ENABLING TCP PACING USING PROGRAMMABLE DATA PLANE SWITCHES

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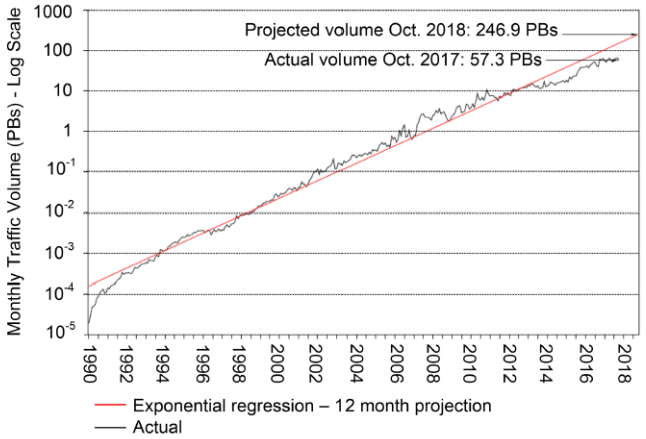
Agenda

- Motivation, Science DMZs
- Pacing
- Programmable switches
- Proposed scheme
- Preliminary results
- Ongoing work

Motivation for a High-Speed Science Architecture

- Science and engineering applications are now generating data at an unprecedented rate
- Instruments produce hundreds of terabytes in short periods of time
- Data must be typically transferred across **high-throughput high-latency** Wide Area Networks (WANs)

Applications

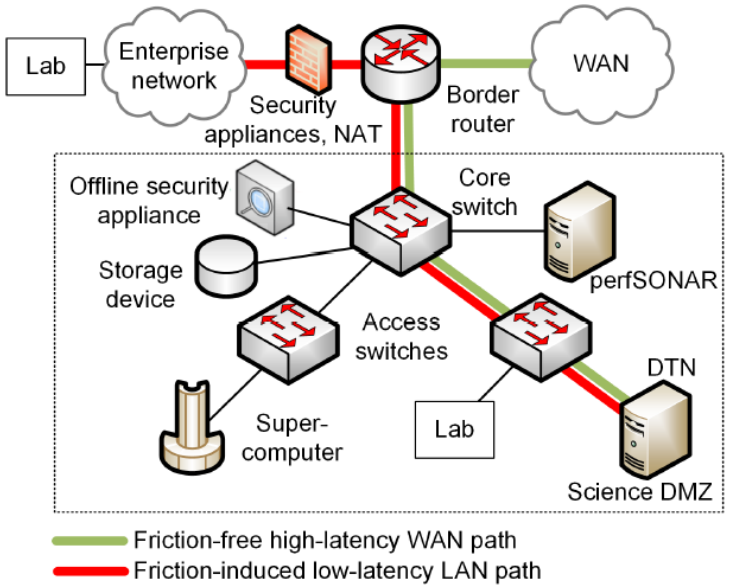


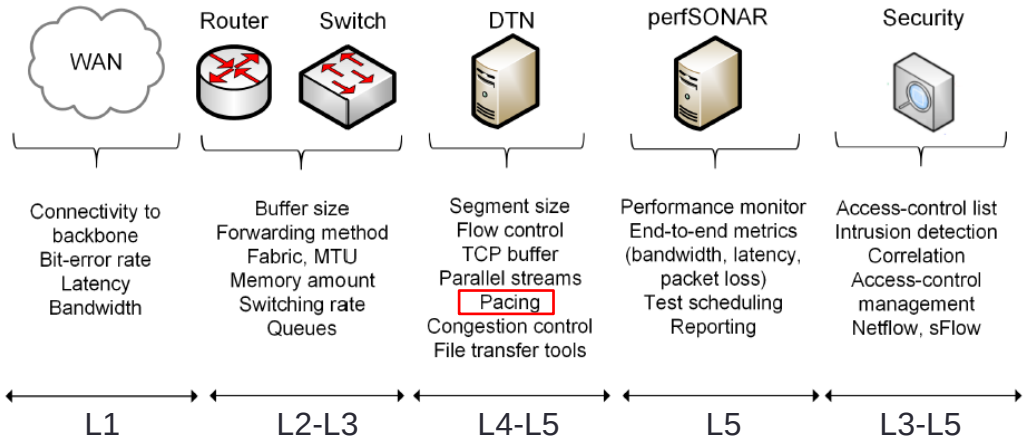
ESnet traffic

The Energy Science Network (ESnet) is the backbone connecting U.S. national laboratories and research centers

