NC STATE UNIVERSITY

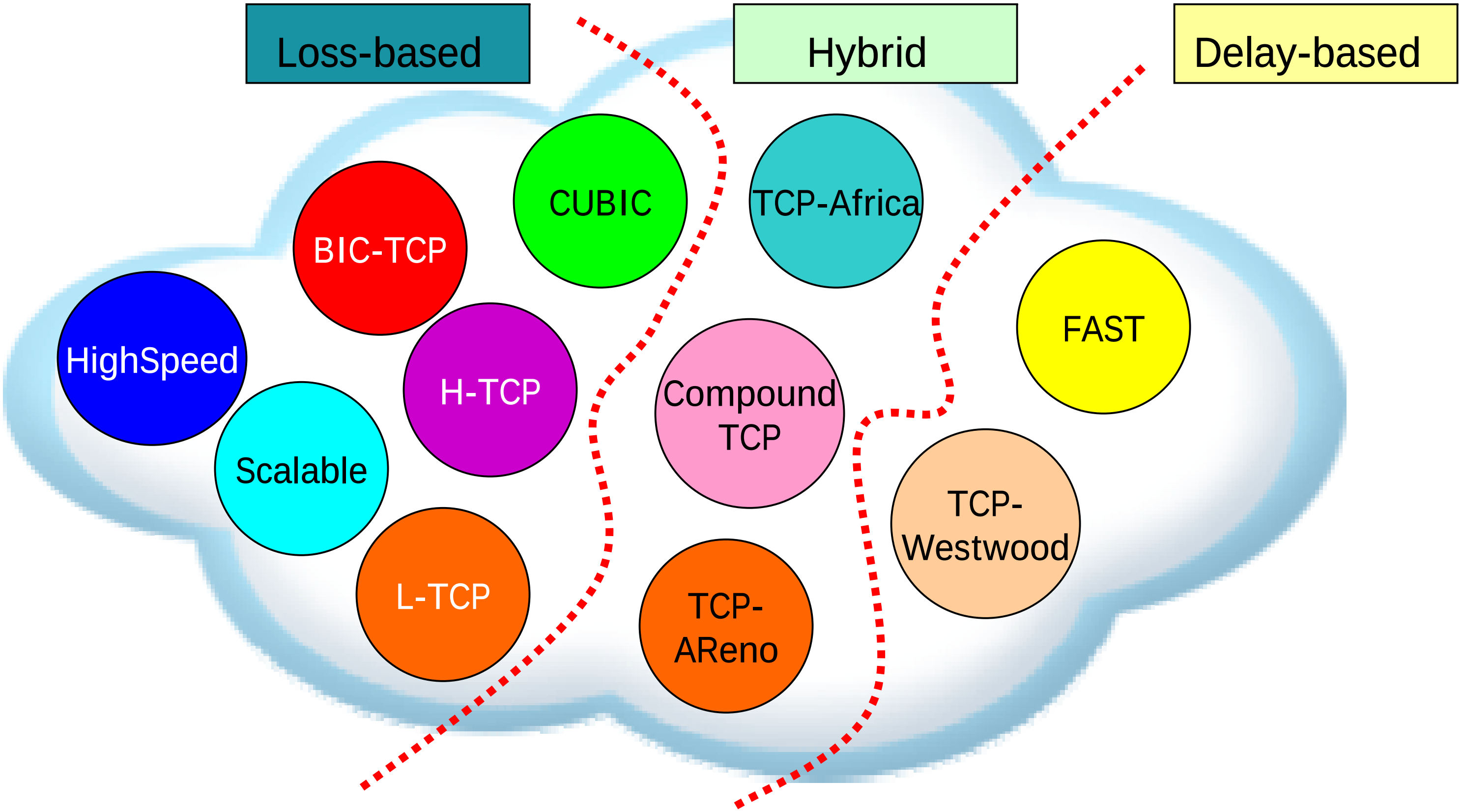
Stochastic Ordering for Internet Congestion Control

