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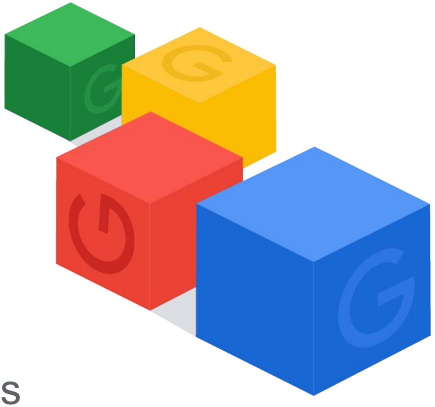

Building Your Technical Career:

- Learn how to make the most of your degree
- Prepare for a career in software engineering

Interview Prep Workshop:

- Watch a mock interview
- Solve sample problems as a group

STEP Resume Workshop (Tech):

- Learn about Google´s STEP internship for 1st/2nd year students
- Get resume tips on how to best present your skills

Hosted by Google Software Engineers **Ian Sutton** and **Faesal Murad**

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Tuesday, October 18th

- **Building Your Technical Career**: *ECS 660* | 5pm - 6:30pm

Wednesday, October 19th

- **Office hours for 1st/2nd year students**: *ECS 223 & ECS 227* | 1pm - 3pm

Thursday, October 20th

- **Interview Prep Workshop**: *ECS 660* | 12pm - 1pm
- **STEP Resume Workshop (Tech)**: *ECS 660* | 5:30pm - 6:30pm

Friday October 21st:

- **Virtual office hours**: *Online* | 12pm - 1pm

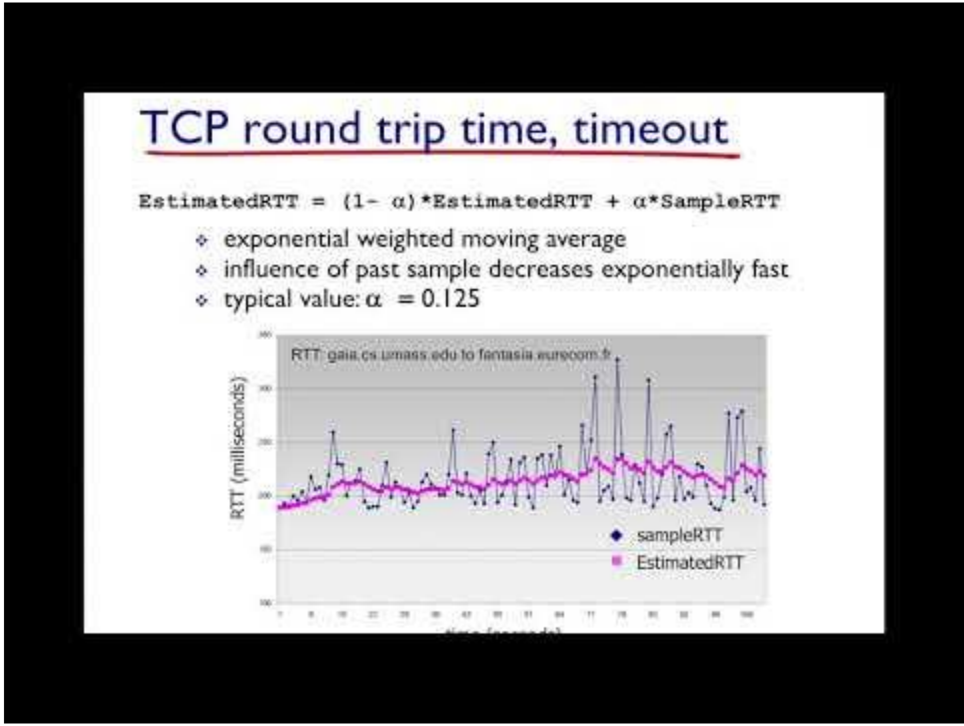
Please RSVP at https://goo.gle/UVictoriaFall2022Events

Check out more career-related content online at https://careersonair.withgoogle.com/

