GAIMD Congestion Control

Y. Richard Yang and Simon S. Lam, "General AIMD Congestion Control," *Proceedings IEEE ICNP 2000*, November 2000.

Motivation for new congestion control protocols

- Reducing *cwnd* to half of its value after a loss indication is too severe a reduction for some real-time apps (e.g., interactive multimedia)

- New apps may use UDP instead of TCP because they do not require reliable delivery

- Increasing use of UDP without congestion control would threaten stability of Internet

  -> Need new CC protocols for apps that prefer an alternative to TCP

TCP-friendly protocols

- Alternatives to TCP congestion control with smaller send rate fluctuations
  - Equation-based rate control
    - Datagram Congestion Control Protocol (RFC 4340)
    - Difficult to measure loss rate and TO in real time
  - GAIMD in this paper

- TCP-friendliness to better co-exist with TCP traffic
  - The send rate of a non-TCP flow should be approximately the same as that of a TCP flow under the same conditions of *round-trip time* and *loss rate*

GAIMD

- Consider a more general version of AIMD; let $\alpha > 0$ and $1 > \beta > 0$; let b denote the number of packets acknowledged by each ack

For each new ack received, $W \leftarrow W + \dfrac{\alpha}{bW}$

For a TD ack, $W \leftarrow \beta W$

For a timeout, $W \leftarrow 1$

- Other mechanisms (Slow Start, congestion indications, and round-trip time estimation) are the same as those of TCP Reno

Previous models of TCP (for $\alpha = 1, \beta = ½$)

- No timeout (Matthis et al. 1997)

$$\text{send rate} = T(p, RTT, b) = \frac{1}{RTT}\sqrt{\frac{3}{2bp}}$$

- Timeouts included (Padhye et al. 1998)

$$\text{send rate} = T(p, RTT, T_0, b)$$
$$= \frac{1}{RTT\left(\sqrt{\frac{2bp}{3}}\right) + \min\left(1, 3\sqrt{\frac{3bp}{8}}\right) p(1 + 32p^2)T_0}$$

GAIMD send rate

$$\text{send rate} = T_{\alpha,\beta}(p, RTT, T_0, b)$$

$$= \frac{1}{RTT\left(\sqrt{\frac{2b(1-\beta)p}{\alpha(1+\beta)}}\right) + \min\left(1, 3\sqrt{\frac{(1-\beta^2)bp}{2\alpha}}\right) p(1+32p^2)T_0}$$

- Same model and assumptions as Padhye et al.
  - p : loss (indication) rate
  - RTT : mean round-trip time
  - T_0 : mean timeout value
- Reduces to previous formula with $\alpha = 1$ and $\beta = \frac{1}{2}$
- Send rate decreases with a larger RTT, larger T_0, or larger b
- Send rate increases for a larger α (> 0), or a larger β (< 1)

Interpreting the send rate formula

- Denominator is sum of the following 2 terms

$$TD_{\alpha,\beta}(p, RTT, b) = RTT\left(\sqrt{\frac{2b(1-\beta)p}{\alpha(1+\beta)}}\right)$$

$$TO_{\alpha,\beta}(p, T_0, b) = Q\ p(1+32p^2)T_0$$

$$\text{where}\quad Q = \min\left(1, 3\sqrt{\frac{(1-\beta^2)bp}{2\alpha}}\right)$$

- Q, probability of a loss indication being a TO, increases towards 1 as *p* increases

- For a small *p*, *TD* = $O(p^{0.5})$ >> *TO* = $O(p^{1.5})$ but as *p* increases, the *TO* term cannot be ignored

Formula validation

- Is the formula accurate? Over what range of loss rate *p* is it accurate?

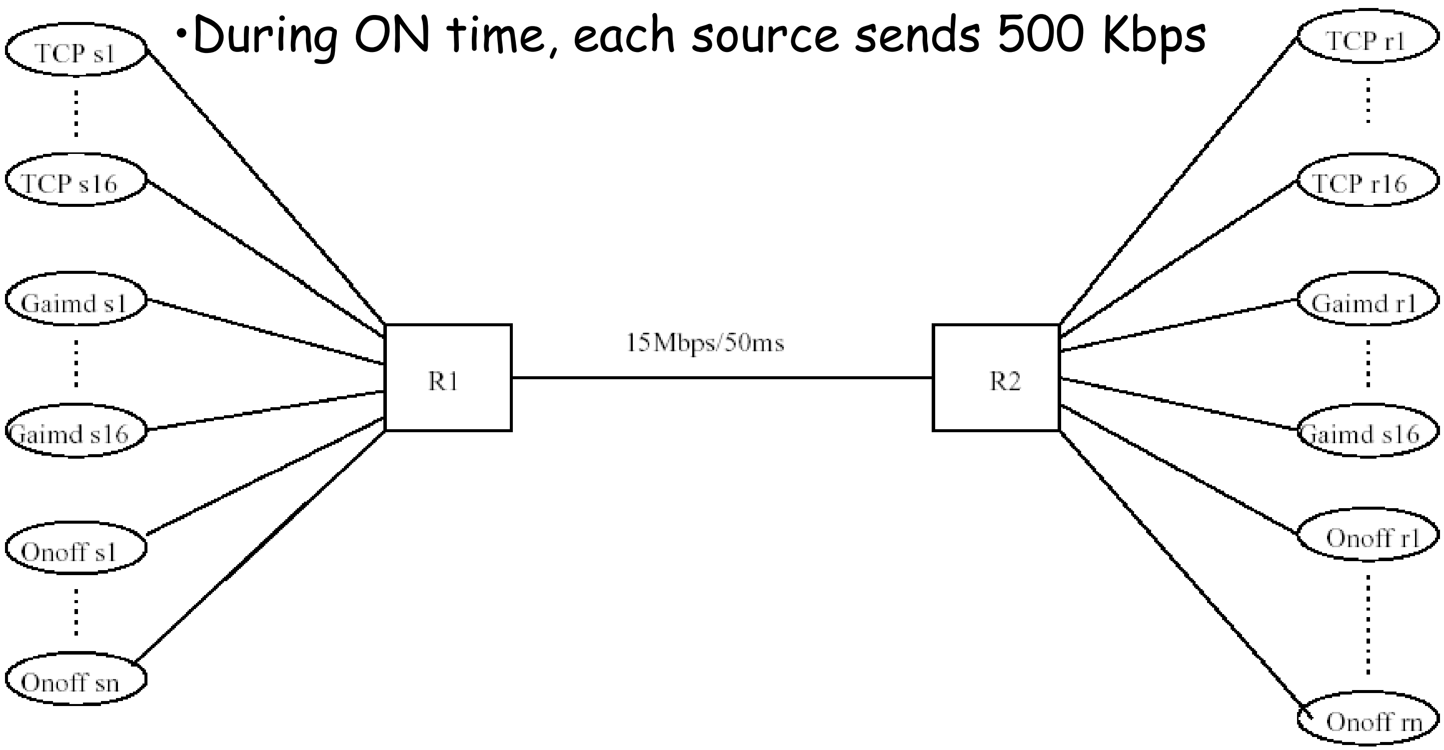
- What is the general trend when the formula loses accuracy?

- When do sending rate variations become significant?