Motivation for a High-Speed Science Architecture

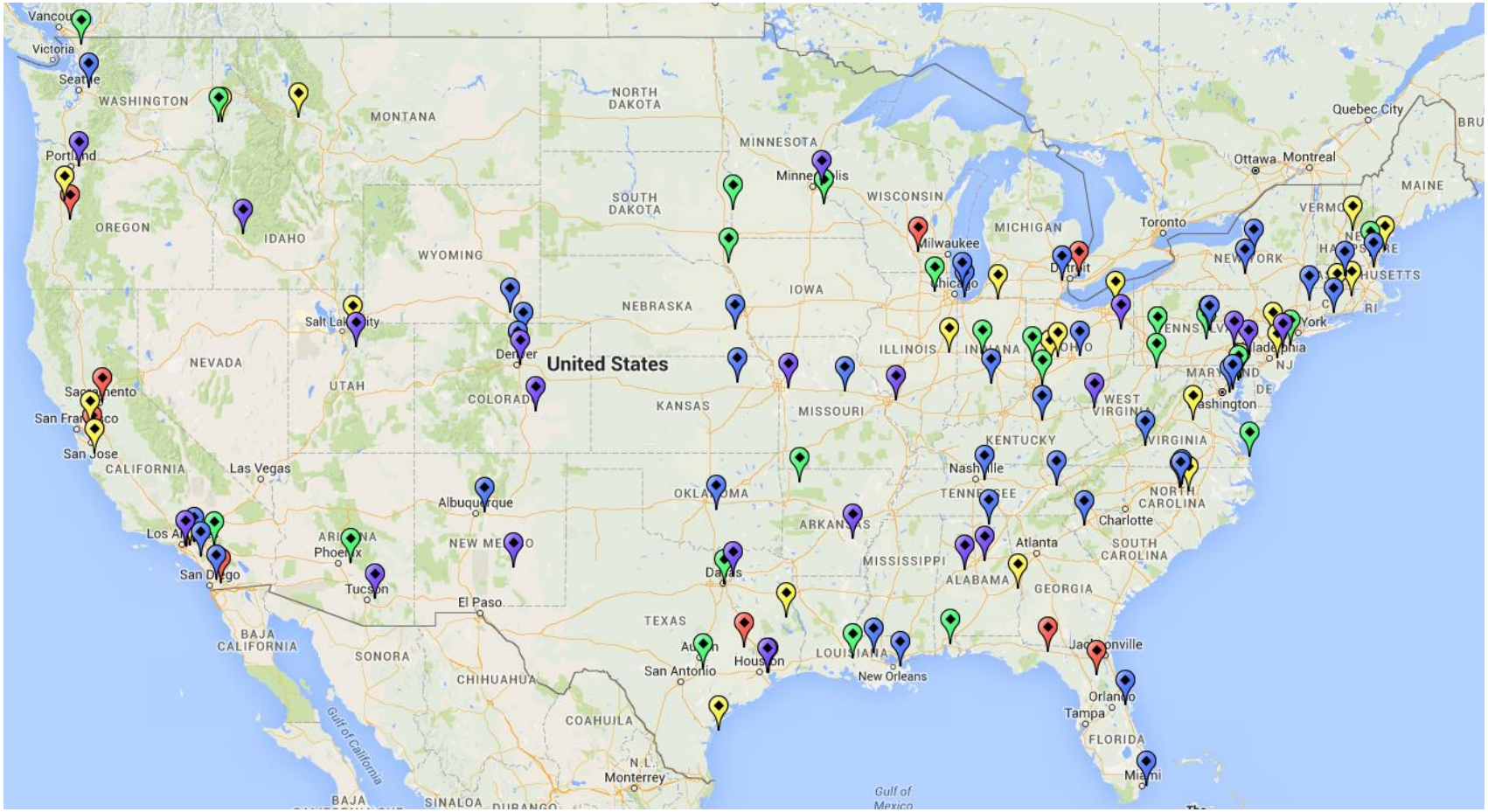
- The Science DMZ is a network designed for big science data
- Main elements
  - High throughput, friction free WAN paths
  - Data Transfer Nodes (DTNs)
  - End-to-end monitoring = perfSONAR
  - Security tailored for high speeds





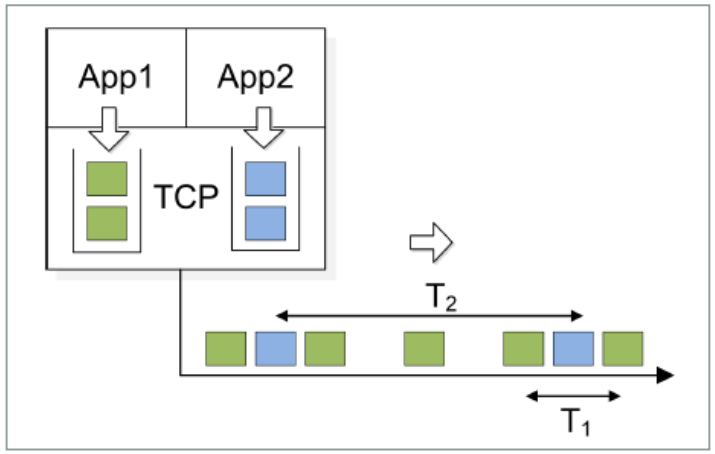
Motivation for a High-Speed Science Architecture

- Science DMZ deployments, U.S.



