On Designing Improved Controllers for AQM Routers Supporting TCP flows

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Outline

- Introduction
- Background
- The Proportional Controller
  - Experiments
  - Limitation
- PI Controller
  - Experiments
  - The Delay Utilization Trade-Off
- Conclusion and Future Work

Introduction

- Uses Classical Control System Techniques for developing controllers.
- Proposes 2 designs
  - Proportional Controller
  - Proportional Integrator Control

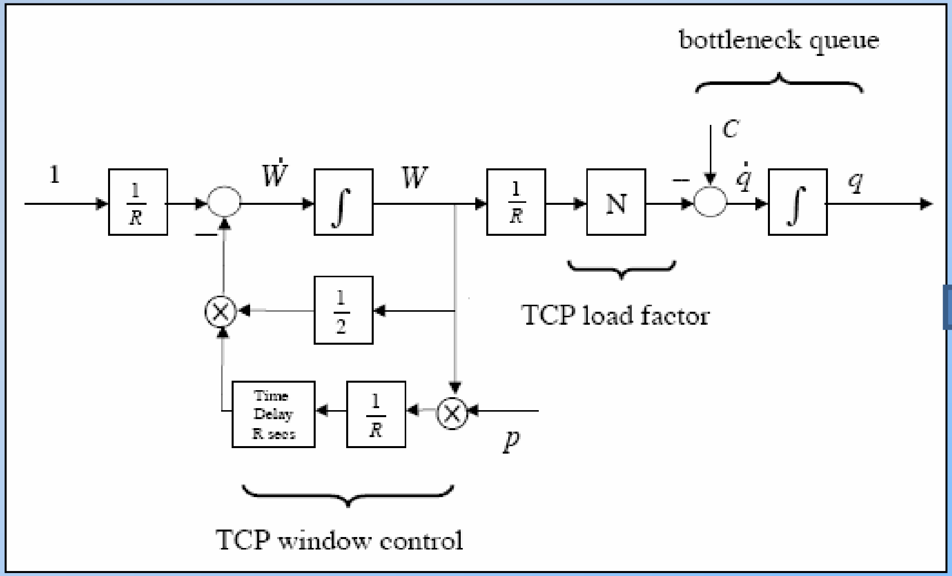
  Uses NS-2 Simulations

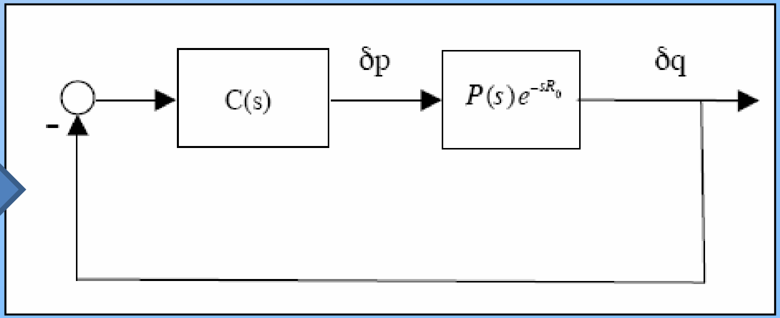
  Performed control theoretic analysis of RED

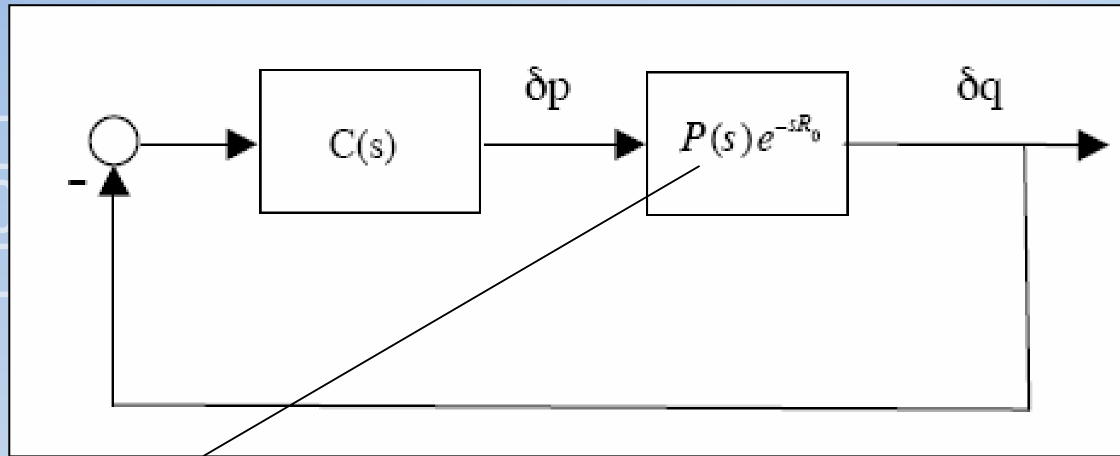
- 2 limitations of RED:-
  - Compromise speed for stability and vice versa
  - Direct coupling between queue length and loss probability

Background

- Linearized the TCP model







$P(s) = P_{TCP}(s)P_{Queue}(s)$

$$P_{tcp}(s) = \frac{\frac{R_0 C^2}{2N^2}}{s + \frac{2N}{R_0^2 C}};$$

$$P_{queue}(s) = \frac{\frac{N}{R_0}}{s + \frac{1}{R_0}}.$$

R0= Round Trip Time at the operating point

C= Link Capacity (packets/sec)

N= Load Factor (No of Connections)

$$C(s) = C_{red}(s) = \frac{L_{red}}{s/K+1},$$

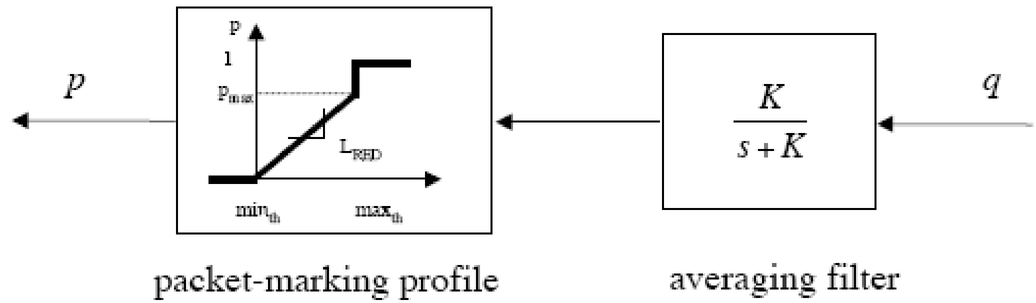


Fig. 3. RED as a cascade of low-pass filter and nonlinear gain element.

