Flow Control

• Sender must transmit data no faster than it can be consumed by the receiver
  – Receiver might be a slow machine
  – App might consume data slowly

• Implement by adjusting the size of the sliding window used at the sender based on receiver feedback about available buffer space
  – This is the purpose of the Advertised Window field
Sender and Receiver Buffering

Sending application

LastByteWritten

TCP

LastByteAced

LastByteSent

Receiving application

LastByteRead

TCP

NextByteExpected

LastBytercvd

= available buffer

= buffer in use

Example – Exchange of Packets

Receiver has buffer of size 4 and application doesn’t read

Stall due to flow control here

SEQ=1

ACK=2; WIN=3

SEQ=2

ACK=3; WIN=2

SEQ=3

SEQ=4

ACK=4; WIN=1

ACK=5; WIN=0

T=1

T=2

T=3

T=4

T=5

T=6

djw // CSE/EE 461, Autumn 2001

L13/14+3
### Example – Buffer at Sender

<table>
<thead>
<tr>
<th>T=1</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
</tr>
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<tbody>
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<tr>
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<td>9</td>
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<tr>
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<td>9</td>
</tr>
</tbody>
</table>

Which layer provides Reliability?

- We’ve been talking about the Transport layer but …

- ARQ is used by some link layers
  - Acknowledgements in 802.11

- Error detection/correction codes boost reliability
  - Ethernet CRC, IP header checksum, etc.

- Where is the “right” place in the protocol stack?
End-to-End Argument

- Key design principle applied in the Internet
- Reliability is needed end-to-end and can’t be replaced by lower layer mechanisms. So put it end-to-end; use lower mechanisms to improve performance as needed.

- TCP provides reliable delivery
  - Checksums packet data as well
- Lower layers keep their residual error rate is low
  - CRC enough for Ethernet; wireless links more problematic