eecs589

ADVANCED COMPUTER NETWORKS

[R+11] Raiciu et al., "Improving Datacenter Performance and Robustness with Multipath TCP," *Proc. of ACM SIGCOMM '11*, 41(4):266-277, Aug. 2011

Data Transport in Datacenter

Clos data center network provides multiple paths between pairs of ToR switches

Randomized load balancing cannot achieve full bisection bandwidth: flows collide with high probability

Centralized flow scheduler can only run periodically, due to monitoring and schedule computation and instantiation overhead ⇒ works well only for large flows and only if flows are network, not host or NIC, limited

Consequently, flows manage only 10% of potential throughput and total network utilization is < 50%

Multipath TCP (MPTCP)

Balance load by path selection and congestion control:

- explore multiple paths simultaneously
- link congestion response of subflows on different paths
- move traffic away from congested links

MPTCP opens multiple subflows (TCP connections) per application-level connection:

- subflows can be differentiated by port numbers or by assigning source and/or destination host multiple IP addresses
- number of subflows negotiated in the initial SYN exchange
- subflows are assigned paths by ECMP
- data delivery is striped across subflows

Multipath TCP (MPTCP)

Each MPTCP subflow has its own sequence space and maintains its own congestion window (`cwnd`)

- on receiving an ACK, a subflow r increases its `cwnd` by a function of total `cwnd` size across all subflows: $\mathrm{MIN}(a/w_{total}, 1/w_r)$, a an "aggressiveness" constant
- on loss, a subflow halves its own `cwnd` only: $w_r /= 2$
- as a result, MPTCP moves traffic away from congested paths

Use of MPTCP is transparent to the app

Evaluation

Uses two kinds of simulation: packet-level and flow-level, numerical analysis to model throughput as a function of loss rate

On Fat-tree, VL2, and BCube topologies

VL2: a Clos network, like Fat-tree, but with order of magnitude higher core link bandwidth and randomized (ECMP) routing instead of static routing

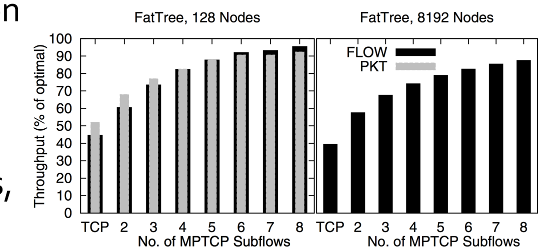
BCube: a hypercube with servers connecting ethernet pods

Traffic Workload

Permutation matrix: each host is paired with a random host in a 1-1 mapping

Each flow is bulk-transfer with infinite data?

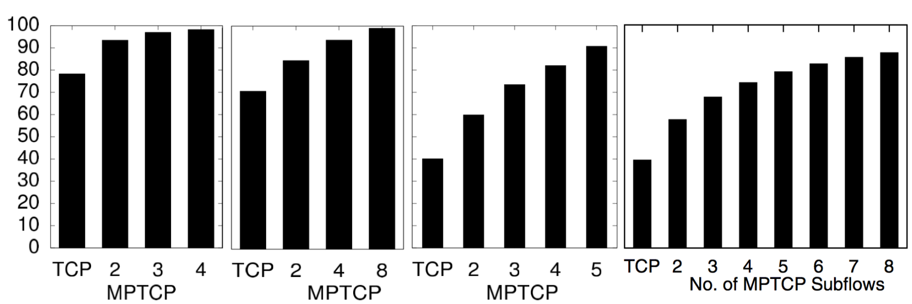
Flow-level simulation can simulate larger networks but is less accurate, does not model loss timeouts, for example



Also studied many-to-one (incast) matrix, not studied: all-to-all matrix

Link Rate and Statistical Multiplexing

VL2's higher capacity core links allow for better statistical multiplexing than the smaller core links of BCube/Fat-tree



