CS 250: Foundations of Computer Systems [Networking]

The Receiver's Buffer

Small it may be
But throttle the mightiest sender
It can

Not just the *how much*
But also the *when*
Or *if at all*

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Frequently asked questions from the previous class survey

- Why do we need lengths in the headers?
- In IPv6 what if the MTU is calculated incorrectly; and, the packets are fragmented with sizes greater than what can be sent?
- Can a machine have both an IPv4 and IPv6 address?
  - Yes; dual-stack
- Checksums

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Topics covered in this lecture

- UDP
- TCP

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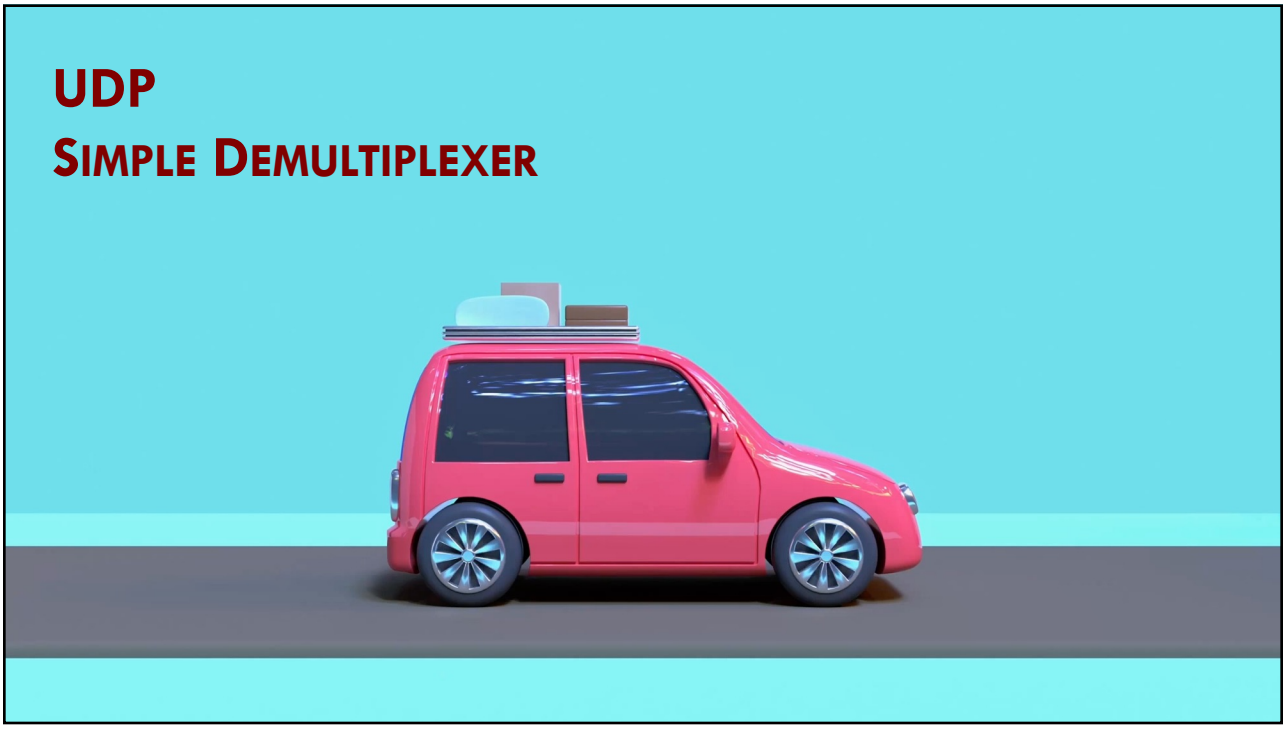
UDP
SIMPLE DEMULTIPLEXER



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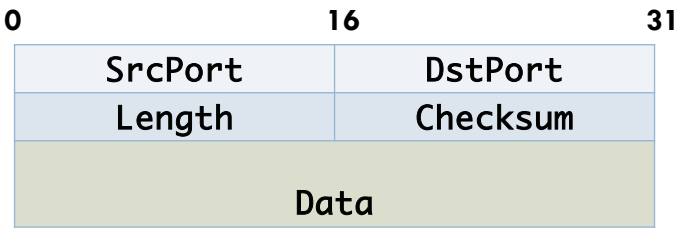
User Datagram Protocol