Simulation setup

16 TCP Reno flows, 16 GAIMD flows, and flows with ON/OFF times to model web-like traffic (UDP flows and short TCP flows)

- Mean ON time = 1 s, mean OFF time = 2 s, Pareto distribution
- During ON time, each source sends 500 Kbps



Prediction accuracy

- Measure of accuracy:
  - predicted sending rate/ave. actual sending rate
- Validity range of the formula
  - For each β, vary α from 0.1 to 1.0
  - For each (α, β), vary the number of ON/OFF flows from 10 to 70 to create a loss rate about 1% to 30%
- Impact of loss pattern on the accuracy of the formula
  - Used different kinds of routers: drop-tail and RED

Accuracy (1)

prediction/measurement

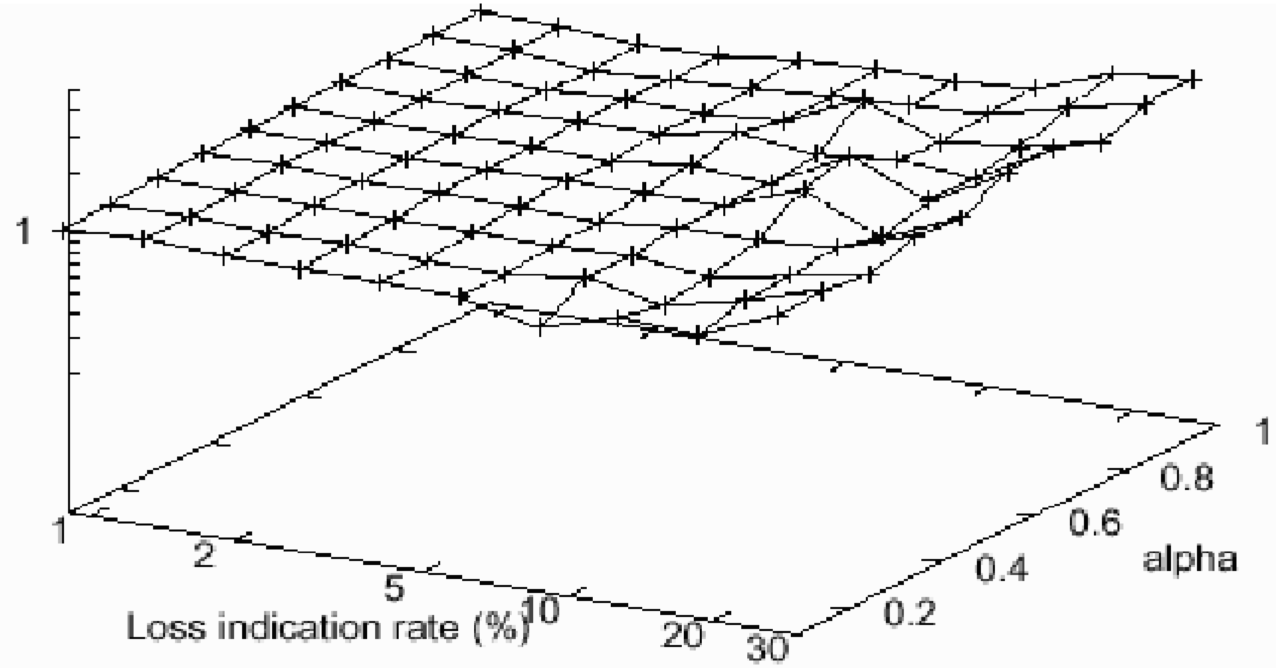
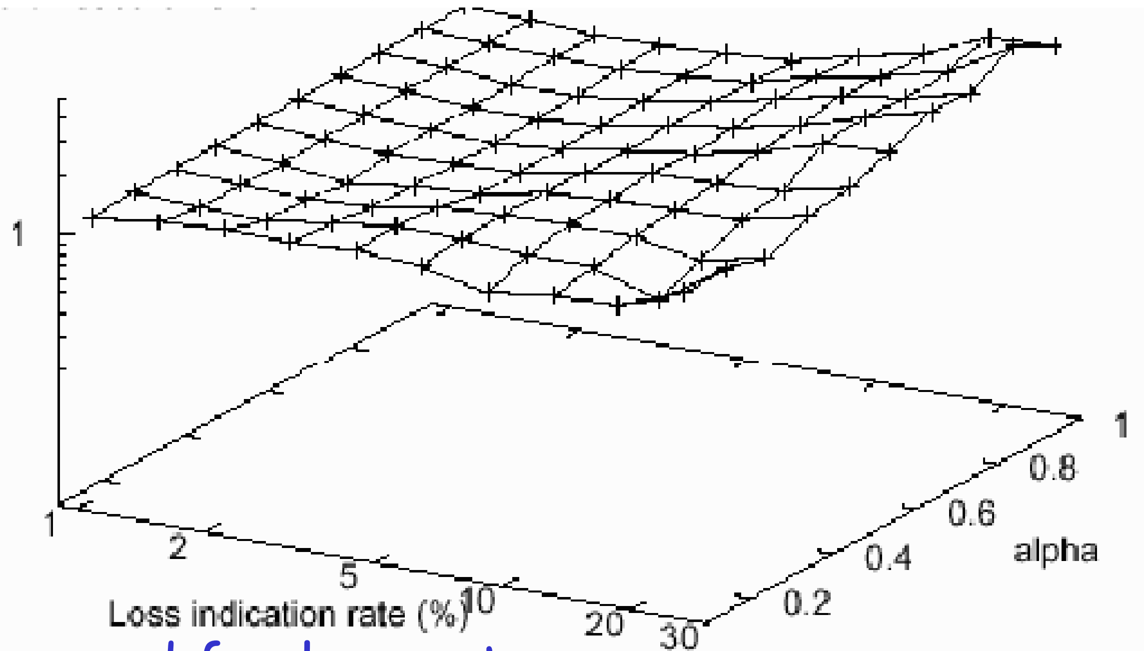


Figure 2: Accuracy for $\beta = 0.5$ and drop-tail

Accuracy (2)

prediction/measurement

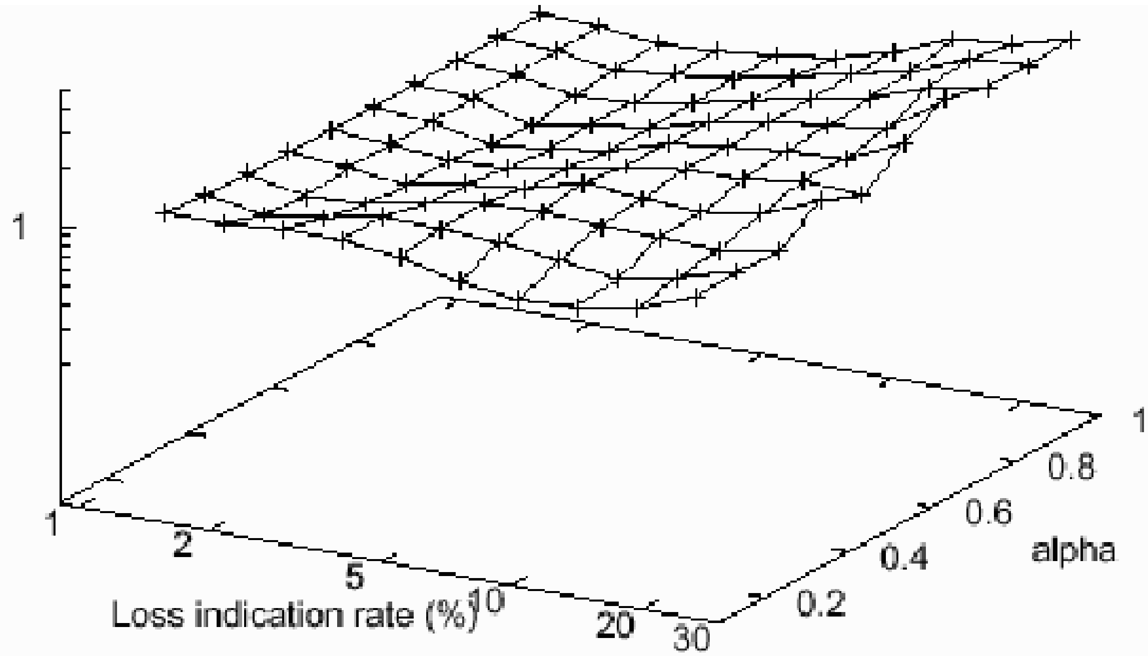


Formula good for loss rate
up to 20%

Figure 4: Accuracy for $\beta = 0.875$ and drop-tail

Accuracy (3)