The Proportional Controller

$\omega_g = 0.1 \min(p_{tcp}, p_{queue})$

- Lag in the low pass filter responsible for the sluggishness of the RED controller
- Not replacing the low pass filter by proportional controller, the authors suggest designing of the stabilizing controller.

- Design:-
  - K=∞

$$L_{red} = \left| \frac{\left(\frac{j\omega_g}{p_{tcp}}+1\right)\left(\frac{j\omega_g}{p_{queue}}+1\right)}{\frac{(R^{+}C)^3}{(2N^{-})^2}} \right|$$

$$\omega_g = \sqrt{p_{tcp}p_{queue}} = \sqrt{\frac{2N^{-}}{R^{+3}C}}$$

  - ωg≈1.5 rad/sec
  - Note: the values are calculated in the Control Theoretic analysis of RED”

Experiments with propotional controller

- X-axis->time(sec)
- Y-axis->Queue Size(packets)
- Experiment 1:-
  - 60 FTP flows
  - 180 http sessions
  - Link bandwidth=15Mb/s
  - Added time-varying dynamics
  - Buffer size=800 packets

Comparison of RED and Proportional controller

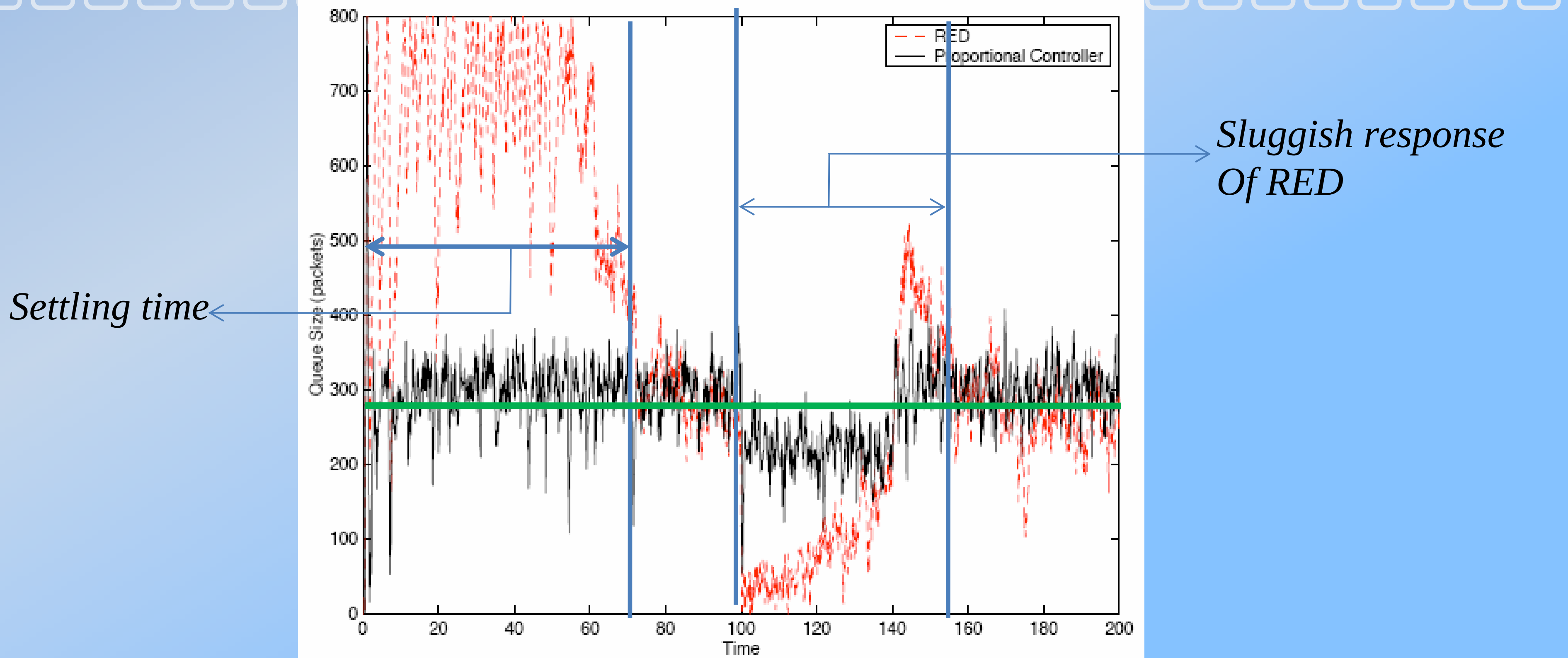
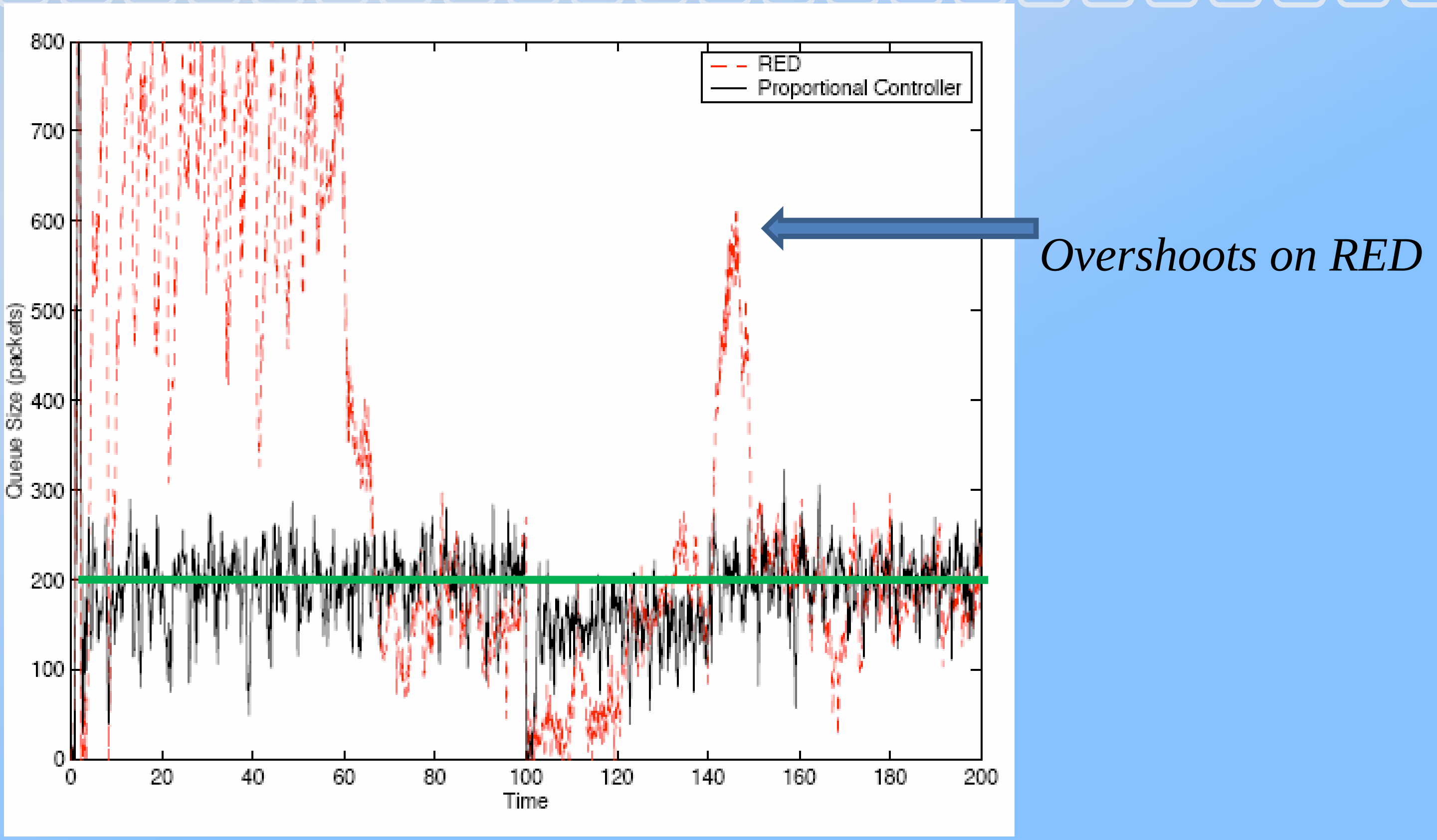
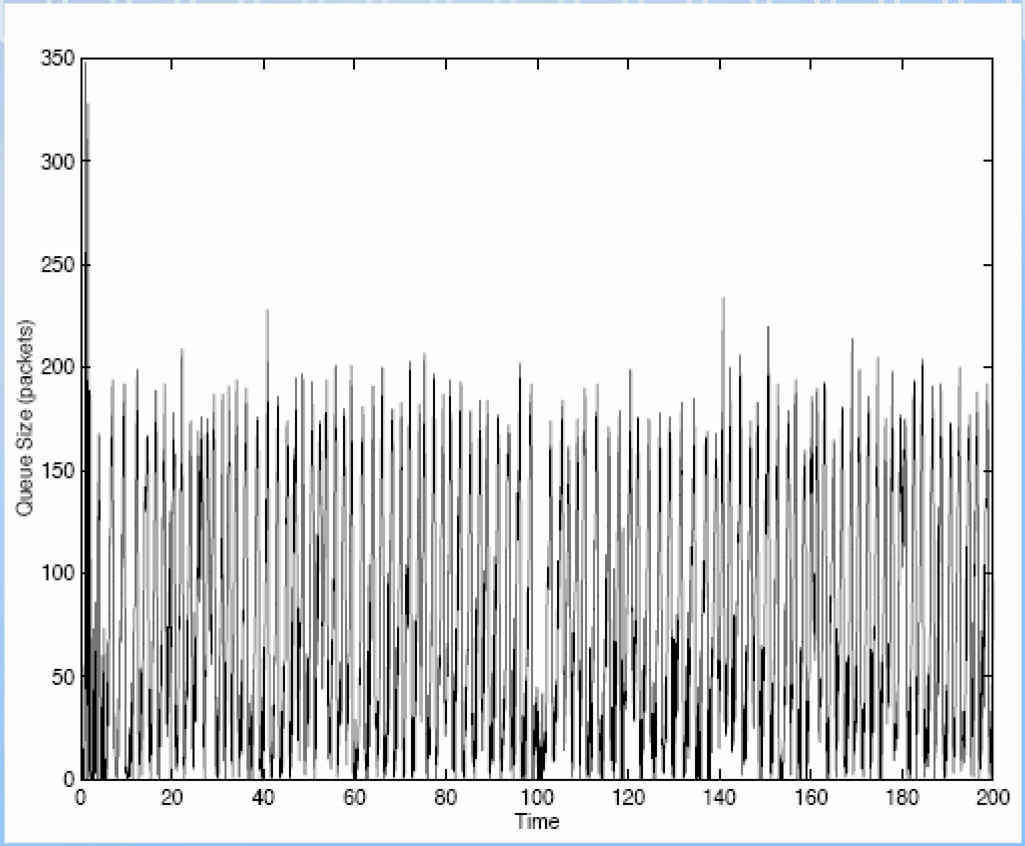


