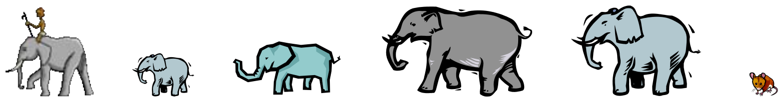
The UNIVERSITY *of* NORTH CAROLINA *at* CHAPEL HILL

# Differential Congestion Notification: Taming the Elephants



*Long Le, Jay Aikat, Kevin Jeffay, and Don Smith*

IEEE ICNP 2004

***http://www.cs.unc.edu/Research/dirt***

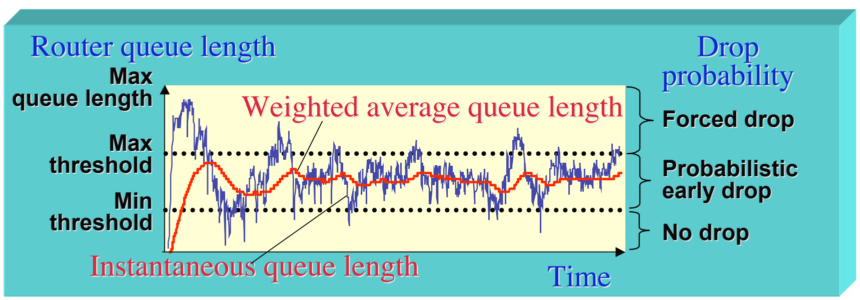
# Outline

- Background: Router-based congestion control
  - Active Queue Management (AQM)
  - Explicit Congestion Notification (ECN)
- Do AQM schemes work?
- The case for *differential congestion notification* (DCN)
- A DCN prototype and its empirical evaluation



# Active Queue Management

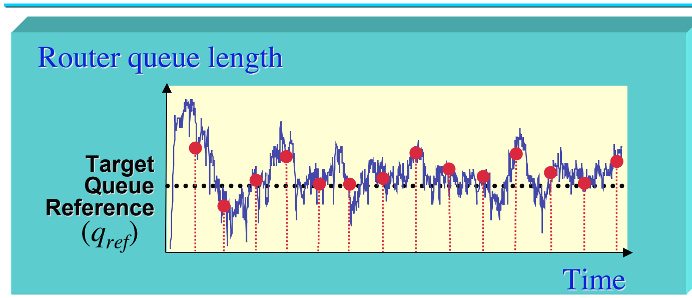
## The RED Algorithm [Floyd & Jacobson 93]




- RED computes a weighted moving average of queue length to accommodate bursty arrivals
- Drop probability is a function of the current average queue length
  - The larger the queue, the higher the drop probability

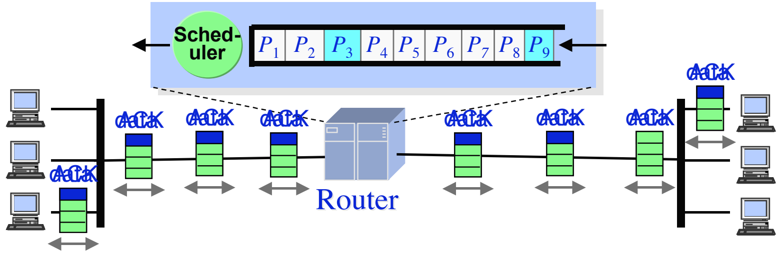


# The Proportional Integral (PI) Controller




- PI attempts to maintain an explicit target queue length
- PI samples instantaneous queue length at fixed intervals and computes a mark/drop probability at $k^{th}$ sample:
  - $p(kT) = a \times (q(kT) - q_{ref}) - b \times (q((k-1)T) - q_{ref}) + p((k-1)T)$
  - $a$, $b$, and $T$ depend on link capacity, maximum RTT and the number of flows at a router

# Explicit Congestion Notification Overview




- Set a bit in a packet's header and forward towards the ultimate destination
- A receiver recognizes the marked packet and sets a corresponding bit in the next outgoing ACK
- When a sender receives an ACK with ECN it invokes a response similar to that for packet loss.

