Improving Performance of Internet Protocols Over Wireless Networks

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"Here come Johnny with the power and the glory; Backbeat the talkin' blues"

Acknowledgments

- Collaborators
  - Wesley Eddy (Ohio Univ.)
  - Shawn Ostermann (Ohio Univ.)
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  - BBN Technologies
  - NASA Glenn Research Center

Outline

- Background
- The problem
- Previously tried mitigations
- New technique: CETEN
- Preliminary evaluation
- Future work
- Summary

- Hopefully there is a little something in here for everyone:
  - theory, practice, math, measurements, simulations, plots, architecture, color pictures & hyperbole
- *Please ask questions as they come up.*

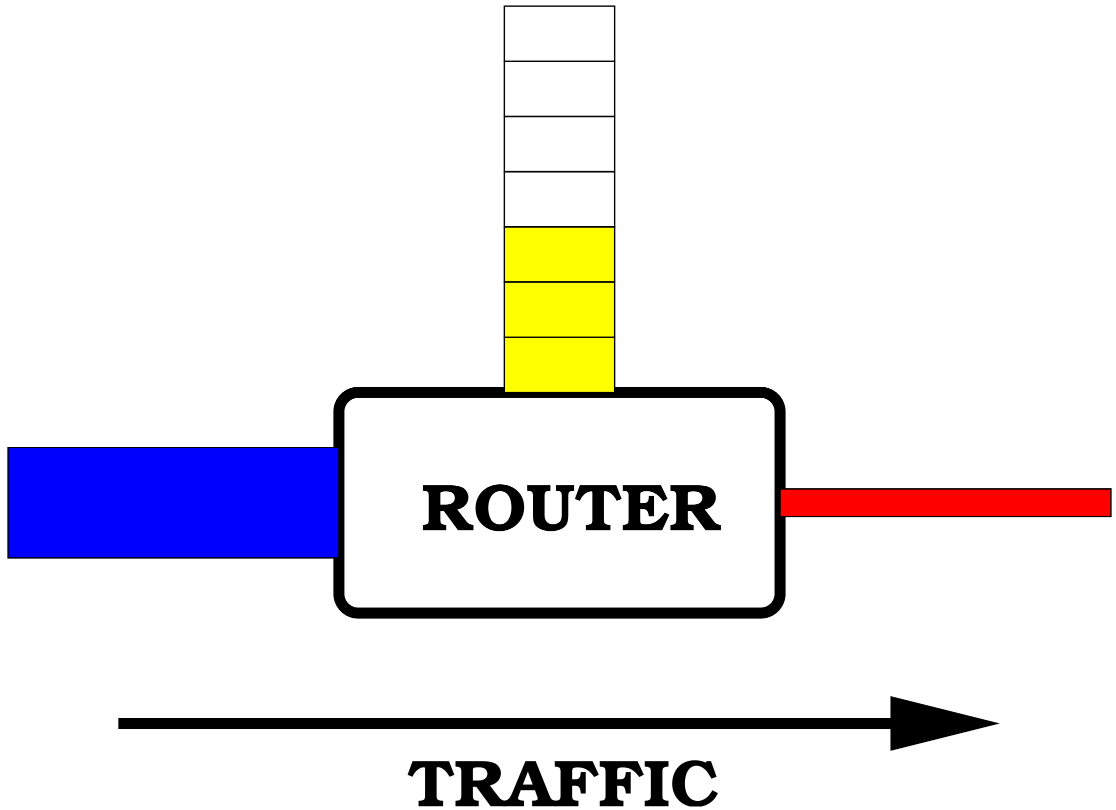
Background

- The transport layer of the network stack is charged with delivering data between applications on end systems.
- TCP is the most heavily used transport protocol on the Internet.
  - Other transports follow TCP’s basic controls and so we expect our work to cover them as well (e.g., SCTP).
- TCP happens to also provide reliable in-order delivery of data bytes.
- TCP is a sliding window protocol that originally used a static sized window so the receiver could control its resources.

Background (cont.)

- TCP worked well until the mid-80s when the Internet suffered from *congestion collapse.*
  - The state when the network is highly utilized carrying a ton of traffic, but very little useful work is getting accomplished.
- Van Jacobson added a set of *congestion control and avoidance* techniques to TCP to combat congestion collapse.
- The key observation is that packet loss is a pretty good implicit signal that congestion is occurring somewhere in the network path.

Background (cont.)

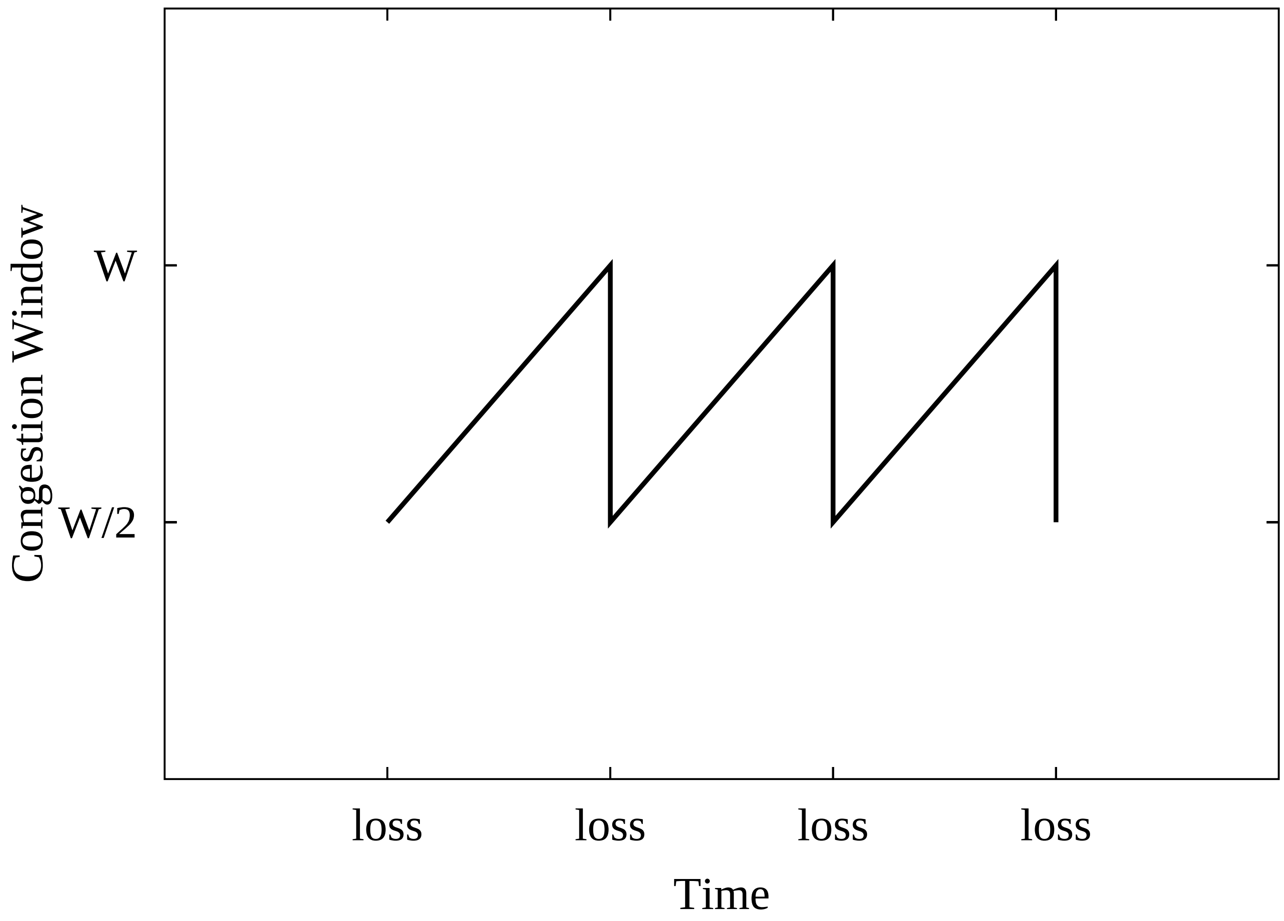


Background (cont.)