- **Simplest** possible transport protocol
  - Extends host-to-host into process-to-process communications
- No additional functionality to best-effort service provided by underlying network
- Adds **demultiplexing**
  - Allows applications on a host to **share** the service

UDP identification of processes

- Processes *indirectly* indentify each other
  - Abstract locator called **port**
- Source sends a message to a port
  - Destination receives messages from a port
- Process is identified by a port on a particular host

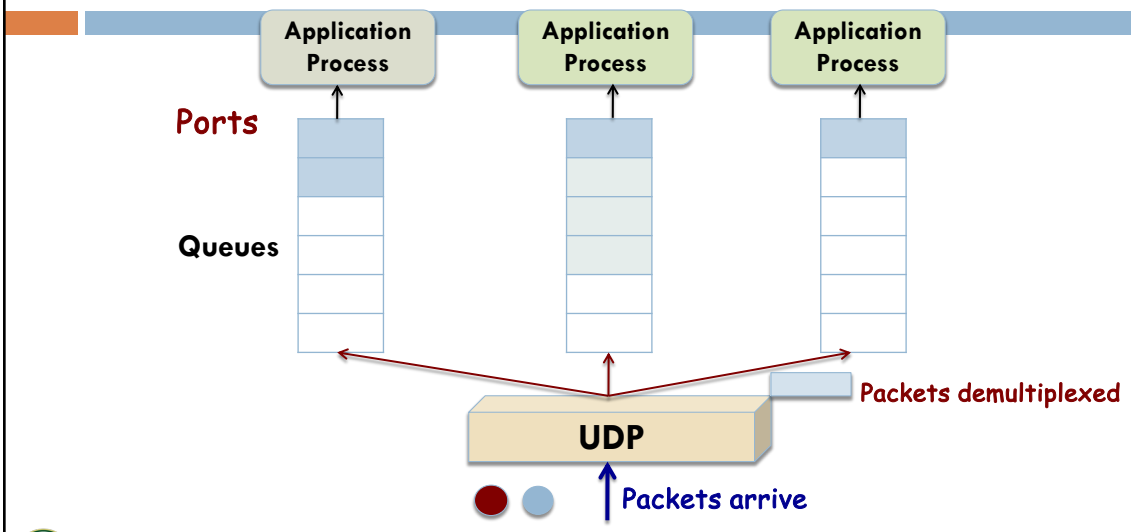
Format of a UDP header



A port is just an abstraction

- Typically implemented as a **message queue**
- When message arrives?
  - Protocol *appends* message to end of the queue
- **UDP**
  - If the queue is full, message is discarded
  - No flow-control mechanism

UDP message queue: The port abstraction



Some work that UDP does do besides demultiplexing: Checksumming

- UDP header
- Message body
- ***Psuedoheader***: From the IP header
  - Protocol number
  - Source IP address
  - Destination IP address

Verify if message is delivered between the correct endpoints

- UDP length
  - Used *twice*

So close, no matter how far
Couldn't be much more from the heart
Forever trusting who we are
And nothing else matters

Never opened myself this way
Life is ours, we live it our way
All these words, I don't just say
And nothing else matters

Trust I seek and I find in you
Every day for us something new
Open mind for a different view
And nothing else matters

Nothing Else Matters; James Alan Hetfield & Lars Ulrich; Metallica.

RELIABLE BYTE STREAM
TCP (TRANSMISSION CONTROL PROTOCOL)

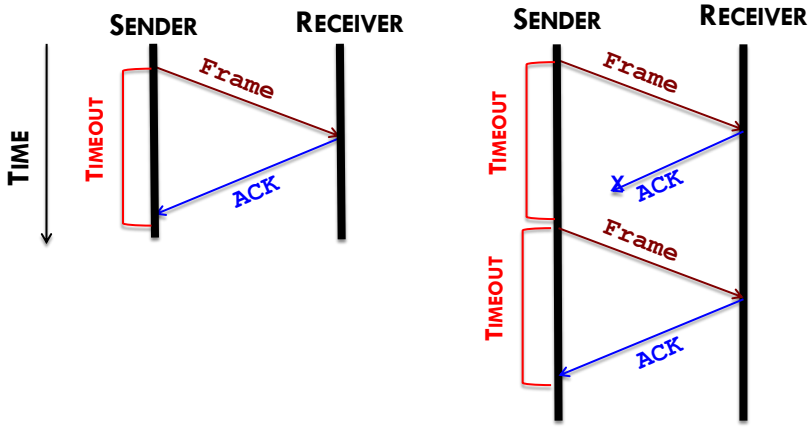
Components of Reliable delivery

- **Acknowledgements**
  - Confirm receipt of data [with an ACK]
- **Timeouts**
  - *Retransmit* if ACK not received within a specified time
- Use of ACKs and timeouts to implement reliable delivery
  - Sometime called ARQ (**a**utomatic **r**epeat re**q**uest)