prediction/measurement

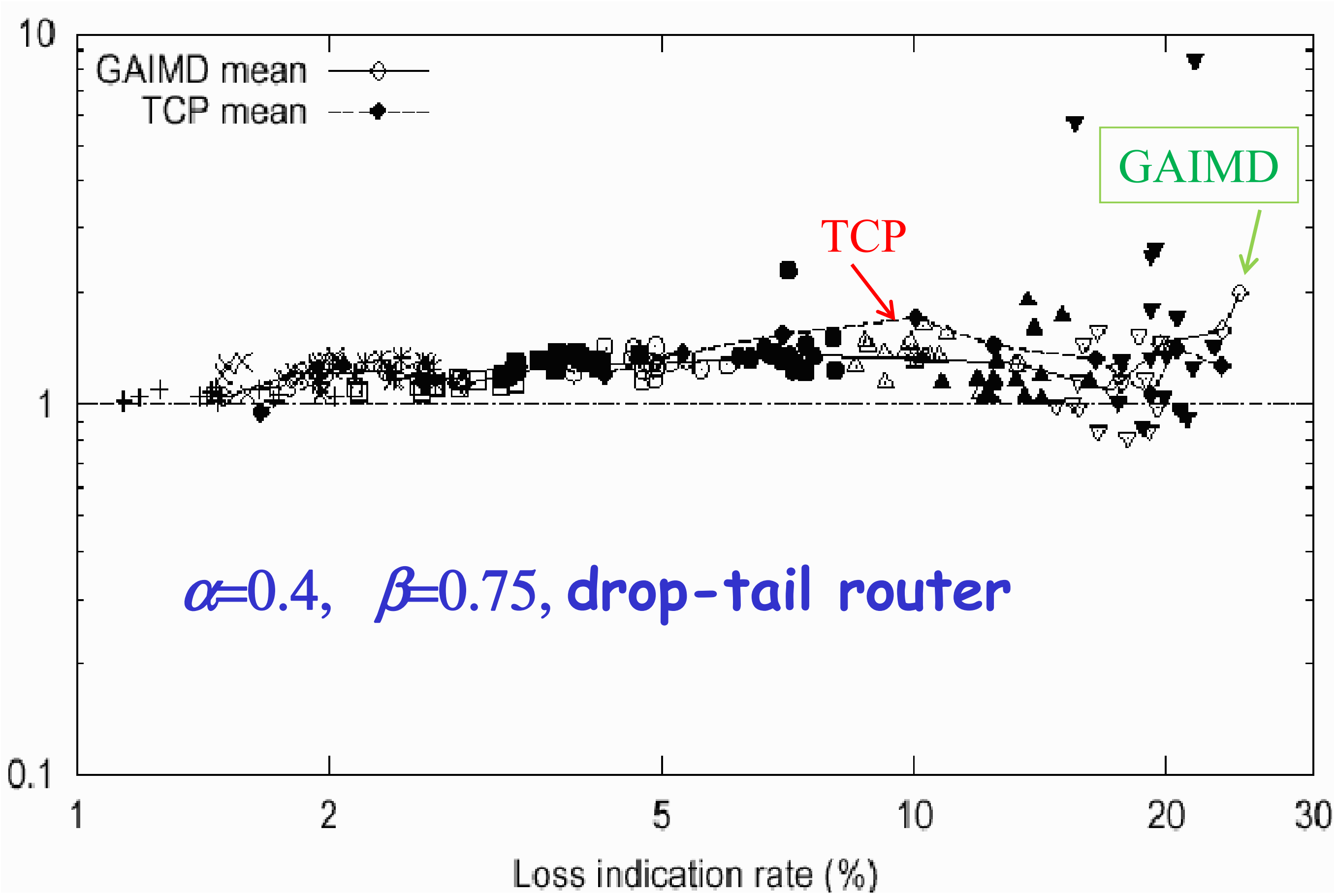


RED router may not satisfy correlated loss assumption

Figure 5: Accuracy for $\beta = 0.875$ and RED

Sending Rate Variation (drop-tail)

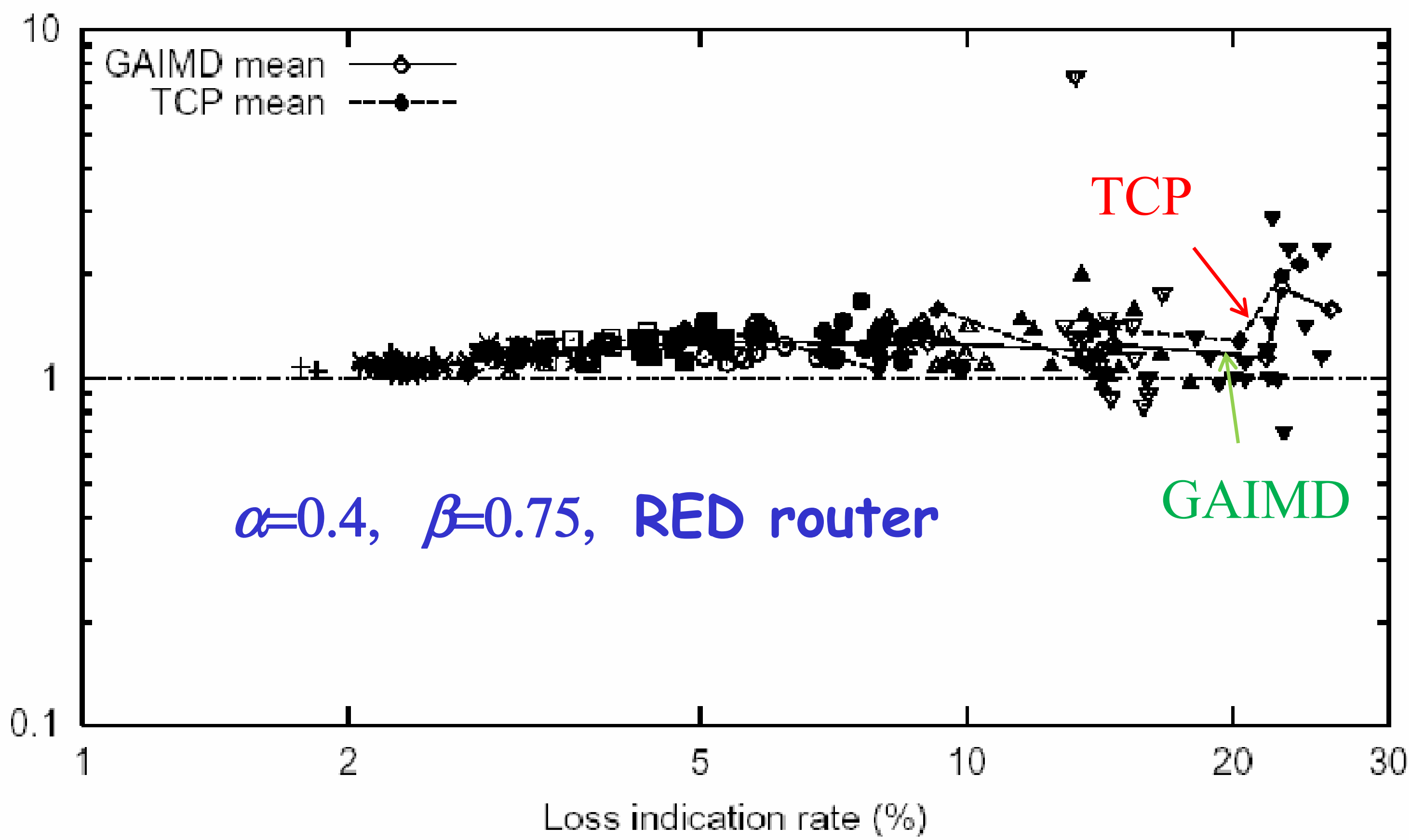
accuracy for individual GAIMD flows and TCP flows



