BBRv3: Algorithm Bug Fixes and Public Internet Deployment

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https://groups.google.com/d/forum/bbr-dev

Outline

- BBR algorithm updates
- BBR deployment status at Google
- BBR code status and open source release plans

Target for this talk:

- Responding to requests from other transport stack maintainers implementing BBR
- Documenting the BBR algorithm
- Announcing a new open source release of Linux TCP BBR
- Inviting the community to…
  - Read the drafts and offer editorial feedback
  - Share algorithm or code fixes or enhancements
  - Share test results
  - Post bug reports

BBR Versions

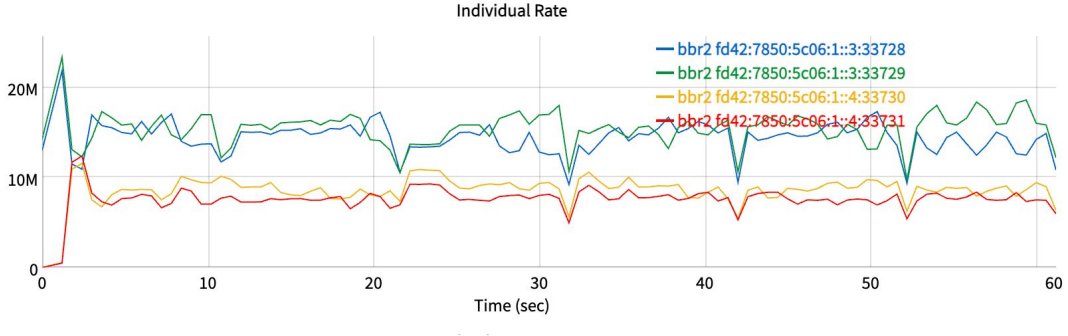
- New: a version increment for BBR, from v2 to v3
  - Recent bug fixes change the bandwidth/fairness convergence properties of BBR
  - So most test results for BBRv2 will not apply to BBRv3
  - So we are incrementing the version number for BBR from v2 to v3
- A summary of BBR versions:
  - **BBRv1: [obsolete/deprecated]**
    - Bandwidth, RTT as signals primary signals; loss used over short time scales
  - **BBRv2: [obsolete/deprecated]**
    - BBRv1 + using ECN, loss as signals (with bugs mentioned previously at IETF**)**
  - **BBRv3**:
    - BBRv2 + bug fixes and performance tuning
  - **BBR.Swift**: [discussed at IETF 109: slide link]
    - BBRv3 + using network_RTT (excluding receiver delay) as primary CC signal

BBRv3 bug fix 1: fix bw convergence *with* loss/ECN

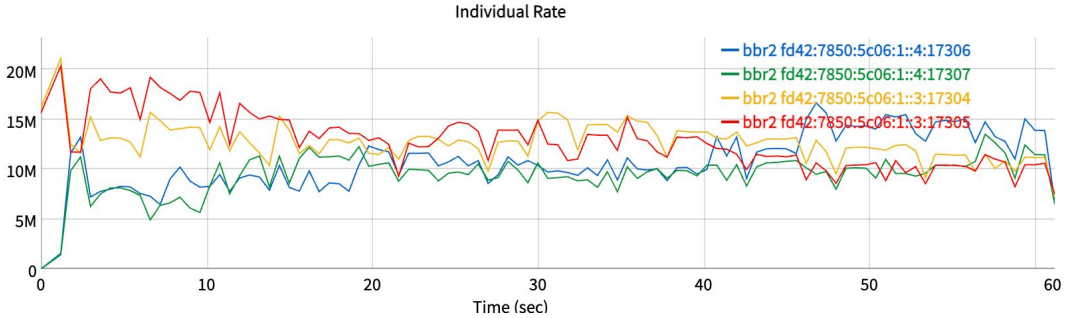
- Bug in BBRv2:
  - Symptoms: after loss/ECN set inflight_hi, later bandwidth probing stopped early
    - Before the flow caused loss/ECN signals again or reached fair share
  - Root cause: circular dependence between max bandwidth, max in-flight data
  - Impact: Caused BBRv2 flows to...
    - Not reach fair share competing vs BBR or Reno/CUBIC
    - Take a long time to reach full utilization when congestion subsides
- Fix:
  - Keep probing for bw until either:
    - Loss rate or ECN mark rate exceed tolerance thresholds, OR
    - Inflight_hi has not limited sending recently and bandwidth saturates
      - Bandwidth saturation estimator is same as in STARTUP mode
      - Estimate bw is saturated if >= 3 round trips w/o bw increasing by 25%
  - Reduces CUBIC/Reno share when competing with >1 BBR flow