Fig. 5. Comparison of RED and the proportional controller

- Experiment 2
  - Repeat the previous experiment by doubling Round Trip Times.





Proportional controller with high gain

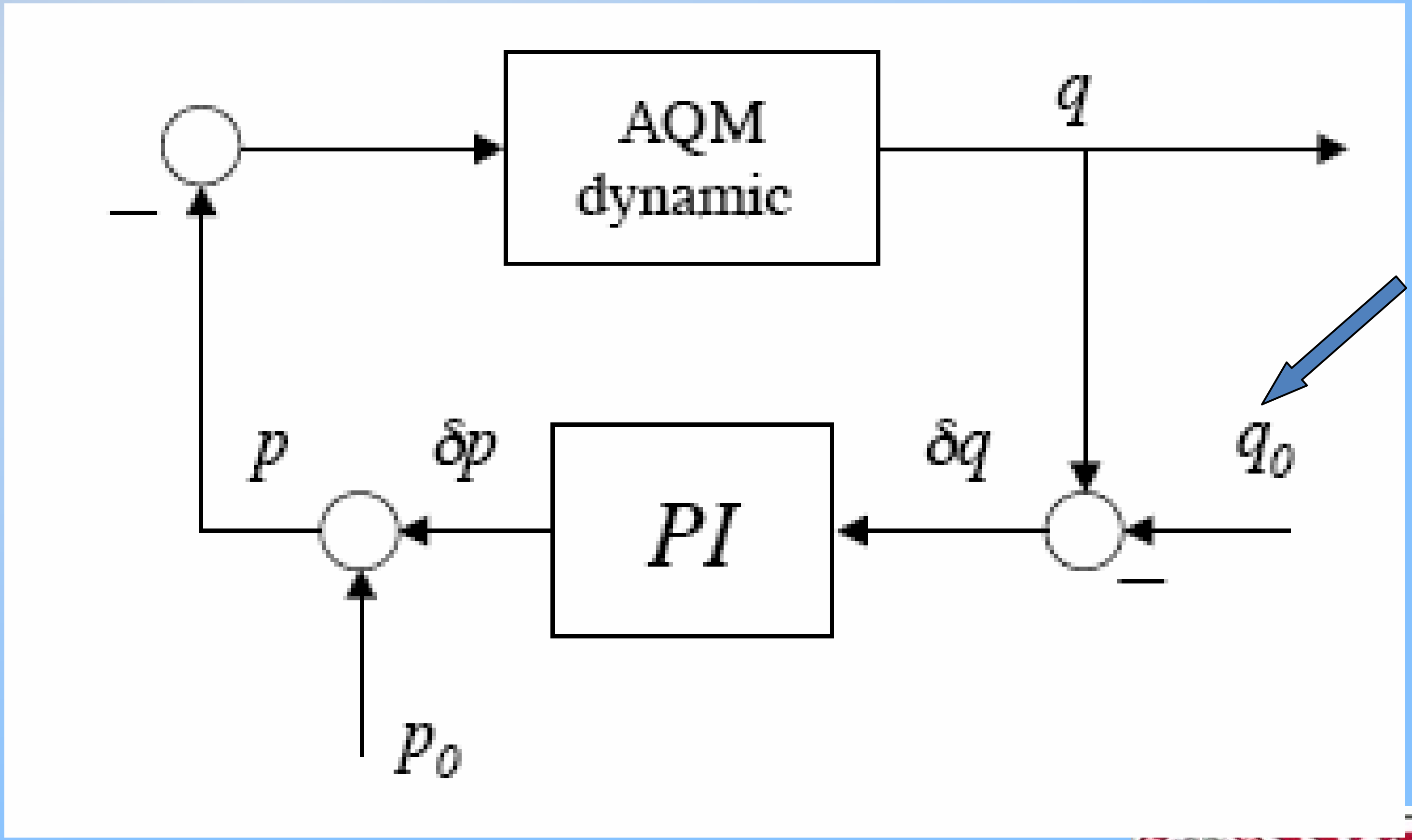
Limitations of Proportional Controller

- For stable operation, a relatively shallow slope in the loss profile required.
- Reason-coupling between queue size and marking probability
- Solution – decouple by using integral control/
- *Steady state error*

Solution to limitations

- Use of proportional Integrator Controller
  - Steady state error=0
  - Can clamp queue size ro reference value "q_{ref}"
  - Much higher loop bandwidth=faster response

The Proportional Integrator (PI) Controller



Higher loop bandwidth = faster response time

Functional Form of the PI Controller

$$C(s) = K_{PI}\frac{(s/z + 1)}{s}$$

Digital Implementation

Difference Equation:

$$p(kT) = a\delta q(kT) - b\delta q((k-1)T) + p((k-1)T)$$

Pseudo Code:

```
p      :=  a*(q - q_ref) - b*(q_old - q_ref) + p_old
p_old  :=  p
q_old  :=  q
```

q_{ref} = desired queue length

Experiment Tools & Parameters

- Used *ns* simulator
- Sampling frequency of 160 Hz
- PI coefficients
  - $a = 1.822\,(10)^{-5}$
  - $b = 1.816(10)^{-5}$
- q_{ref} = 200 packets
- Buffer = 800 packets

$$p(kT) = a\delta q(kT) - b\delta q((k-1)T) + p((k-1)T)$$

Experiment 3

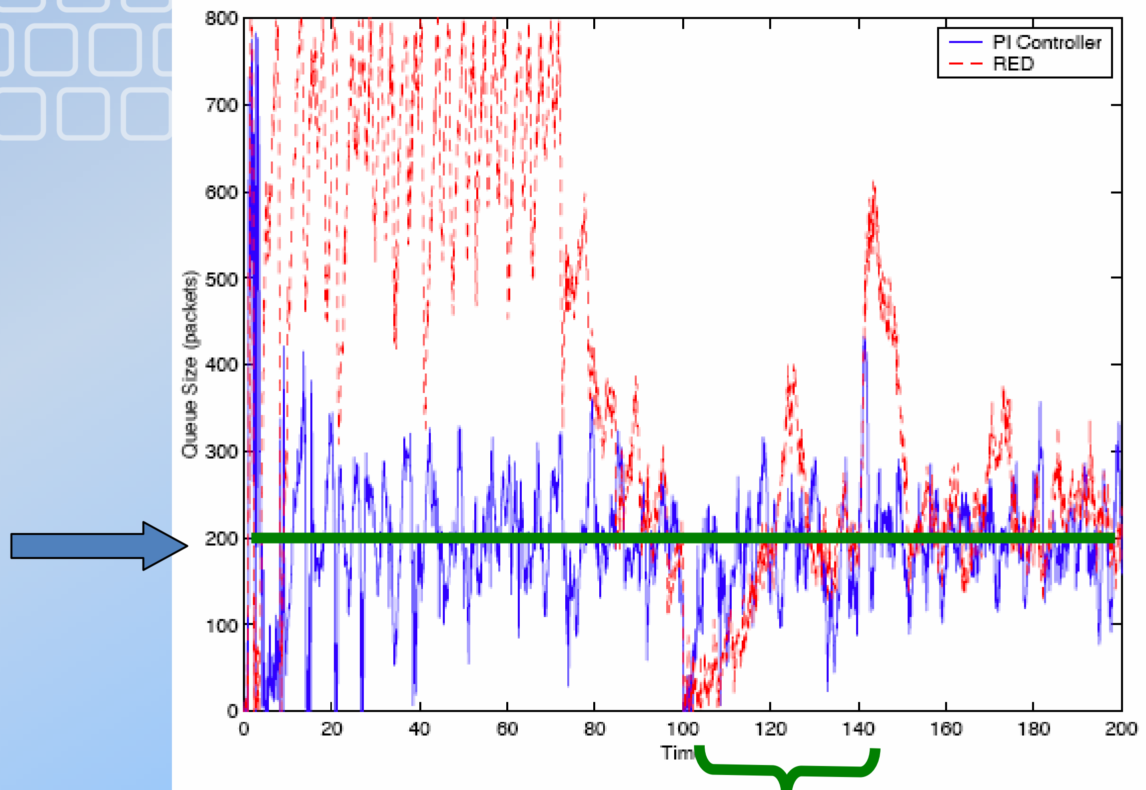


Fig. 10. Experiment 3

- Faster response time
- Regulation of output
- PI Controller insensitive to load level variations

