Congestion Management Protocol Characteristics in Complex Simulation Scenarios with Updates for QCN-Sonar and large RTT

Guenter Roeck, Teak Technologies

Mitch Gusat, IBM Zurich Research Lab

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Outline

- Update Stockholm presentation with new data for
  - ECM with RTT adjustments
  - QCN-SP with RTT adjustments (QCN+)
  - QCN-Sonar
- Present QCN+ details

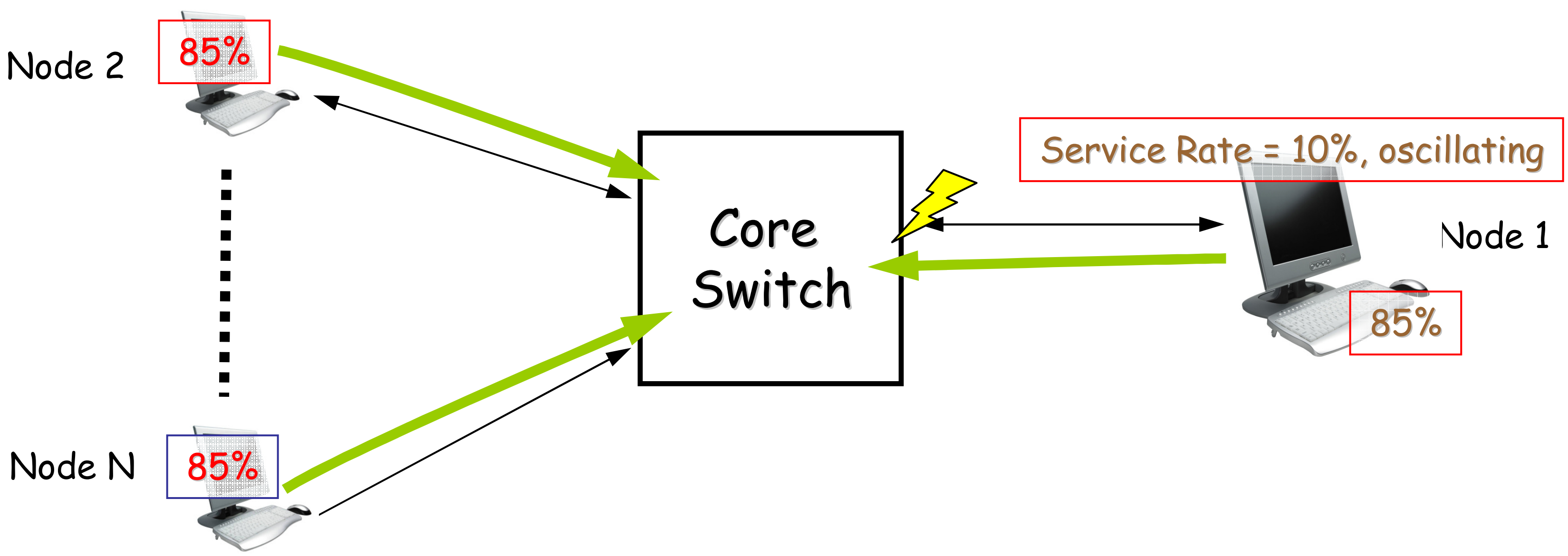
Simulated Protocols

- ECM
  - ECM with <W, Gi, Gd> auto-adjusted for RTT
- QCN
  - As specified
- QCN-Sonar
  - As understood
  - Not all details included
- QCN-SP [QCN+]
  - QCN with Sub-path probes, auto-adjusted for RTT, N

Test Scenarios

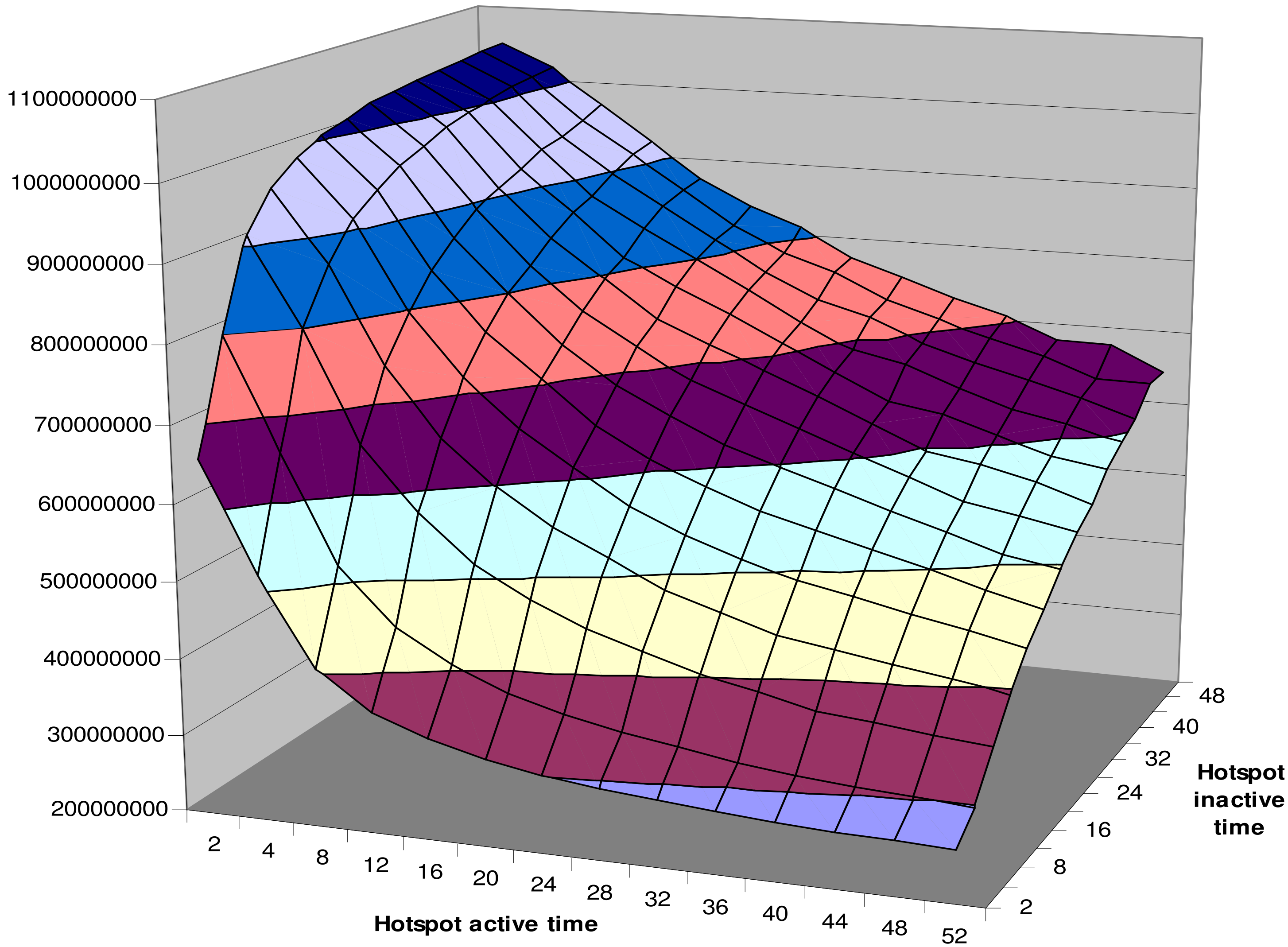
- OG hotspot with oscillating service rate
  - Simulate transient congestion in higher priority CoS
  - Look for overall throughput
- Baseline scenario with large forward latency
  - Simulate network with large BW * latency product
  - Look for stability (throughput, queue length)
- Large number of hotspots with dynamic load
  - Simulate complex network with high load and many CPs
  - Look for overall protocol performance (throughput)

Single Oscillating Hotspot, 20 nodes



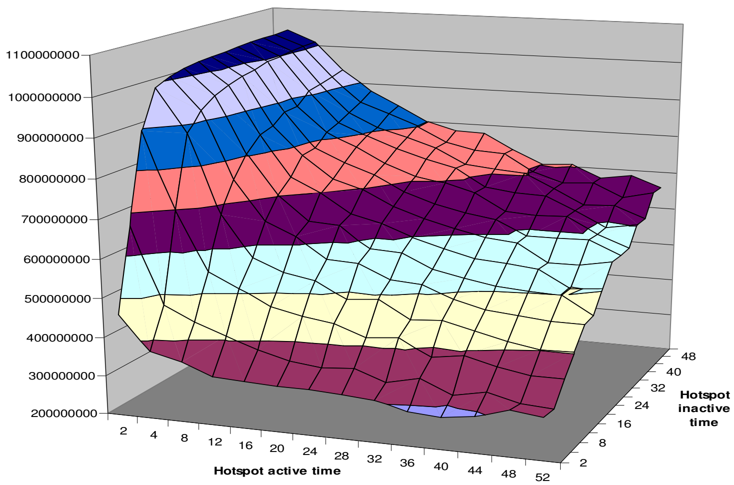
- All nodes (20): Bernoulli distribution, load: 8.5 Gb/s
  - From t=0 to 1s
- Node 1 (hotspot) service rate: 1Gb/s
  - Duration: 800mS from ti=100ms to 900 ms
  - Frequency: tOn=2..50ms, tOff=2..50ms
- Looking for Throughput distribution and bandwidth loss
- Real world scenario: Higher priority CoS with recurring transient congestion

