Roadmap

- TCP congestion control – the problem
- TCP congestion control – solutions
- Performance of TCP congestion control
- The future of TCP

TCP congestion control: the problem

- Arguably the most crucial part of TCP
- Lots of research effort (over 25+ years)

Performance Objectives

- Link utilization
- Fairness
- Keep congestion down

Q: What is the right notion of fairness?

TCP congestion control: the problem

Nodes **do not know** about

- other nodes
- total or available capacity on any link
- the number of packets in a router buffer

So, how does a node sense

- congestion?

  delays, losses,….
- absence of congestion?

  lower delays, fewer losses….

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TCP congestion control – solutions

- "Packet loss indicates congestion"
- Sensing congestion: timeouts, duplicate ACKs

- Reacting to congestion: drastic decrease of sending rates

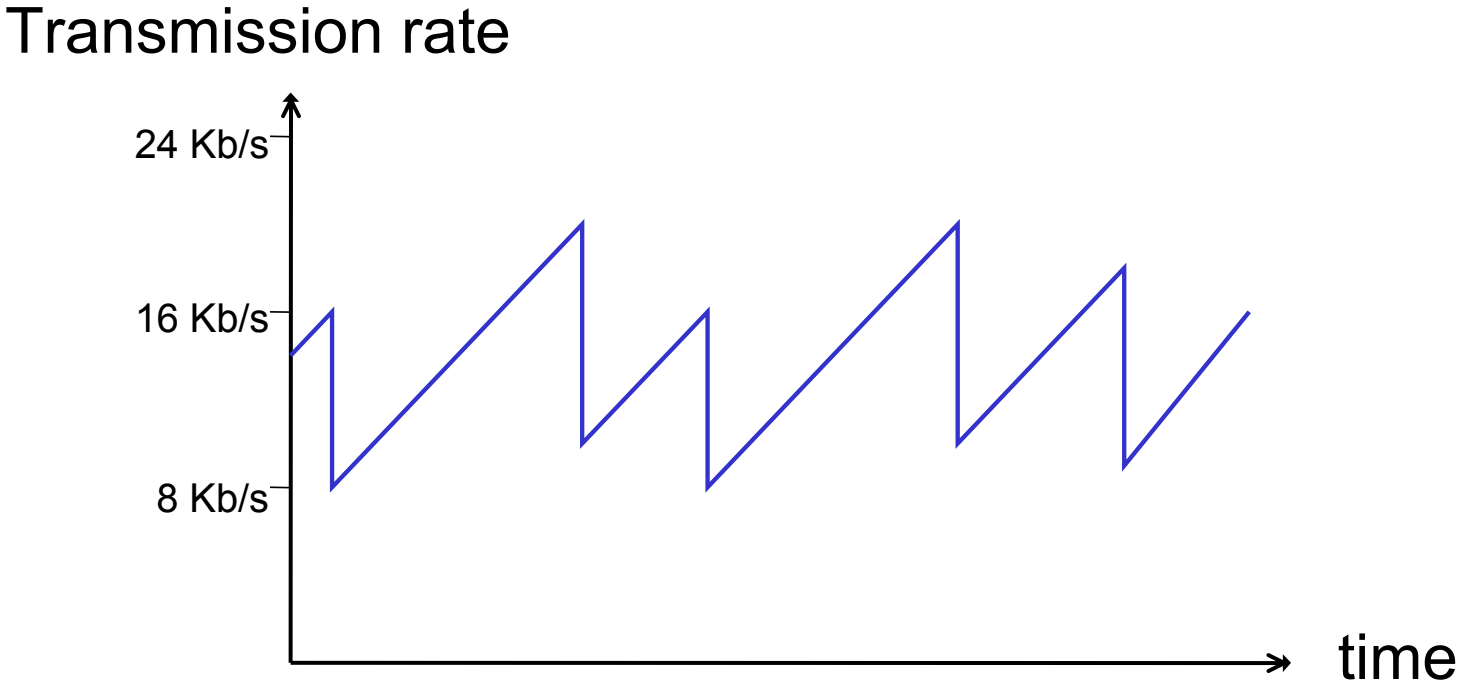
- How/when does a sender recover from congestion?
  - Continuous probing
  - Conservative increases

Q: Formula for increase and decrease ?

