CS640: Introduction to Computer Networks

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Lecture 14
TCP – I -
Transport Protocols

The Road Ahead

- Transport introduction
- Error recovery & flow control basics
- TCP Flow Control basics

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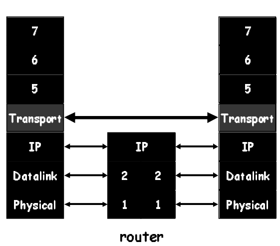
Transport Protocols

- Lowest level end-to-end protocol.
  - Header generated by sender is interpreted only by the destination
  - Routers view transport header as part of the payload



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Functionality Split

- Network provides best-effort delivery
- End-systems implement many functions
  - Reliability
  - In-order delivery
  - De-multiplexing
  - Message boundaries
  - Connection abstraction
  - Congestion control
  - …

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Transport Protocols

- UDP provides just integrity and demux
- TCP adds…
  - Connection-oriented
  - Reliable
  - Ordered
  - Point-to-point
  - Byte-stream
  - Full duplex
  - Flow and congestion controlled
- Request-reply service
  - RPC-like
  - Not covered here

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UDP: User Datagram Protocol

- "No frills," "bare bones" Internet transport protocol
- "Best effort" service, UDP segments may be:
  - Lost
  - Delivered out of order to app
- *Connectionless:*
  - No handshaking between UDP sender, receiver
  - Each UDP segment handled independently of others

Why is there a UDP?
- No connection establishment (which can add delay)
- Simple: no connection state at sender, receiver
- Small header
- No congestion control: UDP can blast away as fast as desired

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More on UDP

- Often used for streaming multimedia apps
  - Loss tolerant
  - Rate sensitive
- Other UDP uses (why?):
  - DNS, SNMP
- Reliable transfer over UDP
  - Must be at application layer
  - Application-specific error recovery

← 32 bits →

Source port #	Dest port #
Length	Checksum
Application data (message)	

Length, in bytes of UDP segment, including header

UDP segment format

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TCP

Reliable, Connection oriented, **In-order, Byte stream abstraction**

Flags: SYN FIN RESET PUSH URG ACK

Source port			Destination port
Sequence number			
Acknowledgement			
HdrLen	0	Flags	Advertised window
Checksum			Urgent pointer
Options (variable)			
Data			

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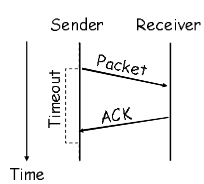
Reliability: Straw-man approaches

- Receiver sends acknowledgement (ACK) when it receives packet
  - Sender waits for ACK and timeouts if it does not arrive within some time period
- Simplest version: Send a packet, stop and wait until ACK arrives
  - Problems?



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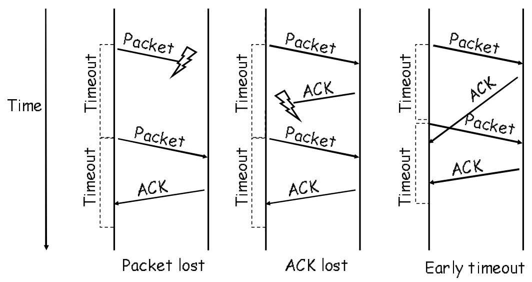
Recovering from Error



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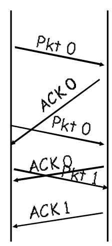
How to Recognize Duplicates?

- Use sequence numbers
  - *both* packets and acks
- Sequence # in packet is finite
  → How big should it be?
- For stop and wait?
  - One bit – won't send seq #1 until received ACK for seq #0
- Problem with Stop and Wait:
  - Poor efficiency



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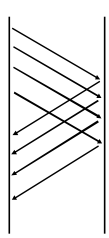
How to Ensure Efficiency?

- How to "keep the pipe full"?
  - Answer: **Pipelining**
- Send multiple packets without waiting for first to be acked
- How many such packets max?
  - Suppose 10Mbps link, 4ms delay, 500byte pkts
  - 1? 10? 20?
  - Round trip delay * bandwidth = capacity of pipe
- Consequences:
  - Cannot use a 1 bit sequence number any more
  - Buffering may be required
  - Range of sequence number and buffer size will depend on loss recovery



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Pipelining Implementation: "Sliding Window"

- Sliding buffer at sender and receiver
  - Packets in transit ≤ sender buffer size
  - Advance when sender and receiver agree packets at beginning have been received
- Receiver has to buffer a packet until all prior packets have arrived
- Goal: provides reliable, ordered delivery
- Two ways to do this:
  - Go-Back-N
  - Selective Repeat

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GBN Window Sliding – Common Case

- On reception of new ACK (i.e. ACK for something that was not acked earlier)
  - Increase sequence of max ACK received
  - Send next packet
- On reception of new in-order data packet (next expected)
  - Hand packet to application
  - Send cumulative ACK – acknowledges reception of all in-sequence packets up to sequence number
  - Increase sequence of max acceptable packet

