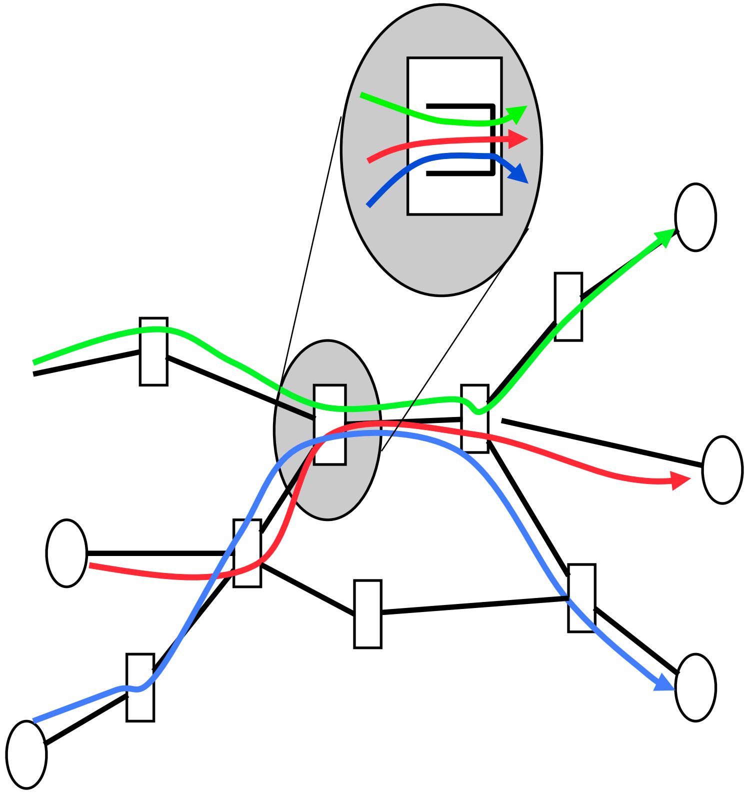
# Fair Queueing

Presented by Brighten Godfrey

Slides thanks to Ion Stoica (UC Berkeley)
with slight adaptation by Brighten Godfrey

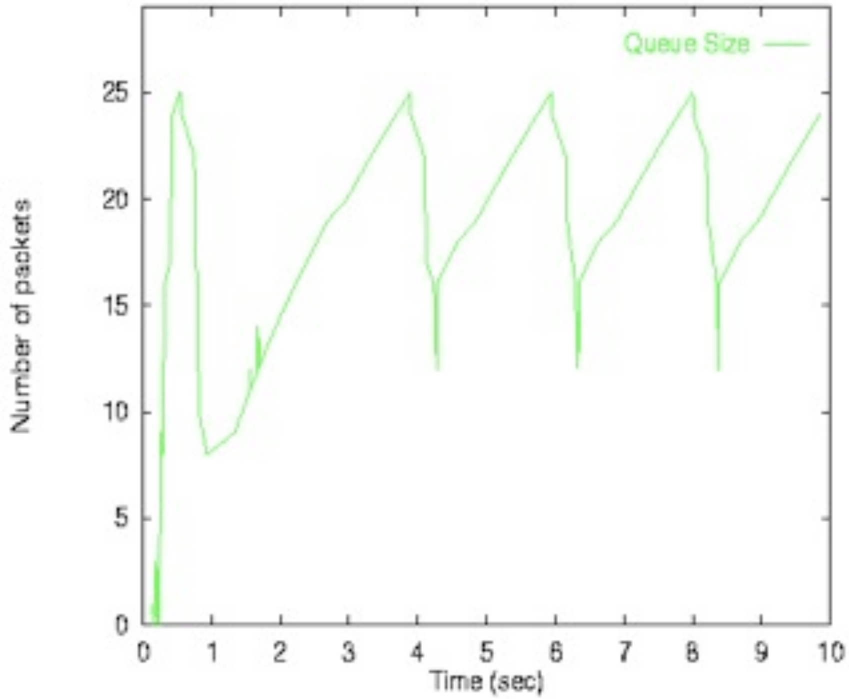
# Traditional queueing

- Traditional Internet
  - Congestion control mechanisms at end-systems, mainly implemented in TCP
  - Routers play little role
- Router mechanisms affecting congestion management
  - Scheduling
  - Buffer management
- Traditional routers
  - FIFO
  - Tail drop