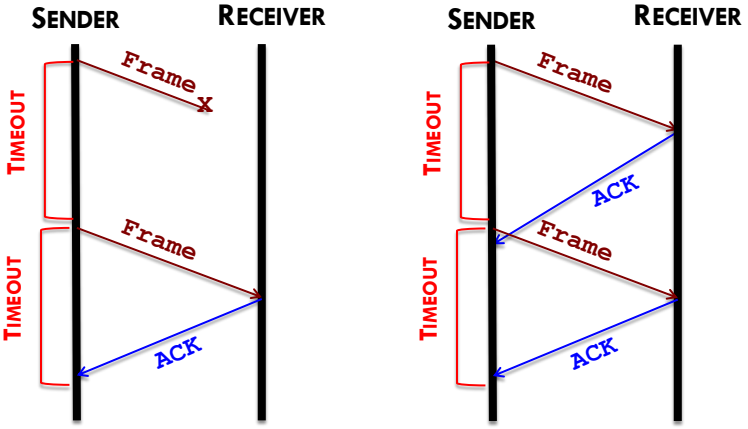
Simplest ARQ is the stop-and-wait algorithm

- After transmitting one frame
  - Sender **waits** for ACK before transmitting the next frame
- If the ACK does not arrive after a period of time
  - Sender **retransmits** the original frame

Stop-and-wait [1/2]



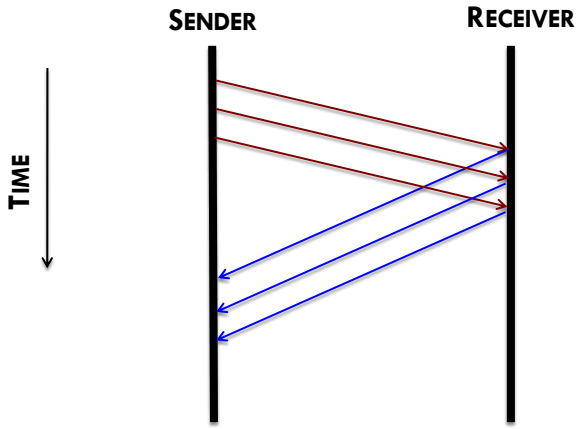
Stop-and-wait [2/2]



Sliding window: Try to fill the network pipe

- DELAY x BANDWIDTH product is 8 KB
- Data frames = 1KB
- Sender could transmit 9th frame
  - When ACK for the 1st frame arrives

Timeline for the sliding window



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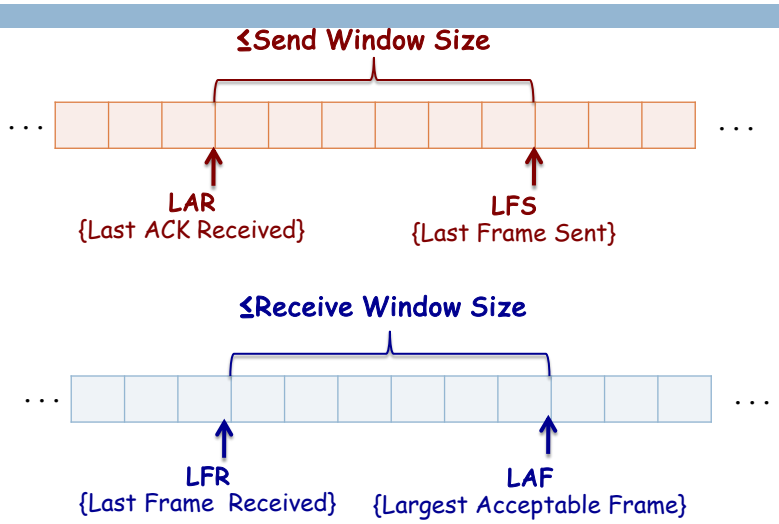
Sliding Window on Sender/Receiver



