Solving Hot Spot Contention Using InfiniBand Architecture Congestion Control

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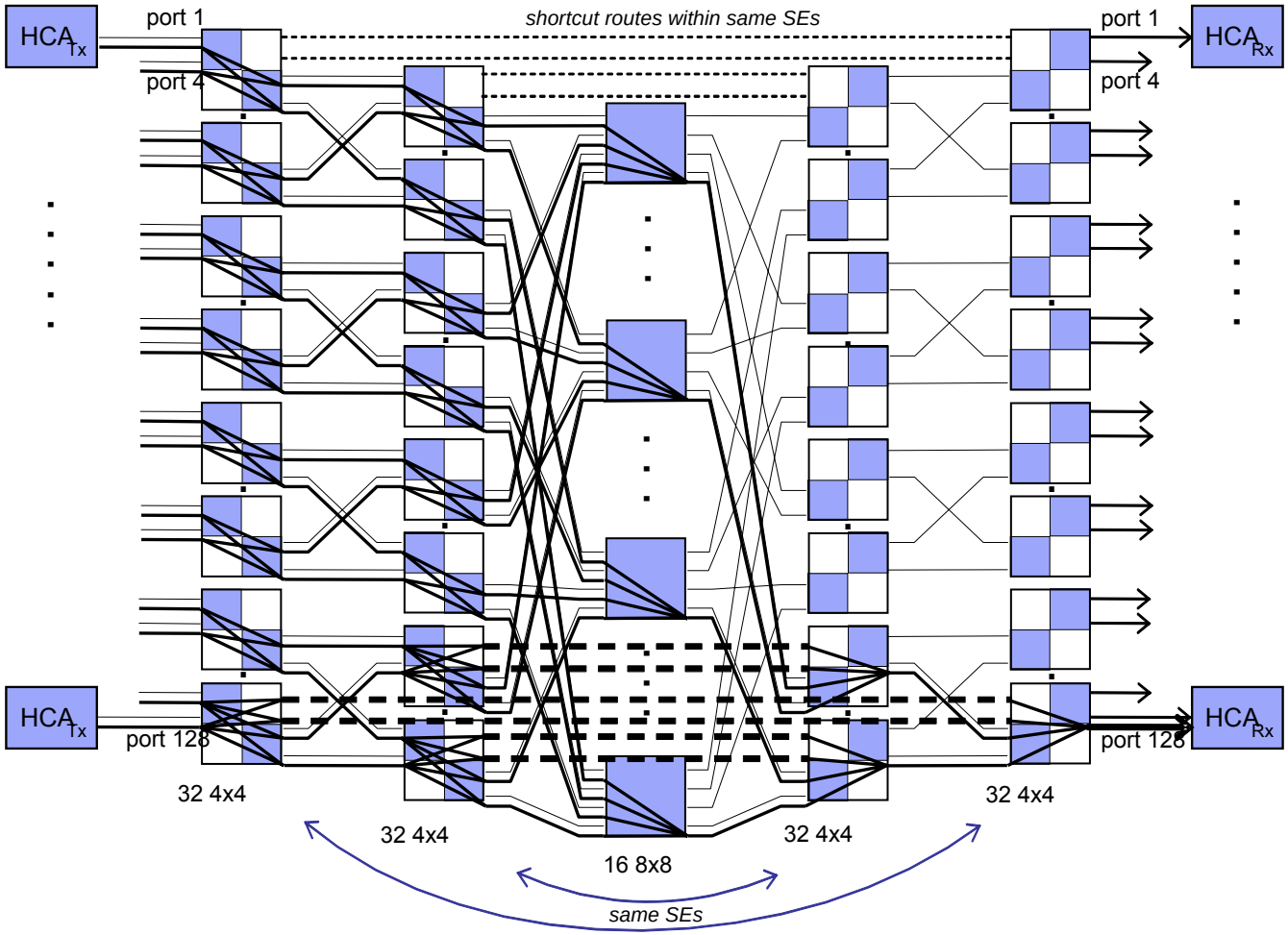
Outline

- The problem
  - Demonstrated solution
- Why the problem matters
- How the solution works
  - Networks behaving badly
  - Preliminary guidelines
- Conclusions and Future directions

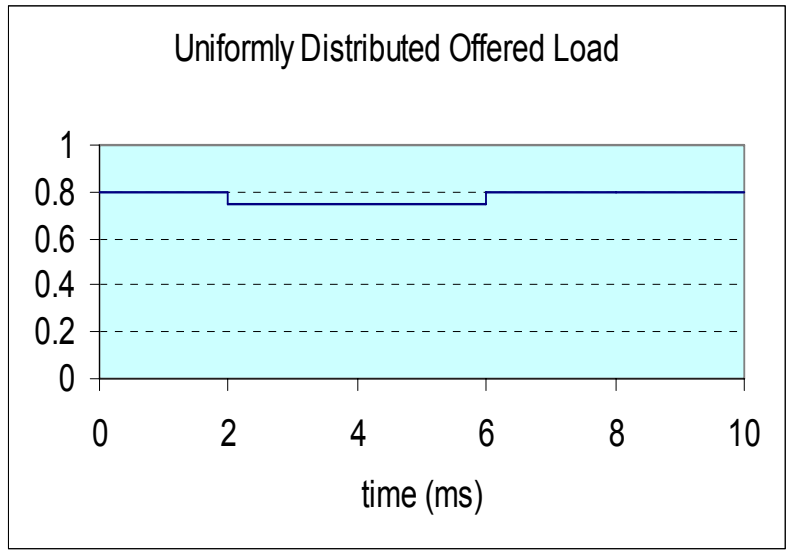
3-Stage 32-Port InfiniBand Fat Tree, Simulated

