Minimizing Flow Completion Times in Data Centers

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User Facing Online Services

- Online services becoming extremely popular
  - e.g., web search, social networking, advertisement systems

Key goal: Minimize user response time!

Why response time matters?

Every 100ms latency costs 1% in business revenue
[Speed matters, G. Lindan]

Traffic reduced by 20% due to 500ms increase in latency
[M. Mayer at Web 2.0]

An extra 400ms reduced traffic by 9%
[YSlow 2.0, S. Stefanov]

Impacts user experience & operator revenue

Challenges in Data Centers

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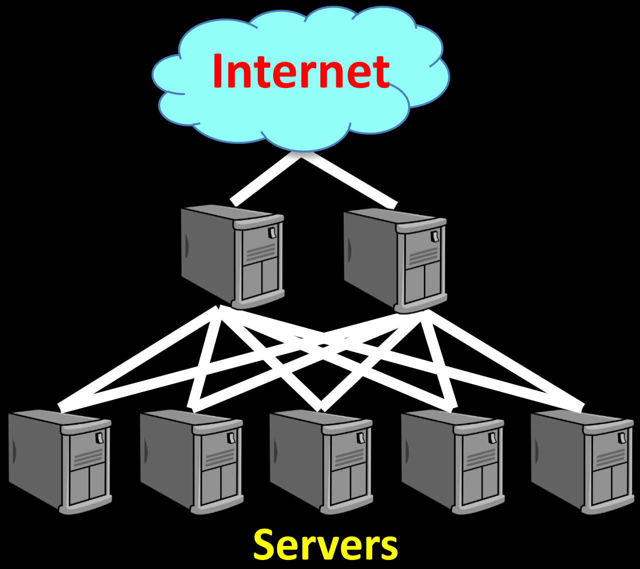
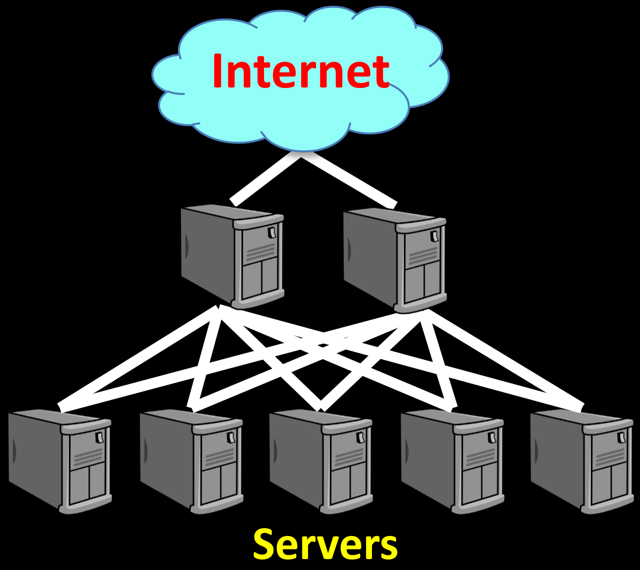
- Partition/Aggregate Structure
  - Leads to synchronized responses



Challenges in Data Centers



- Partition/Aggregate Structure
  - Leads to synchronized responses
- Traffic workloads
  - Short flows (Query) 
    - Delay-sensitive
  - Long flows (Data Update) 
    - Throughput-sensitive

Challenges in Data Centers

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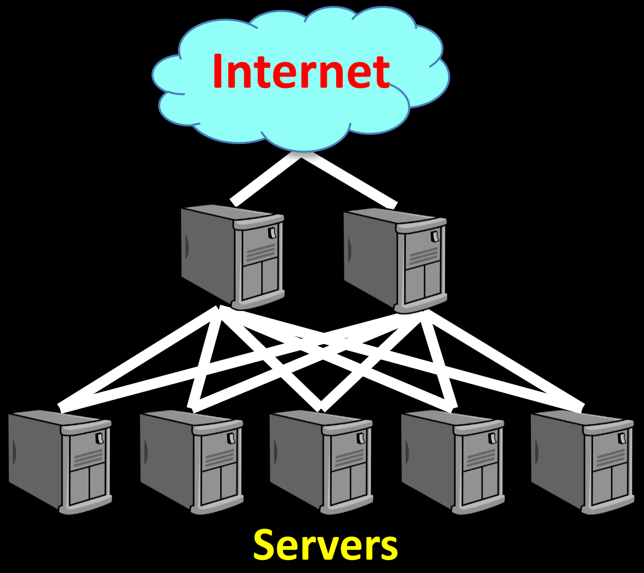
  - Leads to synchronized responses



- Traffic workloads
  - Short flows (Query)
    - Delay-sensitive

  - Long flows (Data Update)
    - Throughput-sensitive

- TCP does not meet the demands of applications
  - Requires large queues for achieving high throughput
    - Adds significant latency

This paper proposes..