Han Cai, Do Young Eun, **Sangtae Ha**, Injong Rhee, and Lisong Xu

PFLDnet 2007

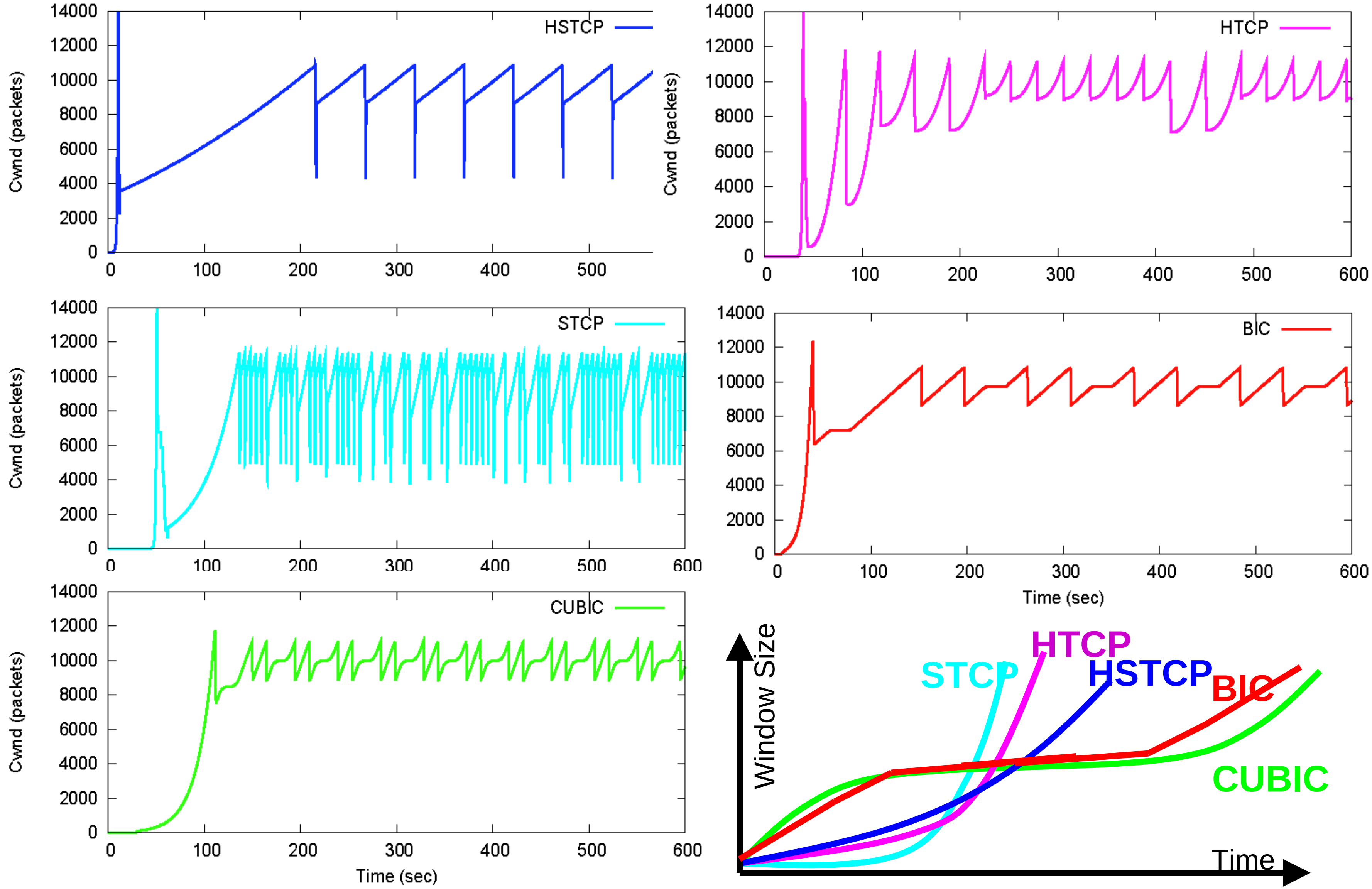
February 7, 2007

High-Speed TCP Variants

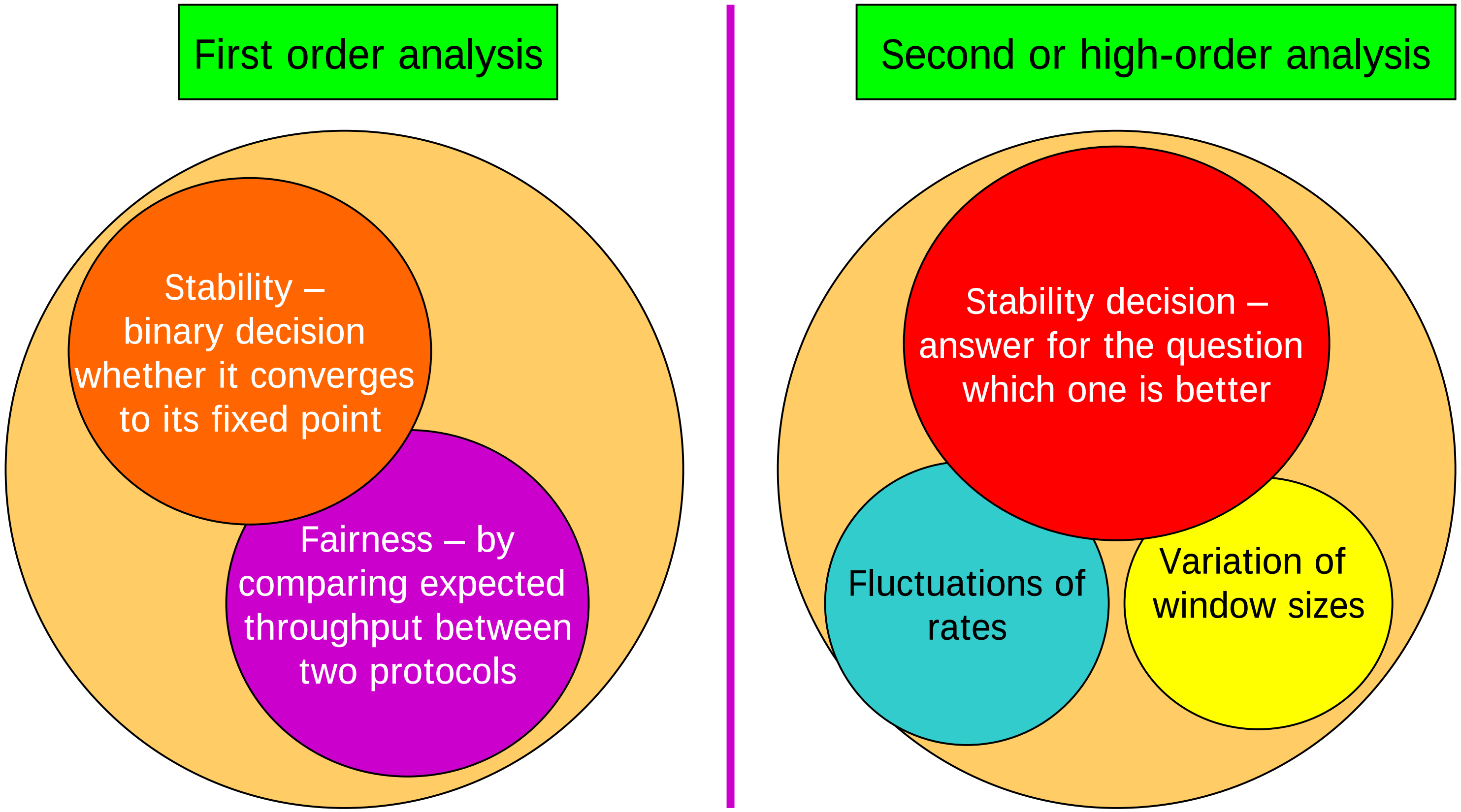


- Many High-speed TCP variants have been proposed
- High-speed protocols can be divided into three categories
- Can we compare loss-based protocols?

Example of Growth Functions



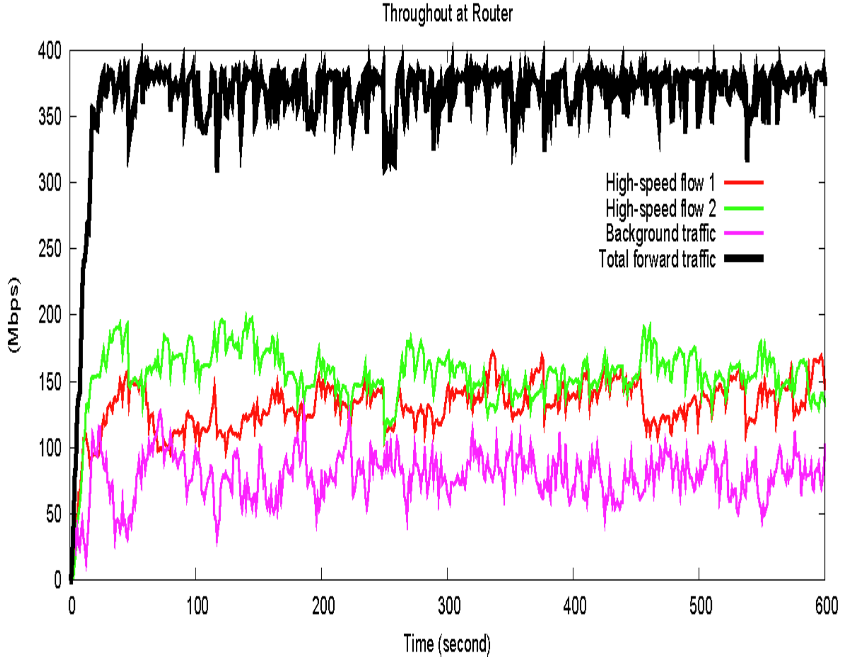
