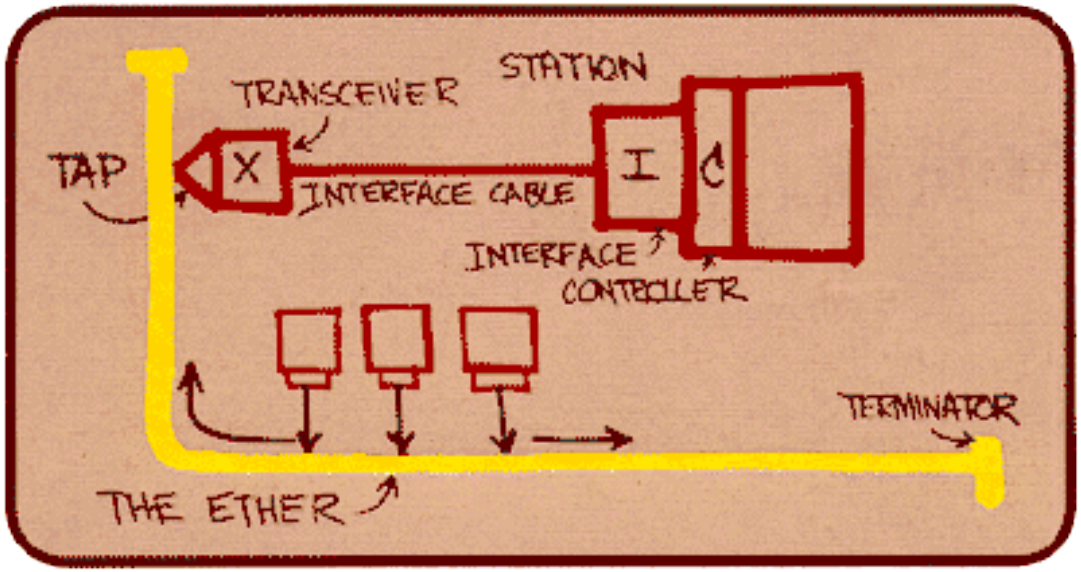
# Randomization

- Randomization used in many protocols
- We'll study examples:
  - Ethernet multiple access protocol
  - Router (de)synchronization
  - Reliable multicast
  - Switch scheduling
  - Active queue management

# Ethernet

- Single shared broadcast channel
- 2+ simultaneous transmissions by nodes: interference
  - only one node can send successfully at a time
- *Multiple access protocol:* Distributed algorithm that determines how nodes share channel, i.e., determine when node can transmit




Metcalfe's Ethernet sketch

# Deterministic algorithms

- Time Division Multiplexing?
- Polling?
- Virtual Ring?

# Ethernet: uses CSMA/CD

**A**: sense channel, **if** idle

```
then {
        transmit and monitor the channel;
        If detect another transmission
         then {
              abort and send jam signal;
              update # collisions;
              delay as required by exponential backoff algorithm;
              goto A
              }
         else {done with the frame; set collisions to zero}
    }
else {wait until ongoing transmission is over and goto A}
```

# Ethernet's CSMA/CD (more)

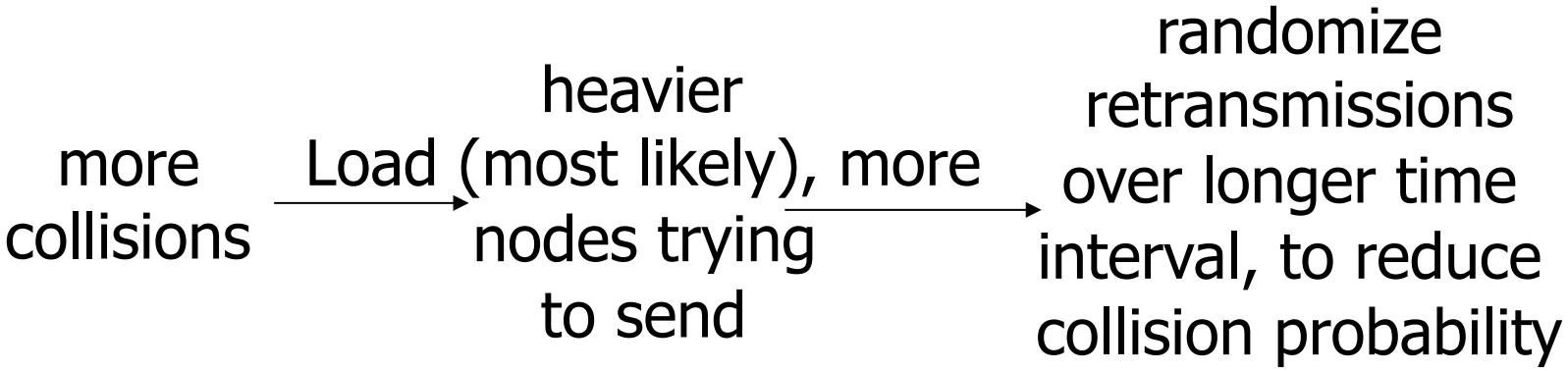
Jam Signal: Make sure all other transmitters are aware of collision; 48 bits;

Exponential Backoff:

- First collision for given packet: choose $K$ randomly from $\{0,1\}$; delay is $K \times 512$ bit transmission times
- After second collision: choose $K$ randomly from $\{0,1,2,3\}$ ...
- After ten or more collisions, choose $K$ randomly from $\{0,1,2,3,4,\ldots,1023\}$

# Ethernet's use of randomization

- *Resulting behavior:* Probability of retransmission attempt (equivalently length of randomization interval) adapted to current load
  - simple, load-adaptive, multiple access



# Ethernet comments

- Upper bounding at $1023 = k$ limits max size
- Could remember last value of $K$ when we were successfull (analogy: TCP remembers last values of congestion window size)
- Q: Why use binary backoff rather than something more sophisticated such as AIMD in TCP congestion control: simplicity
  - Note: Ethernet does multiplicative-increase-complete-decrease (why?)

# The bottom line

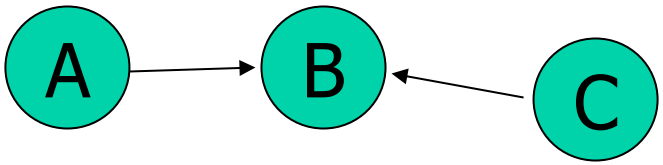
- Why does Ethernet use randomization: to desynchronize:

  A distributed adaptive algorithm to spread out load over time when there is contention for multiple access channel.

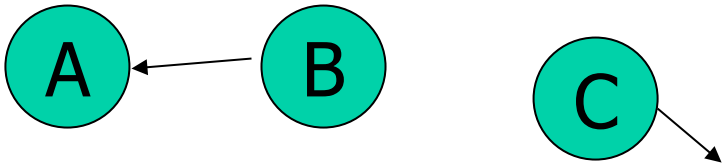
# Excursion: What if wireless?!

## Typical wireless networks:

- are not full-duplex (just one channel)
- nodes cannot sense the medium during own transmissions (just one antenna)
- no bounded propagation domain
- are multihop (hidden and exposed terminal problems):




Hidden terminal: C does not notice that B is currently receiving transmissions from A also => no „remote carrier sense"




Exposed terminal: B sends A and C wants to send to someone on the right: it waits because it hears B, but B would not reach the recipient of C, so actually C could send! => inefficient

# Excursion: Wireless MAC?

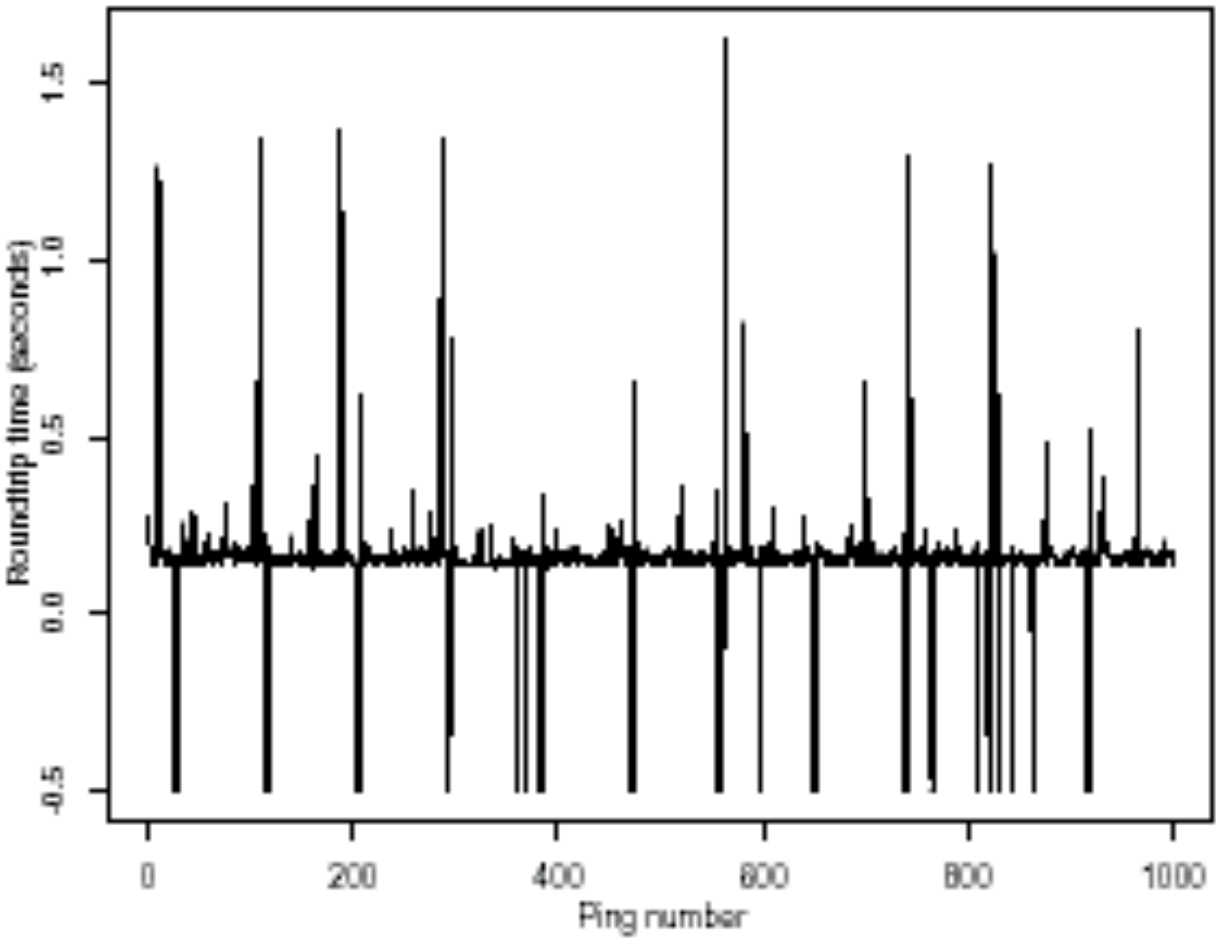
Therefore, CD is often replaced by (best effort) Collision Avoidance (CA, cf *DIFS/SIFS* etc.)