Pacing

- Pacing is a technique by which a transmitter evenly spaces or paces packets at a pre-configured rate
- If the network bottleneck is known, end devices can be set to transfer at a pacing rate rather than ‘discovering’ the rate
- Pacing also helps to mitigate packet bursts

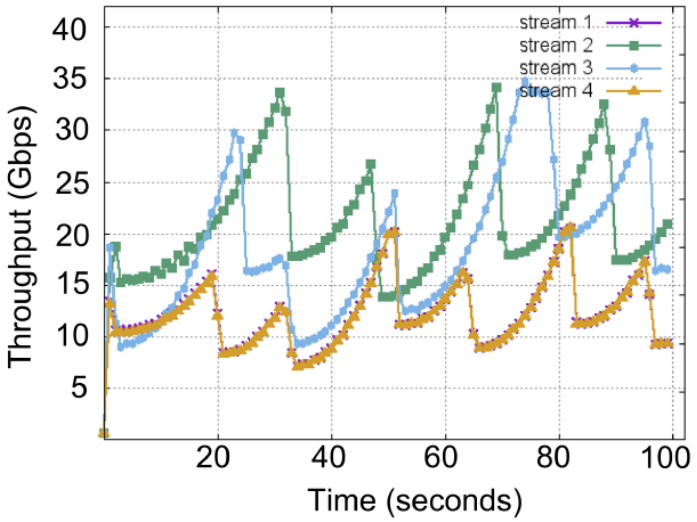


Pacing

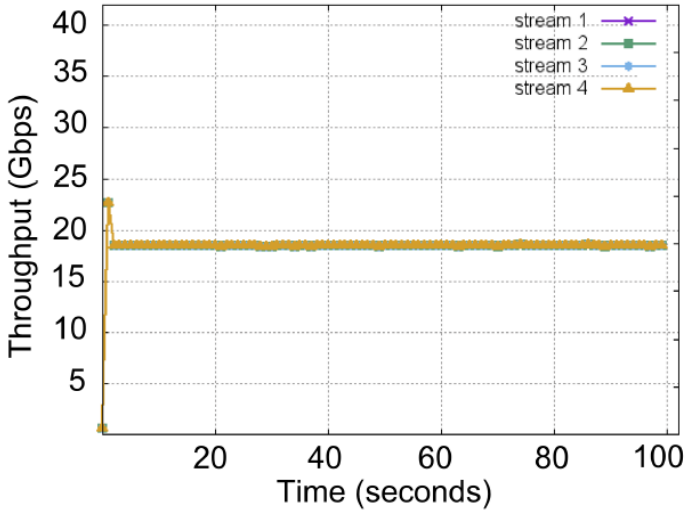
Consider tests over ESnet backbone[1]

Four flows on a 100 Gbps network, 92 msec RTT

- "Consistent loss on the network with four streams, no pacing…"
- "Pacing to match bottleneck link works better yet…"
- ESnet approach requires the network operator to statically set the pacing rate, based on the number of big flows



(a)



(b)

1. https://meetings.internet2.edu/media/medialibrary/2016/10/24/20160927-tierney-improving-performance-40G-100G-data-transfer-nodes.pdf

Programmable Switches

- P4 is a programming language for switches
- P4 permits operators/developers to program the data plane

  Add proprietary features: invent, *develop custom protocols*
- USC partnered with Barefoot Networks to use Tofino's chip to develop custom protocols