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Transmission Control Protocol (TCP) [1/2]

- **Reliable**, **in-order** delivery of byte streams
- **Full duplex** protocol
  - Each connection supports a pair of byte streams
    - Flowing in different directions
- Includes **flow control** mechanism
  - Allows receiver to limit the data sender
    - Control how much data can be transmitted at a time

Transmission Control Protocol (TCP) [2/2]

- Includes **multiplexing** mechanism
  - Multiple applications on a given host
- Implements a **congestion-control** mechanism
  1. *Throttle* how fast TCP sends data
  2. Keep sender from *overloading* the network

Flow control and congestion control

- **Flow control** is an end-to-end issue
  - Don't overrun capacity of *receiver*
- **Congestion control** is about how hosts & networks interact
  - Don't cause *switches* and *links* to be overloaded

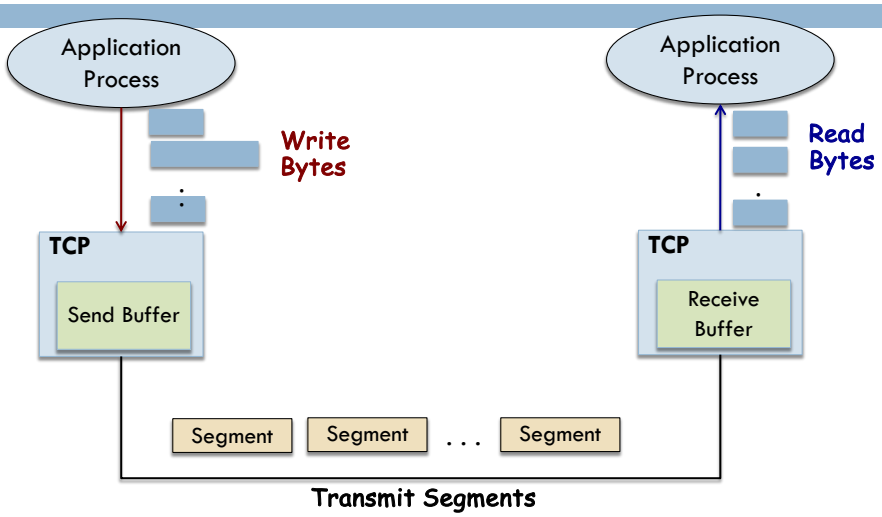
TCP: Setup and Teardown

- Two sides of the connection *agree* to exchange data
  - Establish **shared state**
  - 3 packets exchanged (SYN, SYN-ACK, ACK)
- Connection teardown
  - Let each host know it is OK to *free* the shared state
  - 4 packets exchanged (FIN, ACK, FIN, ACK)

TCP Segments & how they come about

- TCP
  - Accepts data from a data stream
  - Breaks it up into chunks
  - Adds a TCP header … creating a **TCP segment**
- Segment is then *encapsulated* in an IP datagram
- TCP packet is a term that you will often hear
  - Segment is more precise, packets are generally datagrams, frames are at the link layer

