Some ideas for simple congestion management

Rong Pan, Balaji Prabhakar

IEEE 802 Plenary Meeting

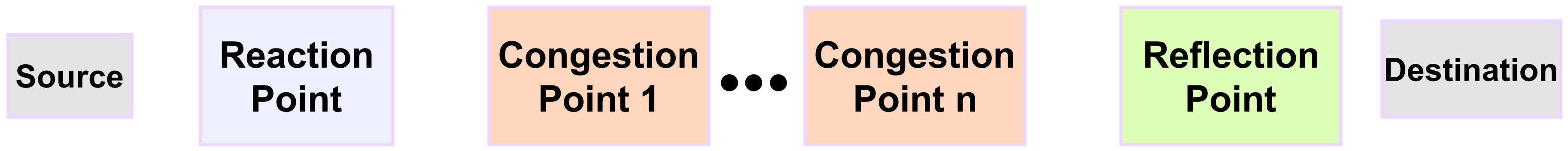
Mar 14, 2007

Orlando, Florida

Overview

- Congestion management scheme
  - Algorithm (what to feedback)
  - Signaling (how to feedback)
- Presentation format
  - Delineate solution space
  - Propose a scheme (algorithm and signaling)
  - Explore performance and complexity issues
- Further work and thoughts

Congestion management loop components



- Rough definitions…

- **Source:** Where data is generated.
- **Reaction Point:** Where the rate of injection of a flow (or flows) is changed due to congestion signals; usually, the place where rate limiters reside.
- **Congestion Point:** Where resources (buffers/links) exist and can be congested, and where congestion signals are generated; usually, switch buffers and the links they are attached to.
- **Reflection Point:** Where congestion signals are reflected back to the source.
- **Destination:** Where data is consumed.
- **Congestion Management Domain:** ReaP -- CPs -- RefP.

- Overarching goals: Good performance (high utilization, low delays, fair, good response, etc), low implementation complexity, low signaling overhead.

CM Architecture

- The overall architecture has the following components
  - Algorithm
    - What congestion signals should the CPs generate?
    - How should the ReaPs react to these signals?
  - Signaling
    - How should the congestion signals be sent back to the ReaP?
      E.g. backward signaling or forward signaling

- Types of algorithm
  - Congestion management
  - Rate allocation

- Types of signaling architecture
  - 3-point architecture: ReaP --> CPs --> RefP (forward signaling)
  - 2-point architecture: ReaP --> CP/RefP (backward signaling)

Rate allocation vs congestion management

- Rate allocation, especially max-min rate allocation, is definitely a solution to the congestion management problem. But it "over-solves" the congestion management problem.
  - Notably, max-min allocation even at a single node is equivalent to a processor-sharing service discipline. Therefore, it entails "per-flow" work. In the network context, the per-flow queues are moved to the edge in the form of rate limiters.
  - Congestion management is, therefore, a smaller problem than rate allocation. This gives the hope that it is simpler.
- Secondly, a rate allocation algorithm needs to know the capacity of the link which it is allocating. When this changes in an unknown fashion, rate allocation involves two steps: determine the link capacity, then allocate it.
  - Congestion management copes with changing link capacities by simply "dinging" the one or two biggest flows. It gets away with this because it does not have equal rate allocation as a goal.

- Fairness is achieved by congestion management schemes as follows
  - Short-term, not packet-by-packet.
  - Proportional fairness, not max-min fairness.
  - Fair congestion management schemes favor the growth of low rate flows and "ding" high rate flows when there is congestion.

CM Algorithm

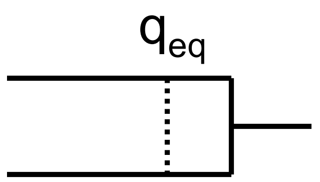
- We now focus on the algorithm and come to signaling later

- Since the algorithm only involves mechanisms at the ReaP and at the CP (the RefP is not involved in the algorithmics), we describe the ReaP and CP mechanisms

- Packet Format
  - We use a Congestion Indication field in the packet header, which we assume will be 6 or 7 bits long. This field will tell the ReaP the amount of congestion in the network. The variable that measures congestion is indicated "Fb."
  - We will see that Fb values can only be 0 or negative, not positive.
  - As an *option,* we could also have a FlowID field in the header.
  - Every packet leaving a ReaP will have Fb value equals 0.

