CS 268: Lecture 7 (Beyond TCP Congestion Control)

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(Based on slides from R. Stallings, M. Handley and D. Katabi)

Outline

- TCP-Friendly Rate Control (TFRC)
- ATM Congestion Control
- eXplicit Control Protocol

TCP-Friendly

- Any alternative congestion control scheme needs to *coexist with TCP in FIFO queues* in the best-effort Internet, or *be protected from TCP* in some manner.
- To co-exist with TCP, it must impose the same long-term load on the network:
  - No greater long-term throughput as a function of packet loss and delay so TCP doesn't suffer
  - Not significantly less long-term throughput or it's not too useful

TFRC: General Idea

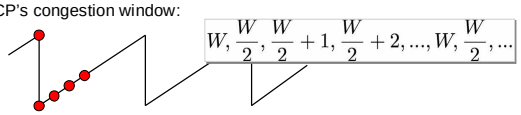
Use a model of TCP's throughout as a function of the loss rate and RTT directly in a congestion control algorithm.

- If transmission rate is higher than that given by the model, reduce the transmission rate to the model's rate.
- Otherwise increase the transmission rate.

TCP Modelling: The "Steady State" Model

The model: Packet size B bytes, round-trip time R secs, no queue.

- A packet is dropped each time the window reaches W packets.
- TCP's congestion window:



- The maximum sending rate in packets per roundtrip time: W
- The maximum sending rate in bytes/sec: WB / R
- The average sending rate T: $T = (3/4)WB / R$
- The packet drop rate p: $p = \frac{1}{\frac{3}{8}W^2}$
- **The result:** $T = \frac{\sqrt{6}B}{2R\sqrt{p}} = \frac{\sqrt{3/2}B}{R\sqrt{p}}$

An Improved "Steady State" Model

A pretty good improved model of TCP Reno, including timeouts, from Padhye et al, Sigcomm 1998:

$$T = \frac{s}{R\sqrt{\frac{2p}{3}} + t_{RTO}(3\sqrt{\frac{3p}{8}})p(1+32p^2)}$$

T : sending rate in bytes/second]
R : round trip time
p : fraction of packets lost
t_{RTO} : TCP retransmission timeout

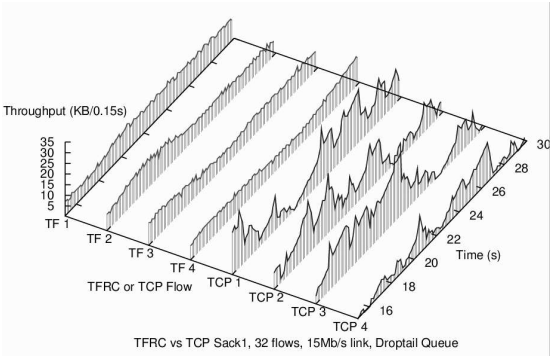
Would be better to have a model of TCP SACK, but the differences aren't critical.

TFRC Details

- The devil's in the details
  - How to measure the loss rate?
  - How to respond to persistent congestion?
  - How to use RTT and prevent oscillatory behavior?
- Not as simple as first thought

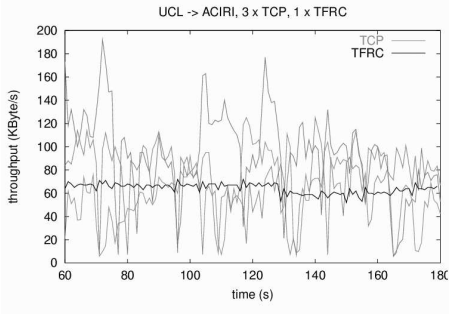
7

TFRC Performance (Simulation)



TFRC vs TCP Sack1, 32 flows, 15Mb/s link, Droptail Queue

TFRC Performance (Experimental)



9

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10

ATM Congestion Control

- **Credit Based**
  - Sender is given "credit" for number of octets or packets it may send before it must stop and wait for additional credit.
- **Rate Based**
  - Sender may transmit at a rate up to some limit.
  - Rate can be reduced by control message.

