Programmability in NICs for Congestion Control and Transport

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Nandita Dukkipati, Konstantin Weitz

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Key Questions

1

What transport and congestion control capabilities make sense in NICs?

2

Which of the transport capabilities require programmability?

3

Can the transport functionality be expressed with P4?

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This Talk

- Context: Congestion Control @Google and Why it Matters.
- Swift Congestion Control and NIC Time as a Service.
- Example: Expressing Congestion Control Functionalities with P4.

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Congestion Control @Google and Why it Matters

Bandwidth Management @Google

Swift[1], BBR[2]	Per-flow congestion control.
BwE [3], B4 TE [4]	Centralized control of flow aggregates over WAN.
QoS	Bandwidth sharing at network queues.
Static Limits	BW configuration based on CPU cores, storage etc.

[1] Swift: Delay is Simple and Effective for Congestion Control in the Datacenter, SIGCOMM 2020
[2] BBR: Congestion-based Congestion Control, ACM Queue, 2016
[3] BwE: Flexible, Hierarchical Bandwidth Allocation for WAN Distributed Computing, SIGCOMM 2015.
[4] B4: Experience with a Globally-Deployed Software Defined WAN, SIGCOMM 2013.

Transport in Host Stacks

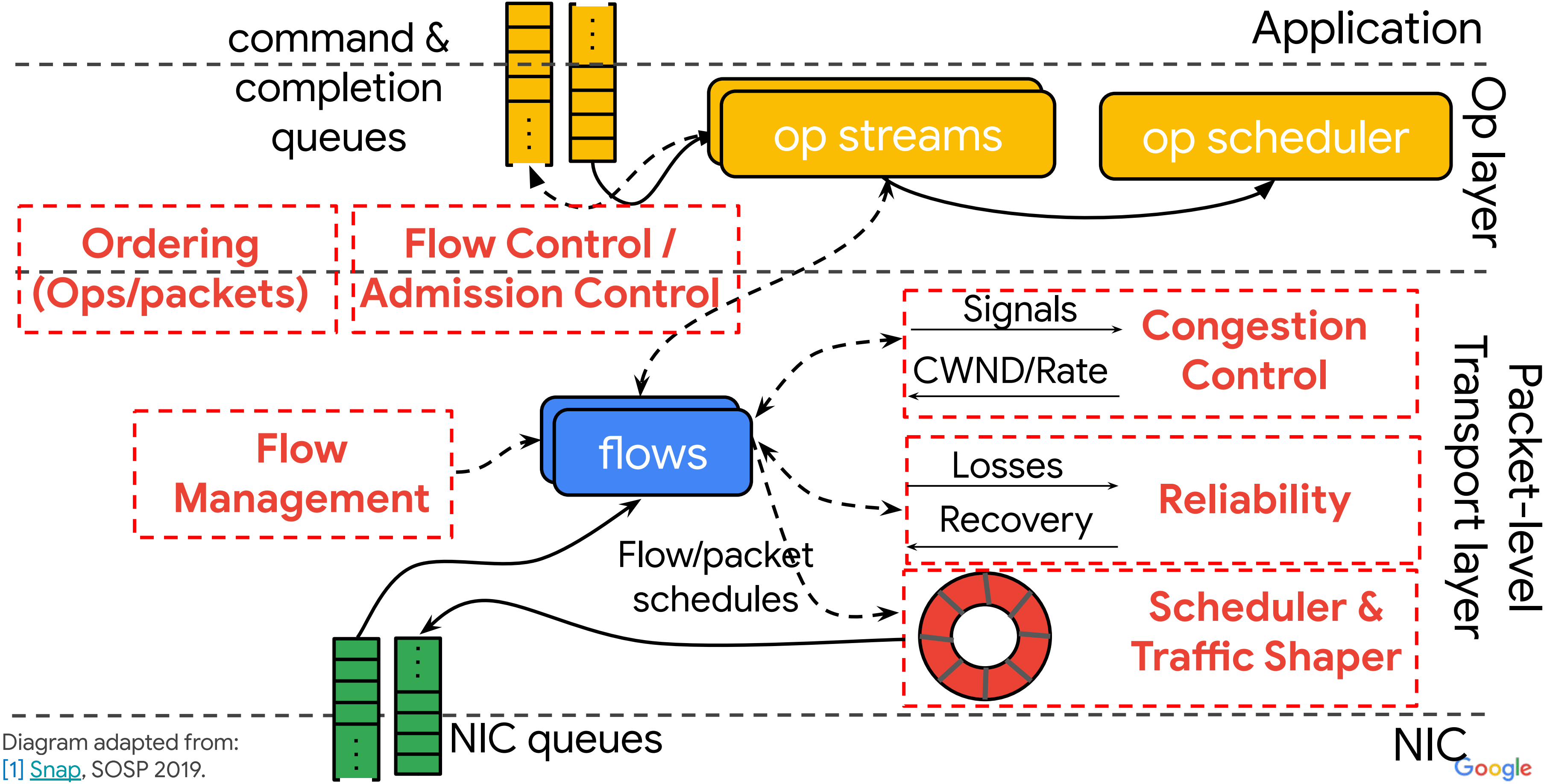

Diagram adapted from:
[1] Snap, SOSP 2019.
[2] Swift, SIGCOMM 2020.

Swift Congestion Control and NIC Time as a Service

Motivated by:
Swift: Delay-based congestion-control algorithm for low-latency networks - External Link

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What is Swift?

Swift is a delay based congestion-control for Datacenters that achieves low-latency, high-utilization, near-zero loss implemented completely at end hosts supporting diverse workloads like large-scale incast across latency-sensitive, byte and IOPS-intensive applications working seamlessly in heterogeneous datacenters with minimal switch support

Swift achieves ~50μs tail latency for short-flows while maintaining near 100% utilization even at 100Gbps line-rate

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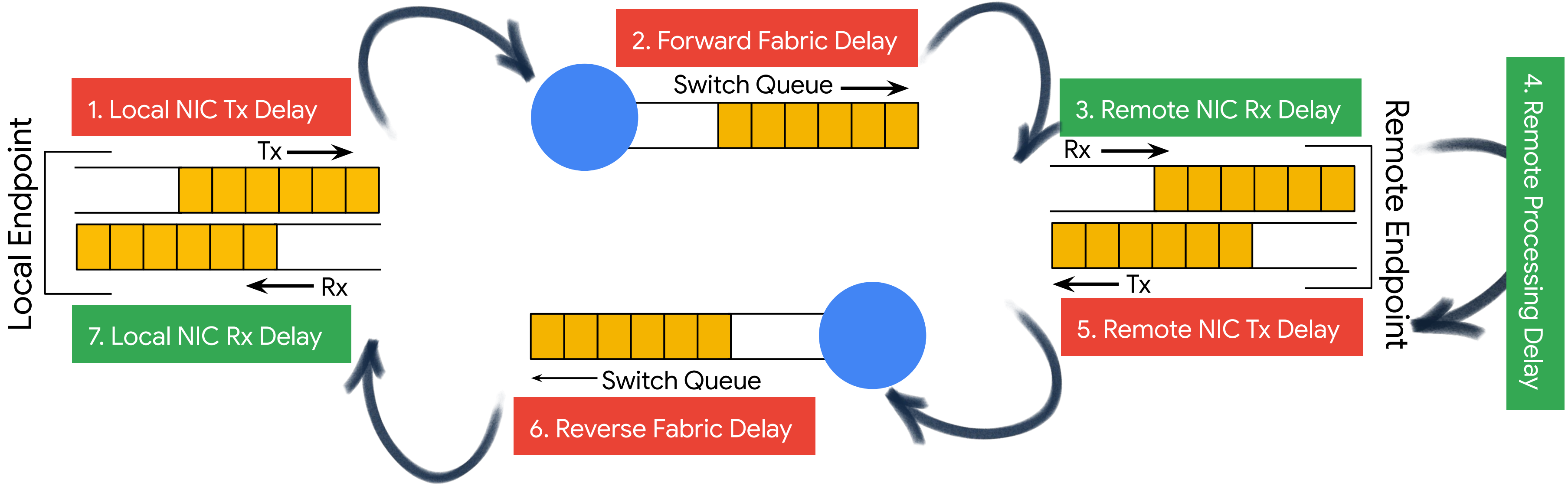
Swift Design