Still ongoing research, e.g., there are randomized distributed medium access protocols which optimally coordinate medium access probabilities and exploit the unpredictable non-jammed (e.g., due to external inteference) time periods (e.g., the Jade protocol).

A Jamming-Resistant MAC Protocol for Multi-Hop Wireless Networks, DISC 2010.

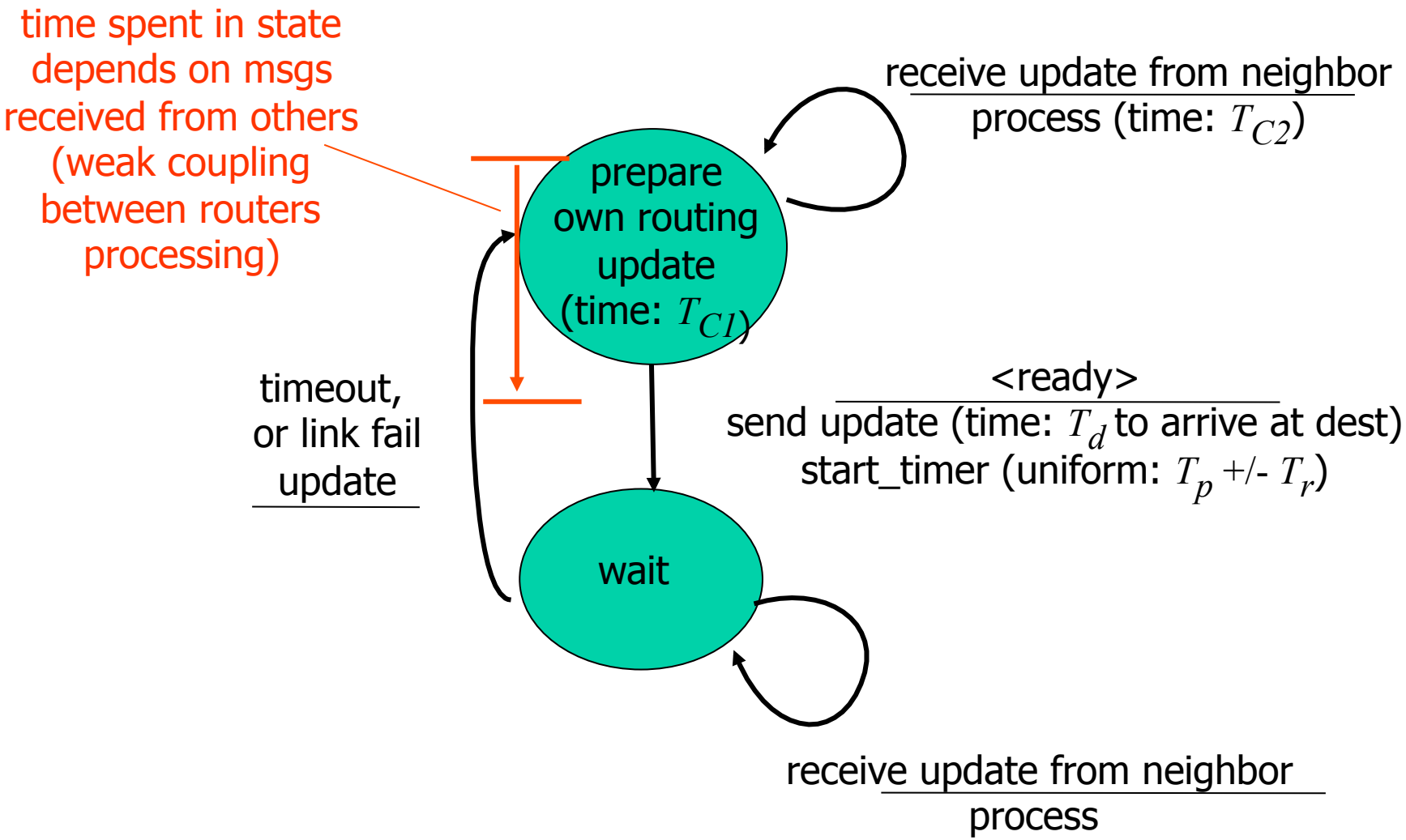
# (de)Synchronization of periodic routing updates

- Periodic losses observed in end-end Internet traffic
- Why?



