No Silver Bullet: Extending SDN to the Data Plane

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CSAIL

The Data Plane is continuously evolving.

- New scheduling and queue management algorithms are proposed every year.
- Each wins in its own evaluation under its own workloads.
- There is a tacit belief in a final answer to these questions.

Yet, there is no silver bullet.

Different applications care about different things.

- Interactive video conferencing apps need both high throughput & low delay.
- Bulk transfers care only about high throughput.
- Web browsers care about flow completion time (FCT).

Applications run different transport protocols.

- Some respond to loss, e.g., TCP Cubic, TCP NewReno.
- Others respond to packet inter-arrival times, e.g., WebRTC, LEDBAT.
- Others respond to per-packet delay, e.g., TCP Vegas.
- Yet others respond to both delay and packet loss, e.g., Compound TCP.

Applications run in diverse network conditions.

- High-speed, low-latency, Data Center networks
- Low-speed, high-latency, transcontinental links
- High-speed, high-variability, bufferbloated LTE links

Applications have cyclic preferences

Workloads:

- *Bulk*:
  - Traffic: A single long-running TCP NewReno stream.
  - Objective: Maximize average throughput.
- *Web*:
  - Traffic: A single on-off TCP NewReno stream.
  - Objective: Minimize flow completion time at the 99.9th percentile.
- *Interactive*:
  - Traffic: A single long-running TCP NewReno stream.
  - Objective: Maximize the ratio of average throughput and average round-trip delay ("power").

In-network schemes:

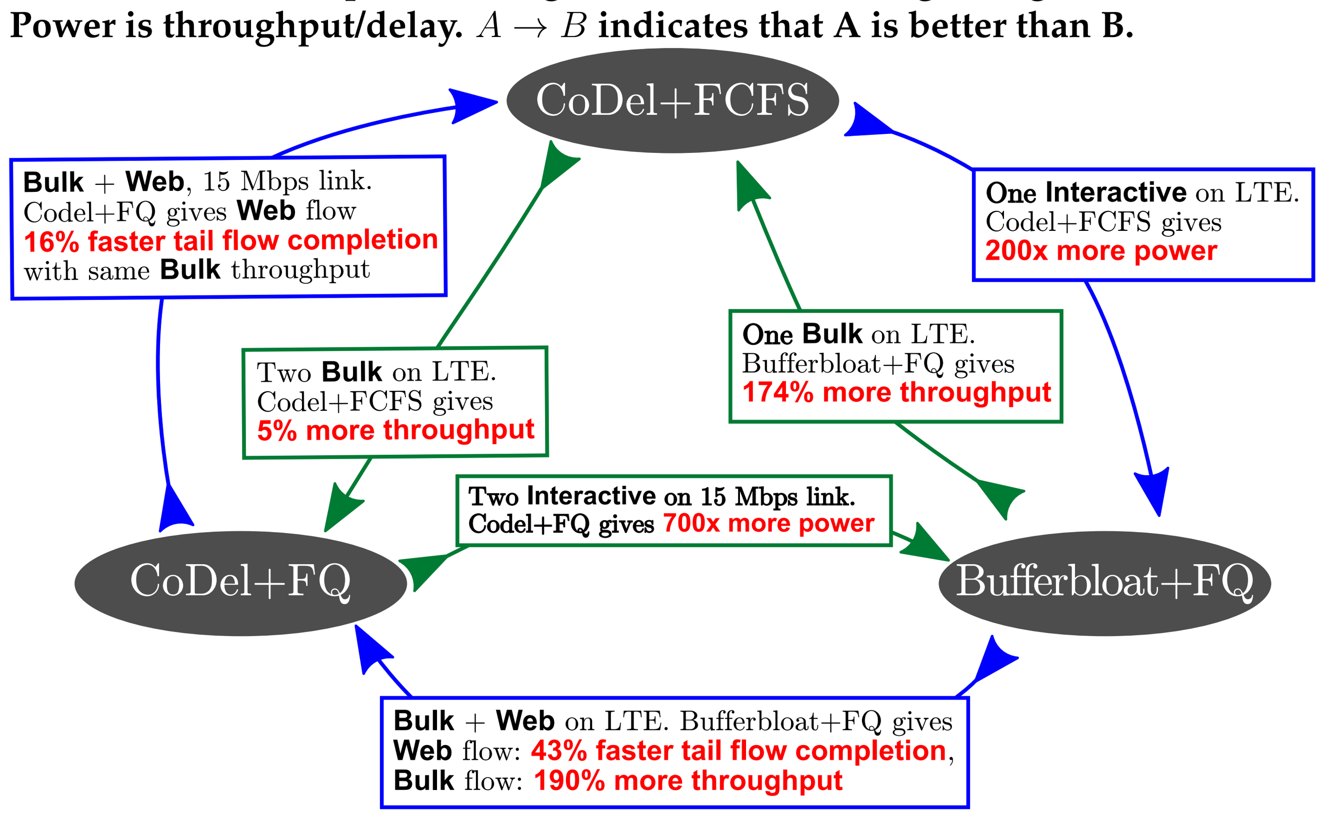
A) CoDel+FCFS:
- Queue management: CoDel
- Scheduling: FCFS

B) CoDel+FQ:
- Queue management: CoDel
- Scheduling: Fair Queuing

C) Bufferbloat+FQ:
- Queue management: Don't drop any packets
- Scheduling: Fair Queuing

Visualizing cyclic preferences

None of the below queue-management and scheduling configurations is best. Power is throughput/delay. $A \rightarrow B$ indicates that A is better than B.