Expected Throughput Distribution

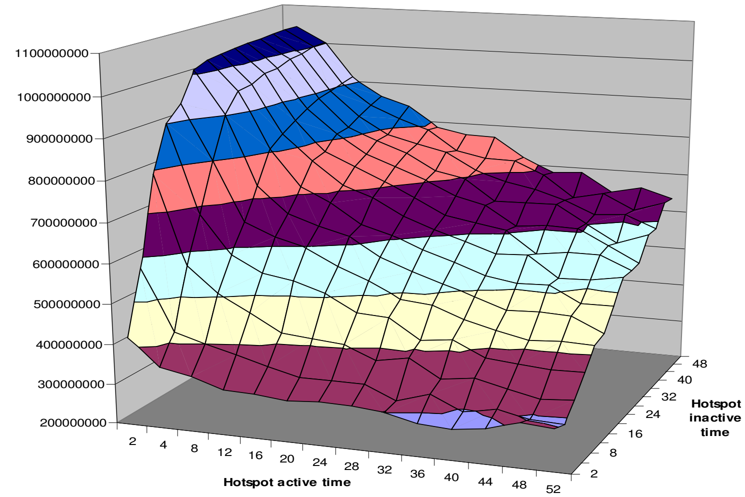


Oscillating Hotspot: Throughput Distribution

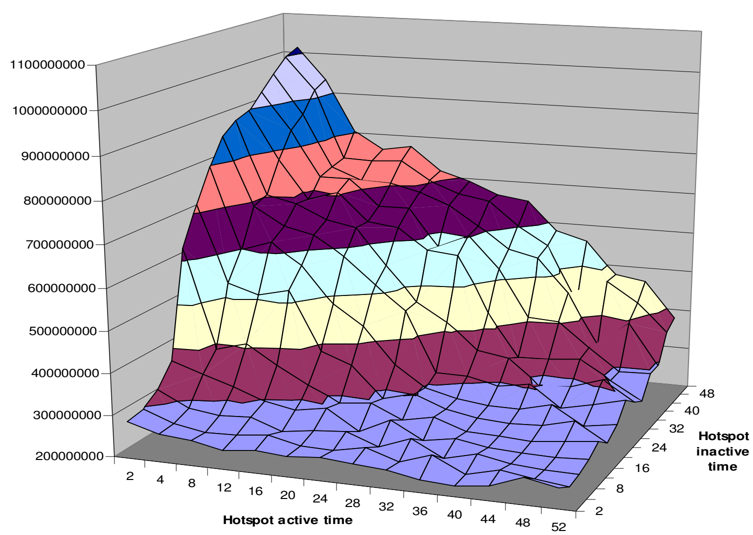
ECM



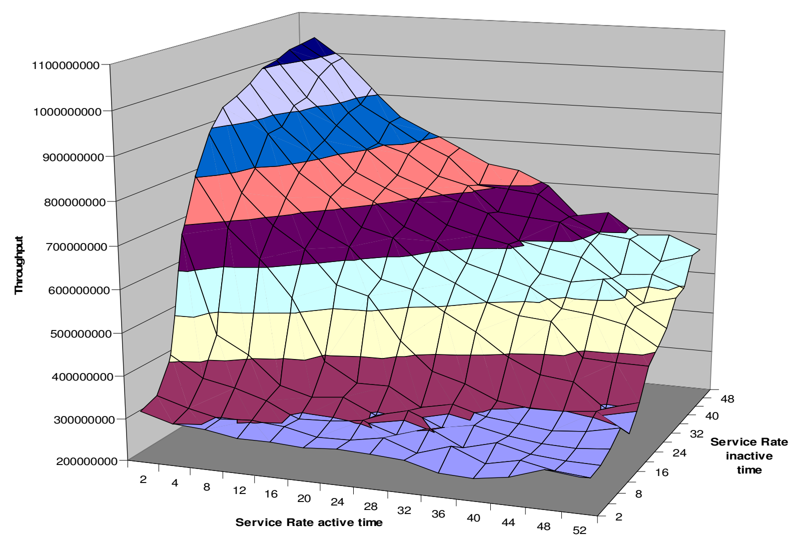
QCN+



QCN

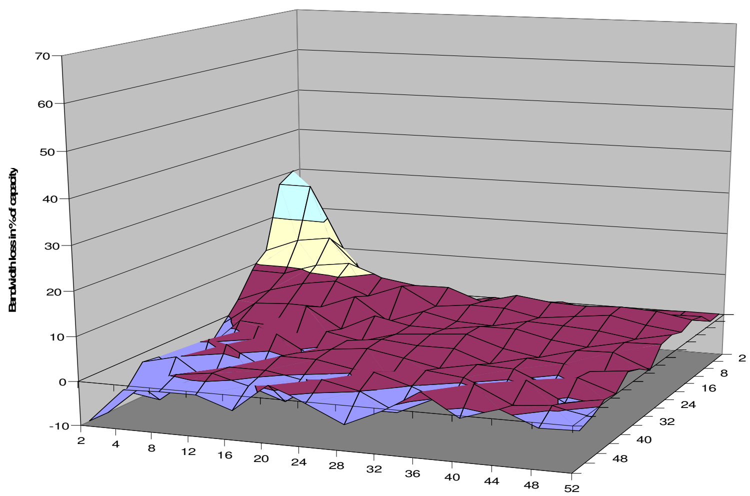


QCN-Sonar

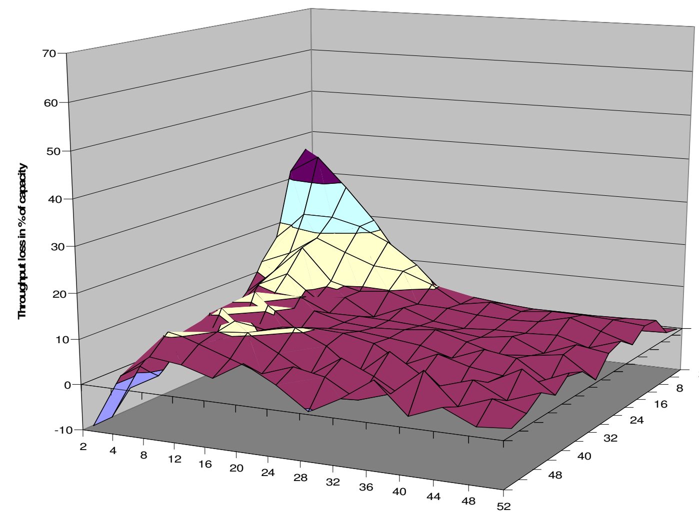


Oscillating Hotspot: Bandwidth Loss

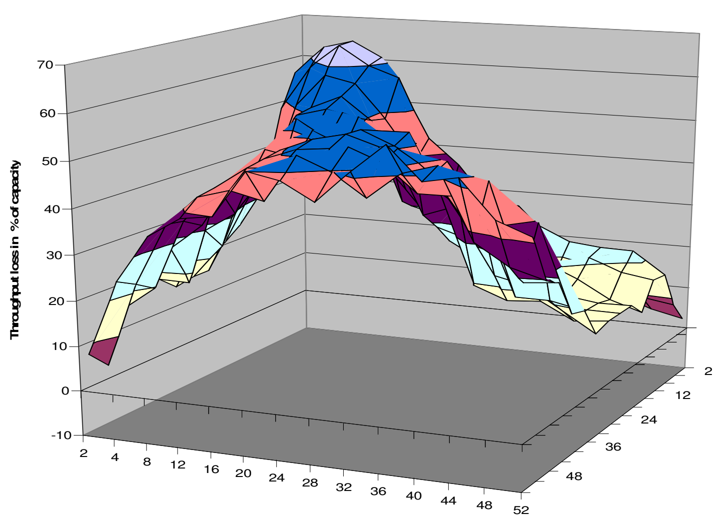
ECM



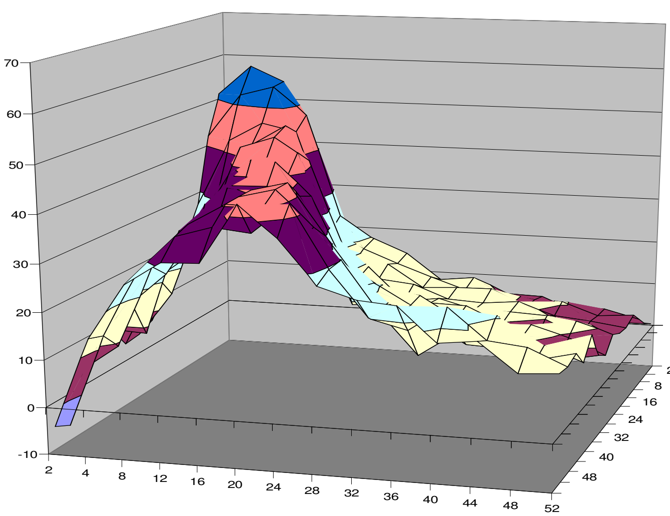
QCN+



QCN



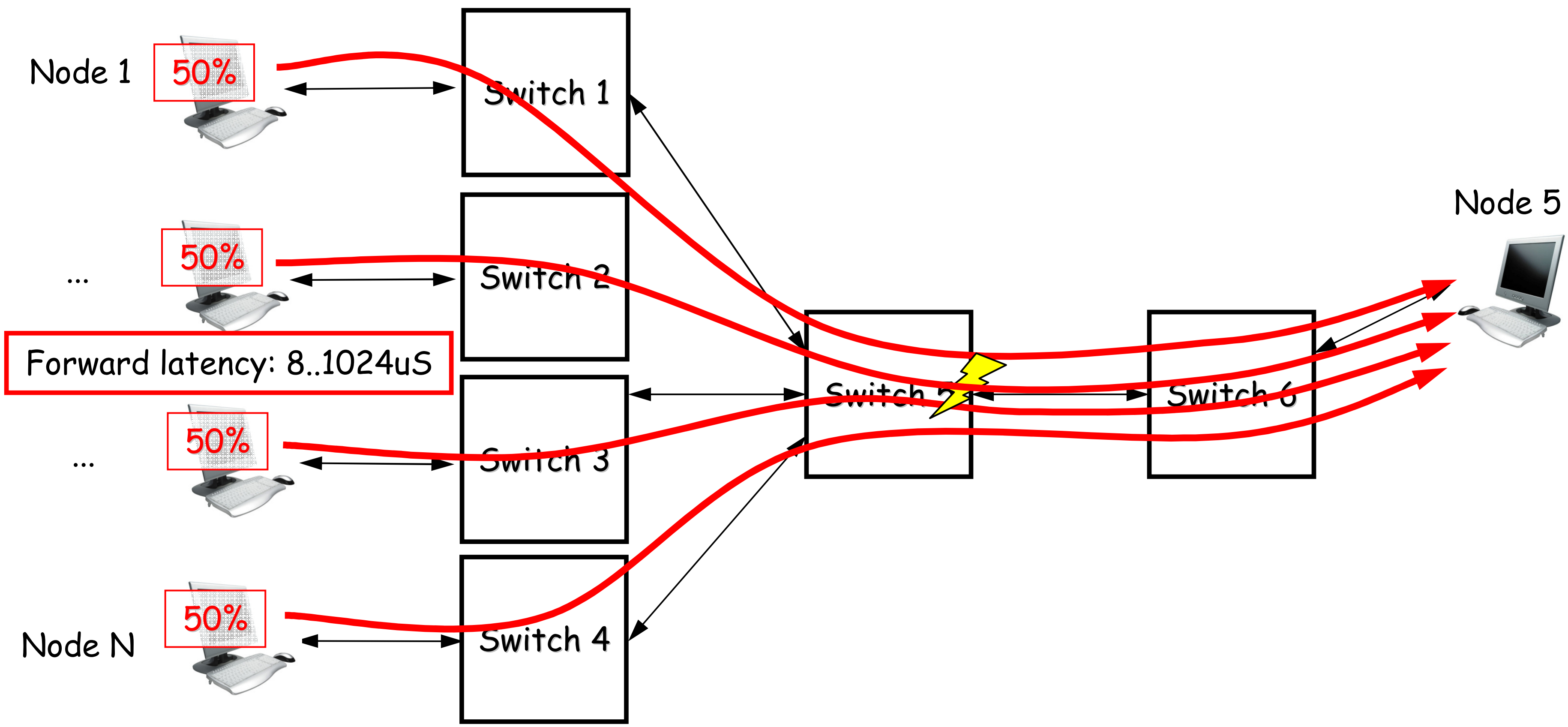
QCN-Sonar



Observations

- QCN-Sonar performs better than QCN and QCN-FbHat
  - Still significant throughput loss
- Best performer is still ECM

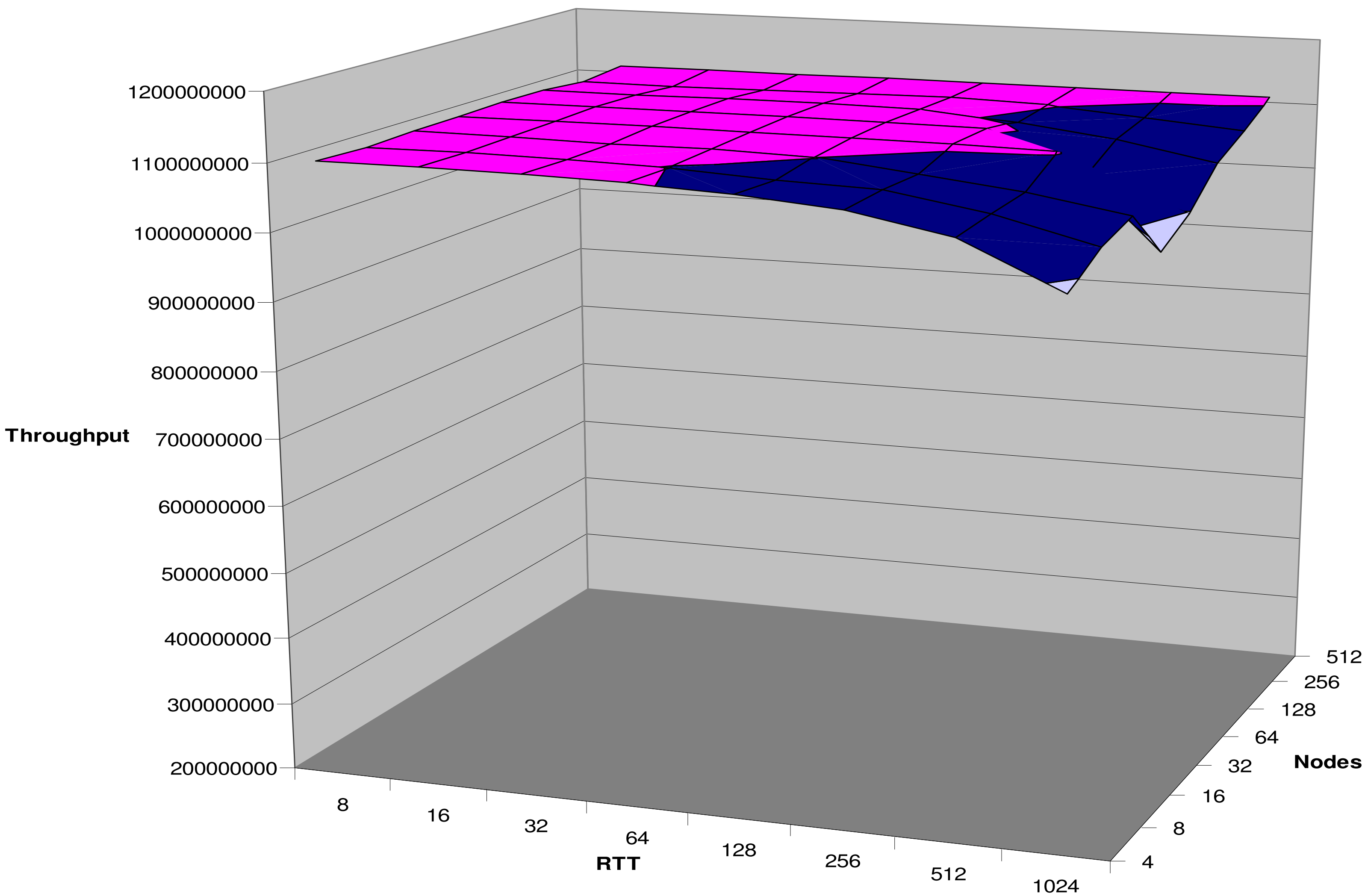
Symmetric Topology, Single HS, Large Forward Latency



- 4 - 512 Nodes
- 8 - 1024 uS forward latency from nodes to switch
- Load factor 4 (load adjusted with number of nodes)
- Simulation runtime 1s, with load from 0.1s to 1.0s
- Measure throughput and average queue length