α=0.4, β=0.75, **drop-tail router**

Sending Rate Variation (RED)

accuracy for individual GAIMD flows and TCP flows



Summary of Validation Tests

- Accurate for loss rate $p < 20\%$

- Loss patterns (RED vs. drop-tail) do not have a large impact on accuracy

- Sending rate variance is small for a loss rate of up to 10%

- Trend: rate formulas tend to overestimate when loss rate is high or when α, β are *aggressive*
  - Overestimates are similar for both TCP and GAIMD (in most experiments)

TCP-friendly GAIMD

- Choose α and β values such that

$$\text{send rate} = T_{\alpha,\beta}(p, RTT, T_0, b)$$

$$= \frac{1}{RTT\left(\sqrt{\dfrac{2b(1-\beta)p}{\alpha(1+\beta)}}\right) + \min\left(1, 3\sqrt{\dfrac{(1-\beta^2)bp}{2\alpha}}\right) p(1+32p^2)T_0}$$

$$= T_{1,\frac{1}{2}}(p, RTT, T_0, b)$$

- For all p, only solution is $\alpha = 1$ and $\beta = 1/2$

TD TCP-friendly curve

$$TD_{\alpha,\beta}(p, RTT, b) = TD_{1,\frac{1}{2}}(p, RTT, b)$$

$$RTT\left(\sqrt{\frac{2b(1-\beta)p}{\alpha(1+\beta)}}\right) = RTT\left(\sqrt{\frac{2b(1-1/2)p}{(1+1/2)}}\right)$$

$$\boxed{\alpha = \frac{3(1-\beta)}{(1+\beta)}}$$

TO TCP-friendly curve

$$TO_{\alpha,\beta}(p, T_0, b) = TO_{1,\frac{1}{2}}(p, T_0, b)$$

$$\min\left(1, 3\sqrt{\frac{(1-\beta^2)bp}{2\alpha}}\right)p(1+32p^2)T_0 = \min\left(1, 3\sqrt{\frac{(1-1/4)bp}{2}}\right)p(1+32p^2)T_0$$

$$\frac{(1-\beta^2)}{2\alpha} = \frac{3}{8}$$

$$\boxed{\alpha = \frac{4(1-\beta^2)}{3}}$$

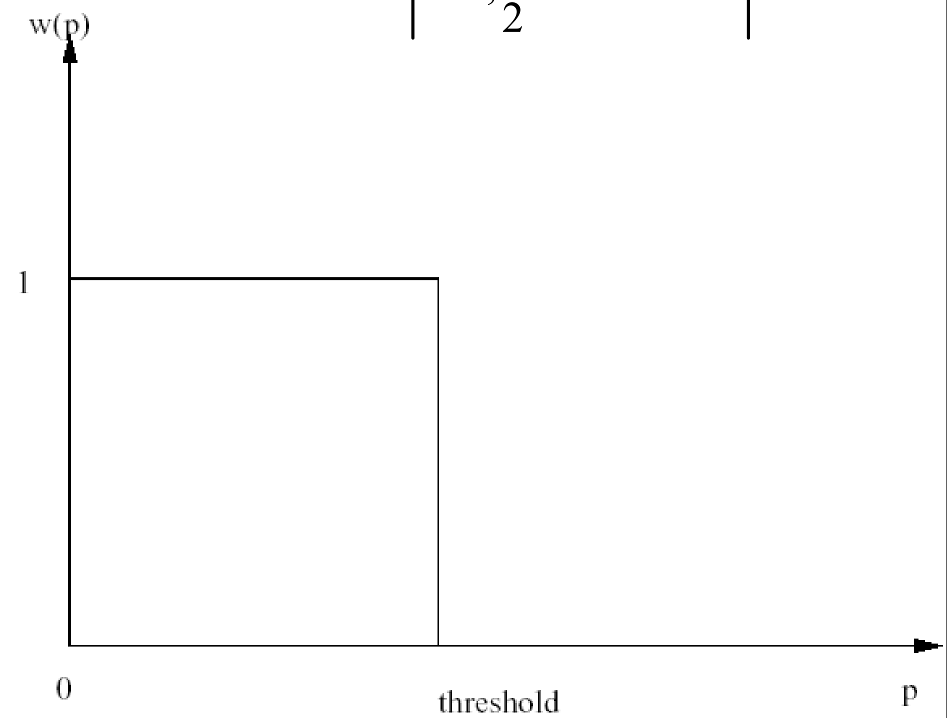
Minimizing error over a range of *p* values

- Error function

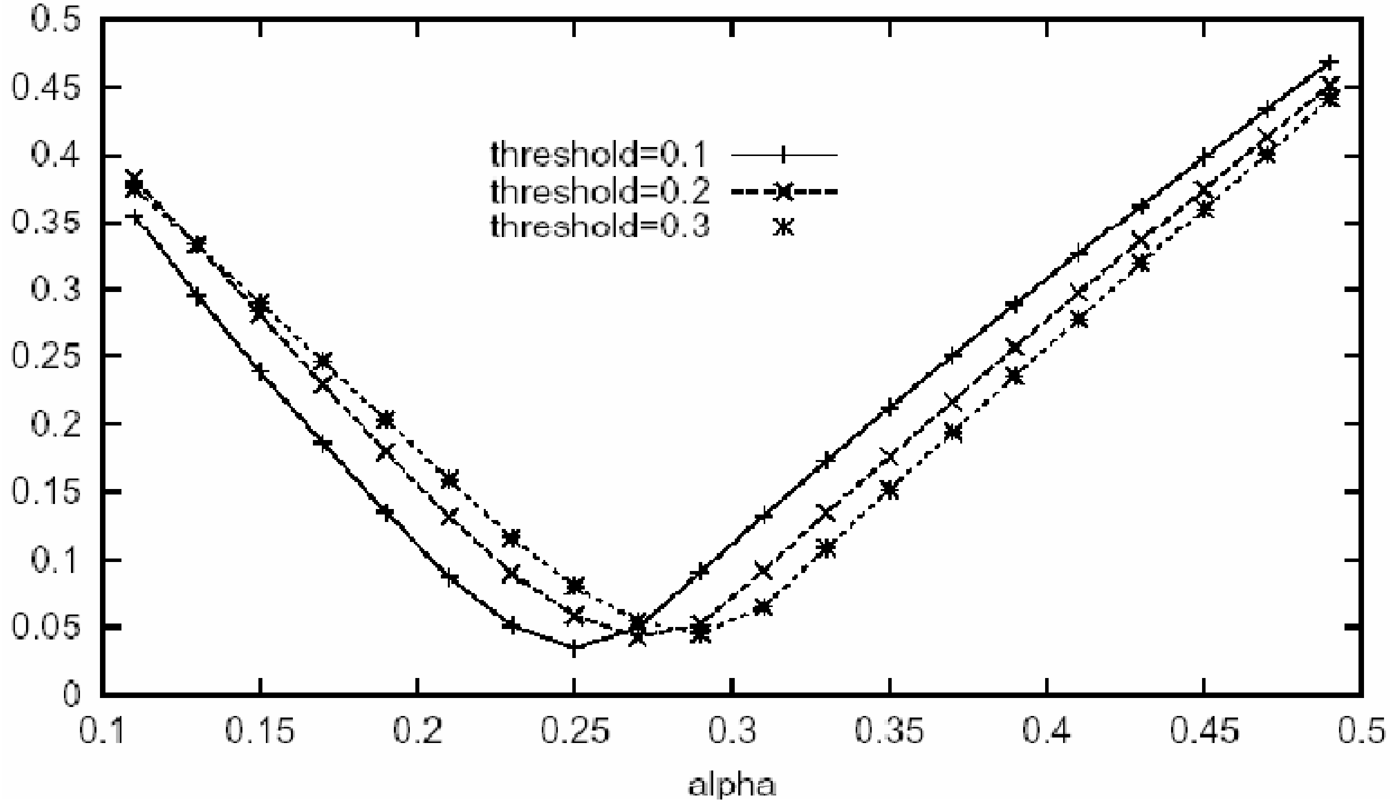
$$E_\beta(\alpha) = \int_0^1 w(p) \left| \frac{T_{\alpha,\beta}(p)}{T_{1,\frac{1}{2}}(p)} - 1 \right| dp$$