First Order vs. Second or High Order Behaviors



- If two protocols have the same average behaviors, they are not distinguishable by the first order analysis (fixed point analysis)
- Even if two protocols have the same first order behaviors (expected throughput), they could have widely different second or high-order behaviors.

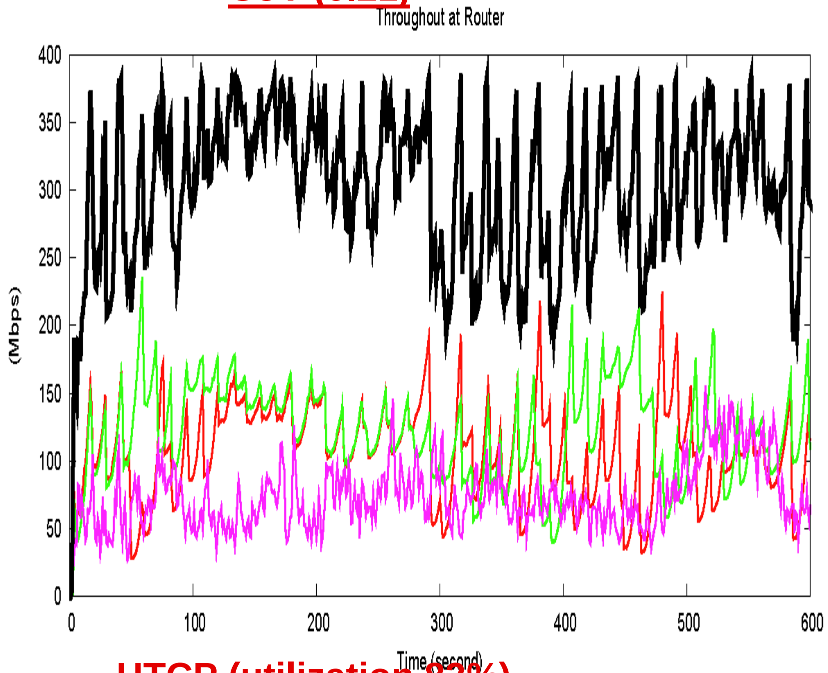
CoV – one example of second order

CoV (0.13)