Computer Networks

TCP Error Control

Jianping Pan
Fall 2022



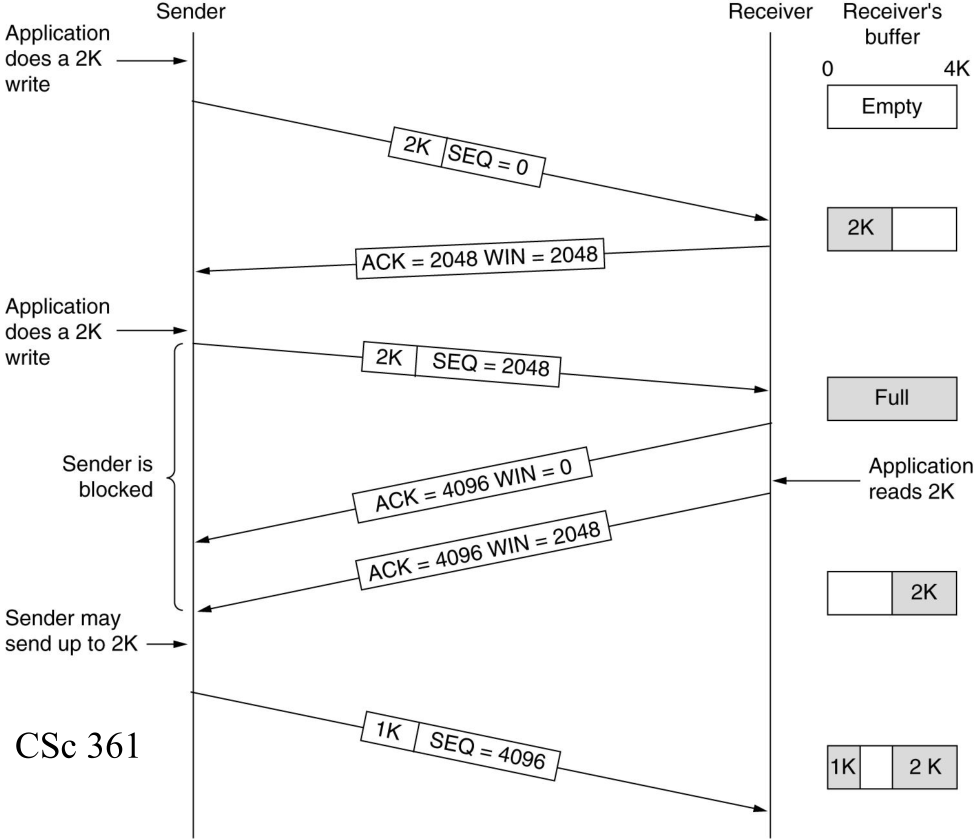
TCP round trip time, timeout

```
EstimatedRTT = (1- α)*EstimatedRTT + α*SampleRTT
```

- exponential weighted moving average
- influence of past sample decreases exponentially fast
- typical value: α = 0.125

Review: TCP flow control

- Purpose
  - to avoid overflow
- Mechanism
  - sliding window
  - variable window