Congestion Point Mechanism

- At the CP
  - Sample packets with probability p
  - Compute: Fb = - [q_{off} + w q_{delta}]
    - If Fb < 0, and if Fb value is smaller (more negative) than Fb value in the packet header, then overwrite Fb value in packet header with computed Fb value
    - Else, do nothing
    - Note: w is a parameter, usually a power of 2



q_{off} = q - q_{eq}
q_{delta} = # pkts enqueued - # pkts dequeued between two packet arrivals (or sampling instants)

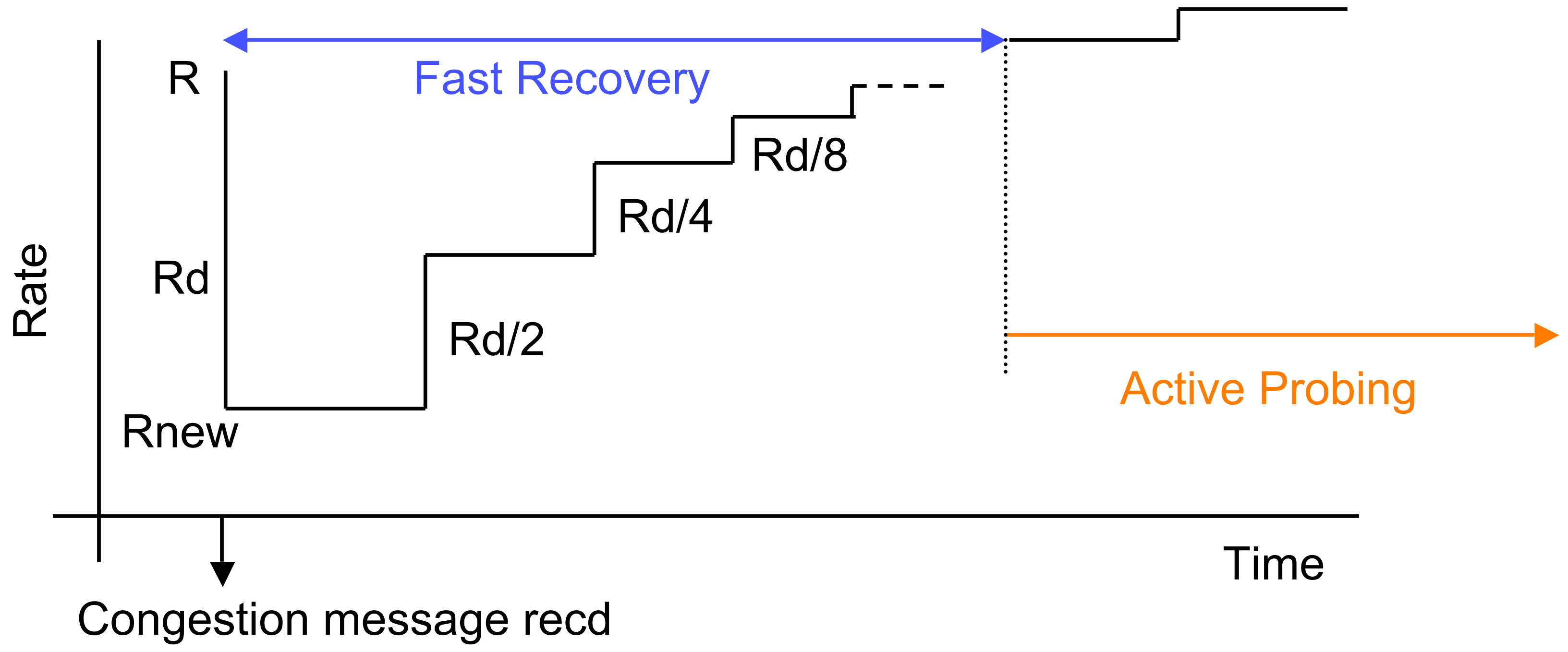
Reaction Point

- ReaP Dynamics
  - Starting rate for every flow equals 10Gbps
  - Insert Fb = 0 in outgoing packet
  - Insert a “flowid” into outgoing packet’s header (optional)