PI Controller regulates the queue length to 200 packets

Experiment 4

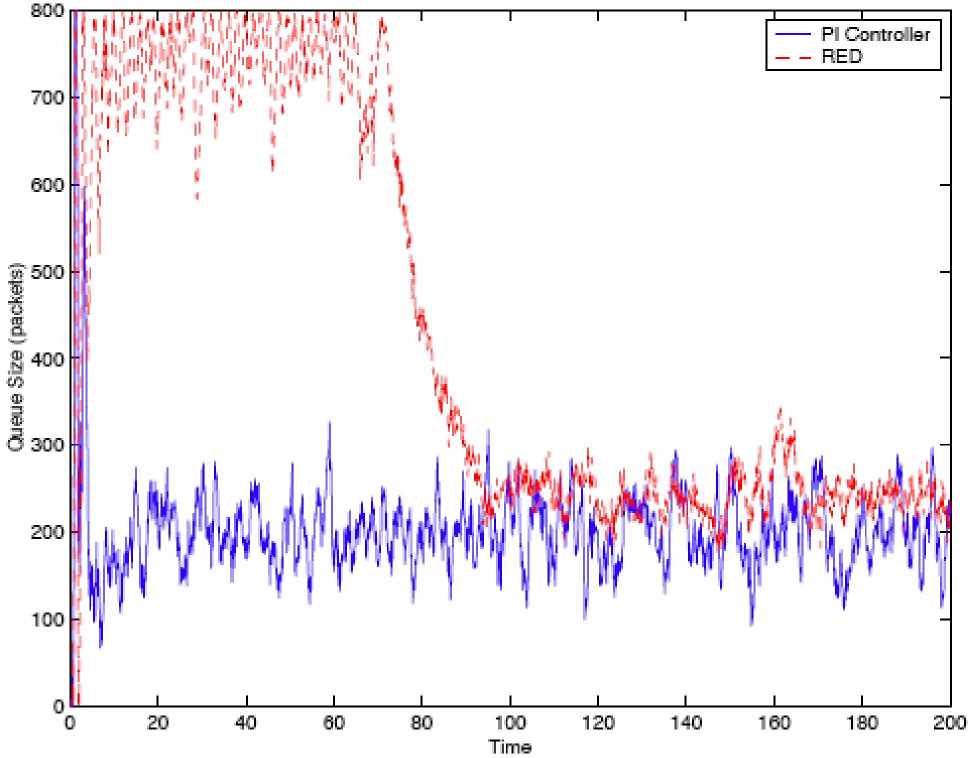


Fig. 11. Experiment 4

- Faster response time

Experiment 5

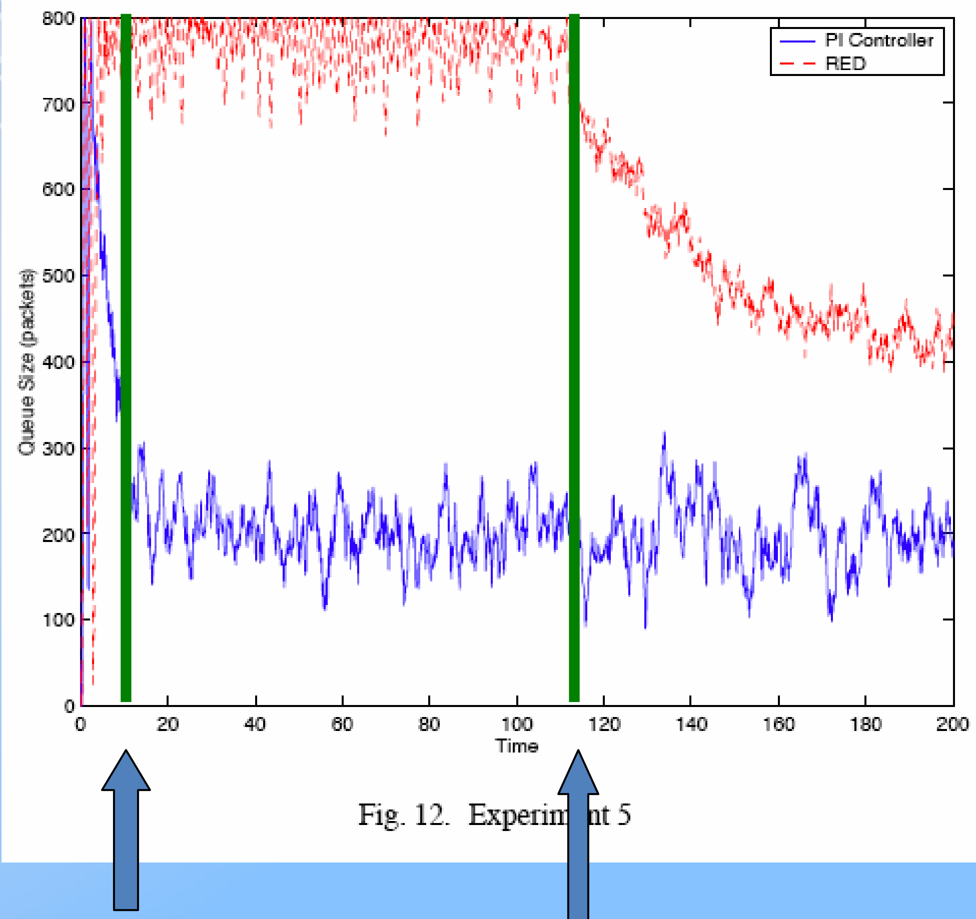


Fig. 12. Experiment 5

- PI controller settles at ~10 milliseconds
- RED settles at ~ 115 milliseconds

PI more robust at higher work loads

Experiment 6