BIC (utilization 94%)

CoV (0.21)



HTCP (utilization 82%)

- CoV, standard deviation over mean, is commonly used by practitioners to compare the stability of protocols.
- Higher CoV also affects the general well beings of the network including utilization, queue oscillation, packet loss characteristics

Stochastic Convex Ordering theoretical tool to analyze the 2nd order.

Definition: for random variables, X and Y,

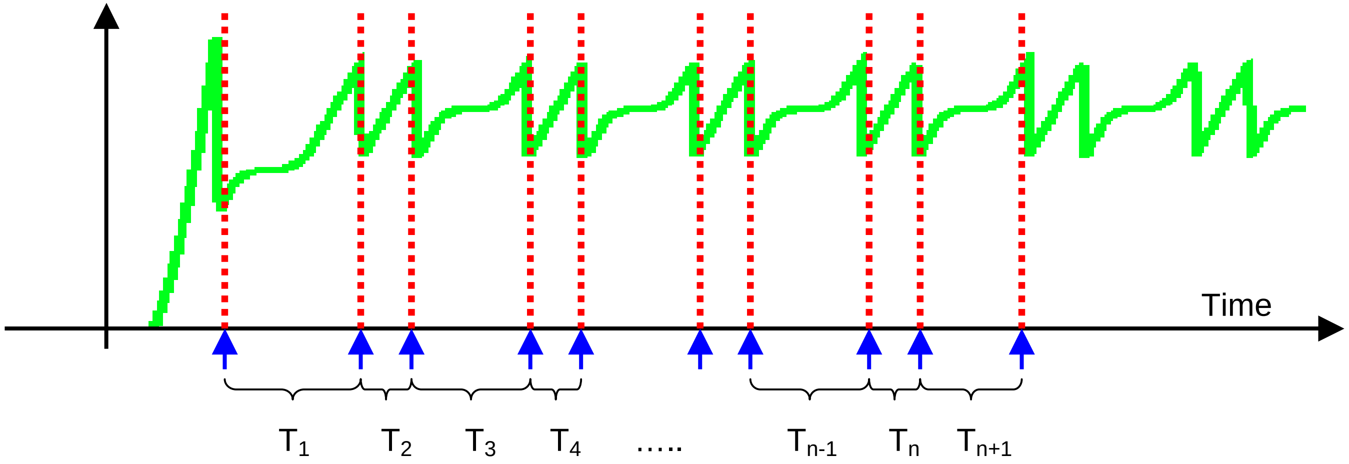
$X \leq_{cx} Y$ means $E\{f(X)\} \leq E\{f(Y)\}$

for any convex function f,

e.g, f = variance.

- If $X \leq_{cx} Y$ in convex ordering, it means X is less variable than Y.

Main Assumption



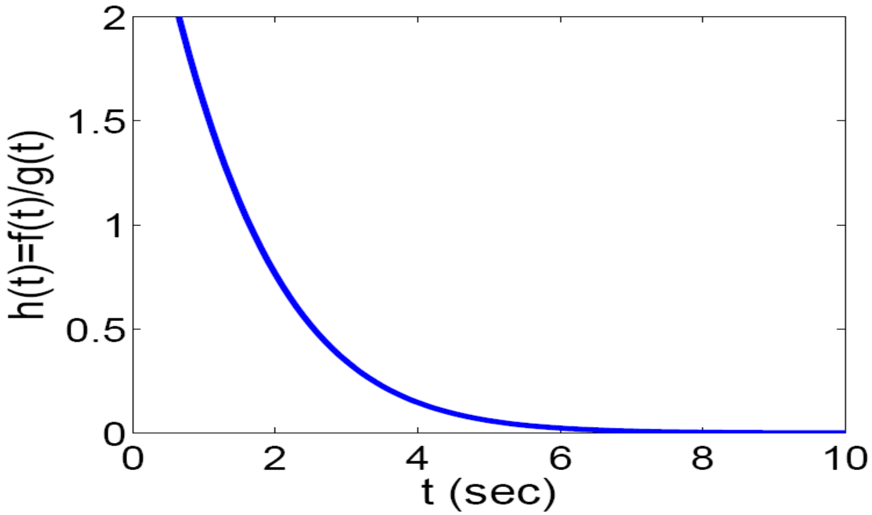
Assumption: The **Inter-loss intervals** T_n are **i.i.d** (independent and identically distributed) – commonly observed by many Internet measurement studies [4,5,6].