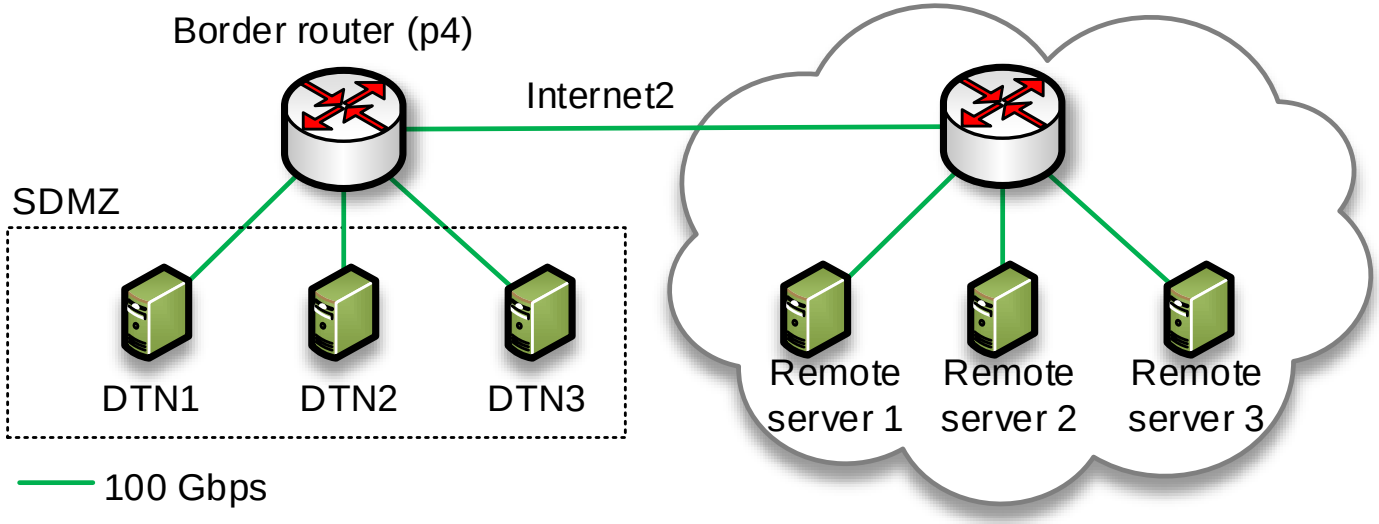
```
136  /*************************************************************************
137  ***********************  P A R S E R  ***********************************
138  *************************************************************************/
139
140      state parse_ethernet {
141          packet.extract(hdr.ethernet);
142          transition select(hdr.ethernet.etherType) {
143              TYPE_IPV4: parse_ipv4;
144              default: accept;
145          }
146      }
147
148      state parse_ipv4 {
149          packet.extract(hdr.ipv4);
150          verify(hdr.ipv4.ihl >= 5, error.IPHeaderTooShort);
151          transition select(hdr.ipv4.ihl) {
152              5             : accept;
153              default       : parse_ipv4_option;
154          }
155      }
```

P4 code

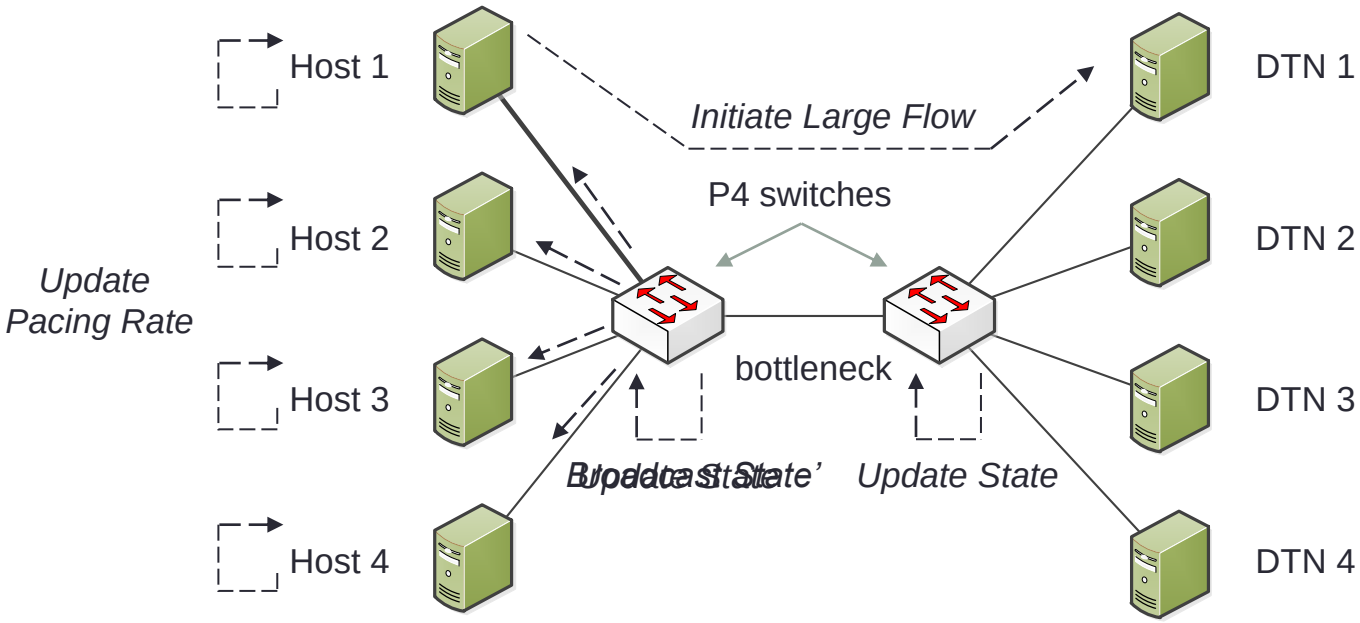
Barefoot's Tofino (2016)

Pacing using Programmable Switches

- What if the rate at a sender node is adjusted based on feedback provided by a P4 switch?
- Feedback includes number of large flows and more

