BBR Update:
1: BBR.Swift; 2: Scalable Loss Handling

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

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Outline

- BBR.Swift: using delay as a signal in the datacenter
- Scalable loss handling: BBR, PRR, and the scalability of multiplicative decrease
- Status of the BBR code and Google deployment
- Conclusion

Target for this talk:

- Sharing our experience with experiments
- Inviting the community share feedback, test results, issues, patches, or ideas

BBR.Swift:
Delay as a signal in the datacenter

Swift Congestion Control

- Swift congestion control algorithm [SIGCOMM-2020]
  - Uses network RTT and host delays as primary signals (also uses loss)
  - Potential scope:
    - Inside network with known topology/RTT properties (e.g. datacenters)
    - With NICs with hardware timestamp support
    - Where all traffic sharing bottleneck is Swift-compatible
  - Algorithm:
    - AIMD, with MD (multiplicative decrease) proportional to the excess delay
    - Uses pacing when cwnd < 1, to handle large-scale multiplexing (e.g. "incast")
  - Usage so far:
    - In Snap userspace network stack [SOSP-2019]
    - Traffic within a Google datacenter
      - Target network RTT is known
      - Known that other traffic sharing QoS queue is Swift-compatible

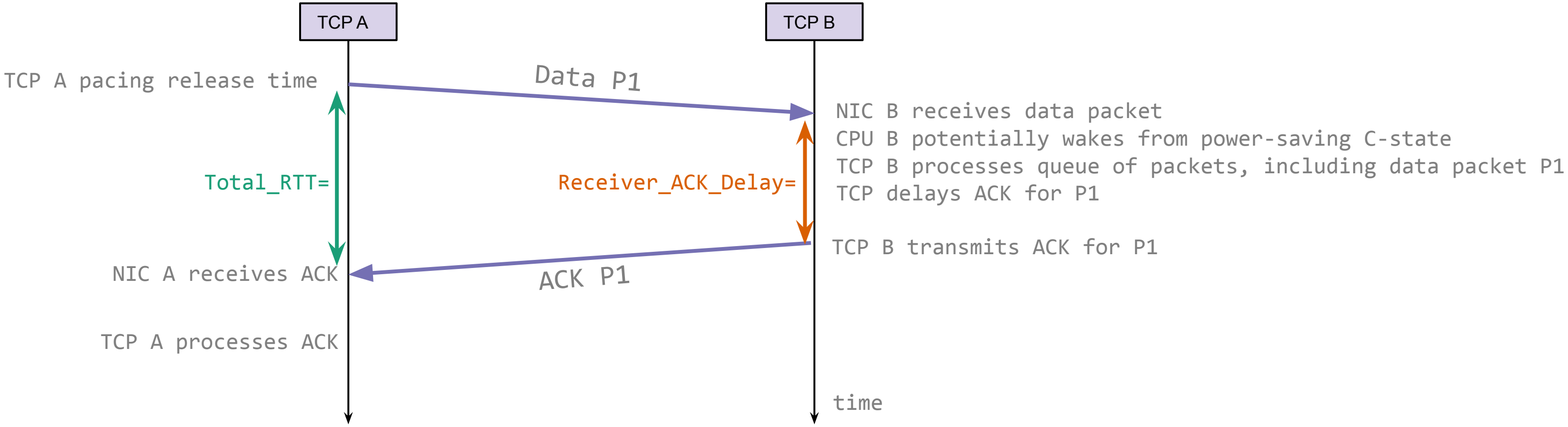
Swift: Delay as a Congestion Signal

- Advantages of using delay as a signal:
    - Provides richer information about the current degree of queuing
        - Allows faster reaction to long queues
        - Avoids overreaction and underutilization with short queues
    - Provides a known target latency for engineering systems
        - Helps applications to predict the latency they should expect
        - Helps set SLOs of network queuing delay for engineering, monitoring, alerting
        - By contrast, loss rate or ECN monitoring is difficult to translate into application performance (e.g. how does x% loss relate to latency?)