TCP congestion control – v1

Let's think in terms of rates:

- **Additive** (conservative) increase, **multiplicative** (drastic) decrease of sending rates (AIMD)
- Starting rate: High? Low?



TCP congestion control – v2

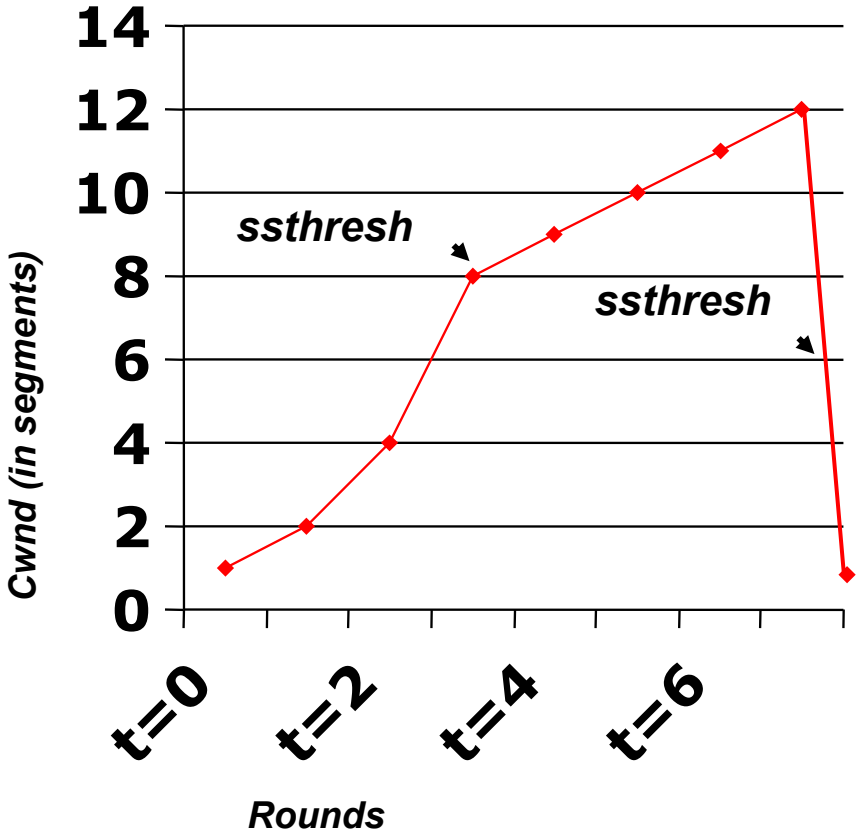
TCP Tahoe (1988)