[4] Y. Zhang, N. Duffield, V. Paxson, and S. Shenker, "On the constancy of Internet path properties," ACM SIGCOMM IMW 2001

[5] E. Altman, K. Avrachenkov, and C. Barakat, "A Stochastic Model of TCP/IP with Stationary Random Loss," ACM SIGCOMM 2000

[6] J. Padhye, V. Firoiu, D. Towsley, and J. Kurose, "Modeling TCP Throughput: a Simple Model and its Empirical Validation," ACM SIGCOMM 1998

Main result



(a) monotone $h(t)$

- Given window profiles f(t) and g(t), h(t) = f(t)/g(t) is monotonically decreasing,

  then $f(t) \le_{cx} g(t)$.

  Concave < Convex

  - E.g.

    $f(t) = \log(t)$ | $g(t) = t^2$

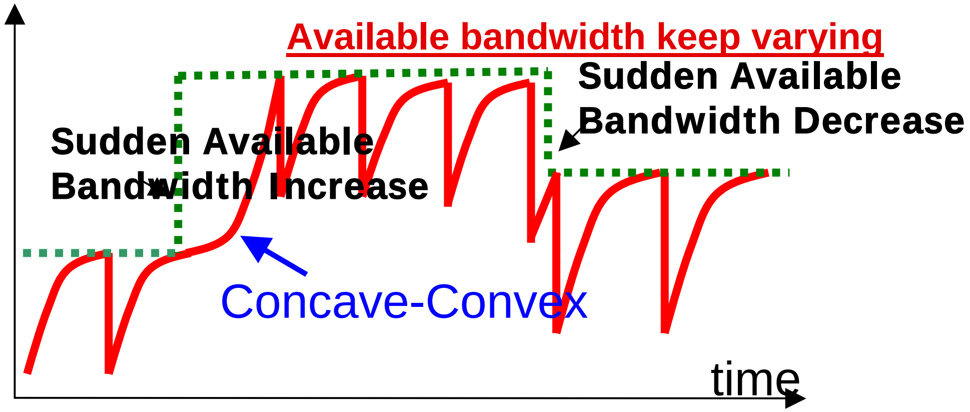
    $f(t) = t^{0.5}$ | $g(t) = t^2$

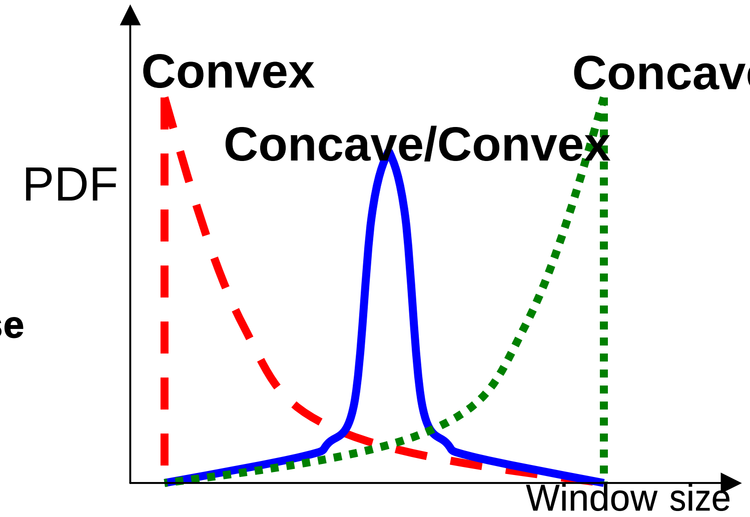
    $f(t) = 0.5t^2$ | $g(t) = 3t^3$

Results - Intuition

Stationary loss

Non-stationary loss