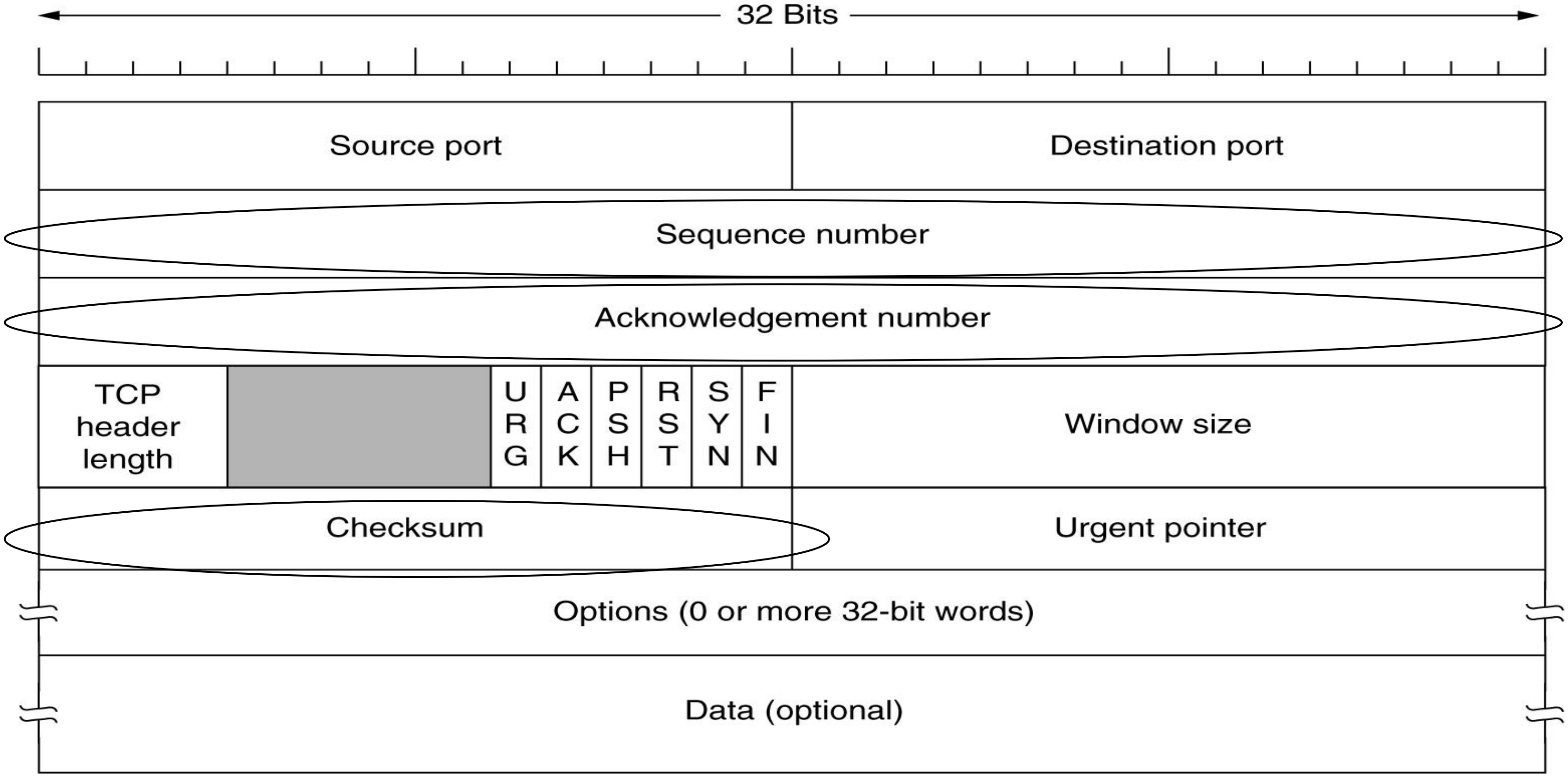
Q: seq, ack, win?

Error control

- Service provided by TCP
  - connection-oriented, **reliable** data transfer
- Service provided by IP
  - connectionless, ***unreliable*** packet delivery
  - packets may get
    - lost
    - duplicated
    - corrupted
    - reordered

Q: why?

TCP packet header



32 Bits

Source port

Destination port

Sequence number

Acknowledgement number

TCP header length

URG

ACK

PSH

RST

SYN

FIN

Window size

Checksum

Urgent pointer

Options (0 or more 32-bit words)

Data (optional)

What can go wrong?

- IP packet delivery
  - lost
    - *transmission error* or network congestion
  - duplicated
    - deleted by referring to sequence number; ***done***
  - corrupted
    - arrived but in “bad shape”
  - reordered
    - rearranged by referring to sequence number; ***done***

Error detection

- Corrupted packets
  – detected by TCP checksum
    - action: drop!
- Lost packets
  – how do you tell if something ***is*** already lost?
  – TCP sender
    - timer for acknowledgment
  – TCP receiver (cumulative acknowledgment)
    - duplicate acknowledgment