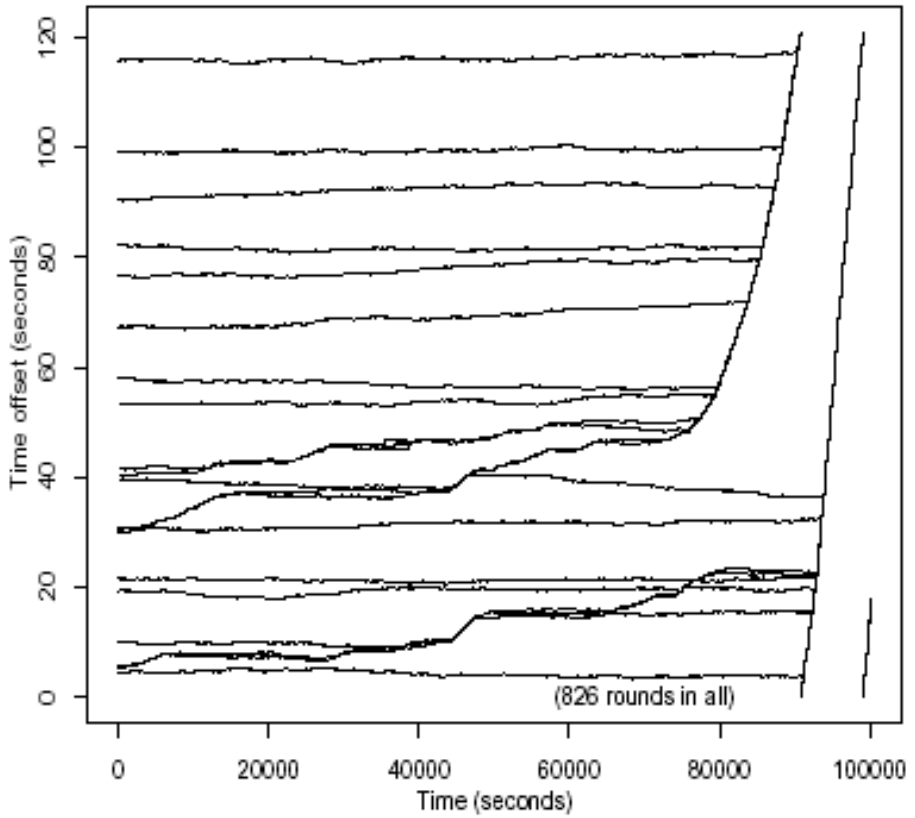

source: Floyd, Jacobson 1994

# Router update operation:



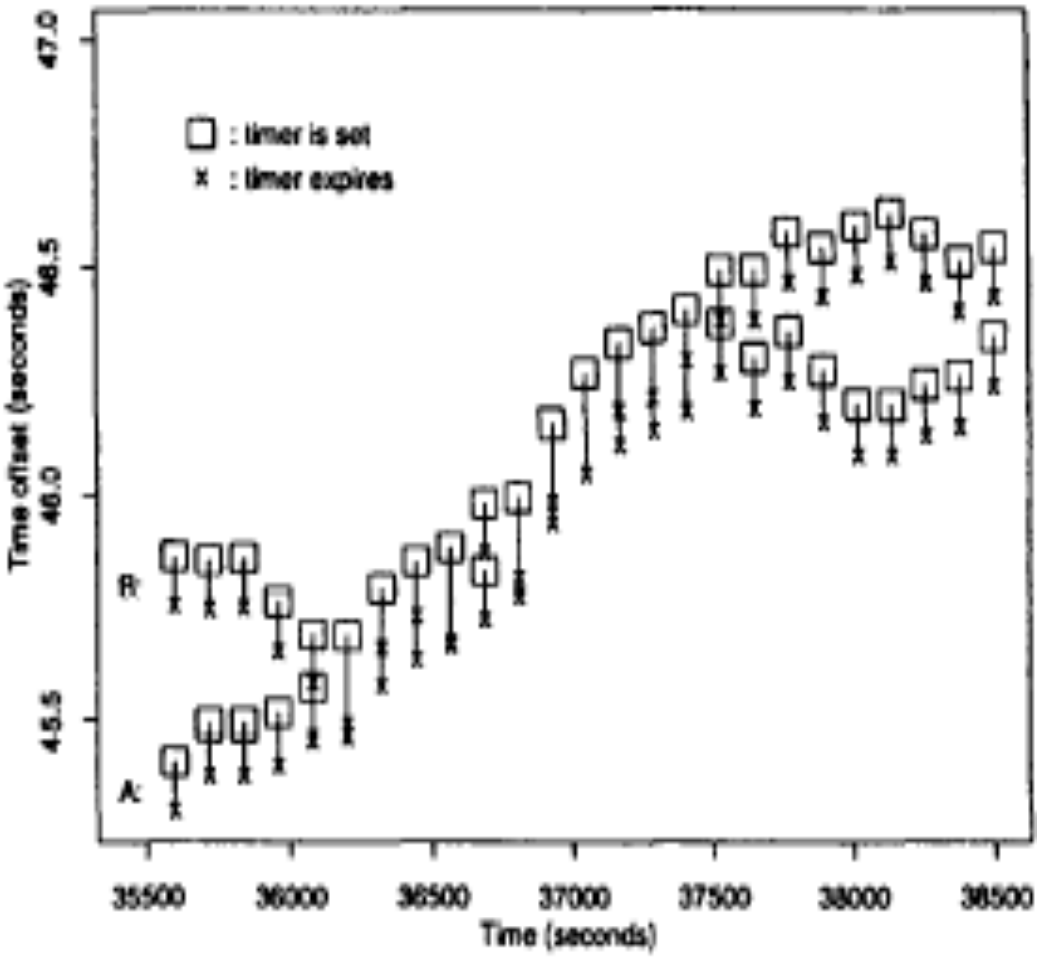
# Router synchronization

- 20 routers broadcasting updates to each other
- $x$-axis: Time until routing update sent relative to start of round
- By $t$=100,000 *all* router rounds are of length 120!
- Synchronization or lack thereof depends on system parameters



# Zooming in ...

- Blowup of previous graph
- Note expansion of computation phase
  → increased period



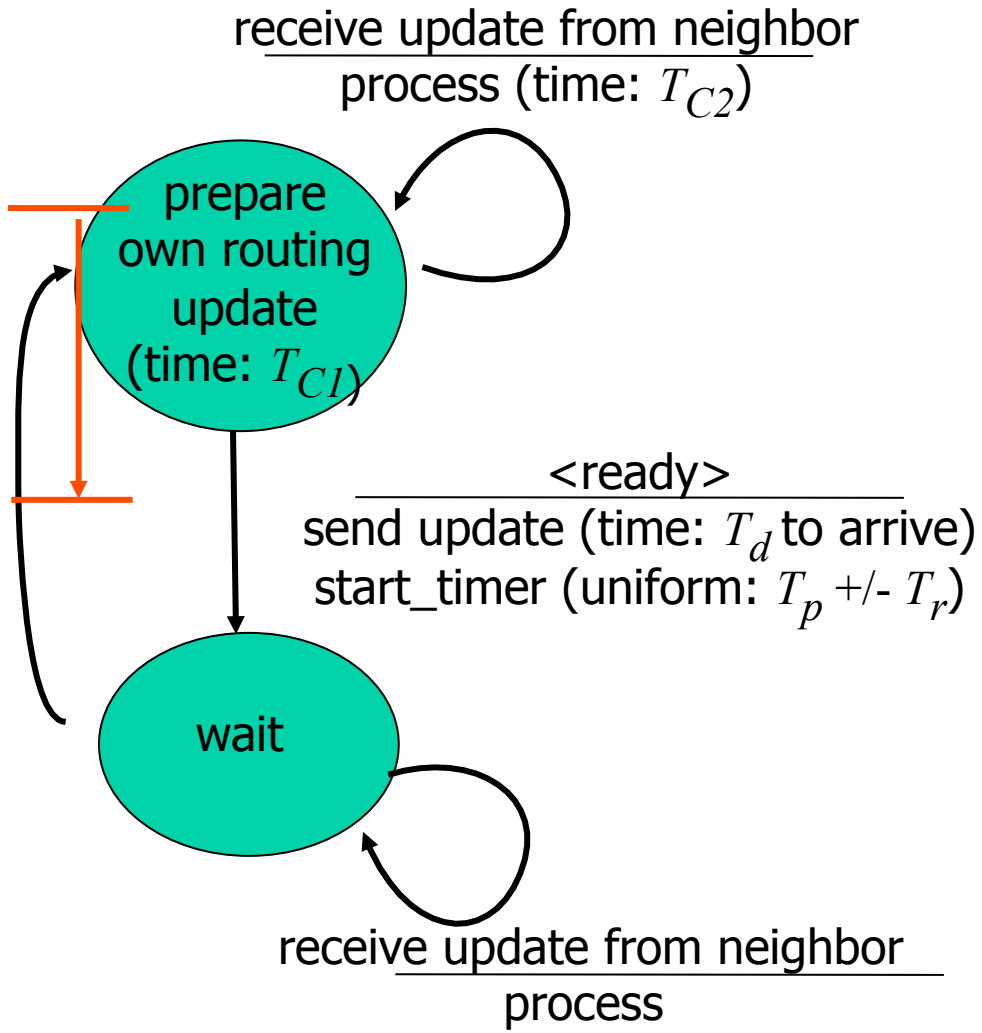
# Sync

- Coupled routers
- Example of spontaneous synchronization
  - Fireflies
  - Sleep cycle
  - Heart beat
  - etc.

    Steven Strogatz. *Sync*, Hyperion Books, 2003.

# Avoiding synchronization

- Enforce max time spent in prepare state
- Choose random timer component, $T_r$ large