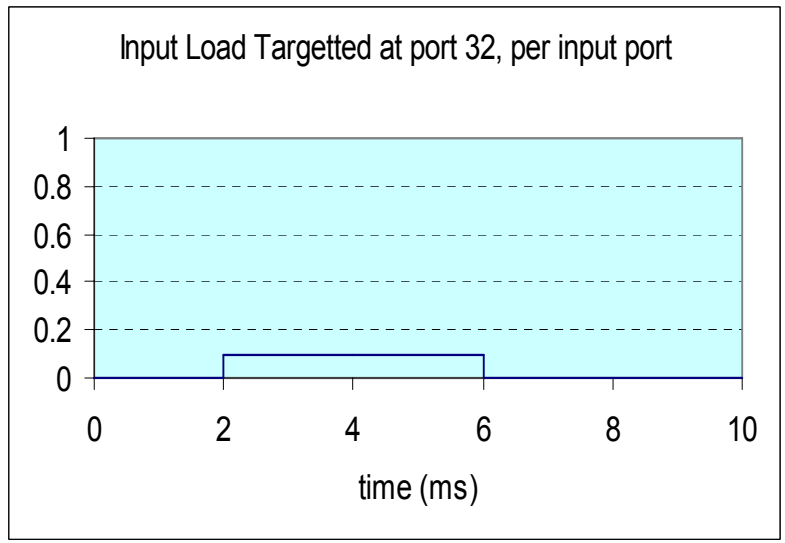


- Drawn unfolded: Up on left, Down on right.
- Dashes & dots are shortcut paths within switches

