Ricochet: Lateral Error Correction for Time-Critical Multicast

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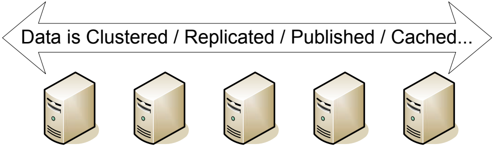
Multicast in the Datacenter

- Commodity Datacenters: Extreme Scale-Out
- Data Replication:
  - Fault Tolerance
  - High Availability
  - Performance



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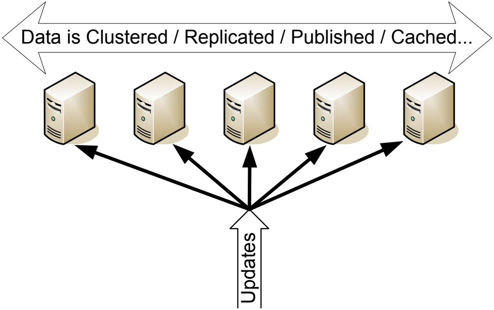
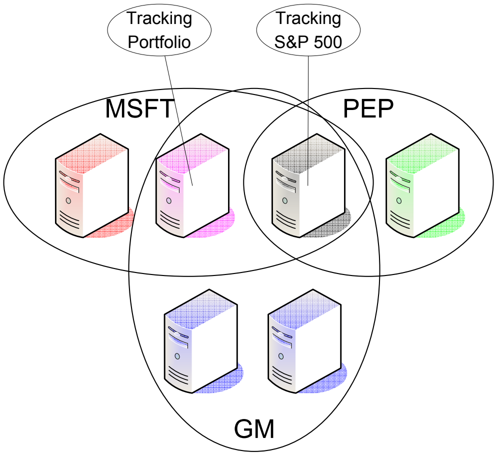
- Data Replication:
  - Fault Tolerance
  - High Availability
  - Performance
- Updating data in multiple locations: Multicast!



How is Multicast Used?

Financial Pub-Sub Example:

- Each equity is mapped to a multicast group.
- Each node is interested in a different set of equities ...



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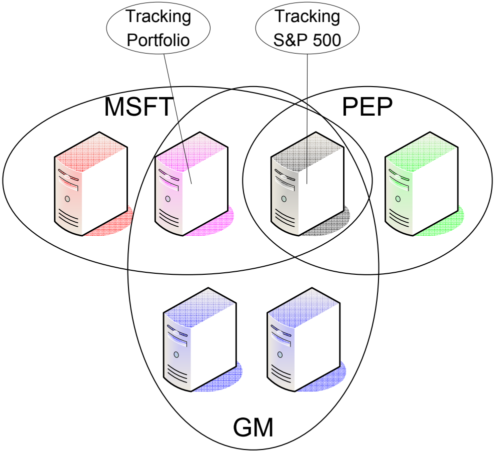
Each node in many groups
$\Longrightarrow$ Low per-group data rate



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Financial Pub-Sub Example:

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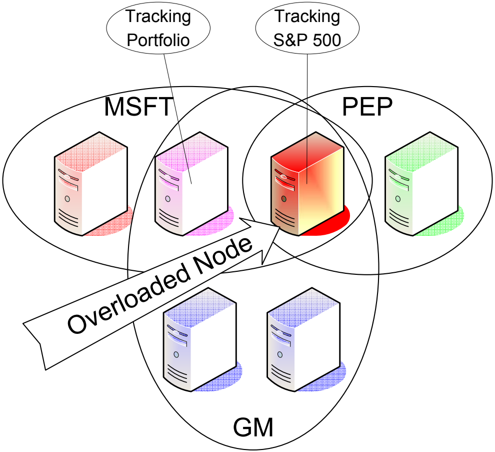
High per-node data rate
$\Longrightarrow$ Overload

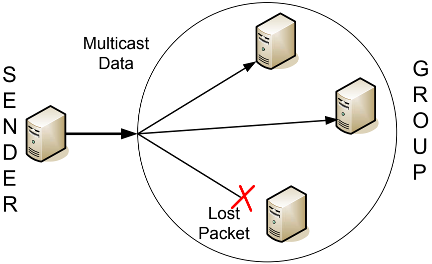


Recovering Lost Packets... Fast!