- The solution: when signals of congestion arrive (packet loss, or later explicit signals of congestion) TCP reduces the sending rate (by half).
- In the absence of a congestion signal TCP increases the sending rate (linearly) in an effort to detect newly available capacity.
- Addative Increase Multiplicative Decrease (AIMD)
- We control the sending rate with a *congestion window.*

Background (cont.)

- Steady state TCP:



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Problems with CC

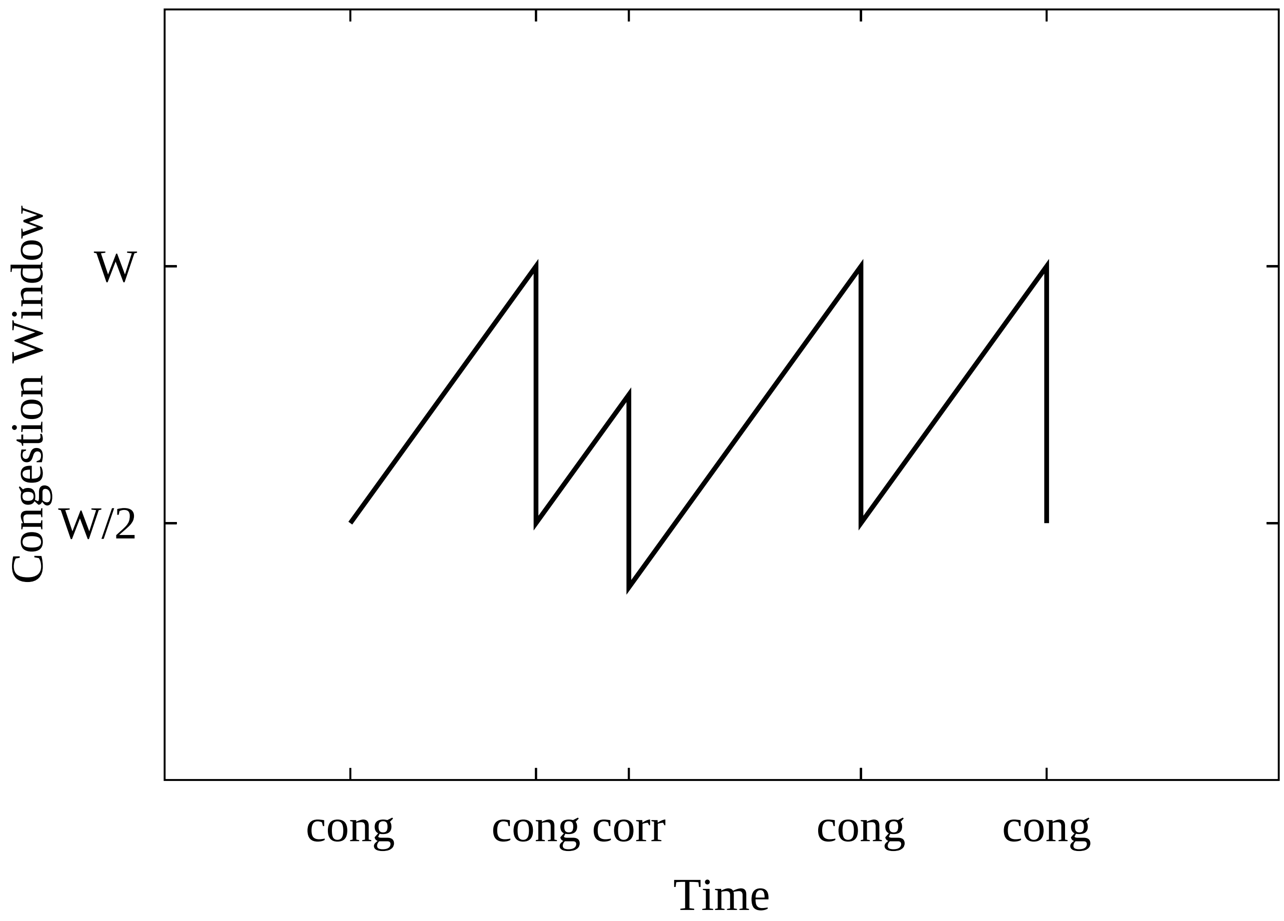
- What could be wrong with TCP's AIMD-based congestion control?
  - well ...
- The premise of Jacobson's work is that *nearly all* packet loss is caused by resource contention in routers.
  - Which was true.
  - And, is still likely true.
- But, not universally true.
  - e.g., what if your connection is via RF?
  - e.g., what if you happen to sit behind lousy hardware (see Stone/Partridge, SIGCOMM 2000)?

Problems with CC (cont.)

- If a TCP connection experiences non-negligible amounts of loss that are not congestion-related then the performance of the connection will suffer.
- E.g., just because a bird flew in front of your antenna does not mean that there is any reason for TCP to reduce the sending rate.
- Fundemental Problem: TCP has no way to derive the cause of a packet loss.

Problems with CC (cont.)

- Steady state with non-congestion-loss:



TCP Model

- An analytical model of TCP performance has been developed:

$$R = \frac{MSS}{RTT \cdot \sqrt{\frac{2bp}{3}} + \left(RTO \cdot \sqrt{\frac{3bp}{8}} \cdot p \cdot (1 + 32p^2) \right)}$$

- Developed by Mathis (CCR 1997), Padhye (SIGCOMM 1998), et. al.

- There are a few variants, but all have the same basic form.

TCP Model (cont.)