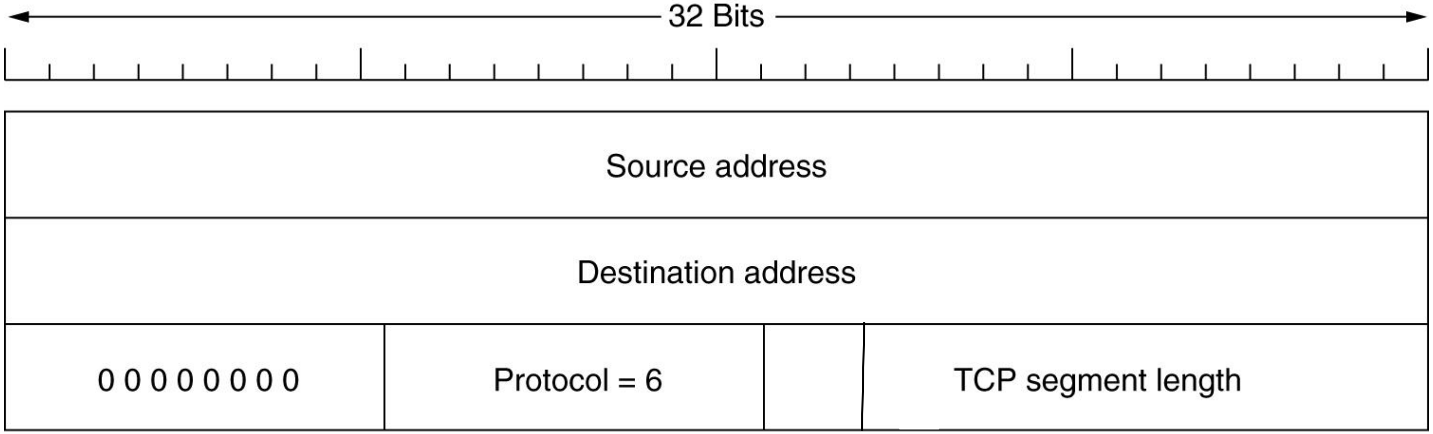
TCP/IP checksum

- Algorithm: 16-bit one complement of one’s complement sum with carry
  - **16**-bit: **padding** when necessary
    - cover: TCP header, payload, pseudo header
  - calculate: pad, sum, carry, complement=>checksum
  - verify: sum with checksum, carry, complement=>0?
- Examples

		1	1	1	0	0	1	1	0	0	1	1	0	0	1	1	0
		1	1	0	1	0	1	0	1	0	1	0	1	0	1	0	1
wraparound	1	1	0	1	1	1	0	1	1	1	0	1	1	1	0	1	1
sum		1	0	1	1	1	0	1	1	1	0	1	1	1	1	0	0
checksum		0	1	0	0	0	1	0	0	0	1	0	0	0	0	1	1

IP pseudo header

- TCP checksum also covers IP pseudo header
  - to detect mis-delivered packets by IP layer
    - include: IP addresses, protocol ID, segment length