- Whenever a ReaP receives a message
  - Decrease rate from R to Rnew = R(1 - IFbIxGd), where Gd is a gain
  - Perform “fast recovery” and “active probing”

- Fast recovery
  - Let Rd = R IFbI Gd be the amount of rate decrease; the idea of fast recovery is to quickly regain as much of this rate as possible
  - Fast recovery proceeds in cycles; each cycle clocked by the “fast recovery timer”
  - Fast recovery timer
    - Increments for every transmitted byte up to B_{FR}, it then resets to zero and counts again
    - The cycles of counting are numbered 0, 1, 2, …
  - The transmission rate is as follows
    - During cycle 0, at rate Rnew
    - During cycle 1, at rate Rnew + Rd/2
    - During cycle 2, at rate Rnew + Rd/2 + Rd/4
    - And so on until cycle 5, as long as it does not receive any further QCN messages
  - If a congestion message is received, then cut rate as before and restart fast recovery
  - At the end of fast recovery, the source moves to Active Probing

Reaction Point



- Active probing (multiplicative increase) always follows fast recovery
  - Active probing is clocked by the “rate increase timer”
    - Rate increase timer expires every T secs
  - When timer expires, the current rate is changed to R*A, where A > 1 is the increase parameter
  - If a congestion message is received, cut rate as before, perform fast recovery and then active probing

Related work and some notes

- The algorithm suggested is heavily influenced by several algorithms
  - It calculates Fb as in BCN, and the REM and PI contollers in the Internet literature
  - The fast recovery part is from the BIC TCP algorithm

- The CP computes $Fb = - [q_{off} + w\ q_{delta}]$
  - This is different from BCN but similar to REM and PI. It is based on the observation that even in BCN the sources merely use Fb and not q_{off} or q_{delta}
  - More fundamentally, Fb becomes the "congestion measure;" a part of it depends on buffer occupancy, another part depends on link utilization, and the switch is best placed to decide how to weigh these resources.

- Simplifications with respect to BCN come mainly from quantization, and lack of CP--RP association through the CM tag.

- A major benefit: Not having the CM tag on allows for perfectly incremental deployment; i.e. no flowid, no CPID, nothing. Congestion messages use SA of sampled packet.
  - Moreover, in this case, we only need exactly one rate limiter per ReaP.

Intuition for Fast Recovery

- The best way to understand fast recovery is by considering TCP
  - Recall
    - TCP cuts the window by 1/2 for every dropped/marked packet
    - And increases window size by 1 each round trip time when there is no drop
  - When the bandwidth-delay product is high, the additive increase by 1 can be very slow, require large buffers, and lead to poor link utilization.
  - Fast recovery, or BIC TCP, is a method for overcoming these problems.

- BIC TCP through an example
  - Suppose the congestion window size equals 512
  - If we now get a packet drop, the window goes down to 256
  - After 1 RTT, if there are no drops, the window increases to 256 + 128 = 384
  - After another RTT (if there are no drops), the window increases to 384 + 64 = 448
  - The complete sequence of window sizes is:
    - 512, 256, 384, 448, 480, 496, 504, 508, 510, 511

- Active (additive) probing would start now, increasing the window size by 1, so we get window sizes: 512, 513, 514, …