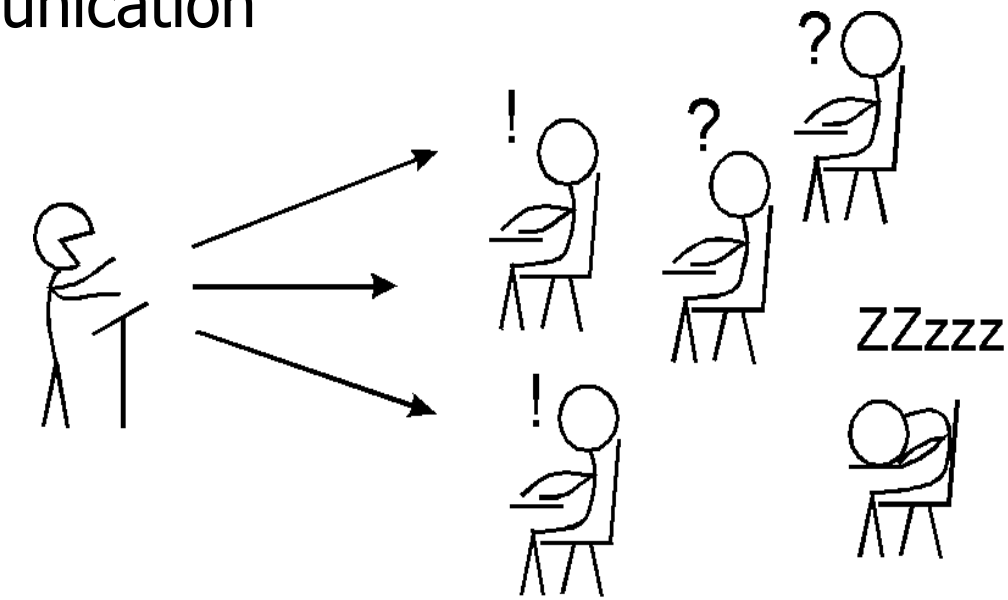


# Router (de)synchronization

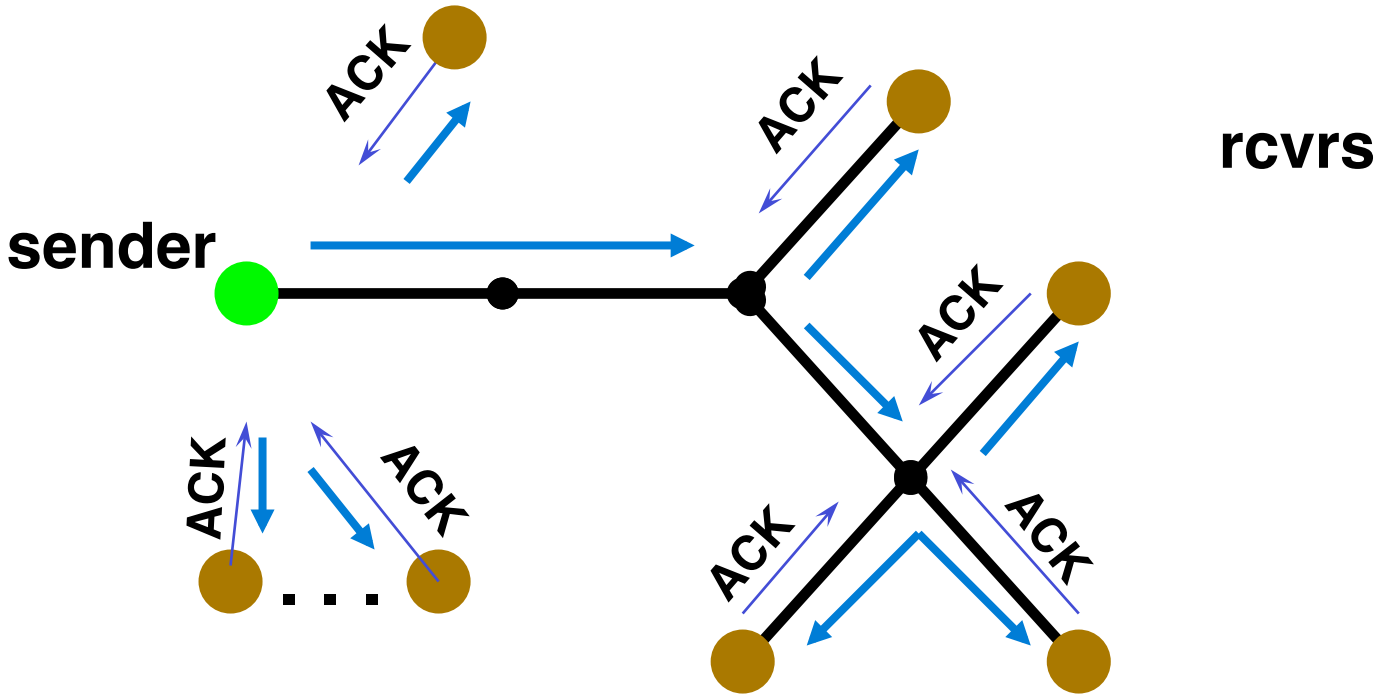
Use of randomization: Desynchronize routers!

# Randomization in Reliable Multicast

- ***RM:*** How to transfer data "reliably" from source(s) to $R$ receivers.
- *Conjecture:* All current RM error and congestion control approaches have an analogy in human-human communication



# Scalability: Feedback Implosion



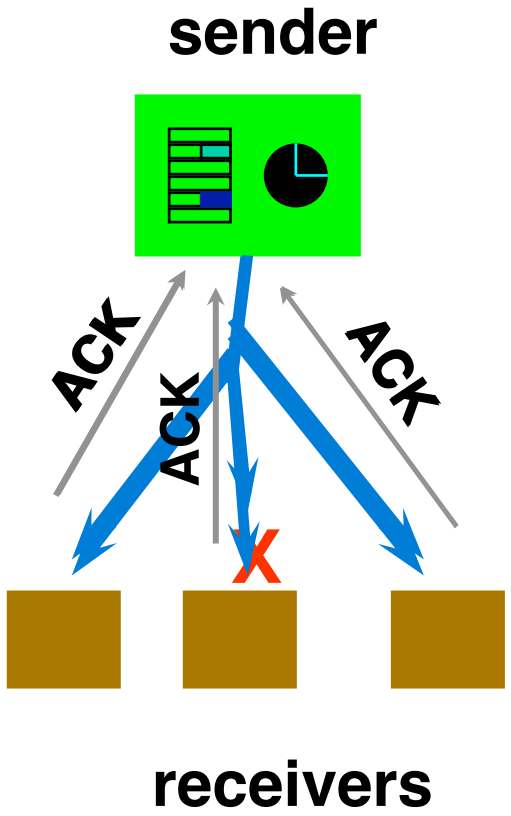
# Sender Oriented Reliable Mcast

**Sender:**

- mcasts all (re)transmissions
- selective repeat
- timers for loss detection
- ACK table
- pkt removed when *all* ACKs are in

**Rcvr:** ACKs received pkts

**Note:** Group membership important



# (Simple) Rcvr Oriented Reliable Mcast

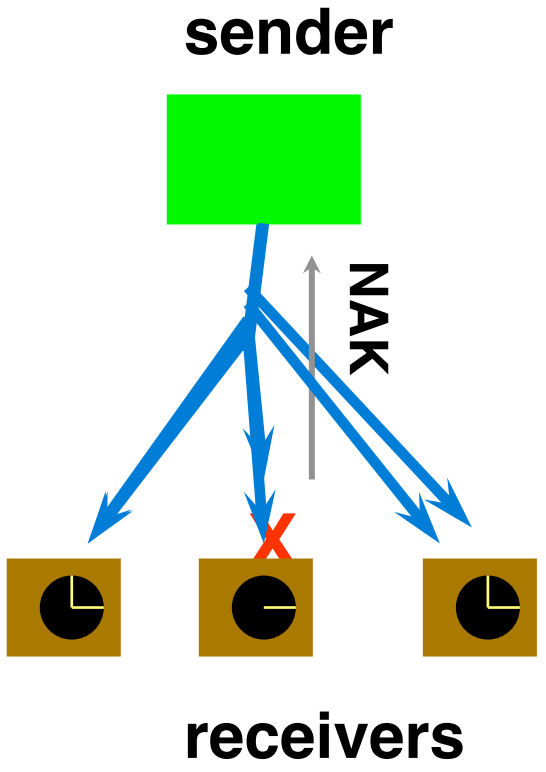
**Sender:**

- mcasts (re)transmissions
- selective repeat
- responds to NAKs
- when no longer buffer pkt?

**Rcvr:**

- NAKs (unicast to sender) missing pkts
- timer to detect lost retransmission

**Note:** easy to allow joins/leaves



# Receiver- versus sender-oriented RM: observations

**Rcvr-oriented:** Shift recovery burden to rcvrs

- Loss detection "responsibility", timers
- Scaling: computational power grow as $R$ grows
- Weaker notion of "group"
- Receivers can transparently choose different reliability semantics

**But** …

- When does sender "release" data rcvd by all?
- Heartbeat needed to detect lost last pkt

# Evaluation of Approaches

Examine resource requirements

- processing requirements
  - expected time to process pkt
    - at sender: $X, E[X]$
    - at rcvr: $Y, E[Y]$
  - mean value approach
- network requirements

# Assumptions for Analysis

- one sender, $R$ receivers
- independent errors, $p$ per rcvr
- lossless signaling

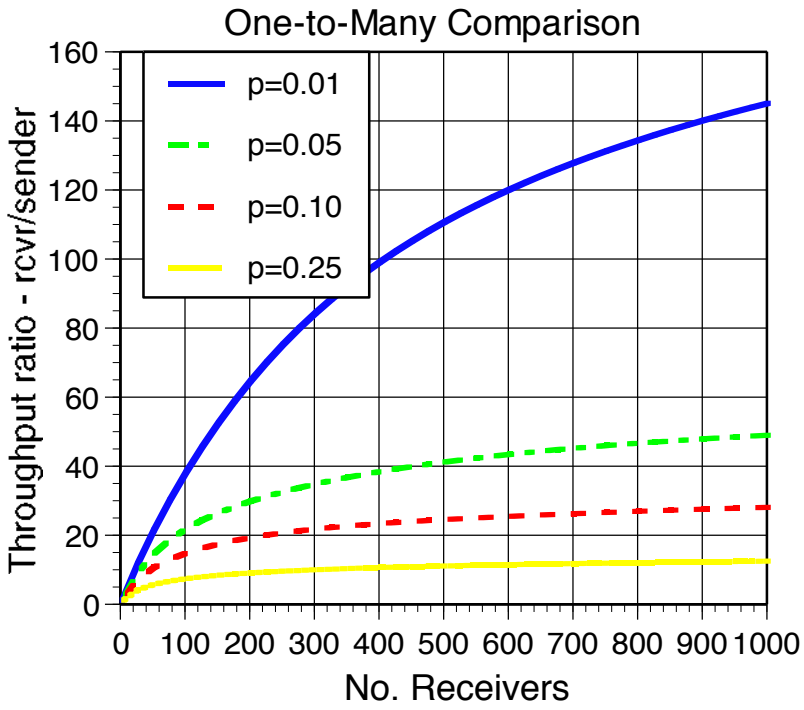
$M$ - total number of transmissions per packet

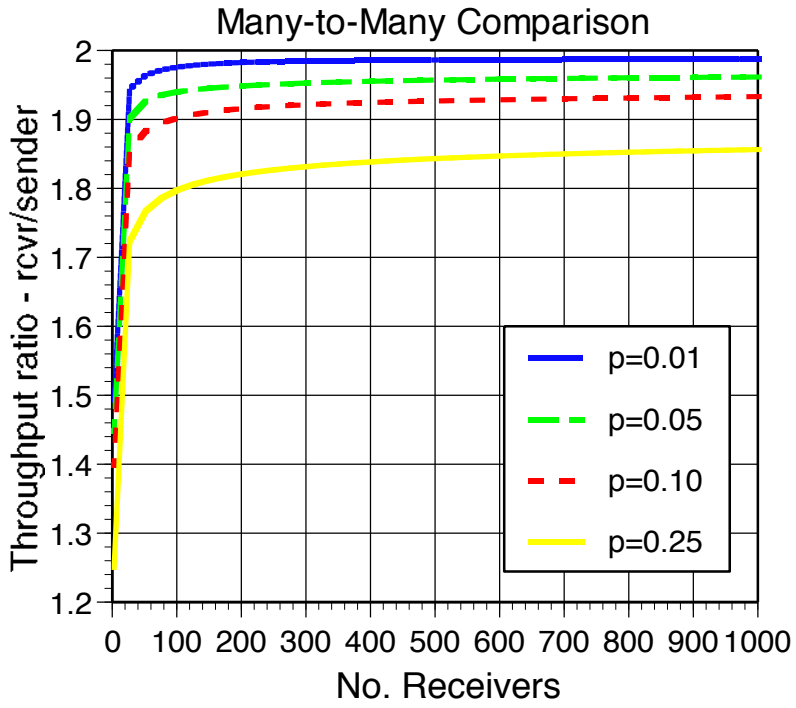
$$P[M \le m] = \left(1 - p^m\right)^R, \qquad m = 1, \ldots$$

$$E[M] = \sum_{m=0}^{\infty} 1 - \left(1 - p^m\right)^R$$

# Sender vs. Receiver (cont.)

Metric - rcvr oriented thruput/sender oriented thruput




Significant performance improvement shifting burden to receivers for 1-many; not as great for many-many