BBRv3 bug fix 1: fix bw convergence *with* loss/ECN

Before bug fix 1:



After bug fix 1:



Example test results from:

transperf bulk TCP transfer test with 4 TCP BBRv3 flows with

bottleneck_bw=50Mbps, min_rtt=40ms, **buffer=1*BDP**

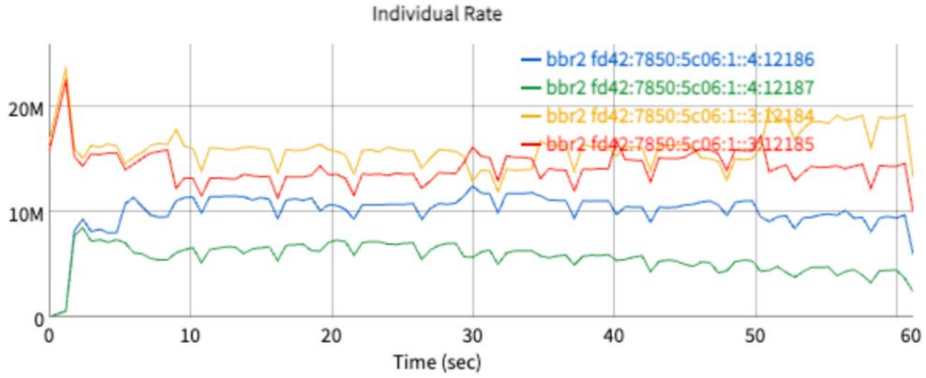
(at t=0s flows 0, 1 start; at t=1s flows 2, 3 start)

BBRv3 bug fix 2: fix bw convergence *without* loss/ECN

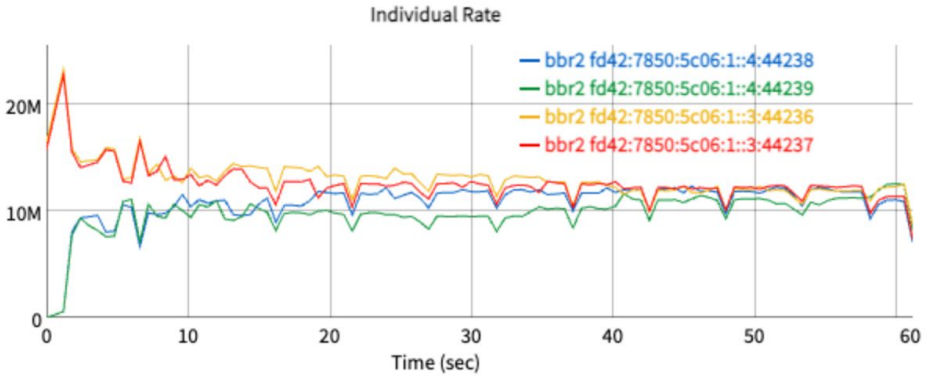
- Bug in BBRv2:
  - Symptoms: in buffer >1.5*BDP, BBRv2 flows often did not converge to fair share
  - Root causes:
    - 1: Fixed cwnd gain could prevent slow flows from raising their sending rate
    - 2: Slow flows holding 0.75*estimated_bw yielded too much bw to fast flows
  - Impact: lack of intra-protocol fairness for BBRv2 w/ buf>1.5*BDP, w/o ECN or loss
- Fixes:
  - 1: Increase cwnd gain from 2.0 to 2.25 when probing for bandwidth (ProbeBW_UP)
    - To ensure sending rate can increase when probing for bandwidth
  - 2: Change pacing gain of 0.75x to 0.9x (ProbeBW_DOWN)
    - 0.9x is derived from on the ProbeBW_UP pacing gain of 1.25x...
    - ...as the minimum pacing gain value that allows slow flows to consistently utilize enough bw to cause fast flows to yield bw for fairness convergence

