Computer Networks

Jiaqi Zheng

Material with thanks Mosharaf Chowdhury, and many other colleagues.

Agenda

- Router-assisted congestion control

ROUTER-ASSISTED CONGESTION CONTROL

Recap: TCP problems

- Misled by non-congestion losses
- Fills up queues leading to high delays
- Short flows complete before discovering available capacity
- AIMD impractical for high speed links
- Saw tooth discovery too choppy for some apps
- Unfair under heterogeneous RTTs
- Tight coupling with reliability mechanisms
- End hosts can cheat

Routers tell endpoints if they're congested

Routers tell endpoints what rate to send at

Routers enforce fair sharing

Could fix many of these with some help from routers!

Router-assisted congestion control

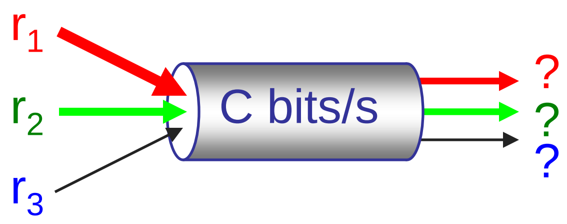
- Three tasks for congestion control
  - Isolation/fairness
  - Rate adjustment
  - Detecting congestion

Fairness: General approach

- Routers classify packets into “flows”
  - Let’s assume flows are TCP connections
- Each flow has its own FIFO queue in router
- Router services flows in a fair fashion
  - When line becomes free, take packet from next flow in a fair order
- What does “fair” mean exactly?

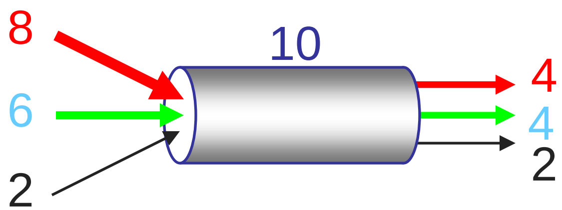
Max-Min fairness

- Given set of bandwidth demands r_i and total bandwidth C, max-min bandwidth allocations are:
  - $a_i = \min(f, r_i)$
  - where f is the unique value such that $\mathrm{Sum}(a_i) = C$



Example

- $C = 10$; $r_1 = 8$, $r_2 = 6$, $r_3 = 2$; $N = 3$
- $C/3 = 3.33 \rightarrow$
  - r_3's need is only 2
    - » Can service all of r_3
  - Remove r_3 from the accounting: $C = C - r_3 = 8$; $N = 2$
- $C/2 = 4 \rightarrow$
  - Can't service all of r_1 or r_2
  - So hold them to the remaining fair share: $f = 4$



$f = 4$:
min(8, 4) = 4
min(6, 4) = 4
min(2, 4) = 2

Max-Min fairness

- Given set of bandwidth demands r_i and total bandwidth C, max-min bandwidth allocations are:
  - $a_i = \min(f, r_i)$
  - where f is the unique value such that $\mathrm{Sum}(a_i) = C$
- If you don't get full demand, no one gets more than you
- This is what round-robin service gives if all packets are the same size