32 Bits

Source address

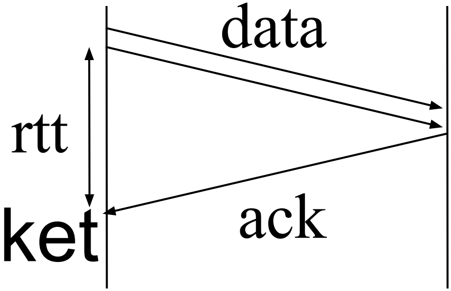
Destination address

0 0 0 0 0 0 0 0

Protocol = 6

TCP segment length

TCP sender timer

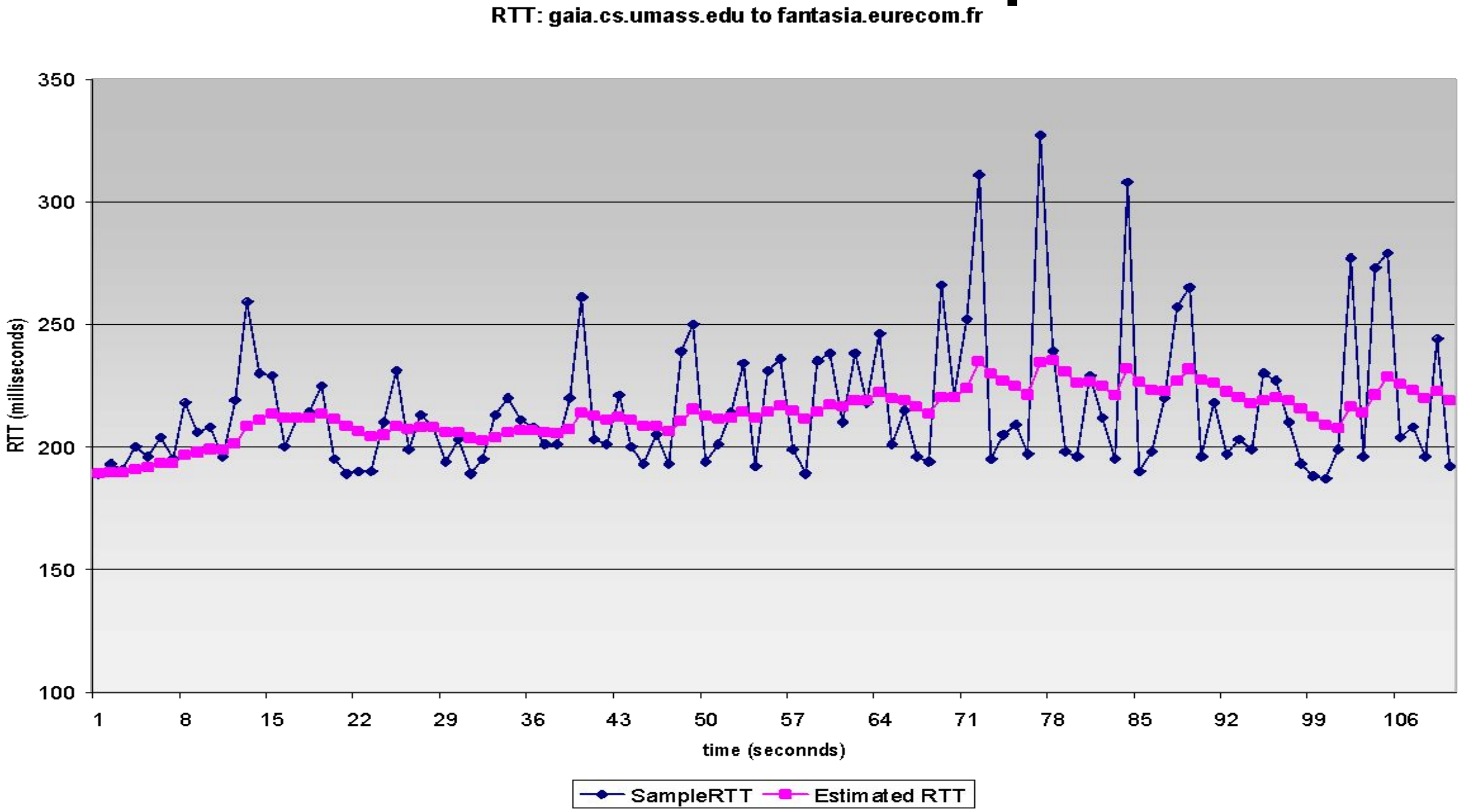


- TCP sender
  - start a timer when sending out a packet
    - in reality: one timer per a window of packets
  - on acknowledgment "covering" this packet
    - cancel the timer and setup another one
  - if timer timeouts: *indicate* packet may be lost
- Timeout value
  - too soon: unnecessary transmission
  - too late: "slow response"

TCP round-trip time

- RTT measurement and calculation
  - RTT sample
    - time from sending a packet to receiving its ack
      - coarse-grained: 500 ms in BSD
    - ignore retransmitted packets for RTT measurement
  - smoothed RTT (SRTT)
    - exponentially weighted moving average (EWMA)
    - $\text{SRTT}_{i+1} = \text{SRTT}_i + a\,(\text{RTT-SRTT}_i)$
    - $a = 1/8$