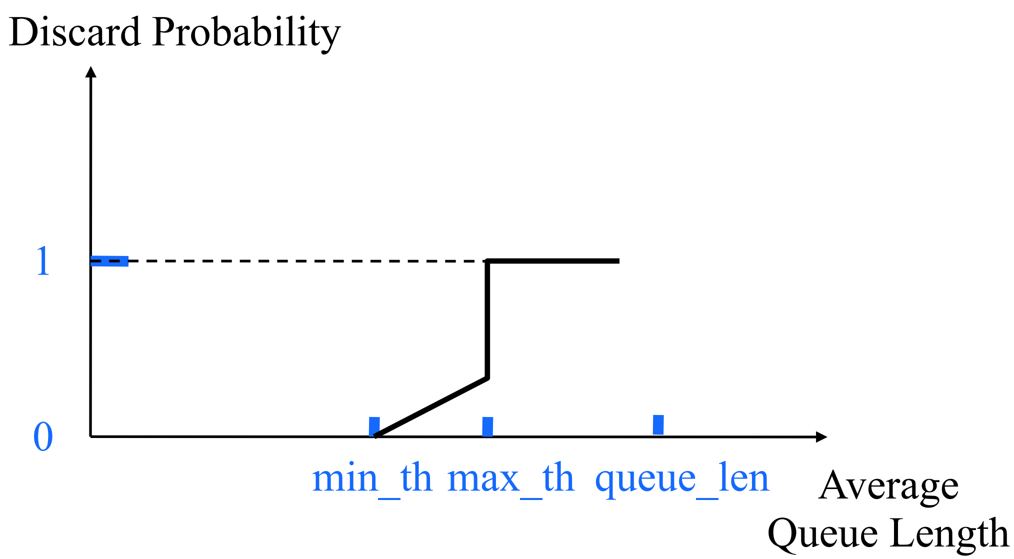
# Drawbacks of FIFO with Tail-drop

- Buffer lock out by misbehaving flows
- Synchronizing effect for multiple TCP flows
- Burst or multiple consecutive packet drops
  - Bad for TCP fast recovery



# RED

- FIFO scheduling
- Buffer management:
  - Probabilistically discard packets
  - Probability is computed as a function of average queue length (why average?)



