TCP-INT: Lightweight INT in TCP Transport

Simon Wass (Intel) & Miao, Mao (Baidu)

Agenda

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- TCP-INT High-Level Design
- Example use cases
- Implementation (Intel)
- Demo
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- Implementation (Baidu)
- Baidu Vision & Planned Usage
- Roadmap

Contributors

Intel

Theo Jepsen
Grzegorz Jereczek
Bimmy Pujari
JK Lee
Simon Wass

Baidu

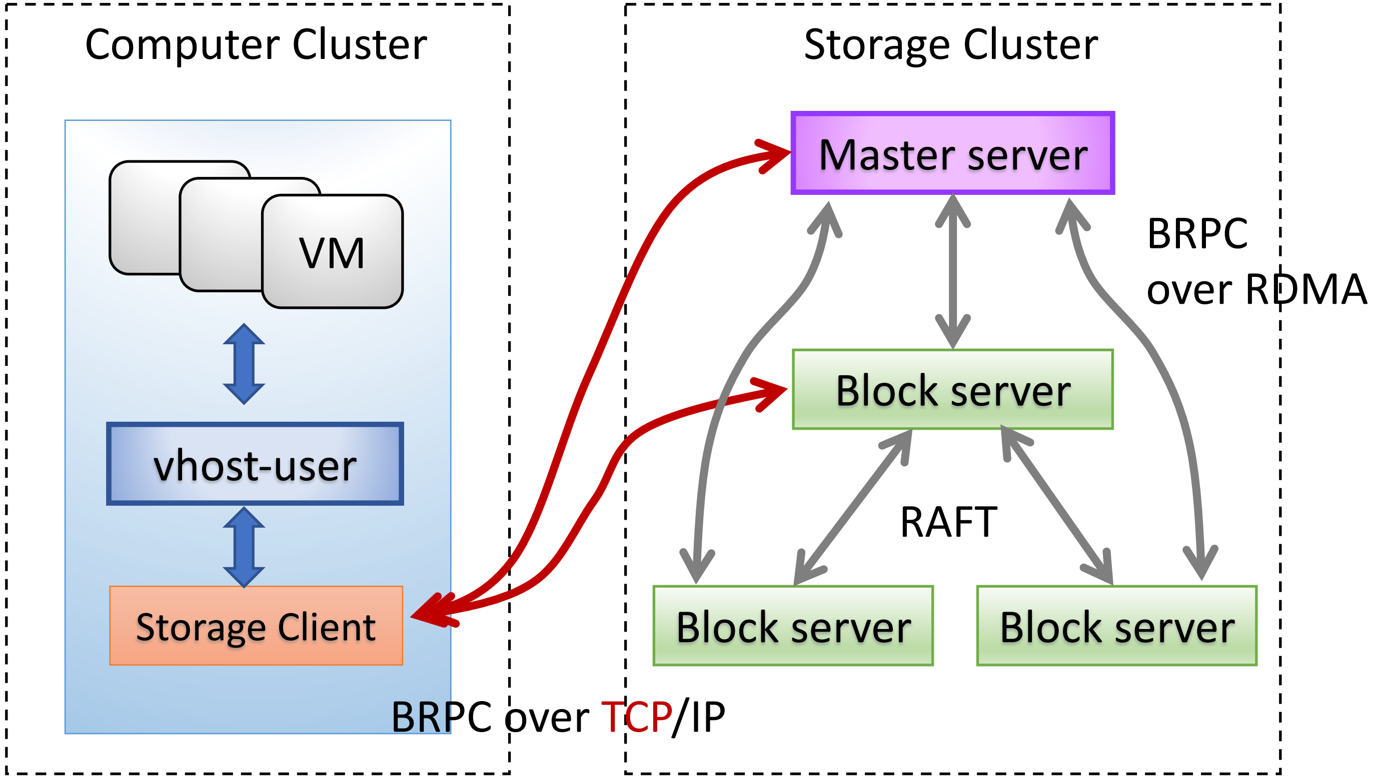
Miao, Mao
Cheng, Gang
Li, Zhaogeng
Xie, Pan

Motivations

- The separation between storage and computation requires a low latency, high throughput fabric to realize the benefit

- BaiduRPC over RDMA is used in the storage cluster

- Congestion & bottleneck exist between Storage client and master/block server due to the use of TCP

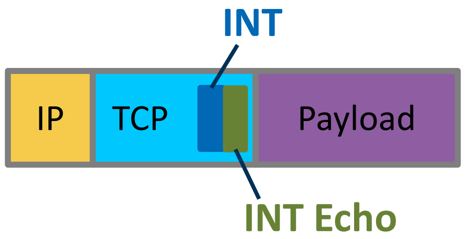


Motivations (2)

