XCo: Explicit Coordination for Preventing Congestion in Data Center Ethernet

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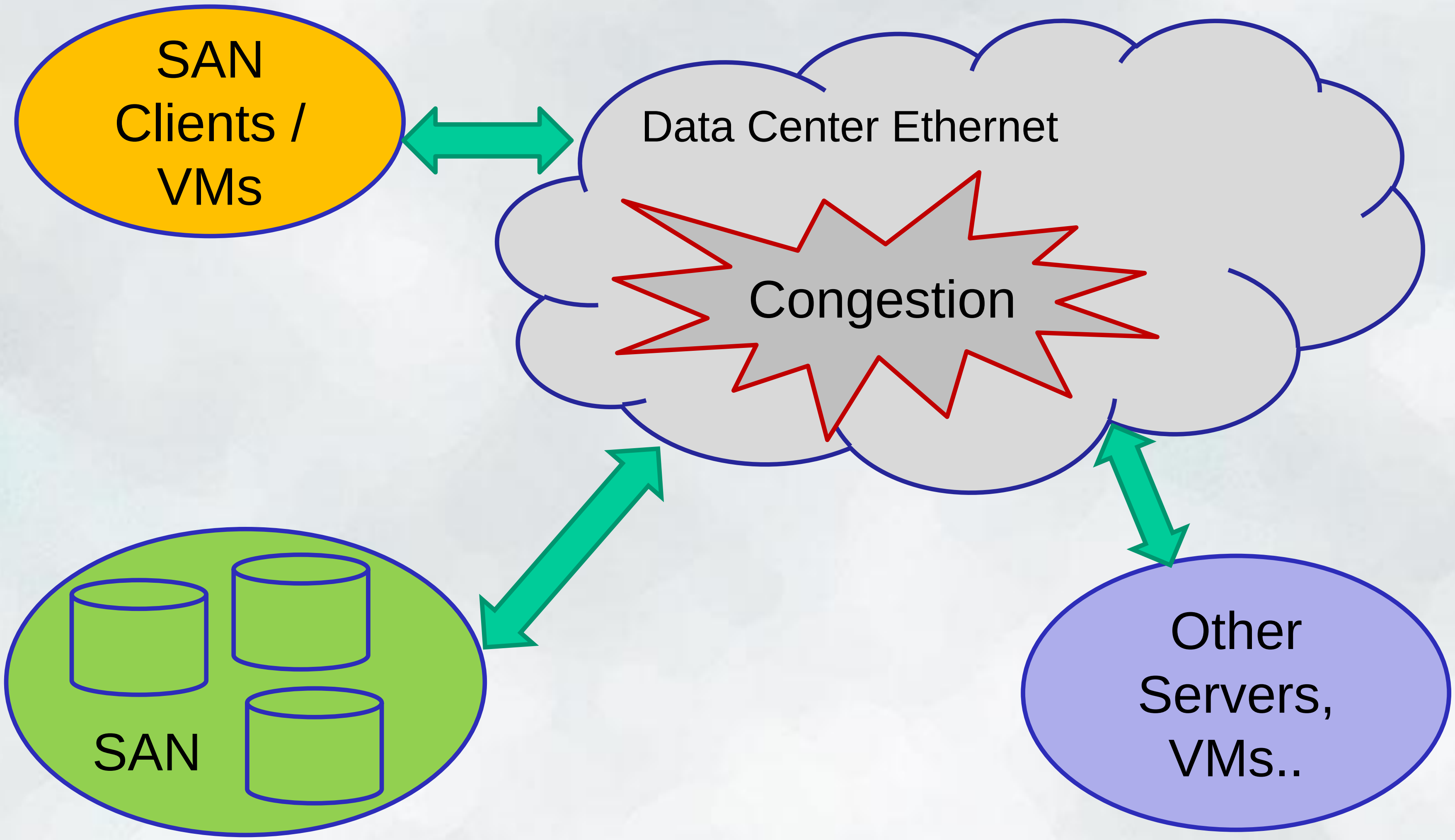
Outline of the talk

- Motivation & Problem Statement
- Our Contributions – Explicit coordination
- Illustrating the impact of congestion
- XCo framework
  - Time slice scheduling
  - Implementation
- Evaluation
- Future work
- Conclusion

Motivation

Congestion in Data Center Ethernet



iSCSI, FCoE,… Streaming Media… Data Mining,… VM Checkpointing, VM Migration,… Voice over IP…, etc…

Problem: Increasing congestion in Data Center Fabric

Our Contribution

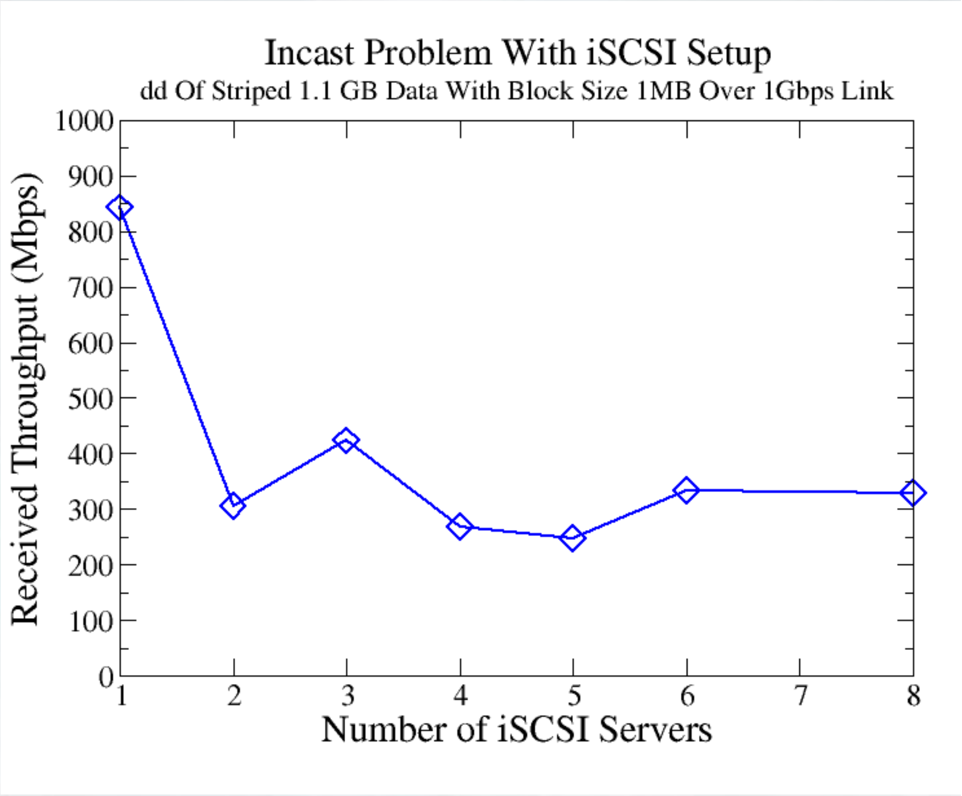
- XCo prevents network fabric congestion
  - By explicitly coordinating the transmissions from end-hosts
- Achieves significantly higher throughput
  - Compared to uncoordinated transmissions
- Completely transparent to the VMs
- Requires no hardware or switch support
- Can be completely implemented on today's commodity Ethernet fabric and switches

Demonstrating Ethernet Fabric Congestion

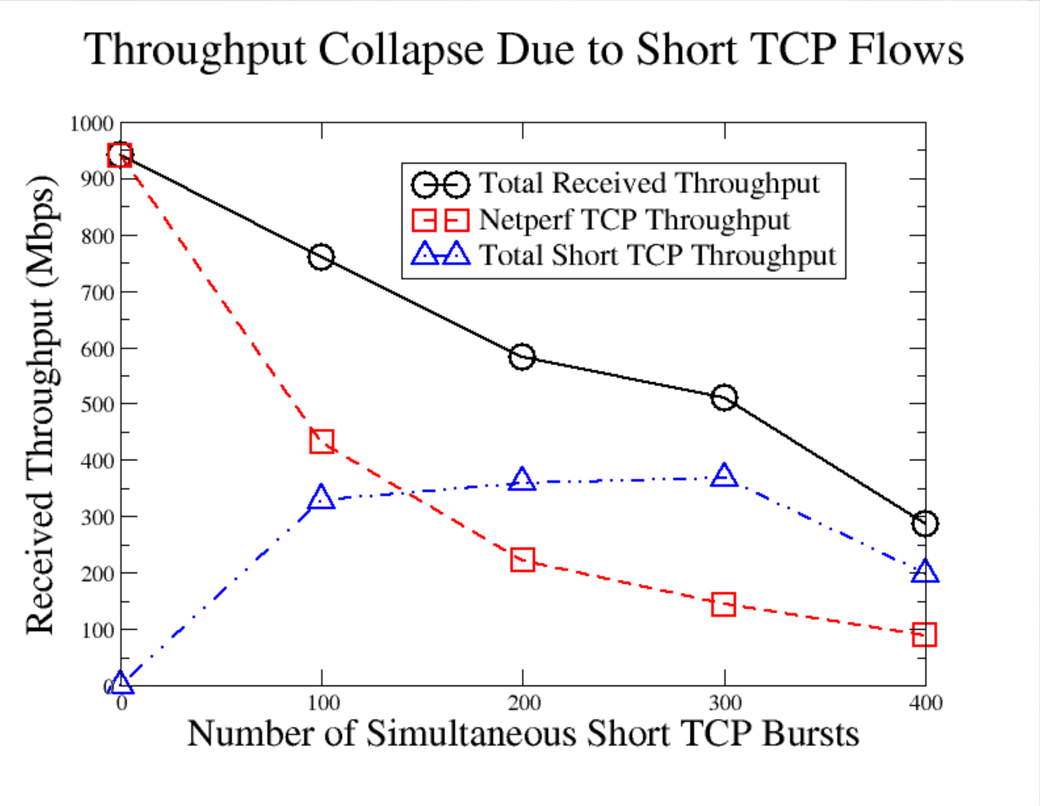
Experimental Testbed

- Switches: Nortel 4526-GTX
  - 24 1000Base-T ports & 2 XFP 10Gbps optical uplink slots
- Hosts: Xen 3.3.1/Linux 2.6.29.2, Dual CPU Quad Core
- Benchmarks: Netperf, Open-iSCSI, ShortTCP

