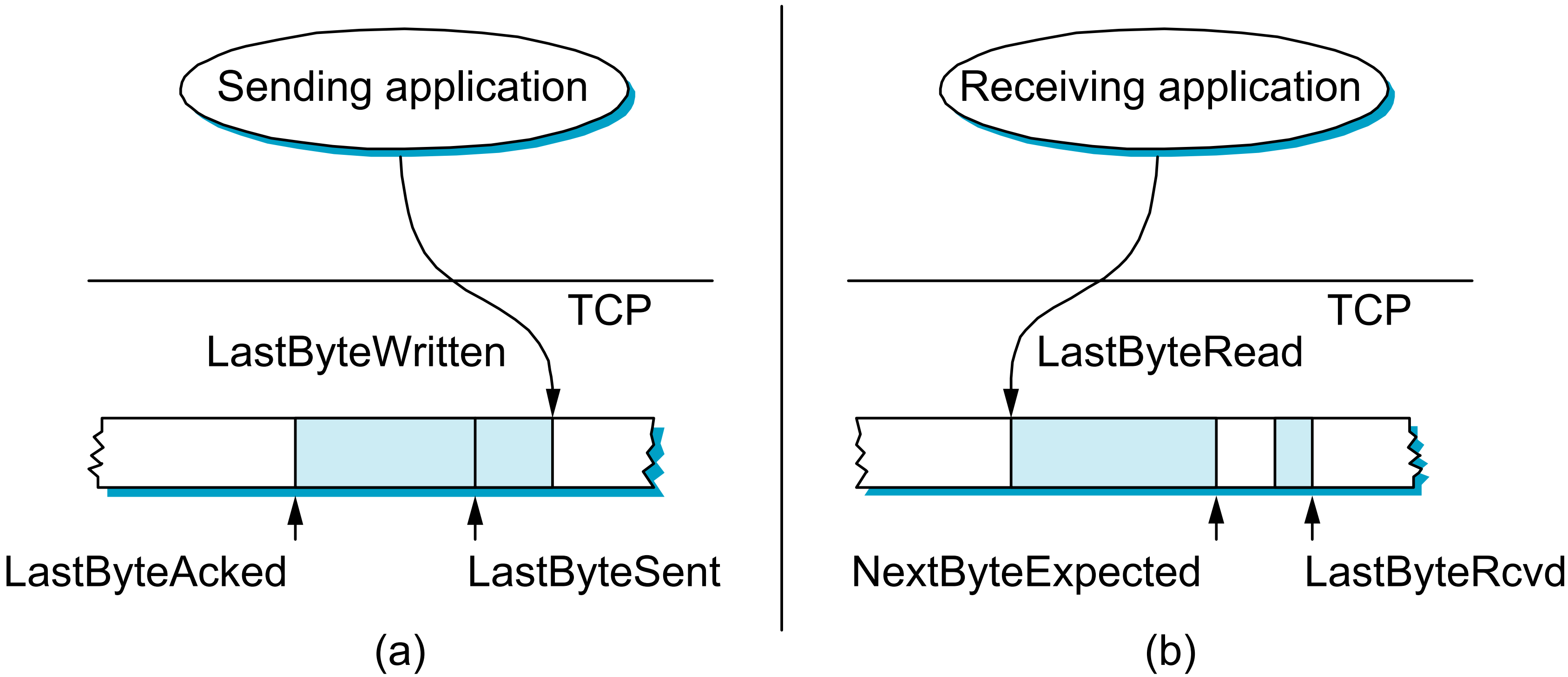


Figure 5.8 Relationship between TCP Send Buffer and TCP Receive Buffer

Receiver's Advertised Window

- The big difference in TCP is that the size of the sliding window size at the TCP receiver is not fixed.
- The receiver *advertises* an adjustable window size (AdvertisedWindow field in TCP header).
- Sender is limited to having no more than AdvertisedWindow bytes of unACKed data at any time.

TCP Flow Control

- The discussion is similar to the previous sliding window mechanism except we add the complexity of sending and receiving *application processes* that are filling and emptying their local buffers.
- Also we introduce the complexity that buffers are of finite size without worrying about where the buffers are stored.

MaxSendBuffer

MaxRcvBuffer

TCP Flow Control

- Receiver throttles sender by advertising a window size no larger than the amount it can buffer.

On TCP receiver side:

$$\text{LastByteRcvd} - \text{LastByteRead} \leq \text{MaxRcvBuffer}$$

to avoid buffer overflow!

TCP Flow Control

TCP receiver advertises:

AdvertisedWindow = MaxRcvBuffer - (LastByteRcvd - LastByteRead)

i.e., the amount of free space available in the receiver's buffer.

TCP Flow Control

The TCP sender must adhere to AdvertisedWindow from the receiver such that

LastByteSent – LastByteAcked ≤ AdvertisedWindow

or use EffectiveWindow:

EffectiveWindow = AdvertisedWindow – (LastByteSent – LastByteAcked)

TCP Flow Control

Sender Flow Control Rules:

1. EffectiveWindow > 0 *for sender to send more data.*
2. LastByteWritten – LastByteAcked ≤ MaxSendBuffer

equality here ➔ send buffer is full!!

*➔ TCP sender process must **block** the sender application.*

TCP Congestion Control

- CongestionWindow :: a variable held by the TCP source for each connection.

* TCP is modified such that the maximum number of bytes of unacknowledged data allowed is the *minimum of* CongestionWindow and AdvertisedWindow.

MaxWindow :: min (CongestionWindow , AdvertisedWindow)

TCP Congestion Control

Finally, we have that

EffectiveWindow = MaxWindow – (LastByteSent – LastByteAcked)

The idea :: the source's effective window can be **no faster** than the slowest of the network (i.e., its core *routers*) or the destination Host.

* *The TCP source receives implicit and/or explicit indications of congestion by which to reduce the size of* ***CongestionWindow.***