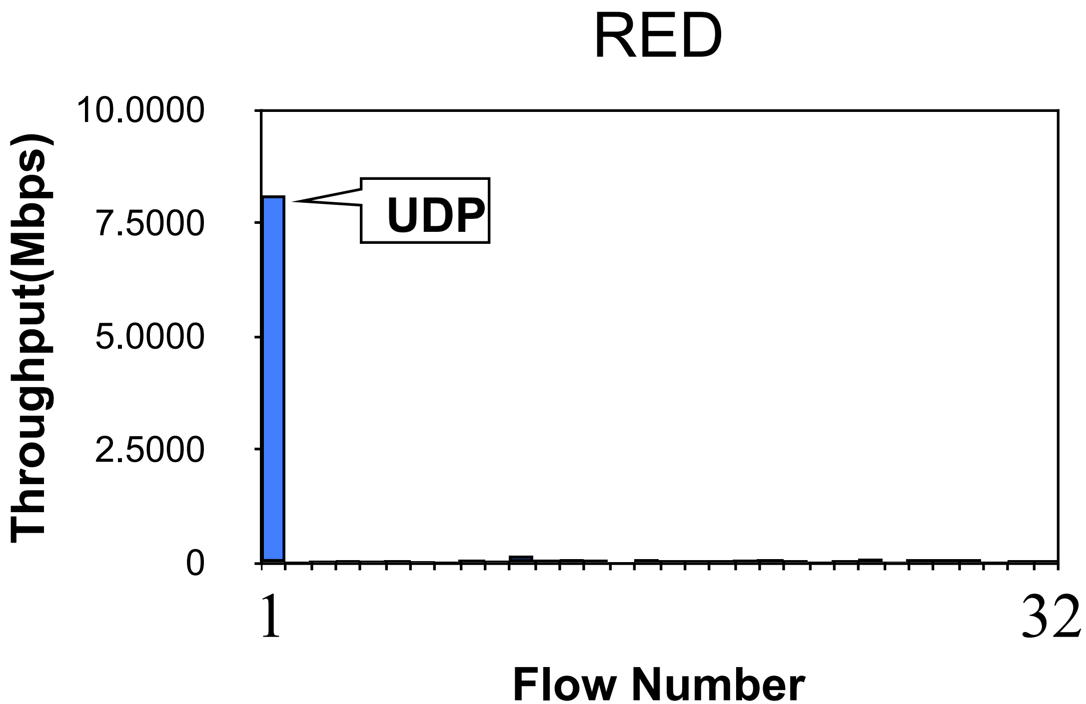
# RED Advantages

- Absorb burst better
- Avoids synchronization
- Signal end systems earlier

- And XCP would be even better than RED in these regards

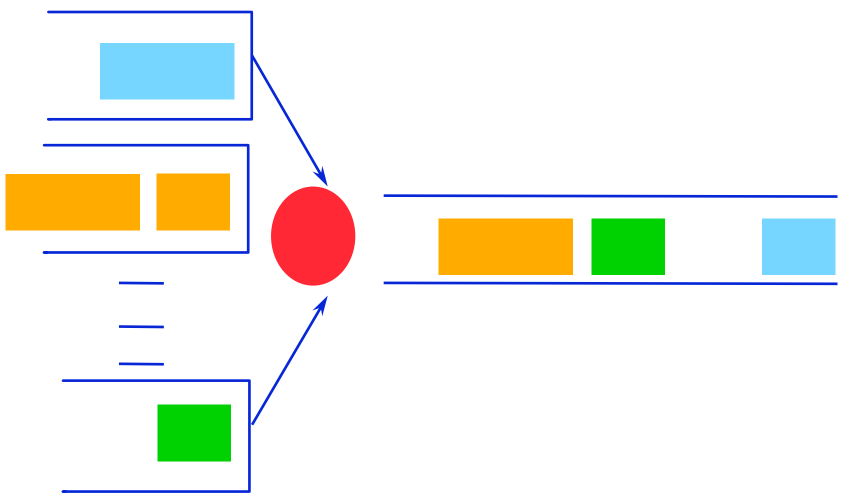
# But still no isolation between flows

- No protection: if a flow misbehaves it will hurt the other flows
- Example: 1 UDP (10 Mbps) and 31 TCP's sharing a 10 Mbps link



# A first solution

- Round-robin among different flows [Nagle '87]
  - One queue per flow



# Round-Robin Discussion

- Advantages: protection among flows
  - Misbehaving flows will not affect the performance of well-behaving flows
  - FIFO does not have such a property
- Disadvantages:
  - More complex than FIFO: per flow queue/state
  - Biased toward large packets – a flow receives service proportional to the number of packets (When is this bad?)

# Fair Queueing (FQ) [DKS'89]

- Define a fluid flow system: a system in which flows are served bit-by-bit
  - i.e., bit-by-bit round robin

- Advantages
  - Each flow will receive exactly its max-min fair rate
  - ...and exactly its fair per-packet delay

# Max-Min Fairness

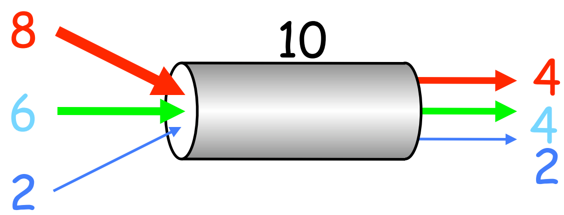
- Denote
  - $C$ – link capacity
  - $N$ – number of flows
  - $r_i$ – arrival rate
- Max-min fair rate computation:
  1. compute $C/N$
  2. if there are flows $i$ such that $r_i <= C/N$, update $C$ and $N$

$$C = C - \sum_{i\ s.t\ r_i \le C} r_i$$

  3. if no, $f = C/N$; terminate
  4. go to 1
- A flow can receive at most the fair rate, i.e., $\min(f, r_i)$