Incast & Short TCP Flows Problem



(a)



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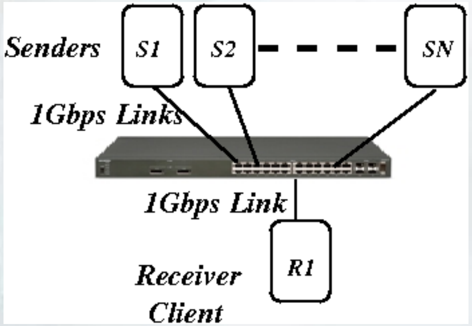
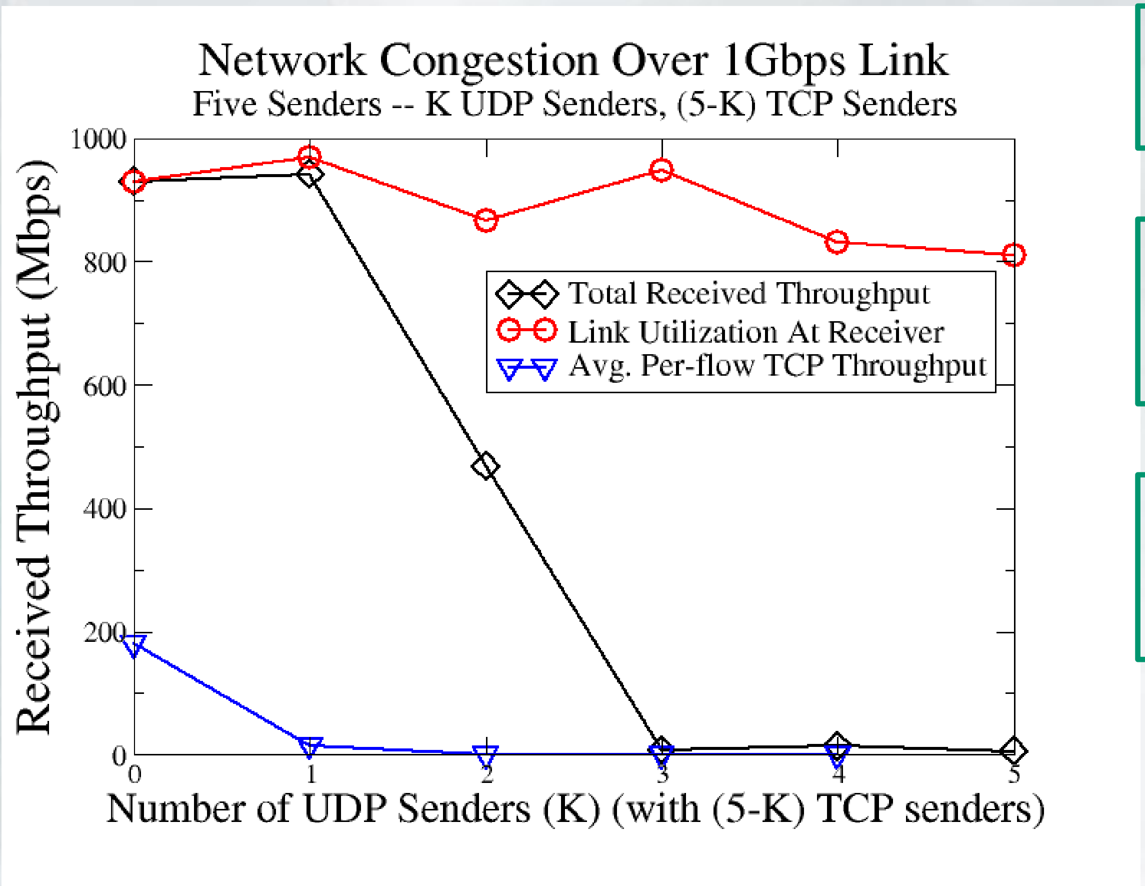
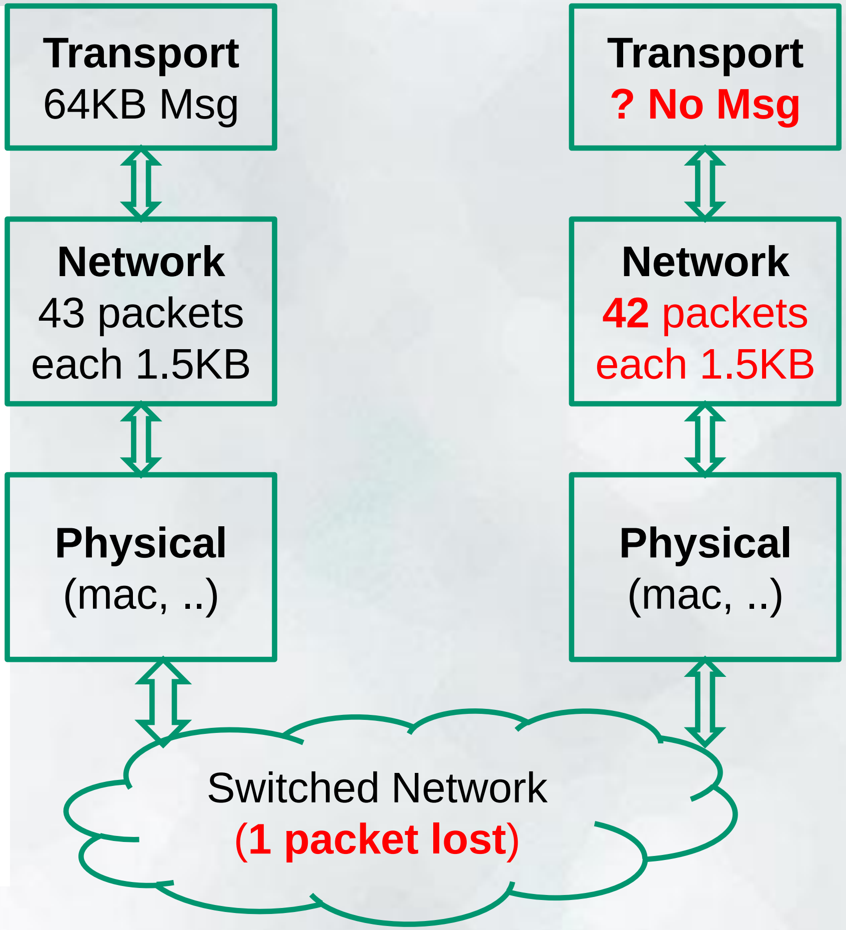


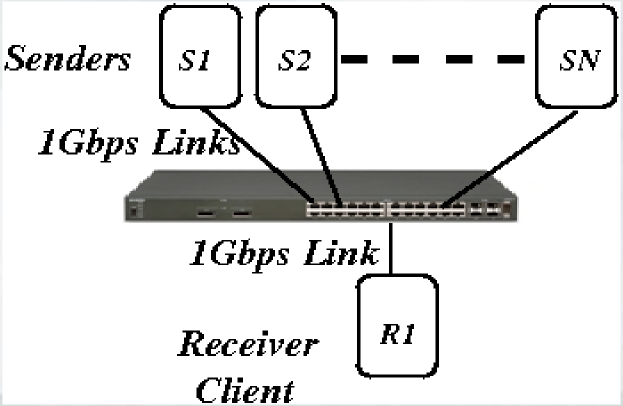
a) Incast effect: Collapse of TCP throughput due to barrier synchronized traffic
b) Short TCP flows behave like UDP