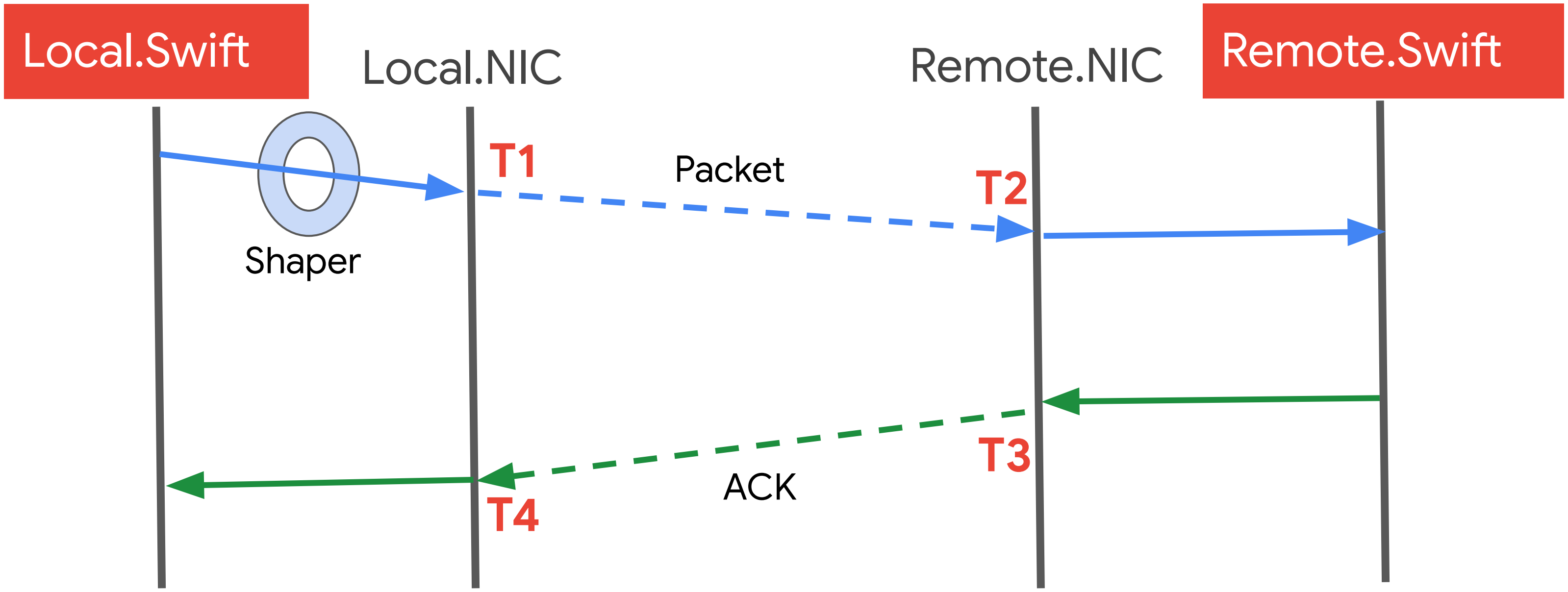
End-to-end delay decomposition of a Packet and its ACK



Swift maintains two congestion-windows (in #packets) - one based on fabric-delay and one based on endpoint-delay with their respective cwnd

Effective cwnd is the **minimum** of the two

Four Key Timestamps



T4-T1	Full round trip delay
(T4-T1)-(T3-T2)	Fabric only round trip delay
T2-T1	Forward fabric delay
T4-T3	Reverse fabric delay

Swift Design contd.

Simple AIMD based on a target-delay

```
if delay < Target
     increase cwnd
   (Additively)
else
     decrease cwnd
   (Multiplicatively)
```

Use of HW and SW timestamps

To provide accurate delay measurements and separate them into fabric and host components

Seamless transition b/w cwnd and rate

Swift allows cwnd to fall below 1 to handle large-scale incast

cwnd < 1 implemented via pacing using Timing Wheel, pacing off when cwnd > 1

Swift Design contd.