# RM: Coping with Scale, Heterogeneity

*Issues*:

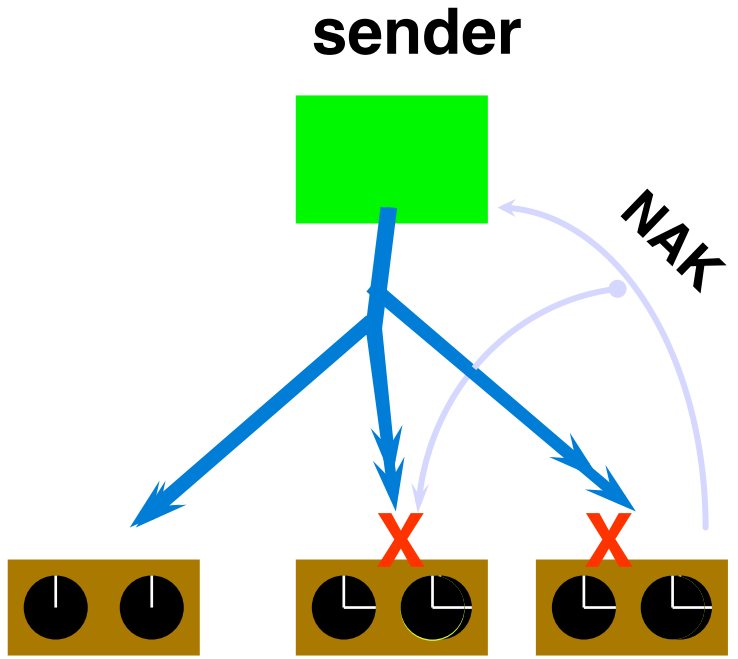
- Avoid feedback implosion in reverse path
- Avoid receiving unneeded data (retrans.) in forward path
- Recover data quickly, avoid long repair times

*Techniques*:

- feedback suppression
- local recovery

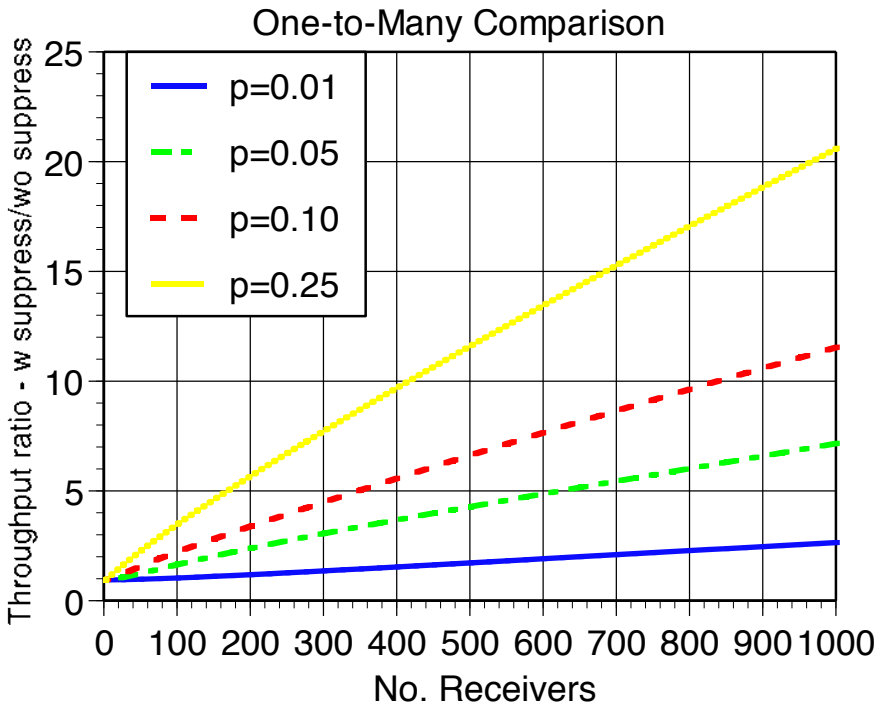
# Feedback Suppression

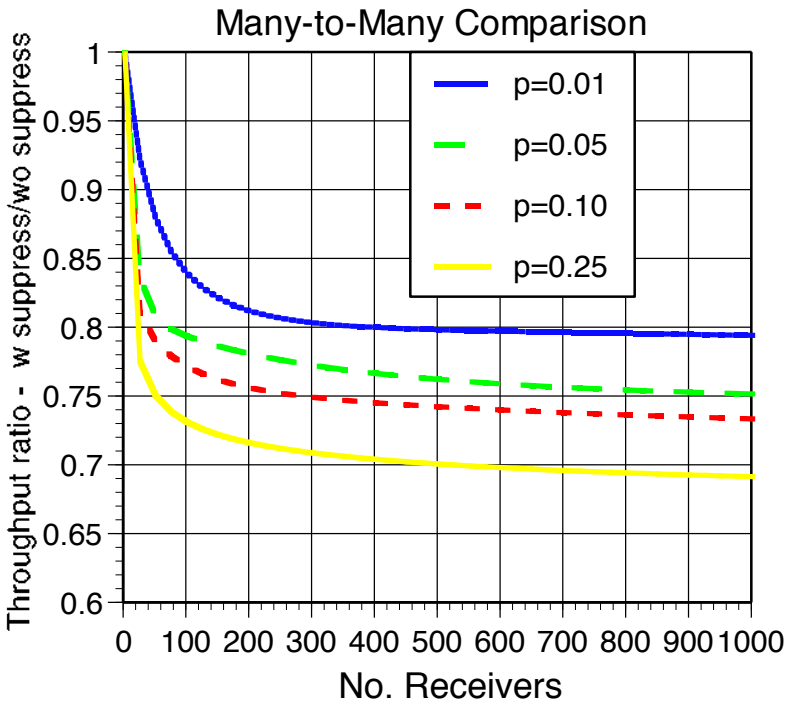
- Randomly delay NAKs
  - "Listen" to NAKs generated by others
  - If no NAK for lost pkt when timer expires, multicast NAK
- Widely used in RM
- Tradeoffs
  - Reduces bandwidth
  - Additional complexity at receivers (timers, etc)



# Feedback Suppression: Performance gains

Metric - suppression thruput/no suppression thruput




gains/loss depends on whether 1-many or many-many

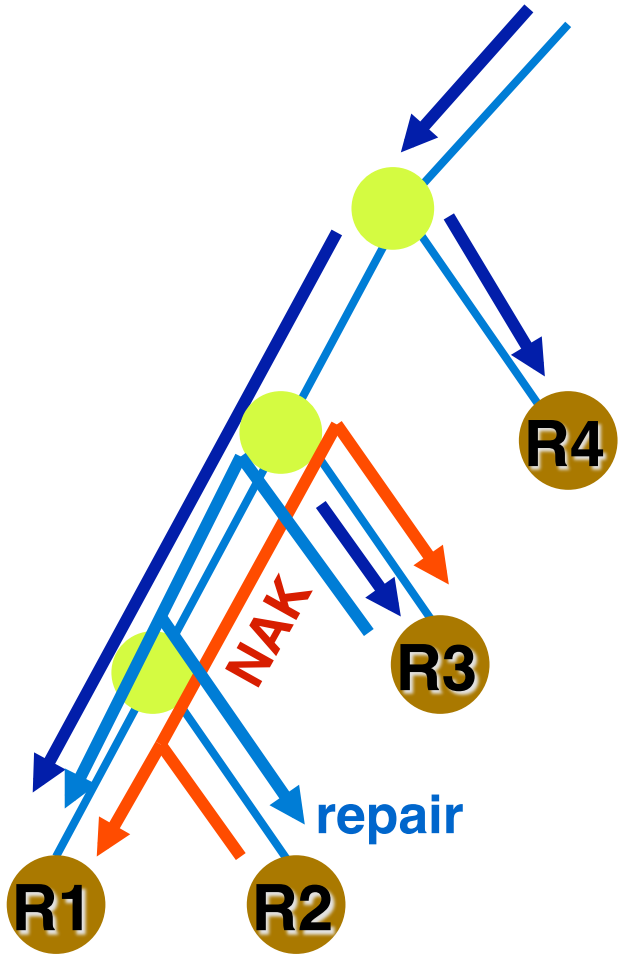
# Local Recovery in SRM

- Allow rcvr to recover lost pkt from "nearby" rcvr
  - "ask your neighbor": send localized NAK (repair request)
  - multicast: randomize local repair transmission time to avoid too many replies
- orthogonal (complementary) to feedback suppression
- who to recover from?
  - don't want repair request to go to everyone
  - scoping: how to restrict how far request will travel: IP time-to-live field

"A Reliable Multicast Framework for Lightweight Sessions …", Floyd et al., ToN 1996