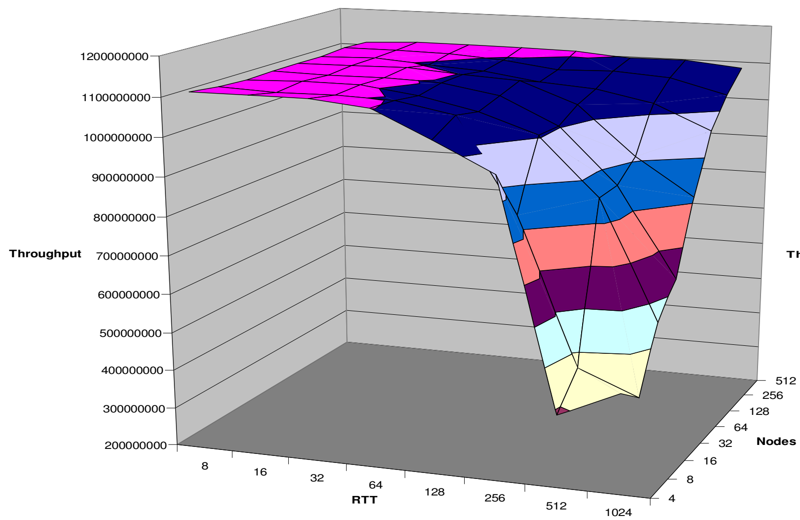
Throughput at Hotspot, ECM

ECM

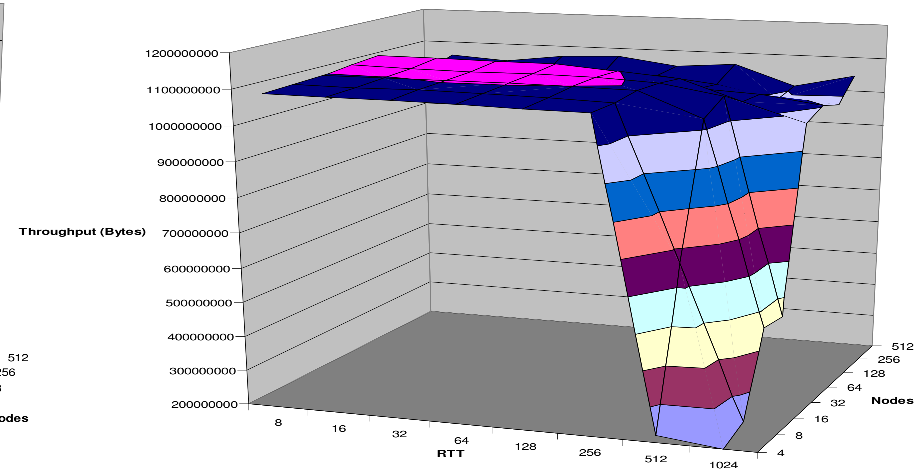


Throughput at Hotspot

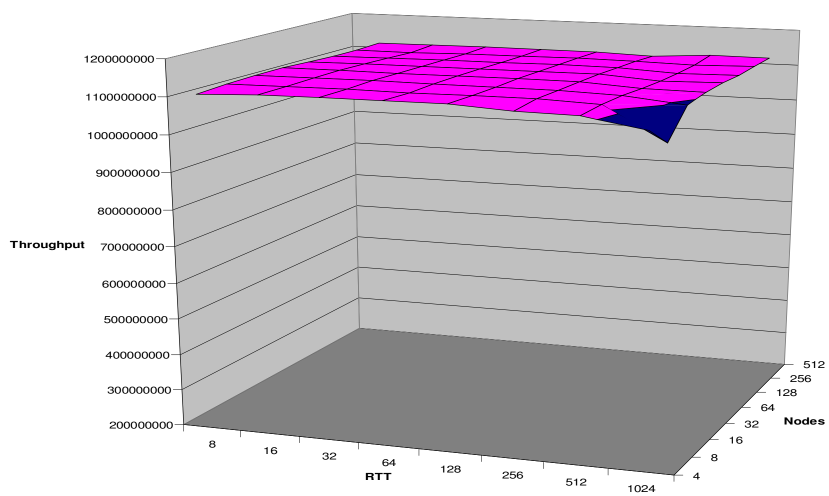
QCN-Sonar, no FR1 rate adjustment



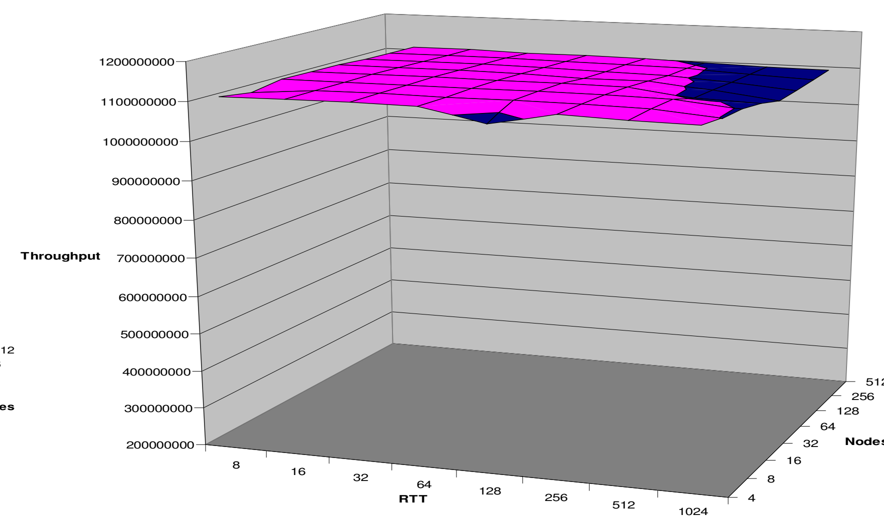
QCN-Sonar, FR1 adjustment



QCN+, adjusted for RTT only

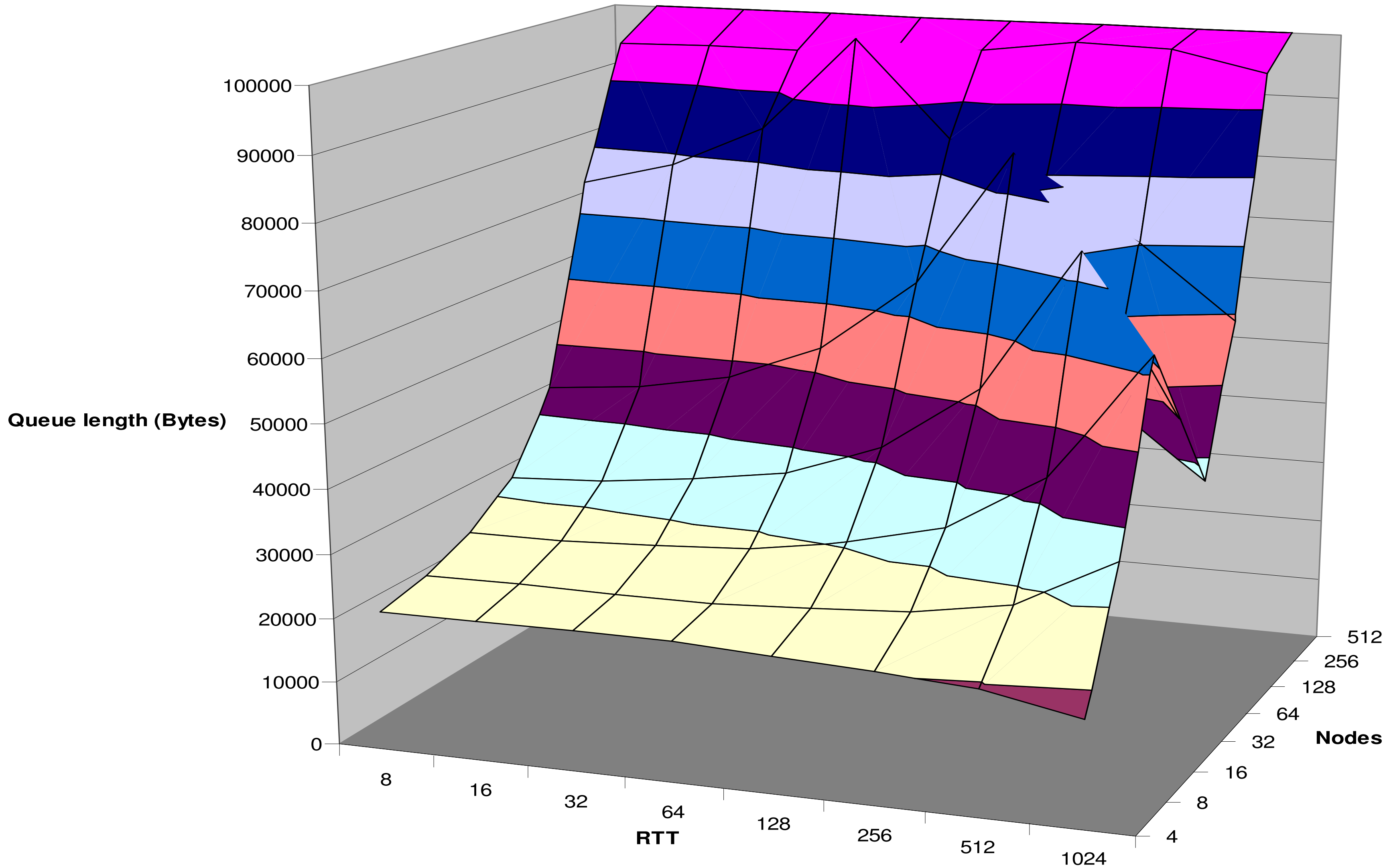


QCN+, adjusted for RTT and N



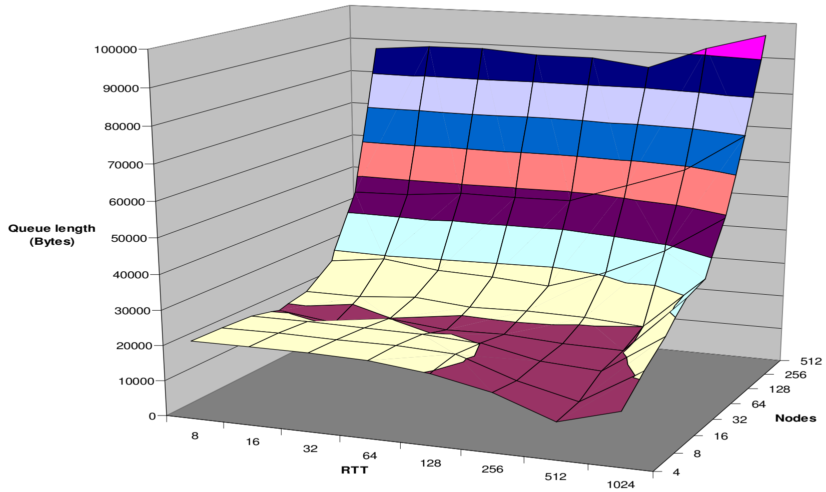
Average Queue Length at Hotspot, ECM

ECM

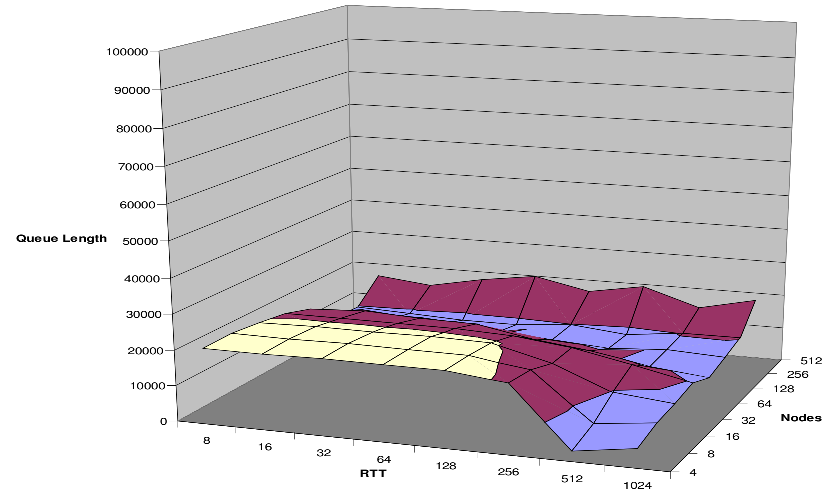


Average Queue Length at Hotspot

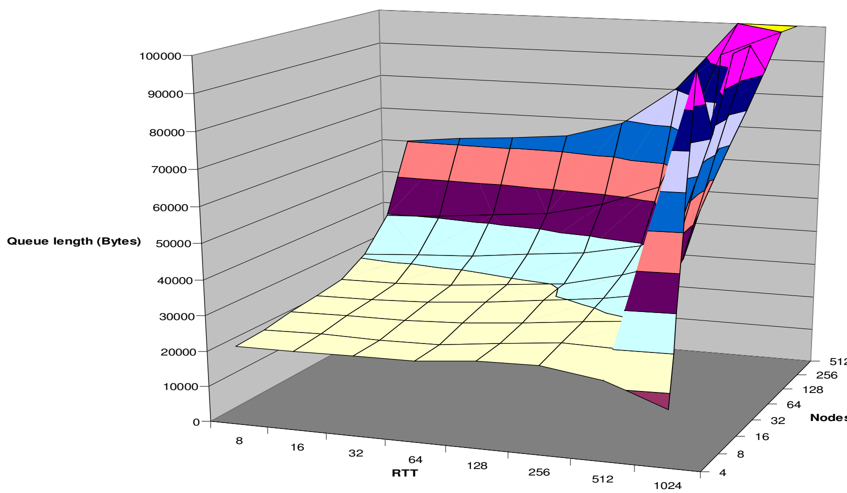
QCN-Sonar, no FR1 adjustment



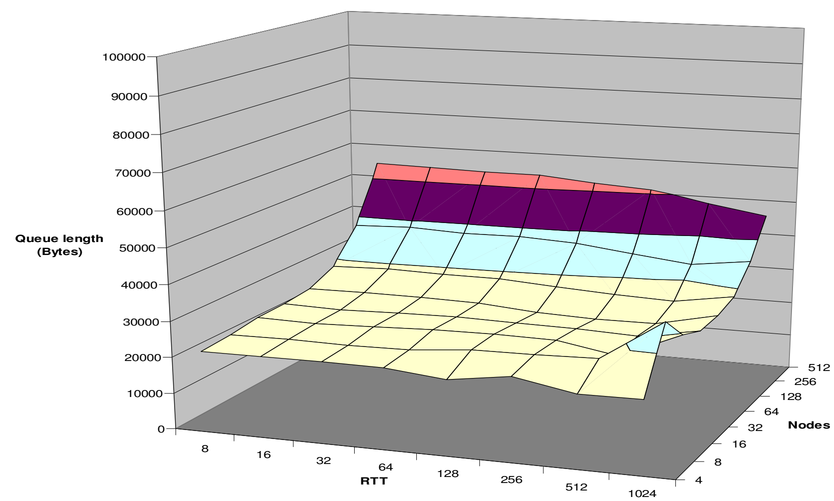
QCN-Sonar, FR1 adjustment



QCN+, adjusted for RTT only

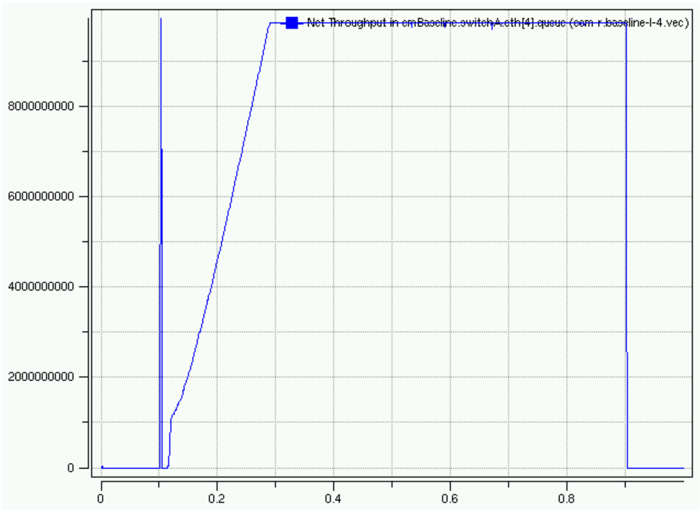


QCN+, adjusted for RTT and N

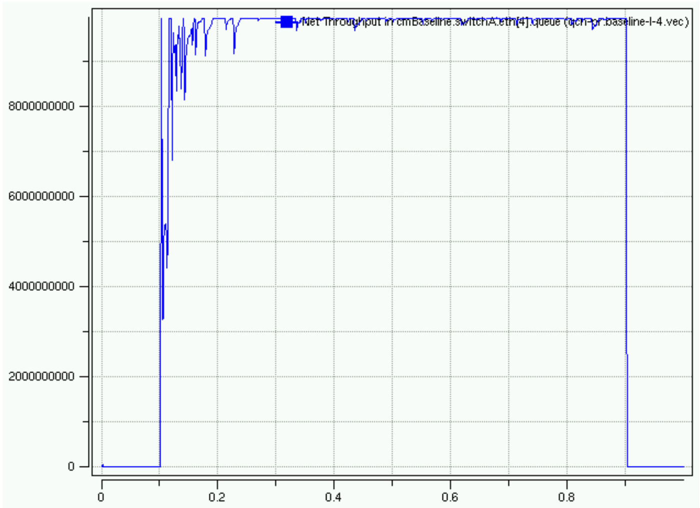


1ms Latency, 4 Nodes: Throughput at Hotspot

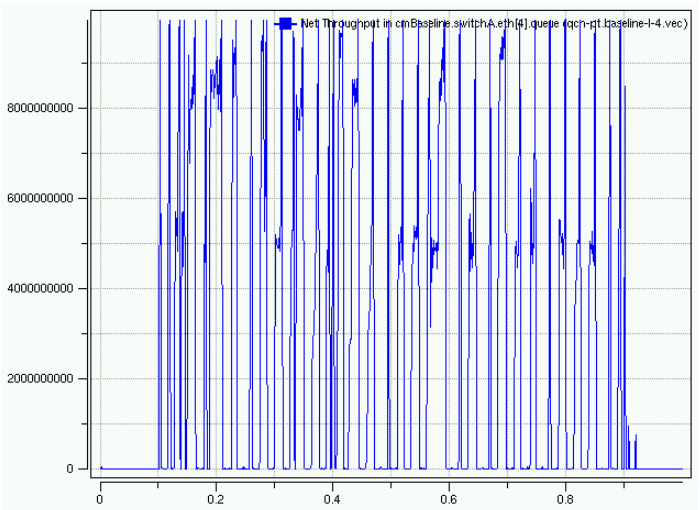
ECM



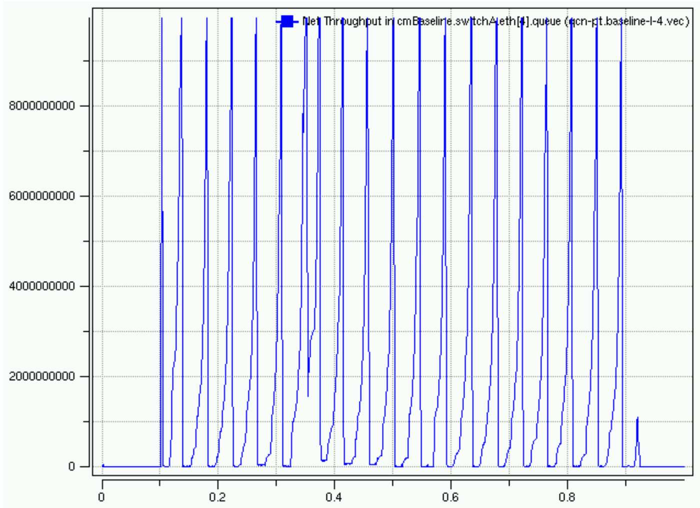