11

Case study: ATM ABR congestion control

ABR: available bit rate:

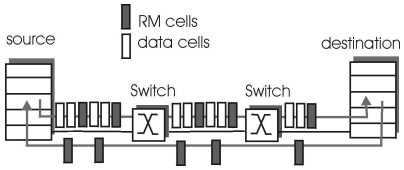
- "elastic service"
- if sender's path "underloaded":
  - Sender should use available bandwidth
- if sender's path congested:
  - Sender throttled to minimum guaranteed rate

RM (resource management) cells:

- Sent by sender, interleaved with data cells
- Bits in RM cell set by switches ("*network-assisted*")
  - NI bit: no increase in rate (mild congestion)
  - CI bit: congestion indication
- RM cells returned to sender by receiver, with bits intact

12

EXPLICIT Case study: ATM ABR congestion control



- Two-byte ER (explicit rate) field in RM cell
  - Congested switch may lower ER value in cell
  - Sender' send rate thus minimum supportable rate on path
- EFCI bit in data cells: set to 1 in congested switch
  - If data cell preceding RM cell has EFCI set, sender sets CI bit in returned RM cell

13

ABR Cell Rate Feedback Rules

- if CI == 1
  - Reduce ACR to a value >= MCR
- else if NI == 0
  - Increase ACR to a value <= PCR
- if ACR > ER
  - set ACR = max(ER, MCR)

ACR = Allowed Cell Rate
MCR = Minimum Cell Rate
PCR = Peak Cell Rate
ER = Explicit Rate

14

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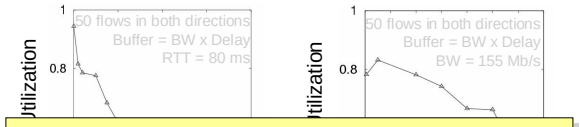
15

TCP congestion control performs poorly as bandwidth or delay increases

Shown analytically in [Low01] and via simulations



Because TCP lacks fast response

- Spare bandwidth is available ⇒ TCP increases by 1 pkt/RTT even if spare bandwidth is huge
- When a TCP starts, it increases exponentially ⇒ Too many drops ⇒ Flows ramp up by 1 pkt/RTT, taking forever to grab the large bandwidth

16

Solution: Decouple Congestion Control from Fairness

High Utilization; Small Queues; Few Drops

Bandwidth Allocation Policy

17

Solution: Decouple Congestion Control from Fairness

Coupled because a *single* mechanism controls both

Example: In TCP, Additive-Increase Multiplicative-Decrease (AIMD) controls both

How does decoupling solve the problem?

1. To control congestion: use MIMD which shows fast response
2. To control fairness: use AIMD which converges to fairness

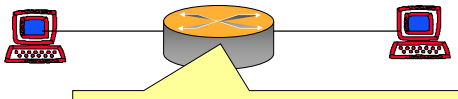
18

Characteristics of XCP Solution

1. Improved Congestion Control (in high bandwidth-delay & conventional environments):
   - Small queues
   - Almost no drops
2. Improved Fairness
3. Scalable (no per-flow state)
4. Flexible bandwidth allocation: min-max fairness, proportional fairness, differential bandwidth allocation,…

19

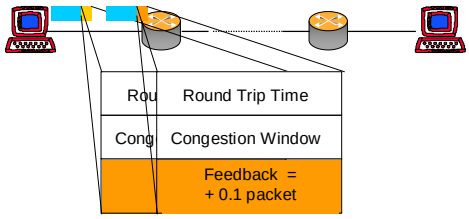
XCP: An eXplicit Control Protocol



1. Congestion Controller
2. Fairness Controller

20

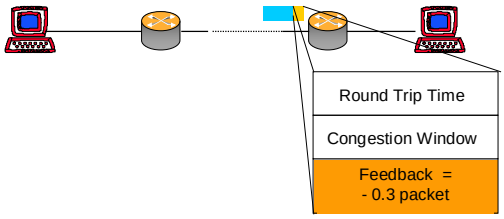
How does XCP Work?



Congestion Header

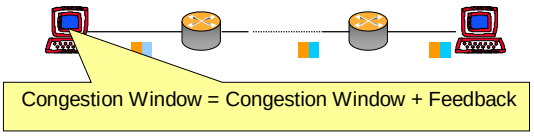
21

How does XCP Work?



22

How does XCP Work?