EWMA example



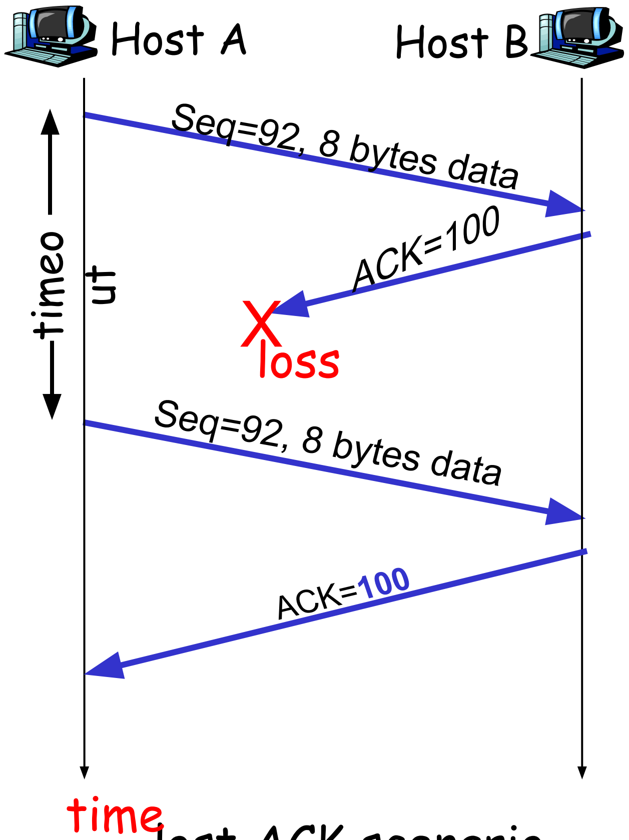
TCP timeout value

- RTO calculation based on SRTT
  - RTT variance (RTTV)
    - $\text{RTTV}_{i+1} = \text{RTTV}_i + b(|\text{RTT}-\text{SRTT}_i|-\text{RTTV}_i)$
    - $b = 1/4$
  - RTO
    - $\text{RTO} = d\ (\text{SRTT} + c\ \text{RTTV})$
    - *c*: initially 2, now 4
    - *d*: backoff factor
      - initially 1, doubled when timeout until reaching the maximum
  - initial SRTT, RTTV and minimum RTO

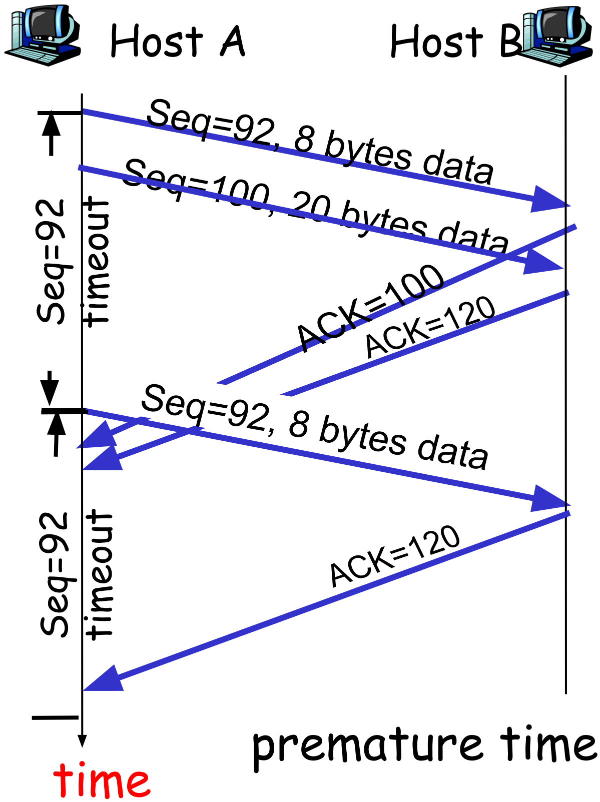
TCP sender (simplified with no flow control and congestion control)

```
send_next = InitialSeqNum
ack = InitialSeqNum

loop (forever) {
  switch(event)

  event: data received from application above
      create TCP segment with sequence number send_next
      if (timer currently not running)
          start timer with timer's seqno = send_next
      pass segment to IP
      send_next = send_next + length(data)

   event: timer timeout
      retransmit not-yet-acknowledged segment with
          smallest sequence number
      start timer with the resent seqno

   event: ACK received, with ACK field value of y
      if (y > ack) {
          ack = y
            cancel timer with timer's seqno < y
        if (timer not running && there are currently not-yet-acknowledged segments)
              start timer
        }
 }  /* end of loop forever */
```