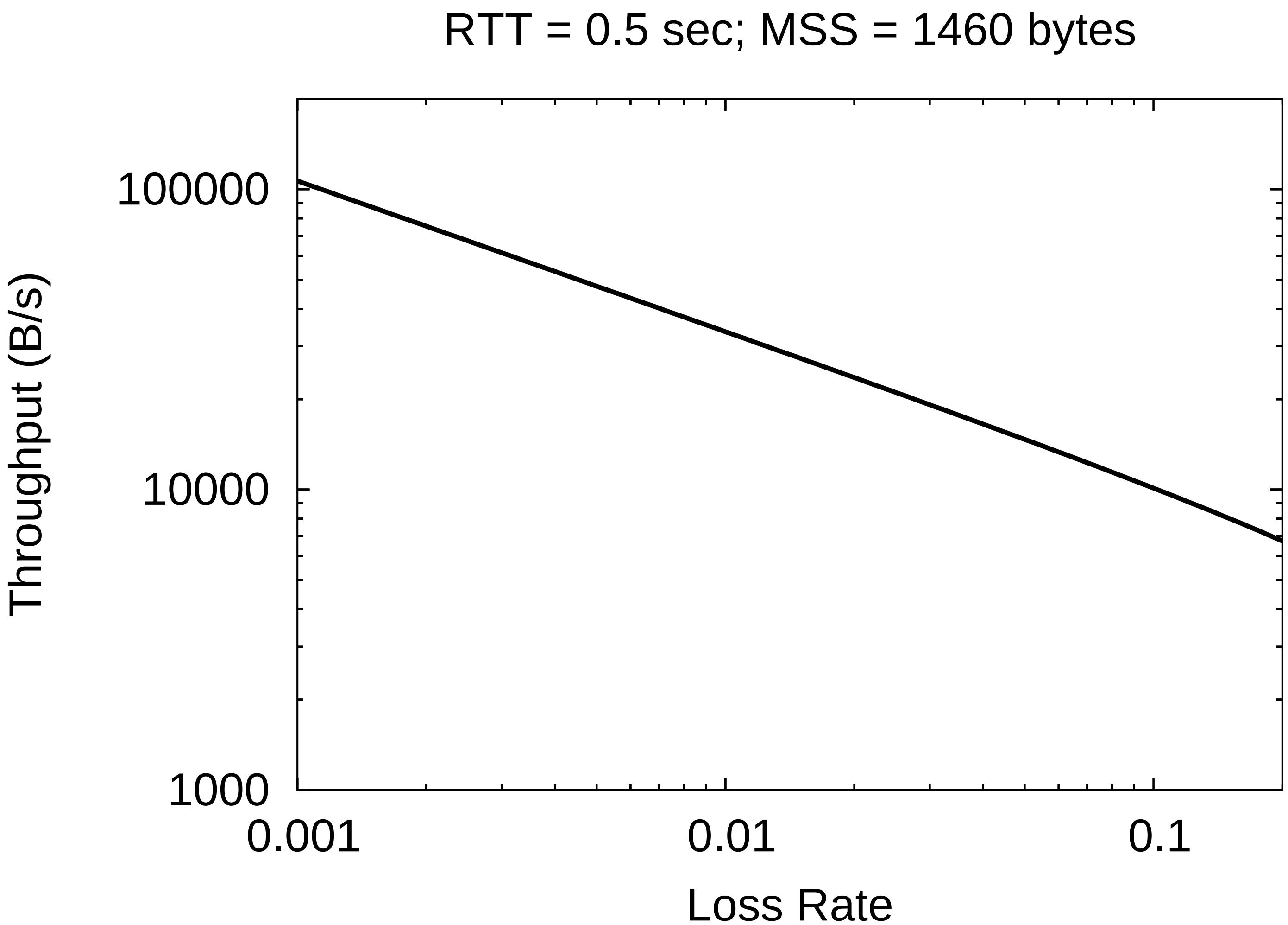
- For our purposes the model can be distilled to:

$$R \propto \frac{1}{\sqrt{p}}$$

- This makes sense because the goal of congestion control is to avoid congestion collapse by adapting the sending rate.
  - So, as the loss rate increases the sending rate decreases.

TCP Model (cont.)

- Model TCP performance:



TCP Model (cont.)

- But, *p* is a combination of congestion-based loss (c) and corruption-based loss (e):

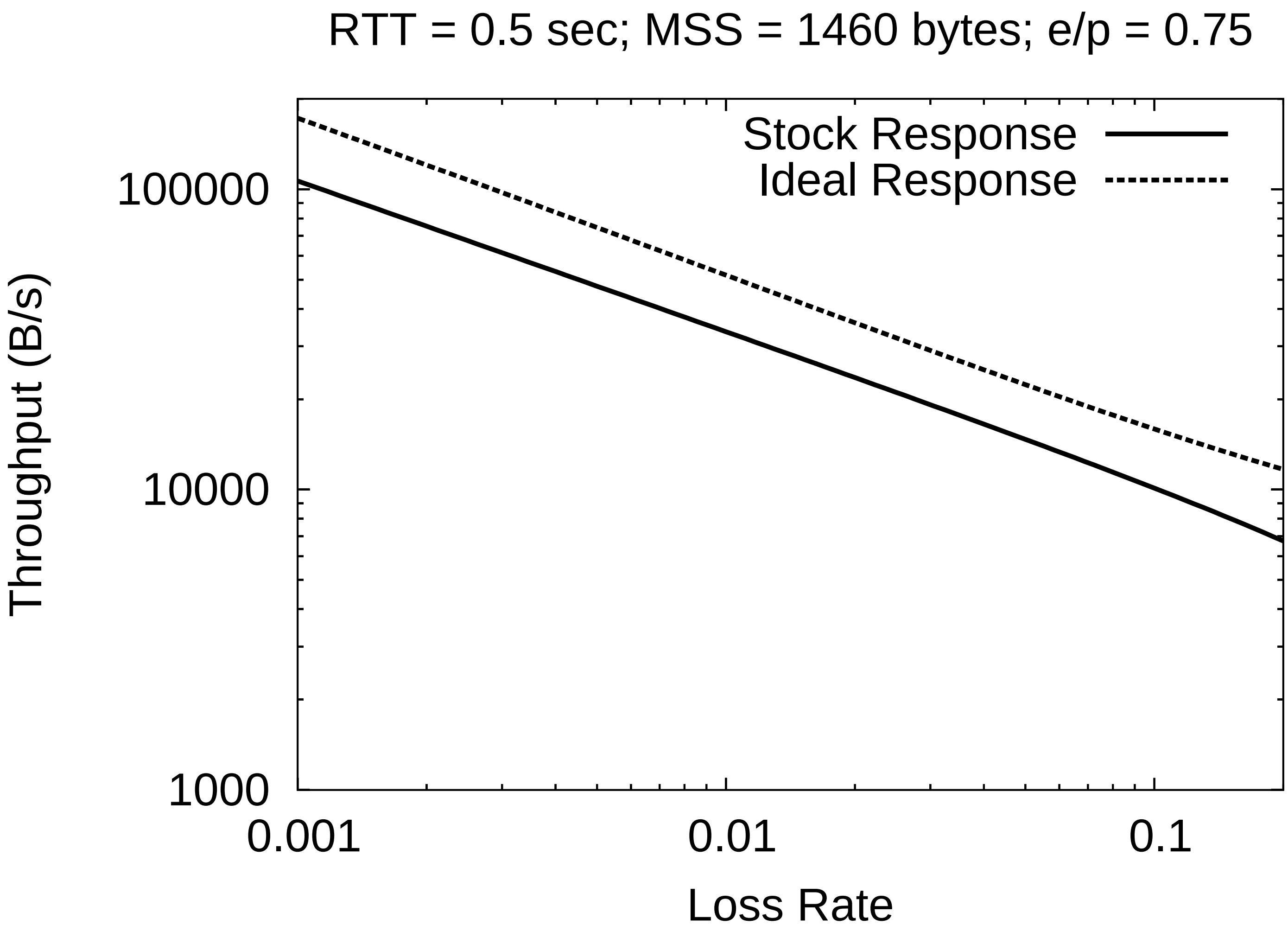
$$p = c + e$$

- Ideally we'd like to change TCP's congestion response function:

$$R \propto \frac{1}{\sqrt{p}} \qquad \Rightarrow \qquad R \propto \frac{1}{\sqrt{c}}$$

TCP Model (cont.)