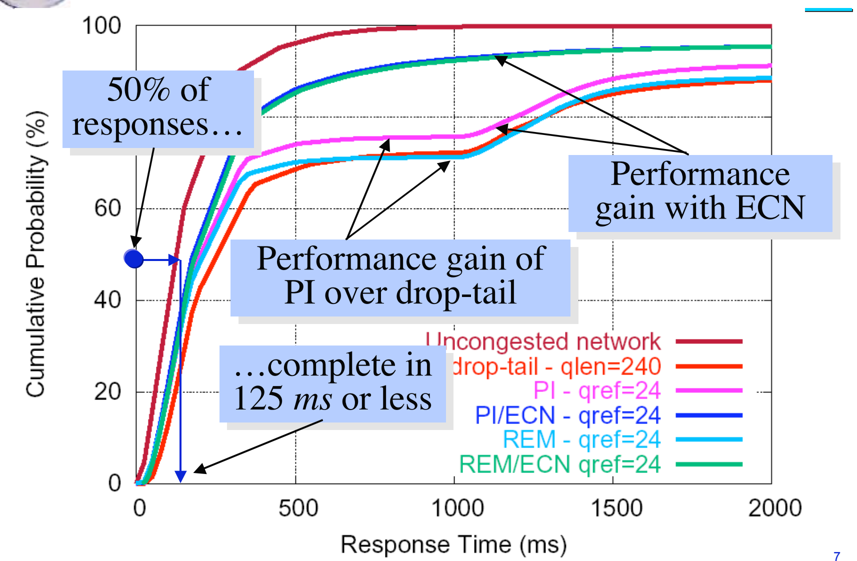


# Do AQM Schemes Work?
## Evaluation of ARED, PI, and REM

- "The Effects of Active Queue Management on Web Performance" [SIGCOMM 2003]. When user response times are important performance metrics:
  - Without ECN, PI results in a modest performance improvement over drop-tail and other AQM schemes
  - With ECN, both PI and REM provide significant performance improvement over drop-tail



# Evaluation of ARED, PI, and REM
## Experimental Results – 98% Load



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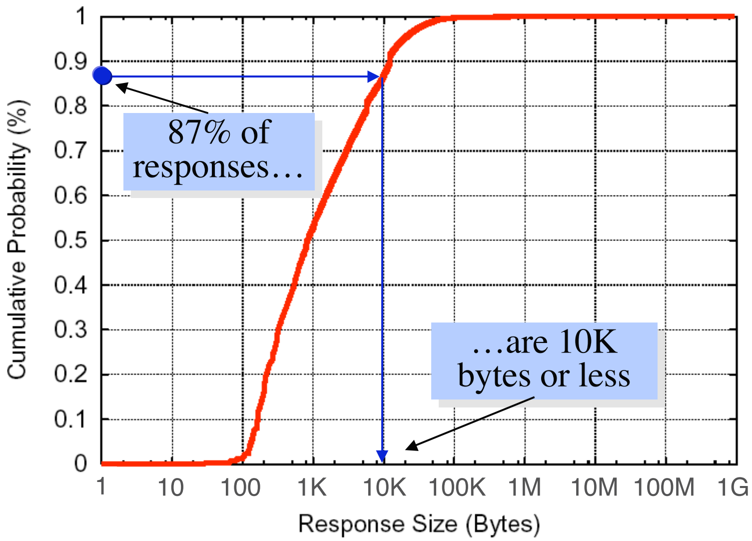
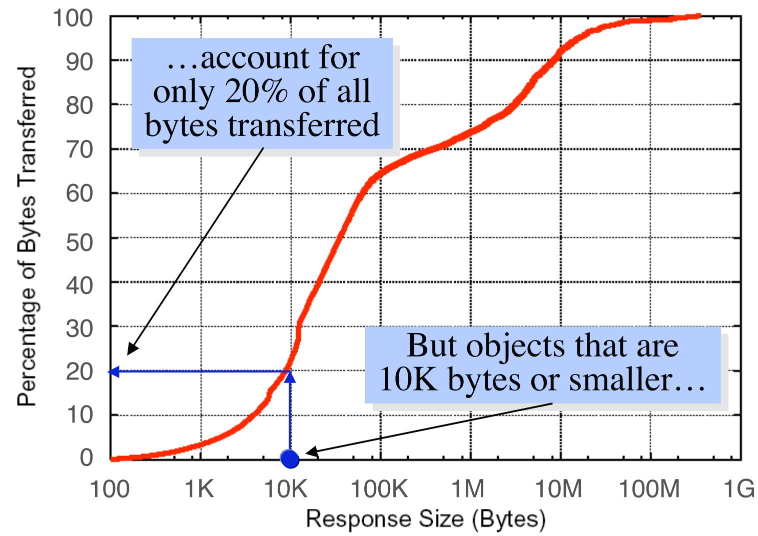
## The Structure of Web Traffic
### Distribution of response sizes