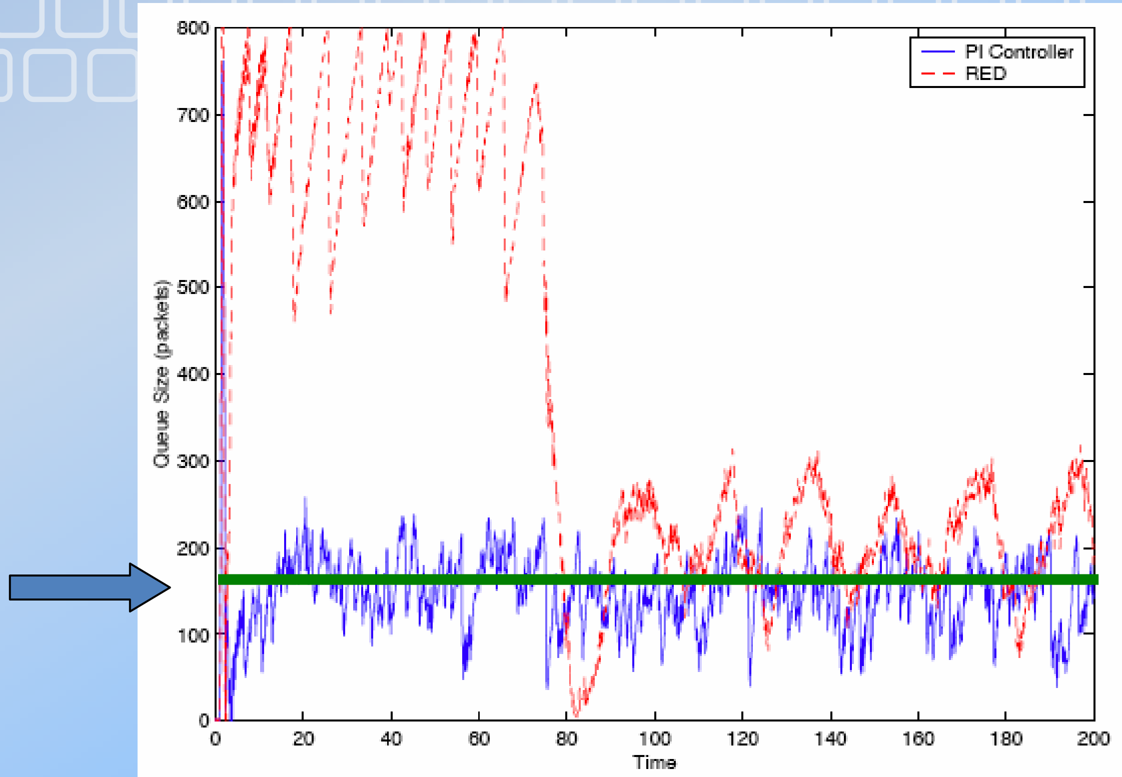


Fig. 13. Experiment 6

- RED experiences oscillations

PI still stable at lower work loads

Experiment 7

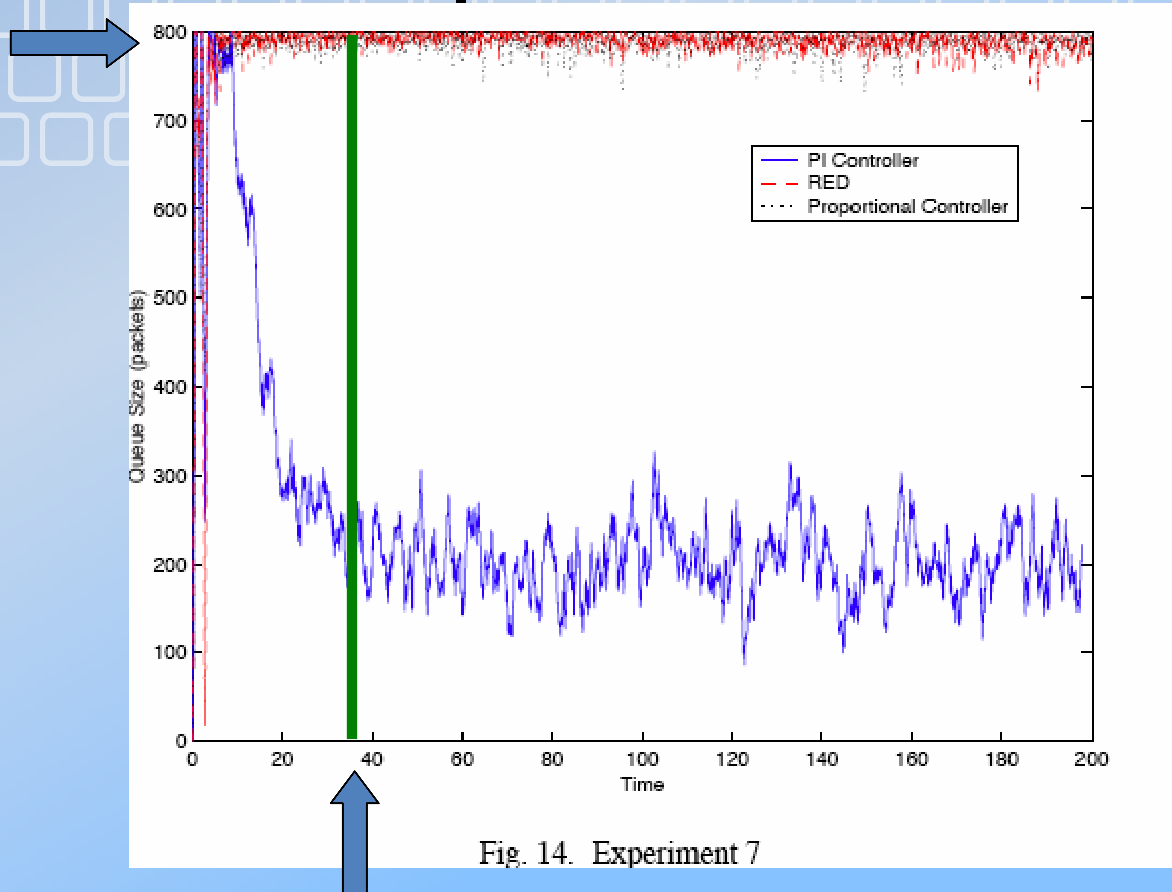


Fig. 14. Experiment 7

- PI controller is still at acceptable performance
- Response time has slowed (~ 40 milliseconds)
- RED and Proportional Controller “hit the roof”

