FI-RED: AQM Mechanism for Improving Fairness among TCP Connections in Tandem Networks

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Contents

AQM (Active Queue Management) Mechanism

- Control the number of packets in a router's buffer
  - By actively discarding arriving packets
- Solve problems of a conventional Drop-Tail router
  - Keep the number of packets in the buffer small
  - Keep a queuing delay in the buffer small

RED (Random Early Detection)

- The most representative AQM mechanism
- Basic operation
  - 1. Calculates the average queue length
  - 2. Randomly drops arriving packets
    - With a probability determined from the average queue length

TCP Fairness Issue in a Tandem Network

- In a tandem network with multiple routers...
  - TCP congestion control will satisfy FA^h fairness [9]

$$F_A^h(x) = \sum_{i=1}^{N} \frac{1}{R_i} \log \frac{x_i}{\frac{1}{R_i} + \frac{h_i}{2}}$$

  - TCP connections with a smaller RTT and/or the number of hops gain higher throughput
- Existing AQM mechanisms cannot solve such unfairness

Objective

- Improve fairness among TCP connections
  - Design a novel AQM mechanism called FI-RED for a tandem network
    - FI-RED: Fairness Improvement for RED
  - Utilize ECN (Explicit Congestion Notification)
    - Suppresses congestion indication to TCP connections with a large number of hops

Design Goals

- AQM mechanism should generally satisfy:

1. Consideration of TCP congestion control time scale
2. Improving fairness among TCP connections
3. Robustness
4. Compatibility with existing network devices

1. Consideration of TCP Congestion Control Time Scale

- AQM mechanism should not interfere with TCP's congestion control
  - TCP operates on the time scale of RTT
    - TCP receives ACK (ACKnowledgement) packets from the destination host
    - Perform window-flow control based on information obtained from ACK packets

2. Improving Fairness among TCP Connections

- AQM mechanism should realize bandwidth allocation as close as Max-Min fairness
  - Max-Min fairness is generally desirable in a packet-switching network

> *Max-Min fairness means maximizing the allocation of each session subject to the constraint that an incremental increase in its allocation does not cause a decrease in some other session's allocation that is already as small as its allocation or smaller.*

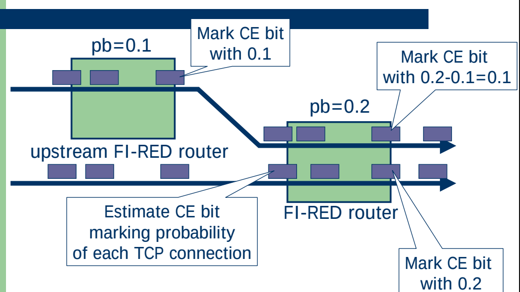
3. Robustness

- AQM mechanism should have robustness against network failures
  - AQM mechanism be decentralized and distributed
  - Even in failures, AQM mechanism should operate without serious performance degradation

4. Compatibility with Existing Network Devices

- AQM mechanism should have a backward-compatibility with other existing network devices
  - Performance of the network should not, at least, be degraded with partial deployment
  - Should support several versions of TCP and TCP-friendly rate control mechanisms

FI-RED Basic Idea



FI-RED Algorithm

- Operate RED in the ECN mode
  - Marking the CE bit of arriving packets
- Distinguish every TCP connection, and estimate the packet marking probability pb(i) in upstream routers

$$p_b(i) = \frac{p_c(i)}{2 - p_c(i)}$$

$$p_c(i) \leftarrow (1-\nu) \times p_c(i) + \nu \times CE$$

- Randomly mark the arriving packet with a probability max(pb - pb(i), 0)
  - pb: RED's packet marking probability

Conformance to Design Goals

1. Consideration of TCP congestion control time scale
   - Time scale is larger than TCP' RTT
   - May not interfere with TCP's congestion control
2. Improving fairness among TCP connections
   - Improve fairness in a tandem network
3. Robustness
   - Just utilizes the CE bit of arriving packets
4. Compatibility with existing network devices
   - Only utilizes the standard ECN mechanism
   - Can be used with arbitrary protocols supporting ECN

