TCP Sliding Windows, Flow Control, and Congestion Control

Lecture material taken from
"Computer Networks *A Systems Approach*", Fourth Ed.,Peterson and Davie,
Morgan Kaufmann, 2007.

Sliding Windows Outline

- Generic Sliding Windows
- Receiver Response Choices
- Introduction to TCP Sliding Windows
  – Flow control and buffers
  – Advertised window
  – Congestion control

Sliding Windows

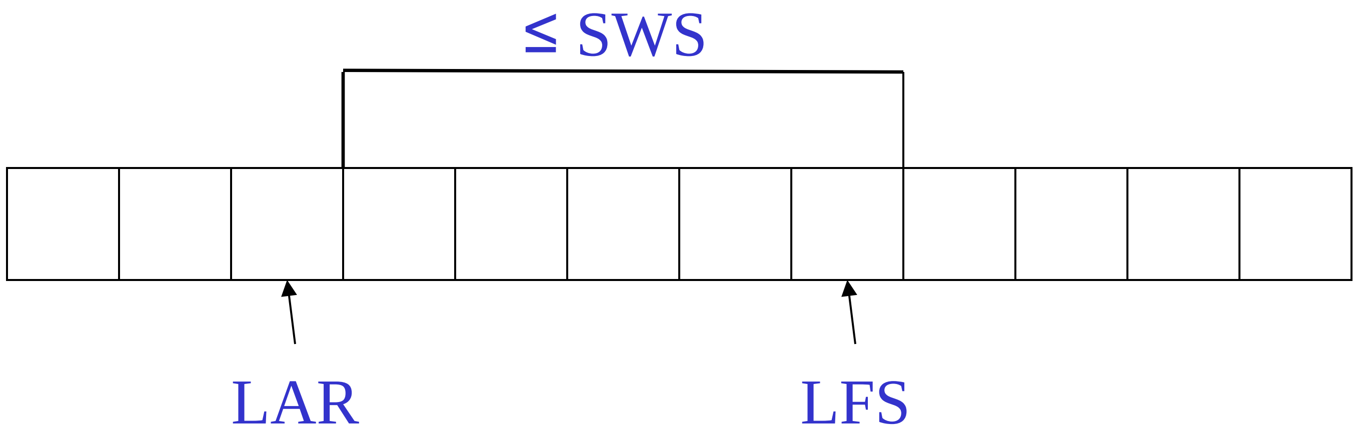
- Normally a data link layer concept.
- Our interest is understanding the TCP mechanism at the transport layer.
- Each frame is assigned a sequence number: SeqNum.
- The sender maintains three variables: send window size (SWS), last ACK received (LAR), and last Frame sent (LFS).

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

$$\boxed{LFS - LAR \leq SWS}$$



Sender Window

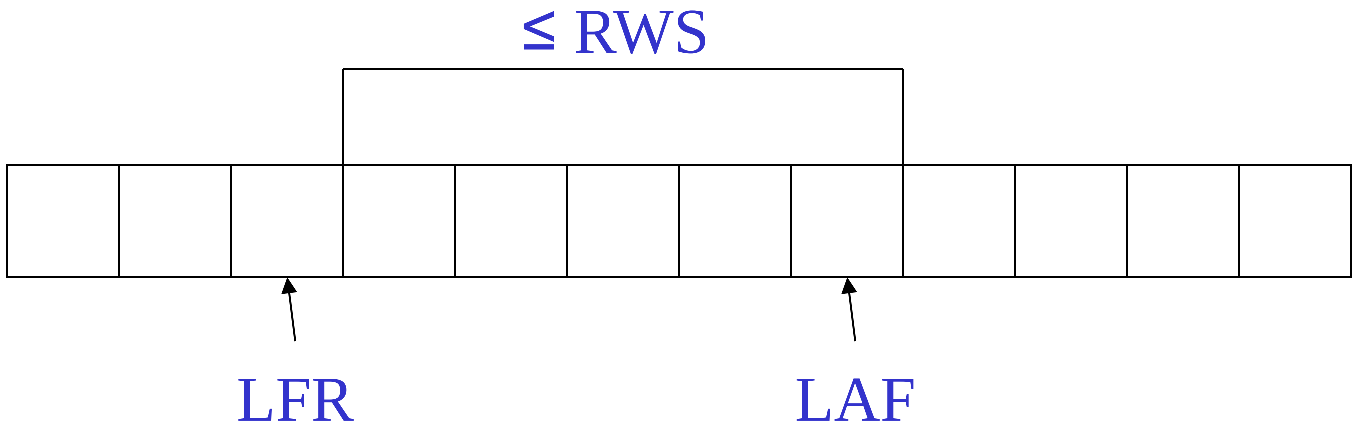
- An arriving ACK ➔ LAR moves right 1
  ➔ sender can send one more frame.
- Associate a ***timer*** with each frame the sender transmits.
- Sender retransmits the frame if the timer *times out.*
- Sender buffer :: up to SWS frames.

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

$$\boxed{LAF - LFR \leq RWS}$$



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 individual ACKs or represent cumulative ACKing.