- Ideal TCP performance:



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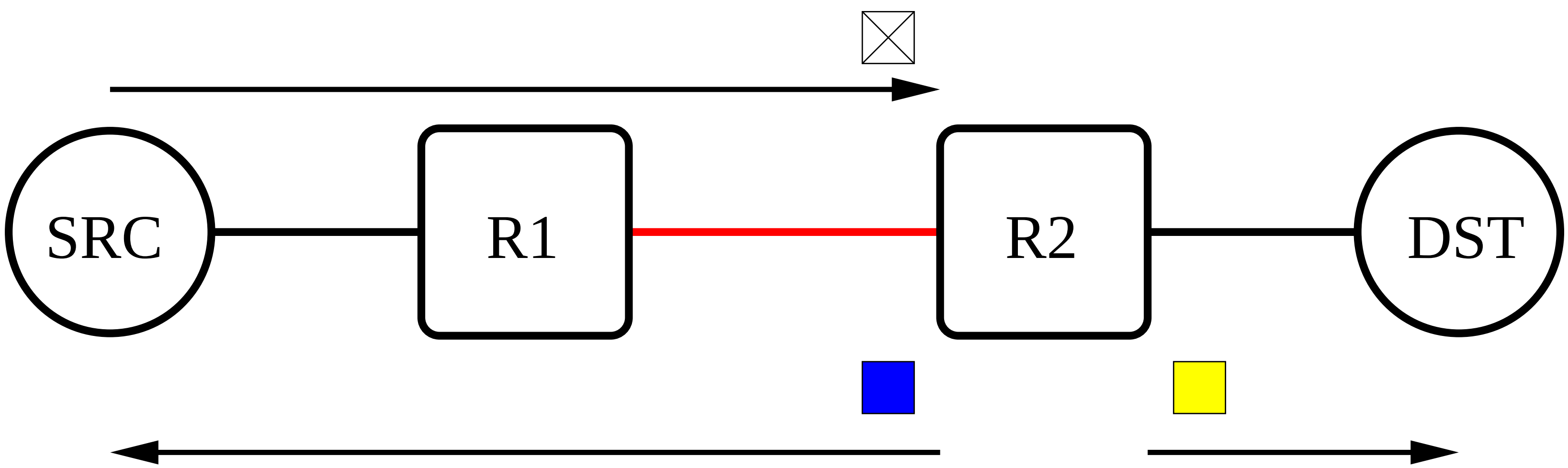
Previous Work

- The literature is filled with potential solutions to the performance problems caused by non-congestion based loss.

- Three general classes:
  - Notification schemes
  - Local repair
  - Connection splitting
    - Breaks the end-to-end nature of TCP
    - Omitting from discussion today

Notification Schemes

- When a packet is detected as corrupted by the data-link layer a notification is sent to one of the endpoints of the connection.
  - What if the addresses are corrupted?
  - What if the addresses are encrypted?



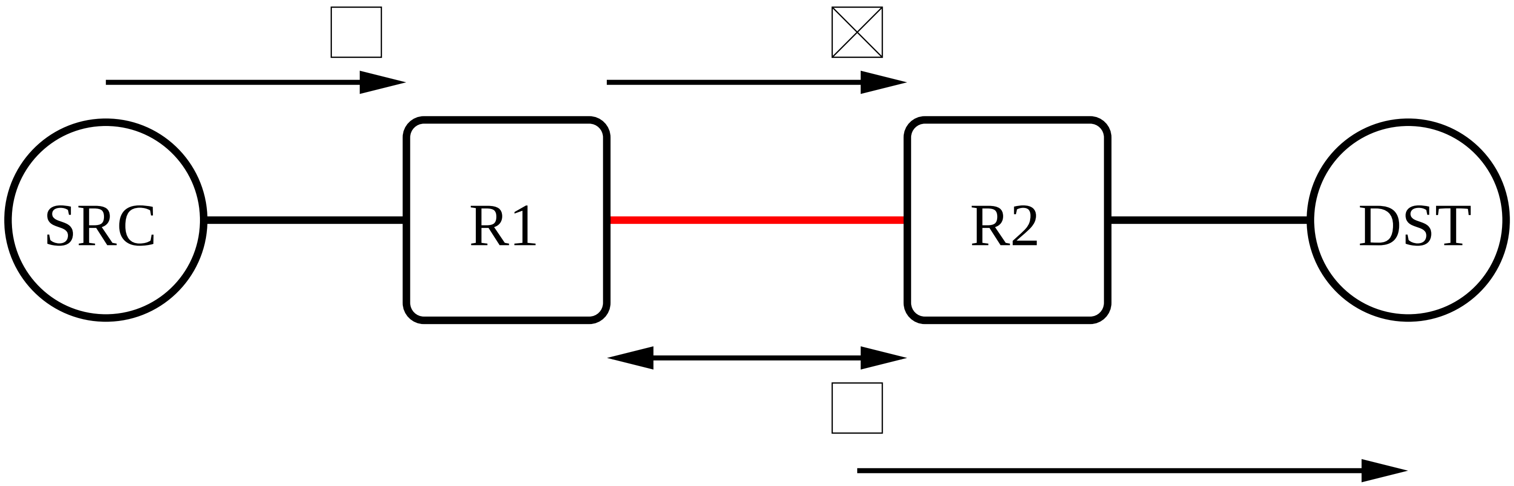
Local Repair

- Each link is responsible for presenting a "clean" (error free) transmission path
  - ARQ (layer 2), snooping (layer 4)
  - FEC (layer 2)

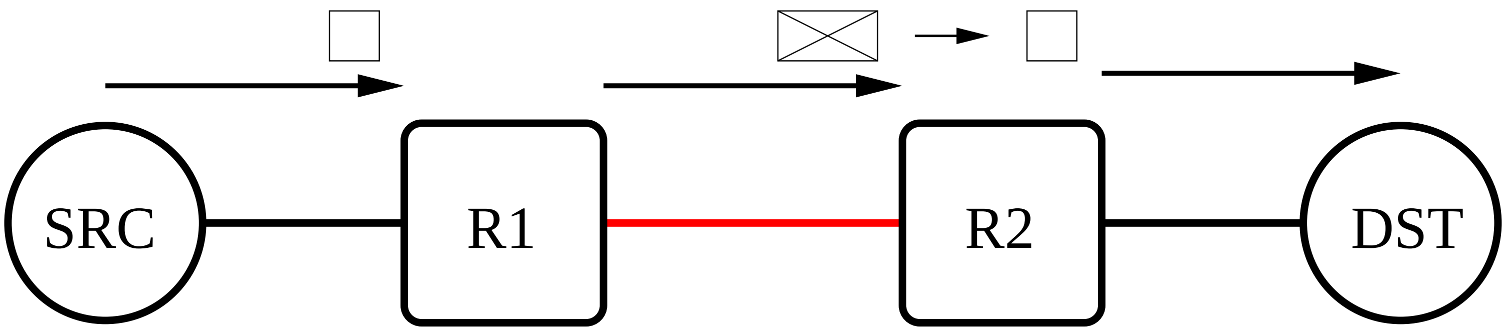
- Potential problems:
  - Requires time or bandwidth

Local Repair (cont.)