## The Structure of Web Traffic
### Percent of bytes transferred by response sizes



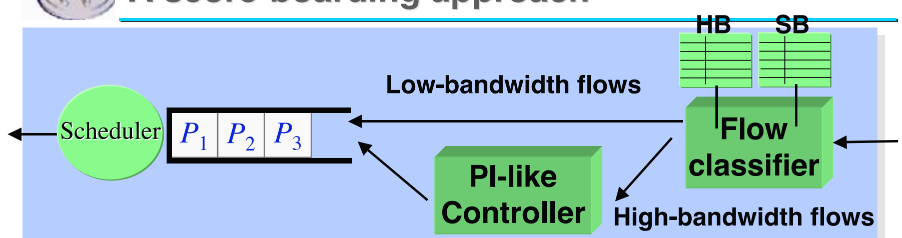



## Realizing Differential Notification
### Issues and approach

- How to identify packets belonging to long-lived, high bandwidth flows with minimal state?
  - Adopt the Estan & Varghese flow filtering scheme developed for traffic accounting [SIGCOMM 2002]
- How to determine when to signal congestion (by dropping packets)?
  - Use a PI-like scheme [Infocom 2001]
- Differential treatment of flows an old idea:
  - FRED
  - CHOKe
  - AFD
  - RIO-PS
  - SRED
  - SFB
  - RED-PD
  - …



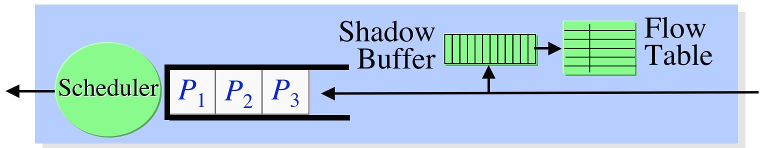
## Classifying Flows
### A score-boarding approach




- Use two hash tables (hash keys are formed by IP addressing 4-tuple plus protocol number):
  - A "suspect" flow table HB ("high-bandwidth") and
  - A per-flow packet count table SB ("scoreboard")
- Arriving packets from flows in HB are subject to dropping
- Arriving packets from other flows are inserted into SB and tested to determine if the flow should be considered high-bandwidth
  - Use a simple packet count threshold for this determination

# An Alternate Approach

## AFD [Pan *et al.* 2003]



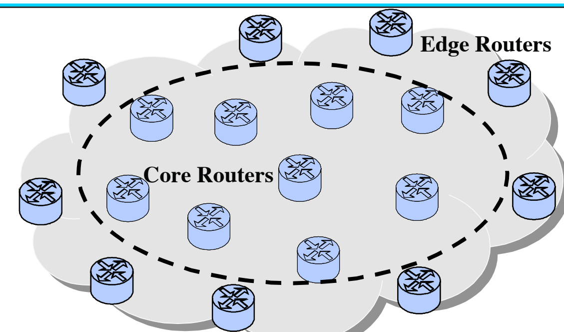

"Approximate Fairness through Differential Dropping"

- Sample 1 out of every *s* packets and store in a *shadow buffer* of size *b*
- Estimate flow's rate as $r_{est} = R \frac{\#\ matches}{b}$
- Drop packet with probability $p = 1 - \frac{r_{fair}}{r_{est}}$