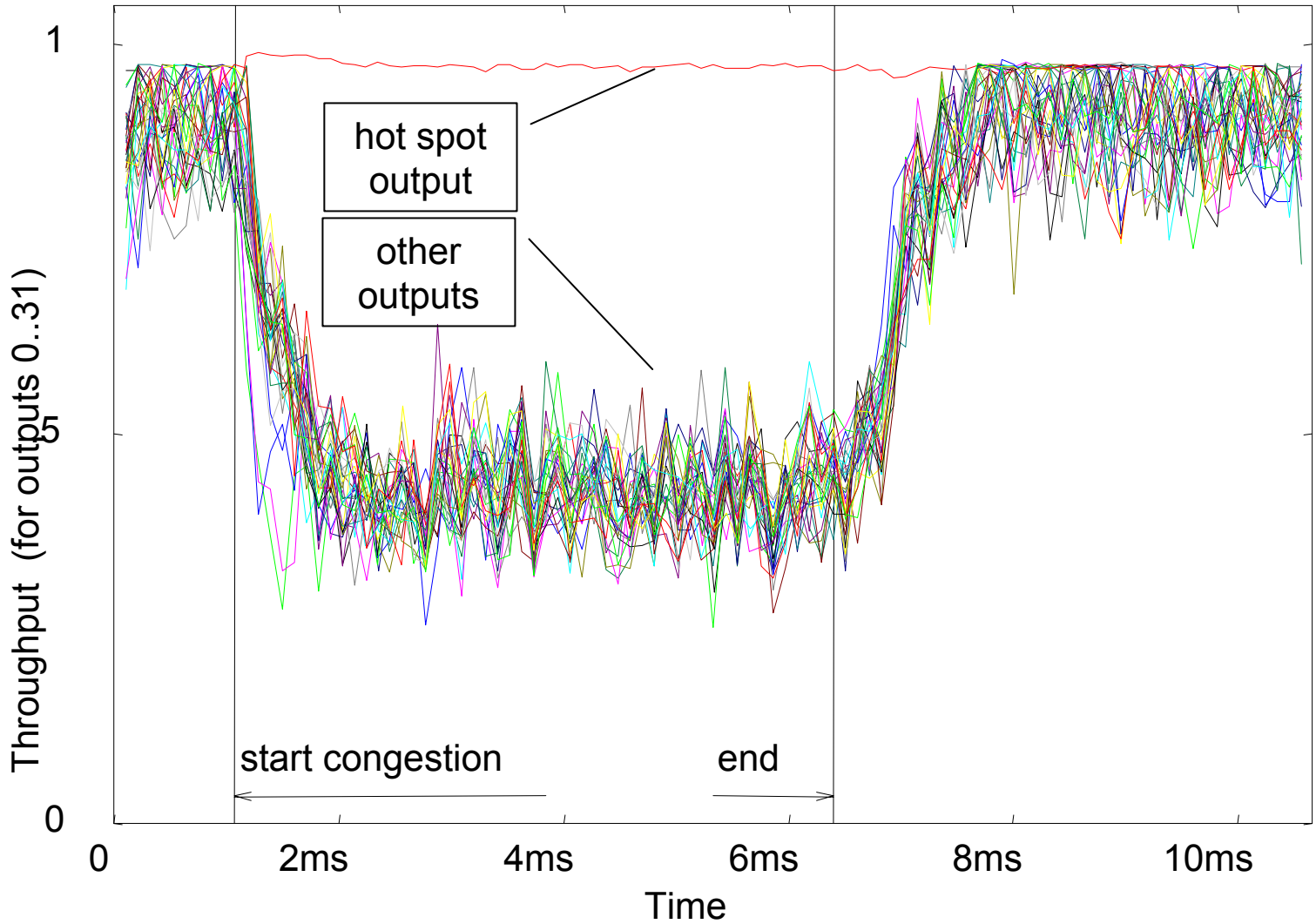
Input Traffic Pattern

- Run for a bit at 80% load, with destinations uniformly distributed from each source to each destination.
- 2 ms. into run, each input moves 9% of its load to port 32
  - Lower uniformly-distributed load to keep aggregate load constant.
- 4 ms. later, go back to original uniform load.