Analysis (Main Results)

- Ti: TCP throughput in steady state

$$T_1 = T(R_1, p_{1,2}) \simeq T(R_1, \sum_{j=1}^{2} p_j) \qquad p_{1,2} = \max(p_1, p_2)$$

$$T_2 = T(R_2, p_1)$$

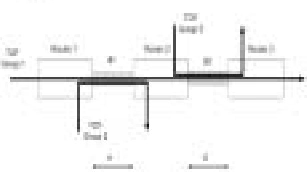
$$T_3 = T(R_3, p_2)$$

$$R_1 = \sum_{j=1}^{2} \left(2\tau_j + \frac{q_j}{B_j}\right)$$

$$R_2 = 2\tau_1 + \frac{q_1}{B_1}$$

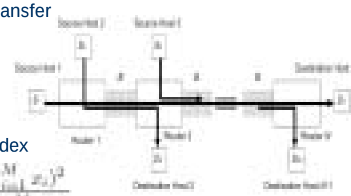
$$R_3 = 2\tau_2 + \frac{q_2}{B_2}$$

$$T(R, p) \simeq \frac{1}{R}\sqrt{\frac{3}{2p}}$$



Simulation Model and Performance Metric

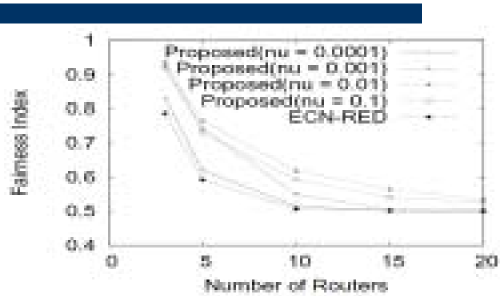
- Tandem network with N routers
- Bulk TCP transfer



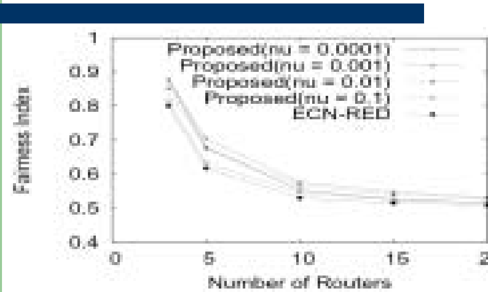
- Fairness Index

$$F = \frac{(\sum_{i=1}^{M} x_i)^2}{M \sum_{i=1}^{M} x_i^2}$$

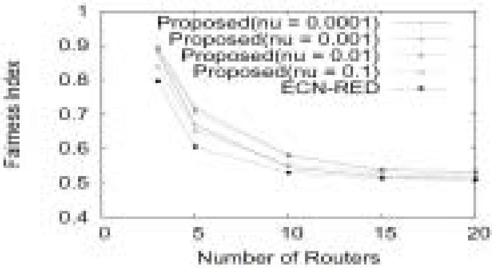
Fairness Index for B = 2 [Mbit/s] and Ni = 10



Fairness Index for B = 2 [Mbit/s] and Ni = 1



Fairness Index for B = 10 [Mbit/s] and Ni = 10



Conclusion

- Discussed general design goals for an AQM mechanism
- Designed a novel AQM mechanism called FI-RED
  - Suppress congestion indication to TCP connections having traversed congested routers
  - Improve fairness among TCP connections with different numbers of hops
- Evaluated performance of FI-RED using steady state analysis and simulation
  - FI-RED shows much better fairness than RED
  - FI-RED parameter is not sensitive to system parameters

Future Work

- Improve unfairness caused by different RTTs
- Investigate interference of FI-RED with non-standard loss-based TCP protocols
  - e.g., TCP Vegas, TCP Westwood, HighSpeed TCP and FAST TCP
- Address scalability issue and show possible solutions