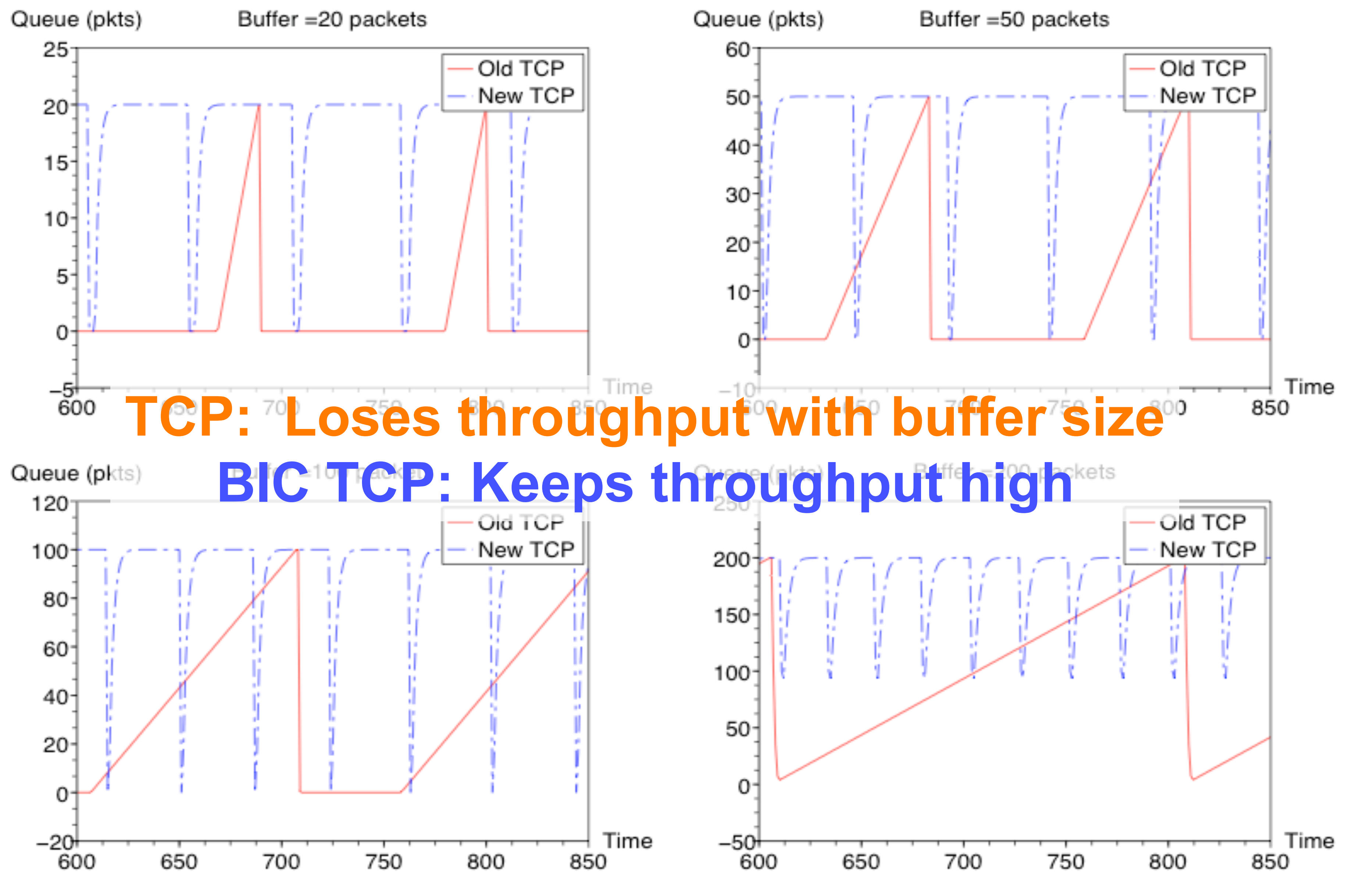
- If another drop occurs any time during this process, we go back to binary increase

Benefits of BIC TCP

- BIC TCP
  - Gets sources high throughputs
  - Keeps links highly utilized (this is not exactly the same as the previous point)
  - *Most importantly,* it does this with small buffers
  - By doing a binary search for the correct window size, *instead of* a linear search, BIC TCP is both quick and gentle in probing for extra bandwidth
  - Note: BIC has been invented by Rhee et al

- Comparison of BIC with plain old TCP
  - Consider a link with capacity 1000 pkts/sec
  - A RTT of 200 msec
  - Bandwidth-delay product worth of buffering = 200 pkts
    - TCP will not give 100% throughput with less than this amount of buffering for a single source
  - We use buffers of depth 20, 50, 100 and 200 pkts