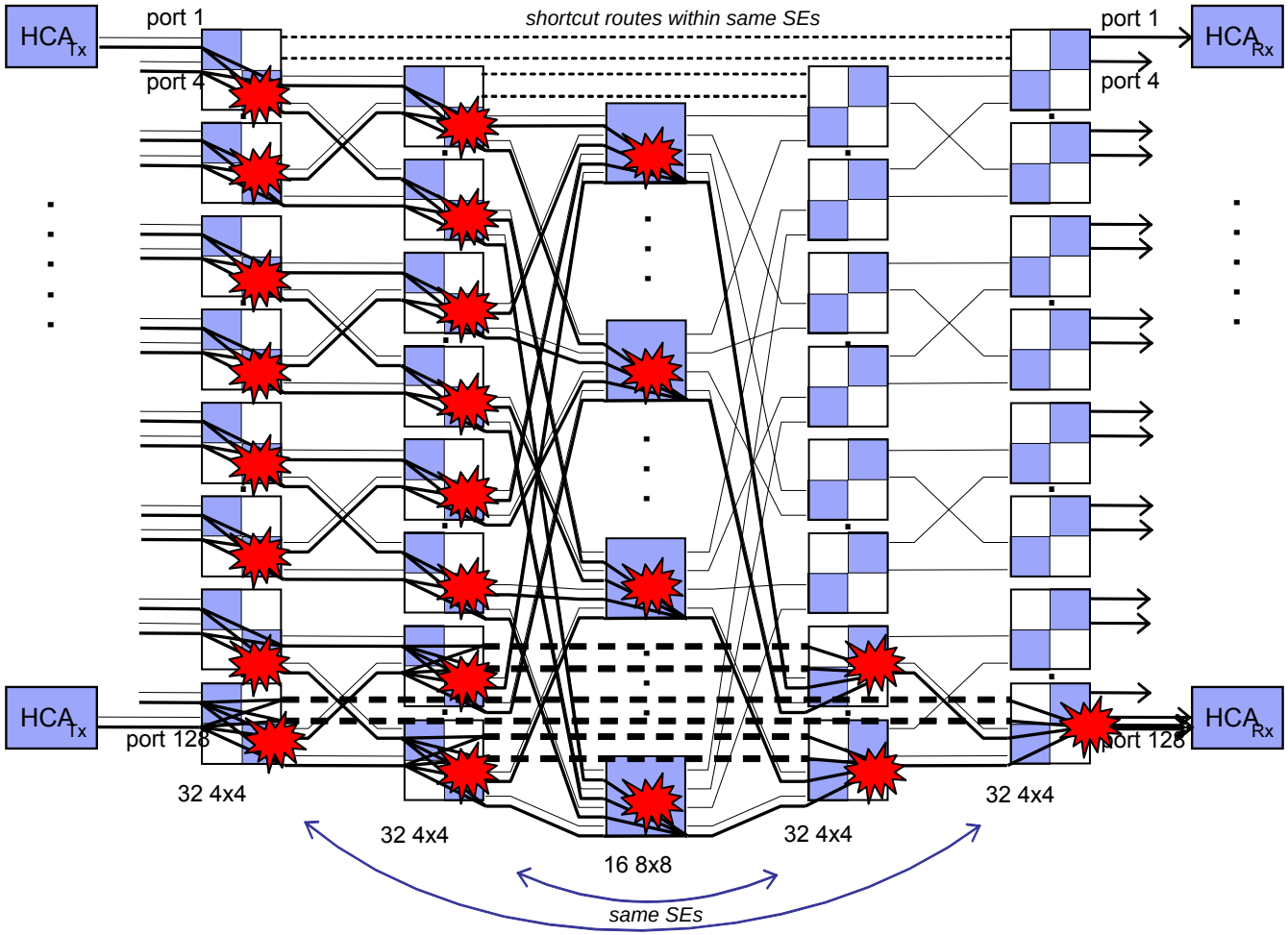


Result: Global Catastrophic Loss of Throughput



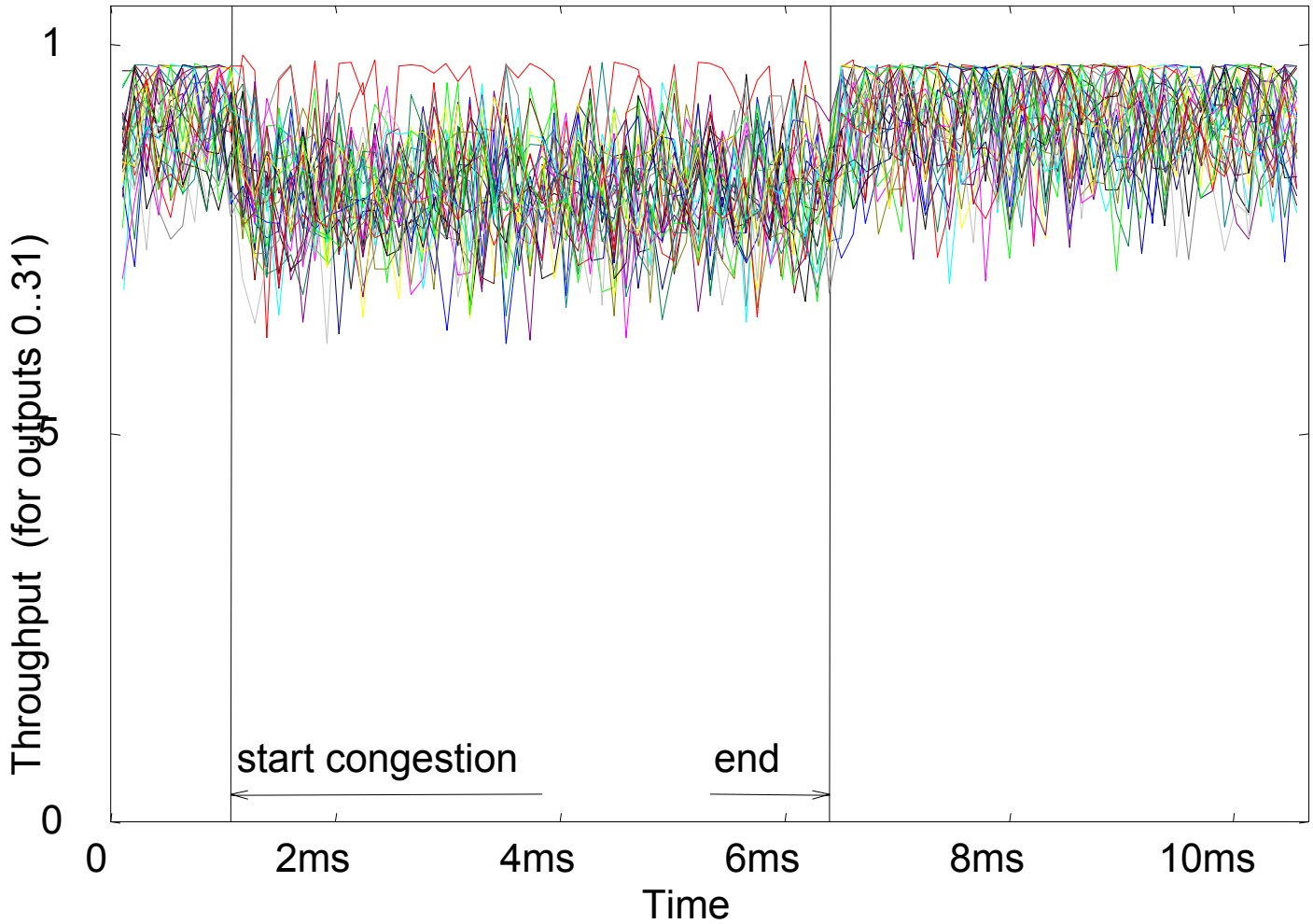
- Traffic to **one** port messes up everybody else.