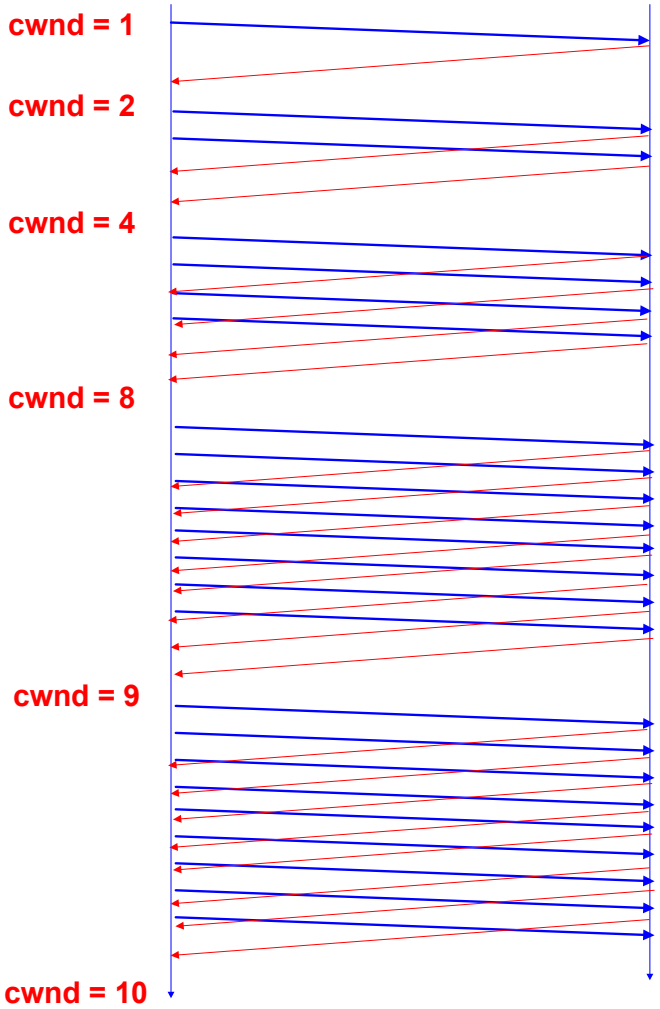
- Two modes: Aggressive probing (Slow start) and careful probing (Congestion avoidance).
- **Slow(!) start mode**: Multiplicative (aggressive) increase, multiplicative decrease of sending rates.

- **Congestion avoidance mode**: Additive (conservative) increase, multiplicative (drastic) decrease of sending rates.