# Local Recovery: Example

- R2 detects lost pkt
- Multicasts repair request
- Limited scope
  - not seen by R4
- R1 and R3 have pkt
  - R3 times out first and sends repair



# Reliable multicast (SRM)

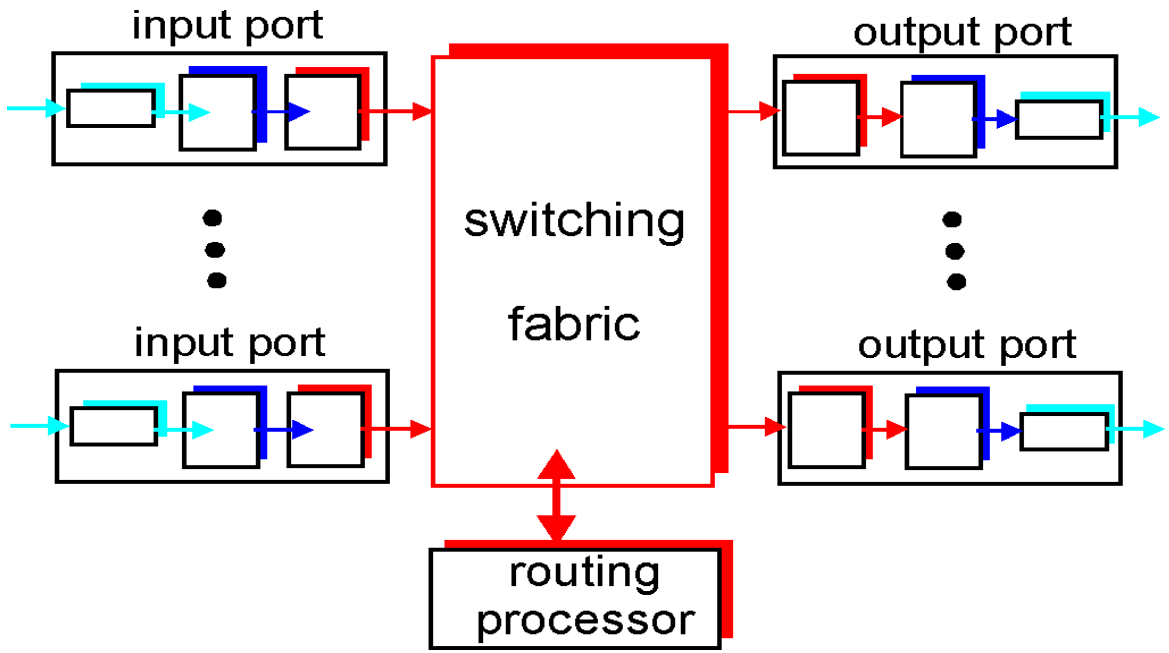
Use of randomization

- Avoid synchronizing all replies
- To reduce feedback implosion
- In local recovery, to reduce number of retransmissions of same message.
- Could scale the randomization interval to be load-adaptive.

# Randomization in Switch Scheduling

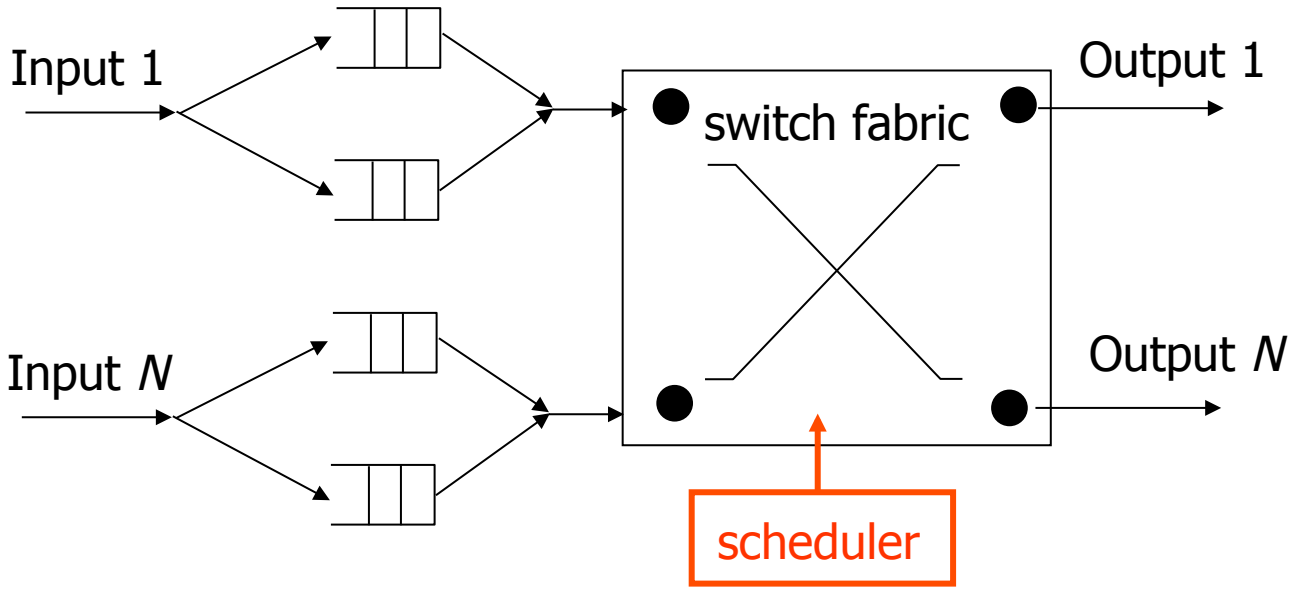
Two key router functions:

- Run routing algorithms/protocol (RIP, OSPF, BGP)
- *Switching* datagrams from incoming to outgoing link (our focus here)



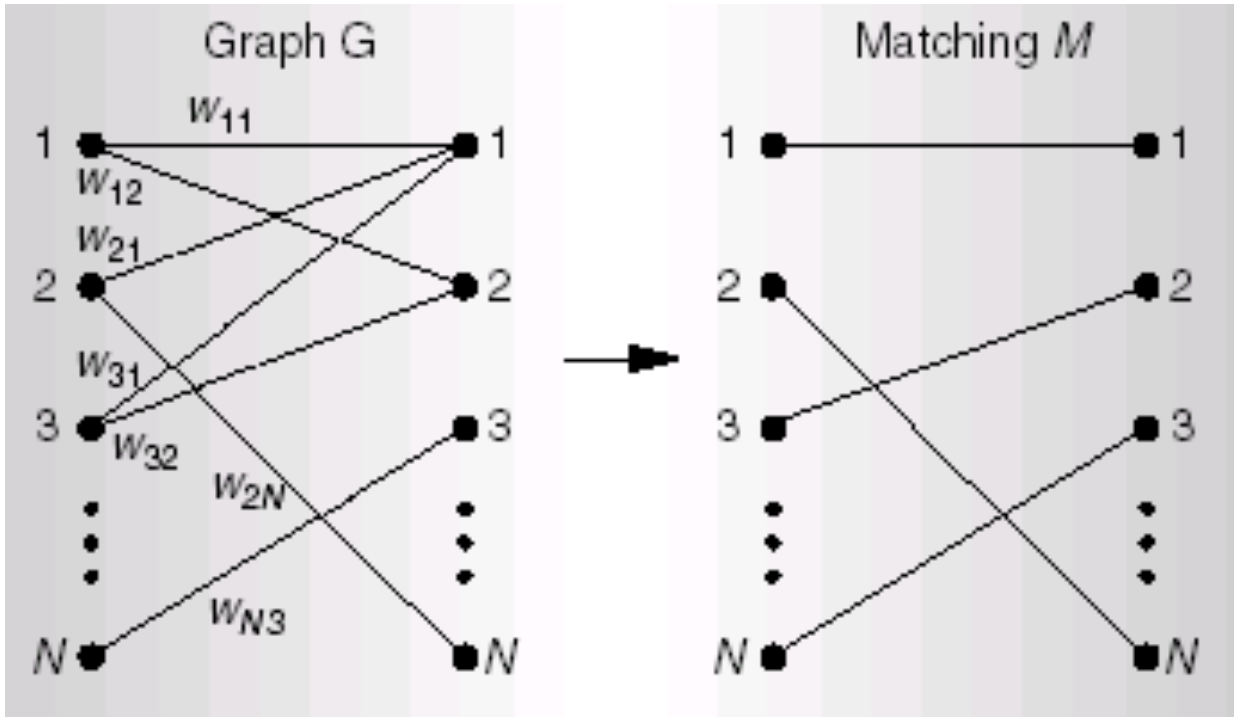
# Input queueing with bufferless outputs

- $N$ input ports, output ports
- Each port has $N$ per-output port queues
- Matching problem: In each time slot
  - Each output port can receive at most one packet from among $N \times N$ input queues
  - Each input port ($N$ queues) can forward at most one packet



# Solving the assignment problem

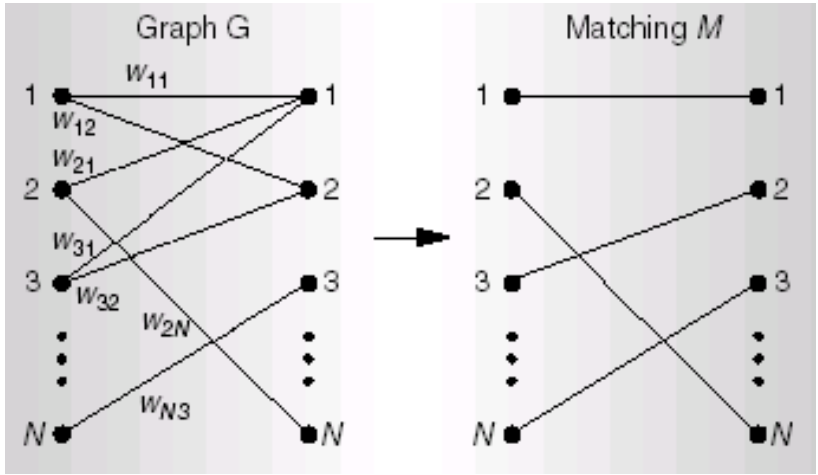
- $W_{ij}$: Queue length (weight) of input $i$, queue $j$
- Maximum weight matching solution: $O(N^3)$ that can deliver 100% throughput
- Can we do better?