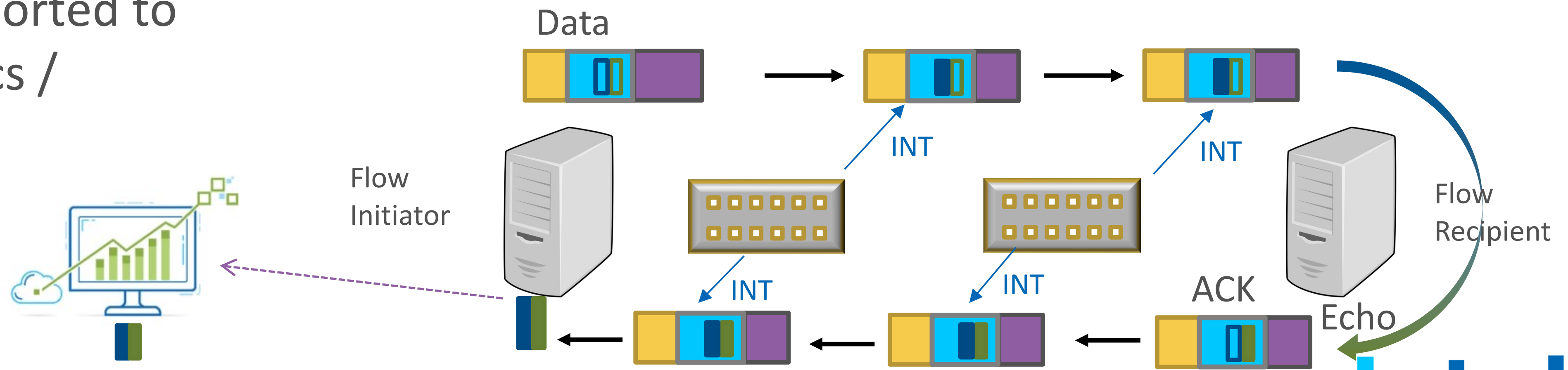
Feedback on INT

1. Flow Scale
2. Telemetry “for Control”
3. Direct mapping to application session/message

TCP-INT High-Level Design (3)

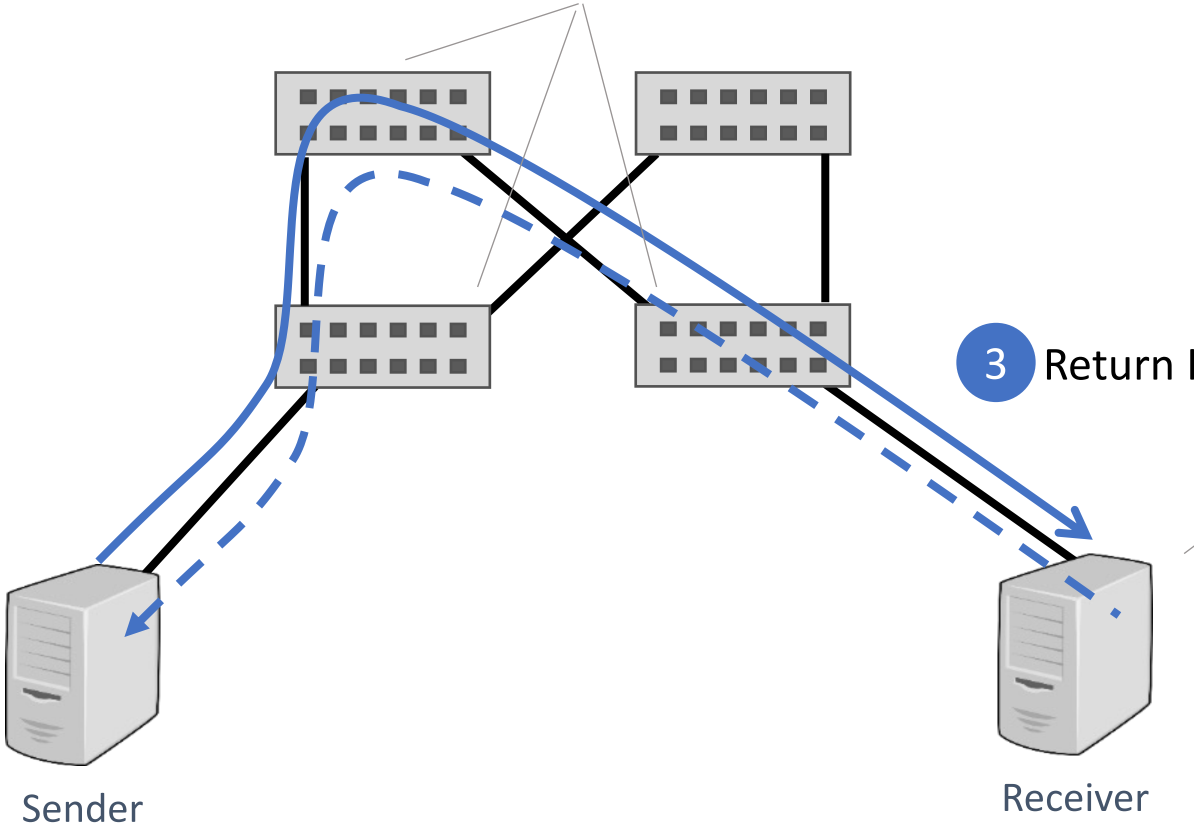


- In-band Network Telemetry (INT) embedded in the TCP header (as TCP Option)
- Correlates fabric telemetry (Q depth) with TCP states (congestion window)
- Lightweight: metrics aggregated (max or sum) over switch hops
- INT enriched with end-host metrics
- Consumed locally by application or exported to centralized metrics / visualization tools