Why: Tree Saturation / Congestion Spreading



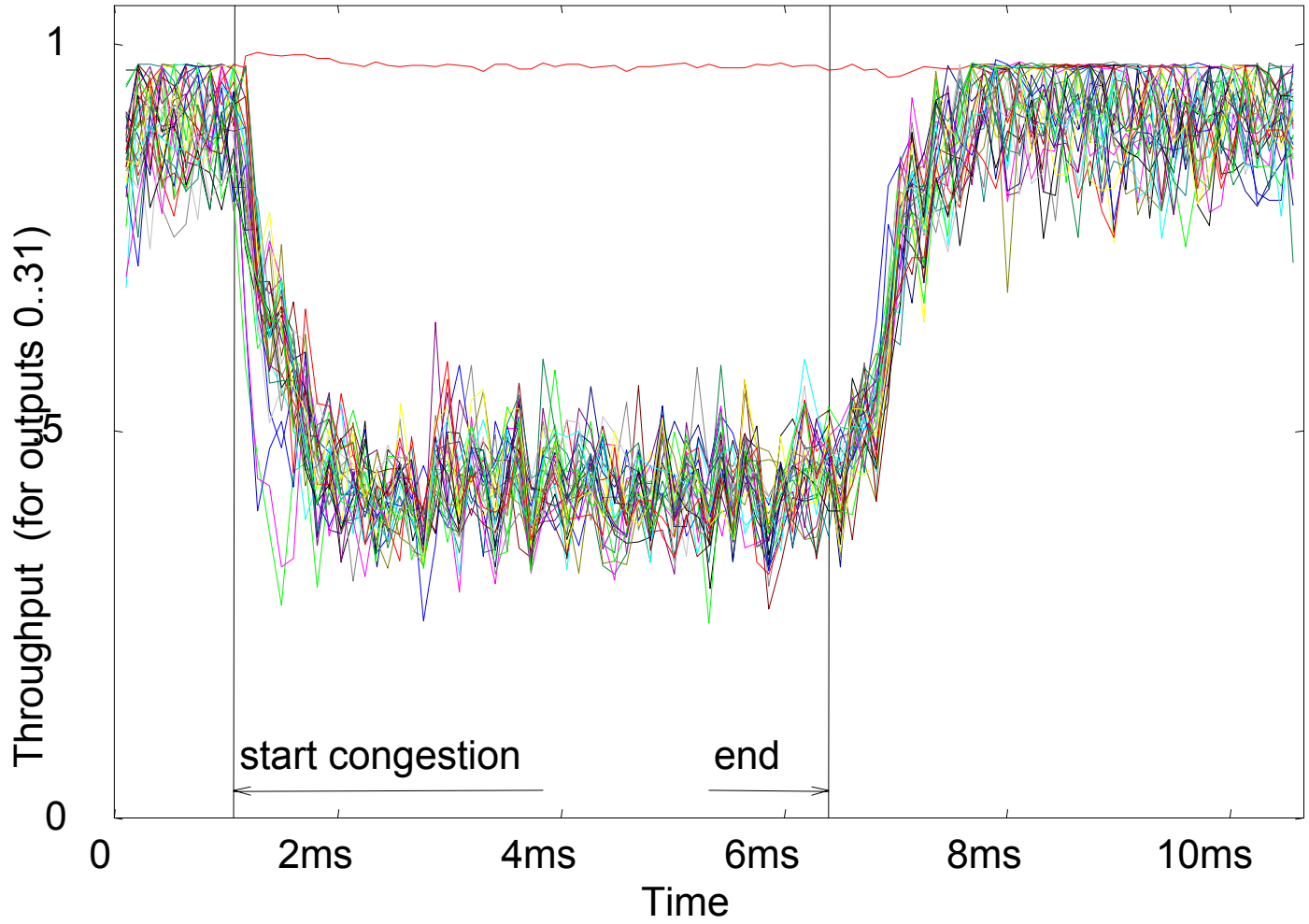
- Hot output link saturates; link-level FC fills queuing of next stage
- Exhausts all storage in switch; backs up to next stage; etc., until all traffic whacked.

Same, With InfiniBand Congestion Control



- Throughput drop = reduction in load keeping aggregate load constant.
- Simulations modeled product-purposed hardware designs as closely as possible.

Same, Without (Repeat)



Why Does This Matter?

- Solves a 20-year outstanding problem…
  - Pfister & Norton, “Hot Spot Contention and Combining in Multistage Interconnection Networks”, IEEE TC, 10/1985
- …for the first time.
  - not all co-authors agree with this; explanation later.
- Original paper spawned a mini-industry of efforts to solve the problem.
  - Eventually died out in the parallel arena because it didn’t seem to occur in practice. Why?

    (There are cases where it’s shown up in practice; has been treated as a bug.)

Why Aren't Networks Falling Over?

Factor	Current / Past	Emerging
Over-provisioning (mainly commercial)	Drown the problem in bandwidth; it's cheap.	Doesn't scale with # of nodes; node # scaling will be increasingly needed (Moore's law freq scaling KO). Msg sizes rising dramatically (XML)
Single use systems (mainly HPC)	One problem per machine → congestion is a bug	Virtualization on and of clusters, so communication not algorithmically predictable
Must have > 1 message outstanding	Early system limit; single use; little multiprogramming	All CPU chips multithread, multi-core; multiprogramming must be used

- Net: They'll start falling over pretty soon.