- ARQ:



- FEC:



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CETEN

- Cumulative Explicit Transport Error Notification
  - Originally outlined by Krishnan, Sterbenz, Partridge, Allman
    - BBN tech report
  - Refined by Eddy, Ostermann, Allman
    - In progress

- If TCP can obtain two of p, c or e we have the whole story about losses and can form a more intelligent congestion response.
  - Surprisingly, the TCP endpoints actually have none of these quantities.
    - We estimate "p" at the sender
    - We ask the network for "e"

Estimating "p"

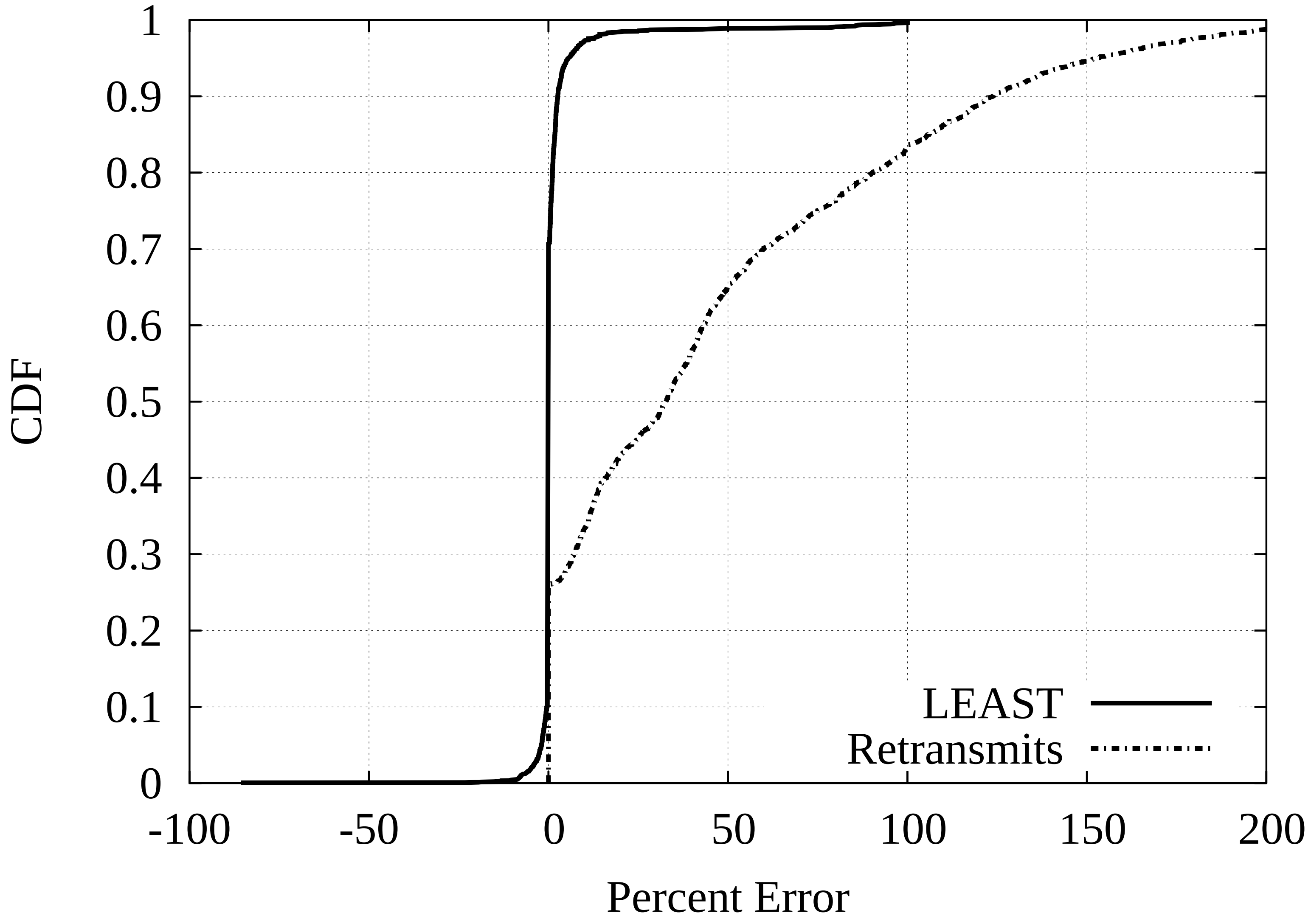
- At first glance it looks easy to determine the total loss rate of a TCP connection since it is reliable.
  - I.e., just count the retransmits
- However, depending on TCP variant the retransmission mechanism is fairly gross.
- We developed several algorithms for estimating the total loss rate based on the number of retransmits and hints coming back from the receiver as to which retransmits were not required.
  - LEAST: Loss Estimation AlgorithmS for TCP
  - Paper under submission.

Estimating "p" (cont.)

- LEAST experiments:
  - 2600+ transfers (5000 packets each)
  - NIMI mesh (20-ish hosts)
  - cap utility (Allman, IMW/2001)
  - tracing on sender and receiver
    - can accurately assess the actual loss rate
    - also, estimate using LEAST on the sender

Estimating "p" (cont.)

- LEAST performance:



Estimating "e"

- No good way for the end hosts to determine why an intermediate node dropped a packet.
- So, we involve the routers.
- Mechanism 1:
  - The TCP sender polls the router (with a TTL-limited request) for the current error rate on their connected link.
  - Pros: no on-the-wire protocol changes
  - Cons: extra network traffic, extra control messages for firewalls to nuke, unreliable

Estimating "e" (cont.)

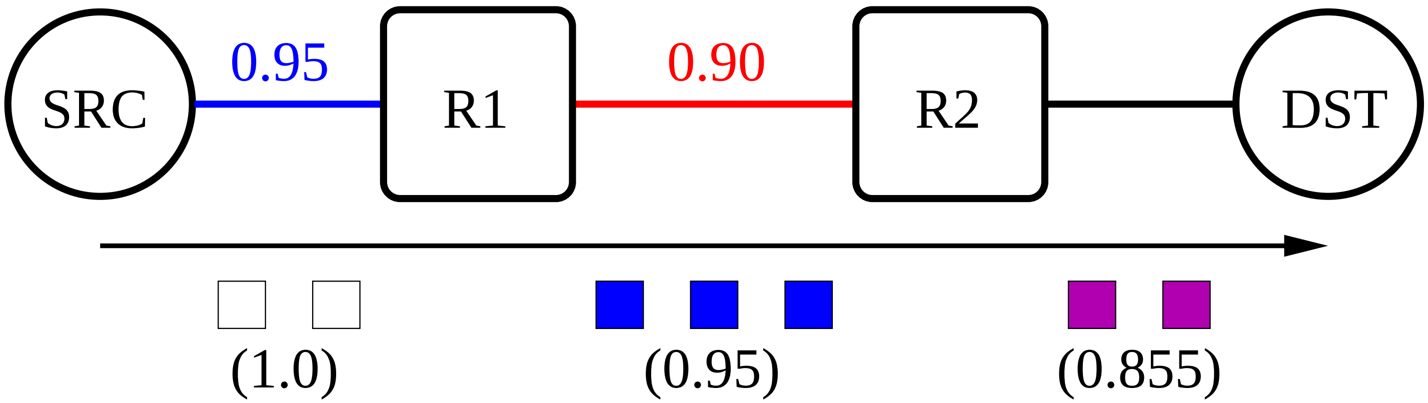
- Mechanism 2:
  - The router probabilistically sends an "e"-report to the packet source for a given random packet that is being forwarded.
  - Pros: no on-the-wire protocol changes
  - Cons: extra network traffic (but more controlled than mechanism 1), extra control messages, unreliable

Estimating "e" (cont.)

- Mechanism 3:
  - A packet is tagged with a "corruption survival probability" header field.
    - Initialized to 1.0 by the sending TCP
    - Updated by each router along the path by multiplying the value in the packet with the probability of corruption survival on the incoming link.
    - When a packet arrives at the receiver the probability in the packet represents the probability of corruption survival across the entire path --- this probability is echoed to the TCP sender in ACKs.
  - Pros: no extra control traffic, more reliable
  - Cons: we have to change (or extend) the network or transport layer protocol

Estimating "e" (cont.)

