TCP Sliding Windows, Flow Control, and Congestion Control

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

$LFS - LAR \leq SWS$
Sender Window

- An arriving ACK $\rightarrow$ LAR moves right 1
  $\rightarrow$ 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

\[ \text{LAF} - \text{LFR} \leq \text{RWS} \]

Diagram:

\[ \leq \text{RWS} \]

Boxes:

- LFR
- LAF
Receiver Window

When a frame arrives with $\text{SeqNum}$:

If $(\text{SeqNum} \leq \text{LFR} \text{ or } \text{SeqNum} > \text{LAF})$

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

If $(\text{LFR} < \text{SeqNum} \leq \text{LAF})$

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
  
  \[ LFR = \text{SeqNumToAck} \]
  \[ LAF = LFR + RWS \]

  **SeqNumToAck** is adjusted appropriately!
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 **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.
TCP Managing a Byte Stream

Figure 5.3

Application process

Write bytes

TCP
Send buffer

Segment
Segment
Segment

Transmit segments

TCP
Receive buffer

Application process

Read bytes

P&D slide
Figure 5.8 Relationship between TCP Send Buffer and TCP Receive Buffer

(a) Sending application
- LastByteWritten
- TCP
- LastByteSent
- LastByteAcked

(b) Receiving application
- LastByteRead
- TCP
- LastByteRcvd
- NextByteExpected

P&D slide
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.
Figure 5.4 TCP Header Format

```
<table>
<thead>
<tr>
<th>Field</th>
<th>Bits</th>
</tr>
</thead>
<tbody>
<tr>
<td>SrcPort</td>
<td>0-3</td>
</tr>
<tr>
<td>DstPort</td>
<td>4-7</td>
</tr>
<tr>
<td>SequenceNum</td>
<td>8-15</td>
</tr>
<tr>
<td>Acknowledgment</td>
<td>16-23</td>
</tr>
<tr>
<td>HdrLen</td>
<td>24-25</td>
</tr>
<tr>
<td>Flags</td>
<td>26-27</td>
</tr>
<tr>
<td>AdvertisedWindow</td>
<td>28-31</td>
</tr>
<tr>
<td>Checksum</td>
<td>0-3</td>
</tr>
<tr>
<td>UrgPtr</td>
<td>4-7</td>
</tr>
<tr>
<td>Options</td>
<td>variable</td>
</tr>
</tbody>
</table>

Data
```

P&D slide
Figure 5.5 Simplified TCP
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:

\[
\text{LastByteRcvd} - \text{LastByteRead} \leq \text{MaxRcvBuffer}
\]

to avoid buffer overflow!
TCP Flow Control

TCP receiver advertises:

$$\text{AdvertisedWindow} = \text{MaxRcvBuffer} - (\text{LastByteRcvd} - \text{LastByteRead})$$

i.e., the amount of free space available in the receiver’s buffer.
The TCP sender must adhere to the **AdvertisedWindow** from the receiver such that

\[
\text{LastByteSent} - \text{LastByteAcked} \leq \text{AdvertisedWindow}
\]

or use **EffectiveWindow**

\[
\text{EffectiveWindow} = \text{AdvertisedWindow} - (\text{LastByteSent} - \text{LastByteAcked})
\]
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
\[ \text{EffectiveWindow} = \text{MaxWindow} - (\text{LastByteSent} - \text{LastByteAcked}) \]

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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