Cumulative ACKs is the most common technique.

Generic Responses to a Lost Packet or Frame

1. Use a duplicate ACK.

2. Use a selective ACK [SACK].

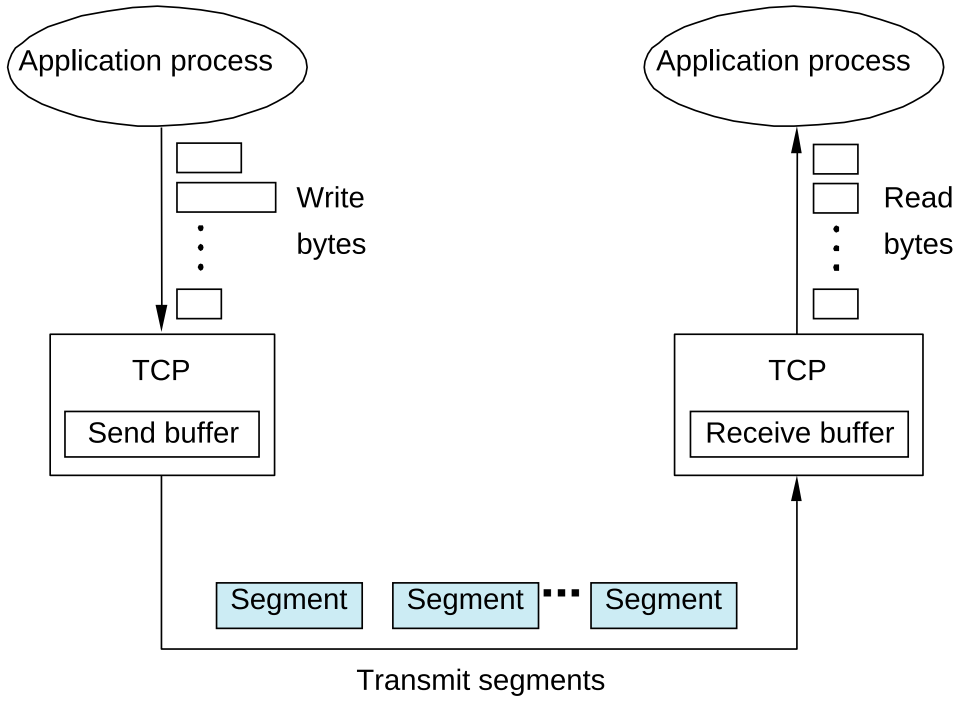
3. Use a negative ACK [NACK] .

TCP Sliding Windows

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

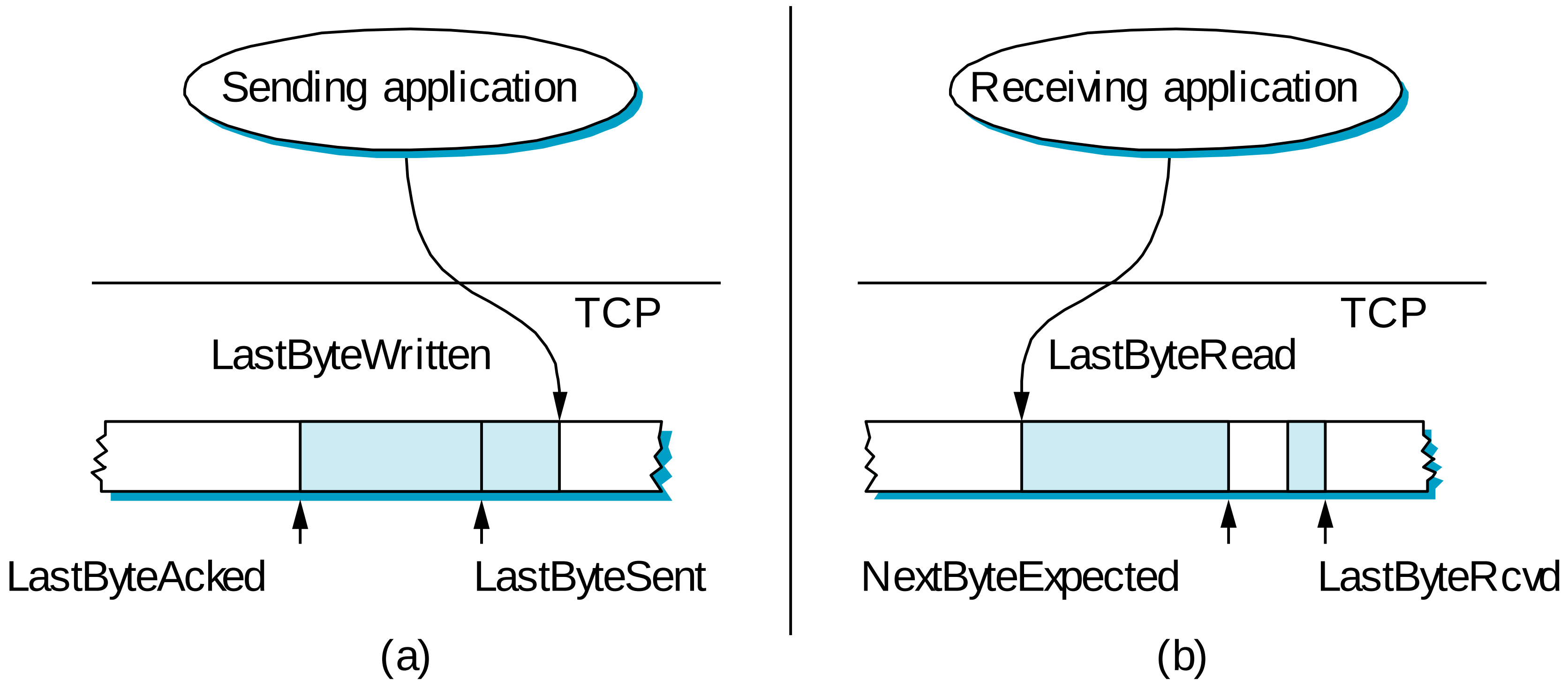
- Guarantees <u>reliable delivery</u> of data.
- Ensures data delivered <u>in order</u>.
- Enforces <u>flow control</u> between sender and receiver.
- The idea is: the sender does not overrun the receiver's buffer.