QCN+, adjusted for RTT and N



QCN-Sonar, no FR1 adjustment

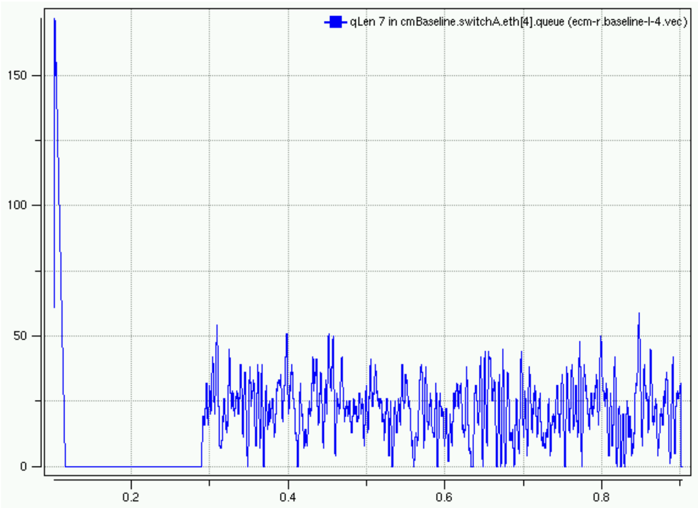


QCN-Sonar, FR1 adjustment

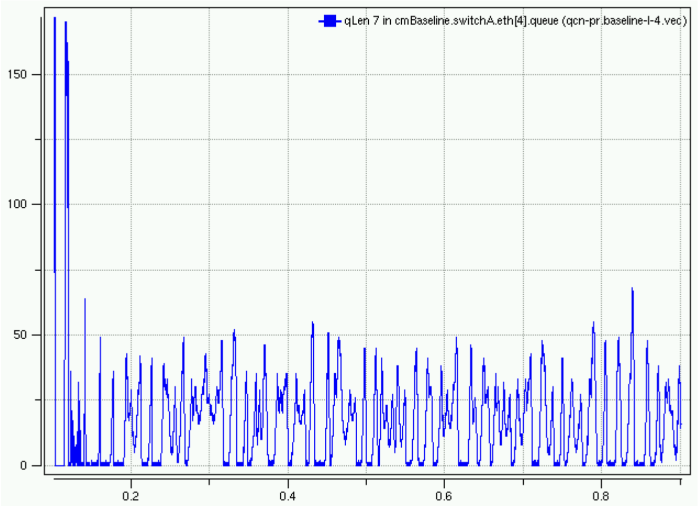


1ms Latency, 4 Nodes: Queue Length at Hotspot

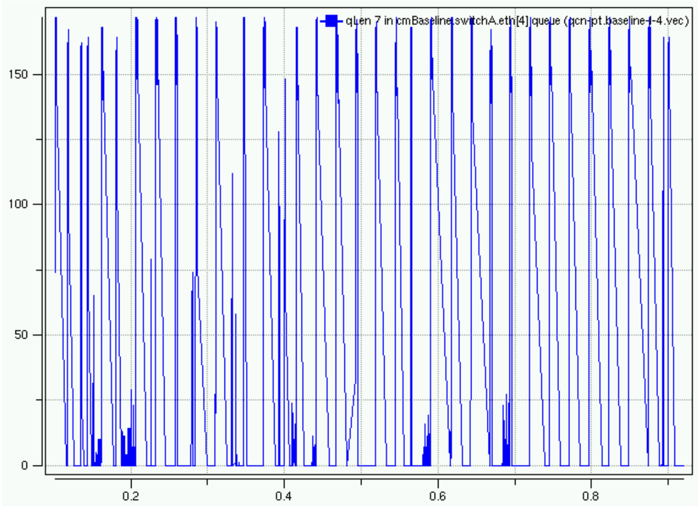
ECM



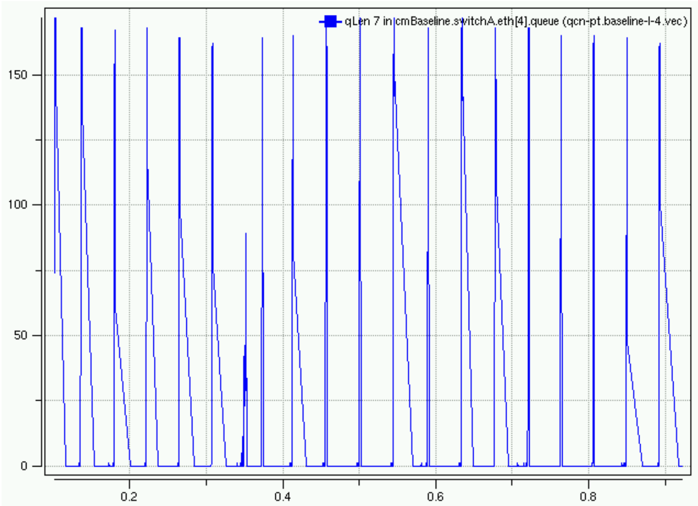
QCN+, adjusted for RTT and N



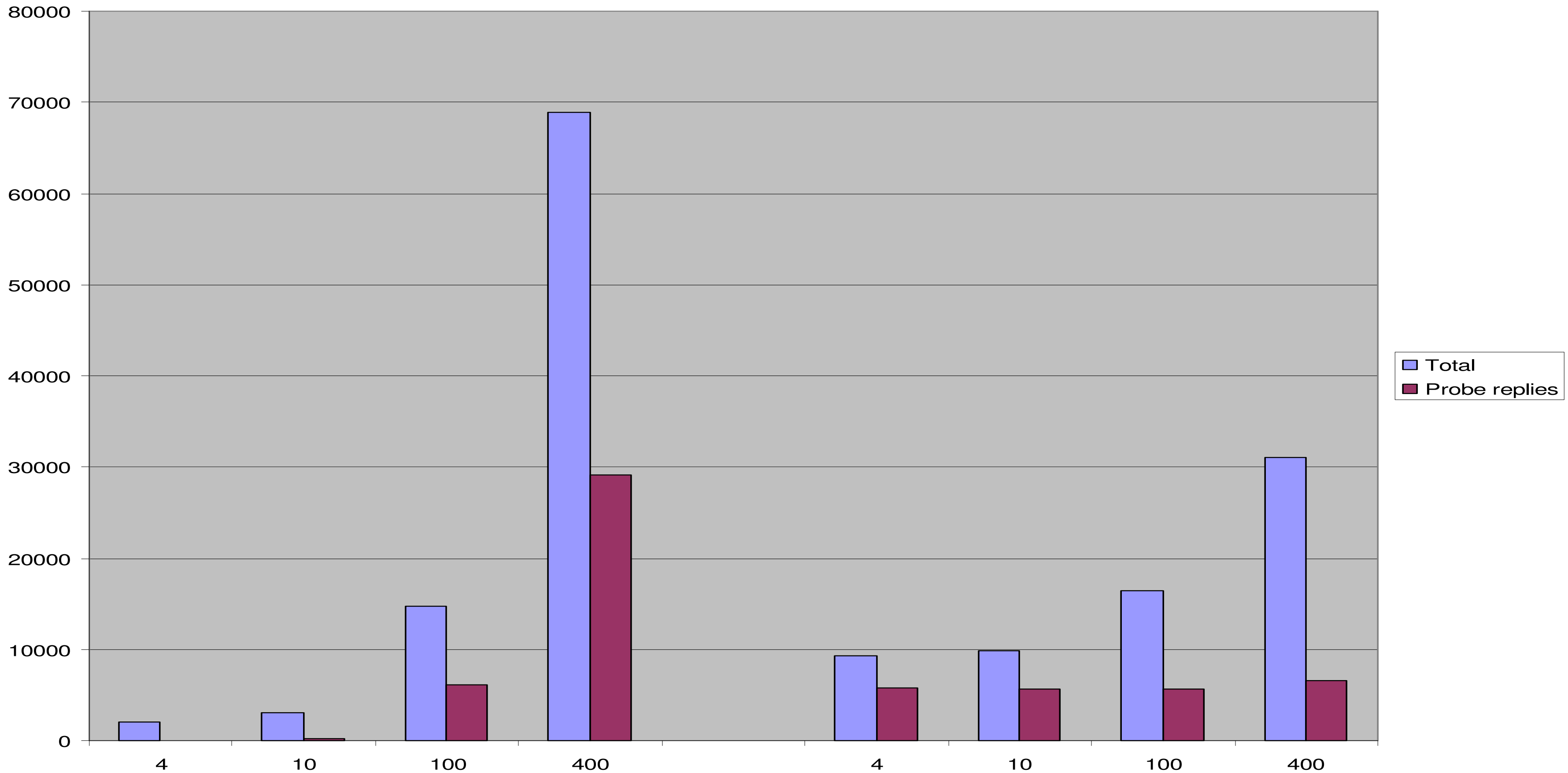
QCN-Sonar, no FR1 adjustment



QCN-Sonar, FR1 adjustment



Probe Traffic vs. Number of Nodes



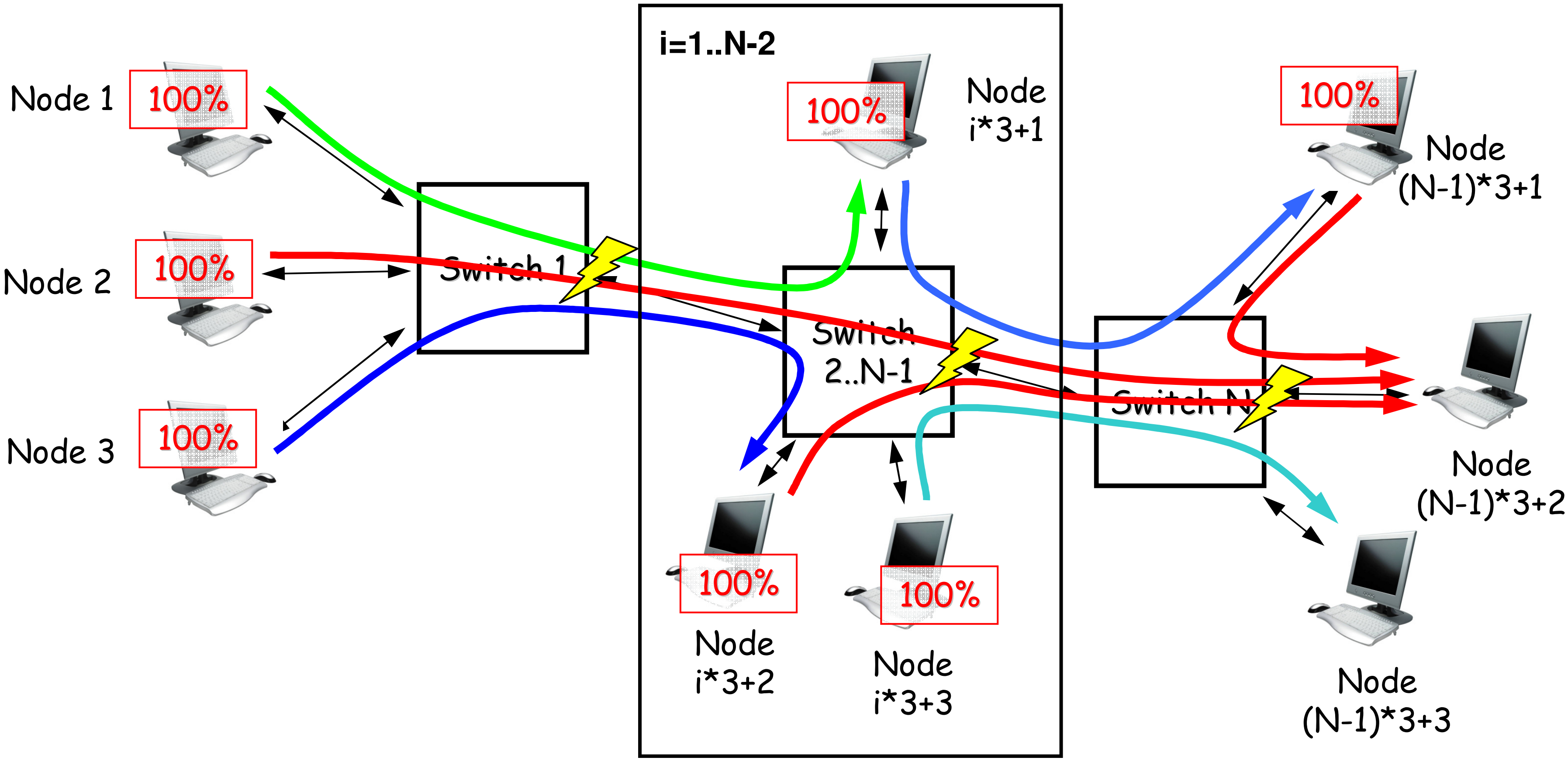
QCN-Sonar (10ms base timer)

QCN+

Observations

- Adjusting probing protocols for RTT / N works well
- QCN-Sonar
  - Works well with large <N>
  - Weak spot with <large RTT, ***small N***>
  - FR1 transient adjustment sounds like a good idea
    - Over-adjustment will need improvements
  - Probe reply rate proportional to number of queues / flows
    - Can get very large, especially with smaller timer values