Scaling of target-delay

Topology-based scaling (TBS) for RTT-fairness

Flow-based scaling (FBS for fairness)

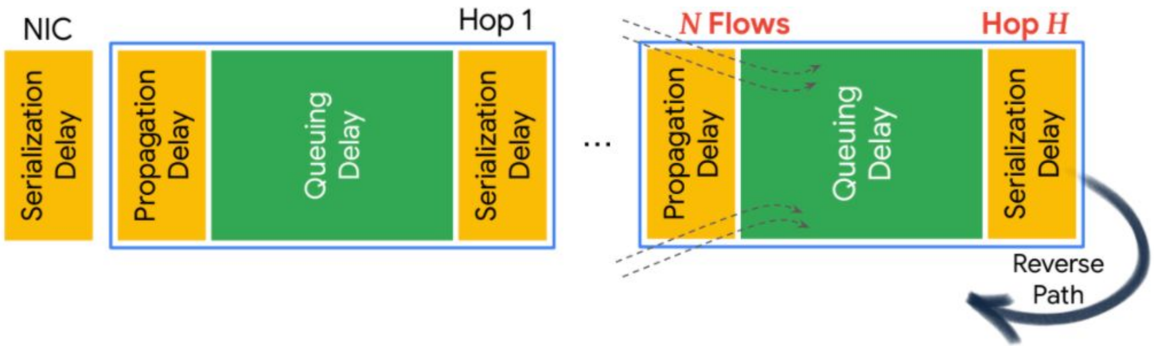
Loss recovery and ACKing policy

Minimal investment in loss-recovery - losses are rare: SACK and RTO.

Coexistence via QoS

Multiple CC in shared deployments, e.g., WAN traffic, Cloud traffic etc.

Subset of QoS queues reserved for Swift



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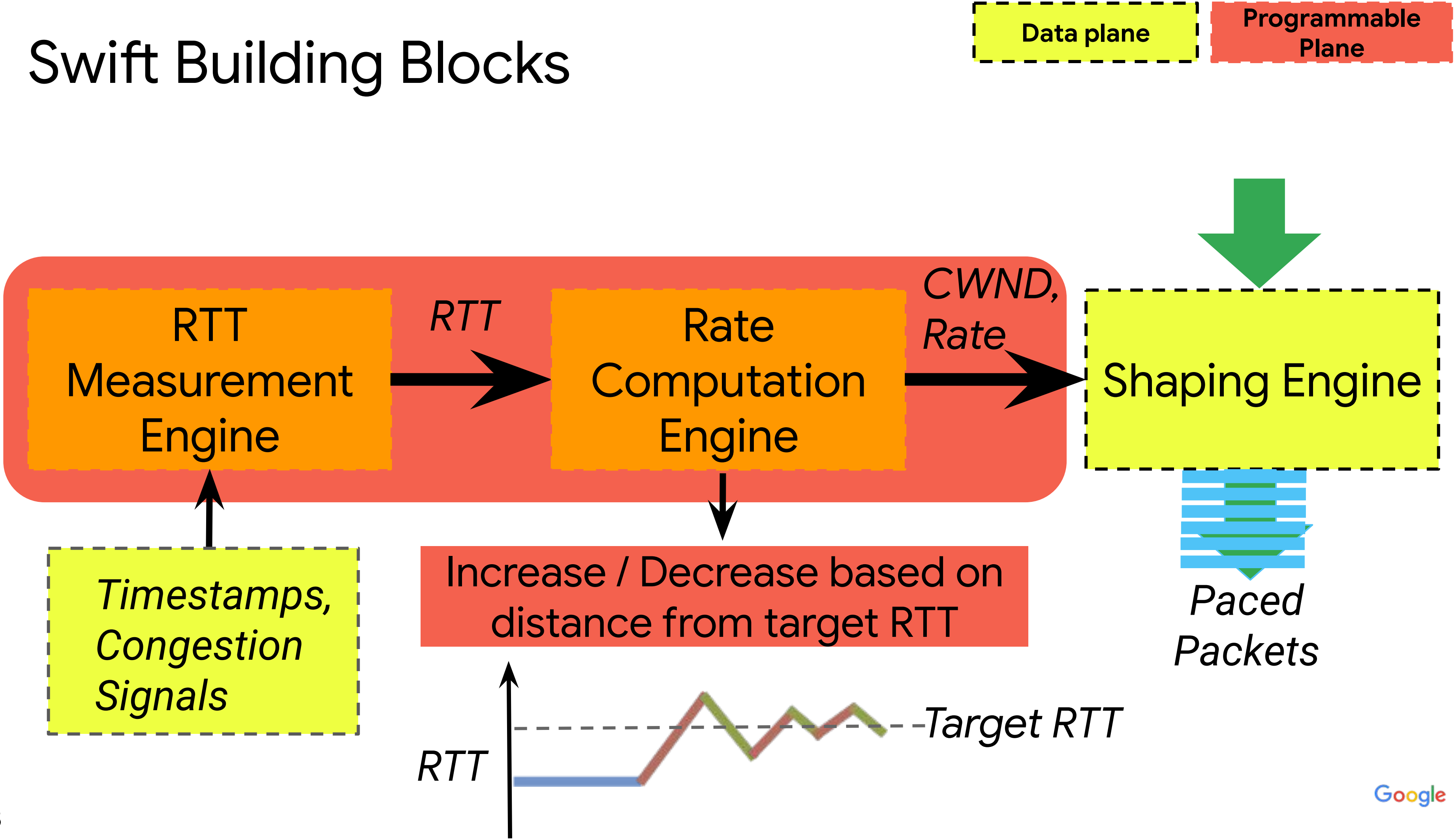
Swift Building Blocks