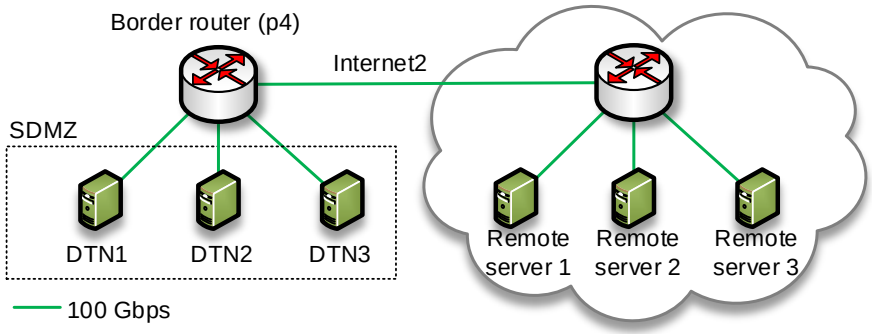


Pacing using Programmable Switches

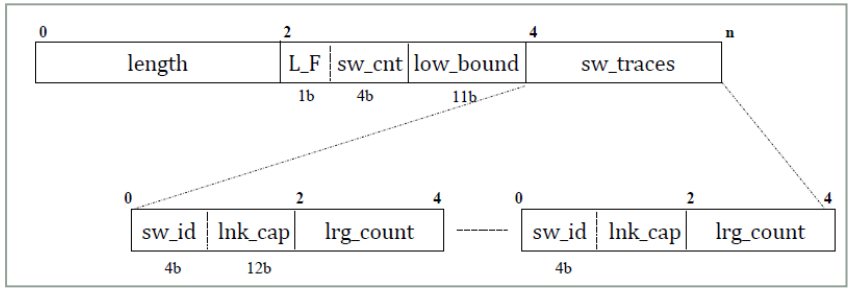


Pacing using Programmable Switches

- Switches store network's state (number of large flows)
- To initiate a large flow, a DTN inserts a custom header during the TCP 3-way handshake, using the IP options field
- Switches parse custom header, update number of large flows
- Number of large flows is returned in the SYN-ACK message, and sent to all DTNs. DTNs update their *pacing* rate



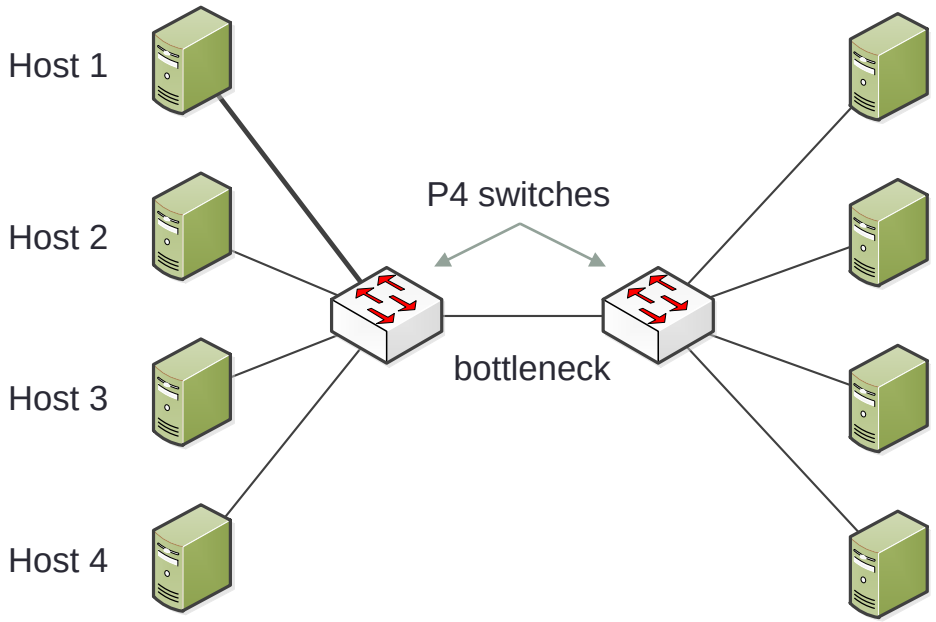
Sample topology



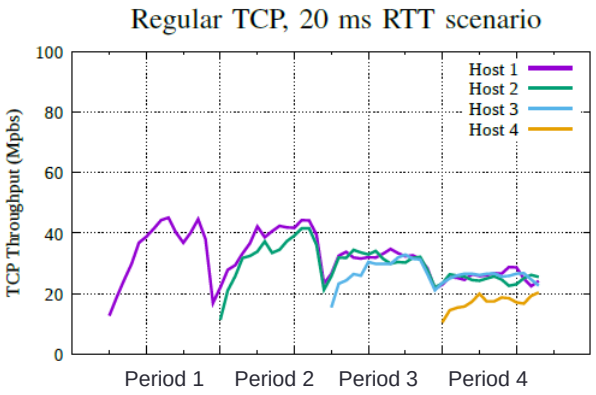
Custom protocol built using IP options field