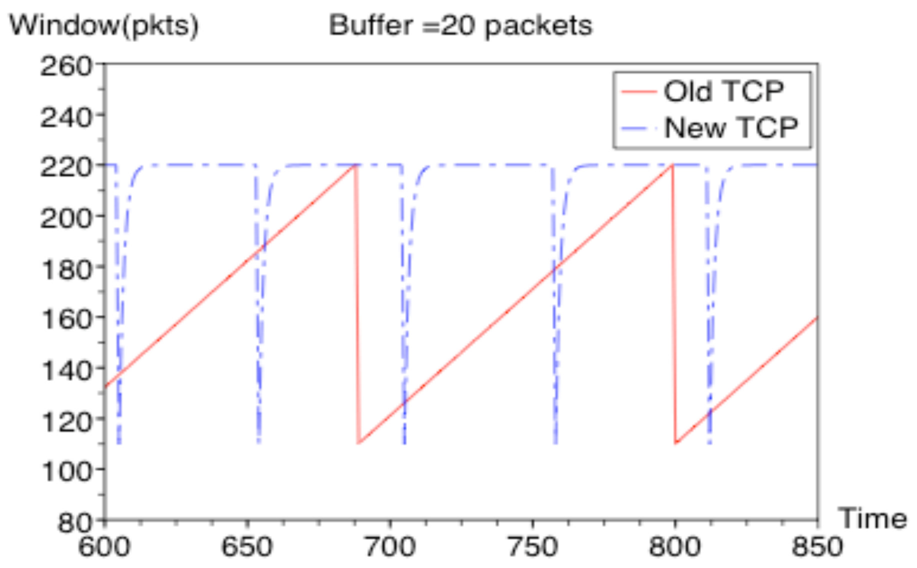
BIC TCP: Queue sizes

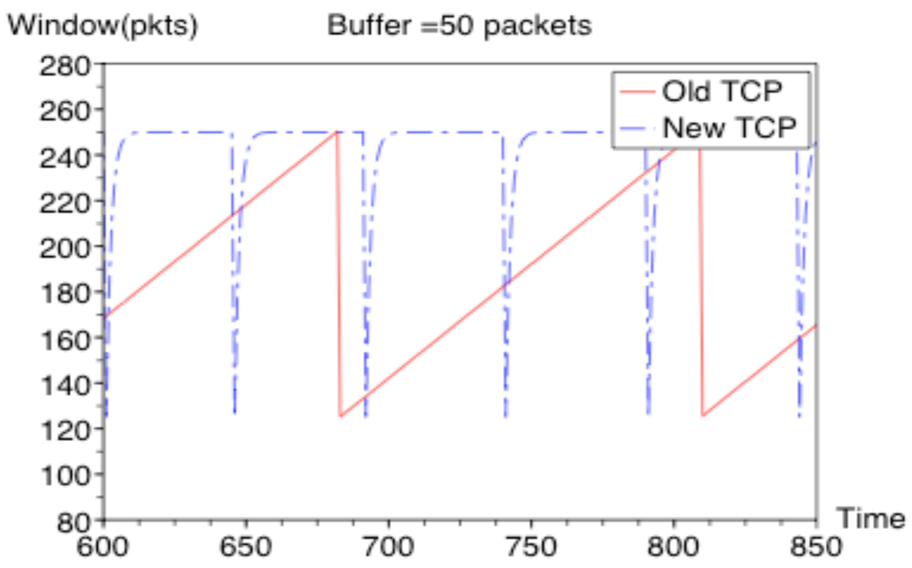


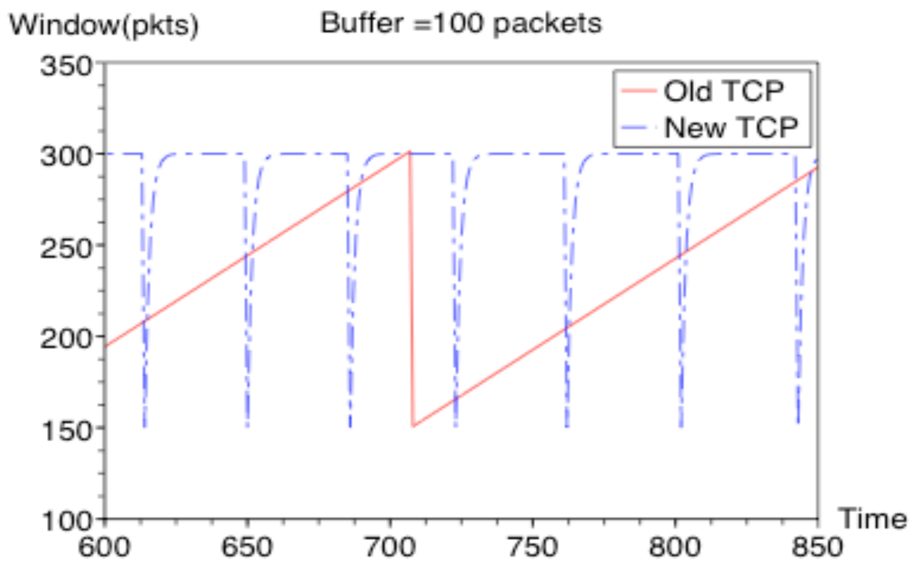
TCP: Loses throughput with buffer size

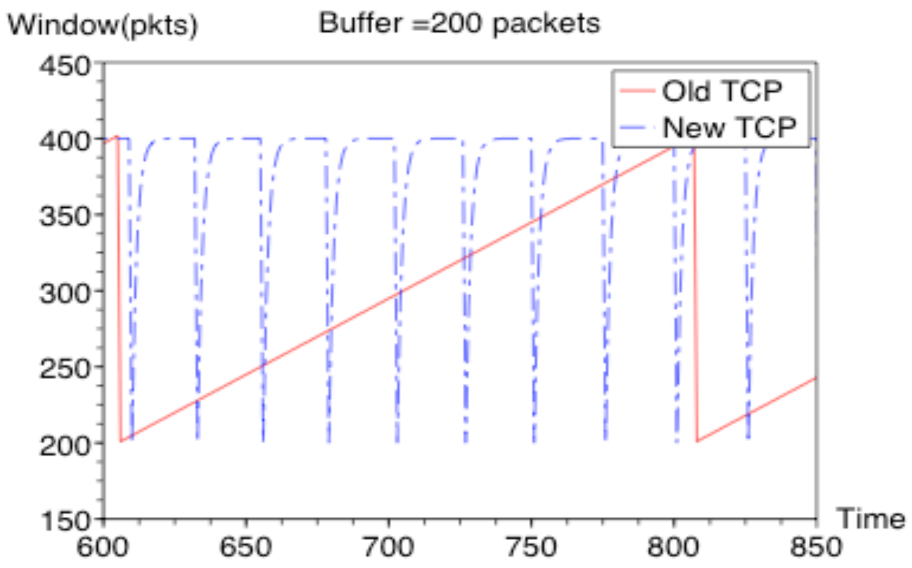
BIC TCP: Keeps throughput high

BIC TCP: Window sizes









Signaling and Reflection Point Dynamics

- Signaling, some motivation: Consider backward signaling as in BCN
  - Amount of signaling
    - BCN uses a sampling probability of p (= 1%, with extra when congestion increases)
    - Without the congestion-related enhancement, the amount of signals is proportional to the *amount of traffic* and not to the *amount of congestion*