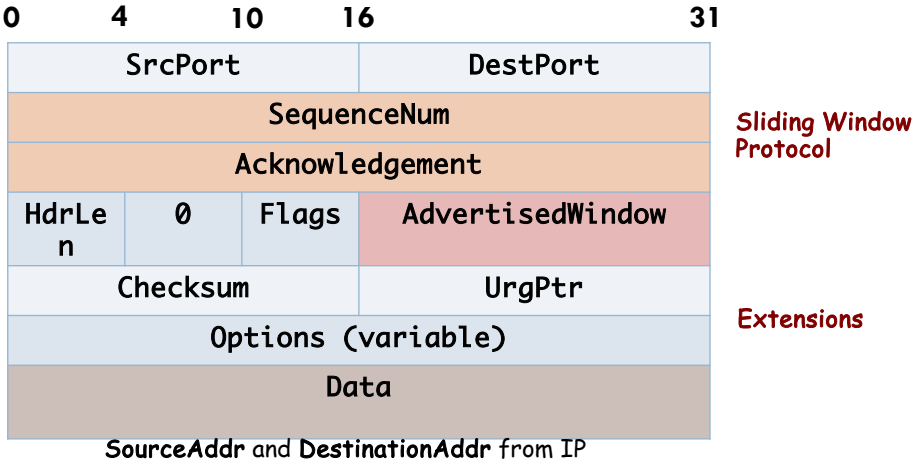
How TCP manages a byte stream



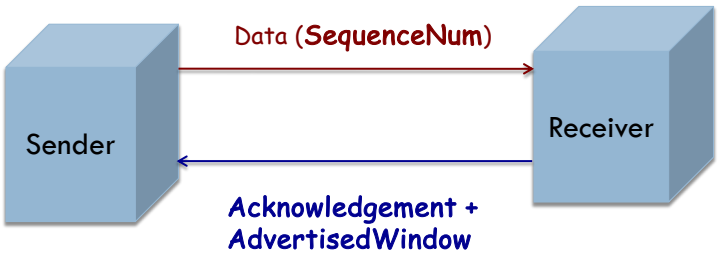
Maximum Segment Size (MSS)

- To avoid fragmentation in the IP layer, a host must specify the MSS as equal to the largest IP datagram that the host can handle **minus** (the IP and TCP header sizes)
- The **minimum** requirements (in bytes) at the hosts are as follows
  - IPv4: 576 – 20 – 20 = 536
  - IPv6: 1280 – 40 – 20 = 1220
- Each direction of the data flow can use a different MSS

TCP Header Format



Relationship between `SequenceNum`, `Acknowledgement` and `AdvertisedWindow`



Each byte of data has a sequence number
SequenceNum contains sequence number for first byte of data in segment

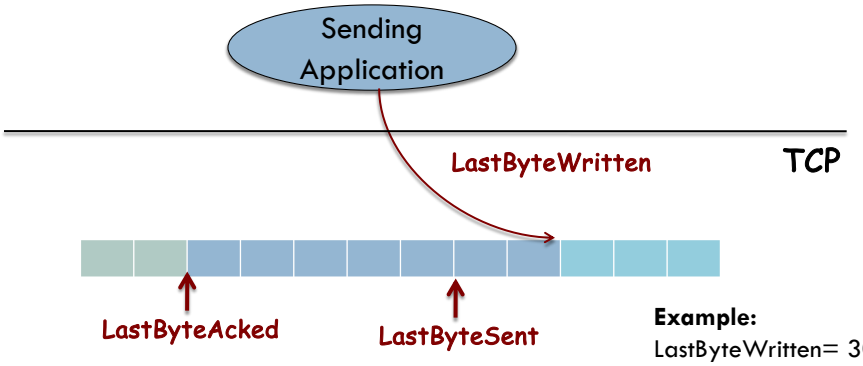
TCP Sliding Window [1/2]

- Guarantees **reliable** delivery of data
- Data is delivered in **order**
- Enforces **flow control** between the sender and receiver

TCP Sliding Window [2/2]

- Sender has a **limit** on unacknowledged data
  - Limited to no more than **`AdvertisedWindow`** bytes of unacknowledged data
- Receiver **selects** **`AdvertisedWindow`**
  - Based on memory set aside for connection's buffer space

TCP Send Buffer

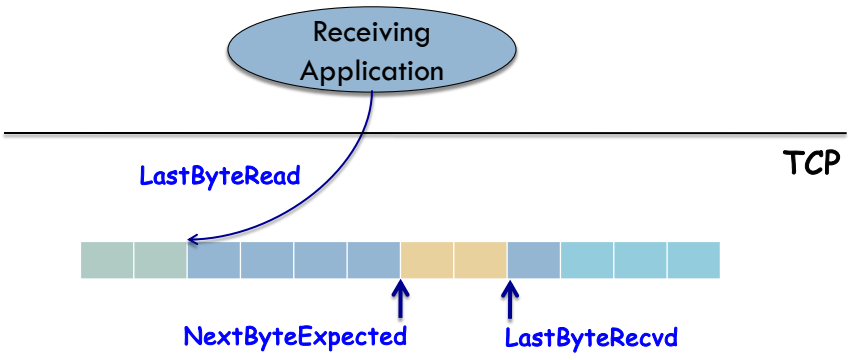


LastByteAcked ≤ LastByteSent

LastByteSent ≤ LastByteWritten

Example:
LastByteWritten= 3000
LastByteSent=2800
LastByteAcked:= 2400
How many unacknowledged bytes?
(3000-2400)= 600