# Example

- $C$ = 10; $r_1$ = 8, $r_2$ = 6, $r_3$ = 2; $N$ = 3
- $C/3$ = 3.33 → $C = C$ – r3 = 8; $N$ = 2
- $C/2$ = 4; $f$ = 4

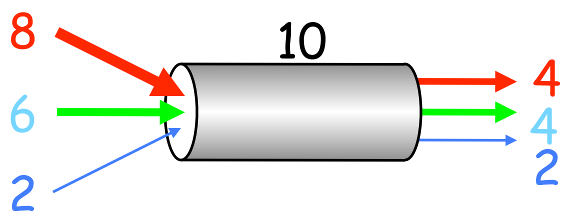



$f$ = 4:
min(8, 4) = 4
min(6, 4) = 4
min(2, 4) = 2

# Alternate Way to Compute Fair Rate

- If link congested, compute *f* such that

$$\sum_i \min(r_i, f) = C$$

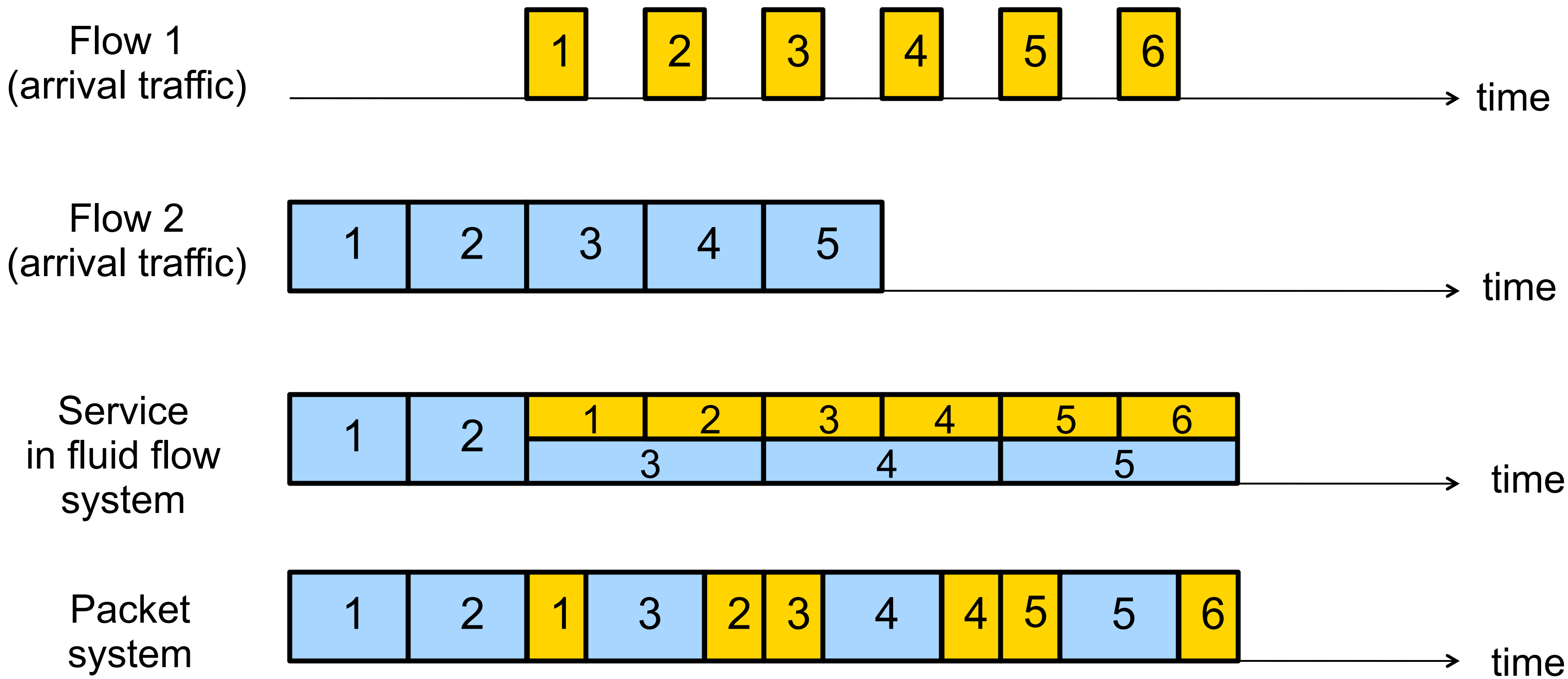



$f$ = 4:
min(8, 4) = 4
min(6, 4) = 4
min(2, 4) = 2

# Implementing Fair Queueing

- What we just saw was bit-by-bit round robin
- Can’t do it – can’t interrupt transfer of a packet (why not?)
- Idea: serve packets in the order in which they would have finished transmission in the fluid flow system
- Strong guarantees
  - Each flow will receive exactly its max-min fair rate (+/- one packet size)
  - ...and exactly its fair per-packet delay (+/- one packet size)

# 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
Packet
system
1
2
1
3
2
3
4
4
5
5
6
time