  where $w(p)$ allocates weight p between 0 and 1

- For a given β, minimize error to get the best α

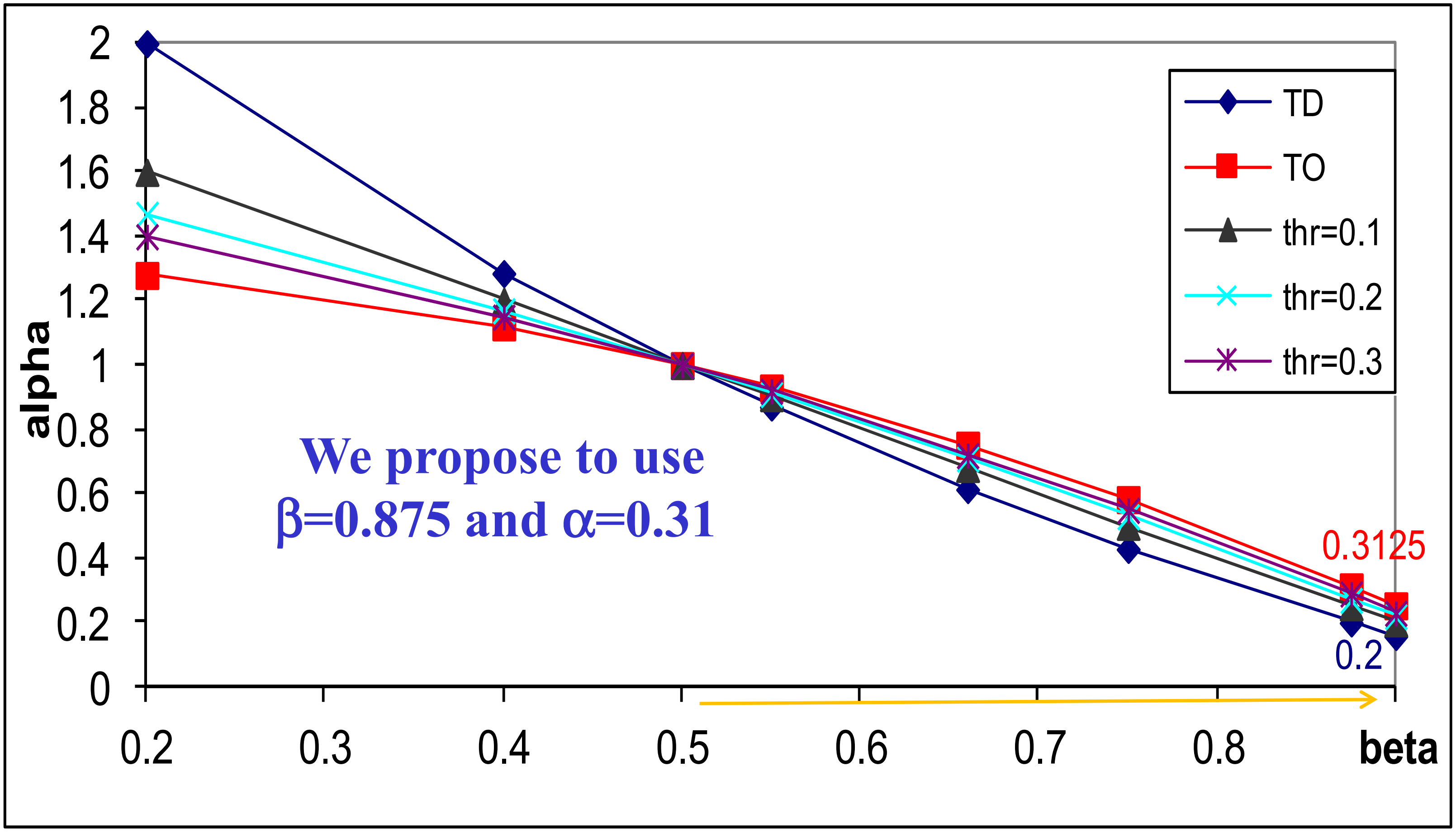


Error as a function of α



- $\beta = 0.875 \quad T_0 = 4(\mathrm{RTT})$
- Optimal value of α increases as threshold increases