- Key requirement: *accurate* delay measurements of network and host

BBR.Swift: Network_RTT Signal

- Data sender computes a Network_RTT sample using:
  - Network_RTT = Total_RTT - Receiver_ACK_Delay



- Data and ACK transmission times: measured by TCP
- Data and ACK reception times: measured by NIC (via NIC hardware rx timestamps)
- Data receiver signals Receiver_ACK_Delay using new timestamp option (draft-yang-tcpm-ets-00, IETF 109 TCPM)

BBR.Swift: Design

- BBR.Swift is an extension of BBRv2
  - Core BBRv2 unchanged
  - Extension to BBRv2 based on Swift [SIGCOMM-2020]
  - New configuration parameter: target_RTT (e.g. O(100us) inside DC)
  - If Network_RTT > target_RTT, multiply cwnd and pacing rate by:

$$\text{MD} = \max\left(1 - 0.8 * \frac{\text{Network\_RTT} - \text{target\_RTT}}{\text{Network\_RTT}}, 0.5\right)$$

- DCTCP-style ECN response is disabled if target_RTT is used
  - For interactions between BBR.ECN WAN flows vs BBR.Swift flows:
    - Exploring ideas, e.g.: dynamically set target_RTT to the Network_RTT at the boundary of ECN marking

BBR.Swift: Example Performance Results in the Lab

- 3 server-class machines w/ 50G NICs on same switch; controlled lab network setting
- 2 senders, 1 receiver; 2000 bulk TCP flows;
- Each sender sends 1000 bulk netperf TCP_STREAM flows for 10 secs
  - Second sender starts ~0.2 sec after first sender
- Results reported for each data sender machine

- DCTCP issues:
  - Floor is cwnd=1
  - Big standing queue
  - Large loss rate
  - Less fair
- BBR.Swift features:
  - Pacing ~= delivery rate
  - Small queue
  - Low loss rate
  - Quite fair

Congestion Control	DCTCP		BBRv2 (ECN)		BBR.Swift	
Sender machine	1	2	1	2	1	2
Throughput (Gbit/sec)	46.6	3.7	25.0	23.5	24.9	25.4
Mean Total_RTT (us)			228	337	196	195
Mean Network_RTT (us)					93	93
Retransmit rate	6.1%	66.2%	1.6%	1.7%	0.053%	0.053%
Jain's fairness index	0.671	0.746	0.69	0.70	0.956	0.957

BBR.Swift: Status and Plans

- Preparing for production testing of BBR.Swift for Google internal traffic
- Plan to release BBR.Swift code as open source and document the algorithm in detail
    - Including implementation of draft-yang-tcpm-ets-00
- Goal: we want transports to be able to use BBR.Swift as their CC
    - On connections where...
        - Target Network_RTT is known
        - It is known that other traffic sharing bottlenecks is using Swift or BBR.Swift
    - On physical machines or virtual machines

Congestion Control in Loss Recovery

Multiplicative Decrease is Not Scalable Enough

- Traditional TCP CC uses multiplicative decrease upon round trips with packet loss
  - e.g., Reno: 0.5x per round; CUBIC: 0.7x per round
- But what if the bandwidth available to a flow suddenly drops by 1000x?
  - Theory: Reno expects log_2(old_bw / new_bw) round trips of high loss rate pain
    - e.g. 1000x cut in fair-share bandwidth can lead to 10 rounds of high loss
  - Reality:
    - With TCP loss recovery before RACK, consecutive rounds of loss => RTO
      - Before RACK, lost retransmits usually caused RTO, cwnd=1, slow-start
    - With TCP RACK but no PRR, reality matches theory
      - And the resulting high loss rate can be painful!
    - With TCP RACK and PRR, sending rate is bounded to be near delivery rate
      - And the loss rate is reasonable and tolerable

How Should BBR Respond to Loss?

- BBRv1 used an approach inspired by PRR
    - First round of recovery: packet conservation
    - Subsequent rounds of recovery: send at 2x the per-packet delivery rate
- Initial revisions of BBRv2 simplified things by using a multiplicative decrease
    - Similar to 0.7x per round used by CUBIC
- Production experience with Google-internal datacenter RPC traffic shows initial BBRv2...
    - Approaches the painful theoretical behavior: high loss for log(old_bw / new_bw)
- Next: experimenting with various PRR-inspired responses to loss recovery for BBRv2
    - Stay tuned for production experiment results...

Wrapping up...