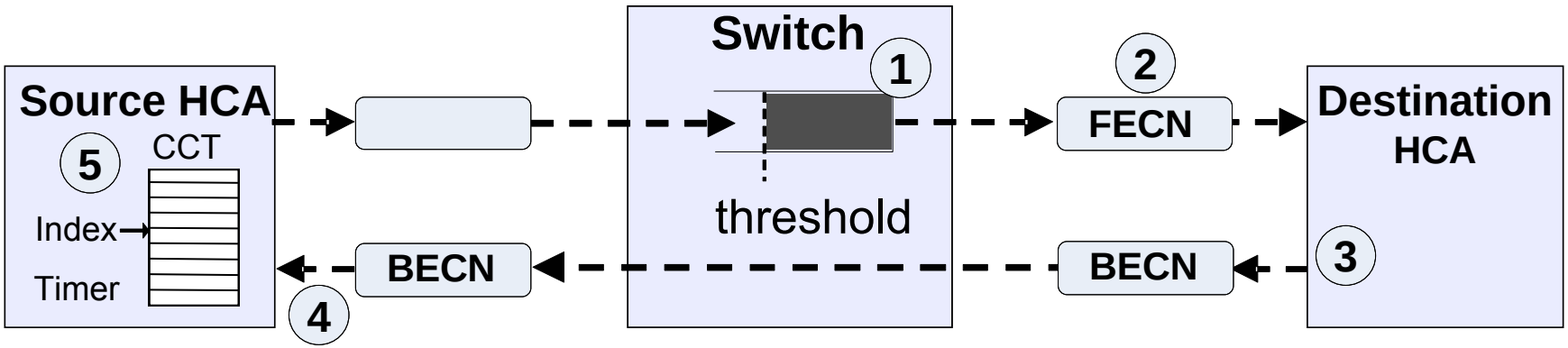
Why Prior Work Doesn't Fix It

- **Assumes hot flow pre-identification before running**
  - Divert hot flow to a separate lane, network, queue, or …
  - Can help, but it's hard to predict bugs. (ISP xmp)
  - Also: Predict → rearrange to avoid the problem
- **Works – if the hot flow stops soon enough**
  - Frantically reorganize switch element buffers to free up space
  - Only works for a limited time
  - IBA CC quenches the source.
- **Shuts down entire offending port**
  - May be many virtual systems behind one physical port.
  - IBA CC just targets the hot flow(s) of a port
- **Targets lossy networks**
  - Large amount of work on IP networks has little applicability: no link-level flow control (also other issues, like speed)

Not that these techniques aren't useful and good; they just aren't sufficient to solve this particular problem.

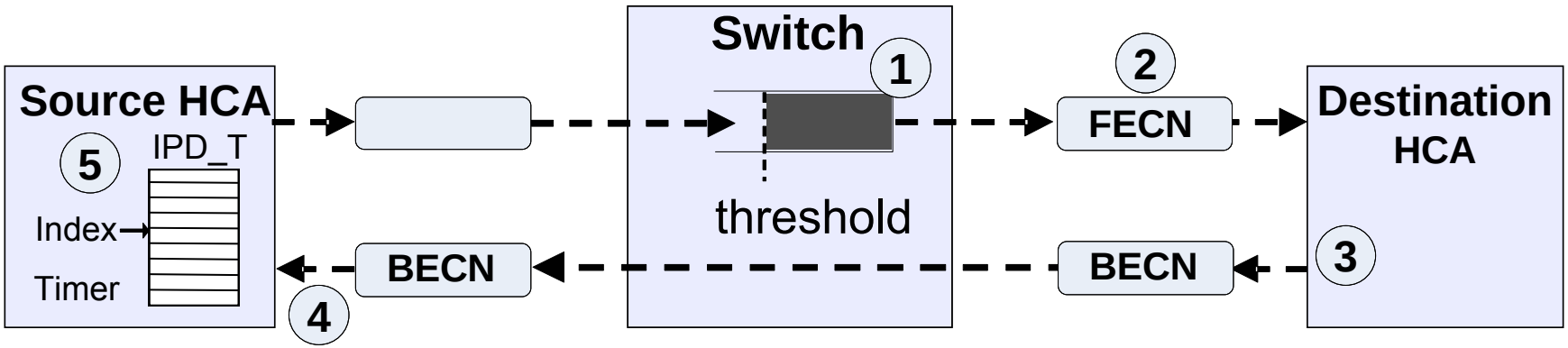
(Detailed references given in the printed paper.)

How It Works (1)



1) **Detect congestion**
   - Queue for VL > threshold
   - Optional: Mark only if root = output credits available
2) **Propagate out**: set Forward Explicit Congestion Notification bit on all packets as long as congestion exists
3) **Propagate back**: receive FECN, respond with Backward Explicit Congestion Notification bit
   - Part of normal response, or congestion notification packet
   - Sent back to source Queue Pair

How It Works (2): Responding



4) **Determine Added Delay**: Whenever receive a BECN for QP, increment index into Inter-Packet Delay Table
   - One index per QP
5) **Apply Delay**: When sending, wait for the Inter-Packet Delay specified in IPD Table entry
6) **Decay the Delay**: Whenever a timer pops, decrement all IPD Table indices on CA.