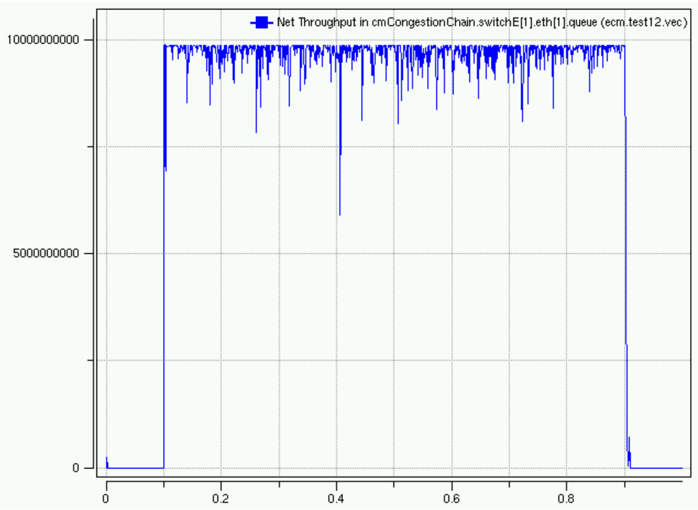
20-stage Hotspot with Bursty Load



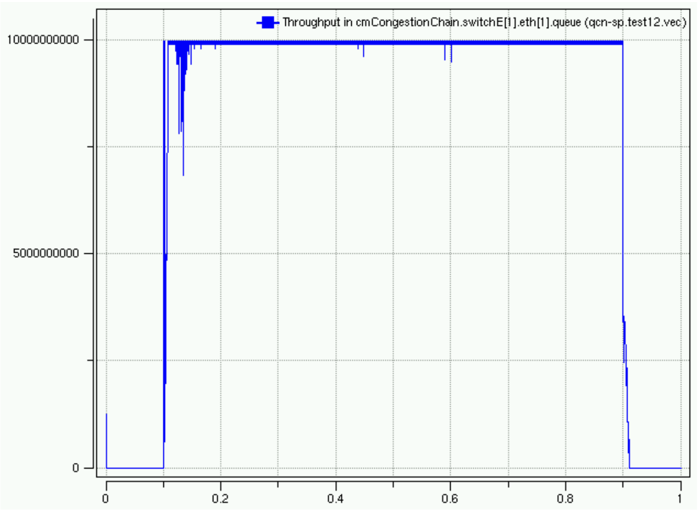
- N=18 switches; 3 hosts per switch
- Node <i> sends to node <i+3>; Node <i+1> sends to node (N-1)*3+2; node <i+2> sends to node <i+4>
- Node <1,4,7,...> sends bursty traffic with interval 1 + <i>*0.1 ms
- 100% load from all nodes
- Node (N-1)*3+2 receives traffic from <N> sources
- N hotspots