TCP-INT High-Level Design

2 Switches update INT fields: sum latency and max qdepth, util

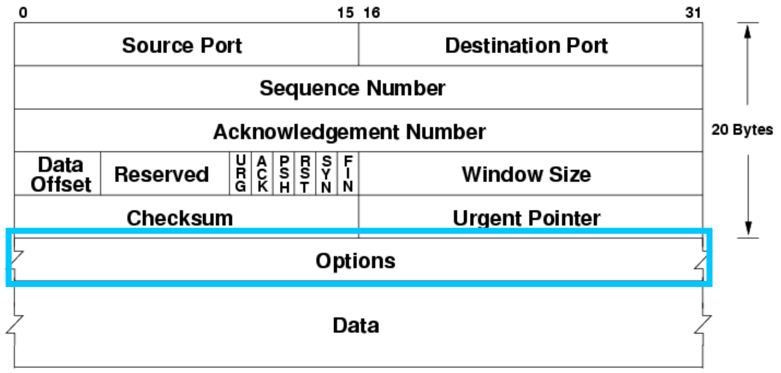


1 Kernel adds INT option to TCP header

3 Return INT header in ACK

TCP-INT High Level Design (2)

New TCP Option – TCP-INT



Used by the end-hosts to echo INTval and ID back to the senders, ignored by the switches

Updated by the switches

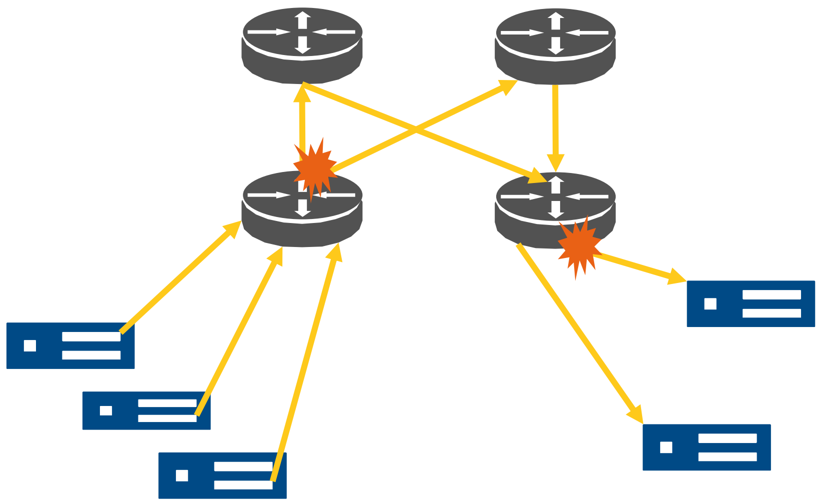
Option-kind (1B)	Option-length (1B)	**INTval** (1B) **(Scaled summation of utilization or queue depth)**	INTecr (1B)	**ID** (1B)	IDecr (1B)	**Lat** (3B)	LatEcr (3B)

0x72	0x0C	if qdepth < qdepth_threshold:
		Bit [7]: 0
		Bits [0-6]: **util** >> y
		(saturates if above max)
		else:
		Bit [7]: 1
		Bits [0-6]: **qdepth** >> x
		(saturates if above max)
			INTval Echo Reply	IP.TTL	IP.TTL Echo Reply	Lat += switchLat	Lat Echo Reply

Example Use Cases

Extend Host Linux TCP Toolset with TCP-INT Information

- Quick view into network state
- Compare different congestion control algorithms
- Develop new congestion control algorithms
- Debug QoS configuration in the fabric (e.g. WRED thresholds)