Impact of Non-TCP traffic

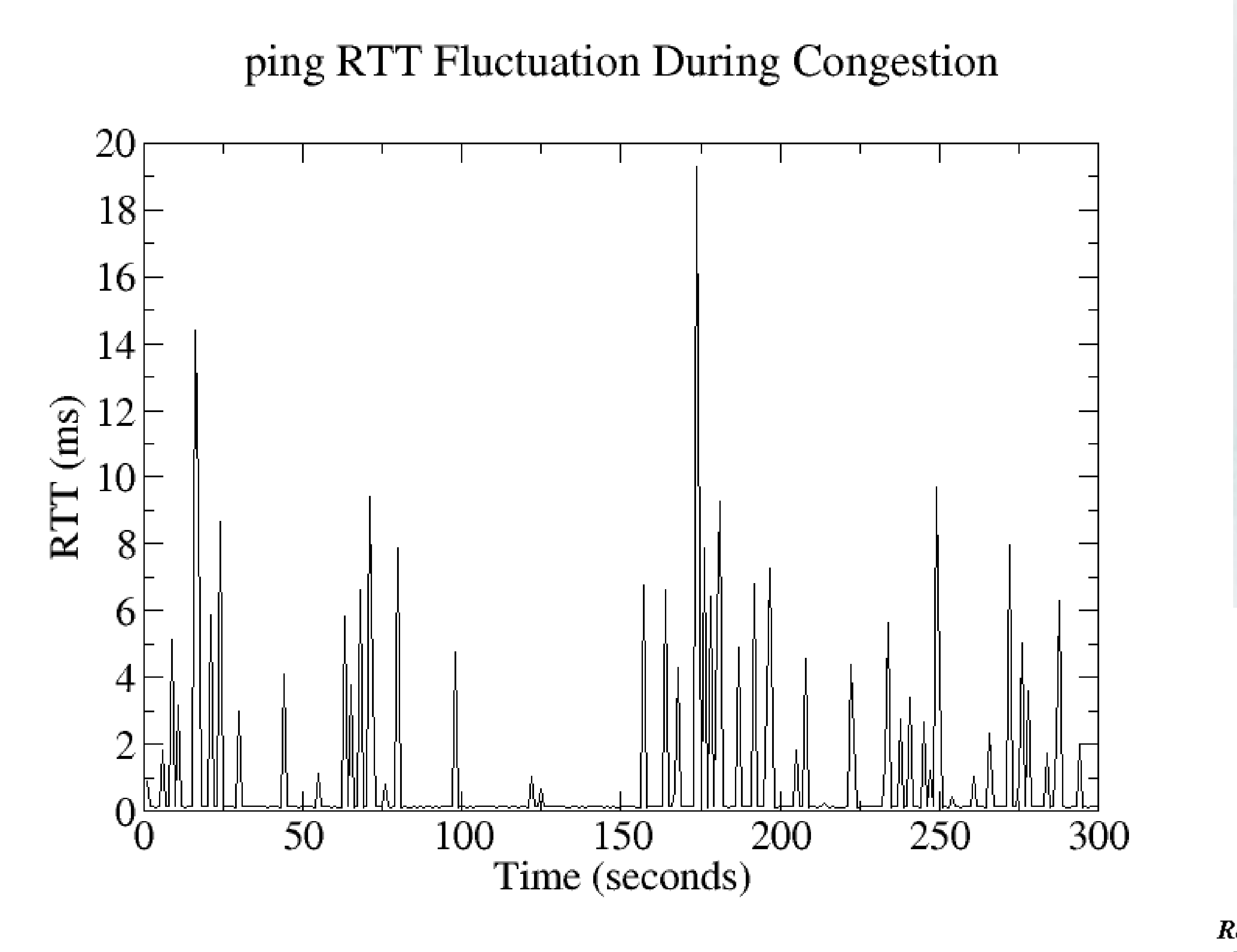


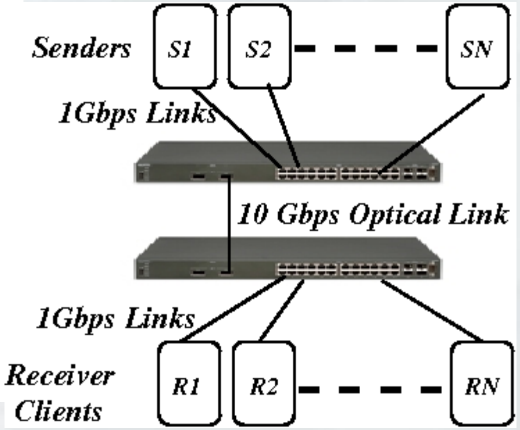


- Bottleneck link is completely utilized
- Total throughput suffers due to large UDP message size
- TCP does not get its fair share due to congestion



Variation in RTT due to congestion





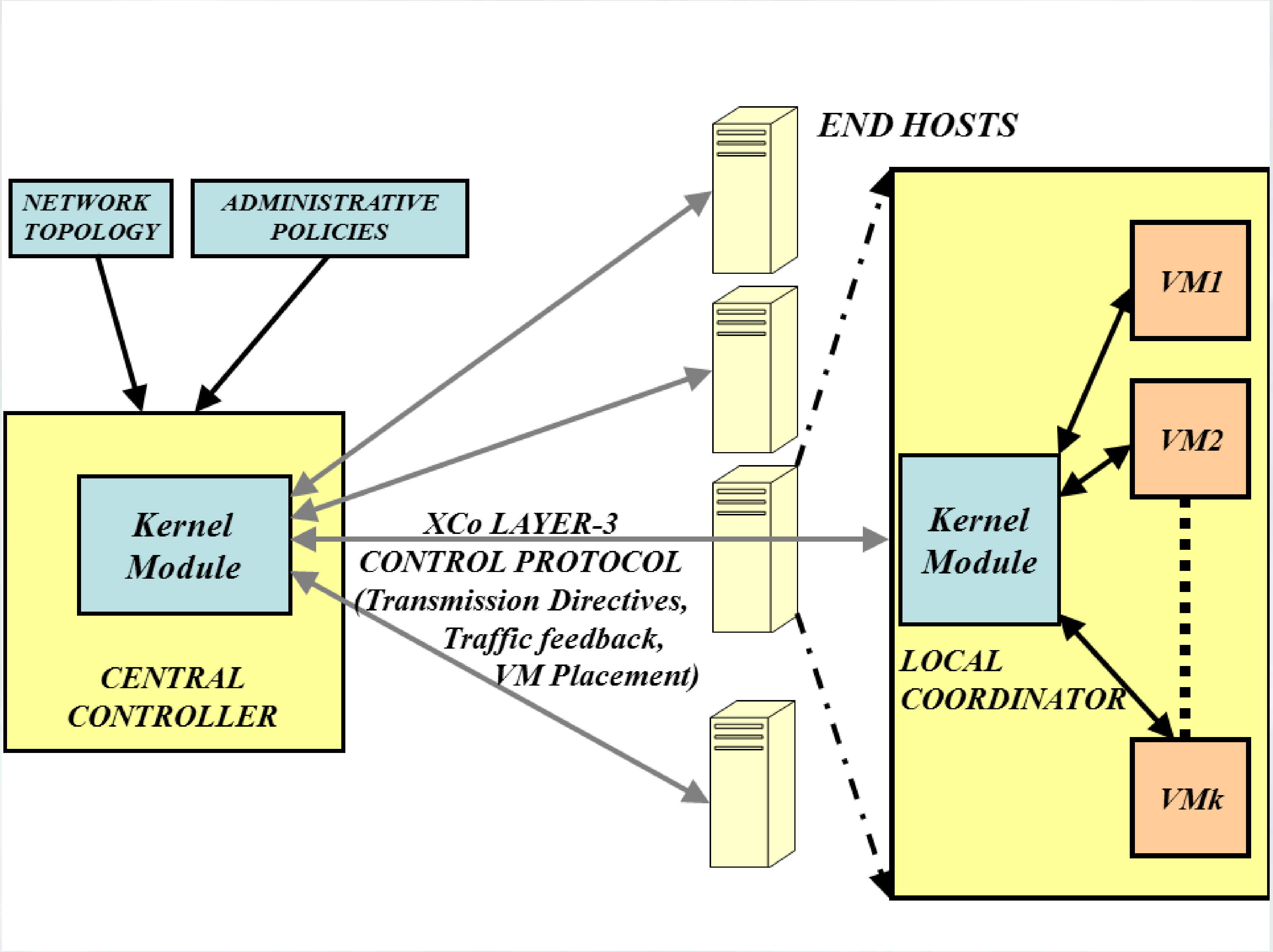
Ping RTT varies significantly due to congestion in the bottleneck link

Our Solution: XCo

Design Goals

- Prevent excessive concurrent transmissions
  - To avoid potential congestion in bottleneck links of the switched network
- Permit sufficient network activity
  - To achieve high network utilization

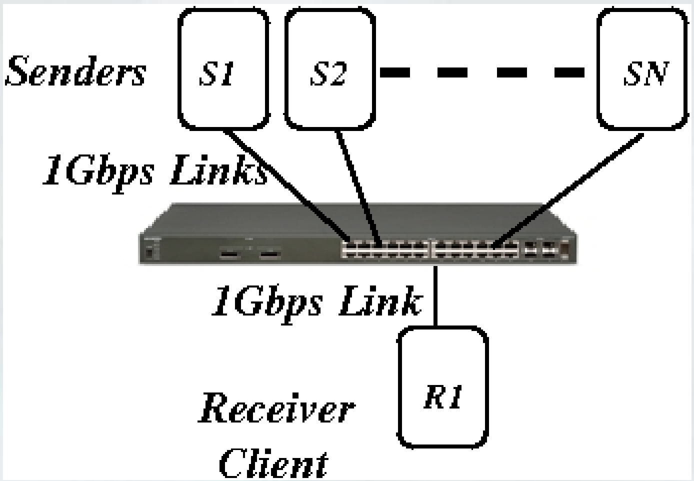
XCo Architecture



Transmission Directive

- Permit just enough senders to transmit so as to saturate the bottleneck link

(a)