  - Node- vs path-centric signaling
    - BCN generates signals from each congested node, doing it per path will again reduce the amount of signaling

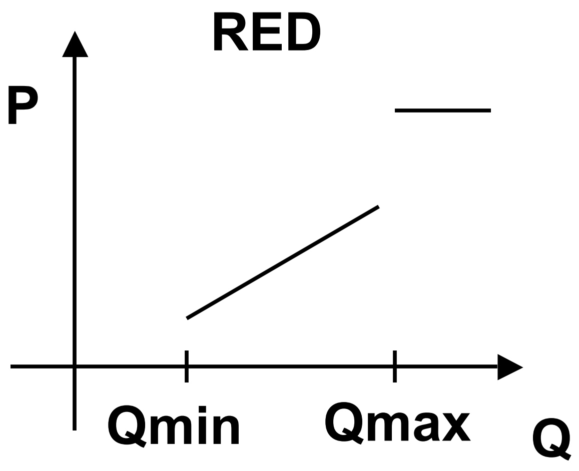
- So, if forward signaling can fix these problems (the first can be fixed by BCN itself), why not jump all the way to the Internet schemes
  - This means just 1-bit per packet (Fb encoded in 1 bit)
    - Unfortunately, it will double the number of packets if we have per-packet acks.
  - If we gather up multiple acks per source (or flow) at the RefP and reflect that…
    - We have to do per-source (or per-flow) work.
    - It is actually per-RTT amount of work or per-flow, whichever is minimum.

