Proportional Rate Reduction for TCP

draft-mathis-tcpm-proportional-rate-reduction-00

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Motivation

- Two widely deployed algorithms in loss recovery: RFC 3517 fast recovery and Rate halving.
- There are cases when both are prone to timeouts.
    - RFC 3517 fast recovery waits for half of ACKs to pass before sending data.
    - Rate halving does not compensate for implicit cwnd reduction under large losses.
- Goals of Proportional Rate Reduction.
    - Reduce timeouts by avoiding excessive window reductions.
    - Converge to cwnd chosen by congestion control by the end of recovery.

Proportional Rate Reduction with Reduction Bound (PRR-RB)

- PRR-RB has two algorithms.
- Proportional rate reduction (PRR):
  - Patterned after rate halving but with a factor that depends on congestion control reduction.
  - Main idea: sending rate = r * queue drain rate in recovery; r is CC reduction factor.
  - For precision, queue drain rate is computed as amount of newly delivered data to receiver.
- Reduction bound (RB):
  - Main purpose: inhibit further cwnd reductions under large losses (pipe < ssthresh).

PRR-RB pseudo code

```
Start of recovery:
ssthresh = CongCtrlAlg() // Target cwnd after recovery.
RecoverFS = snd.nxt - snd.una // FlightSize at start of recovery.

On each ACK in recovery, compute:
// DeliveredData: #pkts newly delivered to receiver.
DeliveredData = delta(snd.una) + delta(SACKd)
// Total pkts delivered in recovery.
prr_delivered += DeliveredData
pipe = RFC 3517 pipe algorithm
```

```
Algorithm:

if (pipe > ssthresh) // Proportional Rate Reduction.
  sndcnt = CEIL(prr_delivered * ssthresh / RecoverFS) - prr_out
else                 // Reduction Bound.
  sndcnt = MIN(ssthresh - pipe, prr_delivered - prr_out)

On any data transmission or retransmission:
prr_out += (data sent) // Smaller than or equal to sndcnt.
```