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Implementation

Intel Implementation Overview

End-hosts

Switch

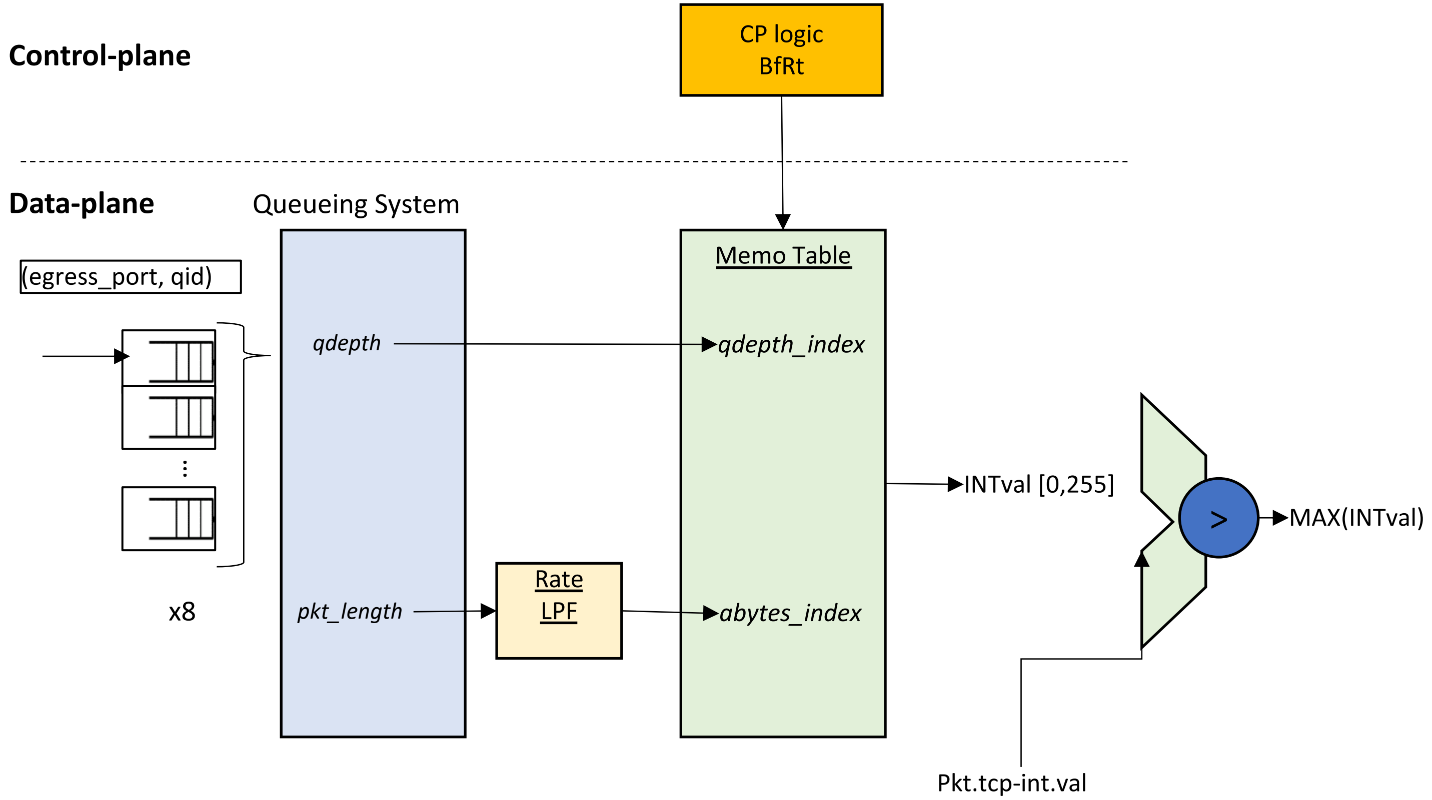
Implementation (2)

Host-side eBPF-based implementation

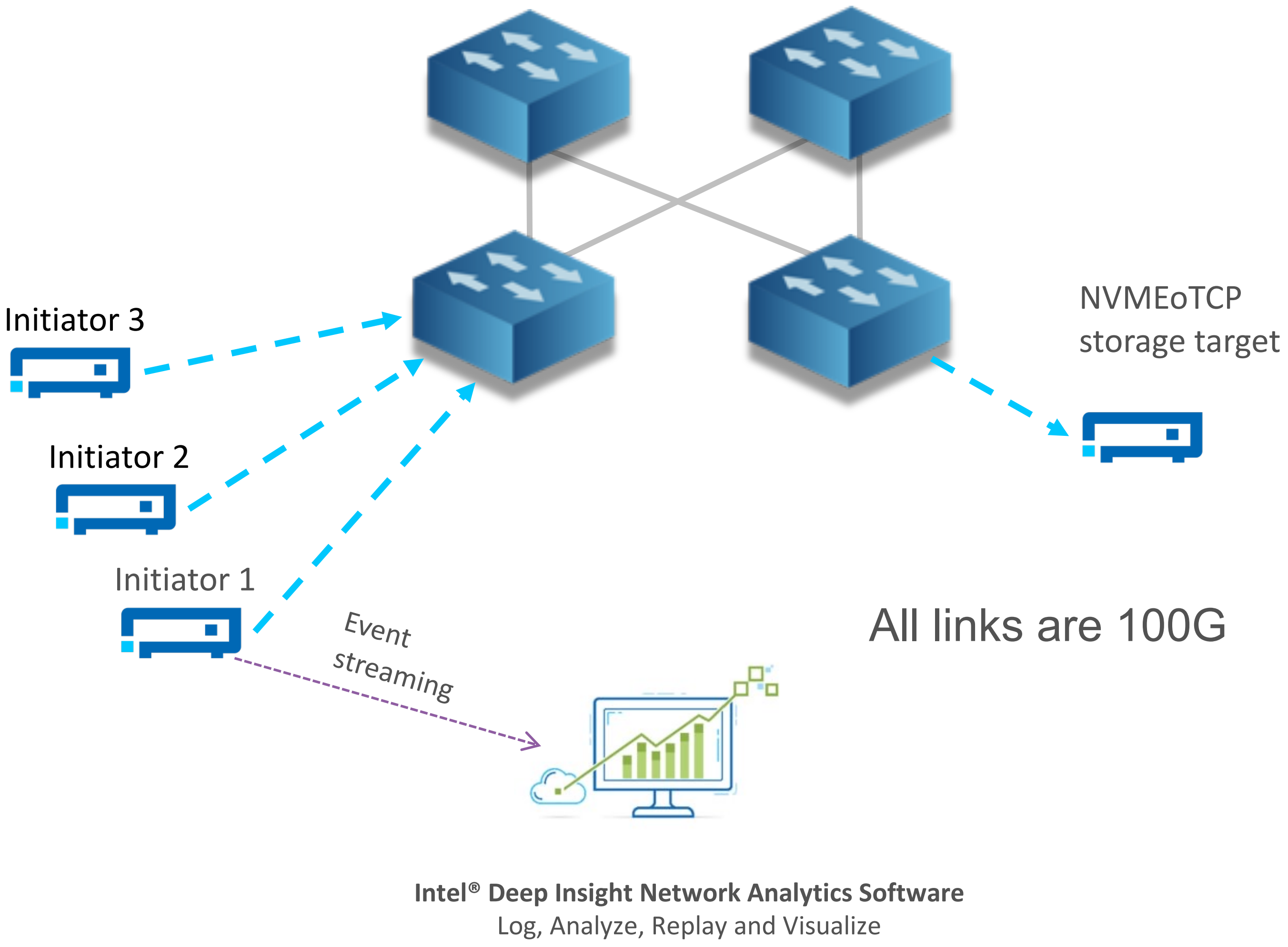
- eBPF callbacks for TCP options (kernel 5.10). TCP-INT eBPF code is called when:
  - new TCP connection is established -> enabling option callbacks for the lifetime of a flow
  - any unknown TCP option is received -> look for and handle TCP-INT
  - TCP adds options to a new outgoing segment -> initialize TCP-INT (INTval=0)
- SK buff local storage (kernel 5.2) used to keep TCP-INT state (echo TCP-INT b2s)
- Perf events and histograms for live data monitoring
  - Exportable via other user-space applications (E.g. gRPC client)
- Configuration maps for enable, disable, disable echo
- User-space application loads, controls, and polls data from eBPF program