AQM system (with finite buffer) needs integral control

Experiment 8

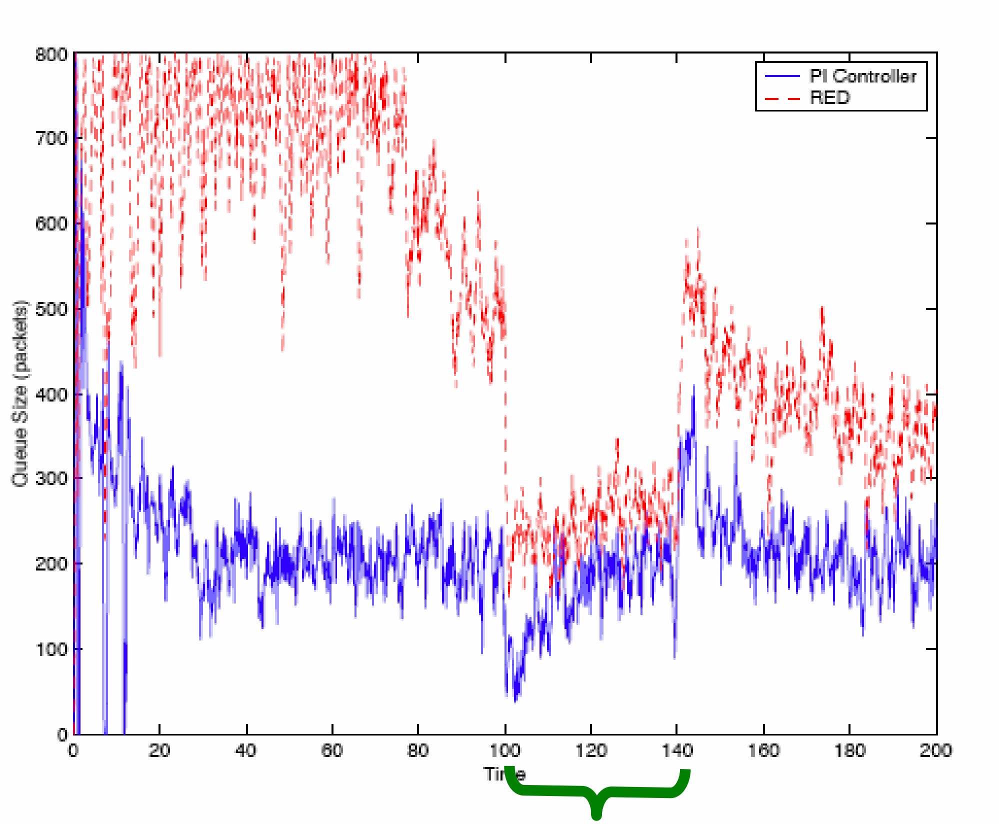
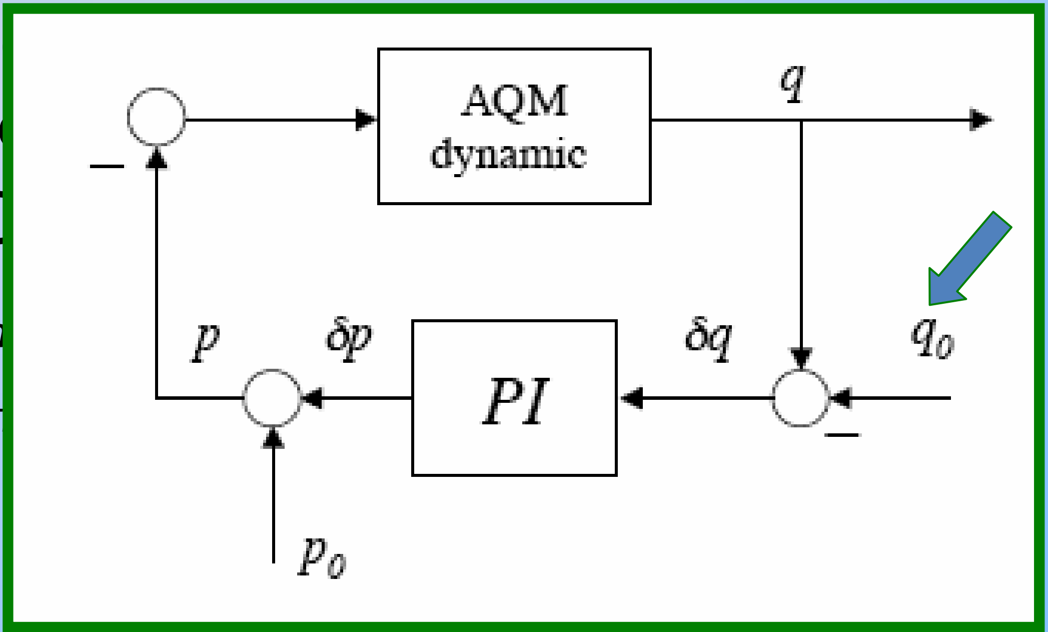


Fig. 15. Experiment 8

- The RED controllers steady state error has increase due to:
  - Shorter RTT
  - Operating Point Queue Length Higher

The Delay Utilization Tradeoff

- Large buffers lead to:
  - High
  - Larg
- In RED
  - min_{th}
  - max_{t}
  - p_{max}



- q0 in the PI Controller controls the delay

Larger values of *q0* = larger delays and utilization

Delay Utilization Tradeoff

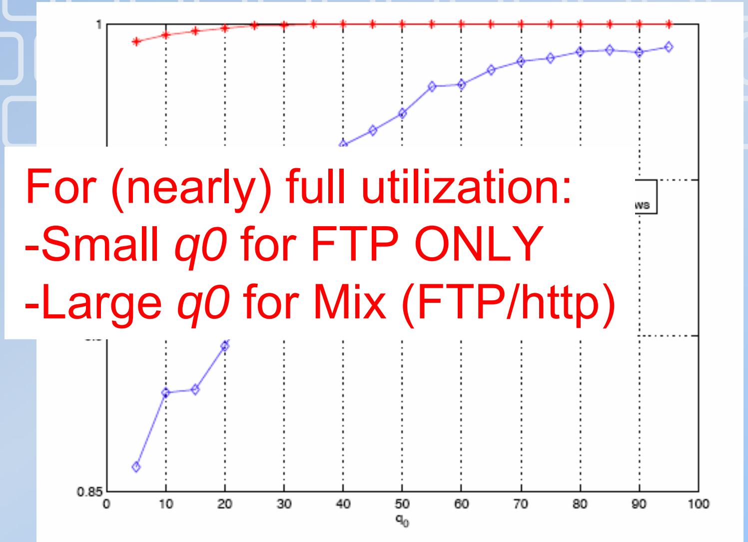


Fig. 16. Utilization versus operating point q_0: PI controller.