Properties of PRR-RB

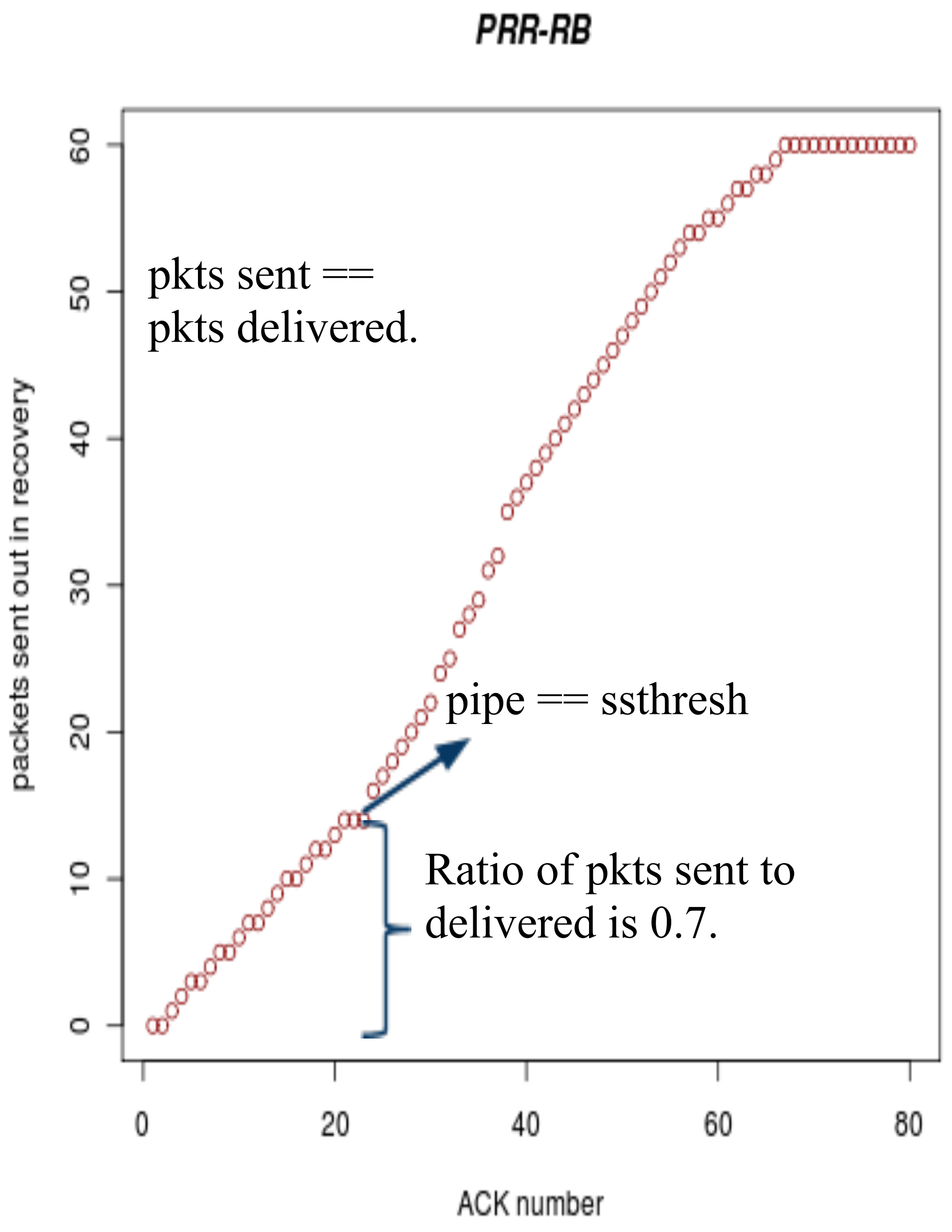
- Spreads out window reduction evenly across the recovery period.
- Converges to target cwnd chosen by CC for minimal losses.
- Maintains ACK clocking even for large burst losses.
- Precision of PRR-RB is derived from computing exact segments delivered to the receiver during recovery.
- On every ACK, cumulative data sent during recovery is bound by the cumulative data delivered to the receiver during recovery.
- Banks the missed opportunities to send if application stalls during recovery.
- Less sensitive to errors of the pipe estimator.