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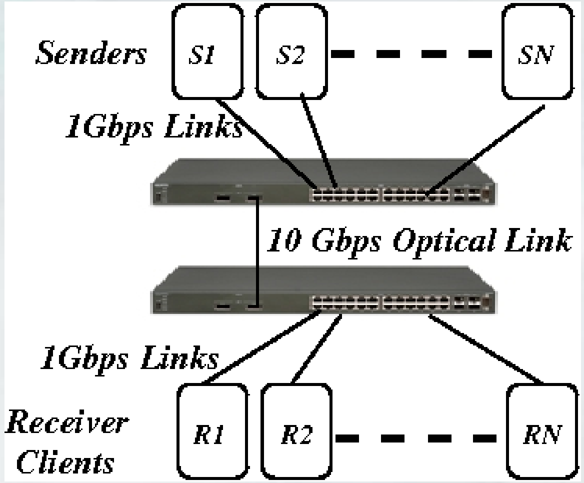
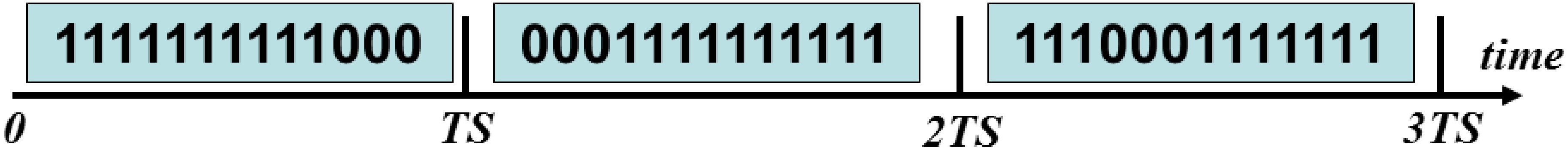
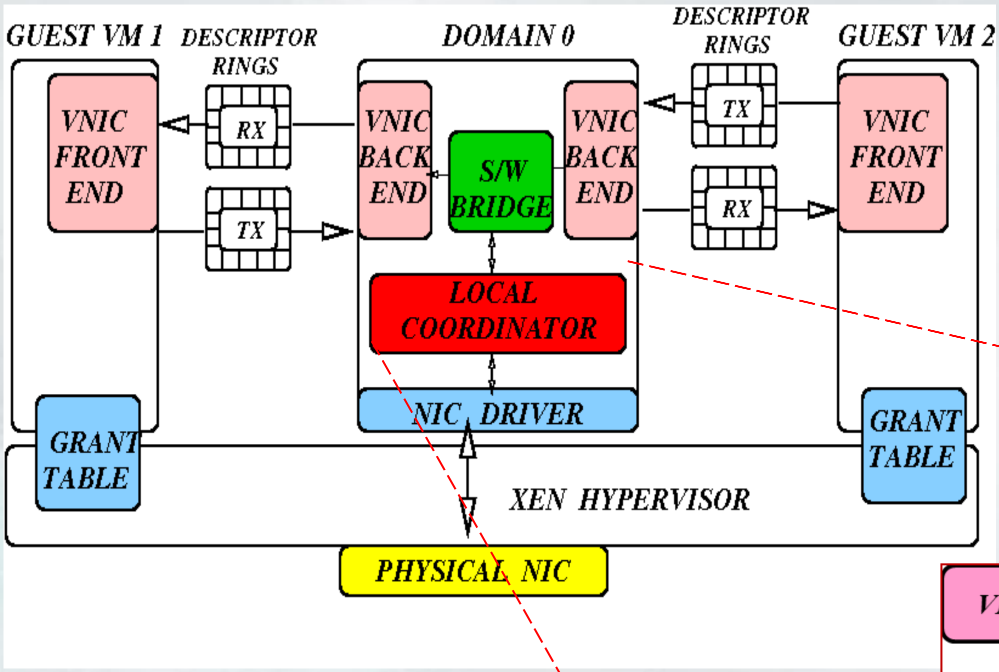


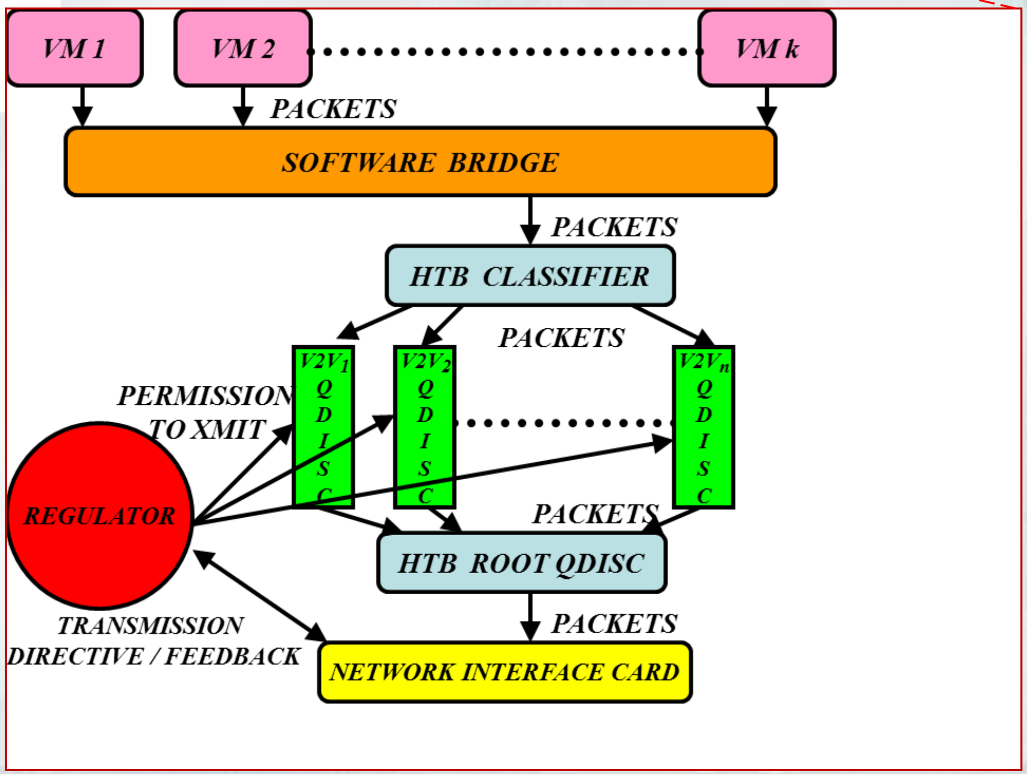
(a) Timeslice scheduling for 1Gig link



(b) Timeslice scheduling for 10Gig link

XCo Design and Implementation





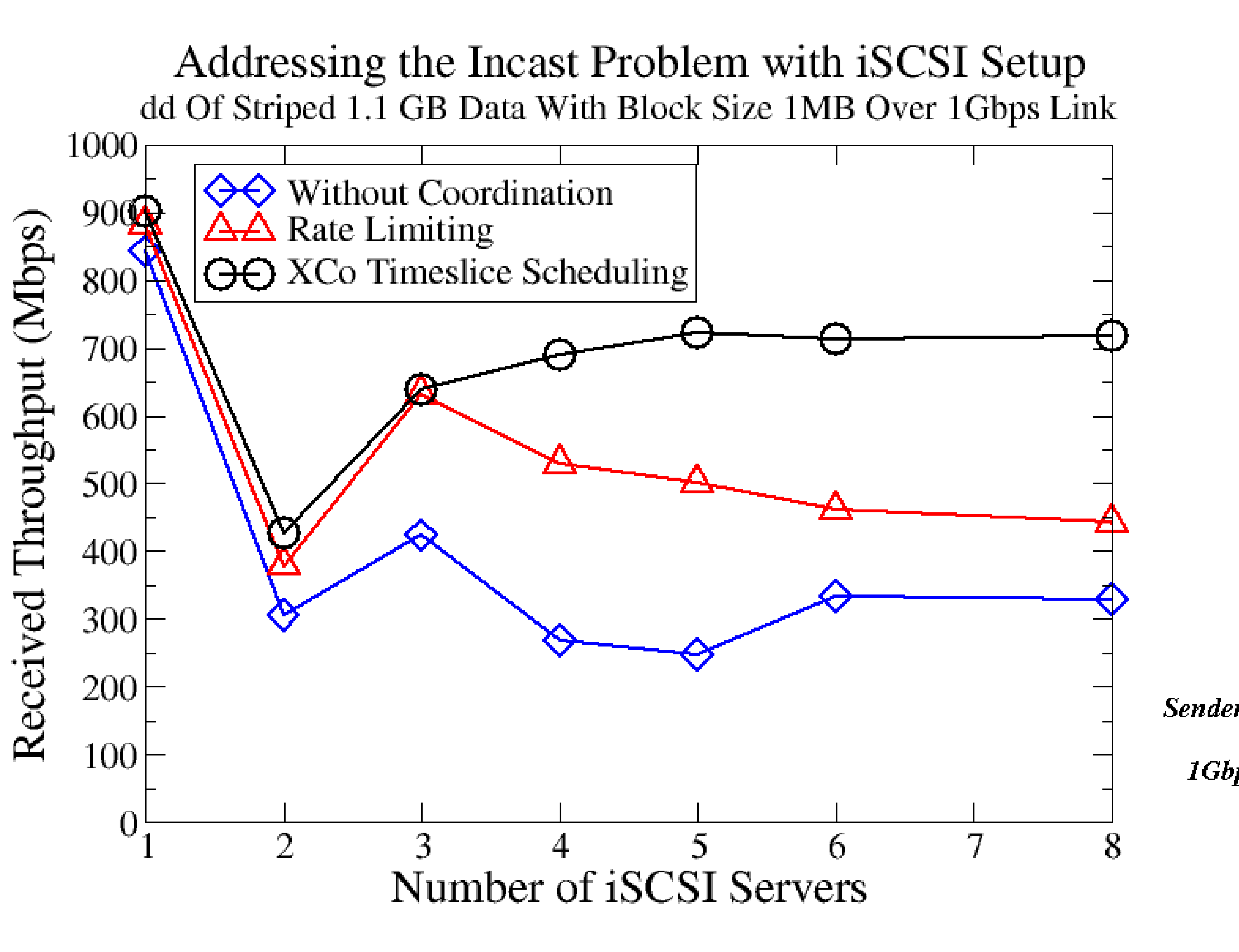
Timeslice Scheduling For General Network Topology