- We chose mechanism 3.
- CETEN "e" collection example:



Adjusting the Response (1)

- On each loss event flip a coin weighted by e/p to determine whether the congestion window is reduced or not.
- On average the long term reduction factor should be based on "c" not "e"
- Denoted "CETEN-C"

Adjusting the Response (2)

- Rather than using a static multiplicative decrease factor (MDF) of 1/2 at the TCP sender a variable MDF is computed as:

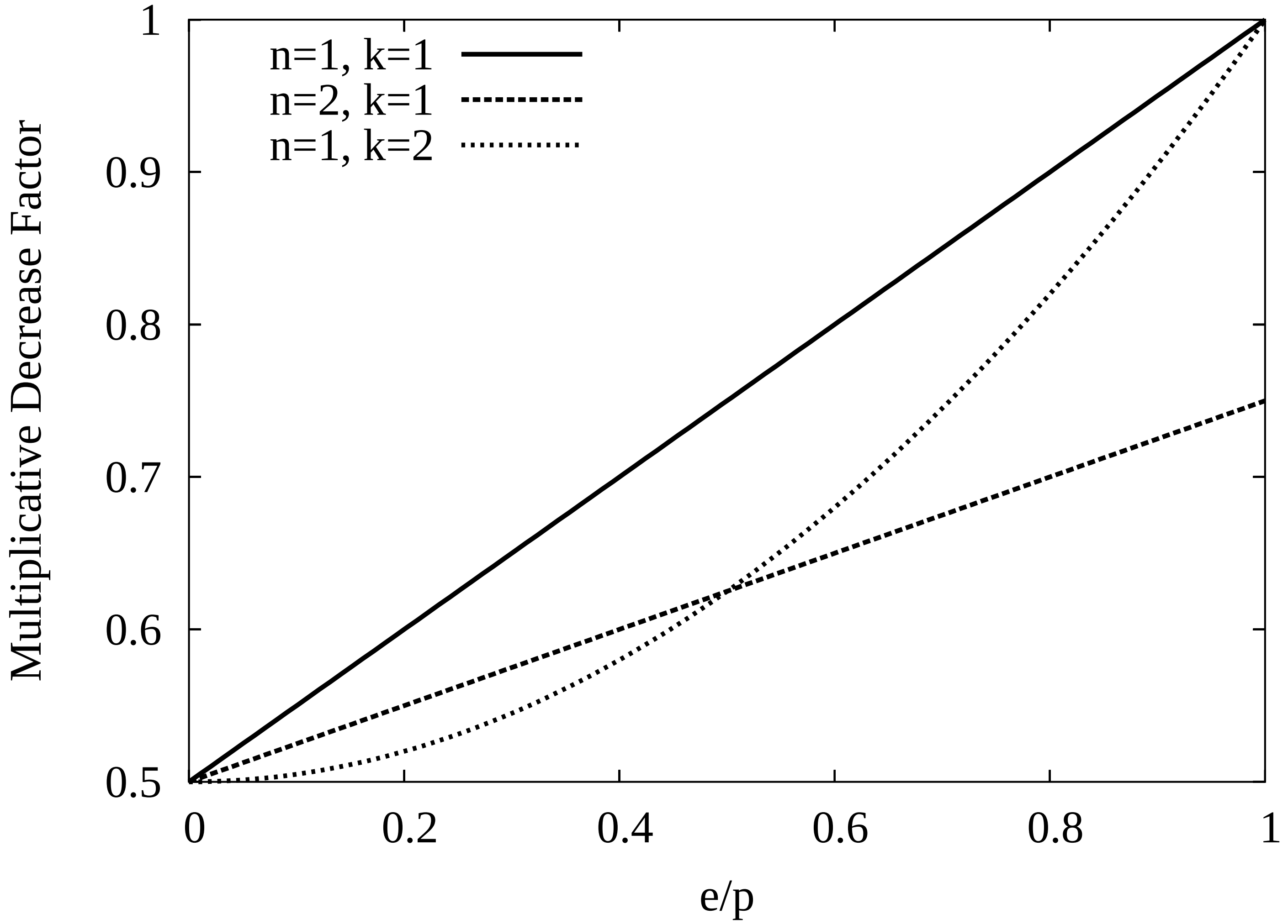
$$MDF = \frac{1 + \left(\frac{e}{np}\right)^k}{2}$$

- Where n and k are shaping and bounding parameters.

- Denoted "CETEN-A"

Adjusting the Response (2) (cont.)

- Example MDF parameter sets:



Deployment

- CETEN does not require ubiquitous deployment.

- Rather, CETEN is only needed on routers/base-stations where there are non-negligible corruption rates.
  - And, *needed* is an overstatement

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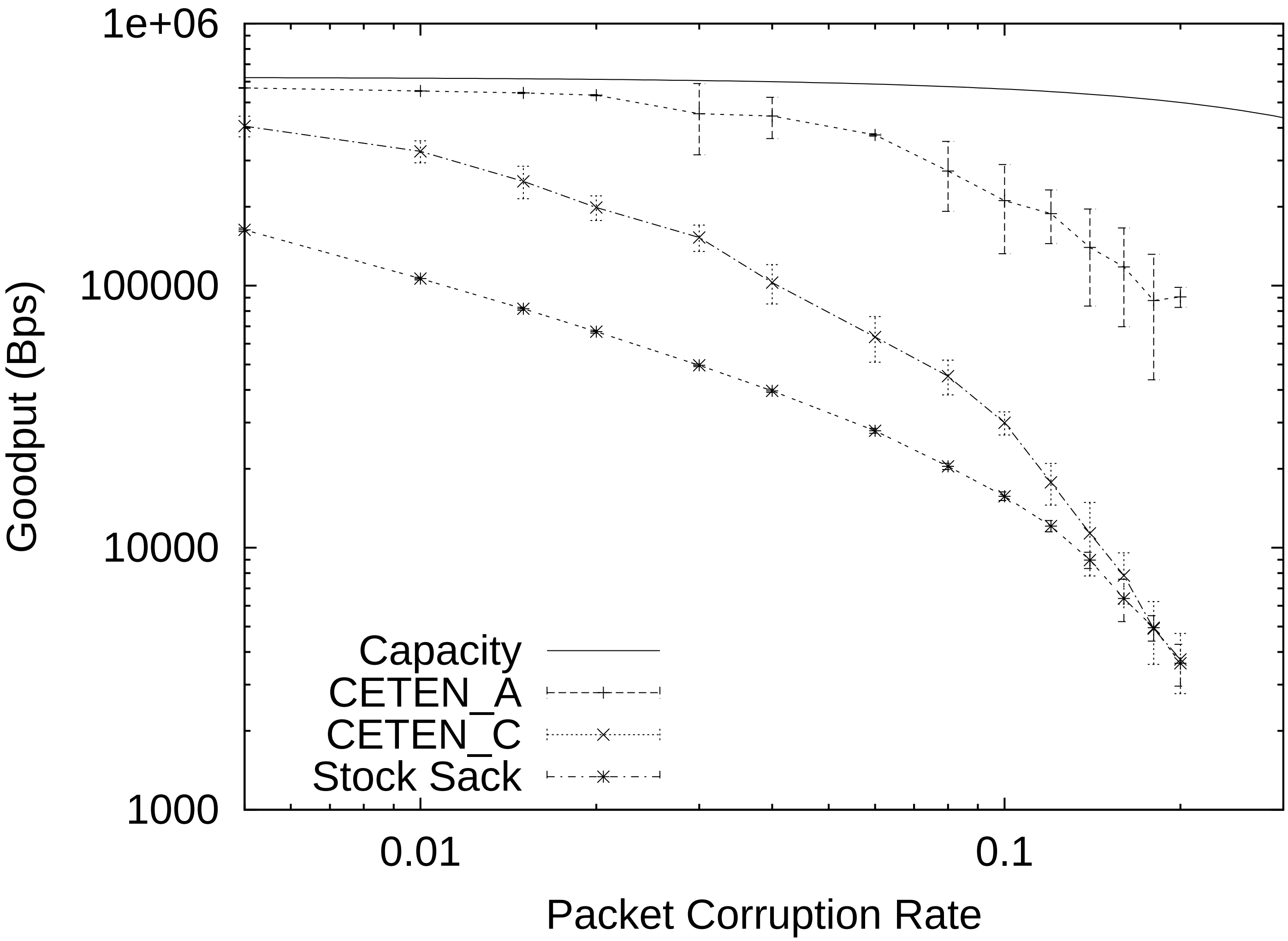
Preliminary Evaluation