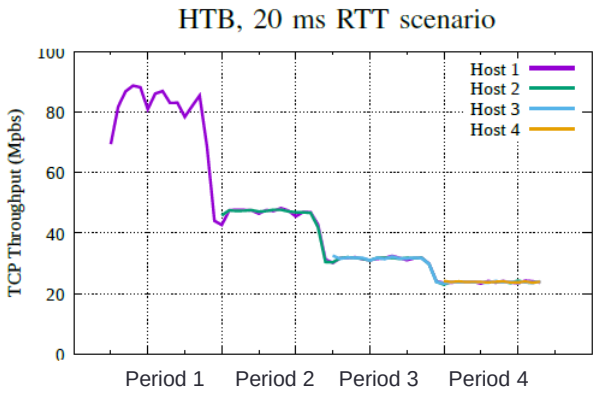
Emulation Results

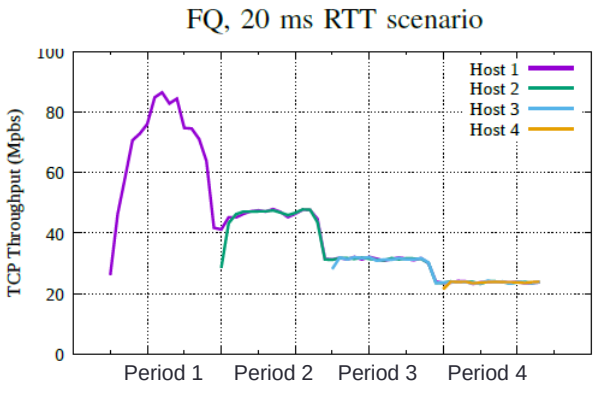
- The custom protocol was implemented in Mininet
- The P4 switch is the BMv2 from P4.org
- Four hosts (DTNs) generating flows; 100 Mbps, 20ms RTT
- Hosts adjusted their pacing rate using two pacing disciplines
  - Fair Queue (FQ)
  - Hierarchical Token Bucket (HTB)



Emulation Results







Throughput

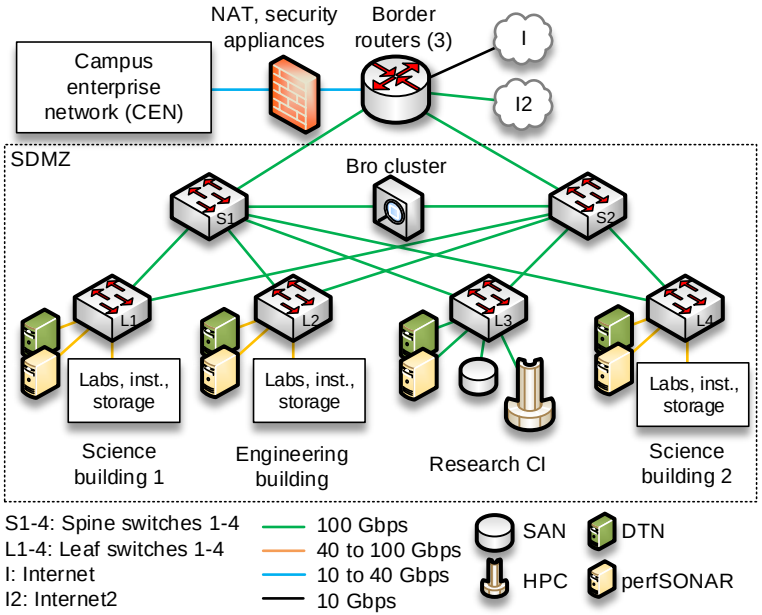
	Regular TCP					HTB					FQ				
Period	$\sum T_i$	T_1	T_2	T_3	T_4	$\sum T_i$	T_1	T_2	T_3	T_4	$\sum T_i$	T_1	T_2	T_3	T_4
P_1 (01-15 sec)	**33.62**	33.62	N/A	N/A	N/A	**81.25**	81.25	N/A	N/A	N/A	**66.59**	66.59	N/A	N/A	N/A
P_2 (16-30 sec)	**67.27**	36.06	31.21	N/A	N/A	**93.1**	46.40	46.70	N/A	N/A	**89.91**	45.85	44.06	N/A	N/A
P_3 (31-45 sec)	**88.83**	31.27	30.61	26.95	N/A	**94.42**	31.40	31.37	31.65	N/A	**93.72**	31.40	31.36	30.96	N/A
P_4 (46-60 sec)	**91.86**	25.32	24.63	25.32	16.59	**95.12**	23.78	23.75	23.73	23.86	**94.52**	23.71	23.71	23.67	23.43