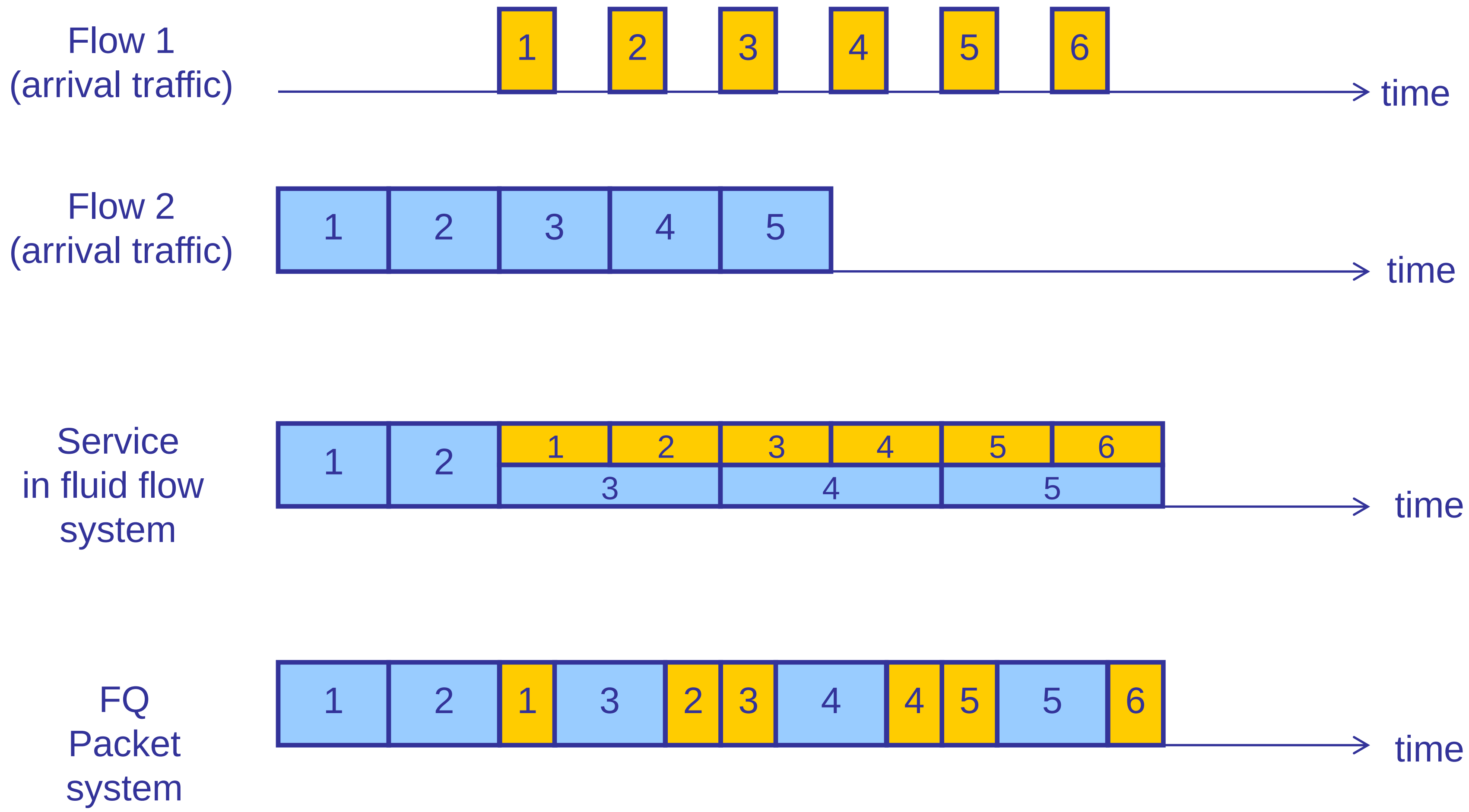
How do we deal with packets of different sizes?

- Mental model: Bit-by-bit round robin (“fluid flow”)
- Can you do this in practice?
  - No, packets cannot be preempted
- But we can approximate it
  - This is what “fair queuing” routers do

Fair Queuing (FQ)

- For each packet, compute the time at which the last bit of a packet would have left the router if flows are served bit-by-bit
- Then serve packets in the increasing order of their deadlines

Example


Flow 1
(arrival traffic)
1 2 3 4 5 6
time
Flow 2
(arrival traffic)
1 2 3 4 5
time
Service
in fluid flow
system
1 2
1 2 3 4 5 6
3 4 5
time
FQ
Packet
system
1 2 1 3 2 3 4 4 5 5 6
time

Fair Queuing (FQ)