- Loss occurs on overloaded end-hosts.
- Real-Time Apps: Financial Trading, Mission Control...
- Foobooks.com?
  - Massive volume...
  - Stale inventory $=$ Lost $$$
- Required: rapid, scalable recovery from packet loss

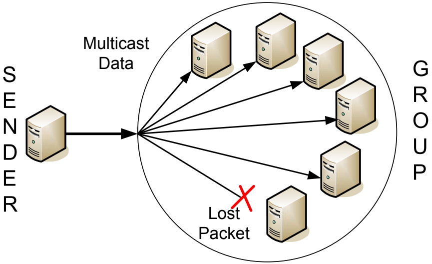
Problem Statement

- Time-Critical Reliable Multicast
- Scalability:



Problem Statement

- Time-Critical Reliable Multicast
- Scalability:
  - Number of Receivers



Problem Statement

- Time-Critical Reliable Multicast
- Scalability:
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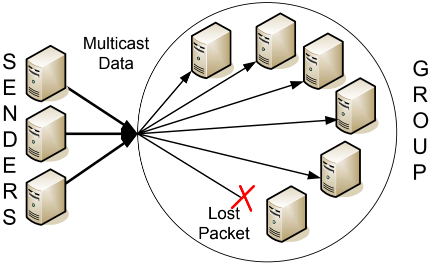
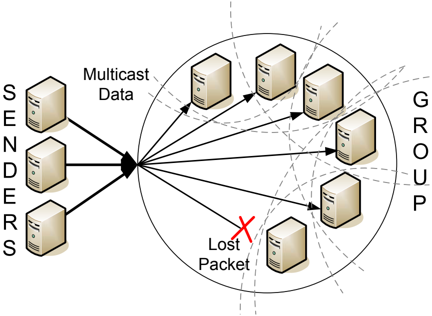


Problem Statement

- Time-Critical Reliable Multicast
- Scalability:
  - Number of Receivers
  - Number of Senders
  - Number of Groups



Design Space for Reliable Multicast

How does latency scale?

Existing mechanisms:

- ACK/timeout: RMTP/RMTP-II
- NAK/sender-based sequencing: SRM
- Gossip-based: Bimodal Multicast, lpbcast
- Forward Error Correction

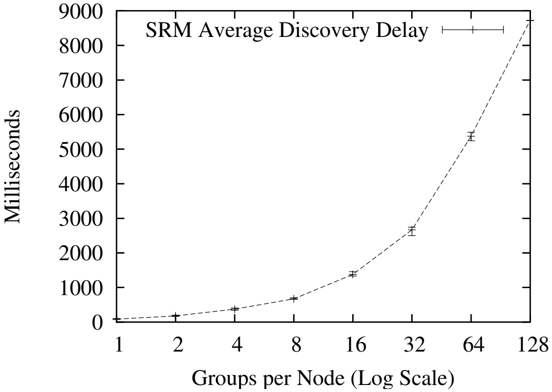
Fundamental Insight: *latency* $\propto \frac{1}{datarate}$

NAK/Sender-Based Sequencing: SRM

Scalable Reliable Multicast - Developed 1997

- Loss *discovered* on next packet from same sender in same group
- *latency* $\propto \frac{1}{datarate}$

  data rate: at a single sender, in a single group



Forward Error Correction

Pros:

- Tunable, Proactive Overhead: (r, c)
- *Time-Critical*: No Retransmission

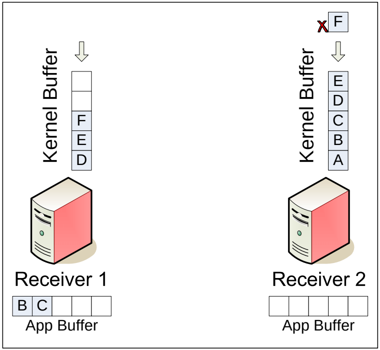
Cons:

- FEC packets are generated over a stream of data
  - Have to wait for r data packets before generating FEC
  - $latency \propto \frac{1}{datarate}$

  data rate: at a single sender, in a single group

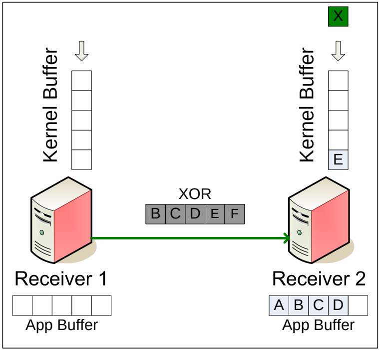
Receiver-Based Forward Error Correction

- Receivers generate XORs of incoming multicast packets ...



Receiver-Based Forward Error Correction

- Receivers generate XORs of incoming multicast packets ...
- ... and exchange with other receivers
- A receiver can recover from at most one missing packet in an XOR



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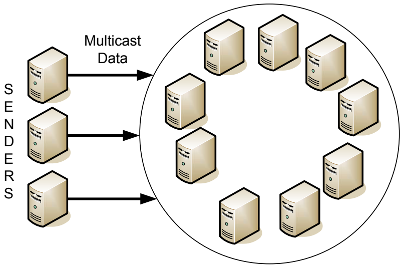
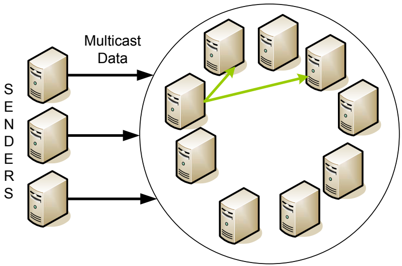