Coefficient of variation and Jain's fairness

	Regular TCP					HTB					FQ				
Period	**F**	**CV_1**	**CV_2**	**CV_3**	**CV_4**	**F**	**CV_1**	**CV_2**	**CV_3**	**CV_4**	**F**	**CV_1**	**CV_2**	**CV_3**	**CV_4**
P_1 (01-15 sec)	1.00	32.32	N/A	N/A	N/A	1.0000	8.188	N/A	N/A	N/A	1.0000	28.427	N/A	N/A	N/A
P_2 (16-30 sec)	.994	22.63	30.08	N/A	N/A	.99998	3.773	2.998	N/A	N/A	.99960	4.351	14.142	N/A	N/A
P_3 (31-45 sec)	.994	9.349	10.90	19.69	N/A	.99998	2.065	2.081	1.985	N/A	.99960	1.618	1.317	3.879	N/A
P_4 (46-60 sec)	.974	7.806	5.260	6.447	17.27	.99999	1.168	1.138	.755	.684	.99997	1.022	1.020	.996	3.336

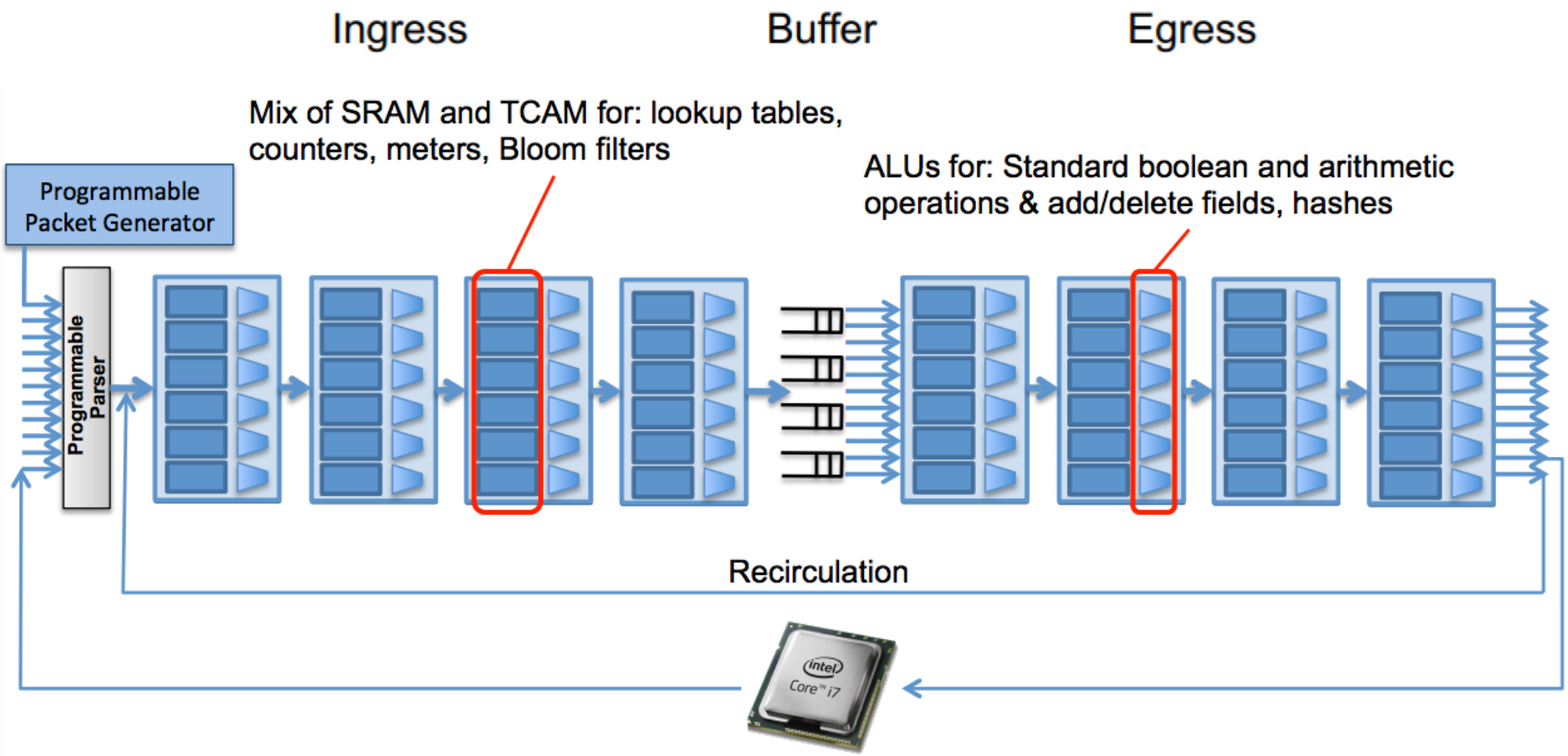
Ongoing Work

- Implement proposed protocol using real P4 switches
- Extend the protocol to support general cases
- Extend the sharing bandwidth scheme for scenarios where an uneven allocation is desirable (priorities)
- Use proposed protocol in USC's production network