TCP Receive Buffer



LastByteRead < NextByteExpected

NextByteExpected ≤ LastByteRecvd + 1

Flow Control: Buffers are of finite size

`MaxSendBuffer` and `MaxRcvBuffer`

- Receiver **throttles** sender
  - Advertises a window
  - No bigger than what it can buffer

LastByteRcvd – LastByteRead ≤ MaxRcvBuffer

AdvertisedWindow =
MaxRcvBuffer − ((NextByteExpected -1) − LastByteRead)

Space Utilized in the receiver's buffer

The advertised window may potentially shrink

- If the process is reading data as fast as it arrives?
  - The advertised window *stays open*
    - i.e., `AdvertisedWindow = MaxRcvBuffer`
- If the receiving process falls behind?
  - Advertised window becomes *smaller* with every segment that arrives
  - Until it becomes 0

Flow Control: Buffers are of finite size MaxSendBuffer and MaxRcvBuffer

- On the sender size, TCP **adheres** to the advertised window from the receiver

LastByteSent – LastByteAcked ≤ AdvertisedWindow

EffectiveWindow =
AdvertisedWindow – (LastByteSent – LastByteAcked)

EffectiveWindow should be > 0 before source can send more data

Reliability is achieved by the sender detecting lost data and retransmitting it

- TCP uses two primary techniques to identify loss
  - Retransmission timeout (RTO)
  - Duplicate cumulative acknowledgements (DupAcks)
    - If the sender receives three duplicate acknowledgements, it retransmits the last unacknowledged packet

Selective Acknowledgements (SACK)

- Using SACK, a receiver informs the sender of **non-contiguous blocks** of data that have been received and queued successfully
- So, the sender need retransmit only the segments that have actually been lost

ISSUES WITH TCP

Protecting against wraparound: 32-bit sequence space

- TCP assumes each segment has a max lifetime
  - **Maximum segment lifetime** (MSL)
  - Currently this is 120 seconds
- Sequence number used on a connection might wrap-around
  - Within the MSL

Time until 32-bit sequence number wraps around

Bandwidth	Time until wraparound
T1 (1.5 Mbps)	6.4 hours
Ethernet (10 Mbps)	57 minutes
T3 (45 Mbps)	13 minutes
FDDI (100 mbps)	6 minutes
STS-3 (155 Mbps)	4 minutes
STS-12 (622 Mbps)	55 seconds
STS-24 (1.2 Gbps)	28 seconds

STS : Synchronous Transport Signal
FDDI: Fiber Distributed Data Interface

Keeping the pipe full

- **`AdvertisedWindow`** field (16-bits) must be big enough
  - To allow sender to keep the pipe full
  - 16 bit allows us a max window size of 64 KB (2^{16})
- If receiver has unlimited buffer space?
  - **`AdvertisedWindow`** dictated by DELAY x BANDWIDTH product

Required Window Size for 100 ms delay

Bandwidth	Delay x Bandwidth Product
T1 (1.5 Mbps)	18 KB
Ethernet (10 Mbps)	122 KB
T3 (45 Mbps)	549 KB
FDDI (100 mbps)	1.2 MB
STS-3 (155 Mbps)	1.8 MB
STS-12 (622 Mbps)	7.4 MB
STS-24 (1.2 Gbps)	14.8 MB

STS : Synchronous Transport Signal
FDDI: Fiber Distributed Data Interface

TCP extensions: Use 32-bit timestamp to extend sequence number space

- **Distinguish** between different incarnations of the same sequence number
- Timestamp not treated as part of sequence number
  - For ordering etc.
  - Just protects against wraparound

TCP Extension: Allow TCP to advertise larger window

- Fill larger DELAY X BANDWIDTH pipes
- Include option defining **scaling** factor
- Option allows TCP endpoints to agree that **`AdvertisedWindow`** counts **larger chunks**

A caveat regarding Options

- You cannot solve all problems with Options
- TCP Header has room for only **44 bytes of options**
  - `HdrLen` is 4 bits long, so header length cannot exceed 16 x 32-bit = 64 bytes
  - Adding a TCP option that extends the space available for options?

The contents of this slide-set are based on the following references

- *Computer Networks: A Systems Approach. Larry Peterson and Bruce Davie. 4th edition. Morgan Kaufmann. ISBN: 978-0-12-370548-8. [Chapter 5, 6]*