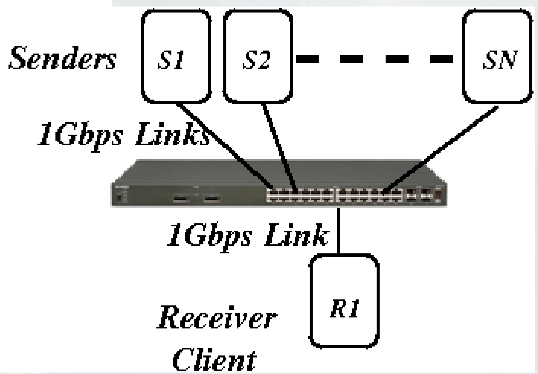
- The timeslice scheduling algorithm runs in the central controller
- The algorithm considers
  - Multiple bottleneck links
  - Work conservation
  - Some level of fairness among senders
- Feasibility condition for bottleneck link:

$$F(\alpha_{ij}, C_{ij}) : \sum_{\forall x \in \alpha_{ij}} C_x \leq C_{ij}$$

Performance Evaluation

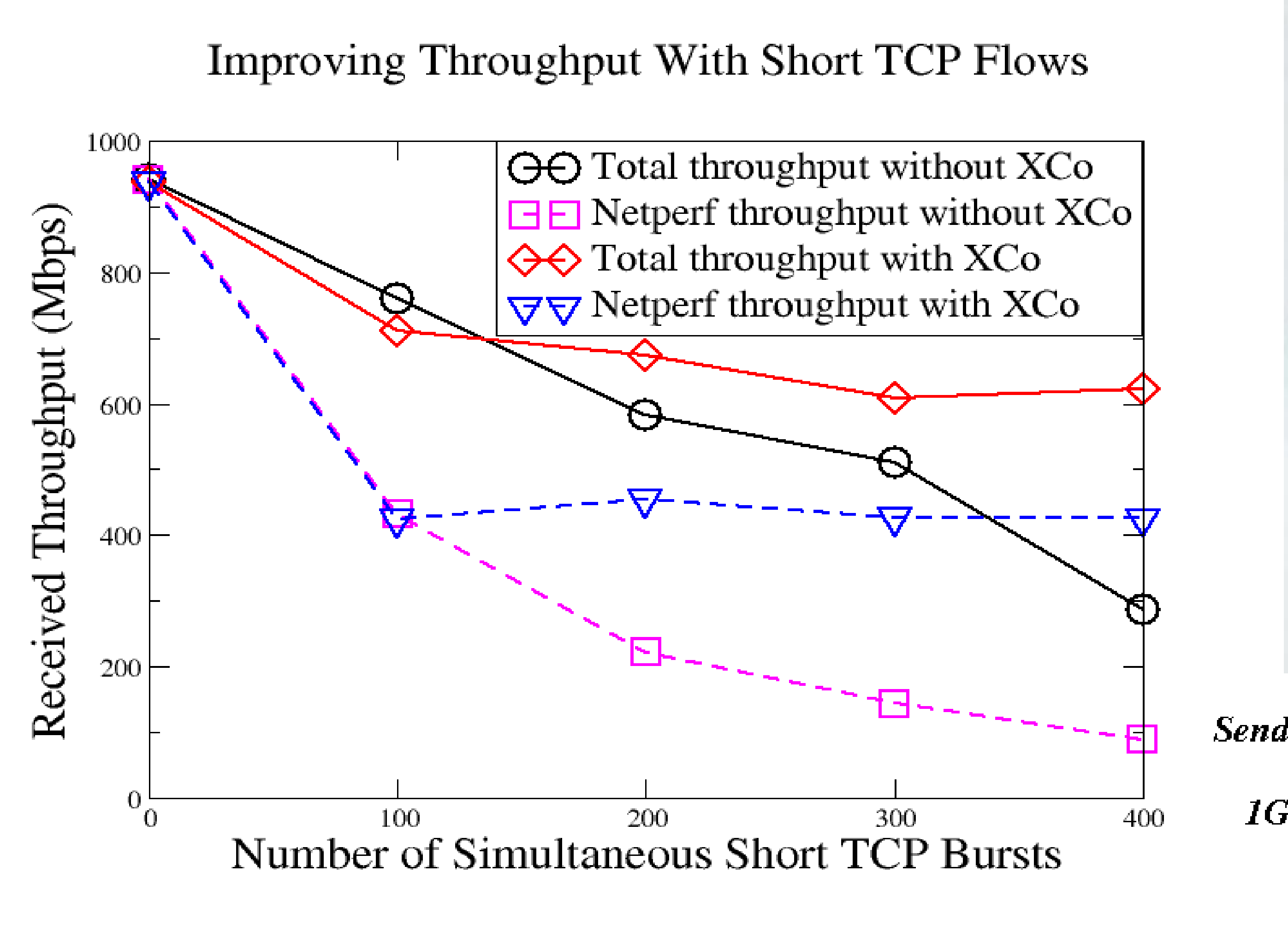
Solving the Incast Problem using XCo

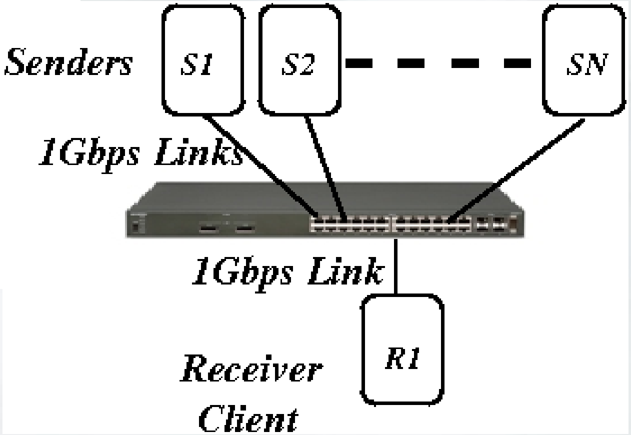




- Incast is alleviated for sufficiently large number of iSCSI servers
- iSCSI throughput improves by 120%

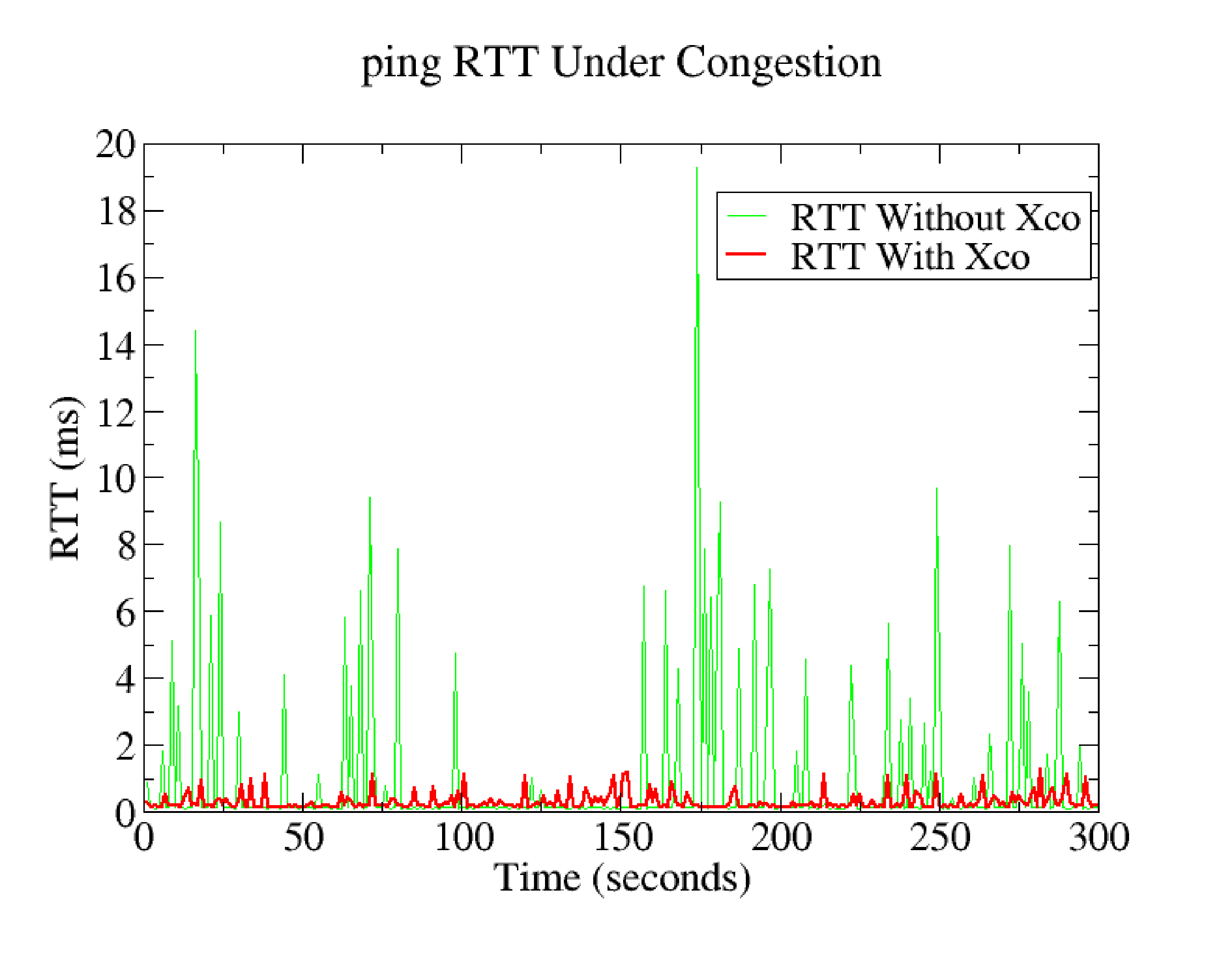
Solving Throughput Collapse Due To Short TCP Bursts using XCo