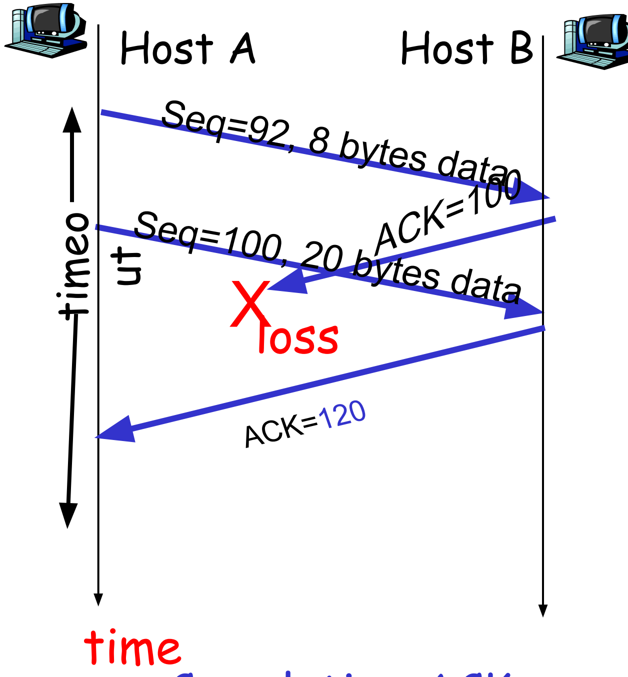
TCP: retransmission scenarios



lost ACK scenario



premature timeout



Cumulative ACK

TCP ACK generation [RFC 1122, RFC 2581]

Event at Receiver	TCP Receiver action
Arrival of in-order segment with expected seq #. All data up to expected seq # already ACKed	Delayed ACK. Wait up to 500ms for next segment. If no next segment, send ACK
Arrival of in-order segment with expected seq #. One other segment has ACK waiting	Immediately send single cumulative ACK, ACKing both in-order segments
Arrival of out-of-order segment higher-than-expect seq. # . Gap detected	Immediately send duplicate ACK, indicating seq. # of next expected byte
Arrival of segment that partially or completely fills gap	Immediate send ACK, provided that segment starts at lower end of gap (accept out-or-order)