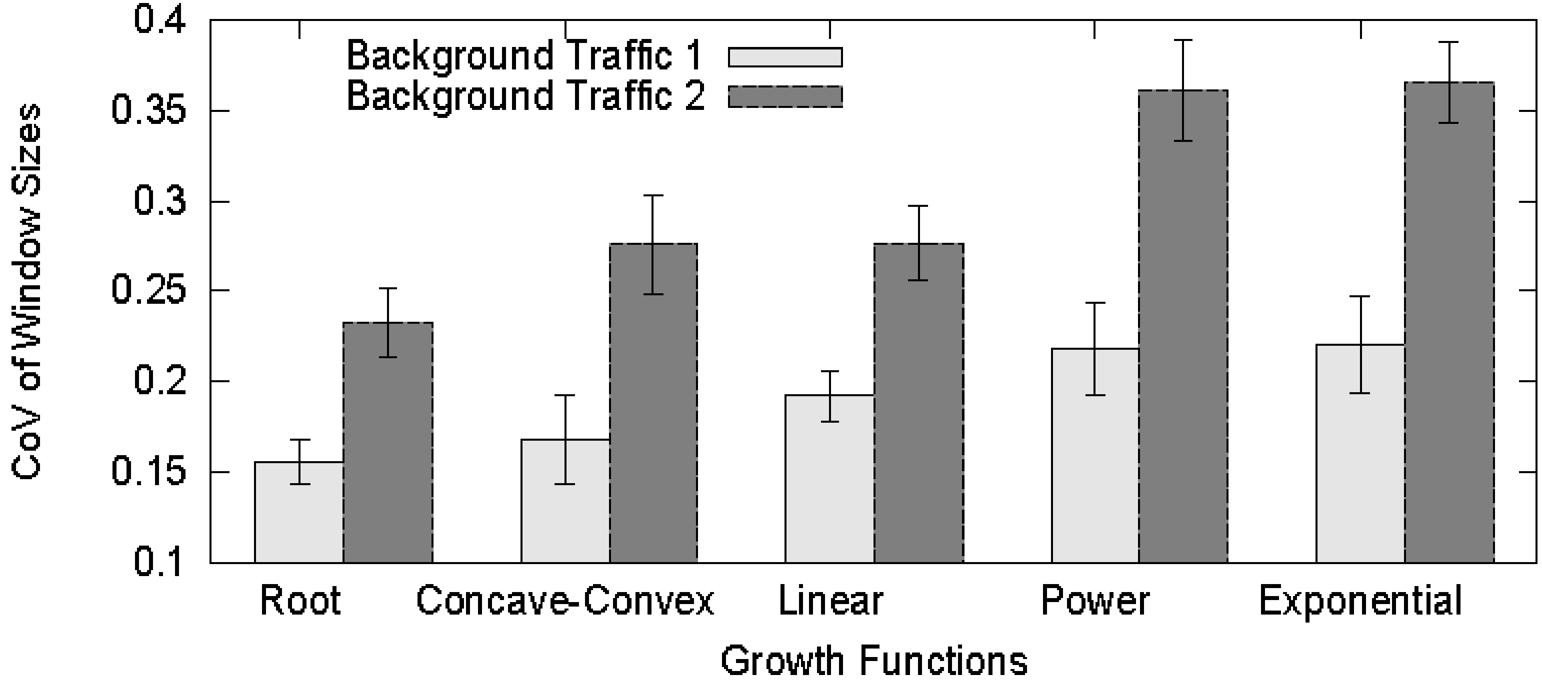


- During stationary loss, concave has less variance because its windows are mostly around the mean so that its variance is small.
- During non-stationary loss, concave-convex has also its windows mostly around the mean.

NS2 Simulation verification

- Dumbbell, bottleneck 250Mbps, RTT 100ms,100% BDP buffer size
- Loss generated by predefined models and by using background traffic
- Background Traffic (20% of total link bandwidth)
  - Type I (five long-lived flows), Type II (300 web sessions)
- Five pseudo protocols simulated
  - Root, Linear, Power (Square), Exponential, Concave-Convex
- Measure the CoVs of window sizes of the five pseudo protocols.

NS2 Simulation Result



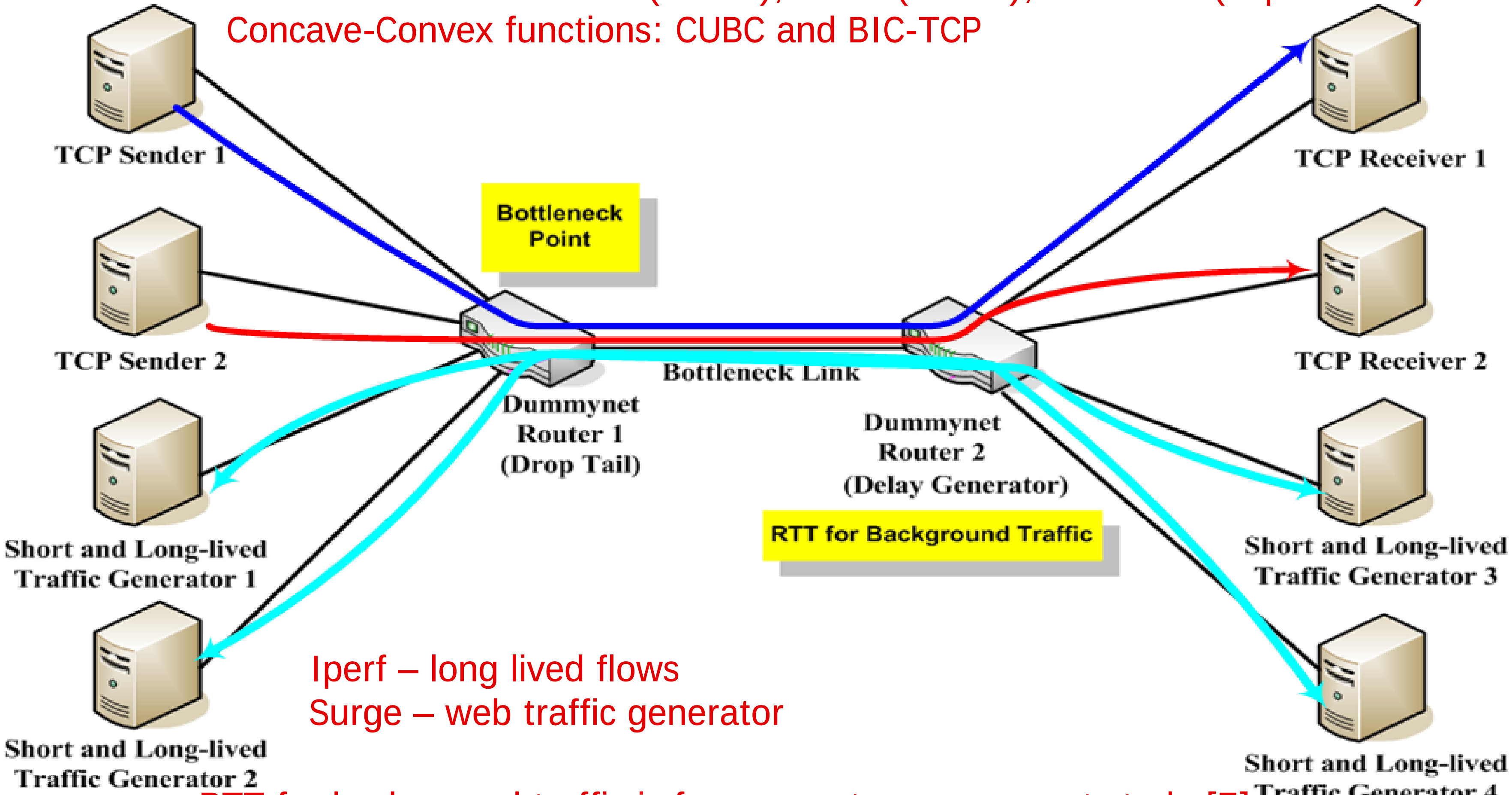
- The result confirms the same ordering predicted by our analytical result