# Guarantees

- Translating fluid to discrete packet model doesn't actually involve a lot of combinatorics.
- Theorem: each packet P will finish transmission at or before its finish time in fluid flow model.
  - assuming (for now) all packets are in queue at time 0
- Proof:
  - Suppose the packet's finish time is T in fluid model
  - Fluid model: packets that have finished by T sum to <= RT bits (possibly less: some packets may still be in progress) where R is link rate
  - Packet model: these will be sent in time <= RT / R = T.
- So, why is the real guarantee (without assumption) only approximate (+/- one packet)?

# Problem

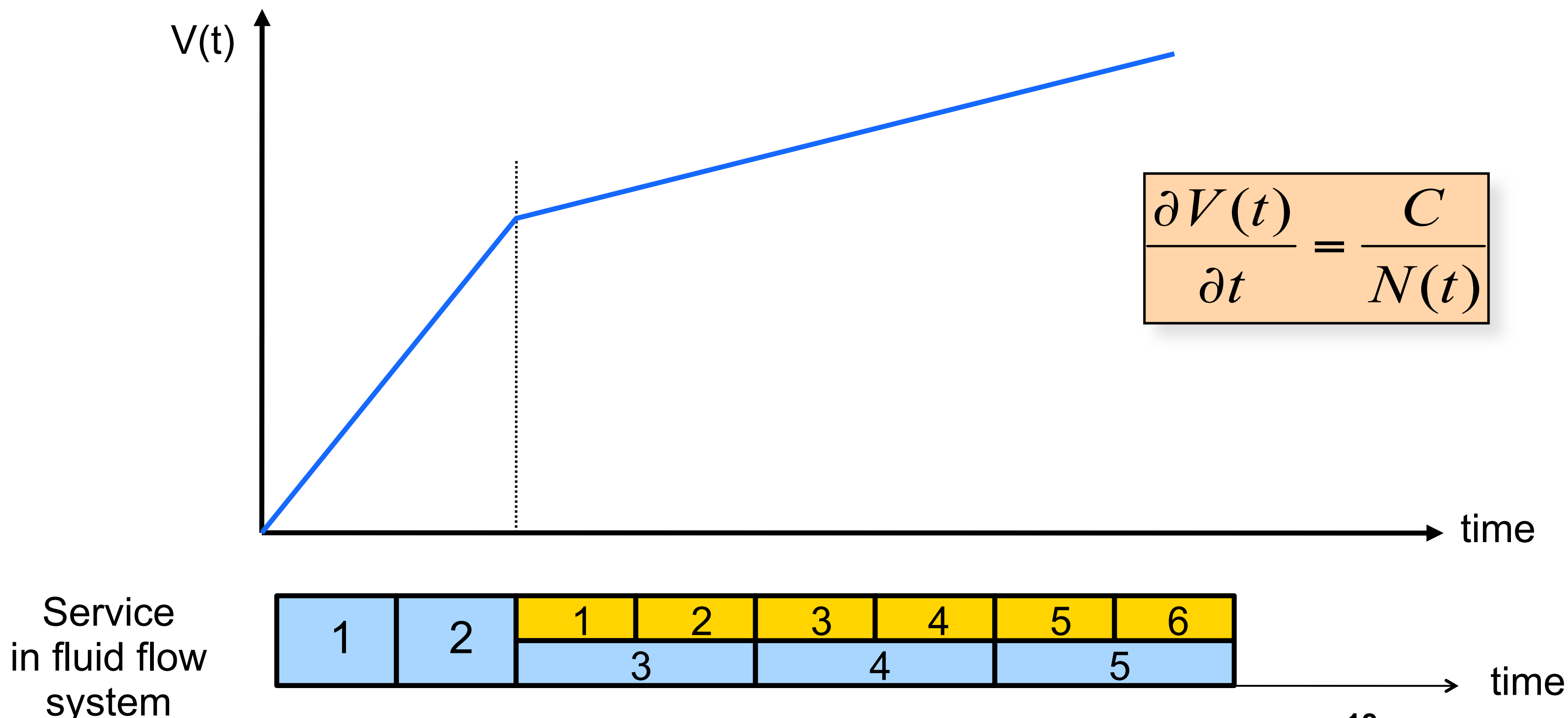
- Recall algorithm: “serve packets in the order in which they would have finished transmission in the fluid flow system”
- So, need to compute finish time of each packet in the fluid flow system
- ... but new packet arrival can change finish times of packets in the system (perhaps all packets!)
- Updating those times would be expensive