Using P4 to realize programmability in Transport

Swift Overview

NIC

Connection State

```
struct ConnectionState {
  bit<16> congestion_window;
  bit<32> last_ack_sequence_number;
};

Register<ConnectionState>(2048) state;
```

maximum number of unacknowledged packets in the network

Packet Headers

```
header SwiftAck {
  bit<32> connection_id;
  bit<32> ack_sequence_number;
  // timestamps
  bit<32> t1;
  bit<32> t2;
  bit<32> t3;
  bit<32> t4;
};
```

RTT Measurement &

Rate Computation Engine

(we need this to be programmable)

Is P4 right for this?

We think **yes**.

Fundamentally, P4 transforms:

- a fixed size **input**, into // Packet, Connection State
- a fixed size **output**, using // Connection State
- a fixed amount of **computation** // No loops, recursion, etc

But there are also challenges:

- P4/PSA are targeted to switches (e.g. output is a packet).
  Portable NIC Architecture (PNA) should help [https://github.com/p4lang/pna]
- Hardware isn't quite right (need more registers/ALUs, and fewer TCAMs).
  We need your help.

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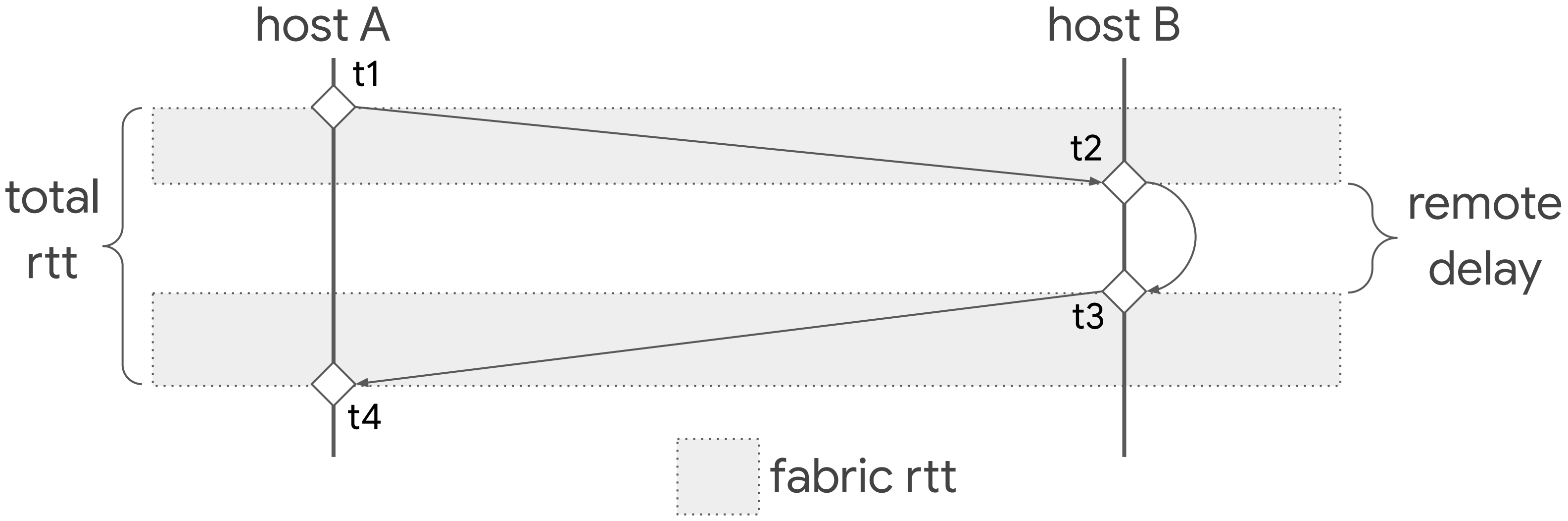
Computing Fabric Round Trip Time




```
bit<32> total_rtt = headers.swift.t4 - headers.swift.t1;
bit<32> remote_delay = headers.swift.t3 - headers.swift.t2;
bit<32> fabric_rtt = total_rtt - remote_delay;
```