20-stage hotspot: Throughput at last hotspot

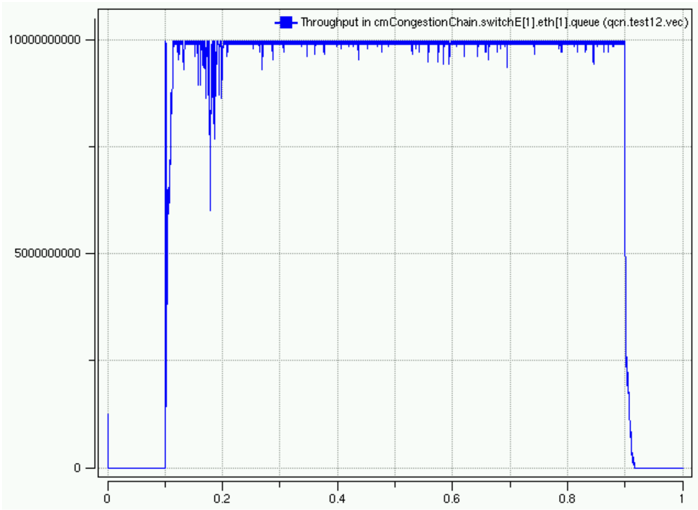
ECM



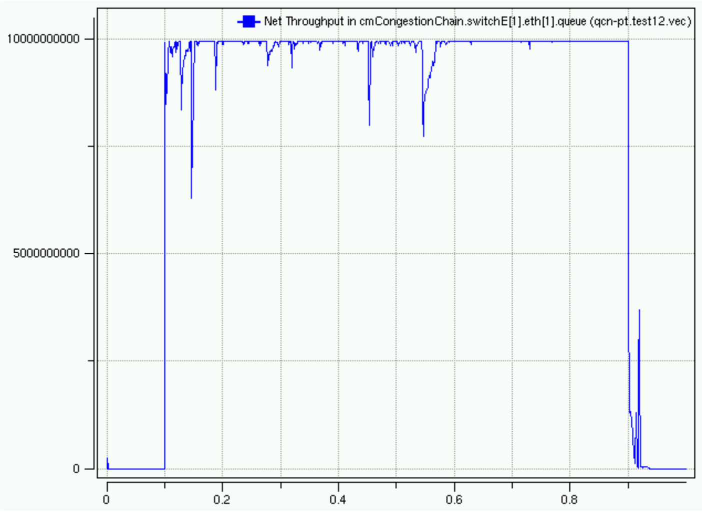
QCN+



QCN

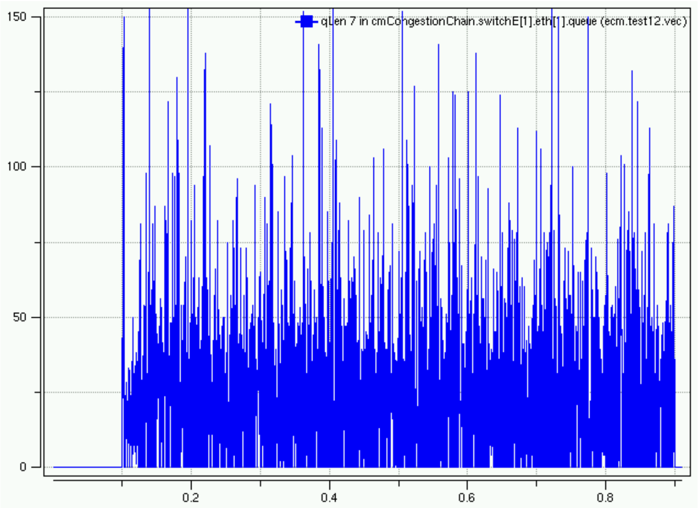


QCN-Sonar

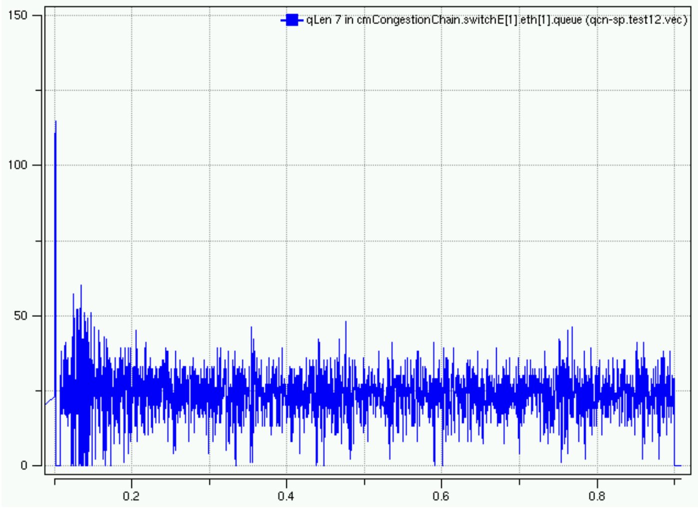


20-stage hotspot: Queue length at last hotspot

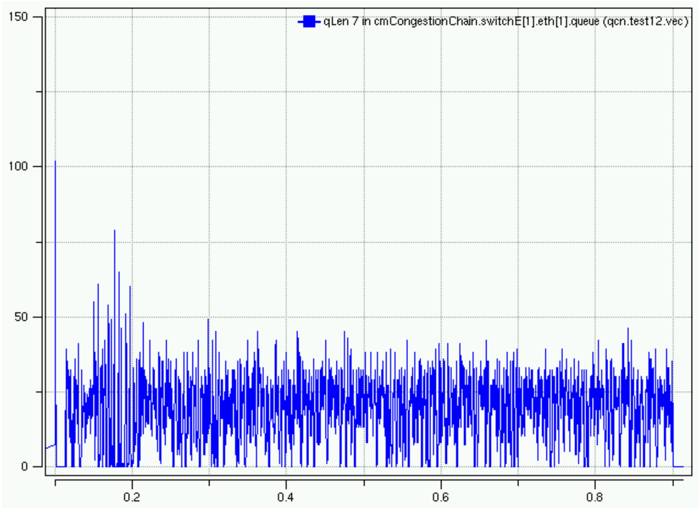
ECM



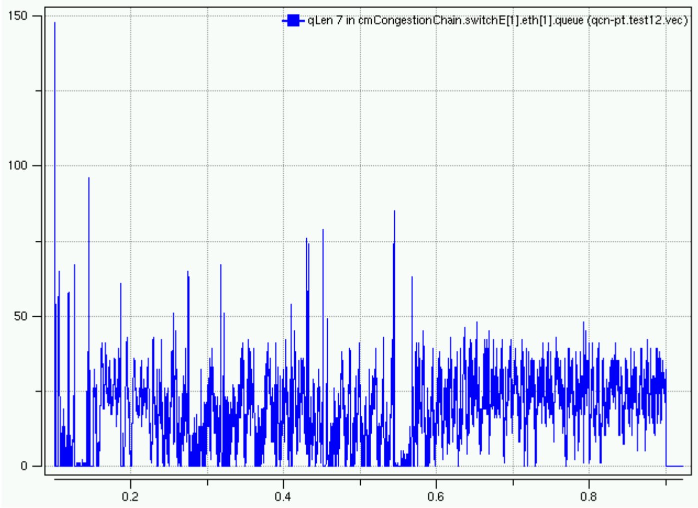
QCN+



QCN

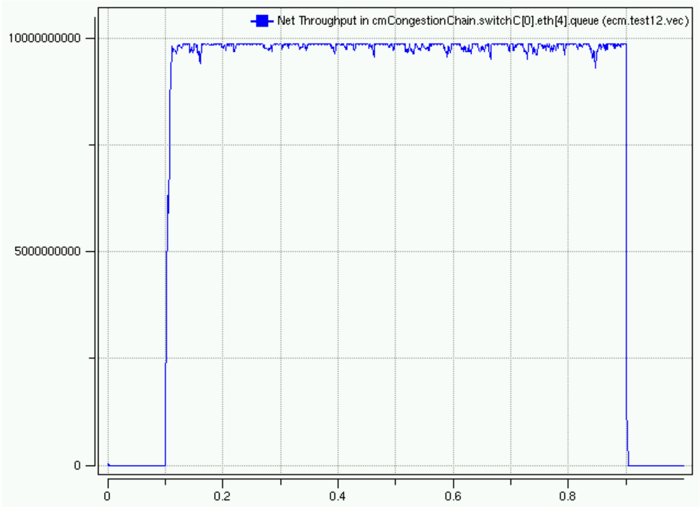


QCN-Sonar

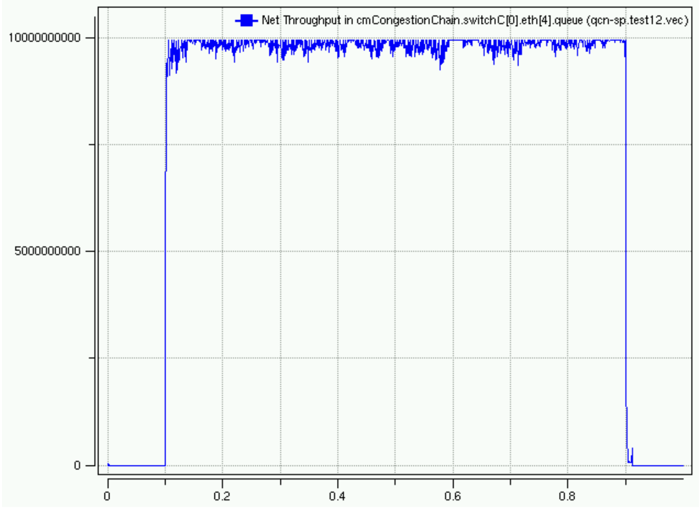


20-stage hotspot: Switch 2 Throughput

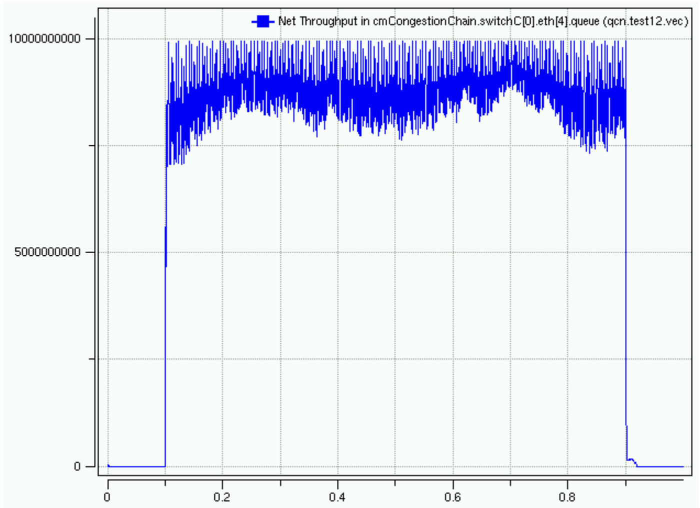
ECM



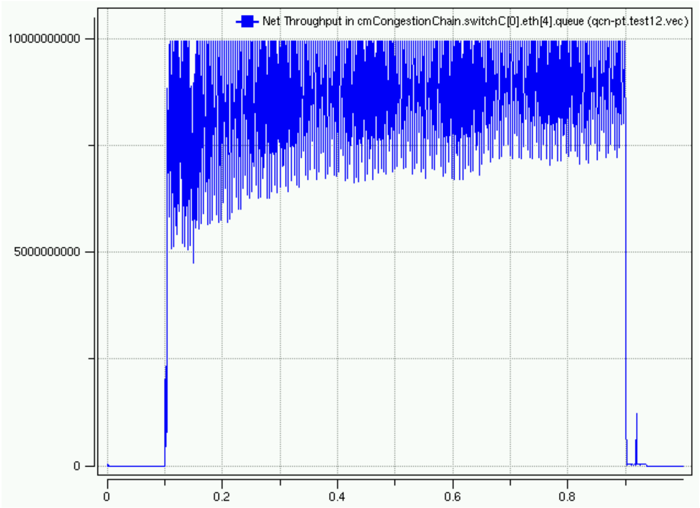
QCN+



QCN

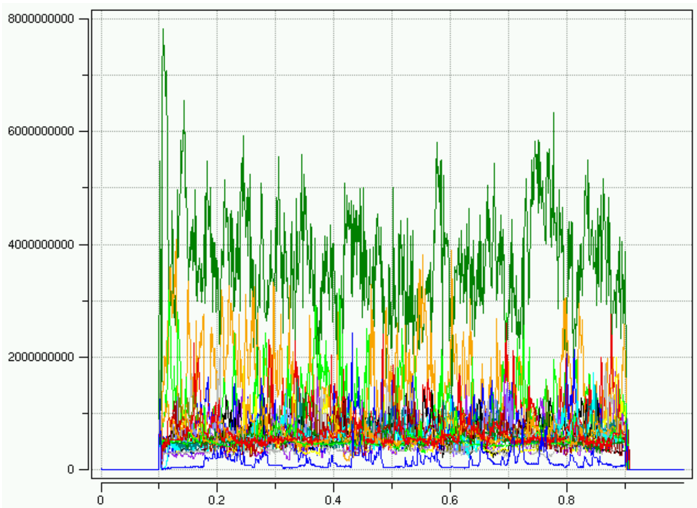


QCN-Sonar

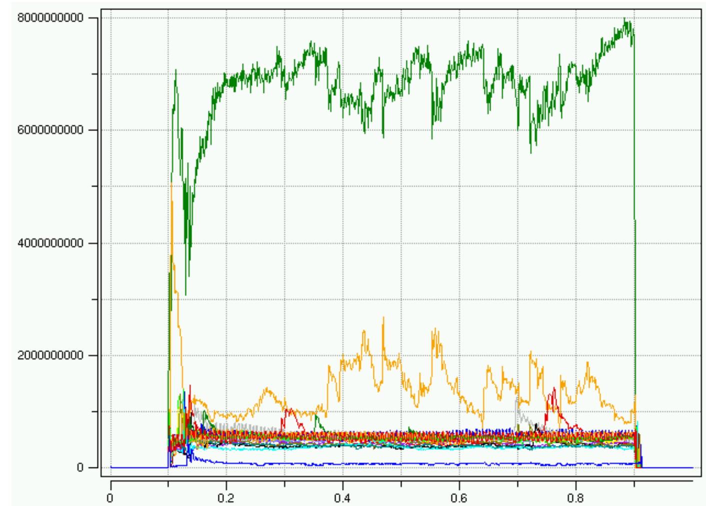


20-stage hotspot: Per-Flow Throughput

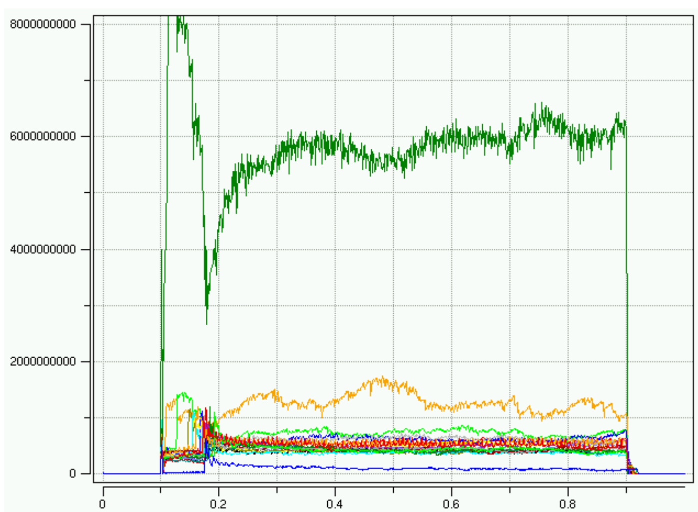
ECM



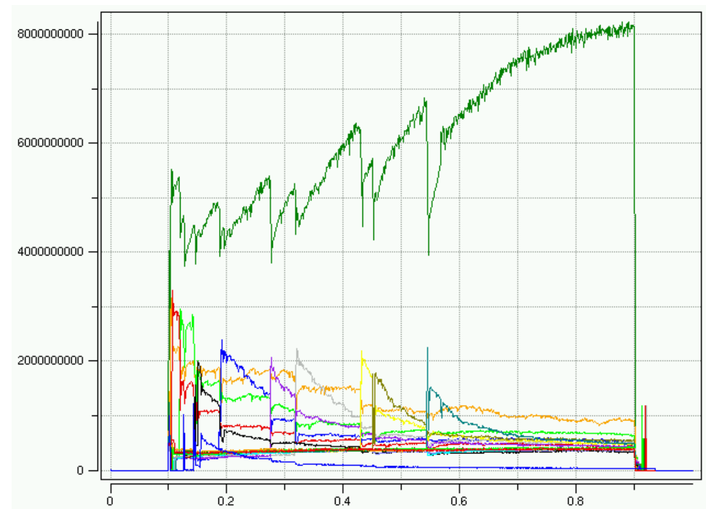
QCN+



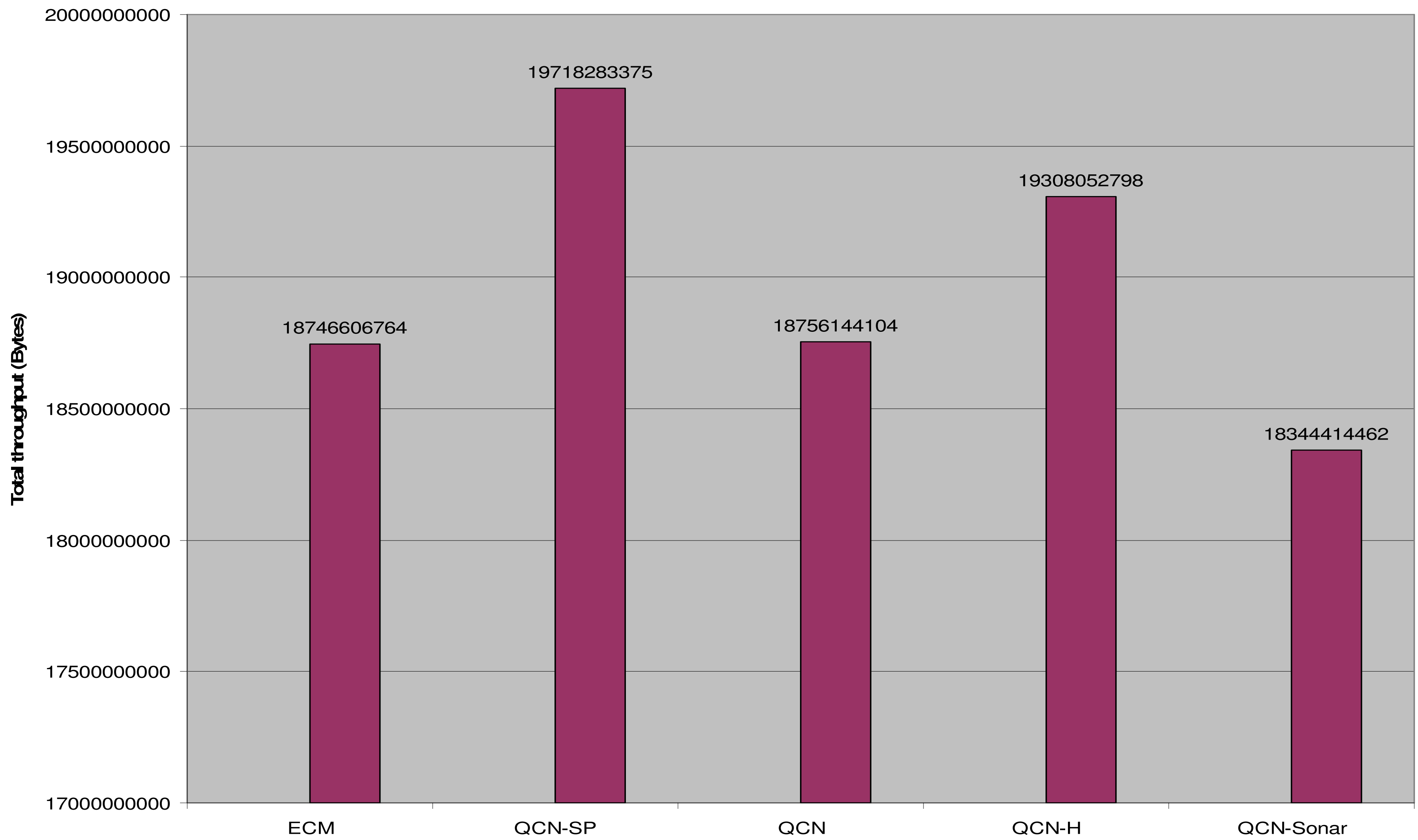
QCN



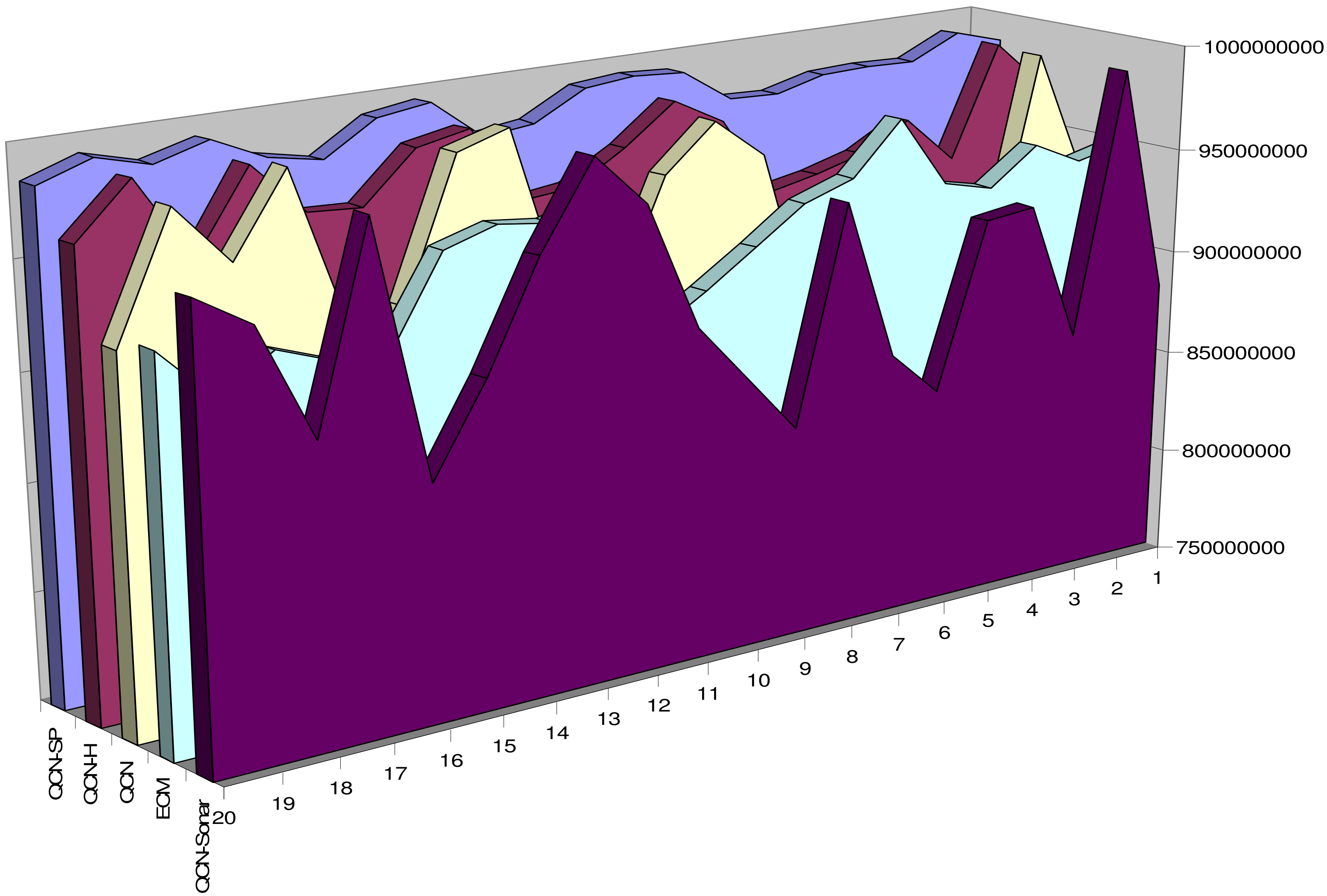
QCN-Sonar



20-stage hotspot: Total Throughput through all hotspots



20-stage Hotspot: Throughput per switch



- QCN-Sonar slightly worse than QCN in this test
  - Maybe due to different parameters

Summary

- QCN-Sonar
  - Improvement over QCN and QCN-FbHat
  - Introduces positive feedback
    - Lack of negative feedback equivalent to explicit positive feedback
  - Introduces gradual positive feedback, especially with low data rates
    - More binary feedback per data rate → impact similar to fewer messages with gradual increase
  - Introduces association to RTT
    - Timer setting reflects maximum supported RTT
  - Problem areas
    - Spurious Rate Limiters
    - Recovering available bandwidth
    - <Large RTT, low N>
  - Impact of timer-based positive rate adjustment needs further study

Summary - continued

- QCN+
  - Good performance if adjusted for RTT, N
- ECM
  - Good performance for small # of flows if adjusted for RTT
  - Would need adjustment for N (# of flows)

CPIDs and Rate Limiters

- CPID enables association of Congestion Points to Rate Limiters
- Thus, CPIDs improve protocol scalability and reduce number of required Rate Limiters
- Without CPIDs, the number of required Rate Limiters strictly depends on the number of L2 flows
  - More RLs will be needed to achieve comparable performance
- There may be a large number of L2 flows per CP from a single source
- As a result, protocol performance will suffer if CPIDs are not available
  - Especially if a CP only supports a few Rate Limiters
  - Protocol scalability will suffer as well

- Timer-based feedback introduces unknown elements
  - Rate gain inversely proportional to data rate
    - In other words, introduces rate based gain adjustment
    - Protocol favors flows with low datarate
  - Timer dependencies on link rate
    - Impact on multi-speed networks (low->high, high->low) ?
  - Feedback rate depends on # of RLs, not on link rate
    - As a result, # of feedback messages can get large with
      - Large number of flows
      - Multiple CPs, unless DE bit is reset
- Introduces RTT dependency
  - “hard” RTT limit depending on timer settings

Timer based feedback - continued

- Protocol overhead depends on the # of Rate Limiters
  - More RLs → more overhead
- As a result, Timer based feedback introduces conflicting objectives
  - Reduce # of RLs and use larger timer values to limit overhead
  - Increase # of RLs and use smaller timer values to improve protocol performance
- In combination with lack of CPID availability, overhead no longer determined by protocol, but by RP implementation decisions
  - RP implementation decisions will have impact on CP workload

QCN-Sonar Congested Condition Detection

- “No longer congested” condition in CP is determined as “Queue length < Qeq/<factor>” for a period of time
- Problem is that even a marginally loaded switch may experience spurious queue length buildup
  - See Stockholm presentation → Spurious rate limiters
- Worse, just one or two jumbo packets will create sufficient queue length
  - 2 * 9k = 18k > Qeq/2
- As a result, switches may not exit “congested” condition for a long period of time, even if their average link utilization is well below 100%

Conclusions

- QCN has come a long way
  - QCN-Sonar promises significant improvement over QCN and QCN-FbHat
  - Introduces positive feedback
- QCN-Sonar introduces several new concepts
  - Timer-based feedback loop
  - “No longer congested” condition in CP
  - Must be carefully studied
- Widest stability range achieved with closed-loop (probing) protocols with RTT and rate based gain adjustment

Conclusions - continued

- Still convinced that we need **explicit** probing
  - Enables RTT calculation and RTT based adjustments
  - Improved transient response
  - Achieve acceptable performance in OG hotspot scenarios
    - Faster recovery due to **explicit** positive feedback
  - Improved performance with large latencies, low N

QCN+

QCN+ (QCN-SP) at a Glance

What is QCN+ ?