# Solution: Virtual Time

- Key Observation: while the finish times of packets may change when a new packet arrives, the order in which packets finish doesn't!
  - Only the order is important for scheduling
- Solution: instead of the packet finish time maintain the number of rounds needed to send the remaining bits of the packet (virtual finishing time)
  - Virtual finishing time doesn't change upon packet arrival
- System virtual time – index of the round in the bit-by-bit round robin scheme

# System Virtual Time: *V*(t)

- Measure service, instead of time
- V(t) slope – rate at which every active flow receives service
  - *C* – link capacity
  - *N*(t) – number of active flows in fluid flow system at time t




$$\frac{\partial V(t)}{\partial t} = \frac{C}{N(t)}$$

# Fair Queueing Implementation

- Define
  - $F_i^k$ - finishing time of packet $k$ of flow $i$ (in system virtual time reference system)
  - $a_i^k$ - arrival time of packet $k$ of flow $i$
  - $L_i^k$ - length of packet $k$ of flow $i$
- Virtual finishing time of packet $k+1$ of flow $i$ is

$$F_i^{k+1} = \max(V(a_i^k), F_i^k) + L_i^{k+1}$$

- Order packets by increasing virtual finishing time, and send them in that order

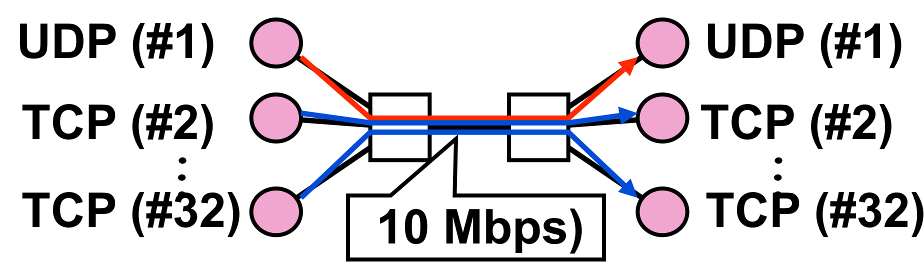
# "Weighted Fair Queueing" (WFQ)