- L^2DCT (Low Latency Data Center Transport)
  - A data center transport protocol that targets minimizing average flow completion times (AFCT)
  - Uses insights from scheduling theory
- L^2DCT reduces AFCT by 50% over DCTCP & 95% over TCP
  - Improves tail latency (99^{th} percentile) by 37% over DCTCP
  - Requires no changes in switch hardware or applications
  - Can co-exist with TCP and is incrementally deployable

Outline

- Background
- L^2DCT Design
- Evaluation
  - At-Scale Simulations
  - Small-Scale Real Implementation
- Related Work and Conclusion

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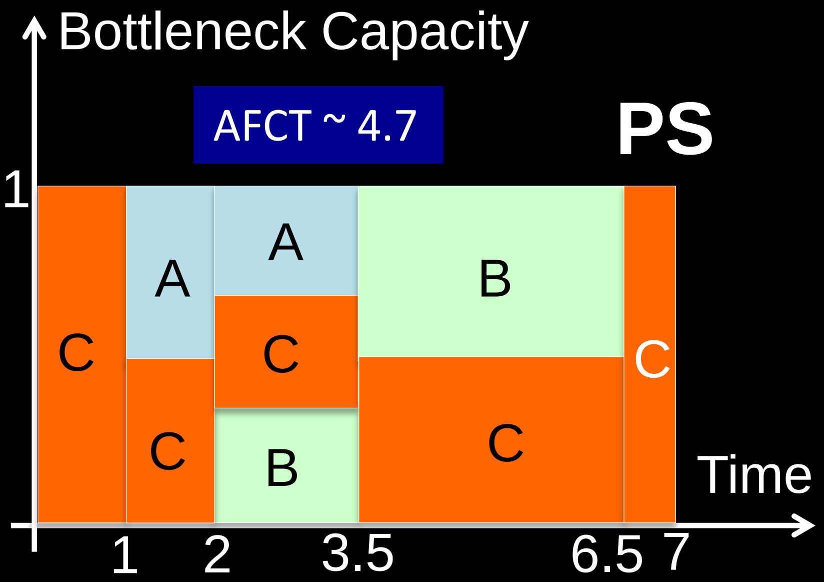
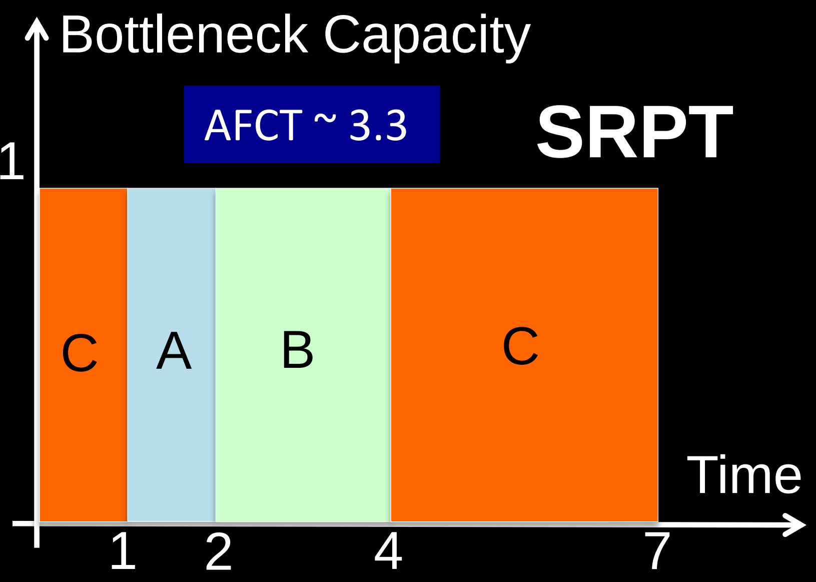
Background

- Shortest Remaining Processing Time (SRPT) is known to be optimal for minimizing AFCT [Schrage, OR'68]
  - Always process the job with least remaining work
- Brings significant improvements in completion times over Processor Sharing (PS) [Bansal et al., SIGMETRICS' 01]
  - Especially if jobs follow a heavy-tailed distribution
  - Shown to hold in data centers environments [Alizadeh et al., SIGCOMM'10, Greenberg et al., SIGCOMM'09]

Example

Flow ID	Size	Start Time
A	1	1
B	2	2
C	4	0





SRPT improves over PS (in this case) by ~30%

SRPT Challenges

- Requires knowledge of flow sizes
- A centralized scheduler
- Deployment challenges