(a) VL2(11520) 1:10 Gbps

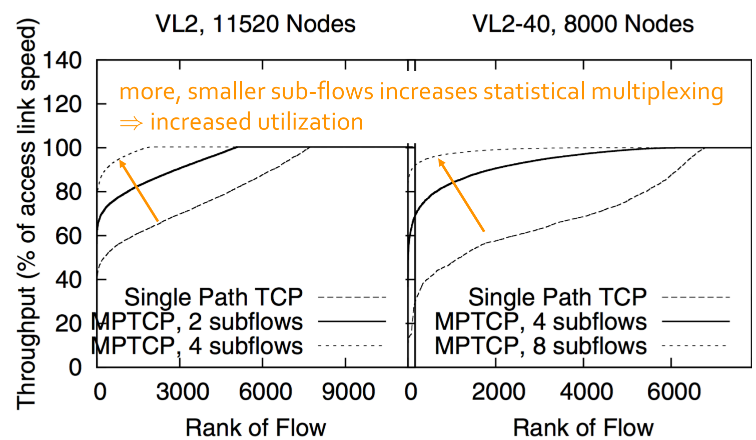
(b) VL2-40(8K) 10:40 Gbps

(c) BCube4,4(1K)

(d) Fat-tree(8K) 100 Mbps links

Flow Size and Statistical Multiplexing

To increase statistical multiplexing, and utilization, on small links, need larger number of smaller flows (each routed to a different core link)



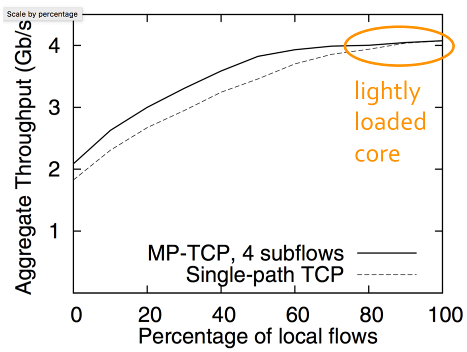
Locality and Oversubscription

Full bisectional bandwidth: nonsensical goal?

- no app constantly sends at full-interface rate
- rack locality further reduces bisectional traffic

Allow for core oversubscription of potential load

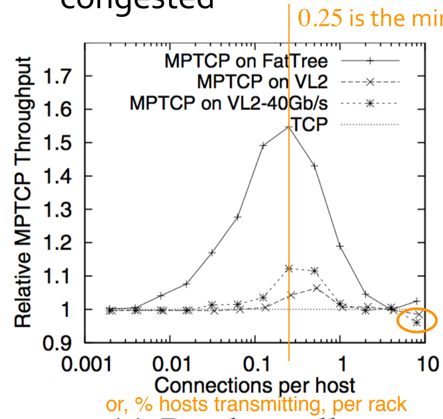
512-node Fat-tree with 4:1 oversubscription, 1 connection per host, local flows: random destination in the same rack as source



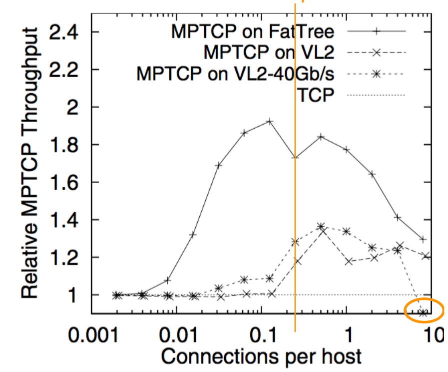
Throughput and Oversubscription

Random traffic matrix: contention on access links

MPTCP increases throughput when core links are congested



(c) Random, all

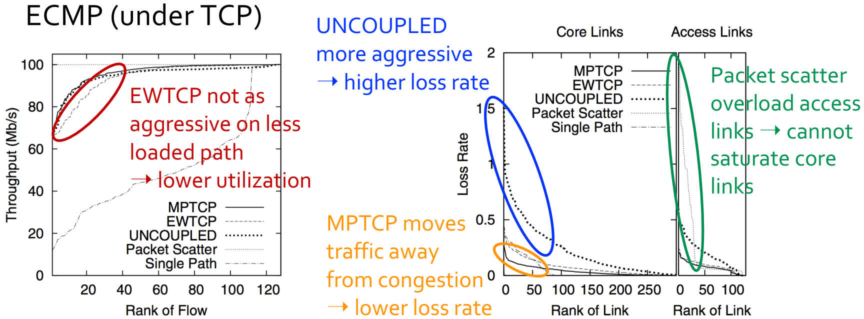


(d) Random, slowest 25%

Which Part of MPTCP Is Effective?