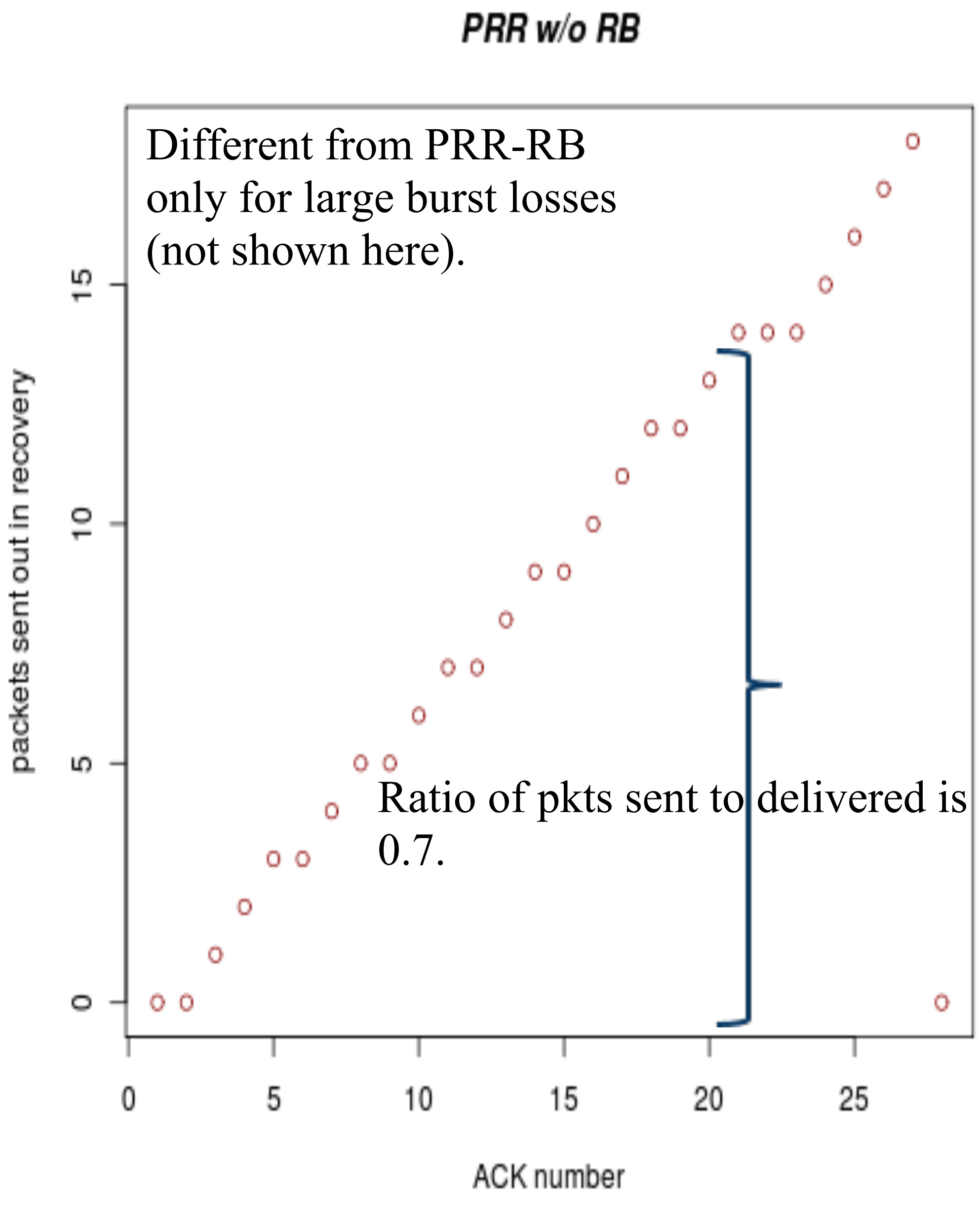
Proportional Rate Reduction without Reduction Bound (PRR w/o RB)

- Observation: there are cases where RFC 3517 sends more than the reduction bound of PRR-RB.
    - Example: pipe == cwnd == 100 packets, lost packets 1 - 90, packet 93 can generate a burst up to 40 packets.
    - RFC 3517 is not conservative in this scenario.
    - PRR-RB bounds #pkts sent by (prr_delivered - prr_out).
- PRR w/o RB: cwnd is bound below only by ssthresh.

