Transport Layer VII

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Chapter 3: Roadmap

3.1 Transport-layer services
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3.3 Connectionless transport: UDP
3.4 Principles of reliable data transfer
3.5 Connection-oriented transport: TCP
   - Segment structure
   - Reliable data transfer
   - Flow control
   - Connection management
3.6 Principles of congestion control
3.7 TCP congestion control
Principles of Congestion Control

Congestion:

• Informally: “too many sources sending too much data too fast for the network to handle”
• Different from flow control!
• Manifestations:
  - Lost packets (buffer overflows)
  - Delays (queueing in routers)
• Important networking problem
Causes/Costs of Congestion: Scenario 1

- Two senders, two receivers
- One router of capacity $C$, infinite buffers, no loss
- No retransmission

Cost 1: queuing delays in congested routers
Causes/Costs of Congestion: Scenario 2

- One router, *finite* buffers (pkt loss is possible now)
- Sender retransmission of lost packet
- During congestion $2\lambda_{net} = 2(\lambda_{in} + \lambda_{retx}) = C$

$\lambda_{in}$: app rate
$\lambda_{net}$: network rate (original + retransmitted pkts)

finite shared output link buffers
Causes/Costs of Congestion: Scenario 2

- We call $\lambda_{out}$ goodput and $\lambda_{net}$ throughput
  - Case A: pkts never lost while $\lambda_{net} < C/2$ (not realistic)
  - Case B: pkts are lost when $\lambda_{net}$ is “sufficiently large,” but timeouts are perfectly accurate (not realistic either)
  - Case C: same as B, but timer is not perfect (duplicate packets are possible)

Cost 2: retransmission of lost packets and premature timeouts increase network load, reduce flow’s own goodput
Causes/Costs of Congestion: Scenario 3

- Multihop case
  - Timeout/retransmit
  - $R_2 = 50 \text{ Mbps}$, $R_1 = R_3 = R_4 = 100 \text{ Mbps}$
  - Flow C-A: sends 90 Mbps

flow B-D suffers packet loss and reduced goodput

green flow D-B is affected by "junk" pkts that are lost at router R2

finite shared output link buffers

Cost 3: congestion causes goodput reduction for other flows
Two broad approaches towards congestion control:

**End-to-end:**
- No explicit feedback from network
- Congestion inferred by end-systems from observed loss/delay
  - Approach taken by TCP (relies on loss)

**Network-assisted:**
- Routers provide feedback to end systems
  - Single bit indicating congestion (DECbit, TCP/IP ECN)
  - Two bits (ATM)
  - Explicit rate senders should send at (ATM)

ATM = Asynchronous Transfer Mode
Case Study: ATM ABR Congestion Control

• For network-assisted protocols, the logic can be **binary**:
  - Path underloaded, increase rate
  - Path congested, reduce rate
• It can also be **ternary**
  - Increase, decrease, hold steady
  - ATM ABR (Available Bit Rate) profile

RM (resource management) packets (cells):

• Sent by sender, interspersed with data cells
• Bits in RM cell set by switches/routers
  - **NI bit**: no increase in rate (impending congestion)
  - **CI bit**: reduce rate (congestion in progress)
• RM cells returned to sender by receiver, with bits intact
Case Study: ATM ABR Congestion Control

- Additional approach is to use a two-byte ER (explicit rate) field in RM cell
  - Congested switch may lower ER value
  - Senders obtain the maximum supported rate on their path
- Issues with network-assisted congestion control?
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TCP Congestion Control

• TCP congestion control has a variety of algorithms developed over the years
  - High-Speed TCP (2002), Scalable TCP (2002)
• Many others: H-TCP, CUBIC TCP, L-TCP, TCP Westwood, TCP Veno (Vegas + Reno), TCP Africa
• Linux: BIC TCP (2004), CUBIC TCP (2008)
• Vista and later: Compound TCP (2005)
  - Server 2019 switched to CUBIC
• Google: BBR (2016)