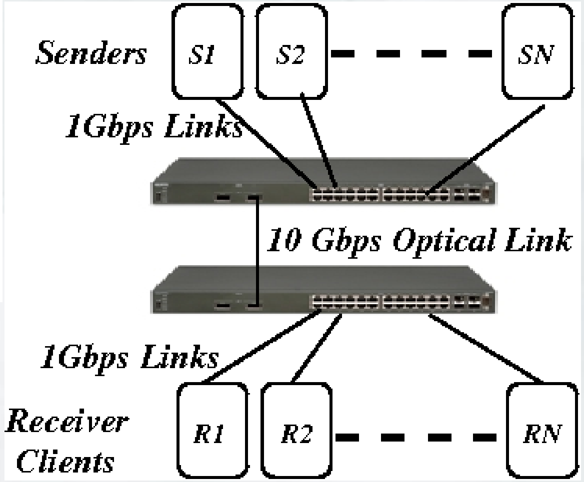




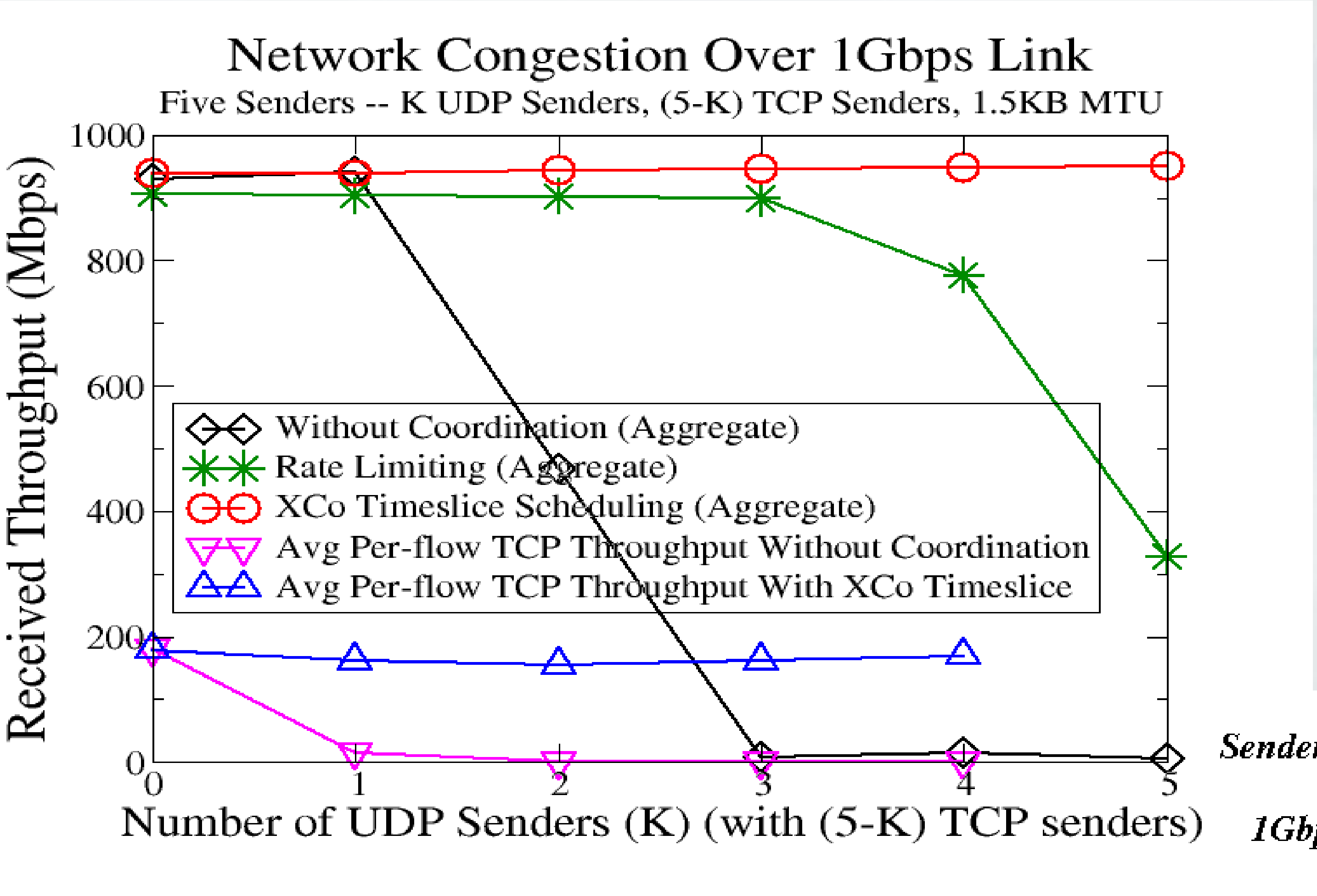
TCP netperf improves up to 320%
Total throughput improves up to 110%

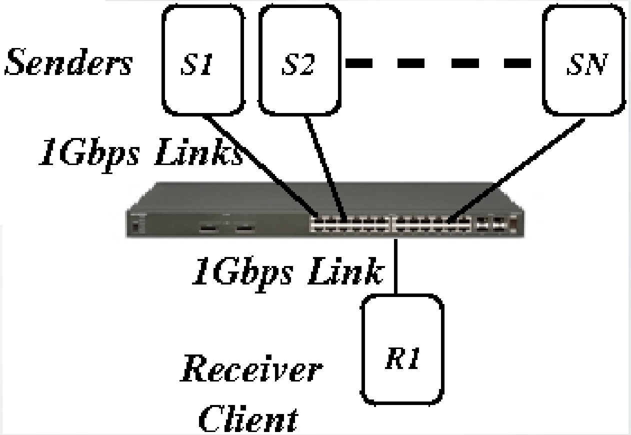
Decreasing RTT variations with XCo



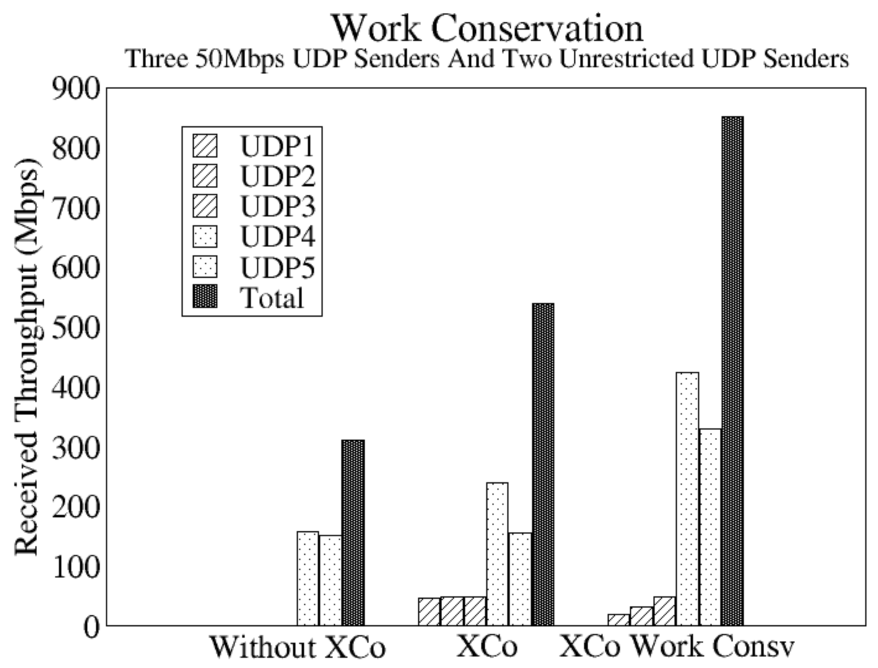


Preventing Throughput Collapse with Non-TCP Traffic

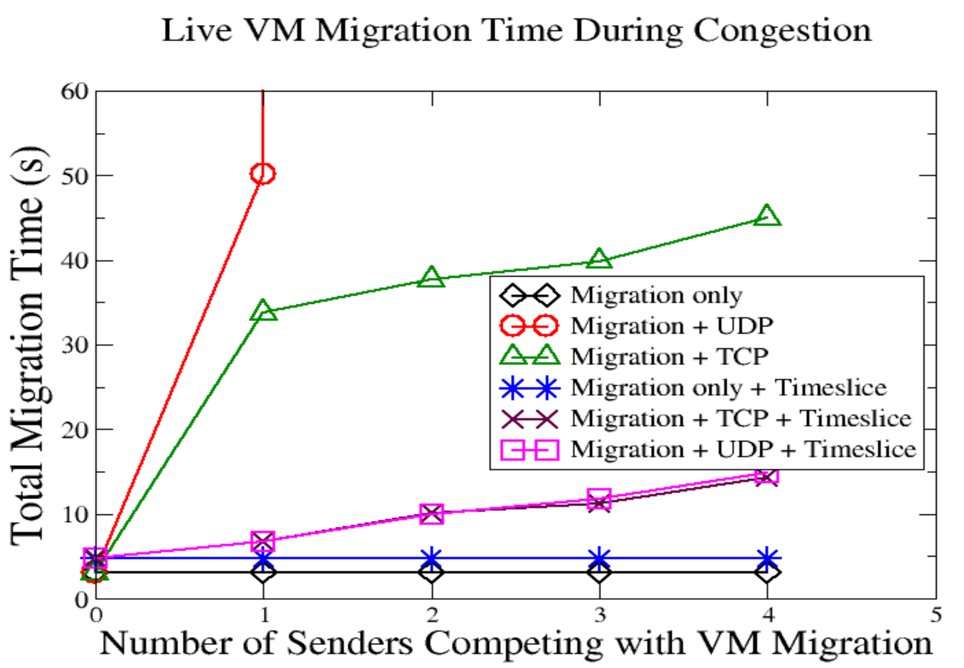




- No throughput collapse with Xco
- TCP gets its fair share



(a)



(b)

(a) Total throughput improves with XCo & with Work-conservation

(b) XCo reduces live VM Migration time in the presence of competing TCP/UDP traffic

Related Work

- 802.3x Pause Frames
  - Cause head of the line blocking
- VLANs
  - Do not provide congestion control
- Data Center Bridging (DCB) Task Group
  - In progress; future switch-level support for congestion control and QoS
- Hedera, Viking, SPAIN, Ethane, Fat-Tree
  - Depend on modifying switch forwarding tables
  - Reconfiguring spanning trees using VLANs/Multi-pathing
  - For flow scheduling in enterprise networks
    - XCo doesn't need to modify switches or VLANs

- TCP Throughput Collapse (Incast)
  - Reducing concurrent iSCSI servers
  - Reducing advertised TCP recv buffer size
  - Reducing RTOmin