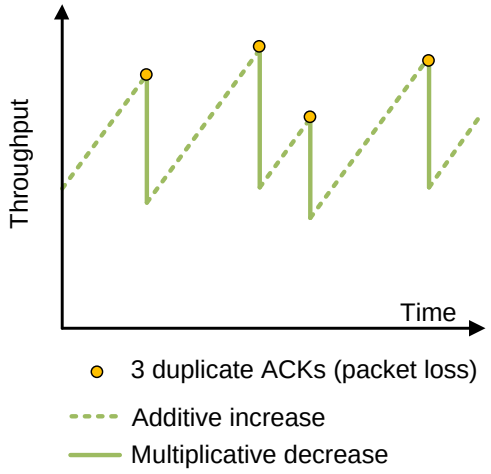
Additional Slides

PISA Architecture



Pacing

- Packet loss is expensive in high-throughput high-latency networks



Sawtooth behavior

Internet2

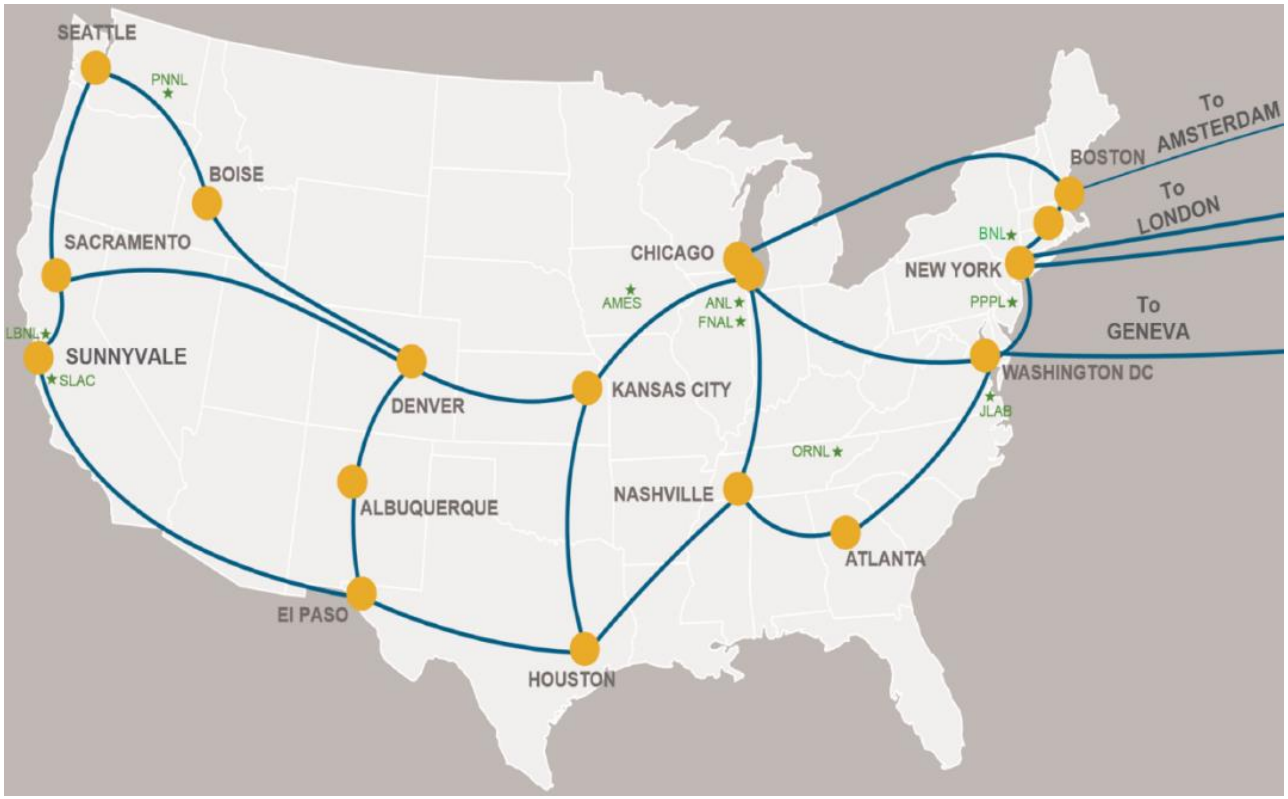
$$\text{TCP throughput} = \frac{c \cdot MSS}{RTT \cdot \sqrt{p}}$$

MSS: maximum segment size
RTT: round-trip time
p: loss rate
c: constant

(c) Average throughput

M. Mathis, J. Semke, J. Mahdavi, T. Ott, "The macroscopic behavior of the tcp congestion avoidance algorithm," *ACM Computer Communication Review*, vol. 27, no 3, pp. 67-82, Jul. 1997.

ESnet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