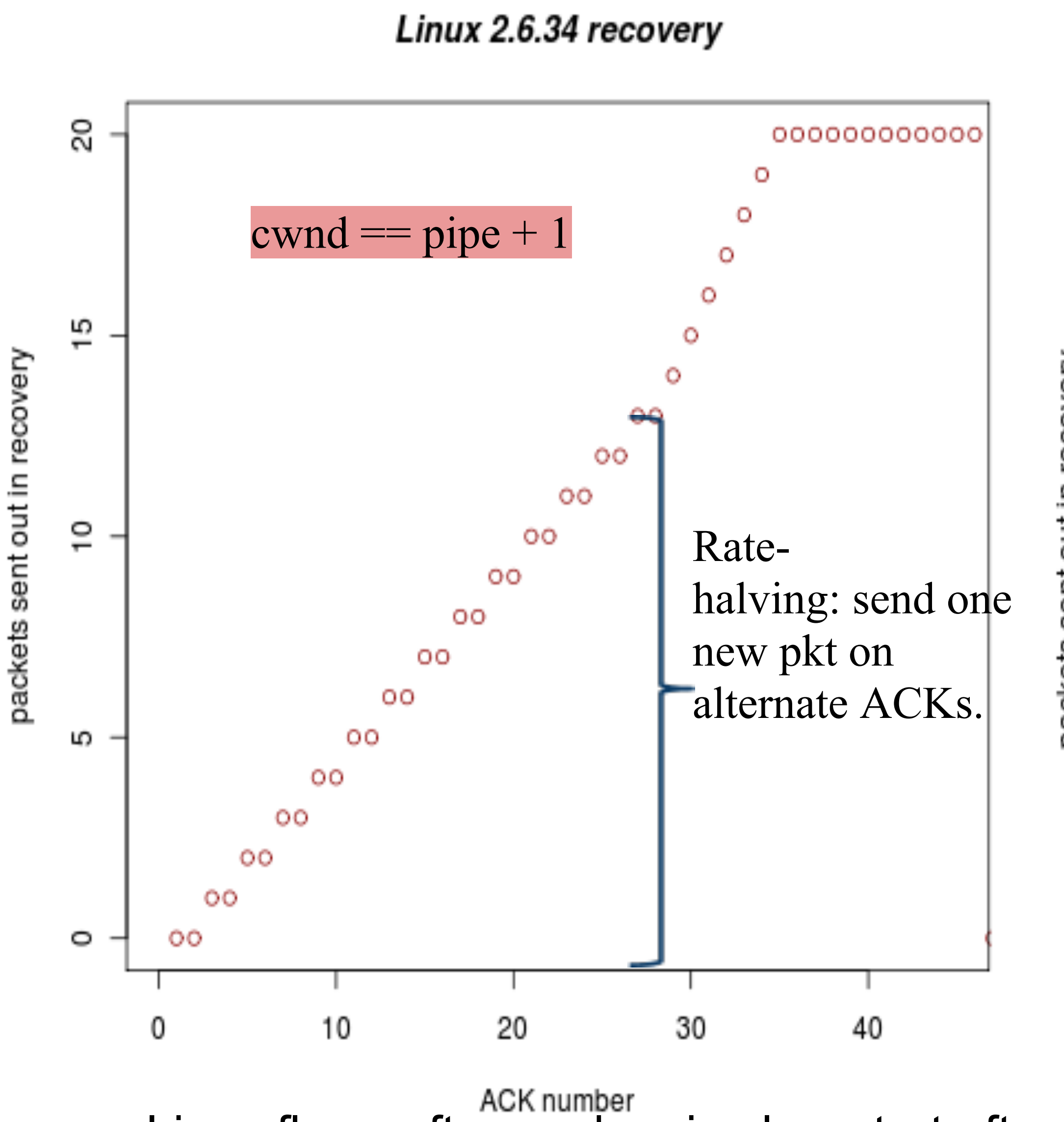
```
if (pipe > ssthresh) // Proportional Rate Reduction
  sndcnt = CEIL(prr_delivered * ssthresh / RecoverFS) - prr_out
else
  sndcnt = ssthresh - pipe
```