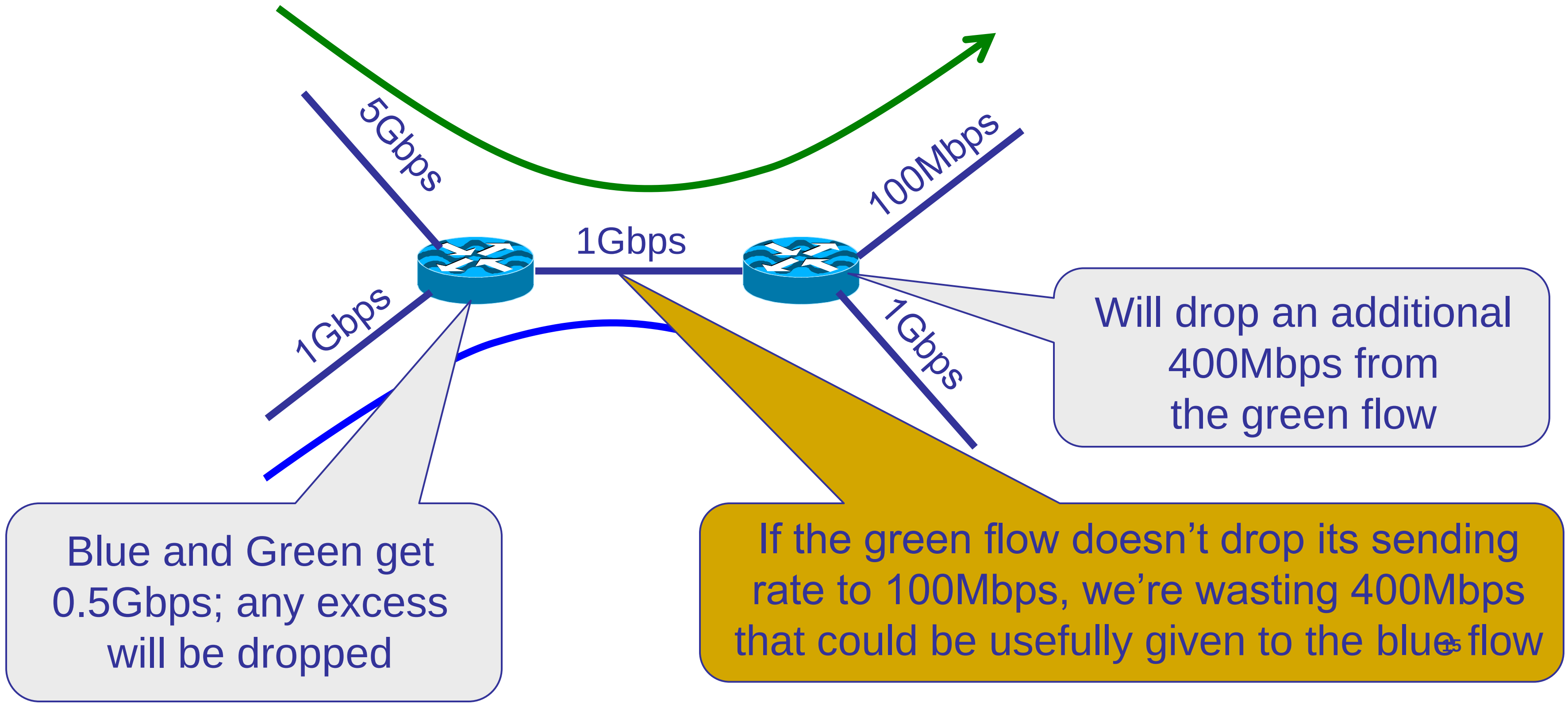
- Implementation of round-robin generalized to the case where not all packets are equal sized
- Weighted fair queuing (WFQ): assign different flows different shares
- Today, some form of WFQ implemented in almost all routers
  - Not the case in the 1980-90s, when CC was being developed
  - Mostly used to isolate traffic at larger granularities (e.g., per-prefix)

FQ vs. FIFO

- FQ advantages:
  - Isolation: cheating flows don't benefit
  - Bandwidth share does not depend on RTT
  - Flows can pick any rate adjustment scheme they want
- Disadvantages:
  - More complex than FIFO: per flow queue/state, additional per-packet book-keeping

FQ in the big picture

- FQ does not eliminate congestion → it just manages the congestion



FQ in the big picture

- FQ does not eliminate congestion → it just manages the congestion
  - Robust to cheating, variations in RTT, details of delay, reordering, retransmission, etc.
- But congestion (and packet drops) still occurs
- We still want end-hosts to discover/adapt to their fair share!
- What would the end-to-end argument say w.r.t. congestion control?

Fairness is a controversial goal

- What if you have 8 flows, and I have 4?
  - Why should you get twice the bandwidth?
- What if your flow goes over 4 congested hops, and mine only goes over 1?
  - Why shouldn’t you be penalized for using more scarce bandwidth?
- What is a flow anyway?
  - TCP connection
  - Source-Destination pair?
  - Source?

Router-Assisted Congestion Control

- CC has three different tasks:
  - Isolation/fairness
  - Rate adjustment
  - Detecting congestion

Why not let routers tell what rate end hosts should use?

- Packets carry "rate field"
- Routers insert "fair share" f in packet header
- End-hosts set sending rate (or window size) to f
  - Hopefully (still need some policing of end hosts!)
- This is the basic idea behind the "Rate Control Protocol" (RCP) from Dukkipati et al. '07
  - Flows react faster

Router-Assisted Congestion Control

- CC has three different tasks:
  - Isolation/fairness
  - Rate adjustment
  - Detecting congestion

Explicit Congestion Notification (ECN)

- Single bit in packet header; set by congested routers
  - If data packet has bit set, then ACK has ECN bit set
- Many options for when routers set the bit
  - Tradeoff between (link) utilization and (packet) delay
- Congestion semantics can be exactly like that of drop
  - i.e., end-host reacts as though it saw a drop

ECN

- Advantages:
  - Don’t confuse corruption with congestion; recovery w/ rate adjustment
  - Can serve as an early indicator of congestion to avoid delays
  - Easy (easier) to incrementally deploy
    - »Today: defined in RFC 3168 using ToS/DSCP bits in the IP header
    - »Common in datacenters

One final proposal: Charge people for congestion!

- Use ECN as congestion markers
- Whenever I get an ECN bit set, I have to pay $$
- Now, there’s no debate over what a flow is, or what fair is…
- Idea started by Frank Kelly at Cambridge
  - “Optimal” solution, backed by much math
  - Great idea: simple, elegant, effective
  - Unclear that it will impact practice

Summary

- Routers can assist in addressing/mitigating many of TCP's shortcomings