Multipathing improves performance, even when `cwnd` is not linked, but obtains different loss rates

- UNCOUPLED: data striped across multiple TCP connections
- Equal-weighted: smaller increase if more subflows, but doesn't move traffic away from congestion
- Packet scatter/spraying: per-packet, instead of per-flow, ECMP (under TCP)



Short-Flows' Finish Times

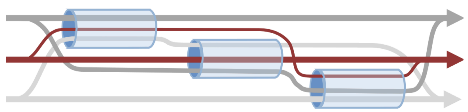
Packet scatter/spray (under TCP) has lowest FCT, but attains low utilization because long flows back off due to transient congestion caused by short flows

Algorithm	Short Flow Finish Time (mean/stdev)	Network Core Utilization
SINGLE-PATH TCP	78 ±108 ms	25%
PACKETSCATTER	42 ± 63 ms	30%
EWTCP	80 ± 89 ms	57%
MPTCP	97 ± 106 ms	62%
UNCOUPLED	152 ± 158 ms	65%

Self Interference

For multi-sender applications, if there are multiple paths with different lengths, EWTCP and Packet scatter can cause long-path flows, with multiple congested links, to congest short-path flows

MPTCP concentrates traffic on short paths, moving it away from long congested ones



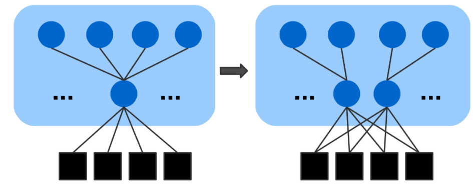
SINGLE-PATH	297 Mb/s
EWTCP	229 Mb/s
MPTCP	272 Mb/s
PACKETSCATTER	115 Mb/s

Dual-homed Fat-tree

Realistic traffic does not fill full-bisection bandwidth

- can oversubscribe core links, or
- if bottleneck is at host NICs: most hosts have 2 NICs, connect both to ToR switches, reduce ToR to aggregation switch connectivities

ToR switch redundancy also helps eliminate the biggest single cause of correlated node failures

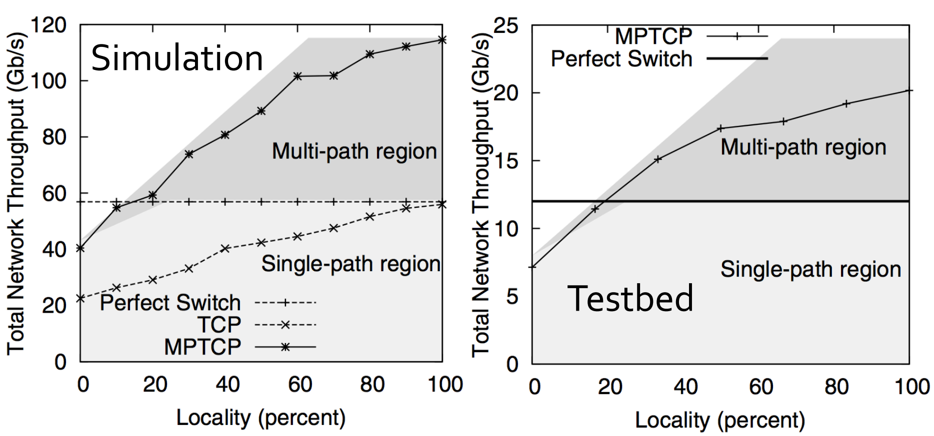


Single-path TCP cannot take advantage of this topology

Dual-homed Fat-tree

Some apps can take advantage of rack locality

Some flows are host limited



On Amazon EC2

Doesn't know topology or background traffic

Hosts are virtual machines, may share a physical host

65% of flows have 2 (50%), 3 (25%), up to 9 alternate paths

For these, MPTCP with 4 subflows achieves 3x the throughput of single-path TCP