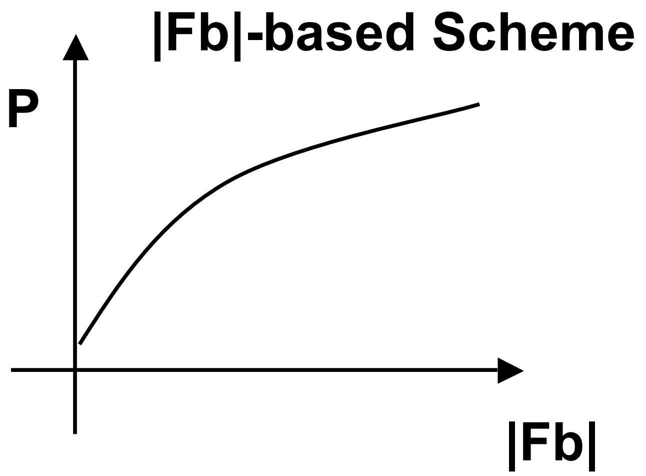
Signaling

- There is also more going on in the Internet…
  - Packet sequence numbers, RTT estimation, etc
  - So, there is more state at each source which is usable, the 1-bit is misleading
- So while a 1-bit scheme is really tantalizing, esp because we could use the DE (Discard Eligible) bit, it imposes an overhead.
- Actually, the Ethernet congestion management problem is interesting and distinct from the previous work because
  - Ethernet is not a state-ful network like ATM.
  - Ethernet hosts do not keep transport-related state like in TCP/IP.
  - This really forces a fundamental rethinking of algorithm and signaling.
- To conclude, we want signaling to
  - Depend on amount of congestion and be path-centric.
  - Not be complicated to implement.
- We propose a multi-bit, congestion-dependent signaling scheme

Forward signaling and RefP Dynamics

- Each CP computes Fb per packet
  - It replaces the Fb value in the packet with the computed value if the computed Fb is more negative
  - Thus, Fb values can only decrease as as a packet goes though its path
- RefP Dynamics
  - When a packet is received, reflect the Fb value to the source with a probability which increases with IFbI





To summarize

- The scheme we propose has
  - Reaction Points, Contestion Points and Reflection Points.

1. Reaction Points: Insert Fb = 0 in outgoing packets. When congestion message arrives: perform multiplicative decrease, fast recovery and active problng.
2. Congestion Points: Compute Fb, overwrite Fb in packet header.
3. Reflection Points: Reflect Fb values to ReaPs with a probability biased by the Fb value in the packet.

Further work, refinements

- Due to packet-level, random effects some refinements of the basic algorithm are useful to make
  - The main point is that Control Theoretic analyses lose their fidelity due to the discrete, packet-level, random effects present in a real network, *especially* when the buffers are short. This needs us to be careful when going from theory to practice. The following points are worth noting in this regard.

  1. BIC TCP makes a binary fast recovery, as opposed to linear or constant recovery. Binary and linear recovery delineate extreme points in a spectrum from more aggressive to less aggressive recovery. We could, of course, use something in between.
  2. Suppose a source gets multiple congestion messages in a burst, driving its rate down by a lot. Say that the rates of decrease were Rd1, Rd2 and Rd3. Fast recovery only uses the *last* amount of decrease Rd3. Using Rd1+Rd2+Rd3 or max(Rd1, Rd2, Rd3) for fast recovery, *when* congestion messages arrive in a burst, improves performance.

- A significant advantage of forward signaling is that *both decrease and increase* messages can be signaled by the reflection point, without the need for CM-type tags. This is purely because forward signaling gathers “path capacity,” not node capacity. This feature is not explored in our current proposal, but is worth considering.

- Another aspect has to do with the byte-counter timers. These timers make the system self-clocked and are hence v.useful. However, when the source transmission is very low, the timers can take too long to expire. So some “state recovery timers” may be needed here.