Switch-Side TCP-INT

- Control planes determines the mapping between (qdepth, txRate) and INTval
- This increases flexibility and allows complex mapping functions that include division



Demo: End-to-End Performance Bottleneck Identification



FIO NVMe Storage Benchmark

- As number of initiators increases, storage application latency increases
- Identifying the root-cause is a big problem in large distributed systems

Demo: End-to-End Performance Bottleneck Identification

Enhancing CC Algorithms with TCP-INT

1. Initialize TCP-INT option

```
INTval = 0
Lat = 0
```

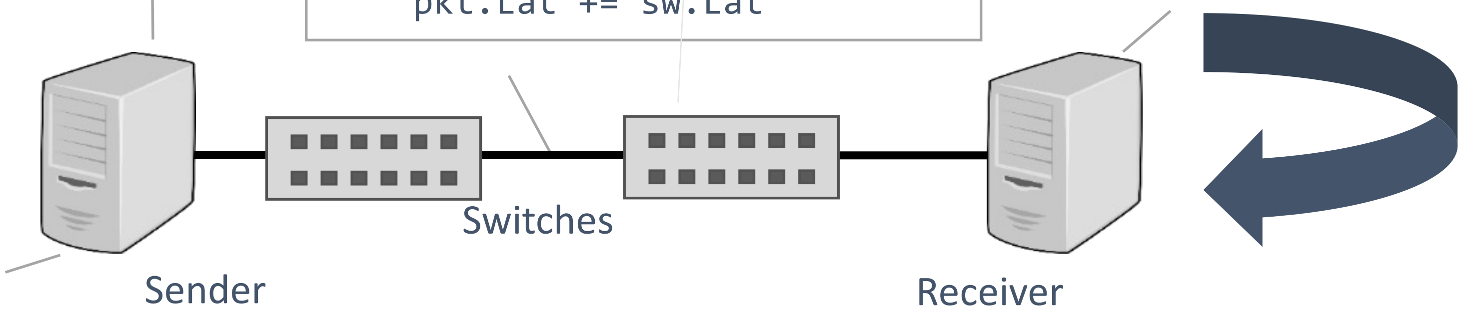
2. Calculate and update INTval + Lat

```
if sw.INTval > pkt.INTval:
    pkt.INTval = sw.INTval
    pkt.INTid = sw.INTid
pkt.Lat += sw.Lat
```

3. Echo received INTval & Lat back to the sender

4. **TCP-INTsink:**

- **congestion control**
  - **HPTCP**
  - **DCTCP++**
  - **AI-CC**
  - …
- **state monitoring and debugging**
- …



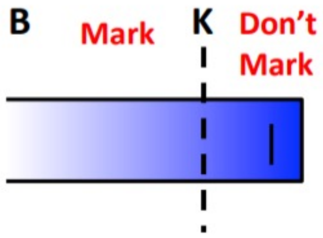
Goal: Simple implementations to allow customers add their secret sauce

ECN+INT Congestion Control

DCTCP: Algorithm

Switch side:

– Mark packets when **Queue Length > K.**



Sender side:

– Maintain running average of ***fraction*** of packets marked **(α)**.

$$\text{each RTT}: F = \frac{\#\ \text{of marked ACKs}}{\text{Total}\ \#\ \text{of ACKs}} \Rightarrow \alpha \leftarrow (1-g)\alpha + gF$$

➢ **Adaptive window decreases:** $W \leftarrow (1 - \frac{\alpha}{2})W$

– Note: decrease factor between 1 and 2.