Root $\leq_{cx}$ Linear $\leq_{cx}$ Power $\leq_{cx}$ Exponential

Root $\leq_{cx}$ Concave-Convex $\leq_{cx}$ Exponential

Testbed (Dummynet) Setup

400Mbps Bottleneck,
Convex functions: HSTCP (Linear), HTCP (Power), and STCP (Exponential)
Concave-Convex functions: CUBC and BIC-TCP

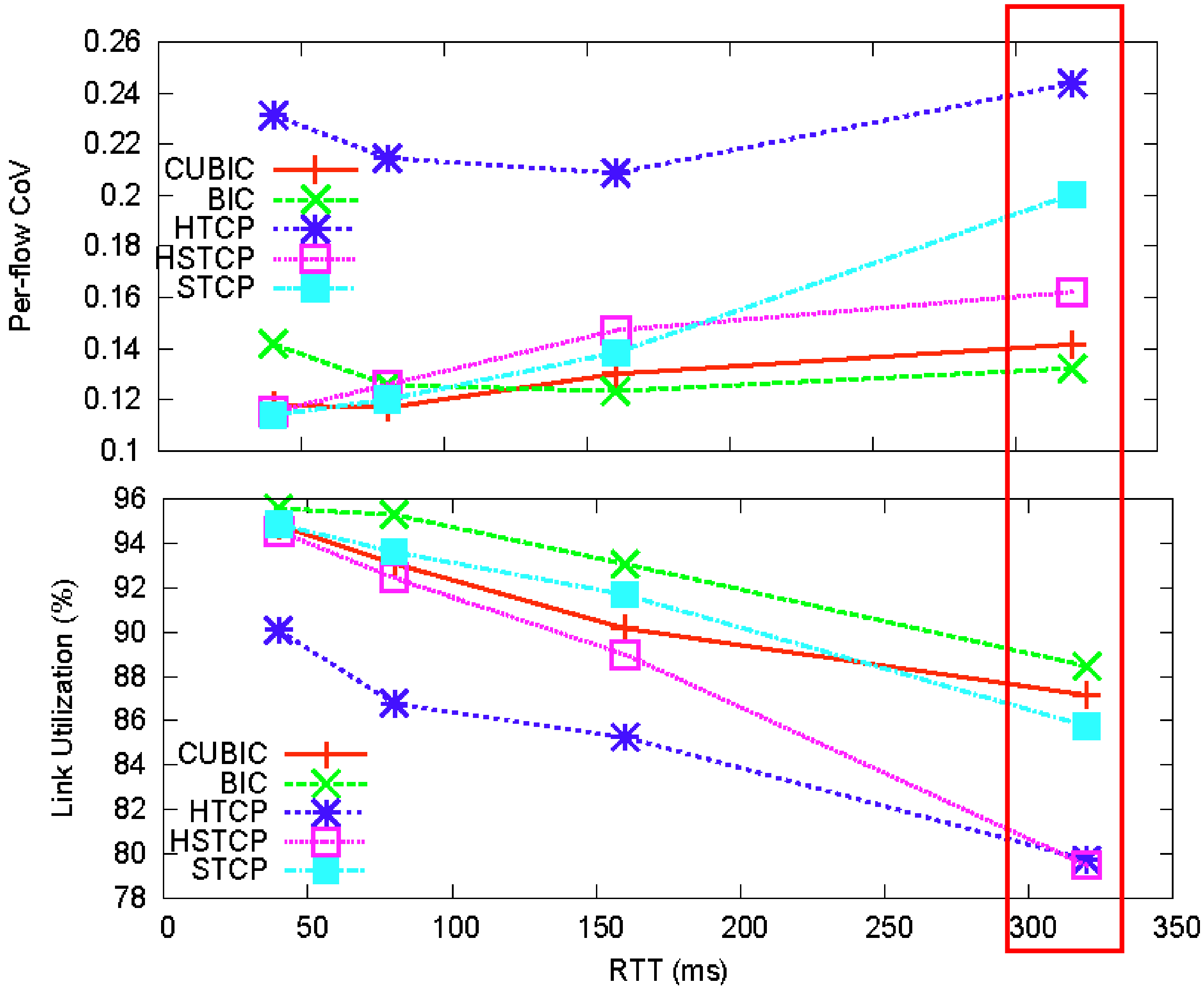


Iperf – long lived flows
Surge – web traffic generator

RTT for background traffic is from recent measurement study [7]