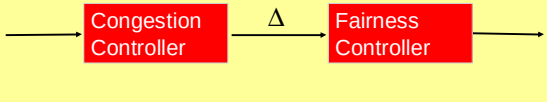


XCP extends ECN and CSFQ

Routers compute feedback without any per-flow state

23

How Does an XCP Router Compute the Feedback?



queue

Algorithm: MIMD

Aggregate traffic changes by Δ

Δ ~ Spare Bandwidth

Δ ~ - Queue Size

So, $\Delta = \alpha d_{avg} Spare - \beta Queue$

Congestion He

Algorithm: AIMD

If Δ > 0 ⇒ Divide Δ equally between flows

If Δ < 0 ⇒ Divide Δ between flows proportionally to their current rates

24

Getting the devil out of the details …

Congestion Controller

$\Delta = \alpha\, d_{avg}\ Spare - \beta\ Queue$

Theorem: System converges to optimal utilization (i.e., stable) for any link bandwidth, delay, number of sources if:

$$0<\alpha<\frac{\pi}{4\sqrt{2}} \quad and \quad \beta=\alpha^2\sqrt{2}$$

No Parameter Tuning

Fairness Controller

Algorithm:

If $\Delta > 0 \Rightarrow$ Divide Δ equally between flows

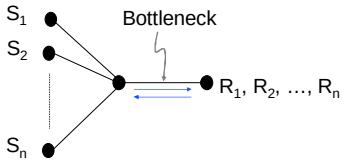
If $\Delta < 0 \Rightarrow$ Divide Δ between flows proportionally to their current rates

Need to estimate number of flows *N*

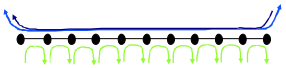
$$N = \sum_{pkts\ in\ T} \frac{1}{T \times (Cwnd_{pkt} / RTT_{pkt})}$$

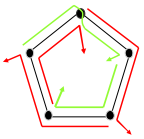
No Per-Flow State

Subset of Results



Similar behavior over:

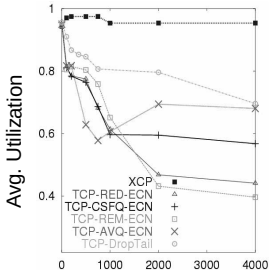




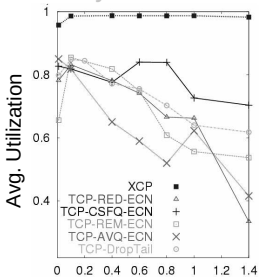
26

XCP Remains Efficient as Bandwidth or Delay Increases

Utilization as a function of Bandwidth



Utilization as a function of Delay



27

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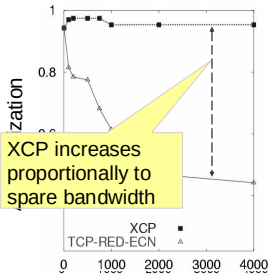
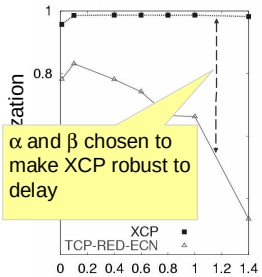
Utilization as a function of Bandwidth

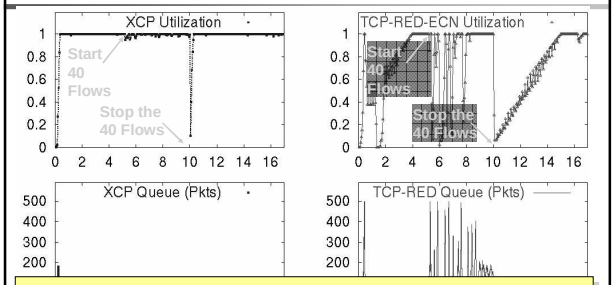


Utilization as a function of Delay



28

XCP Shows Faster Response than TCP



XCP shows fast response!

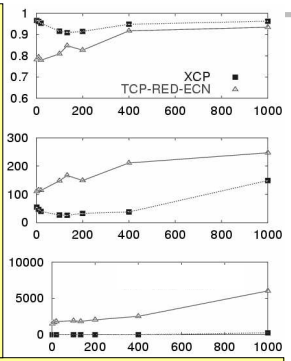
29

XCP Deals Well with Short Web-Like Flows

Average Utilization

Average Queue

Drops

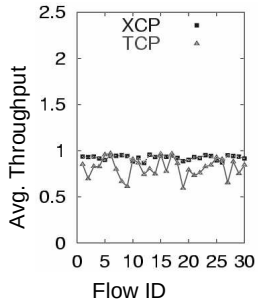


Arrivals of Short Flows/sec

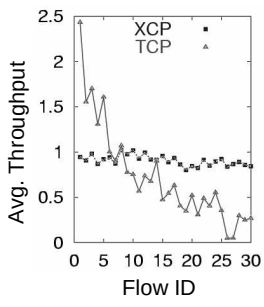
30

XCP is Fairer than TCP

Same RTT



Different RTT



(RTT is 40 ms → 330 ms)