TCP Tahoe illustration

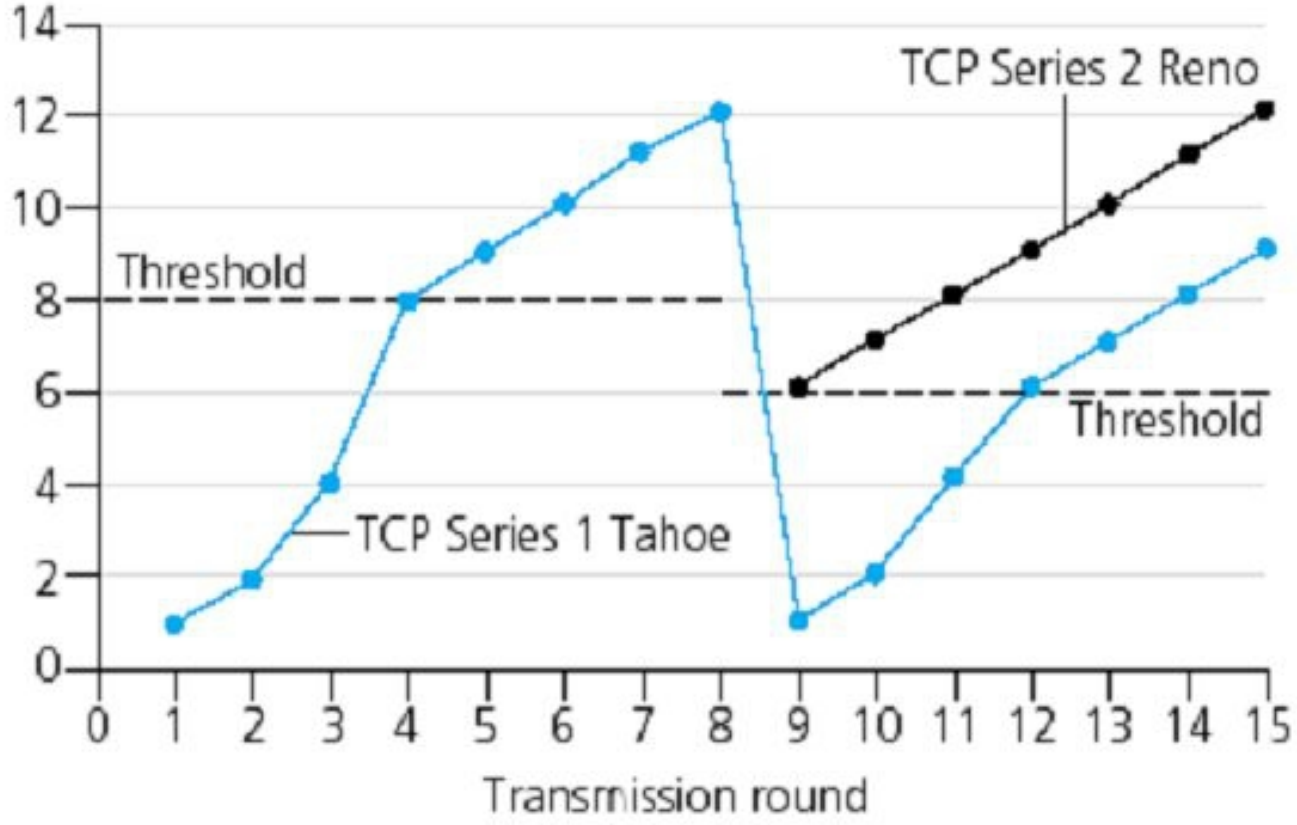
Assume that *ssthresh = 8*





A further improvement

- **TCP Reno(1990)** and Fast recovery
- Intuition: Distinguish between loss and 3-dup ACK



Windows vs rates