# Using randomization to optimize

## Key observations:

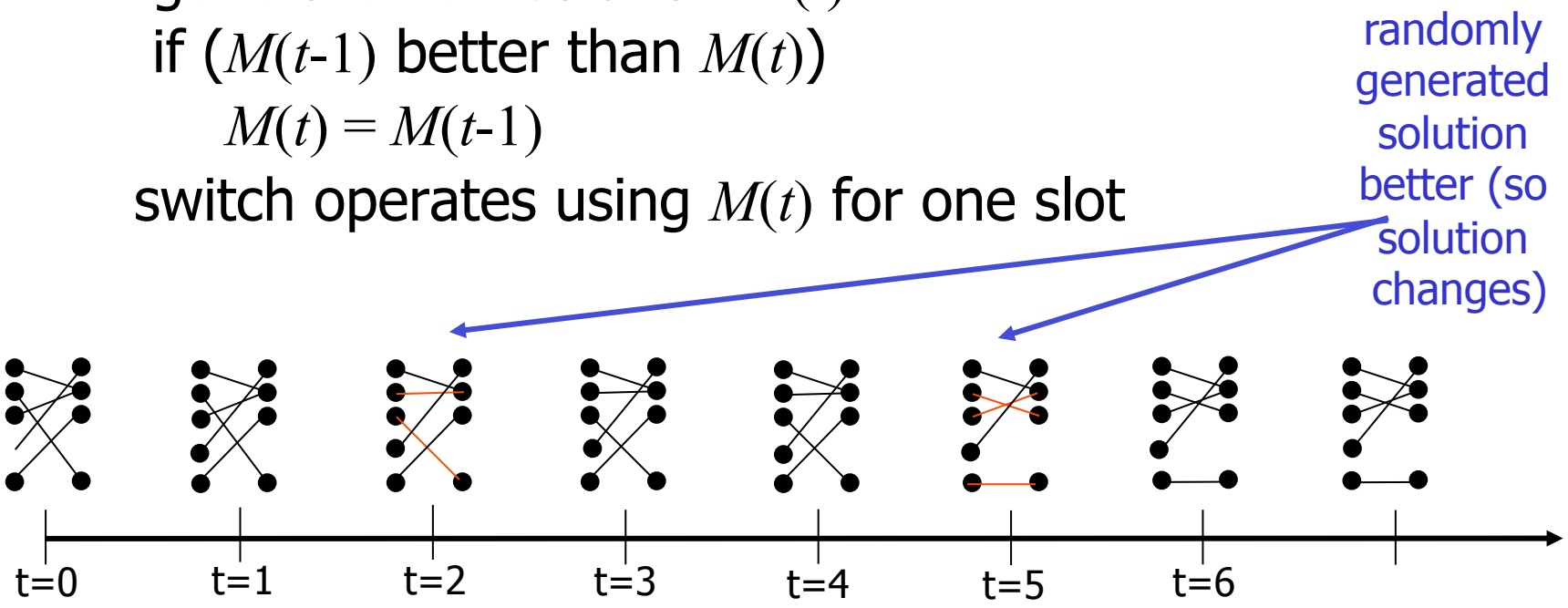
1. State of switch (input queue lengths) changes little from slot to slot
   - "good" solution at $t$, is close to "good" solution at $t+1$
2. A new, randomly-chosen solution will sometimes be better solution at $t+1$ than solution used at $t$



# Using randomization to optimize

## Algorithm:

$t$=0 choose any matching $M(0)$
switch operates using $M(0)$ for one slot
for ($t$=1;  ; $t$++)
  generate new solution $M(t)$
  if ($M(t\text{-}1)$ better than $M(t)$)
    $M(t) = M(t\text{-}1)$
  switch operates using $M(t)$ for one slot



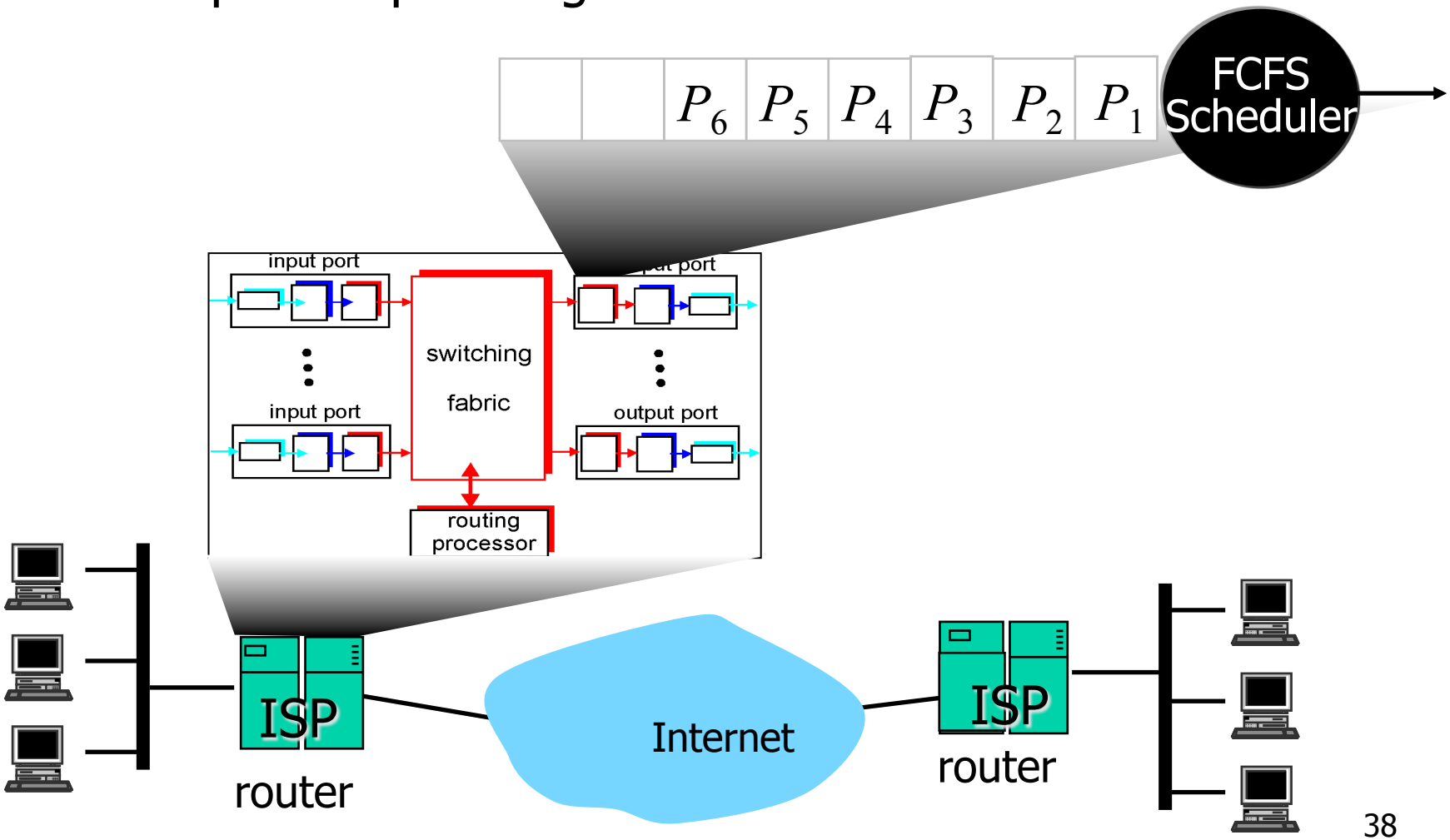
# Using randomization to optimize

Result [Tassiulas;Shah et al.]: Randomized algorithm achieves 100% thoughput (i.e., as good as brute force, non-randomized $O(N^3)$ optimization algorithm).