Status of BBR v2 algorithm and code

- TCP BBRv2 "alpha/preview" release:
  - Linux TCP (dual GPLv2/BSD): **github.com/google/bbr/blob/v2alpha/README.md**
- QUIC BBR v2:
  - Chromium QUIC (BSD):on chromium.org in bbr2_sender.{ cc, h }

- BBR v2 release is ready for research experiments
  - We invite researchers to share...
    - Ideas for test cases and metrics to evaluate
    - Test results
    - Algorithm/code ideas
  - Always happy to see patches or look at packet traces...
- BBR v2 algorithm was described at IETF 104 [slides | video]
- BBR v2 open source release was described at IETF 105 [slides | video]

BBR v2 deployment status at Google

- YouTube and google.com: deployed for a small percentage of users
    - Reduced queuing delays: RTTs lower than BBR v1 and CUBIC
    - Reduced packet loss: loss rates closer to CUBIC than BBR v1
- Google-internal traffic:
    - BBRv2 being deployed as default TCP congestion control for internal Google traffic
    - Used as the congestion control for most traffic within Google
        - Currently using bandwidth * min_rtt, loss, ECN as signals
        - Preparing for production testing using Network_RTT
- Continuing to iterate using production experiments and lab tests

Conclusion

- Actively working on BBR v2, BBR.Swift at Google
    - Tuning performance to enable full-scale roll-out at Google
    - Improving the algorithm to scale to larger numbers of flows
    - We invite the community share test results, issues, patches, or ideas

Q & A

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

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

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Backup slides...

ECN: Responsiveness vs Utilization Trade-Offs

- [RFC3168]-style ECN:
    - Coarse once-per-RTT signal forces high queues or low utilization
- DCTCP/Prague-style ECN:
    - Per-ACK ECN signal is much better than [RFC3168], but still has a dilemma...
    - How to choose the magnitude of the multiplicative decrease (MD)?
    - MD based on EWMA of ECN mark rate (DCTCP, TCP Prague, BBRv2):
        - Delays response to suddenly long queues
    - MD using instantaneous ECN mark rate in current round trip (GCN):
        - Allows fast reaction to long/congested queues
        - But if queue is actually short or RTT is long, a big MD causes underutilization
- Ideally we'd like:
    - An MD proportional to a per-ACK signal that quantifies the magnitude of the queue
    - Adapts to use a large MD to drain long queues quickly
    - Adapts to use a small MD to allow high utilization even for short queues

BBR.Swift: Network_RTT via ETS timestamps

- Extensible Timestamp option (ETS): draft-yang-tcpm-ets-00 (see TCPM at IETF 109)
  - Has TSval, TSecr, like [RFC7323] timestamp option, but...
  - Explicitly signals Receiver_ACK_Delay
  - TSval, TSecr, Receiver_ACK_Delay are all in microsecond granularity
- Data sender computes Total_RTT using ETS timestamp options:
  - Total_RTT = (time NIC received ACK) - (scheduled pacing release time of data)
- Data receiver computes Receiver_ACK_Delay:
  - Receiver_ACK_Delay = (scheduled release time of ACK) - (time NIC received data)
  - Data receiver sends Receiver_ACK_Delay using ETS timestamp option

BBR.Swift: ETS Timestamp Option Header Format

```
        +--------+--------+--------+--------+
        |  Kind  | Length |      ExID       |
        +--------+--------+--------+--------+
        |               TSval               |
        +--------+--------+--------+--------+
        |               TSecr               |
        +--------+--------+--------+--------+
        |Un|   EcrDel   |R|    MaxACKDel    |
        +---------------+-+-----------------+
        |                 |
       /                   \
  .---'                     `---------------------.
 /                                                 \
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|  Unit  |            EcrDel               |Reserved|
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
  2 bits |            13 bits              | 1 bit
```

Kind: 1 byte, value 254, [RFC6994] experimental option
Length: 1 byte option length, value is 16 if SYN bit is set,
otherwise 14 (value MAY be higher in later versions).
ExID: 2 bytes, [RFC6994] experiment ID: value 0x4554.
TSval and TSecr: 32 bits each, have the same definition as
[RFC7323] but are in **microseconds**.
EcrDelUnit: 2 bits; allowed values are:
0: indicates EcrDel is in microsecond units
1: indicates EcrDel is in millisecond units
2: indicates EcrDel is invalid (should be ignored)
3: reserved in this protocol version
EcrDel: 13 bits, the value of EcrDel.
Reserved: 1 bit, in this protocol version, sender MUST set to 0
And receiver MUST ignore.
MaxACKDel: 16 bits, max expected ACK delay in microseconds,
only present in SYN.