Decreasing Congestion Window

Adjust congestion window almost proportionally to rtt, e.g.

fabric rtt = 60μs   current congestion window = 3 packets
target rtt = 40μs   updated congestion window = 2 packets

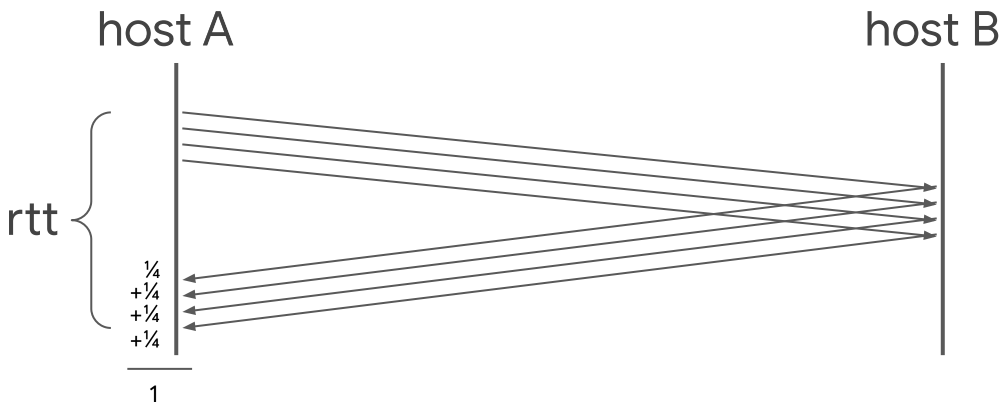
```
if (fabric_rtt > target_delay) {
    bit<32> delay_delta = fabric_rtt - target_delay;
    bit<32> decrease_scale = delay_delta / fabric_rtt;
    bit<32> decrease_factor = 1 - decrease_scale * 0.8;
    connection.congestion_window *= decrease_factor;
}
```

that's why it's just "almost" proportional

Increasing Congestion Window

Increase congestion window by 1 every RTT

e.g. congestion_window = 4, increase by ¼ for every ACK




```
if (fabric_rtt < target_delay) {
    bit<32> num_packets_acked = headers.swift.ack_sequence_number -
                                connection.last_ack_sequence_number;
    connection.last_ack_num = headers.swift.ack_num;
    connection.congestion_window += num_packets_acked / connection.congestion_window;
}
```