# Another Alternate Approach

## RIO-PS [Guo and Matta 2001]

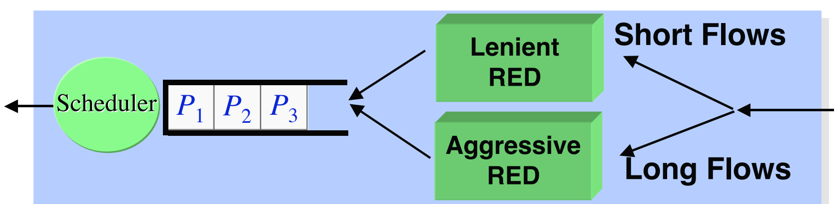



- Edge routers: maintain per-flow counters and classify flows into two classes: "Short" or "Long"
- Core routers:
  - use different RED engines for short and long flows
  - use different RED parameter settings to give preferential treatment to short flows



# Another Alternate Approach

## RIO-PS [Guo and Matta 2001]




**Core router's architecture**

- Edge routers: maintain per-flow counters and classify flows into two classes: "Short" or "Long"
- Core routers:
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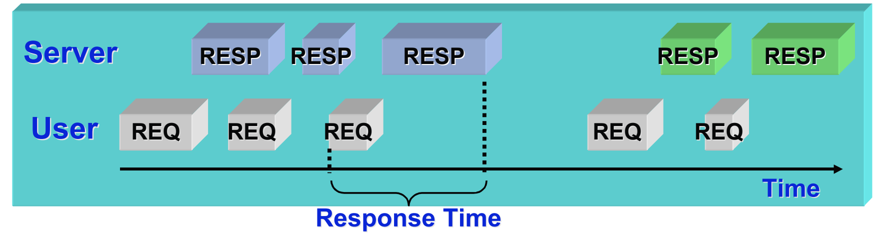
# Evaluation Methodology

- Evaluate AQM schemes through "live simulation"
- Emulate the browsing behavior of a large population of users surfing the web in a laboratory testbed
  - Construct a physical network emulating a congested peering link between two ISPs
  - Generate synthetic HTTP requests and responses but transmit over real TCP/IP stacks, network links, and switches
  - Also perform experiments with mix of TCP applications



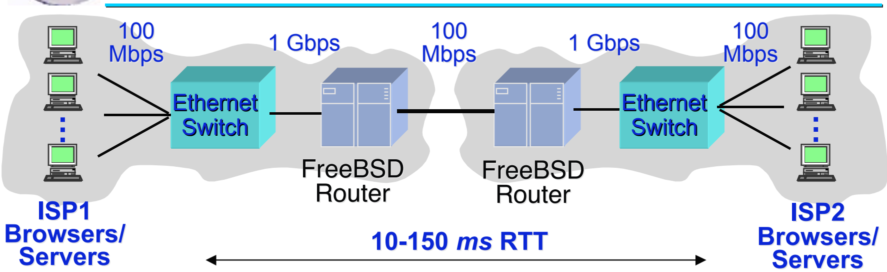
# Experimental Methodology
## HTTP traffic generation




- Synthetic web traffic generated using the UNC HTTP model [SIGMETRICS 2001, MASCOTS 2003]
- Primary random variables:
  - Request sizes/Reply sizes
  - User think time
  - Persistent connection usage
  - Nbr of objects per persistent connection
  - Number of embedded images/page
  - Number of parallel connections
  - Consecutive documents per server
  - Number of servers per page



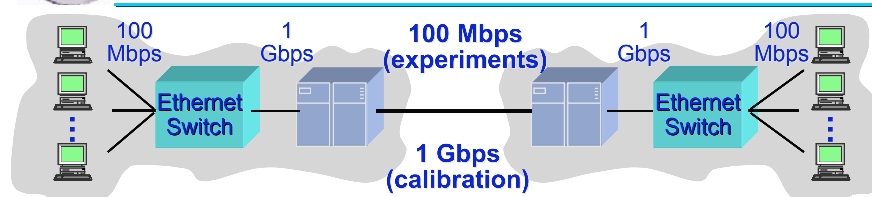
# Experimental Methodology
## Testbed emulating an ISP peering link




- AQM schemes implemented in FreeBSD routers using ALTQ kernel extensions
- End-systems either a traffic generation client or server
  - Use *dummynet* to provide *per-flow* propagation delays
  - Two-way traffic generated, equal load generated in each direction