- A hybrid between QCN and ECM with Sub-path probing. Architecture, operation, pseudo-code and simulation results are available.

What is mandatory / optional?

- M: Closed loop for increase <u>and</u> decrease controllers.
- O1: Probing → [Robustness]
- O2: Open loop rate increase → [cope w/ failures, ECN loss]

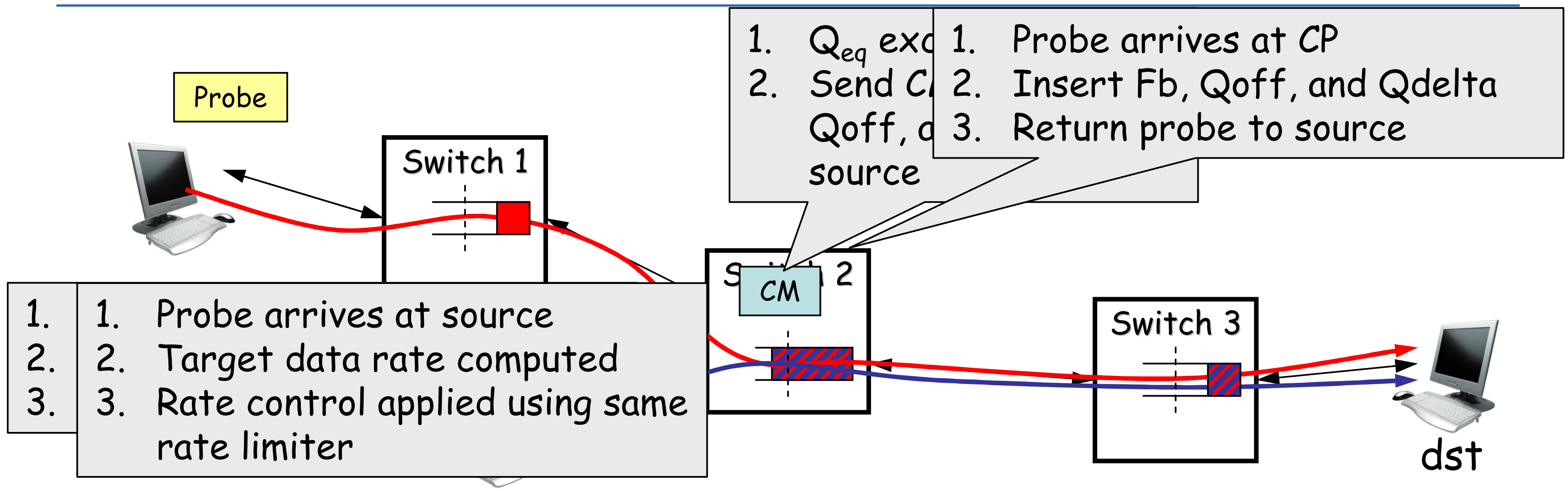
Distinctive feature(s)? Probing, positive feedback, fail-safe.

- Robust and scalable. Self-tuning [w/ probing].
- Closed loop => improved capacity tracking and dynamic response.
- Reliable: failures drive QCN+ into “fail-safe mode” (baseline QCN).

Complexity / performance ratio?

- Algorithm: simple fast rate recovery
- Implementation: comparable to baseline QCN

QCN+ Operation



- Probes sent for rate limited flows in regular intervals
- Probe destination address is most recent CP requesting a rate decrease
- Only rate limited frames are probed
- Probes sent at same priority as data frames
- Probe replies include Qoff, Qdelta
- Reaction Point takes RTT into account when adjusting its transmit rate

QCN+ Details

- Negative feedback as with QCN
- CP sends Qoff/Qdelta in addition to Fb
- Sub-path probes from RP to CP
  - To solicit explicit positive feedback
  - To enable RTT calculation
  - Probes sent whenever TO_THRESHOLD expires
  - Probe handling
    - All Probes replied to
    - In-path switches adjust Qoff/Qdelta/Fb
    - Negative feedback discarded at RP
- Quantized Qoff, Qdelta
  - Quantization against Qeq
    - qQoff = Qoff * 64 / Qeq;
    - qQdelta = Qdelta * 64 / Qeq;
  - Fb calculation at RP
    - Fb = -(qQoff - W * qQdelta) / (2*W+1)

QCN+ Details - Continued

- RTT based loop gain control in RP
  - Accept one negative adjustment per RTT
  - Adjust TO_THRESHOLD based on RTT and current datarate
  - Adjust W (and calculate Fb) based on RTT and current datarate
  - Reduce positive loop gain based on RTT
- ToThreshold adjustment
  - Set ToThreshold to max(TO_THRESHOLD, RTT * 2 * rate)
  - Effect on positive feedback similar to QCN-Sonar’s timer based approach
    - Smaller data rate → more probes per amount of data sent
- W adjustment
  - N = <switch link capacity> / <current rate>
  - W = baseW + (RTT * <factor> / N)

QCN+: Other changes from QCN

- Use variable sampling interval instead of sampling probability to generate CM packets
  - Next sample interval is calculated when a sample is taken
  - More stable than using sampling probability
    - Sampling packet generation is more predictable
    - Integration effect when calculating next sample interval
      - Protocol does not immediately react to short spikes in queue length
- Use Qoff to determine if to send negative CM adjustment messages
  - Create RL at RP if resulting Fb is negative
  - No more spurious rate limiters

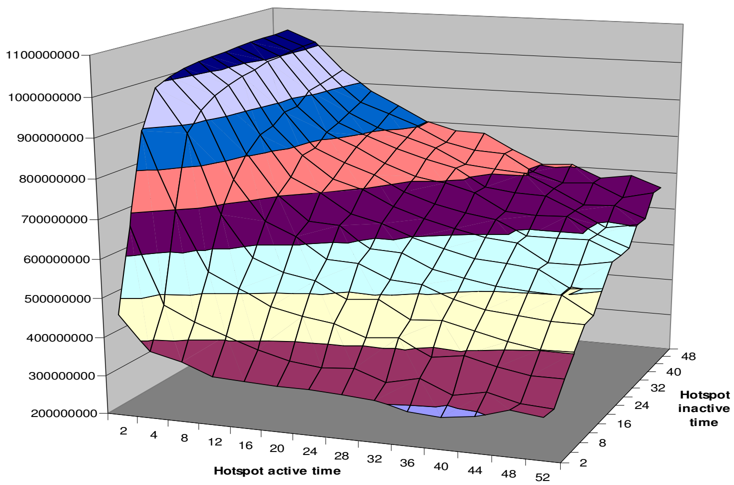
QCN+: Transient reaction

- Tested (or, rather, played with) several methods
  - Qsat as with ECM
  - Unlimited Qoff/Qdelta (not limited to multiples of Qeq)
  - Rate adjustments based on link capacity reported by switch
    - $F = \langle C_i \rangle / \langle C_{i-1} \rangle$
    - $R_i := R_{i-1} * F$
    - use this rate if lower than Fb-calculated rate
- Needs further study
  - QCN-Sonar approach looks promising

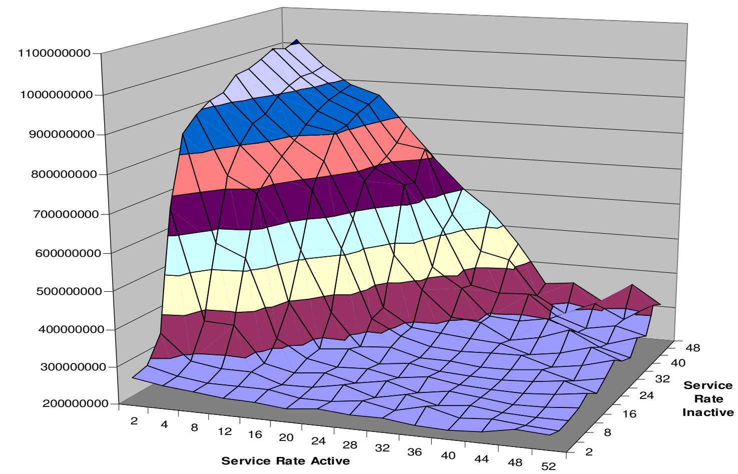
Why keep pushing ?