See IB Architecture Vol. 1 Rel 1.2 for details.

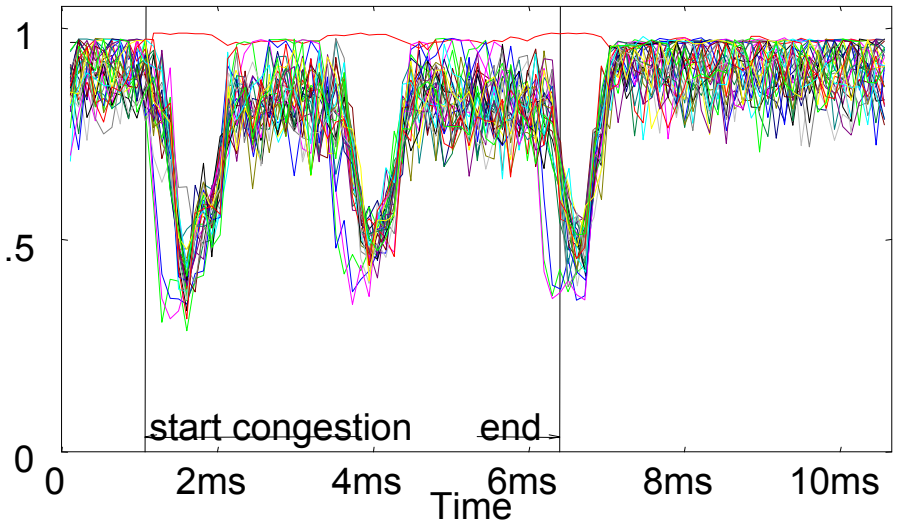
But Does That Really Work?

- Many parameters need to be chosen:
  - Length of IPD Table
  - IPD Table entry values
  - Timer period
  - Detection threshold
  - IPD Table index increment
- This is a feedback system with delay
  - Worse because of forward/back propagation, chosen to keep switches simple while targeting only the hot flows
- Can you get bad behavior?
- Yes.

Networks Behaving Badly

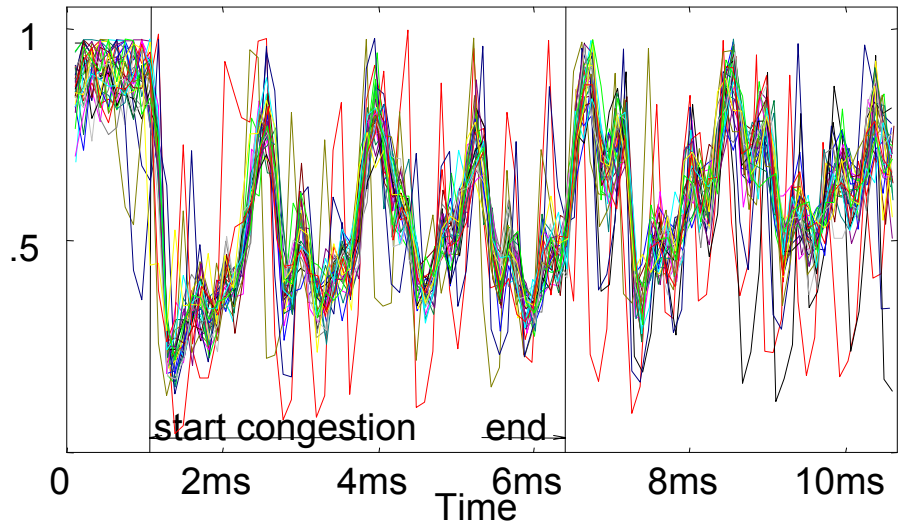
Traffic case 4 (a)
high load: 0.9
large hotspot degree: 32
hotspot severity: 300%

IPD index step too low (=2)



Traffic case 4 (b)
high load: 0.9
large hotspot degree: 32
hotspot severity: 300%

IPD index step too high (=40)