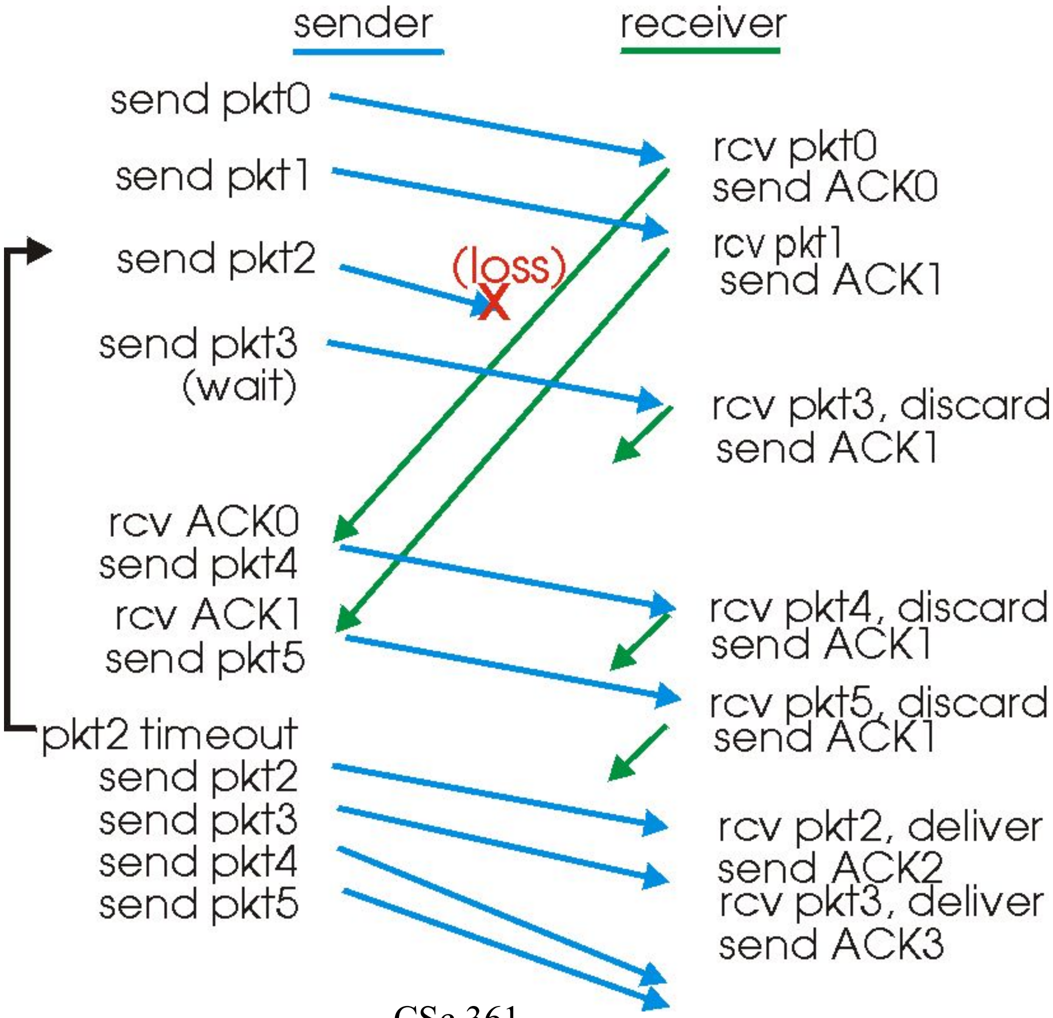
Duplicate acknowledgment

- TCP acknowledgment
  - cumulative acknowledgment
  - example
    - rcv: [0, 500),[500, 1000),[1500, 2000),[2000, 2500)
    - ack: 500,1000,1000 (1st dupack),1000 (2nd dupack)
- Enough duplicate acknowledgments
  - *indicate* packet loss may have occurred
    - ack: 500, 1000, 1000, 1000, 1000 (3rd dupack)
    - packet [1000,1500) is considered lost

Error recovery

- End-to-end retransmission
  - go-back-N (GBN)
    - retransmit from ackno and upward
  - selective retransmission
    - only retransmit those “known” to be lost
- TCP’s error recovery
  - mostly GBN
    - receiver can buffer out-of-order packets
  - explore further: TCP selective acknowledgment

GBN in action (N = 4)



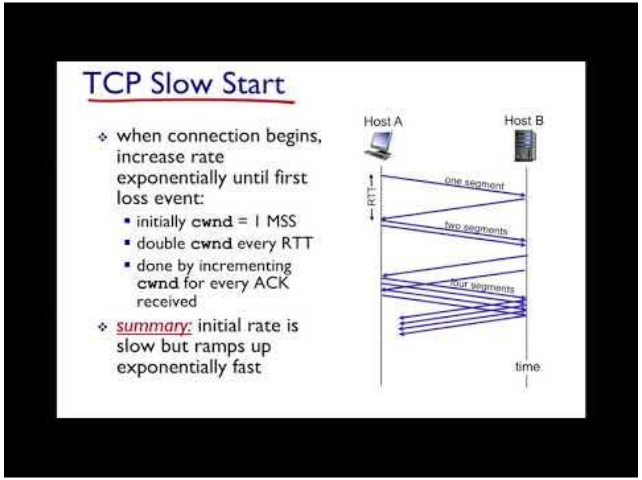
Q: how does SR look like?

This lecture

- TCP error control: wow!
  - purpose (why) and approaches (how)
  - mechanisms (what)
    - detection
    - recovery
- Explore further
  - TCP selective acknowledgment (SACK)
  - http://www.icir.org/floyd/

Next lecture

- TCP congestion control
  - * the thing that keeps the Internet still ***alive***
  - * Chapter 3, all sections required this month



TCP Slow Start

- when connection begins, increase rate exponentially until first loss event:
  - initially **cwnd** = 1 MSS
  - double **cwnd** every RTT
  - done by incrementing **cwnd** for every ACK received
- *summary:* initial rate is slow but ramps up exponentially fast