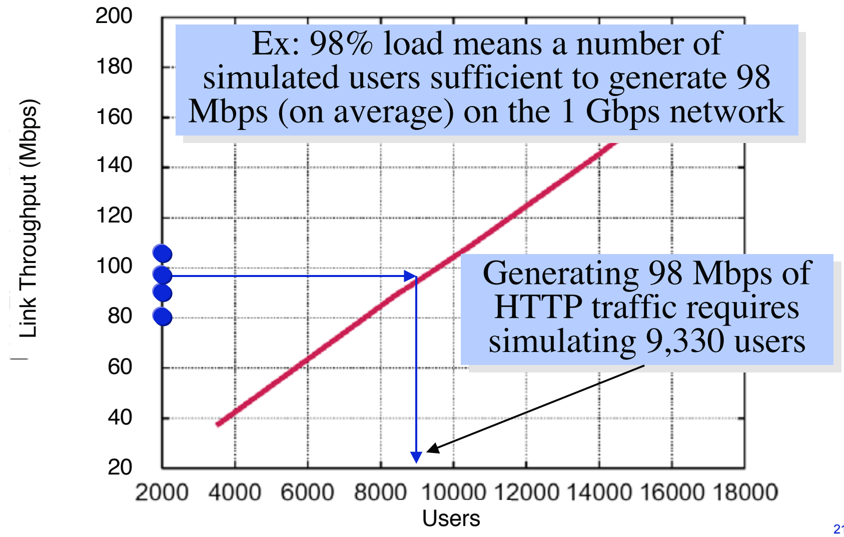


# Experimental Methodology
## 1 Gbps network calibration experiments




- Experiments run on a congested 100 Mbps link
- Primary simulation parameter: Number of simulated browsing users
- Run calibration experiments on an uncongested 1 Gbps link to relate simulated user populations to average link utilization
  - (And to ensure offered load is linear in the number of simulated users — *i.e.*, that end-systems are not a bottleneck)

## Experimental Methodology
### 1 Gbps network calibration experiments





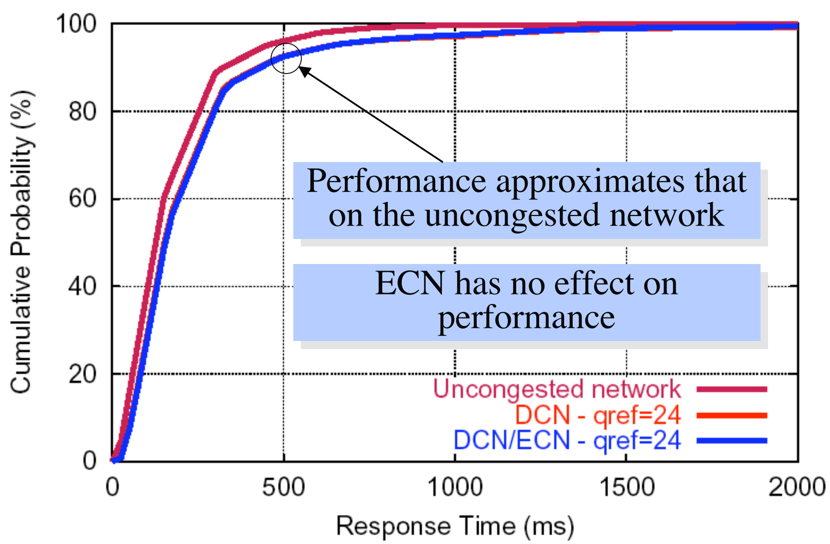

## DCN Evaluation
### Experimental plan

| | 80% | 90% | 98% | 105% |
|---|---|---|---|---|
| uncongested drop-tail<br>DCN<br>AFD<br>PI<br>RIO-PS | *loss rate*<br>*utilization*<br>*response times*<br>*completed requests* | | | |

- Run experiments with DCN, AFD, RIO-PS, and PI at different offered loads
  - PI always uses ECN, test AFD and RIO-PS with and without ECN
  - DCN always signals congestion via drops
- Compare DCN results against…
  - The better of PI, AFD, and RIO-PS (the performance to beat)
  - The uncongested network (the performance to approximate)