Source: https://web.stanford.edu/class/ee384m/Handouts/handout16.pdf

ECN+INT Congestion Control

Switch Side

- INTval conveys absolute qdepth

Sender Side

- Introduce α_{int}:

  $\alpha_{int} = qdepth_{smoothed} / qdepth_{target}$

  $qdepth_{smoothed} \leftarrow (1 - g)*qdepth_{smoothed} + g*qdepth$

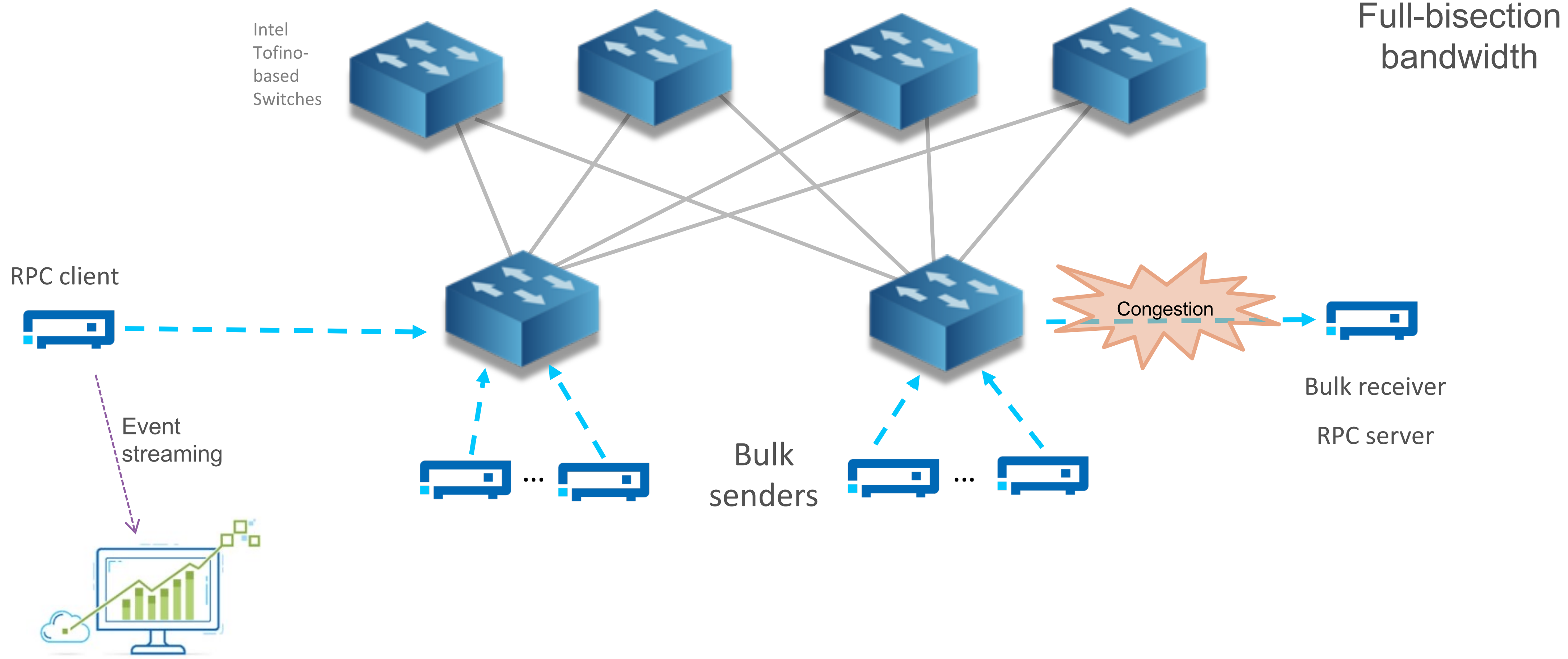
  g – smoothing factor

- Combine α_{DCTCP} and α_{int}:

  $\alpha = \max(\alpha_{DCTCP}, \alpha_{int})$

This approach ensures interoperability with switches that do not support TCP-INT

ECN+INT CC Demo Topology



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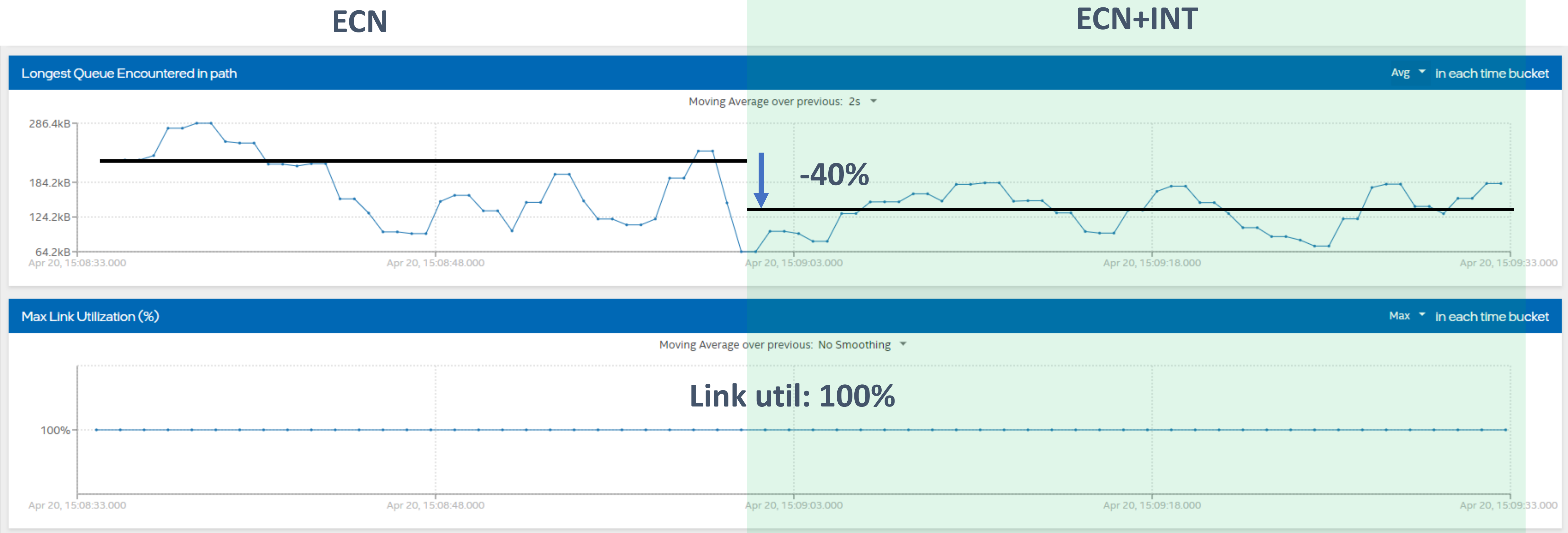
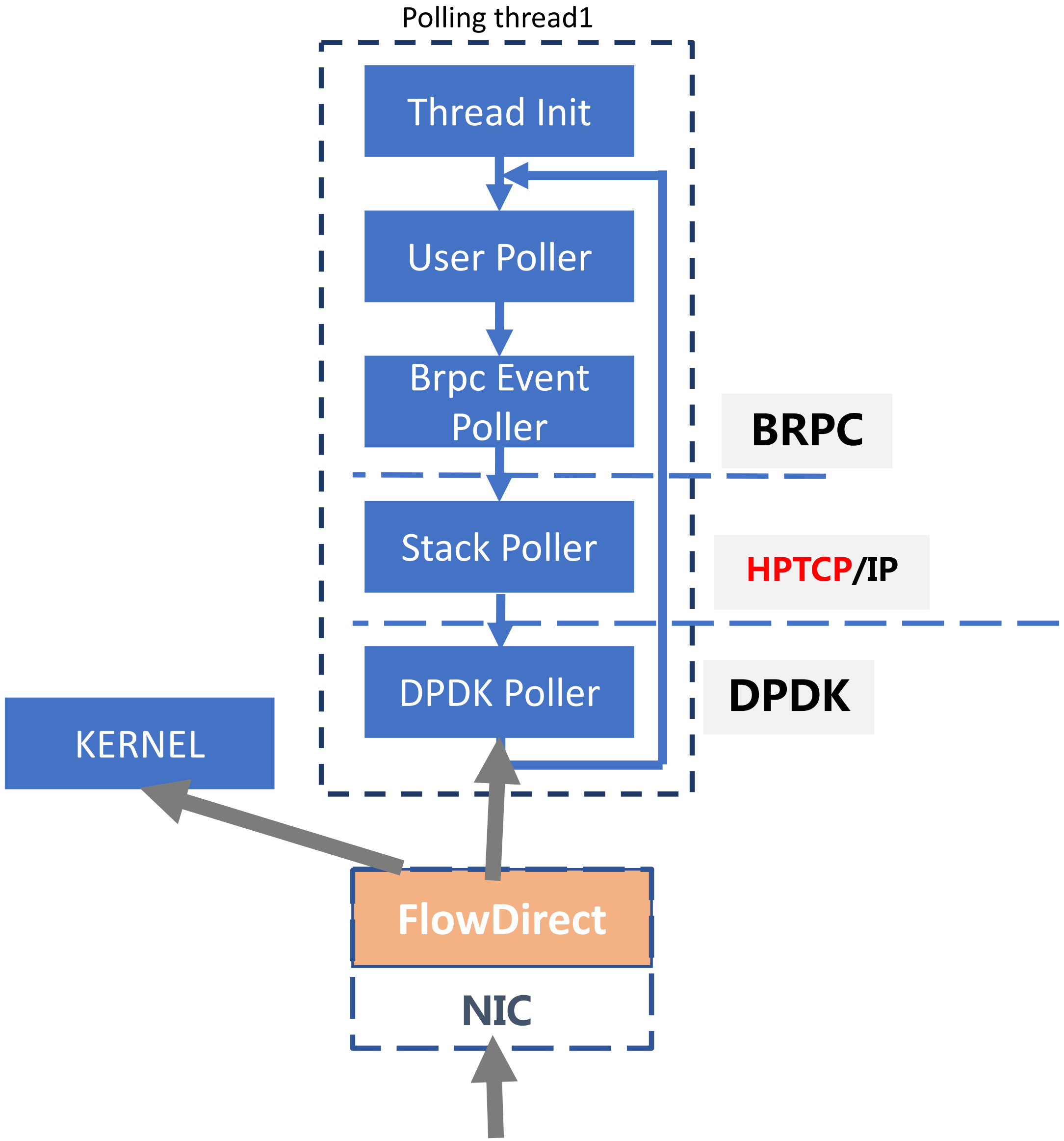


ECN		ECN+INT
157 us average latency	-43%	67 us average latency
172 us p99 tail latency	-23%	126 us p99 tail latency
6K reqs/s	2.5x*	15K reqs/s

*For workloads and configurations visit www.intel.com/PerformanceIndex. Results may vary.