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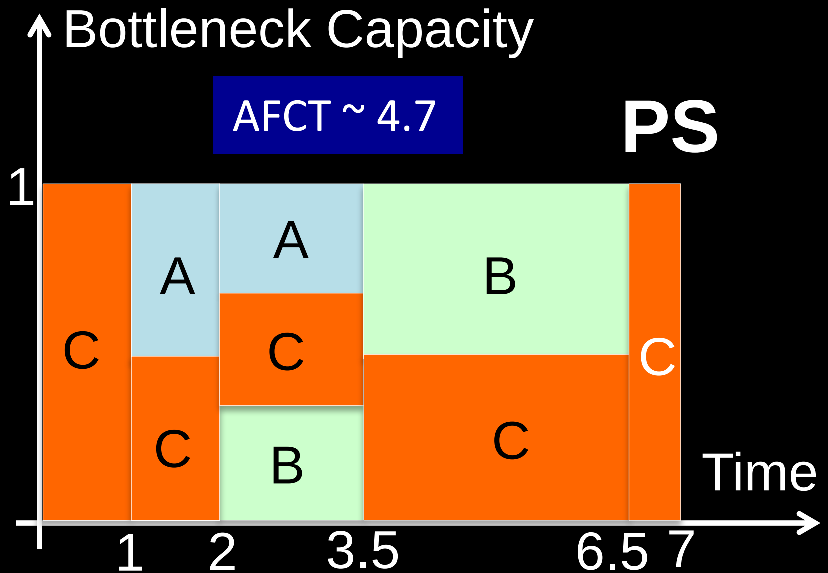
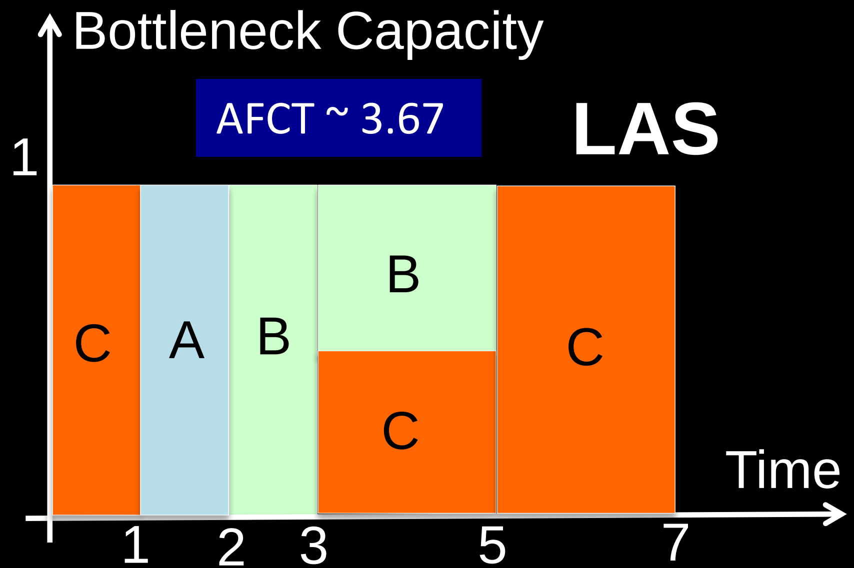
SRPT Challenges

- Requires knowledge of flow sizes
  - Use LAS (Least Attained Service) scheduling
    - Uses the data sent so so far for scheduling
    - Closely approximates SRPT for heavy-tailed distributions
- A centralized scheduler
- Deployment challenges

LAS vs PS

Flow ID	Size	Start Time
A	1	1
B	2	2
C	4	0





LAS improves over PS (in this case) by ~22%

SRPT Challenges

- Requires knowledge of flow sizes
- A centralized scheduler
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SRPT Challenges

- Requires knowledge of flow sizes
- A centralized scheduler
  - Incorporate LAS in distributed congestion control protocol
- Deployment challenges

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SRPT Challenges

- Requires knowledge of flow sizes
- A centralized scheduler
- Deployment challenges
  - The designed protocol should not require changes in switches or applications
  - It should be able to co-exist with TCP

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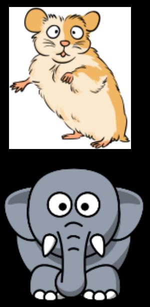
L^2DCT addresses these challenges

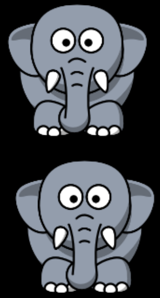
- Uses LAS
  - Flows modulate window sizes based on priority (data sent so far) and network congestion
  - Does not require flow size information
- Requires no changes in applications or switches
- Can co-exist with TCP

Goals

- Long flows should allow a greater short term share of the bandwidth to short flows



- When only long flows are present, they should be able to achieve high throughput and not be penalized any more than TCP



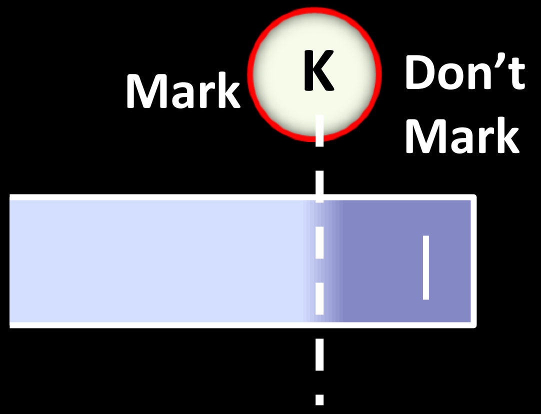
- When congestion becomes severe, all flows should converge to applying full backoff, similar to TCP, to prevent congestion collapse