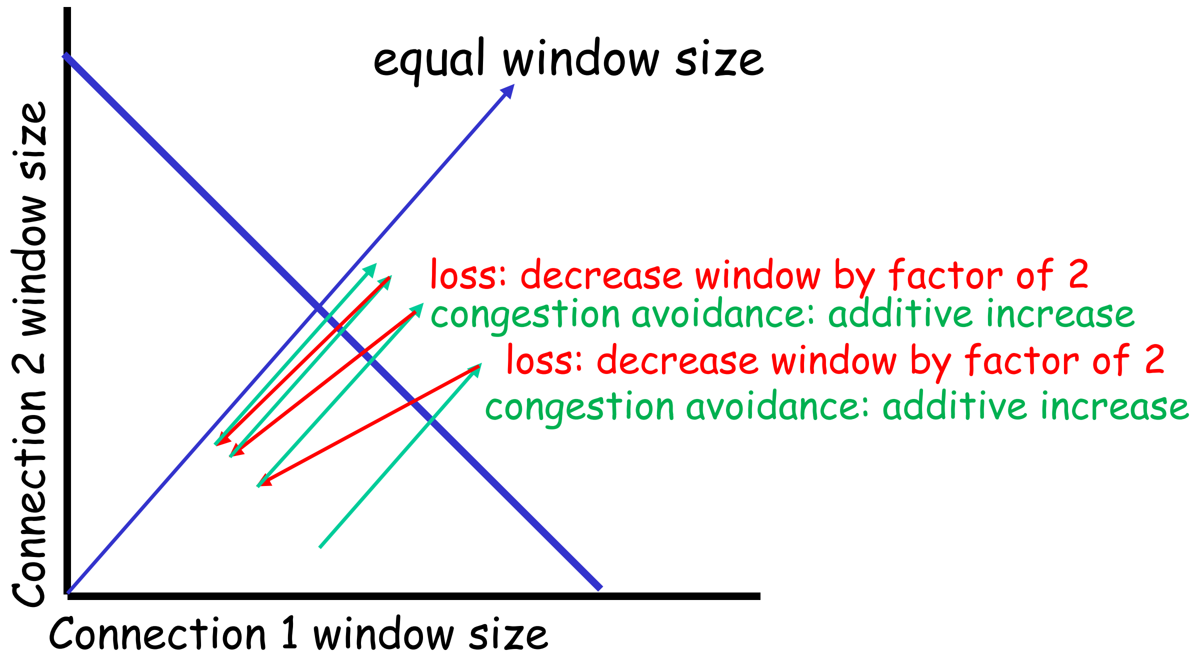
(α, β) curves for the three approaches



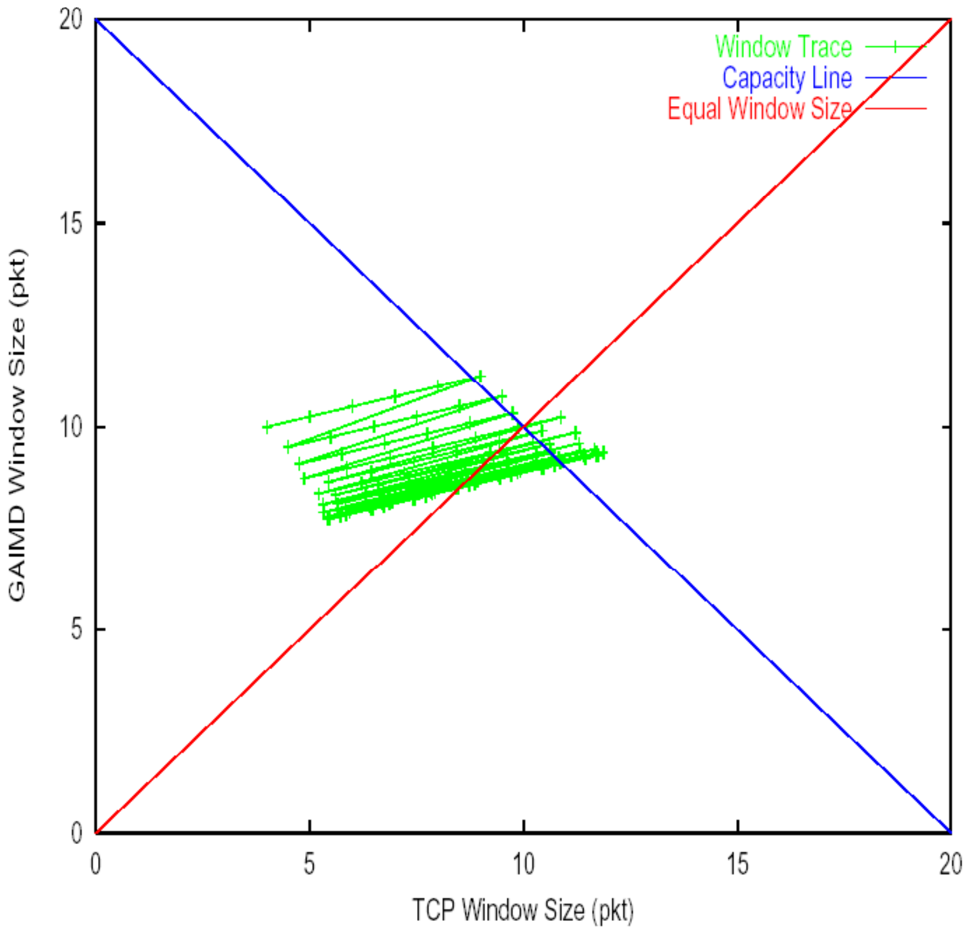
Chiu and Jain model

Two competing TCP Reno flows:

- Additive increase gives slope of 1, as window size increases
- Multiplicative decrease reduces window size proportionally



Evolution of Window Sizes



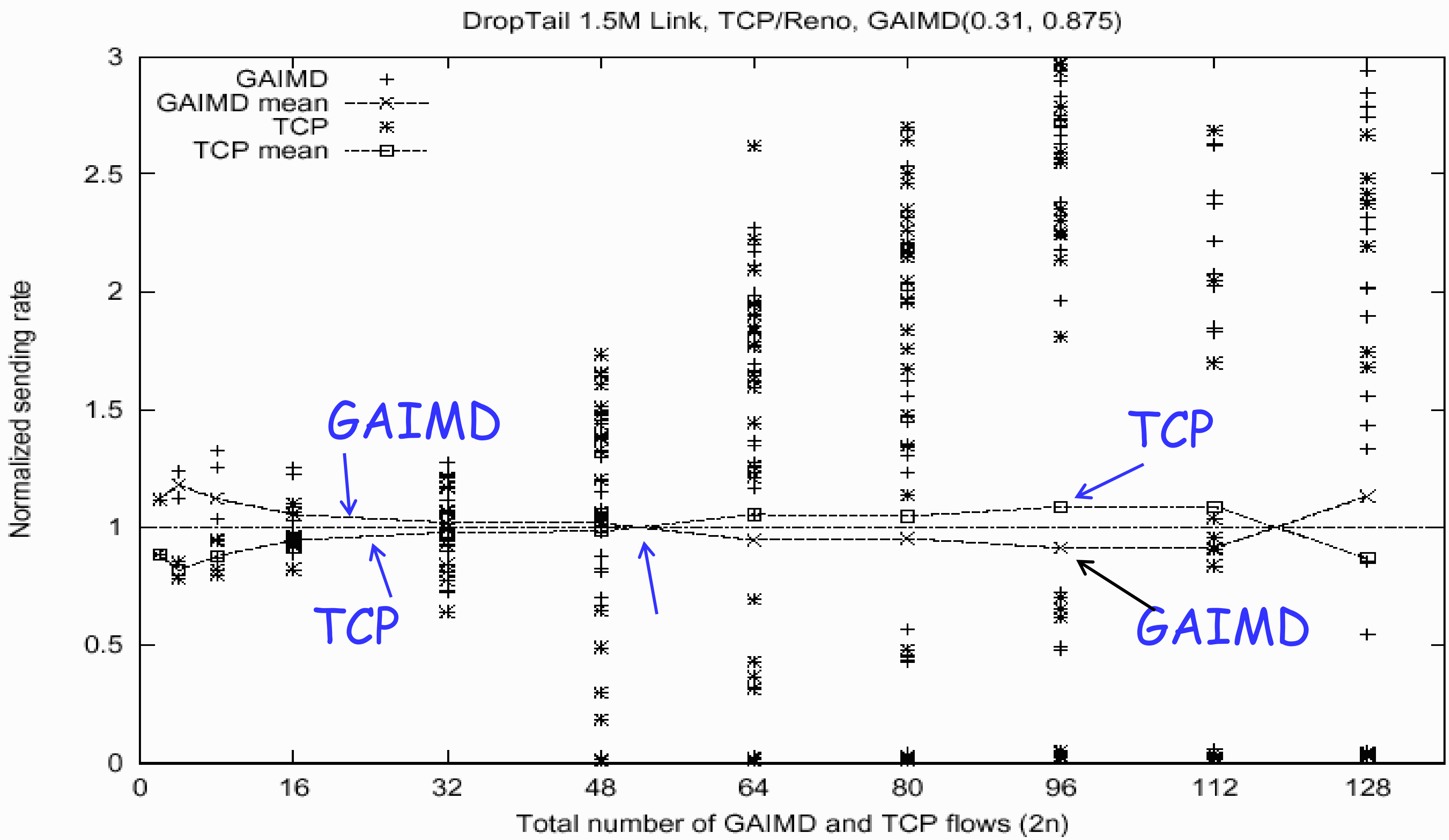
- Apply Chiu and Jain [5] model to a TCP flow and a GAIMD flow (no timeout, *same* RTT)
- GAIMD with α = 0.31 and β = 0.875
- Windows of the two flows do not converge to equal window size curve, but zigzag across it
- GAIMD has smaller window size oscillations

Experiments on TCP friendliness

- TCP Reno flows compete with GAIMD(0.31, 0.875) flows, *n* flows each, same simulation topology
- Drop-tail or RED bottleneck link
- Each run for 120 seconds of simulated time
- Vary *n* from 1 to 64
- Loss rate controlled by n value and link bandwidth

