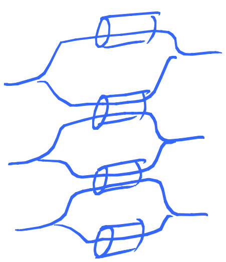
Coupled congestion controllers for multipath

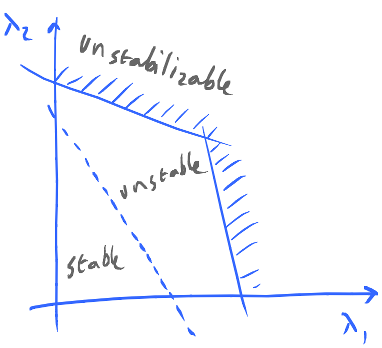
We have considered window-based coupled congestion control

The alternative is to control window size by formulae based on rates, as in Kelly + Voice. We wanted to explore "TCP-style" controllers first.

Questions:



- For a fixed number of flows, what is the rate that each flow gets? What sort of fairness does it achieve?



- Is there resource pooling?
  i.e. if flows arrive as an exogeneous process (open-loop), then for what arrival rates is the network stable? Is it the largest possible, subject only to generalized cut constraints?
  Do we see analogous effects in a closed-loop system, i.e. where users wait until a flow ends before starting the next?

A simple family of coupled controllers

We chose a simple family of controllers to study:

increase v_r by $a_r \left(\frac{v_r}{\frac{1}{n} w_s} \right)^{\alpha} w_s^{\beta}$ when subflow r receives an ACK

decrease v_r by $b_r \left(\frac{v_r}{\frac{1}{n} w_s} \right)^{\alpha+\varepsilon} w_s^{\beta+\delta}$ when it detects a drop.

v_r = window on subflow r, w_s = total window size for flows, n = # subflows

It generalizes "independent subflows"

increase v_r by $\frac{1}{v_r}$ per ACK_r

decrease v_r by $\frac{v_r}{2}$ per $drop_r$

$a = n$, $b = \frac{1}{2n}$, $\alpha = -1$, $\varepsilon = 2$, $\beta = -1$, $\delta = 2$

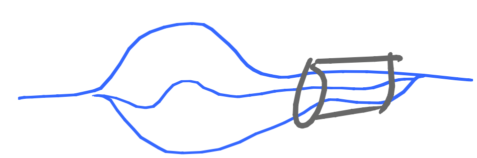
it generalizes "be like a single TCP"

increase v_r by $\frac{1}{w_s}$ per ACK_r

decrease v_r by $\frac{w_s}{2}$ per $drop_r$.

$a = 1$, $b = \frac{1}{2}$, $\alpha = 0$, $\varepsilon = 0$, $\beta = -1$, $\delta = 2$

This parameterization makes it easy to control fairness: if the subflows all share a common bottleneck link, then total window size w_s depends only on a and b, not on n etc.



"Throughput" Equation

Flappy case ($\varepsilon=0$):

e.g. "be like a single TCP"

⚠ no flow at all on paths where $\frac{a_r/b_r}{p_r} < \max_{r'} \frac{a_{r'}/b_{r'}}{p_{r'}}$

total window size is $w_s = \theta^{1/\varepsilon}$ where $\theta = \max_r \frac{a_r/b_r}{p_r}$

⚠ individual window sizes v_r undetermined;
thus the total rate $x_s = \sum v_r / RTT_r$ is undetermined

Hardened case ($\varepsilon>0$)

e.g. "independent subflows" has $\varepsilon = 1$.

total window size is $w_s = \theta^{1/\varepsilon}$ where $\theta = \left(\frac{1}{n} \sum \left(\frac{a_r/b_r}{p_r} \right)^{1/\varepsilon} \right)^{\varepsilon}$

window size on subflow r is $v_r = \frac{\theta_r^{1/\varepsilon}}{\sum \theta_{r'}^{1/\varepsilon}} w_s$ where $\theta_r = \frac{a_r/b_r}{p_r}$

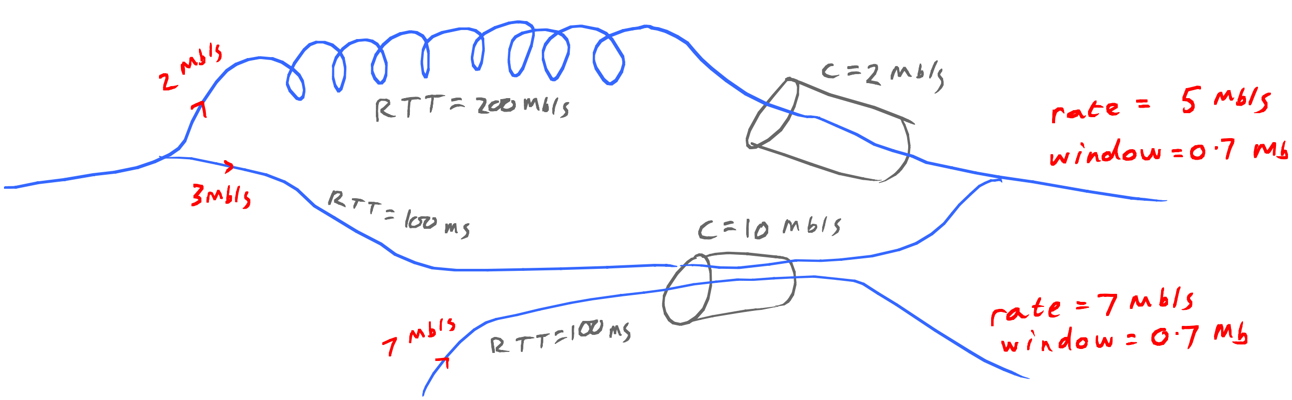
The smaller ε, the closer this is to the flappy case
(and so, presumably, the more perturbable the total rate)

Hunch: the "flappy case" moves flows around with greater facility, so it is more efficient at resource pooling

Teleology

Flappy case ($\varepsilon = 0$):

The resulting flow rate allocation is likely "trying" to maximize $\sum_{\text{flows } s} \frac{a_s}{b_s} \frac{w_s^{1-\delta}}{1-\delta}$ subject to capacity constraints.



i.e. it tries to allocate window size as fairly as possible, subject to network topology, and ignores rate-unfairness.

In effect, flows "try" to move their traffic onto paths with large RTT, since this lets them get large window sizes without hurting the network.

Hunch: this is an intrinsic problem with window-based controllers like TCP, made very visible by the freedom of multipath.

Other parameter choices

ε controls lability.

$\varepsilon = 0$: moves flows around with great facility, using only the very best routes; this should give a high degree of fairness & resource pooling

$\varepsilon > 0$: less flexibility, less variability

design issue for multipath

DJW choice: $\varepsilon = \frac{1}{2}$

δ controls scalability

in the increase phase, window grows like $t^{\frac{1}{\delta - 1}}$ (or e^t if $\delta = 1$).

TCP: $\delta = 2$. Scalable TCP: $\delta = 1$.

δ controls fairness under synchronized drops

TCP: $\delta = 2$ → converges to a fair allocation

Scalable TCP: $\delta = 1$ → does not converge

design issue for regular single-path TCP

DJW choice: $\delta = \frac{3}{2}$

$\beta = 1 - \delta$ assuming we want multiplicative decrease

α: unknown

something to do with relative rates of convergence on subflows?