Swift-motivated Features and Programmability

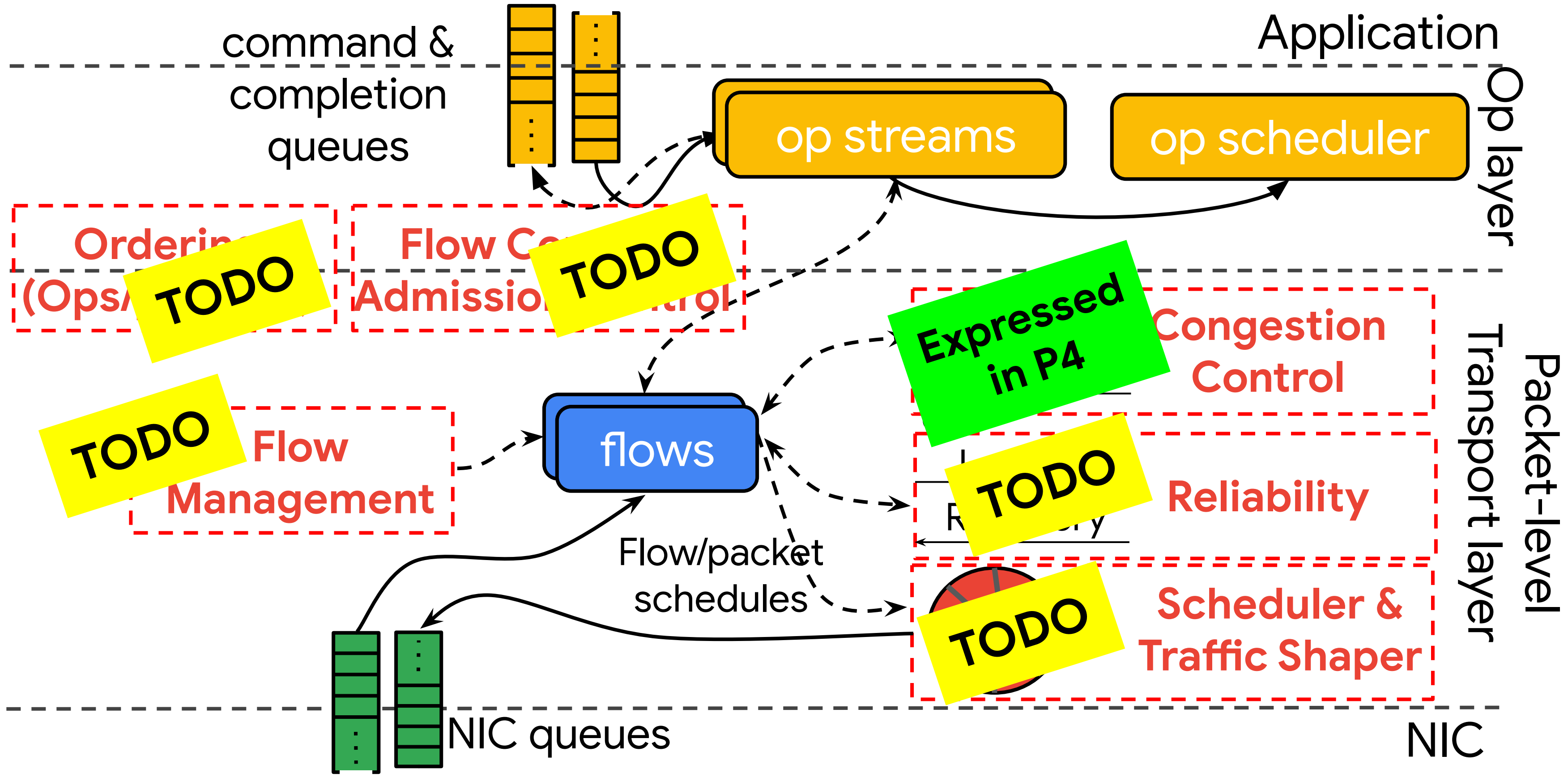
Features:

- Accurate **Tx** `(T1,T3)` and **Rx** `(T2,T4)` timestamps for every packet.
- Availability of `T1,T2,T3,T4` at Senders for LAN and RDMA datapaths.
- Accurate one-way delay (OWD) measurements based on synchronized NIC clocks.

Programmability: delay and rate computations.

- Instantaneous RTT; windowed min-RTT.
- Inference of congestion at end-host vs. fabric, sender vs. receiver.
- Congestion window adaptations based on RTT and OWD.

Takeaways



Future work: Express other building blocks that require programmability in P4 / P4++.

Open problem: Building hardware to run P4-expressed-transport.

Thanks to Many Contributors

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