XCo can work with unmodified TCP stack and any number of iSCSI servers

Future Work

- Empirical Studies
  - More detailed studies on complex topologies with multiple bottlenecks
- Scalability
  - Multiple or hierarchical controllers. NS3 simulations for thousands of nodes under multi-tiered multi-rooted data center topologies
- Active and On-demand Coordination
  - Use feedbacks to trigger central coordination only during times of network congestion
- Fault Tolerance
  - Controller failure, end-host failure
- Alternative Coordination Strategies
  - Hybrid of timeslice scheduling and rate-limiting

Conclusion

- Virtualization offers new opportunities for mitigating Data Center Ethernet Congestion
- XCo: A system to explicit coordinate the network transmissions from multiple senders at millisecond granularity
- No changes to the VMs, applications, protocols & switches
- A central controller issues transmission directives (or permissions to transmit) to end-hosts
- Temporally separates transmissions competing for bottleneck links
- XCo has the potential to prevent congestion-induced performance problems in today’s unmodified Gigabit and 10GigE switched Ethernet
- Future work: more complex topologies, scalability, on-demand coordination, fault-tolerance, and alternative coordination strategies

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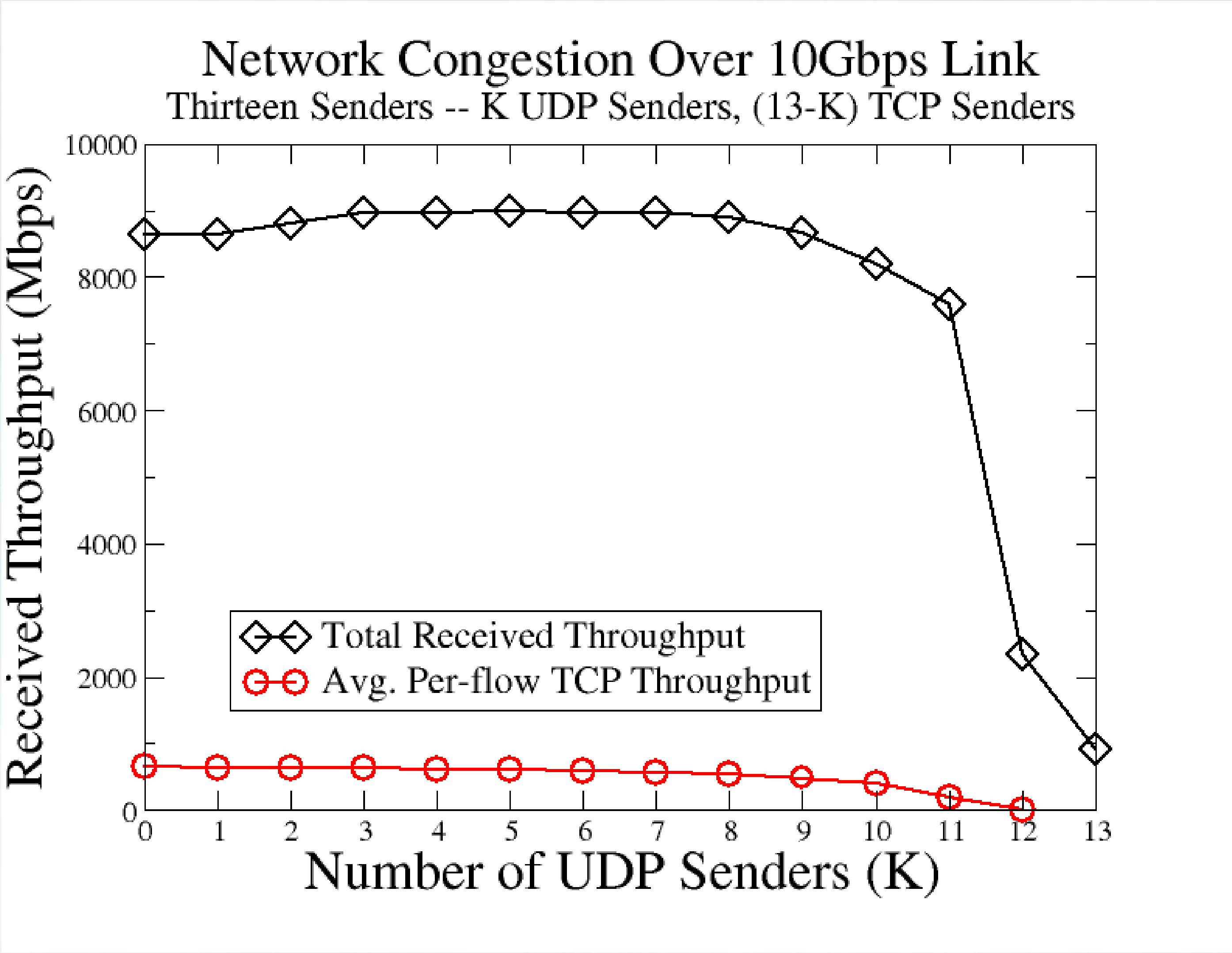
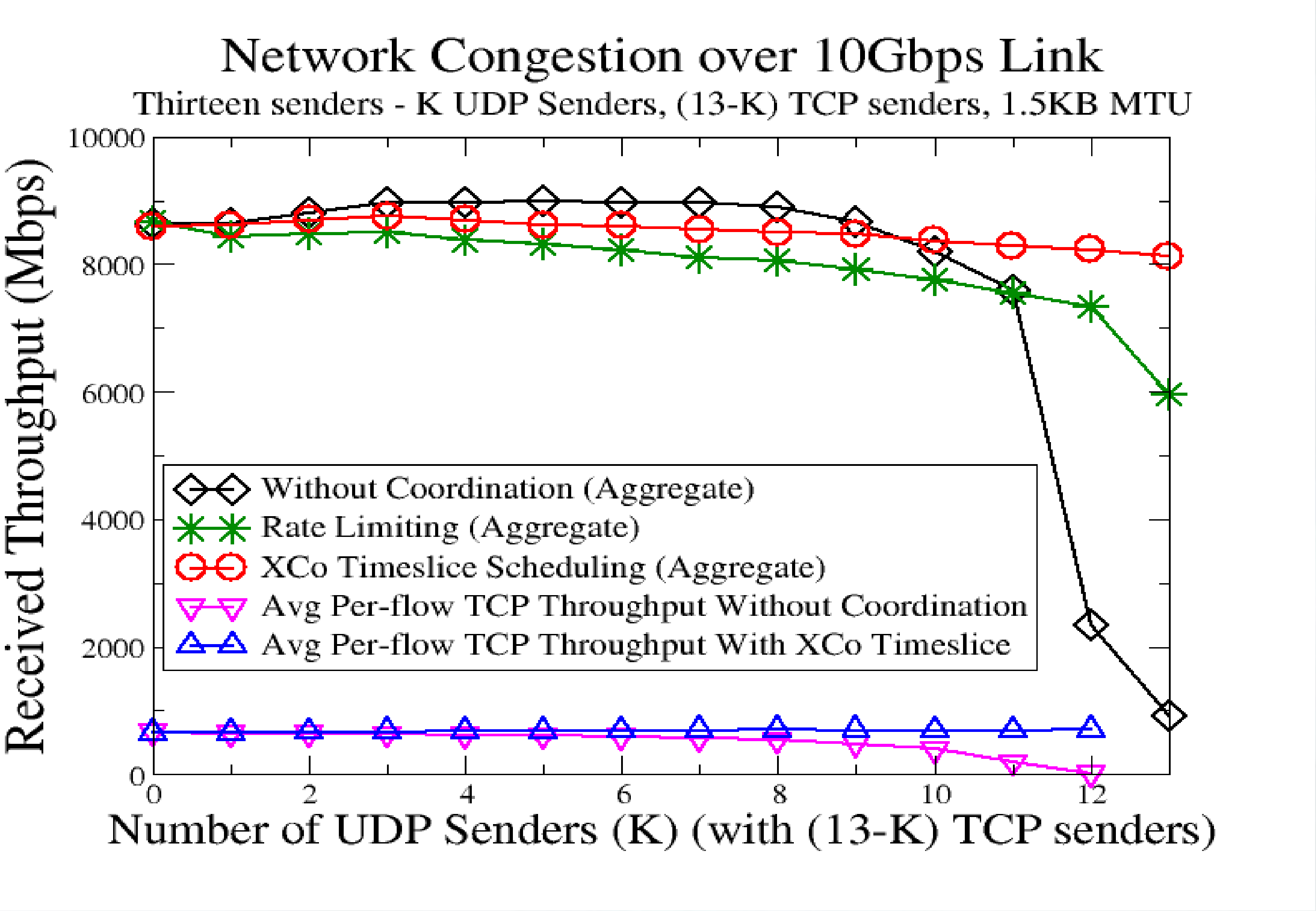
Thank You!