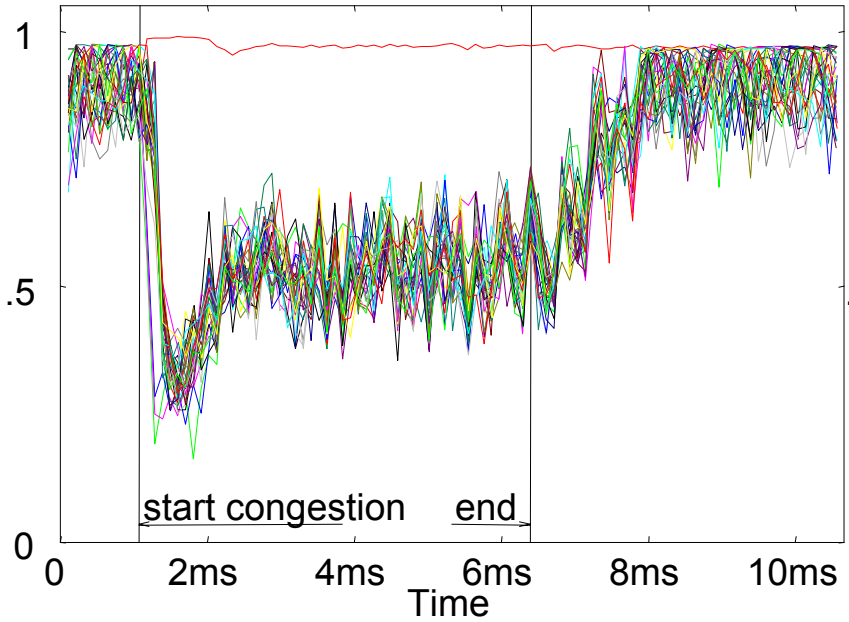


- Cannot chose value at one end of the scale; either end produces bad behavior.

Networks Behaving Badly, 2

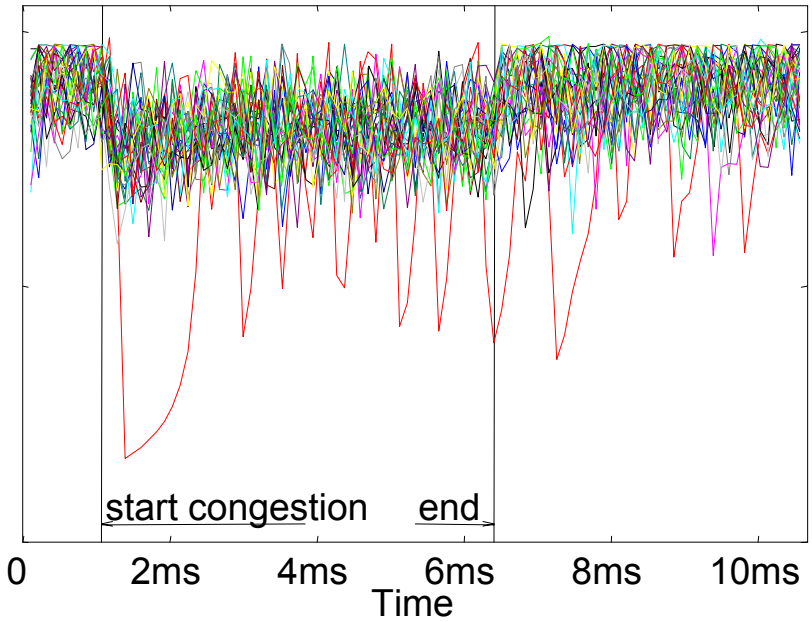
Traffic case 4 (c)
high load: 0.9
large hotspot degree: 32
hotspot severity: 300%

IPD recovery timer too fast (=2.6us)



Traffic case 4 (d)
high load: 0.9
large hotspot degree: 32
hotspot severity: 300%

IPD recovery timer too slow (=84us)



- Recovery timer can't be pushed to an extreme, either

But It Appears Tunable

- We have run literally 100s of simulation cases
  - Networks: 8, 32, 128, 432, 256, 512 ports; 2x2, 8x8, 16x16 switches; 2, 3, 8 stages of switching; fat tree and Omega (Banyan) network.
  - Traffic & hot-spot cases:
    - 50%-90% base background rate
    - All nodes contribute to hot spot, or just 3 (fire hose effect)
    - Hot spot very severe (300% link capacity) or just enough to cause trouble (100%+ε).
- Have ***always*** managed to find a set of parameters that squelch the problem.

Preliminary Guidelines

- N = network size, i.e., number of ports
- H = maximum hot spot degree
  - Worst case = N, but can be less if system partitioning known.
- Absolute time (μsec) values are referenced to simulated RTTs of 2-20 μsec. without congestion.

Item	**Value**
IPD Table size	128
Switch threshold for detection	90% of queue capacity, with some hysteresis (not critical)
IPD table index increment	Min(1/6•N, 1/2•H)
Max IPD value	2/3 H μsec.
Recovery timer	10 μsec.

Conclusions & Future Work

- The 20-year-old problem of tree saturation (congestion spreading) is reappearing.
- Automatic congestion control is necessary; congestion avoidance becoming difficult or impossible
  - cannot assume pre-knowledge or congestion time limits
  - application dynamics create traffic unpredictability
  - resilient self-healing systems running mission-critical applications – application migration, virtualization, etc.
  - peer-to-peer protocols increase difficulty rebalancing
  - Bugs!
- InfiniBand's Congestion Control offers a solution, which we have verified in a wide variety of cases.
- But it is a feedback system that can behave badly.
- We've offered preliminary guidelines for parameter setting
- Future:
  - More detailed guidelines
  - Other cases: output throttling, multiple hot spots
  - Investigate other marking and throttling mechanisms.