- TCP uses windows (number of packets sent without waiting for ACKs)

- Transmission rate = W * Packet size/RTT

  RTT = round trip time

- Self-clocking

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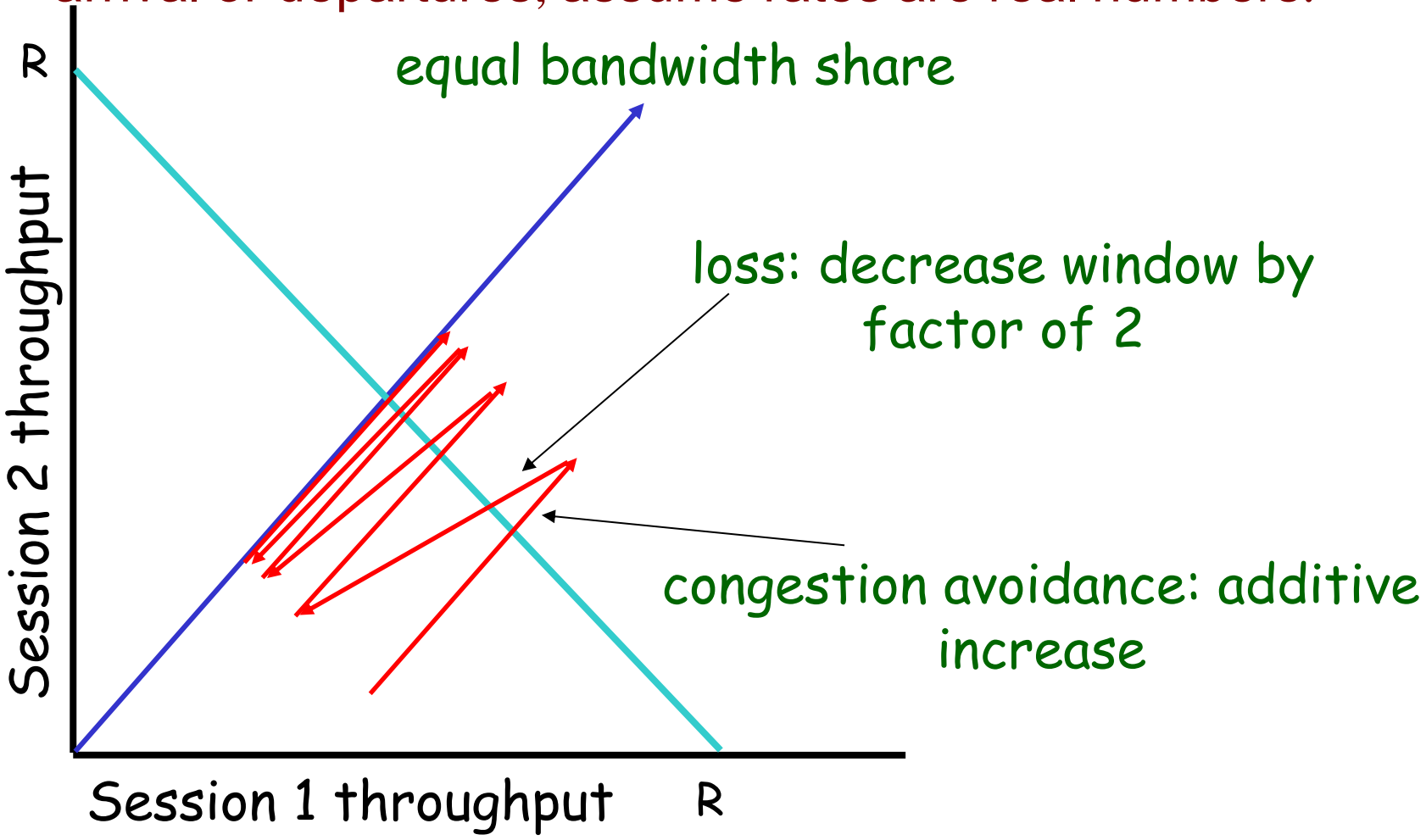
Performance of TCP congestion control