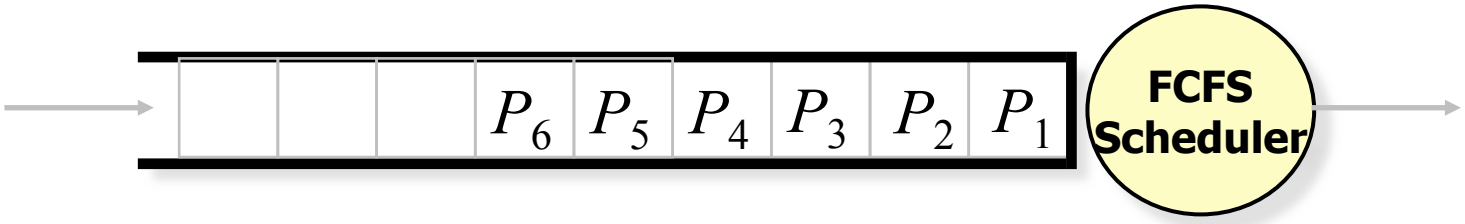
"Linear complexity algorithms for maximum throughput in … input queued switches", Tassiulas, 1998
"An Efficient Randomized Algorithm for Input-Queue Switch Scheduling", Shah et al., 2001

# Randomization in Router Queue Management

- Normally, packets dropped only when queue overflows
  - "Drop-tail" queueing

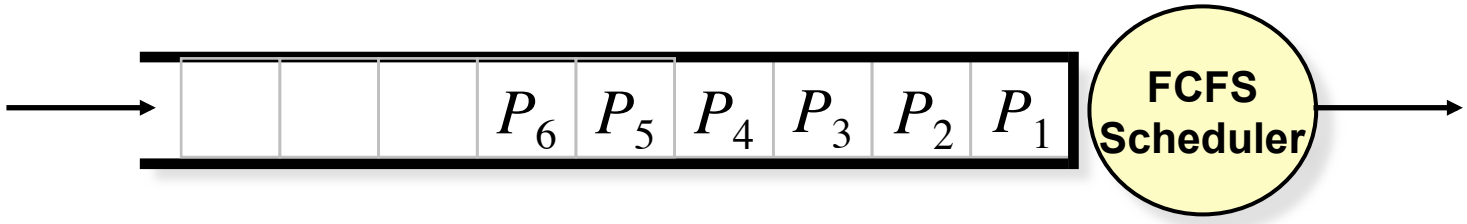


# The case against drop-tail queue management



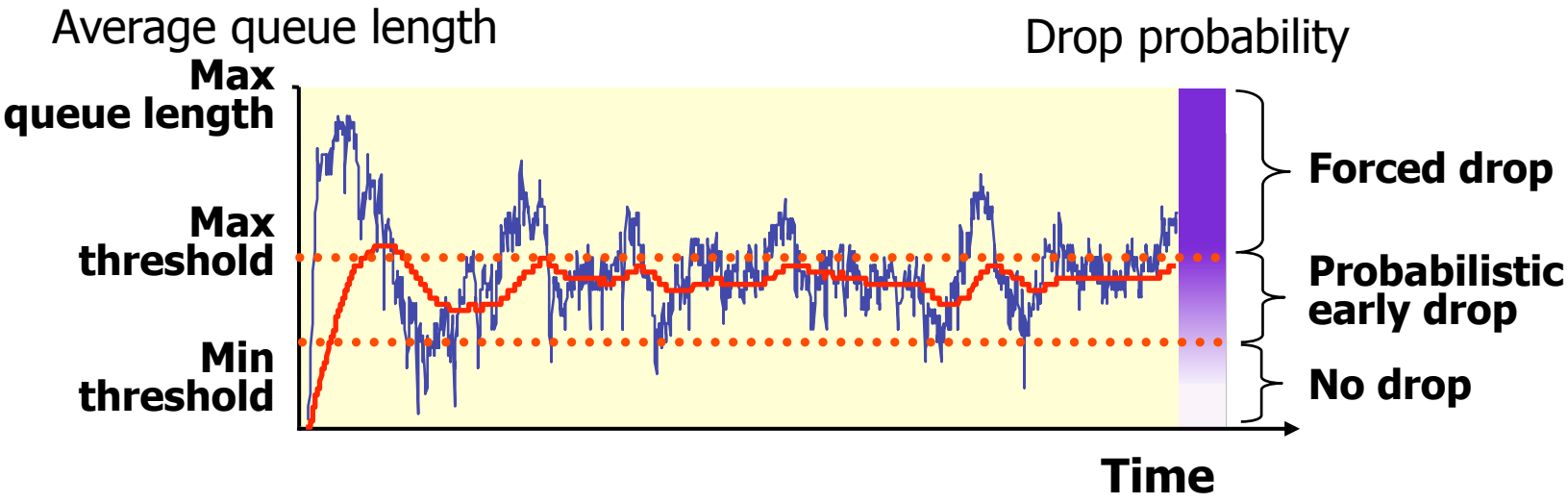

- Large queues in routers are "a bad thing"
  - End-to-end latency dominated by length of queues at switches in network
- Allowing queues to overflow is "a bad thing"
  - Connections transmitting at high rates can starve connections transmitting at low rates
  - Connections can *synchronize* their responses to congestion

# Idea: Early random packet drop



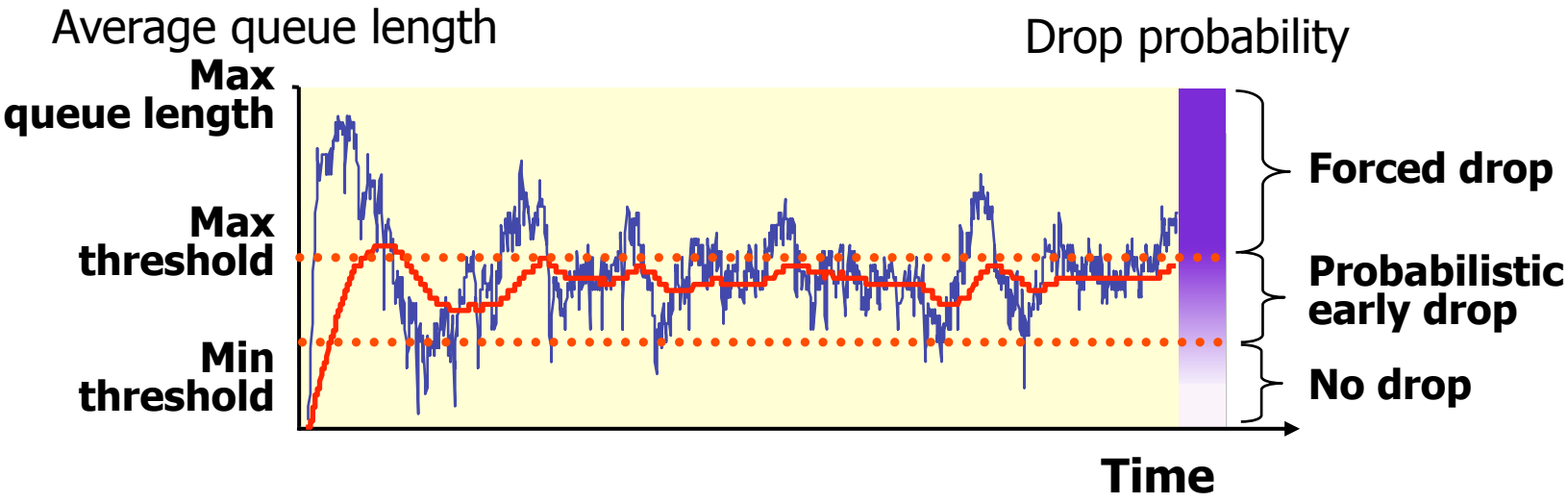

- When queue length exceeds threshold, packets dropped with fixed *probability*
  - Probabilistic packet drop: Flows see same loss *rate*
  - Problem: Bursty traffic (burst arrives when queue is nearly full) can be over-penalized

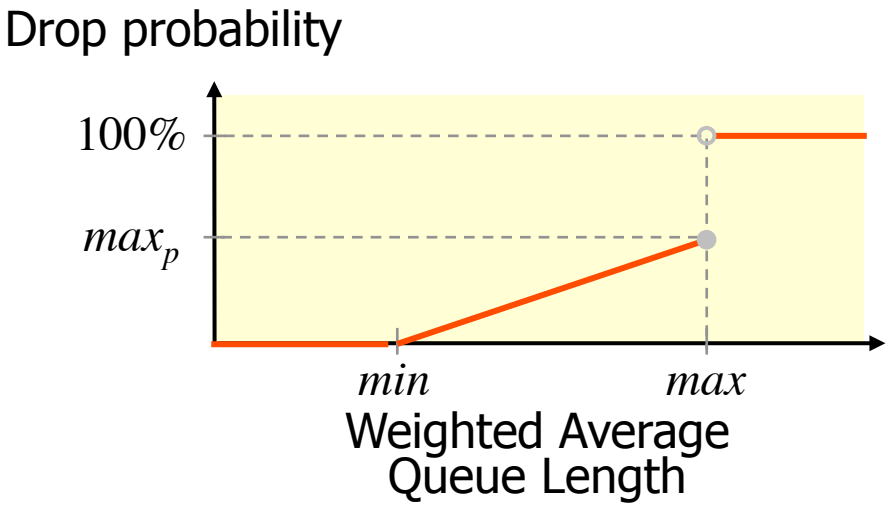
# Random early detection (RED) packet drop




- Use exponential *average* of queue length to determine when to drop
  - Avoid overly penalizing short-term bursts
  - React to longer term trends
- Tie drop prob. to weighted avg. queue length
  - Avoids over-reaction to mild overload conditions

# Random early detection (RED) packet drop



# Random early detection (RED) packet drop

- Large number (5) of parameters: difficult to tune (at least for http traffic)
- Gains over drop-tail FCFS not that significant
- Still not widely deployed …

# RED: Why probabilistic drop?

- Provide gentle transition from no-drop to all-drop
  - Provide “gentle” early warning
- Provide same loss rate to all sessions:
  - With tail-drop, low-sending-rate sessions can be completely starved
- Avoid synchronized loss bursts among sources
  - Avoid cycles of large-loss followed by no-transmission

- Randomization used in many protocols:
  - CSMA/CD: to desynchronize senders
  - BGP: to desynchronize routing updates
  - SRM: feedback suppression
  - Switch scheduling: performance increase
  - Active queue management