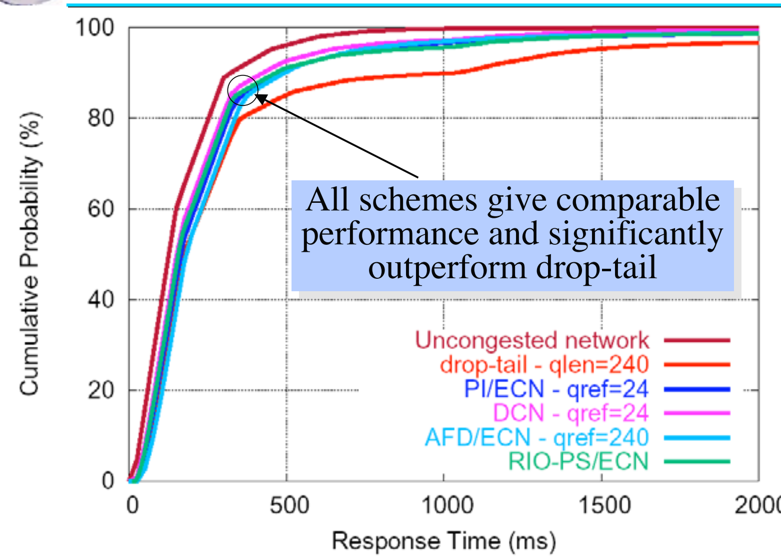


## Experimental Results — 90% Load
### DCN performance






## Experimental Results — 90% Load
### Comparison of all schemes



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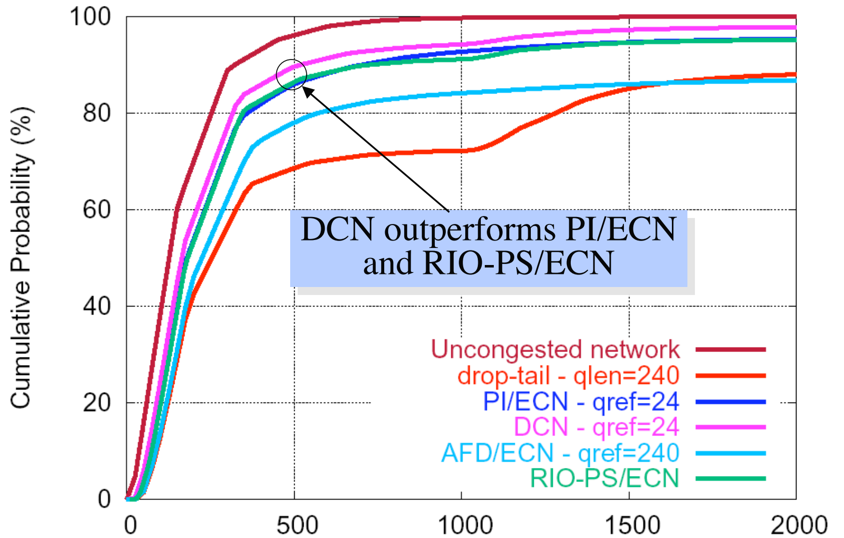




## DCN Evaluation

### Summary

- DCN uses a simple, tunable two-tiered classification scheme with:
  - Tunable storage overhead
  - $O(1)$ complexity with high probability
- DCN, without ECN, meets or exceeds the performance of the best performing AQM designs with ECN
  - The performance of 99+% of flows is improved
  - More small and "medium" flows complete per unit time
- On heavily congested networks, DCN closely approximates the performance achieved on an uncongested network

## Summary and Conclusions

- For offered loads of 90% or greater there is benefit to control theoretic AQM but only when used with ECN
- Heuristically signaling only long-lived, high-bandwidth flows improves the performance of most flows and eliminates the requirement for ECN
  - One can operate links carrying HTTP traffic at near saturation levels with performance approaching that achieved on an uncongested network
- Identification of high-bandwidth flows can be effectively performed with tunable overhead and complexity