Key Findings

- Dropping packets on a variable link results in substantial throughput loss.
  - Reason: There is an inherent delay-throughput tradeoff, unlike static links.
- FCFS is preferable to Fair Queuing in some cases.
  - Reason: When competeing flows are equally aggressive, they don't need protection from each other.
- Fair Queuing is required in some cases.
  - Reason: When competing flows are not equally aggressive, they need isolation from each other.
- Dropping packets hurts Flow Completion Time.
  - Reason: Packet drops occur near the end of a flow, preventing DUP ACKs.

The Solution:

Make the data plane more flexible.

- There will never be one conclusive queueing and scheduling scheme.
- Application demands on the network will continue to evolve.
- Networks supporting these application will evolve as well.
- The Data Plane should support new queueing and scheduling schemes.
- Not the same as just picking between multiple existing schemes.

But, do so in a controlled manner.

- Disallow arbitrary programs from running on the switch.
- Allow the network operator to determine only queuing and scheduling.

A blueprint for a flexible data plane

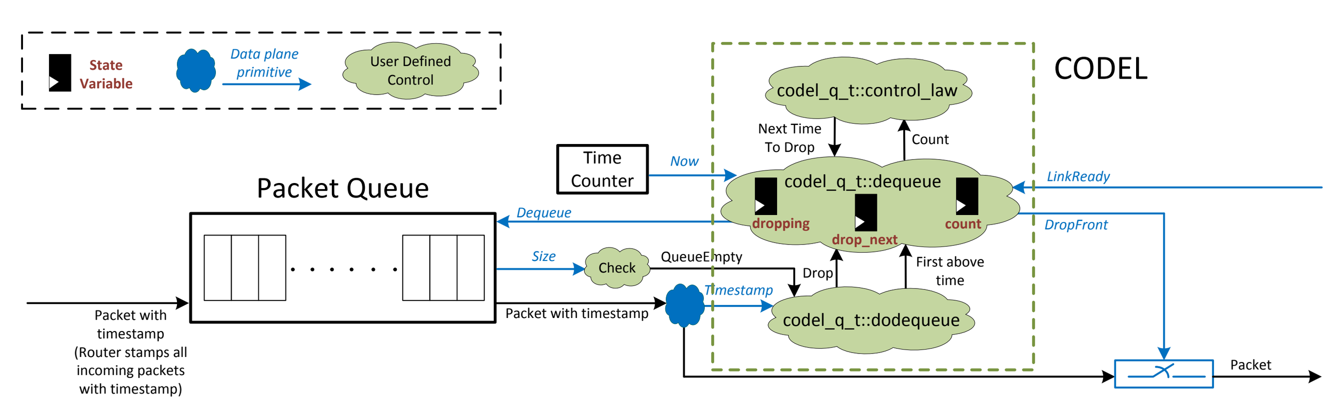
- Standardized interfaces to the rest of the switch

Class of primitive	Primitive Name	Description
Utilities	*Now*	Get current time.
Queue primitives	*Size*	Get queue length.
Queue primitives	*DropFront*	Drop packet from head of queue.
Queue primitives	*DropTail*	Drop packet from tail of queue.
Queue primitives	*Enqueue*	Enqueue packet at tail of queue.
Queue primitives	*Dequeue*	Dequeue packet from head of queue.
Queue primitives	*Transmit*	Transmit single packet.
Signaling primitives	*LinkReady*	Link is ready to accept packet.
Signaling primitives	*Arrival*	New packet just arrived.
Packet primitives	*Timestamp*	Packet's arrival timestamp.
Packet primitives	*Mark*	Set ECN bit.
Cross-layer primitives	*LinkRates*	Get current link rate.

- Designate a portion of the switch for reconfigurable logic.
- Hard resource limits on the amount of reconfigurable logic.
- Express queuing/scheduling logic as code in a high-level language.

Example implementation: CoDel

- CoDel implementation in SystemVerilog.
- Synthesized into gate-level netlist using Xilinx's freely available Vivado WebPacket compiler.
- Block diagram of implementation:



- CoDel resource utilization on Xilinx Kintex-7

Resource	Usage	Fraction of FPGA
Slice logic	1,257	2%
Slice logic dist.	1,969	4%
IO/GTX ports	27	6%
DSP slices	0	0%
Maximum speed	12.9×10^6 pkts/s	N/A

Limitations

- Cannot express several important network functions:
  - "Deep packet" inspection
  - Intrusion detection
  - Spam Filtering
- Mechanism for signaling application objectives to the network.
  - Could use DiffServ codepoints.
  - But ASes generally don't honor codepoints from other ASes.
  - May be a non-issue inside a Data Center.
- Most switches today have a shared pipeline with more demanding requirements.
  - Top-of-the-line switches have 64 ports, each running at 10G.
  - Implies that queueing/scheduling logic should run at 64*10G.
  - If queue management is enqueue-based, e.g., RED, this problem cannot be fixed by replicating digital logic on each port.
- Mechanism to map flows onto per-port queues is required for scheduling.
  - Also need to decide on the number of such queues.
- Interoperability
  - Across switch vendors.
  - Across FPGA vendors.