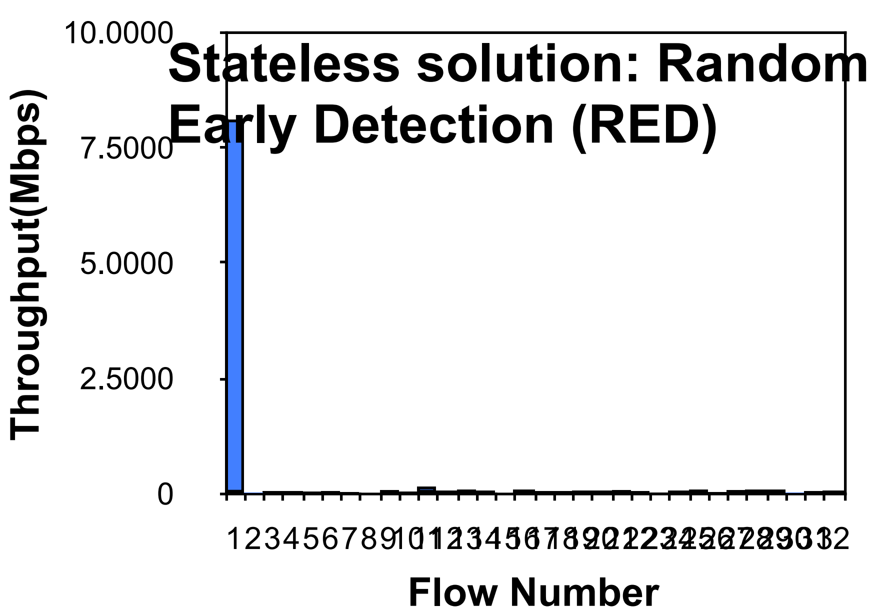
- What if we don't want exact fairness?
  - E.g.,: file servers
- Assign weight $w_i$ to each flow $i$
- And change virtual finishing time

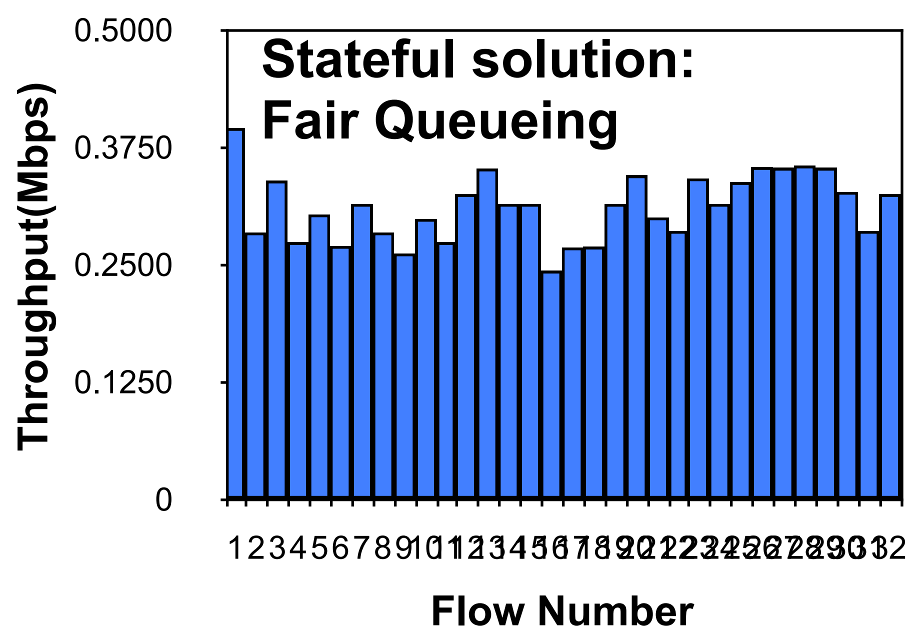
$$F_i^{k+1} = \max(V(a_i^k), F_i^k) + \frac{L_i^{k+1}}{w_i}$$

# Simulation Example

- 1 UDP (10 Mbps) and 31 TCPs sharing a 10 Mbps link



# Summary

- FQ does not eliminate congestion; it just manages the congestion
- You need both end-host congestion control and router support for congestion control
  - End-host congestion control to adapt
  - Router congestion control to protect/isolate
- Don't forget buffer management: you still need to drop in case of congestion. Which packet's would you drop in FQ?
  - One possibility: packet from the longest queue

# Announcements

- Got my emails?
- Project proposals due Tuesday
- Watch for survey