L^2DCT Sender

- Flows adapt AIMD parameters based on
  - Priorities: captured by w_c = f(data sent so far)
  - Network congestion: captured by the alpha parameter
- L^2DCT meets the desirable goals by dynamically adapting the AIMD parameters

Marking at the Switches

- Queue length based marking



  - Similar to DCTCP [Alizadeh et al., SIGCOMM'10]

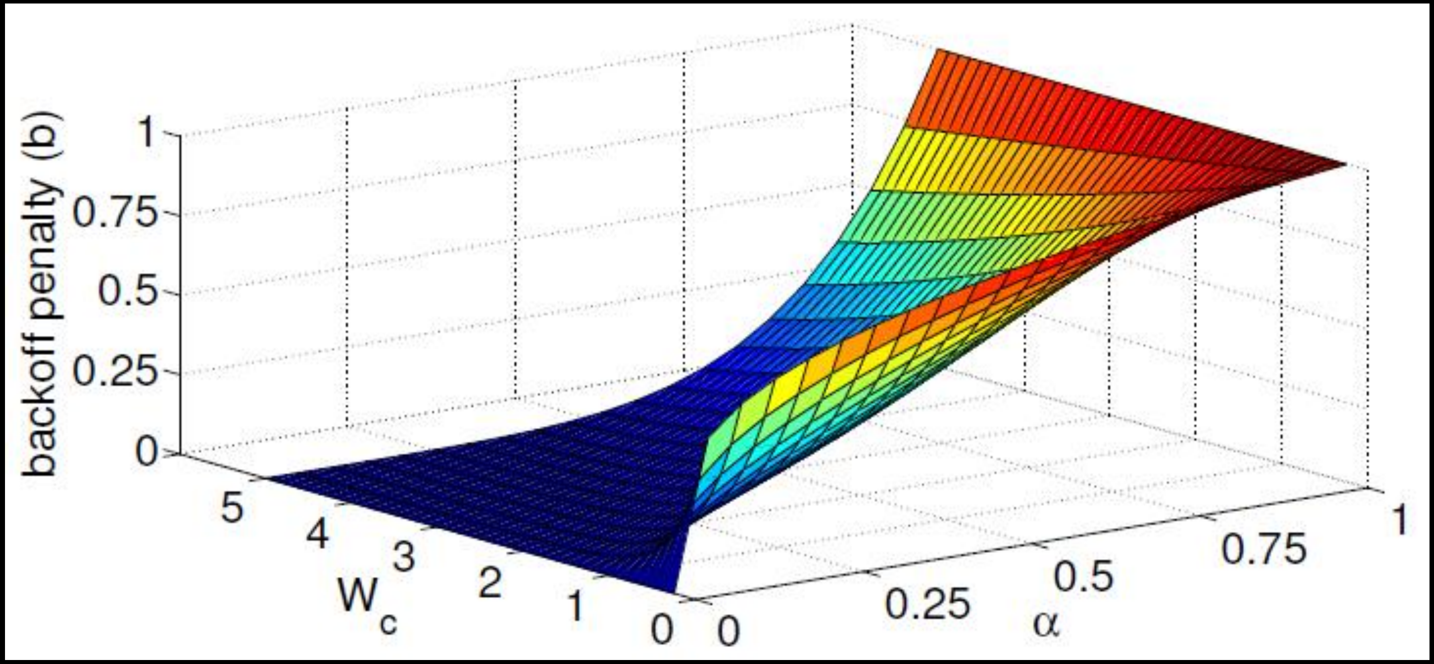
- Senders compute the fraction of marked packets F

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

- Allows senders to react the extent of congestion

Decrease Rule

- Decrease: cwnd = cwnd x (1-b/2), where b= α^{w_c}



- Small increase in congestion causes long flows ($0<w_c<1$) to backoff more than short flows
  - But no more than TCP when congestion becomes severe

Increase Rule

- Increase: cwnd = cwnd + k, where $k=w_c/w_{max}$
  - New flows set $w_c = w_{max}$
  - Short flows start with k=1 and as flow progresses w_c decreases causing k to decrease