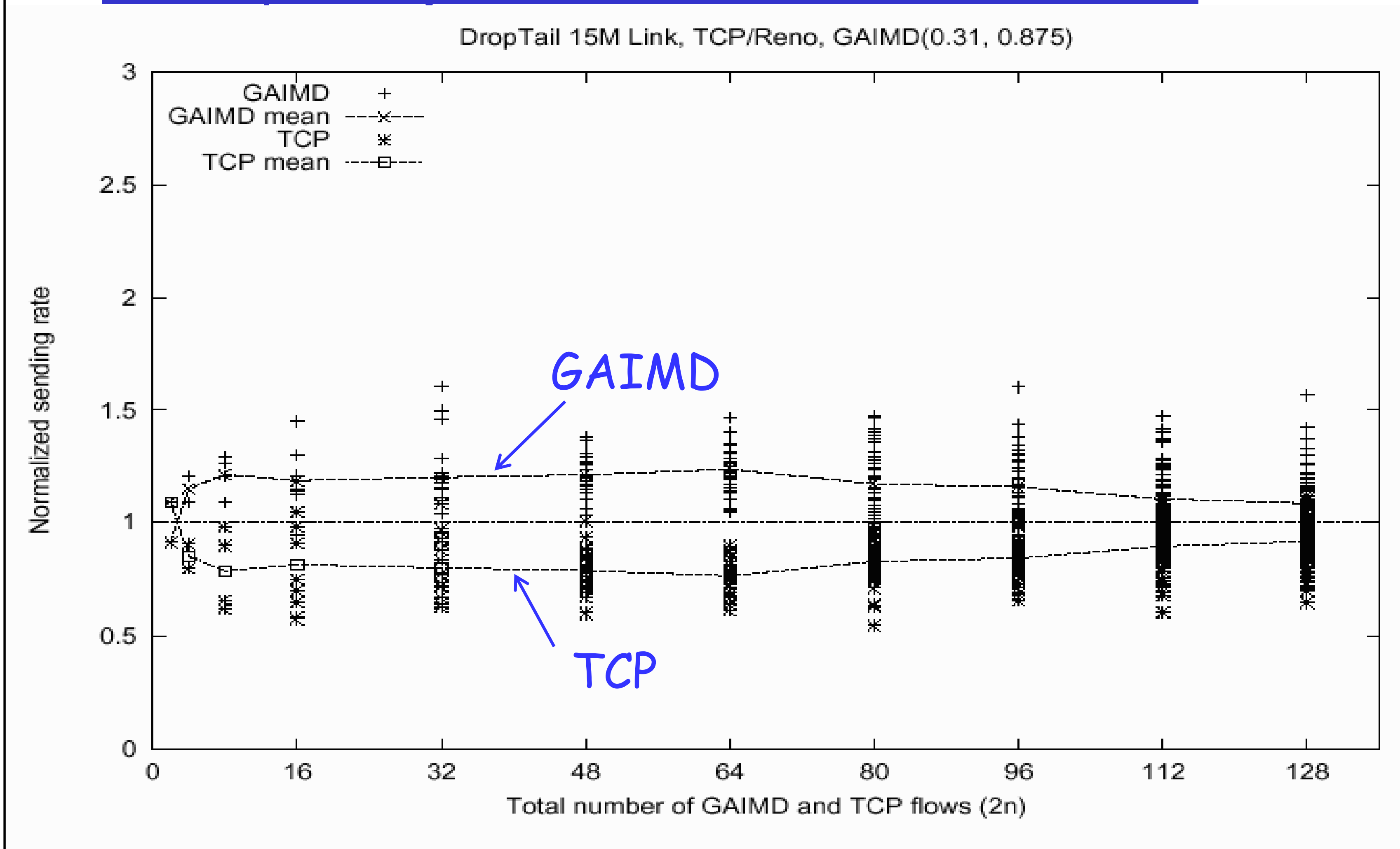
GAIMD competing with Reno

1.5 Mbps **droptail** link (high loss rate)

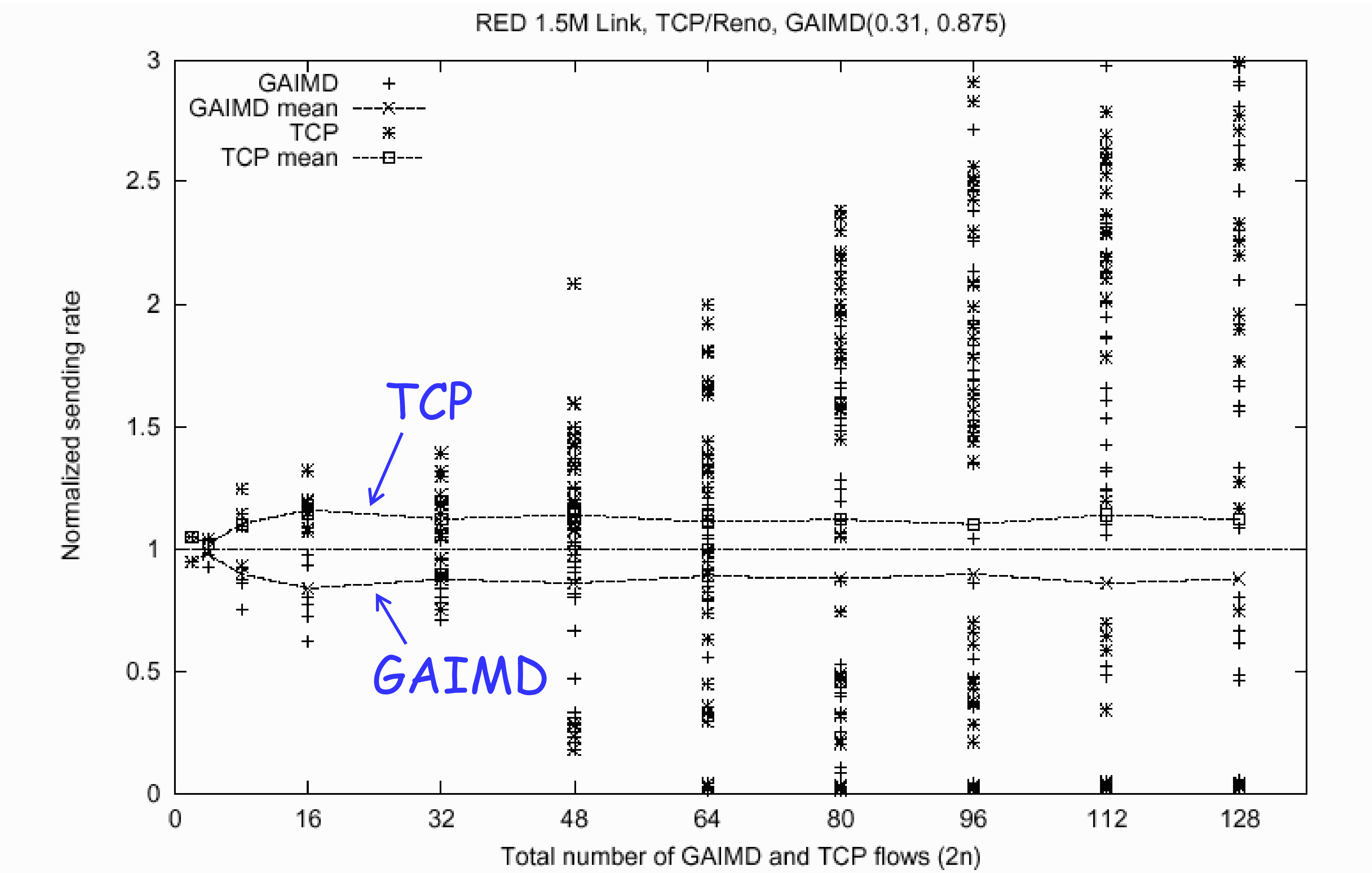


GAIMD competing with Reno

15 Mbps **droptail** link (-> smaller loss rate)

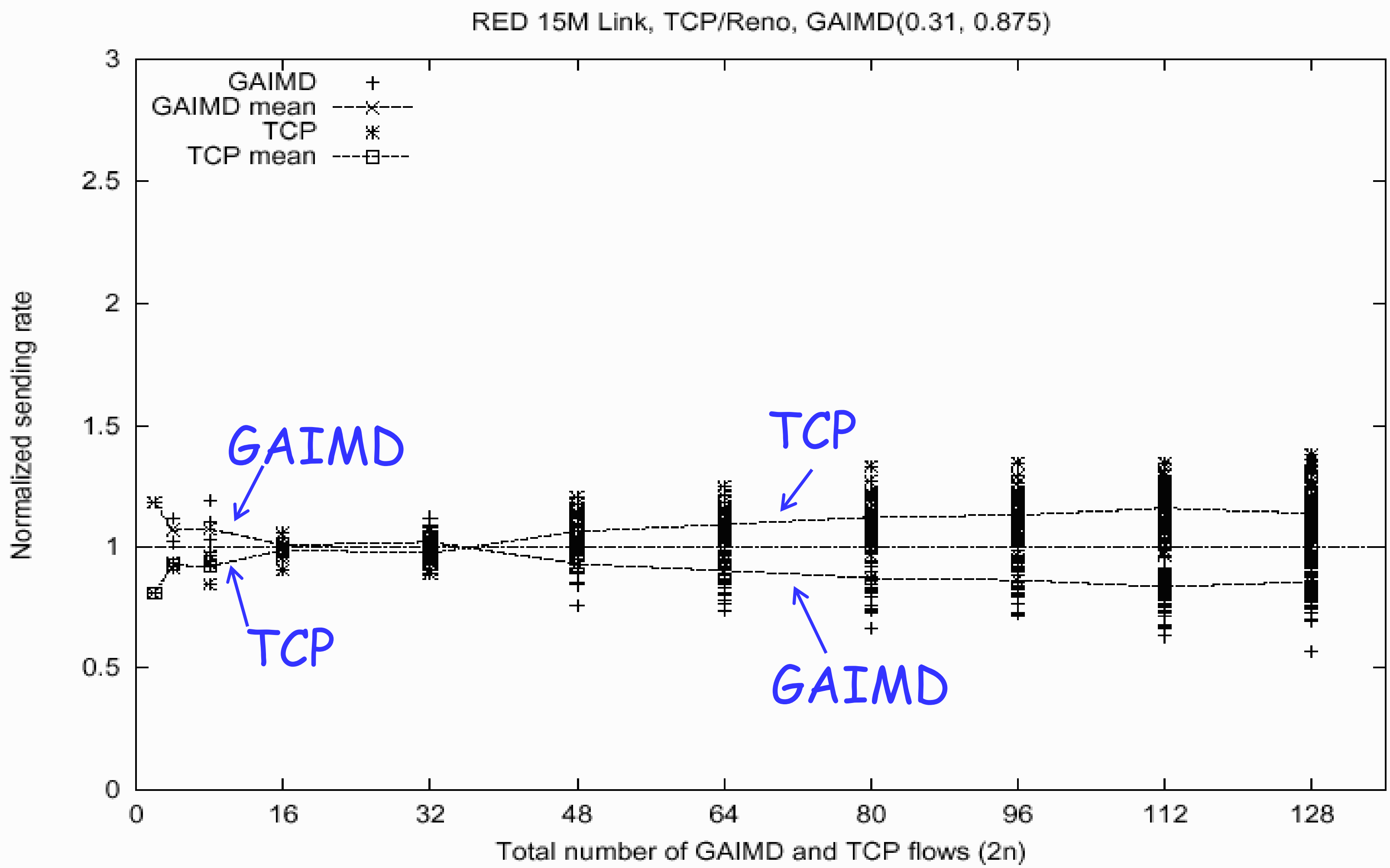


GAIMD competing with Reno
1.5 Mbps **RED** link (high loss rate)



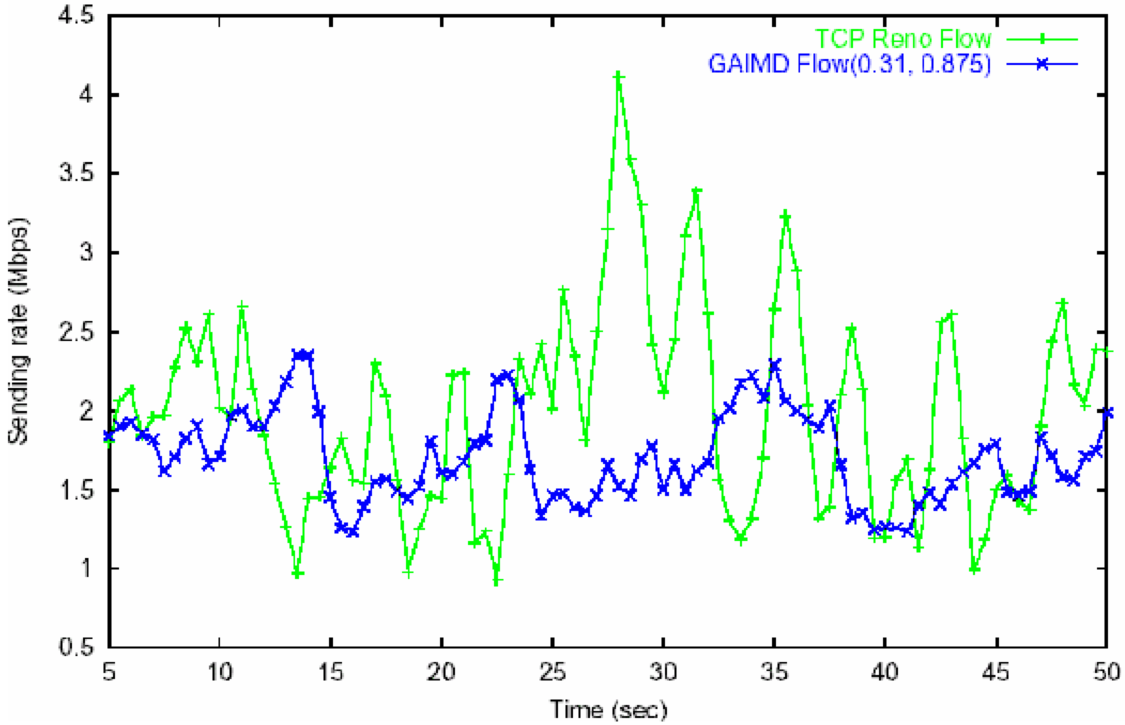
GAIMD competing with Reno

15 Mbps **RED** link (-> smaller loss rate)



Rate Fluctuations vs. time

4 GAIMD(0.31, 0.875) flows & 4 TCP Reno flows share



- 15 Mbps RED link
- Each point in a trace obtained by averaging over 150 ms, about 2-3 times RTT, of a flow
- From [33] we know that the CoV of GAIMD(0.31, 0.875) send rate is about **half** the CoV of TCP send rate

Conclusions

- A general version of AIMD with α and β parameter values
  - A formula for the (mean) send rate of a GAIMD flow as a function of α, β, p, b, RTT, and T_0 ; it is accurate for p up to 20%
  - Very easy to implement – modify a few lines of code
  - Equation-based rate control is complex and needs to measure p and *TO* which is hard
- Relationship between α and β for GAIMD to be TCP-friendly
  - Simulation results from experiments show that GAIMD(0.31, 0.875) flows compete with TCP Reno (also SACK flows), at a drop-tail or RED bottleneck link, in a friendly manner
  - GAIMD(0.31, 0.875) has smaller rate fluctuatons

The End