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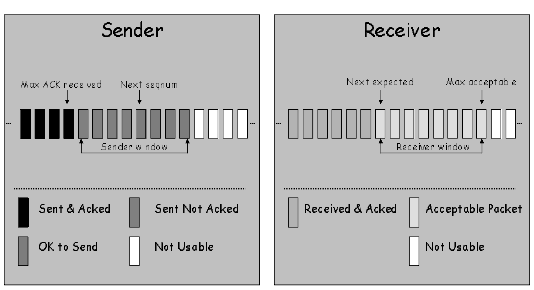
Go-Back-N: Sender/Receiver State



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Go-Back-N with Losses

- On reception of out-of-order packet
  - Don't ACK (wait for source to timeout)
  - Discard out of order packets
  - Cumulative ACK (helps source identify loss)
- Timeout (Go-Back-N recovery)
  - Set timer upon transmission of packet
  - Retransmit all unacknowledged packets

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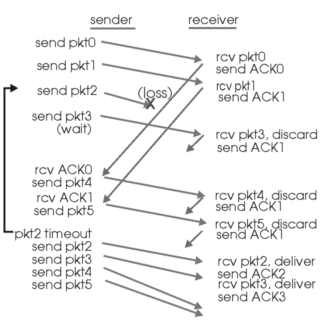
Go-Back-N With Losses



- Simple behavior
  - One timeout
  - Simple buffering
- Performance during loss recovery
- No longer have an entire window in transit
- Can have much more clever loss recovery

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Selective Repeat

- Receiver *individually* acknowledges all correctly received pkts
  - Buffers packets, as needed, for eventual in-order delivery to upper layer
- Sender only resends packets for which ACK not received
  - Sender timer for each unACKed packet
- Sender window
  - N consecutive seq #'s
  - Again limits seq #s of sent, unACKed packets

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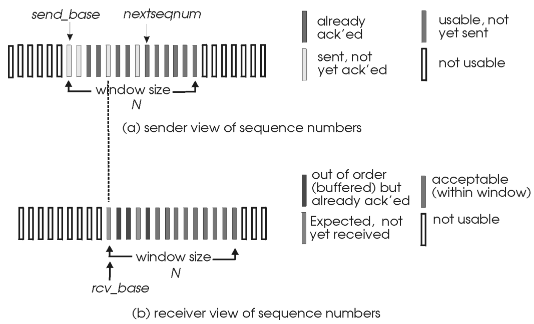
Selective Repeat: Sender, Receiver Windows



Sequence Numbers

- How large do sequence numbers need to be?
  - Depends on sender/receiver window size
    - Must take wrap-around into account
- E.g.
  - Max seq = 7, window_size = 7
  - If pkts 0..6 are sent successfully and all acks lost
    - Receiver expects 7,0..5, sender retransmits old 0..6!!!
- Max sequence must be ≥ 2 * window_size
- TCP uses 32 bit sequence numbers

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TCP Flow Control

- TCP is a sliding window protocol
  - For window size *n*, can send up to *n* bytes without receiving an acknowledgement
  - When the data is acknowledged then the window slides forward
- Each packet advertises a window size
  - Indicates number of bytes the receiver has space for
- Original TCP always sent entire window
  - Congestion control now limits this

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TCP Sequence Numbers

- Sequence Number Space
  - Each *byte in byte stream* is numbered.
  - 32 bit value
  - Wraps around
- Initial values selected at start up time
  - TCP breaks up the byte stream in packets.
- Packet size is limited to the Maximum Segment Size
  - Each packet has a sequence number.
  - Indicates where it fits in the byte stream

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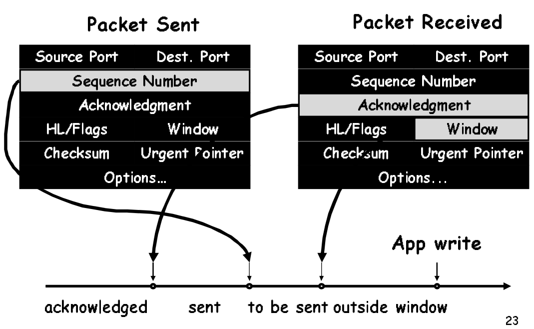
Window Flow Control: Send Side



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Summary

- Transport service
  - UDP → mostly just IP service
  - TCP → congestion controlled, reliable, byte stream
- Types of ARQ protocols
  - Stop-and-wait → slow, simple
  - Go-back-n → can keep link utilized (except w/ losses)
  - Selective repeat → efficient loss recovery
- Sliding window flow control
  - Addresses buffering issues and keeps link utilized
  - TCP uses sliding window
  - 32bit sequence numbers

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