Figure 5.3
TCP Managing a Byte Stream



P&D slide

Figure 5.8 Relationship between TCP Send Buffer and TCP Receive Buffer



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Receiver's Advertised Window

- The big difference in TCP is that the size of the sliding window size at the TCP receiver is <u>not fixed</u>.
- 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.

Figure 5.4 TCP Header Format

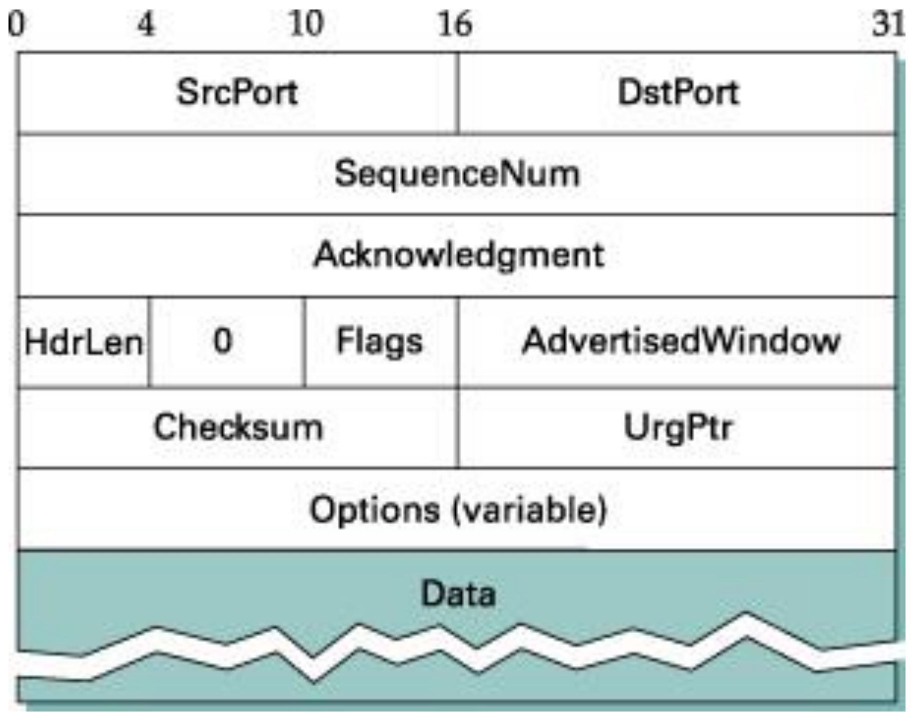

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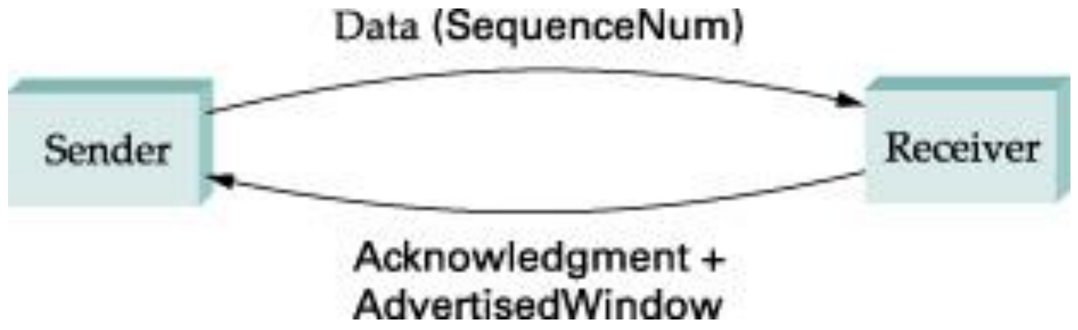
Figure 5.5 Simplified TCP



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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

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

  On TCP receiver side:

  LastByteRcvd - LastByteRead ≤ 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 the **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.**

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