Baidu Implementation



- Congestion window update
  - Baidu implements HPTCP Algorithm
  - HPTCP is based on HPCC algorithm for RDMA networks, ported to TCP
  - Uval is calculated from INTVal field in TCP-INT

  HPCC:https://dl.acm.org/doi/pdf/10.1145/3341302.3342085

- Uval calculaction
  - If INTval[7]=1, INTval[6:0]=qdepth, then:

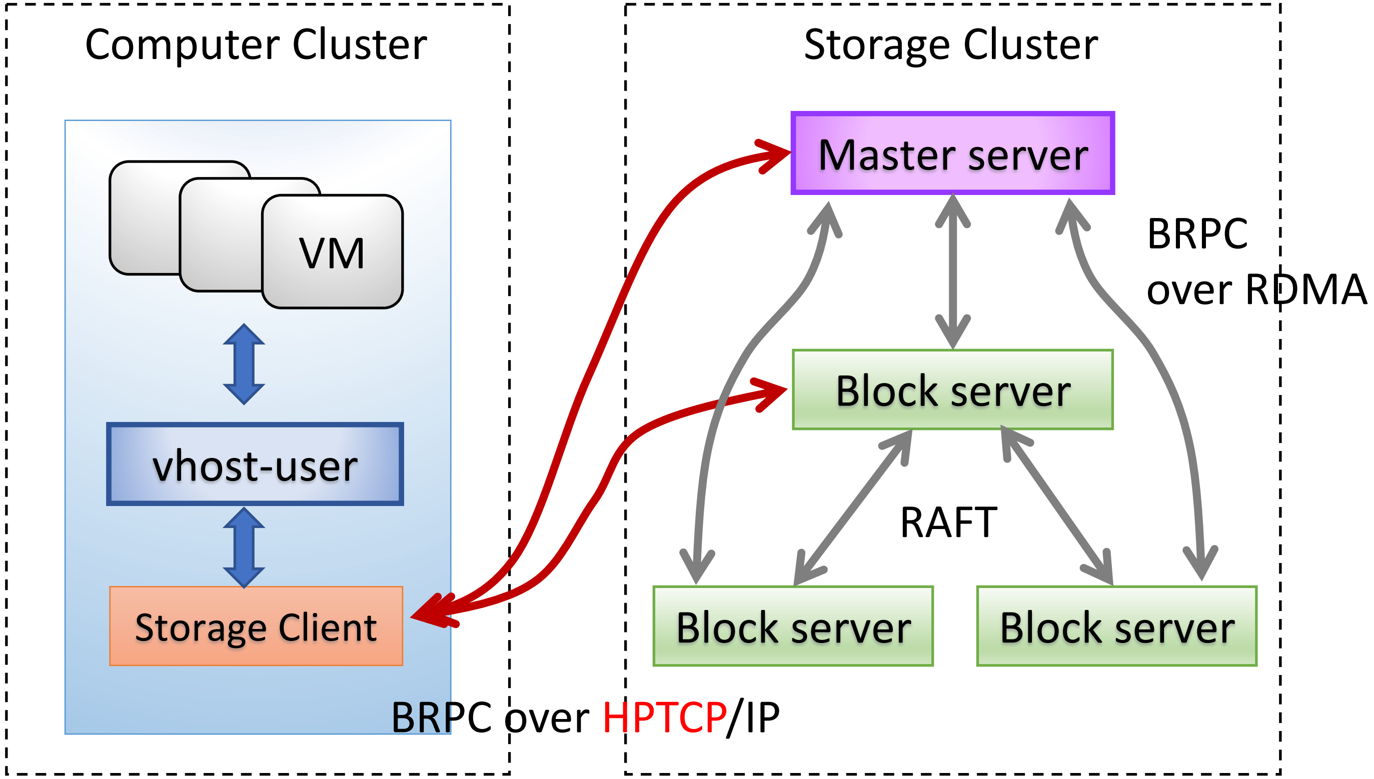
  $$Uval = \frac{qdepth}{B * RTT} + \frac{txRate}{B} = \frac{qdepth}{B * RTT} + 1$$

  - If INTval[7]=0, INTval[6:0]= Uval << bitshift

- Fast retransmit: snd_cwnd = snd_cwnd / 2
- RTO: snd_cwnd = min(snd_cwnd/2, Winit)

Baidu Vision & Planned Usage

- Intend to be used in Storage Client
- Comparison of various technical solutions is in progress
  - SWIFT
  - HPTCP
  - …
- Aim to compete with the storage networks from top cloud vendors



Roadmap (Intel)

- Open-Source TCP-INT host-side code
- Delivering network telemetry directly to applications
- Scale out testing with 100s of nodes
- Continue research into congestion control improvement and network mgmt. utilizing TCP-INT telemetry

Baidu Roadmap

- Continue to test HPTCP in Baidu's testbed
- Keep optimizing HPTCP congestion control algorithm
- Compare the performance of HPTCP with SWIFT and RDMA schemes
- Deploy the new transport stack in Storage client to improve the entire storage networks

Notices and Disclaimers

- Performance varies by use, configuration and other factors. Learn more at www.Intel.com/PerformanceIndex.
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