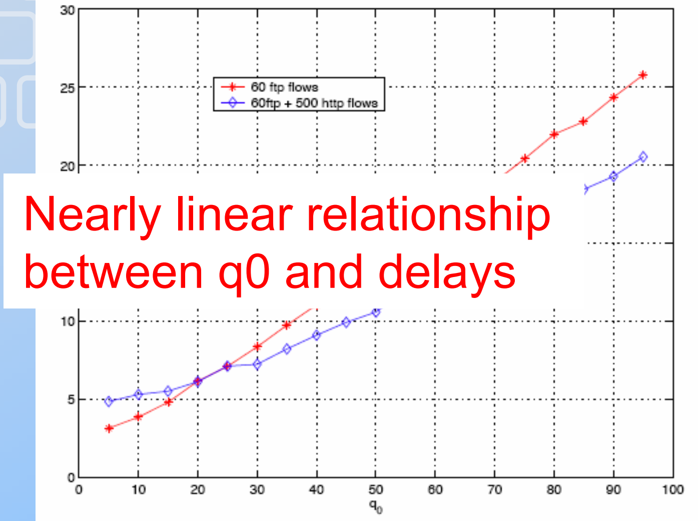


Fig. 17. Queuing delay versus operating point q_0: PI controller.

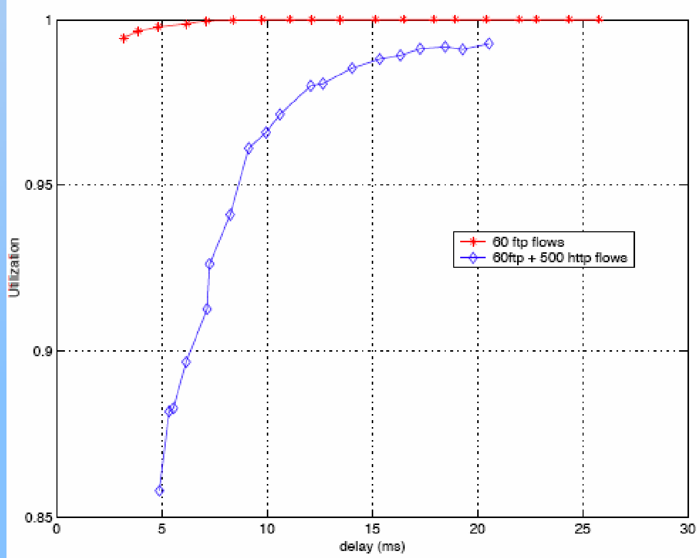


Fig. 18. Utilization versus queueing delay: PI controller.

RED vs PI

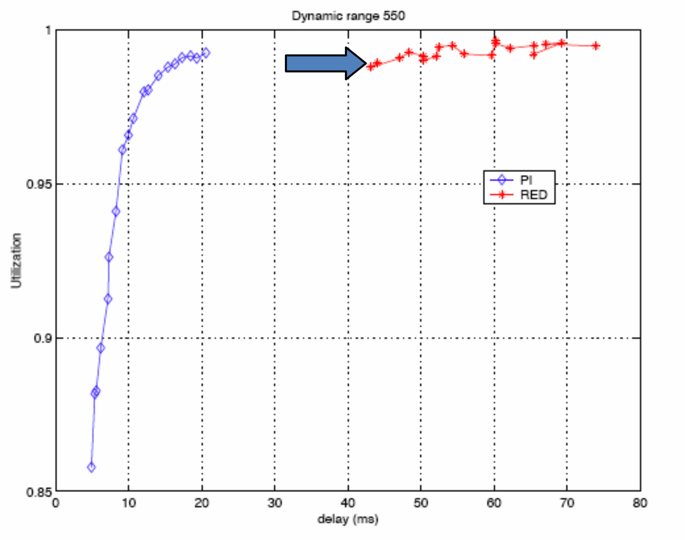


Fig. 19. RED vs PI: RED dynamic range 550.

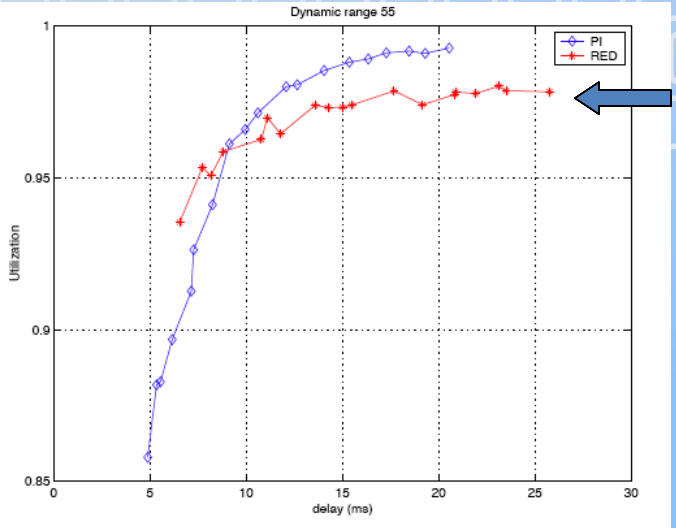


Fig. 20. RED vs PI: RED dynamic range 55.

- Delay in RED controlled by min_{th}
- To dynamic ranges (max_{th} _min_{th})used for RED:
  - Fig. 19 used 550
  - Fig. 20 used 55
- Mixed flows were used

PI Controller capable of handling low delay and high utilization

The Importance of ECN

- PI Controller can regulate the queue to a low level

  + Lower Delay

  - less efficient performance

- Dropping packets leads to higher transmission completion time

AQM used with ECN produces an almost lossless system

Conclusions

- Two controllers:
  - Proportional
    - Simple to implement
    - AQM response time better then REDs
  - Proportional Integrator
    - Improves network performance
    - AQM response time better then REDs
    - Able to handle and regulate queue level
- Objectives:
  - Queue Usage
  - Latency Reduction
- PI Controller out performed RED

Limitations and Future Work

- Limitations
  - Used linear models
  - Focused on classical control methods
  - Did not look at global or optimal results
- Future Work
  - More complex controllers

THANK YOU!