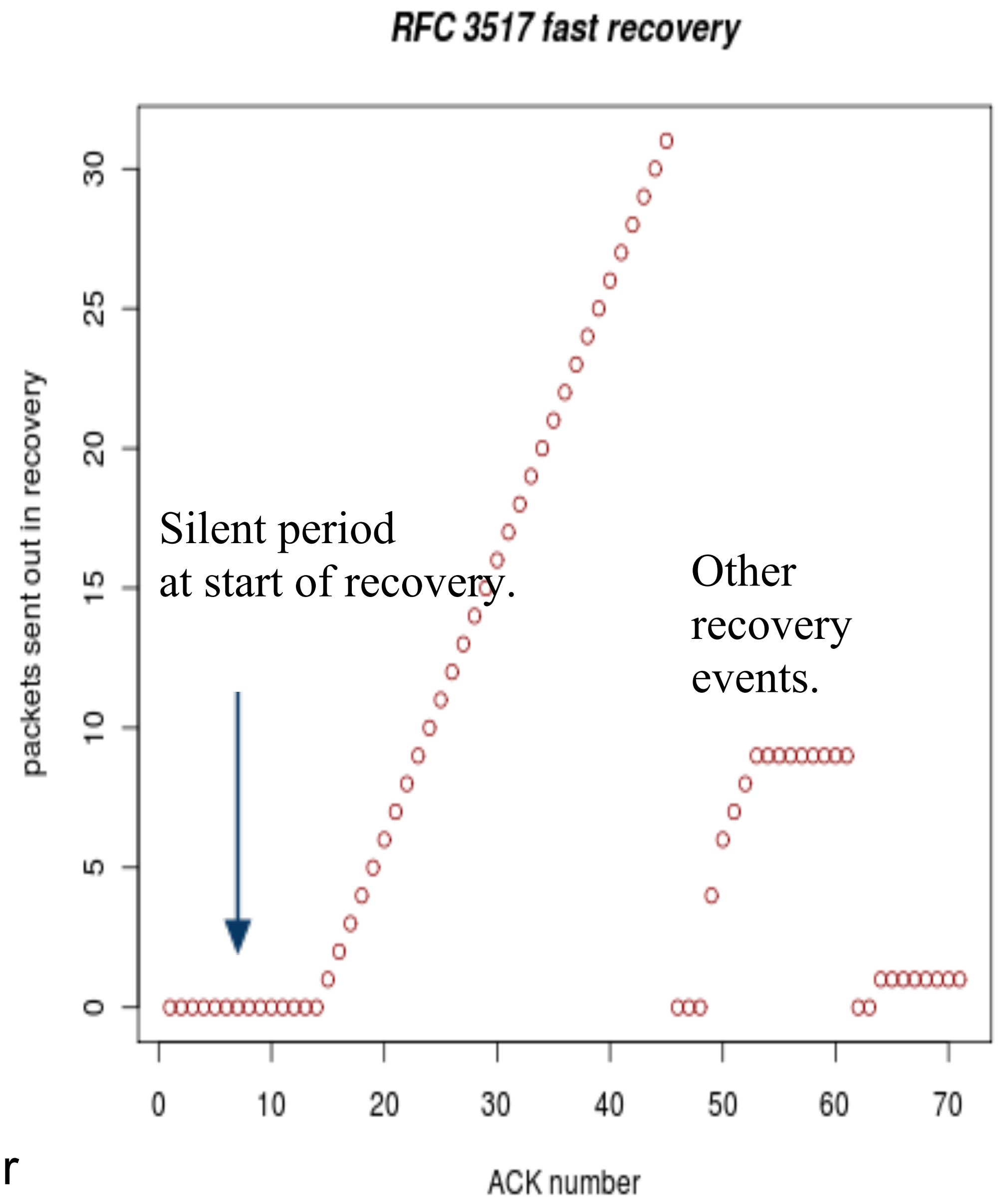
Example flow in PRR-RB, PRR w/o RB





Example flow in Linux and RFC 3517





Linux flows often end up in slow start after recovery when short responses have no new data to send and pipe reduces to 0 .

Performance

Two kinds of experiments: Google Web server, datacenter traffic.

- PRR w/o RB reduces timeouts in recovery.
- Reduces tail latency of 1MB RPCs by 35% (w.r.t. RFC) and 16% (w.r.t Linux).

	PRR w/o RB	RFC 3517	Linux
FastRecovery events	1,759	2,755	1,738
TotRetrans	8,471	15,236	8,282
FastRetrans	8371	14881	8158
RegularFastRetrans	7,916	13,202	7,971
ForwardFastRetrans	455	1,679	187
TimeoutRetrans	41	177	50
TimeoutOnOpen	7	17	16
TimeoutOnRecovery	18	148	20
TimeoutOnDisorder	16	12	14
99% latency of 1MB RPCs (us)	15,064	23,105	17,956

Data in this spreadsheet: http://goo.gl/xl6cF

Benefits and costs

- Benefits:
  - Smaller number of timeouts.
  - In some cases, smaller number of recovery events.
  - Lower tail latencies of request-response traffic.
- Cost:
  - Need to investigate if there are indirect costs to sending packets early on in recovery as opposed to letting more ACKs pass first.

Going forward

- Should the PRR draft be a WG item?
  - Design of PRR improves upon the current standard in reducing timeouts.
  - Initial experiments demonstrate promising results.
  - Goal: adopt as experimental so people can gain experience.