Oscillating Hotspot: Throughput Distribution

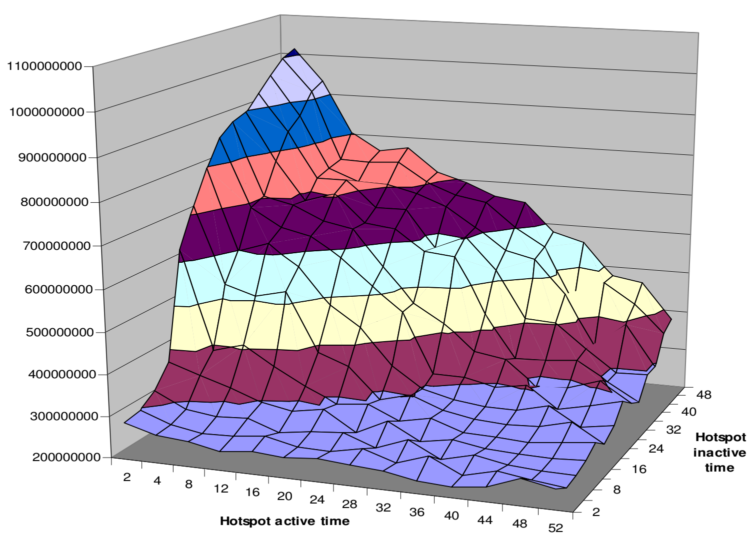
ECM



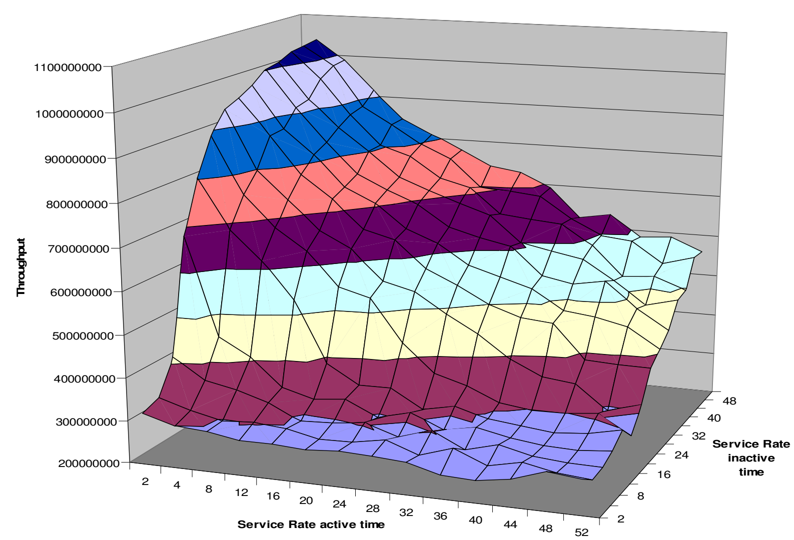
QCN, No hyperactive increase



QCN, Hyperactive increase

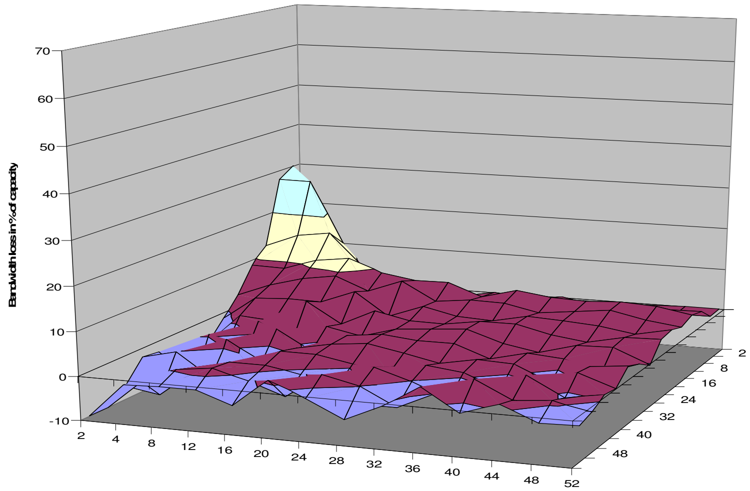


QCN-Sonar

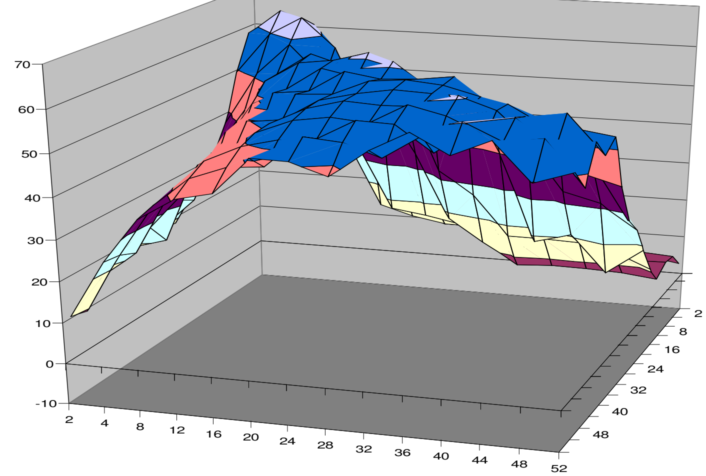


Oscillating Hotspot: Bandwidth Loss

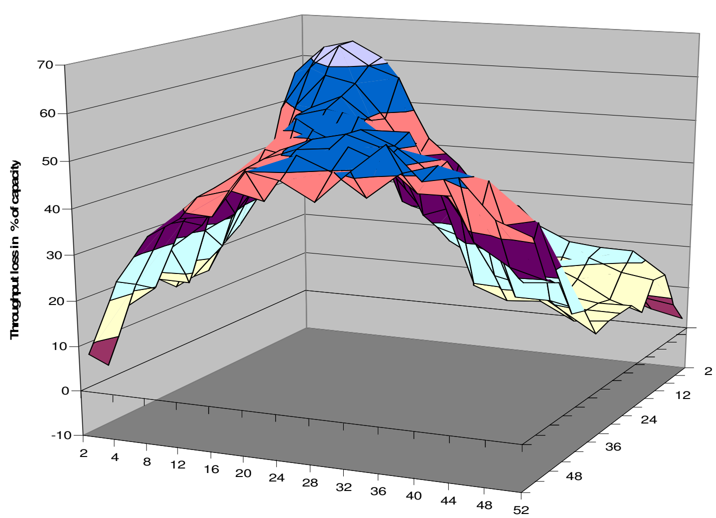
ECM



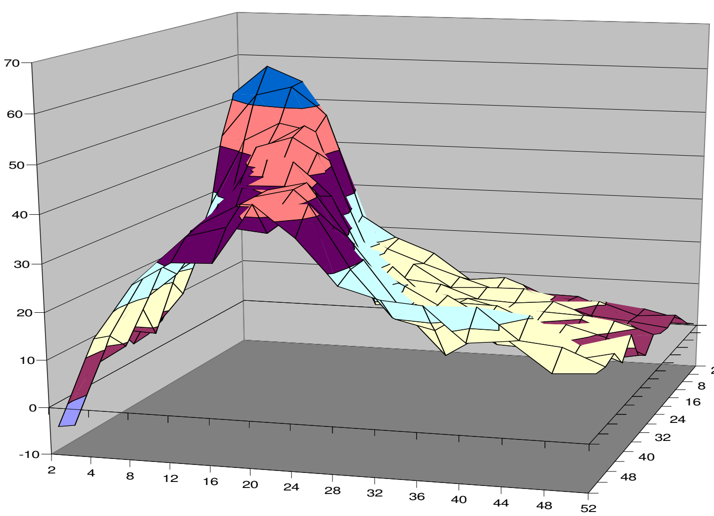
QCN, No hyperactive increase



QCN, hyperactive increase

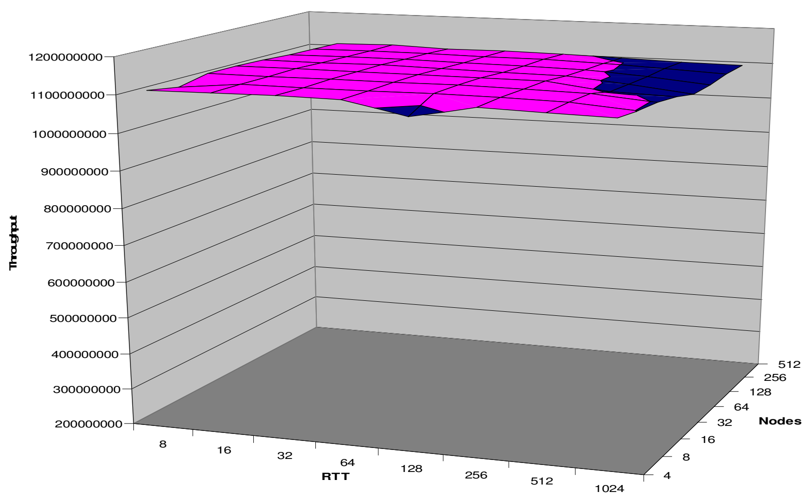


QCN-Sonar

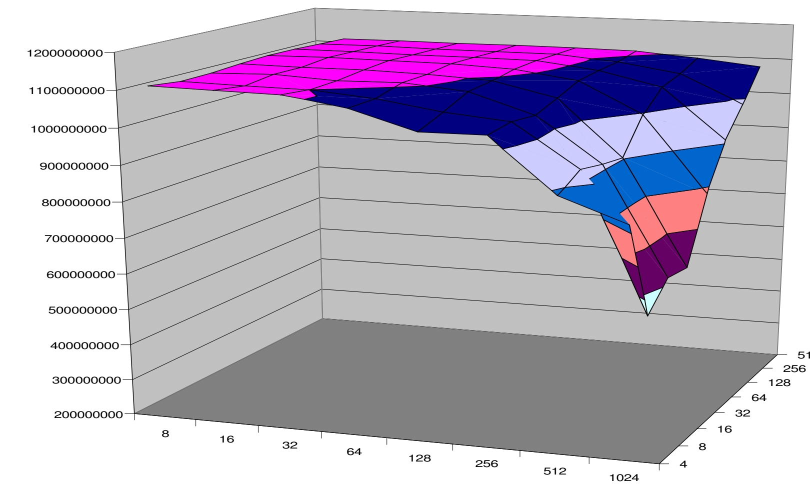


Large RTT/N: Throughput at Hotspot

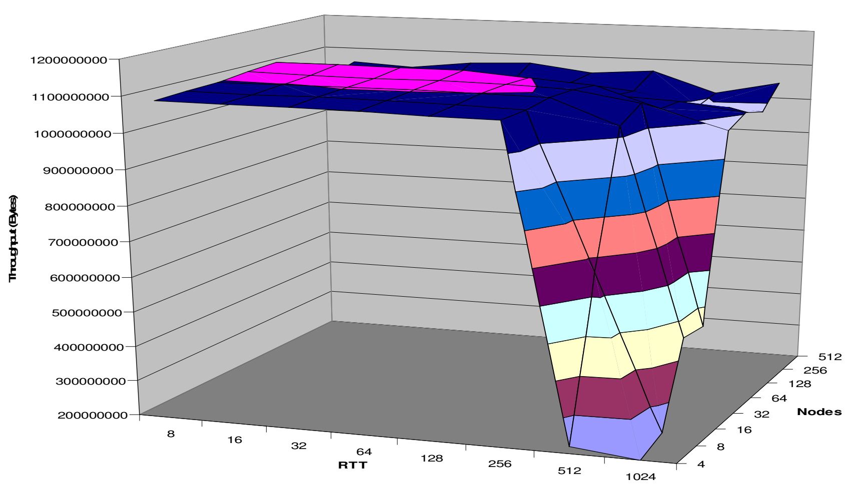
QCN+



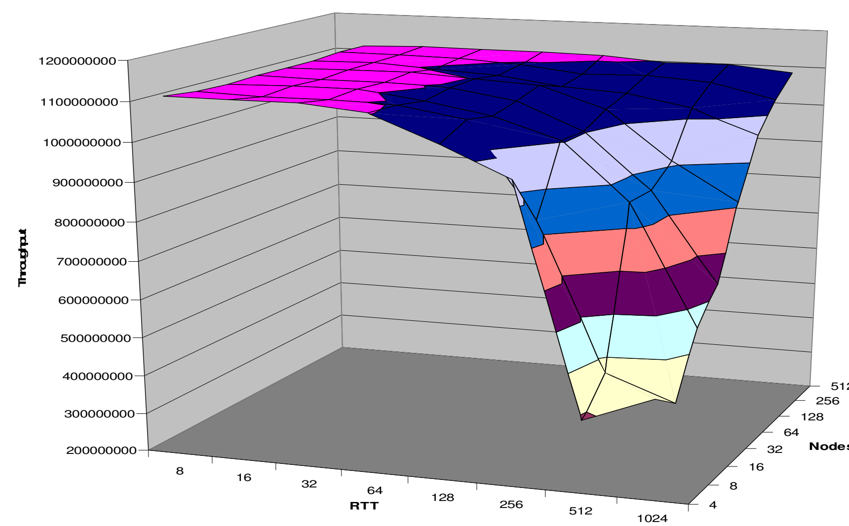
QCN, No hyperactive increase



QCN-Sonar, FR1

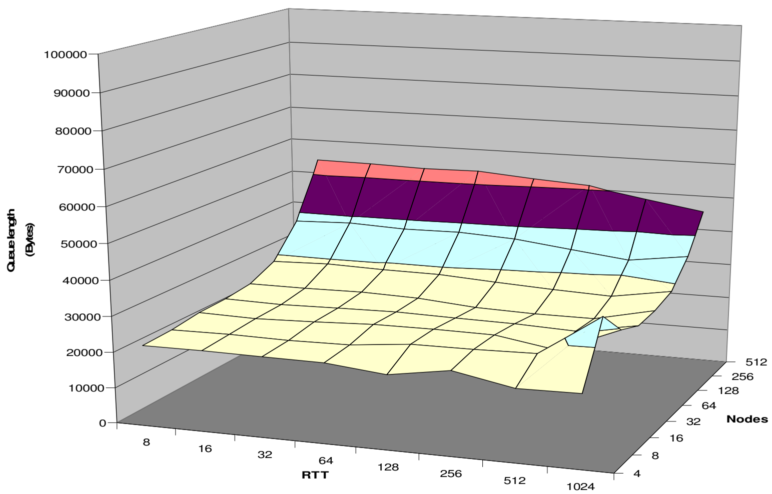


QCN-Sonar, No FR1

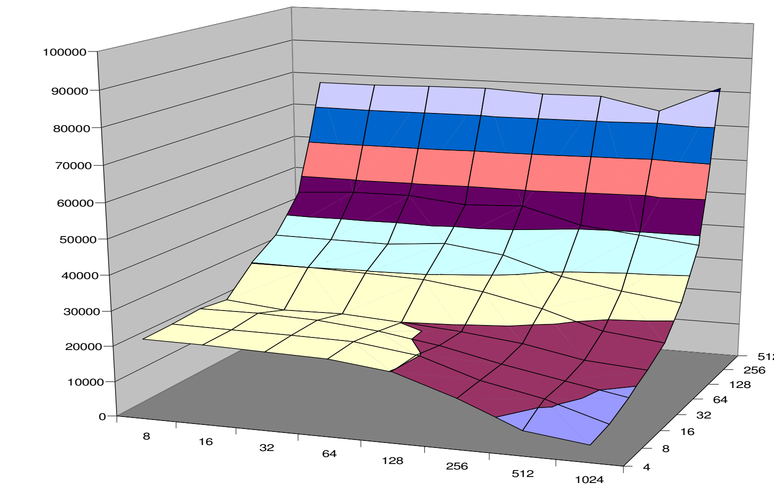


Large RTT/N: Average Queue Length at Hotspot

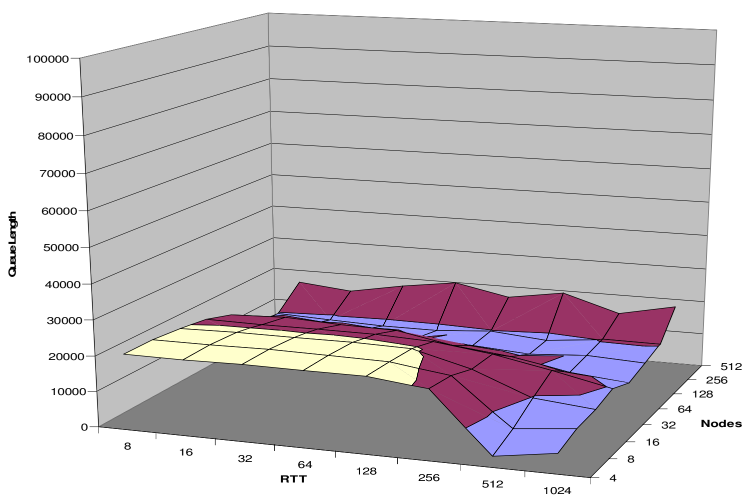
QCN+



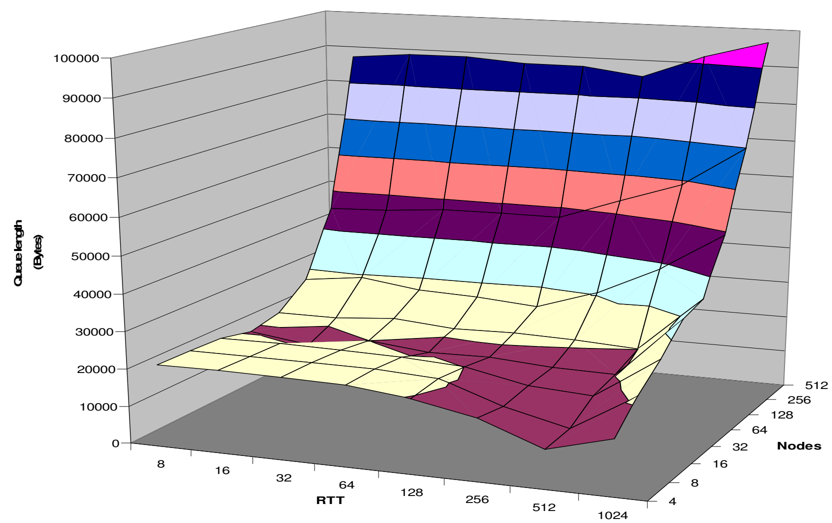
QCN, No Hyperactive increase



QCN-Sonar, FR1 adjustment



QCN-Sonar, no FR1 adjustment



- Since it was introduced, QCN has much improved
- Without pushing, improvements would not have happened
  - In fact, each time we keep hearing that my simulation results would not be correct
  - Which is then followed by protocol improvements
- QCN, if adopted, still needs significant improvement
  - Still not at par with ECM or QCN+
- Either fix, or adopt another scheme

Further study

- QCN-Sonar, after Pseudo-code published
- Transient reaction
  - Improve protocol reaction time for <large N, low bandwidth> scenarios
- QCN-style non-linear increase/decrease may have negative impact on stability w/ large RTT, especially with low N
  - Test ECM with adjustments for N/rate
  - Test ECM-style increase/decrease with Sub-path probing
- Optimize probe traffic
  - Can be reduced significantly, especially with low N (high data rate)

Teak simulation code access

- OMNET++
  - Download from www.omnetpp.org
- INET framework
  - git access (linux):

```
git clone git://teaktechnologies.com/var/git/INET.git INET
cd INET
git checkout –b my_branch origin/teak
```

- Latest code not yet included
  - Will be added after cleanup
- **Please keep in mind that this is GPL code**
  - **You are expected to publish your modifications**

Thank You

Backup Slides

Transforming QCN-Sonar into a Positive Feedback Scheme

1. Send explicit probes instead of tagging data packets
2. Drop probe if node in path is congested
3. At CM domain edge (switch or NIC), echo probe if not congested
4. At RP, increase rate if probe reply was received

Simulation Parameters

- Traffic
  - Bernoulli
  - 1500 byte frames
- System
  - Switch latency (processing time) = 1us
  - Link latency = 500ns
  - Switch frame capacity = 200kB, 250 packets
  - PAUSE generated by switch
  - RP egress buffer size 100 packets

Simulation Parameters - QCN-xx

- Drift factor = 1.0005
- Timer period = 1ms (or disabled)
- Extra fast recovery enabled
- EFR MAX disabled
- A = 12 Mbit
- Fast Recovery Threshold = 5
- Gd = 1/128
- TO_THRESH = 150 kBytes
- Qeq = 24kB
- QCN packet processing latency = 5uS
- Hyperactive Increase enabled/disabled
- Psample = 1% .. 10%
- W and gain adjusted for RTT

Simulation Parameters - ECM

- Qeq = 375
- Qsc = 1600
- Qmc = 2400
- Qsat enabled/disabled
- Gi = 0.53333 (adjusted for RTT)
- Gd = 0.00026667 (adjusted for RTT)
- Ru = 1,000,000
- Rd = 1,000,000 (10,000 for large N)
- Td = 1ms
- Rmin = 1,000,000
- W = 2.0 ..32 (adjusted for RTT)
- samplingInterval = 150000