- Fairness
- Link utilization
- Algorithmic perspective?
- Note: Many other TCP versions have been proposed. No one version outperforms all others in all situations

TCP Performance – Fairness

[Chiu and Jain, 89] Two competing LONG sessions, no arrival or departures, assume rates are real numbers.

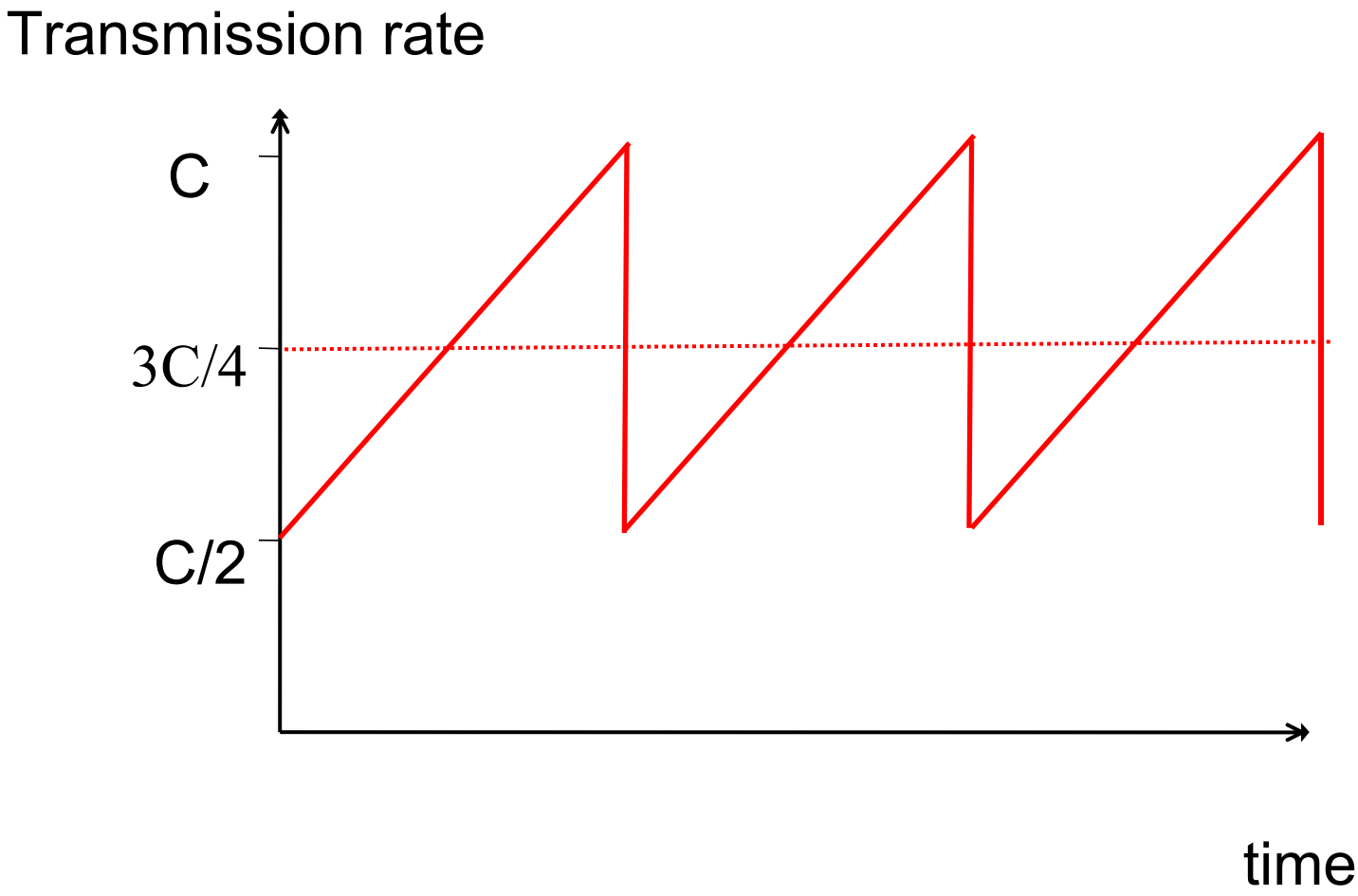


Lessons

- Caveat: In reality, both sessions may not detect congestion at the same time
- Once the trajectory hits x=y line, it stays there
- For real-valued rates, reaches x=y only as t $\rightarrow\infty$
- Will *leave* optimal point after reaching it (continuous probing)
- Generalizes to n sessions
- MIMD, MIAD, AIAD all unfair
- Can be shown to hold in the presence of arrivals and departures if all sessions are long [Edmonds, Datta, Dymond, 03]

TCP Performance – link utilization

- At least 25% capacity lost



TCP Performance – algorithmic view

- How good an algorithm is it?

  i.e. Optimal? Near-optimal? ….

- Very difficult question
  - Does not correspond to clean theoretical models.

- [Edmonds, Datta, Dymond, 03] TCP "performs well" (is competitive against a limited adversary) when each session is of a minimum specified size…

TCP Performance – problems

When/where does TCP not work well?

- Multimedia networking
  - Non-smooth (sawtooth) bit rate
  - Best-effort: no QoS guarantees
- Wireless/hybrid networks
  - "Packet loss indicates congestion" ?
  - Congestion and loss are not always correlated
- Very high-speed networks
- Fairness issues: parallel sessions, multiple bottlenecks, small sessions…

TCP/IP Design issues

- Co-operative algorithm
- Policing is hard to do
- Tracing of malicious hosts/users difficult

Roadmap

- A 2-minute introduction to the TCP/IP architecture
- The role of TCP
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The Future of TCP

- Active queue management schemes
  - Drop packets proactively to reduce congestion
  - RED, REM, BLUE,…
- TCP for ultra-high speed networks
  - FastTCP, HSTCP,….
  - Usually use delay for being more responsive to congestion
  - Less draconian
- TCP for wireless, hybrid networks
  - Treats wireless parts separately