- Implemented CETEN in the *ns* network simulator
- Dumbell topology:
  - RTT of roughly 85 msec
  - Bottleneck bandwidth of 5 Mbps
  - Drop-tail routers with 150 packets worth of queueing capacity
- SACK TCP
  - MSS = 1460 bytes
  - with delayed ACKs
- Uniform loss model (!)

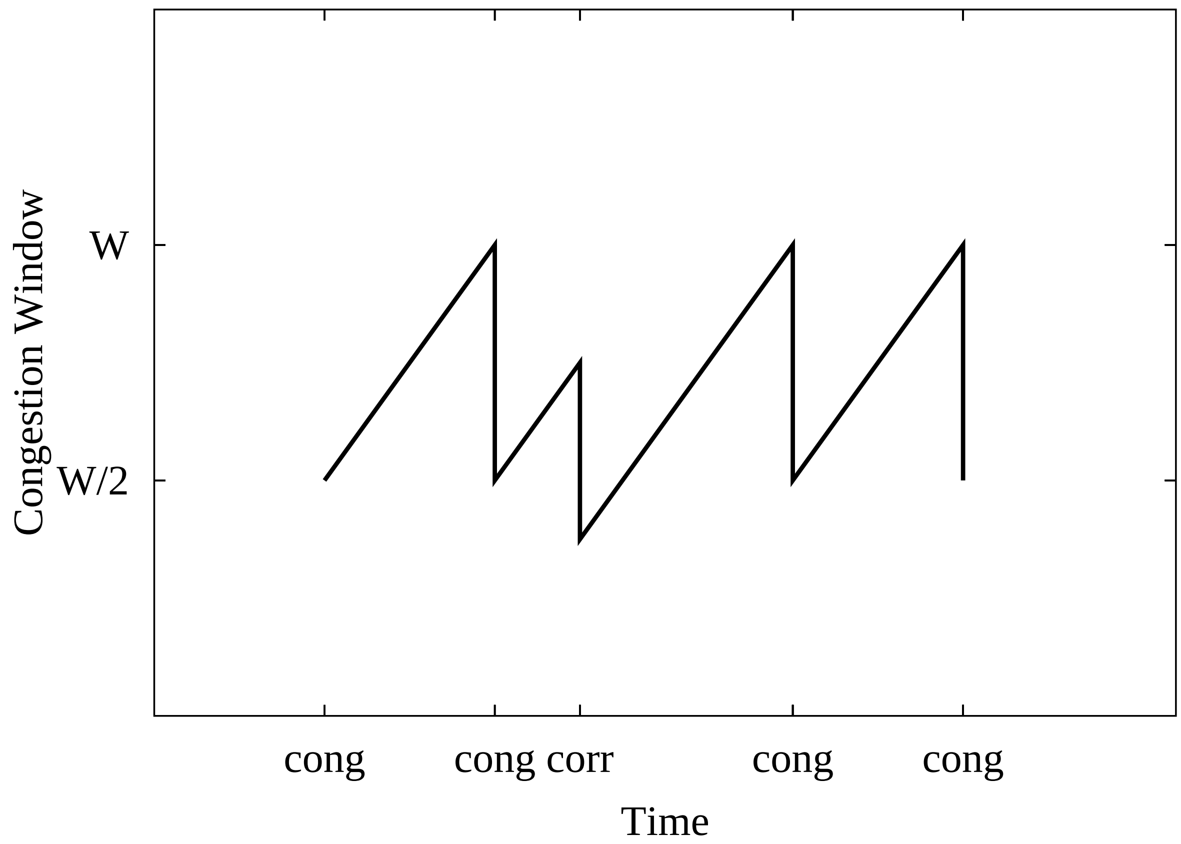
Single Flow Tests

- One end-to-end TCP flow



Single Flow Tests (cont.)

- CETEN-C is flawed in that it does not account for the change in the loss probabilities caused by its congestion response