- Helps short flows to attain a greater short term share of bandwidth

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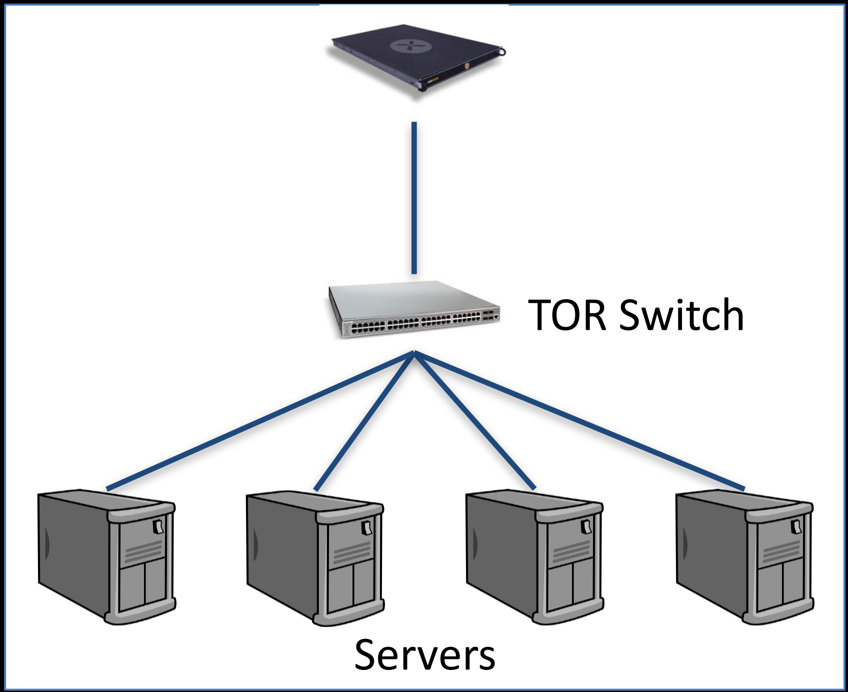
At-Scale Simulations

- Implemented L^2DCT in ns2
  - Comparison with TCP SACK, DCTCP, and D^2TCP

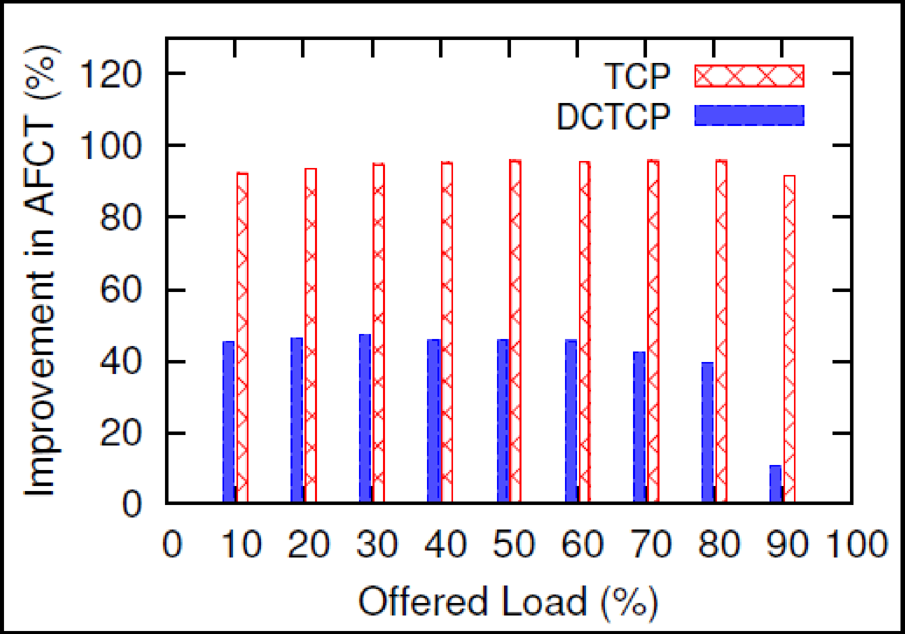
- Basic Topology: Single-rooted tree
- 1Gbps interfaces
- Round-trip delay: 300us
- Buffer Size: 250KB



Evaluation Scenarios

- Data center specific scenarios
  - Incast, Benchmark settings, Pareto distributed traffic
    - Impact of number of senders, flow size
- L^{2}DCT evaluation as a congestion control protocol
  - Single and multiple bottleneck scenarios, effect of sudden short flow bursts, impact of the weight function
- Deadline constrained flows
- Co-existence with TCP
- Realizing other scheduling policies with L^{2}DCT

AFCT Improvement



Settings:

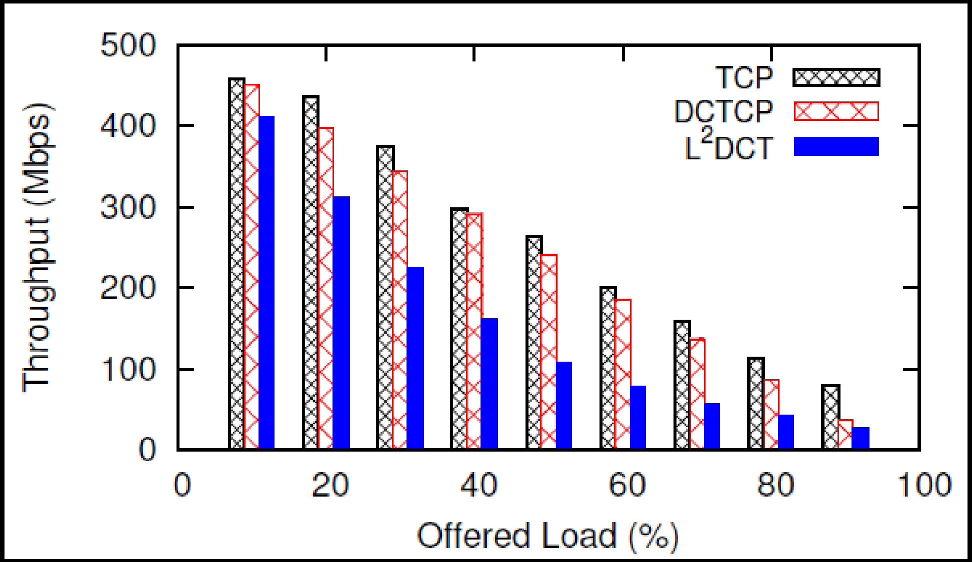
- Short Query Traffic: Uniformly distributed in [2KB, 98KB]

- Two Long-Lived Flows

  - 75th percentile of concurrent large flows [Alizadeh et al., SIGCOMM'10]

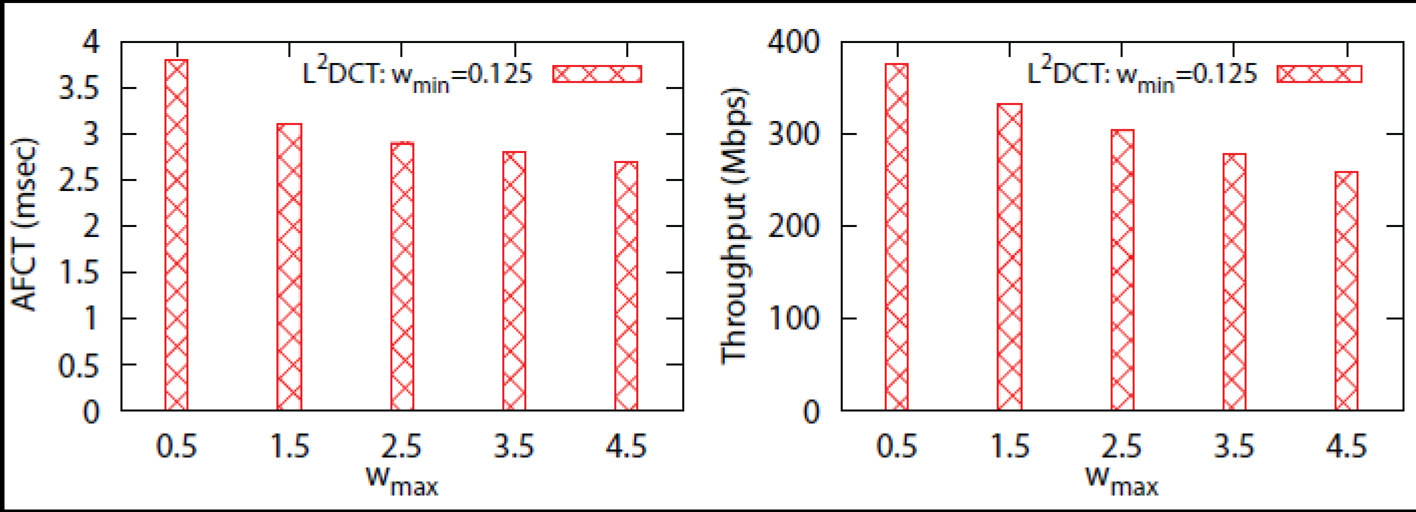
- At least 85% improvement in AFCT over TCP and at least 35% (for up to 80% load) over DCTCP
- 99th percentile of completion time improves by 37% over DCTCP
  - Similar results with Pareto distributed flow sizes