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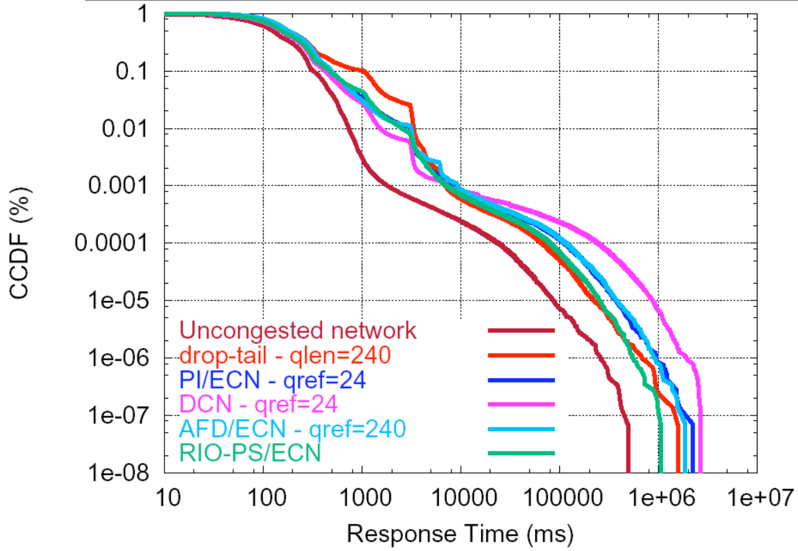




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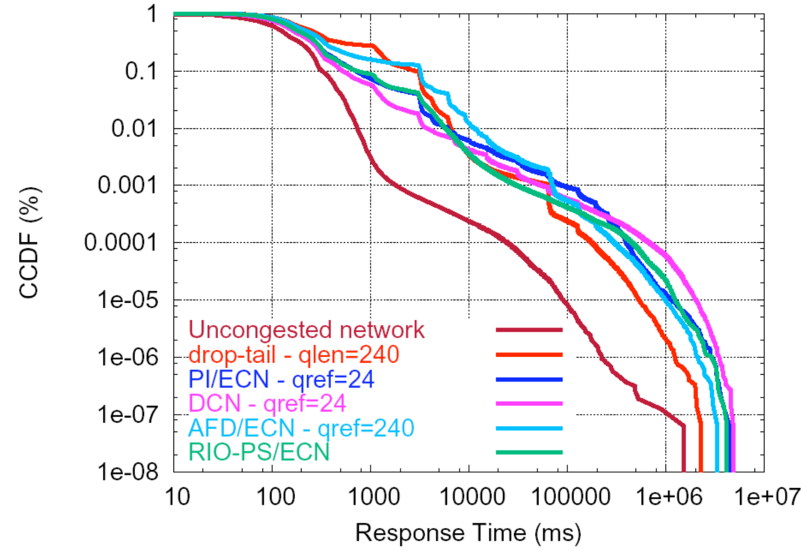
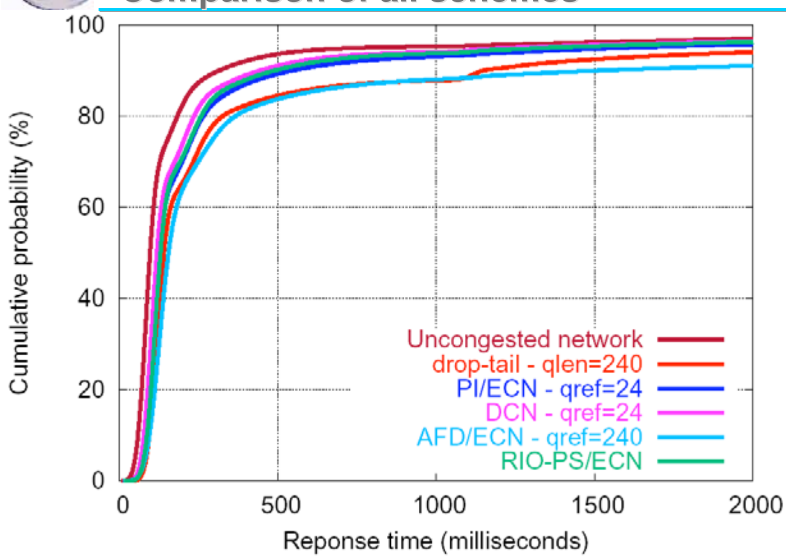





## Experimental Results with General TCP Traffic
### Comparison of all schemes






## Experimental Results with General TCP Traffic
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