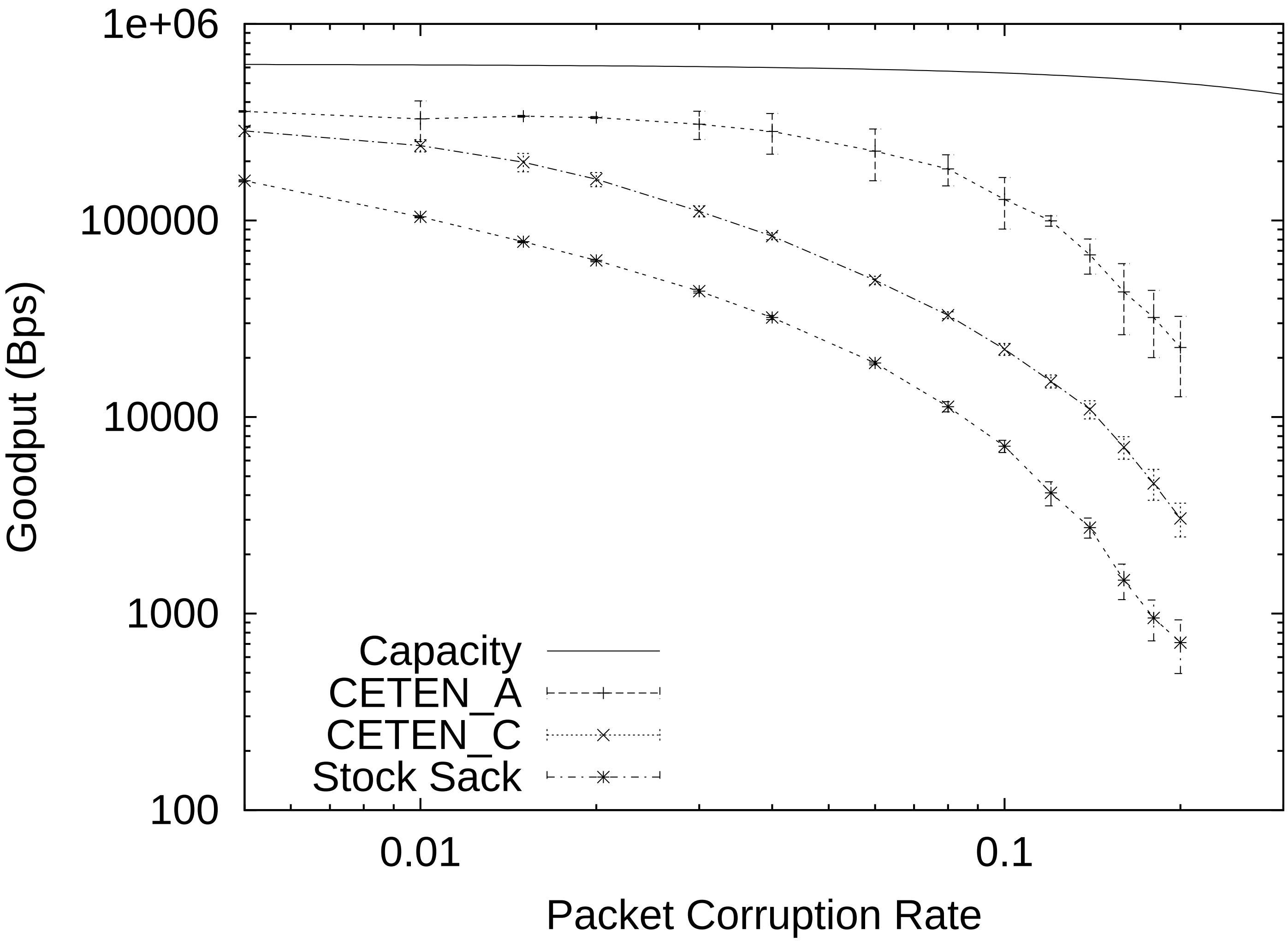


Tests with Cross Traffic

- One TCP connection in each direction
- 5 on/off CBR flows in each direction
  - Mean on time: 2.5 seconds
  - Mean off time: 10 seconds
  - When on each flow sends at 1 Mbps (one-fifth of the bottleneck bandwidth)

Tests with Cross Traffic (cont.)

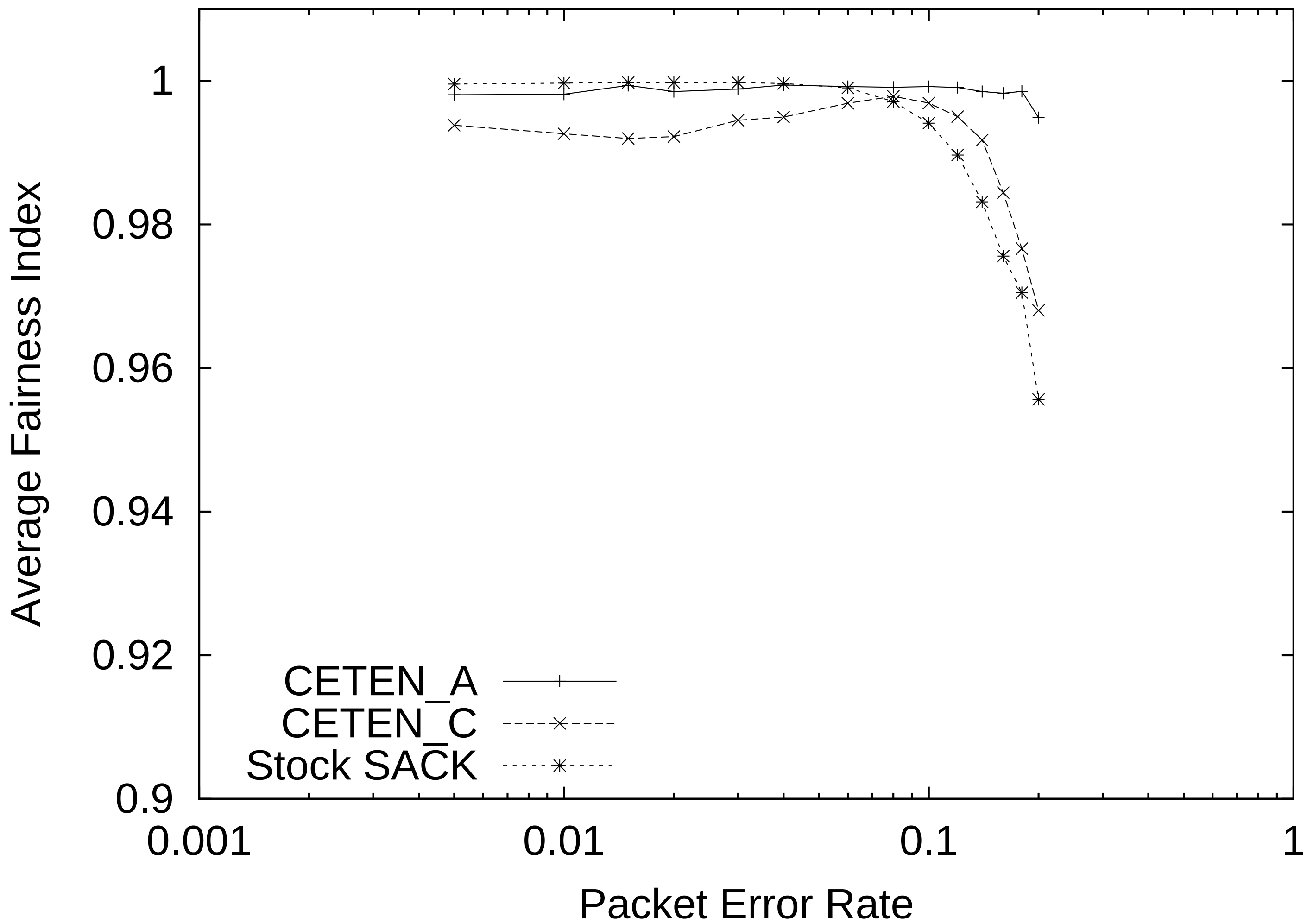
- Results from congested network:



Fairness Experiments

- TCP (mostly) shares evenly across like flows
- Does CETEN?
- Experiment
  - 20 competing flows
    - all of the same variant
  - Metric: Jain's fairness index

Fairness Experiments (cont.)



Results Summary

- Both versions of CETEN aid performance, with CETEN-A gaining better performance than CETEN-C

- CETEN-A is a promising technique
  - Offers nice performance benefits
  - Offers good fairness properties

- But, CETEN is still is a heavy-weight mechanism

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Future Work

- While CETEN looks and sounds promising there are a whole raft of practical issues that need to be solved.
- E.g., How do routers average corruption rates? Over what timescales?
- E.g., Should the end host average the "e" reports?
- E.g., How often should the end host request an "e" report?
- E.g., Can routers manipulate packets to include "e" in an efficient enough way? At what speeds?

Future Work (cont.)

- E.g., How friendly is CETEN?
- E.g., How do we encode these probabilities? Where?
- E.g., What does CETEN performance look like under a more realistic corruption loss model?
- E.g., How do we prevent lying receivers from gaming the sender's congestion control for their own benefit?
- E.g., How do we prevent DoS attacks on routers that involve making them spend more cycles on every packet than they otherwise would?

Future Work (cont.)

- The bigger picture:
  - How much information should the network be expected to provide to the end hosts?
    - e.g., for CETEN?
    - e.g., for Quick Start?
    - e.g., for XCP?
    - e.g., ??? (queueing delay, reordering, etc.)
- When does the network become "too smart"?
- When does the amount of information requested by the end hosts become too much of a burden?
- Or, does it?

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Summary

- CETEN is an interesting and potentially useful technique for improving performance for a certain class of network traffic
  - E.g., the increasing amount of wireless traffic
- There are many issues that still need to be worked out. This is still very much research.
  - (much grist for the grad student energy mill!)

More Information

- Me:
  `mallman@icir.org`
  `http://www.icir.org/mallman/`

- Project web page:
  `http://www.icir.org/mallman/research/proj-eten.html`

- Questions? Comments? Concerns?