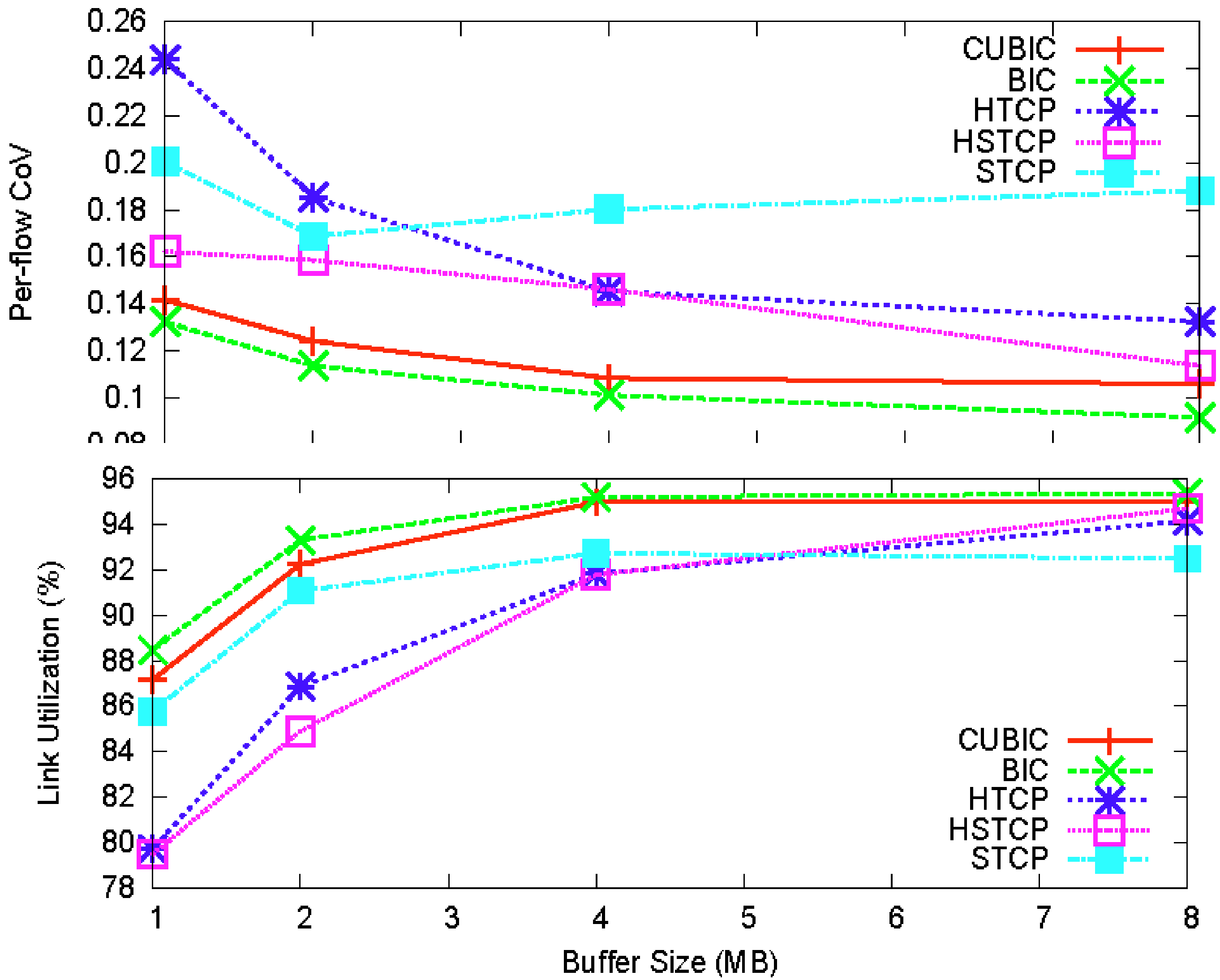
[7] J. Aikat, J. Kaur, F. D. Smith, and K. Jeffay, Variability in TCP round-trip times, IMC 2003

CoV and Link Utilization



- Buffer size (1MB), four HS flows with the same RTT (40ms – 320ms)

Impact of buffer sizes



- Buffer size (1 – 8MB), four HS flows with the same RTT (320ms)

Conclusion and Future Work

- Window growth function determines its relative stability.
- Stochastic Convex Ordering can be applicable to loss-based protocols.
- Concave-Convex protocols tends to give the smallest rate variation (BIC, CUBIC).
- Rate variations can affect the general well-beings of the network including utilization, queue oscillations and packet loss characteristics.
- Dynamics of aggregated flows and their impact on the general health of the networks would be our future work.

Q & A

More experimental results are available at http://netsrv.csc.ncsu.edu/convex-ordering

Thank you for your participation