Backup

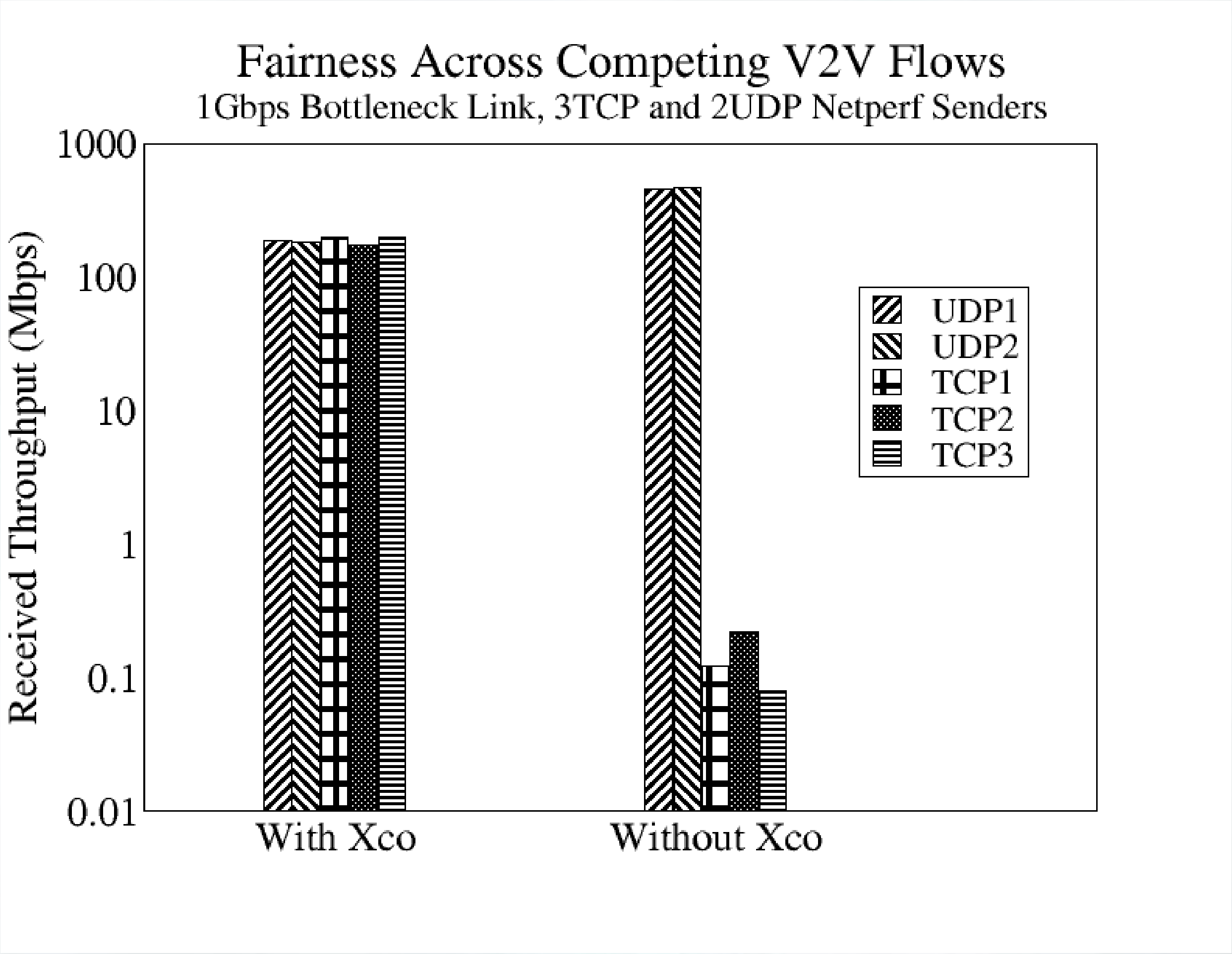
Throughput Collapse with 10Gig Link



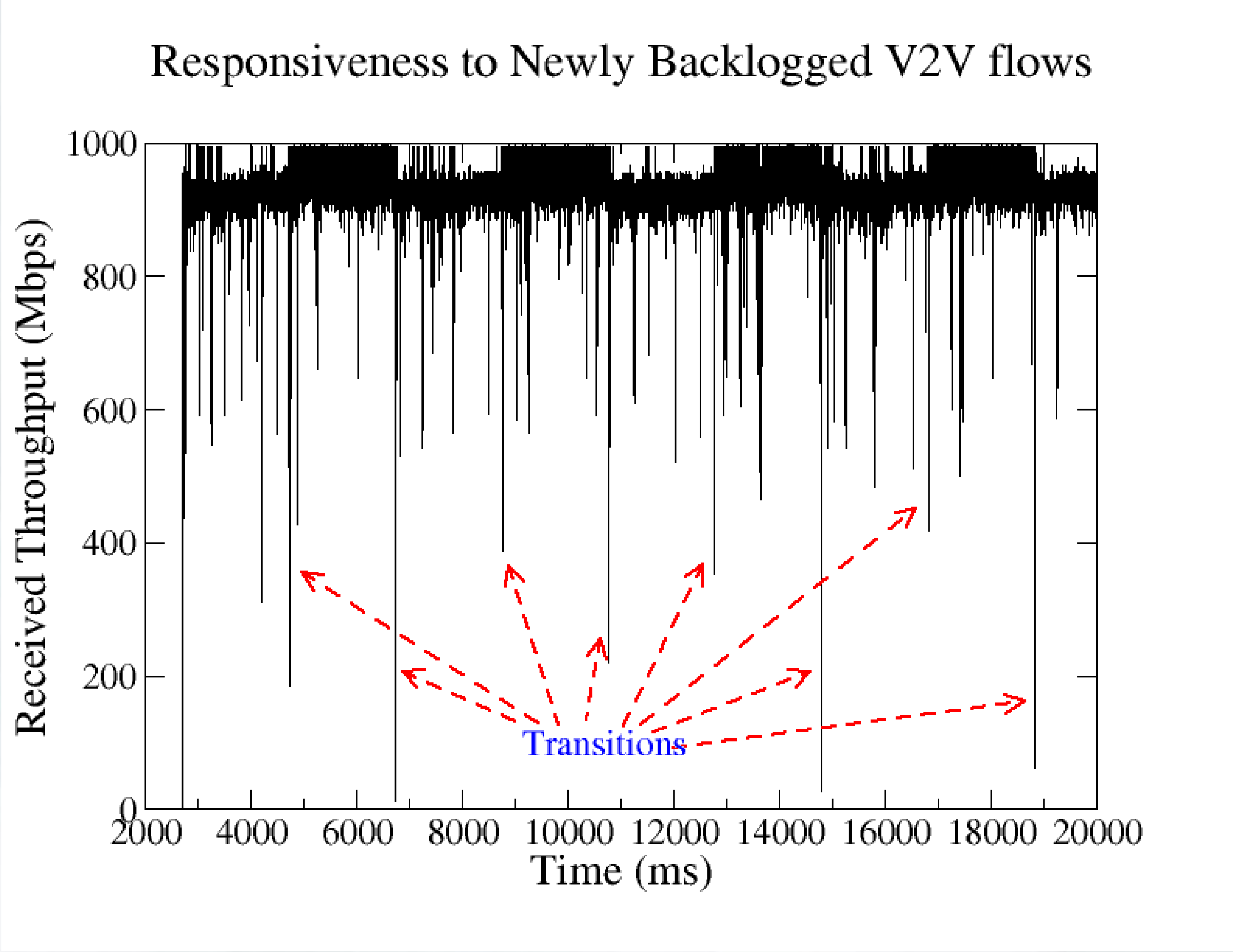
Solving 10Gig Link Throughput Collapse



Fairness With Different Flows Achieved By XCo



XCo Responsiveness To Flow Changes



Responsiveness is about 75ms one time to create new flow classifiers and about 10ms each time when senders change

XCo Algorithm

$$P_{sd} = \{\ (i,j) \mid (i,j) \text{ lies in the path from } s \text{ to } d \text{ in the spanning tree } ST\ \}$$

$$\beta_{ij} = \{\ s \mid \exists d \text{ where } d \in B_s \text{ and } (i,j) \in P_{sd}\ \}$$

$$\alpha_{ij} = \{\ s \mid D_s \neq null \text{ and } (i,j) \in P_{sD_s}\ \}$$

$$F(\alpha_{ij}, C_{ij}) : \sum_{\forall x \in \alpha_{ij}} C_x \leq C_{ij}$$

XCo Algorithm

Input: (a) Current spanning tree ST
(b) Maximum link capacity $C_{ij} \forall (i.j) \in ST$
(c) Pre-computed paths $P_{xy} \forall$ nodes x, y
(d) Current backlog group $B_x \forall$ nodes x
(e) Current contention group $\beta_{ij} \forall$ links (i, j)
(f) Current active contention group $\alpha_{ij} \forall$ links (i, j)
(g) Last transmission directive $D_x^{old} \forall$ nodes x
(h) Type of scheduling event
(i) Node t which triggered the scheduling event

Output: Next transmission directive D_x for each node x affected by the scheduling event

$A := \emptyset$ /*set of nodes affected by scheduling event*/
for each node $d \in B_t$ **do**
  for each link $(i, j) \in P_{td}$ **do**
    $A := A \cup \beta_{ij}$
  end for
end for
if $D_t^{old} \neq null$ **then**
  for each link $(i, j) \in P_{tD_t^{old}}$ **do**
    $\alpha_{ij} := \alpha_{ij} - \{t\}$
  end for
  if (scheduling event = work conservation) **then**
    $B_t := B_t - \{D_t^{old}\}$ /*t has no backlog to D_t^{old}*/
  end if
end if

XCo Algorithm

26: $N := \emptyset$ /*set of nodes with new schedule*/
27: **while** $A \neq \emptyset$ **do**
28: $x :=$ some node in A
29: $D_x := null$
30: **for** each node $d \in B_x$ **do**
31: **for** each link $(i, j) \in P_{xd}$ **do**
32: /*Check feasibility condition*/
33: **if** $F(\{x\} \cup \alpha_{ij}, C_{ij}) = false$ **then**
34: Skip to next d in line 30
35: **end if**
36: **end for**
37:
38: $D_x := d$ /*d satisfies feasibility at each link*/
39:

XCo Algorithm

if $D_x^{old} \neq null$ **then**
/*x will stop transmitting to D_x^{old}*/
for each link $(i, j) \in (P_{xD_x^{old}} - P_{xD_x})$ **do**
$\alpha_{ij} := \alpha_{ij} - \{x\}$
$A := A \cup (\beta_{ij} - N)$ /*more nodes affected*/
end for
end if
for each link $(i, j) \in P_{xd}$ **do**
$\alpha_{ij} := \alpha_{ij} \cup \{x\}$
end for
break;
end for
$A := A - \{x\}$
if $D_x \neq null$ **then**
/*newly scheduled; don't reschedule again*/
$N := N \cup x$
end if
end while
for each $x \in N$ **do**
Send D_x to x
$D_x^{old} := D_x$
end for