BBRv3 bug fix 2: fix bw convergence *without* loss/ECN

Before bug fix 2:



After bug fix 2:



Example test results from:

transperf bulk TCP transfer test with 4 TCP BBRv3 flows with

bottleneck_bw=50Mbps, min_rtt=40ms, **buffer=100*BDP**

(at t=0s flows 0, 1 start; at t=1s flows 2, 3 start)

BBRv3 performance tuning

- Performance tuning changes:
  - STARTUP cwnd gain: 2.89 => 2.0 [analytic derivation]
  - STARTUP pacing gain: 2.89 => 2.77 [analytic derivation]
  - When exiting STARTUP, set inflight_hi based on:
    - max(estimated BDP, max number of packets delivered in last round trip)
  - To trigger exit of STARTUP based on packet loss...
    - Require fewer loss events in a single round trip (6 rather than 8)
- Primary impact of these changes:
  - Lower queuing delays and packet loss rates during and shortly after STARTUP

BBR deployment status at Google

- Google-internal traffic:
  - **BBRv3** is TCP congestion control for all internal **WAN traffic**
  - **BBR.Swift** is TCP congestion control used **within a datacenter**
- Google-external traffic:
  - **BBRv3** is TCP CC for all Google.com public Internet traffic
  - A/B experiments: BBRv3 vs v1 for small % of users for:
    - TCP for YouTube
    - QUIC for google.com and YouTube

BBRv3 performance impact for public Internet traffic

- Impact of BBRv3 vs BBRv1 on Google.com and YouTube TCP public Internet traffic:
  - Lower retransmit rate (12% reduction)
  - Slight latency improvement (0.2% reduction) for:
    - Google.com web search
    - Starting YouTube video playback
  - Latency wins seem to be from lower loss rate (less/faster loss recovery)

BBR Open Source Code

- TCP BBRv3 release:
  - Linux TCP (dual GPLv2/BSD): github.com/google/bbr/blob/v3/README.md
  - Main updates: the bug fixes described in this presentation
  - TCP BBR v3 release is open source (dual GPL/BSD), available for review/testing
  - Plan to email patches to propose inclusion in mainline Linux TCP in August
- BBRv1 code in Linux TCP "bbr" module will be upgraded to BBRv3
- Why upgrade BBRv1->BBRv3 in place rather than a separate module? BBRv3 has...
  - Better coexistence with Reno/CUBIC, vs v1
  - Lower loss rates, vs v1
  - Lower latency for short web requests (from google.com, YouTube data), vs v1
  - Throughput similar to v1 (within 1% of v1 on YouTube)

Conclusion

- Summary:
  - Open sourced BBRv3 on github with significant bug fixes vs BBRv2
  - BBRv3 used for all TCP for Google.com public Internet and internal WAN traffic
  - BBRv3 under A/B testing for YouTube TCP, YouTube and Google.com QUIC
- Next:
  - Plan on submitting BBRv3 for inclusion in mainline Linux TCP in August
  - Will update BBR Internet Drafts to cover BBRv3:
    - Delivery rate estimation: draft-cheng-iccrg-delivery-rate-estimation
    - BBR Congestion control: draft-cardwell-iccrg-bbr-congestion-control
- We invite the community to share…
  - Feedback on the algorithm, code, or drafts
  - Test results, issues, patches, or ideas
- Thanks!

Q & A

https://groups.google.com/d/forum/bbr-dev

Internet Drafts, paper, code, mailing list, talks, etc.

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