Impact on the Throughput of Long Flows



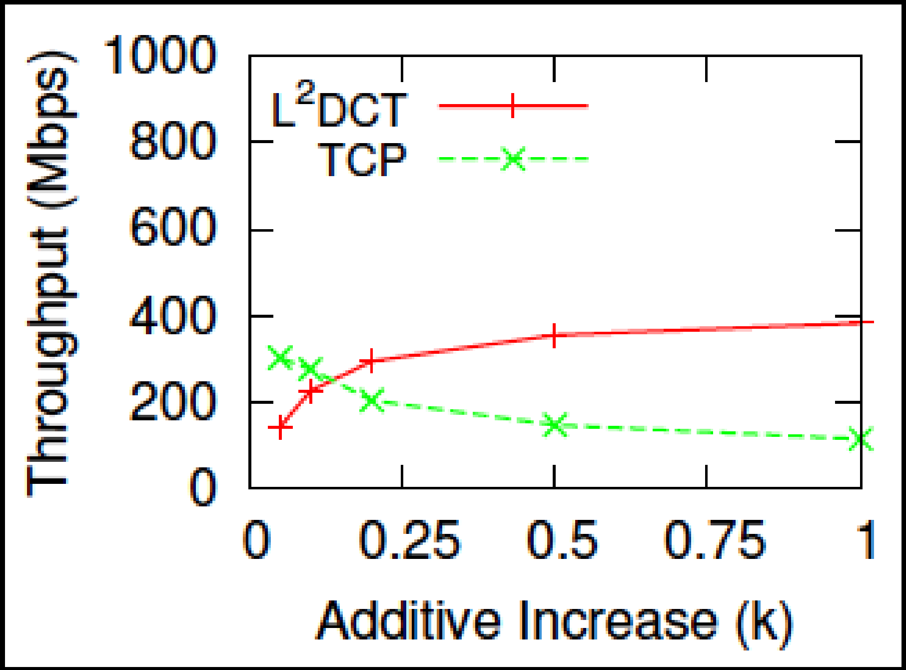
- At low load, throughput difference is small
- At high loads, more short flows arrive per sec, which increases the difference in throughput
- Different throughput/completion time tradeoff can be achieved by adjusting the cap on w_c

Impact of adjusting the cap on w_c



- As w_{max} increases, short flows become more aggressive
  - Leads to improvement in AFCT of short flows but also reduces the throughput of long flows
- Impact of changing w_{min} is similar

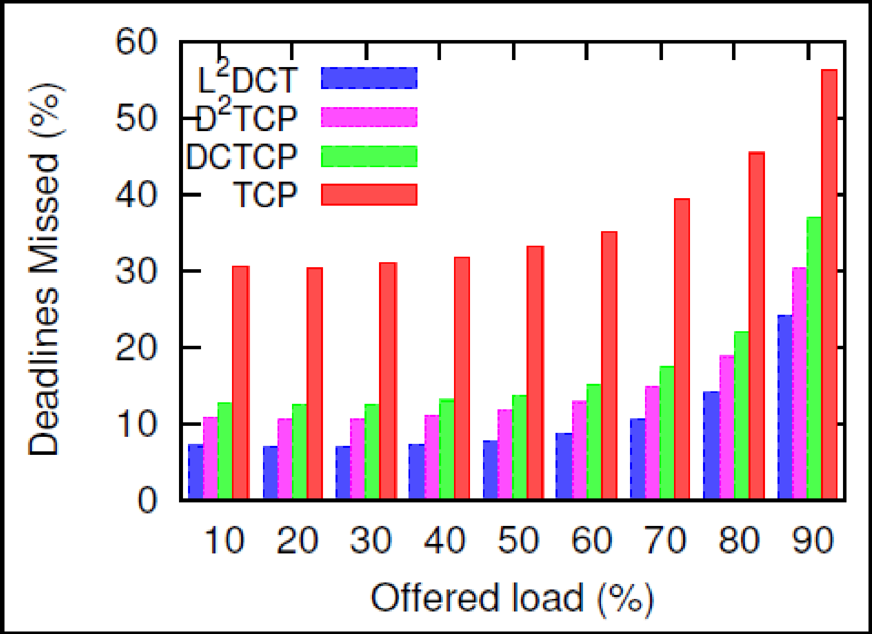
Co-existence with TCP



2 long-lived L^{2}DCT flows competing with 2 long-lived TCP flows

- L^{2}DCT can co-exist with TCP
  - Small values of k can yield similar throughput

Meeting Deadlines



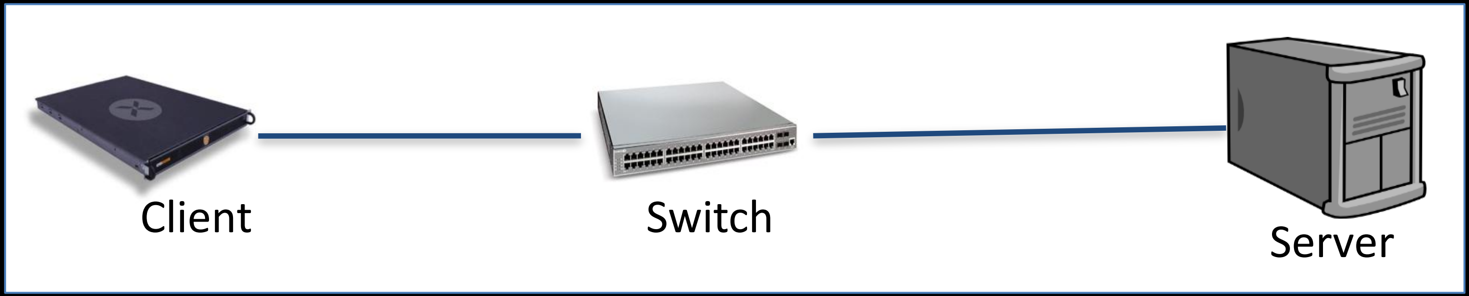
Settings:

- Flow deadlines ~ exponential with mean 40ms [Wilson et al., SIGCOMM'11]
- Short Query Traffic: Uniformly distributed in [2KB, 98KB]
- Two Long-Lived Flows

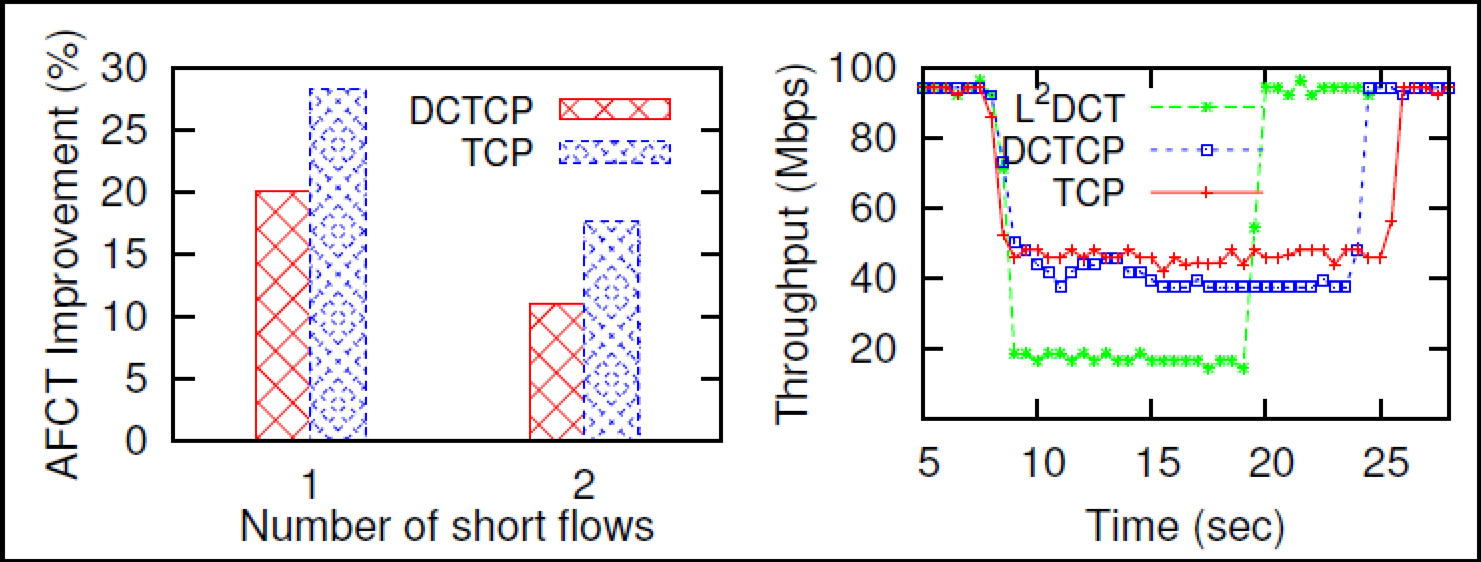
- L^{2}DCT consistently outperforms TCP, DCTCP and D^{2}TCP across a range of offered load
- Insight: A deadline agnostic protocol, which minimizes completion times, can achieve better or comparable performance than deadline-aware protocols

Testbed Evaluation

- Implemented L^2DCT in Linux
- We use the RED queue implementation in Linux for realizing the L^2DCT switch
- 3 Linux Machines (Client, Server, Switch)
  - 100Mbps interfaces



Results



- Single long-lived flow in the background
  – Multiple short flows are started
- L^2DCT improves AFCT by 20% and 29% over DCTCP and TCP, respectively

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Prior Work

- PDQ [Hong et al., SIGCOMM'12]
  - Allows approximation of SRPT in a distributed manner
  - Requires changes in switch hardware and applications
  - Co-existence with TCP is challenging
- D^3 [Wilson et al., SIGCOMM'11], D^2CTCP [Alizadeh et al., SIGCOMM'12]
  - Deadline aware protocols
    - May not necessarily optimize AFCT
  - Require changes in applications (D^3 requires hardware changes)
  - We show that deadline-agnostic protocols can provide comparable performance
- HULL [Alizadeh et al., NSDI'12], DeTail [Zats et al., SIGCOMM'12]
  - Trades off some link bandwidth for latency – L^2DCT is complementary to HULL
  - DeTail: Focuses on tail latency and not AFCT

Conclusion

- L^2DCT reduces flow completion times by approximating LAS
  - Leads AFCT by up to 95% over TCP
  - Also reduces the tail latency
- It is incrementally deployable
  - Requires no changes in switches or applications
  - It can co-exist with TCP
- Can achieve comparable performance to deadline-aware protocols

Thank you!