Receiver-Based Forward Error Correction

- Receiver sends XOR to *c* randomly chosen receivers



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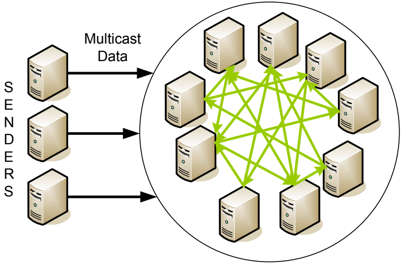
- Gossip-style Randomness
- Tunable Overhead: (r, c) *rate-of-fire*



Receiver-Based Forward Error Correction

- Receiver sends XOR to *c* randomly chosen receivers
- Gossip-style Randomness
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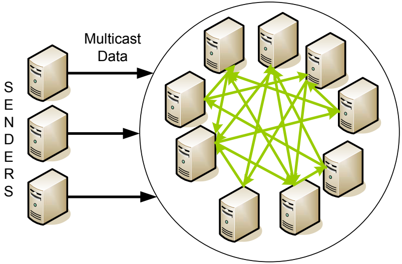
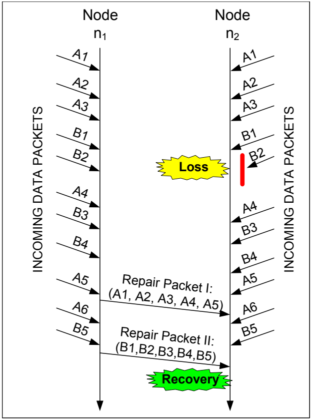
- $latency \propto \frac{1}{\sum_s datarate}$
  data rate: across all senders, in a single group



Lateral Error Correction: Principle



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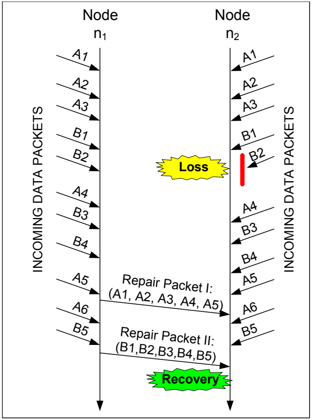
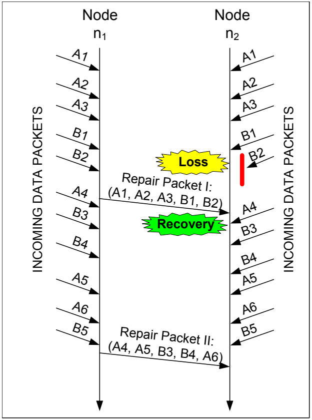
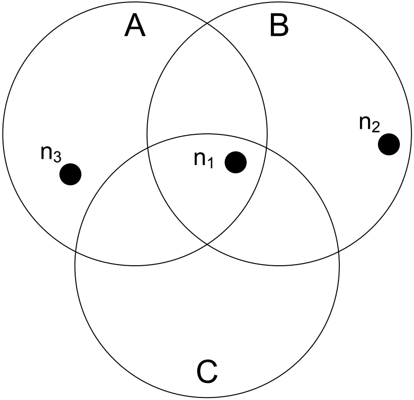




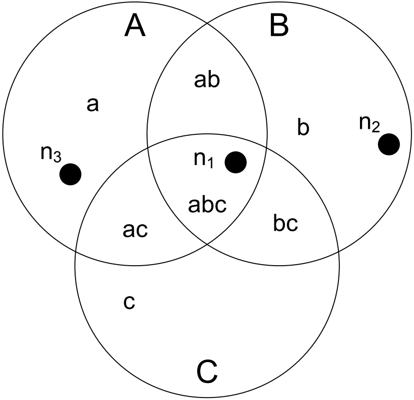
- Repairs from n_1 to n_2 include data from common groups.

Nodes and Intersections



- Node n_1 belongs to groups A, B, and C

Nodes and Intersections



- Node n_1 belongs to groups A, B, and C
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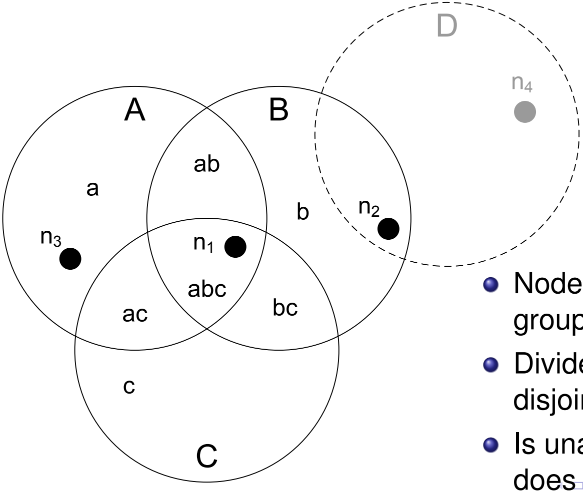
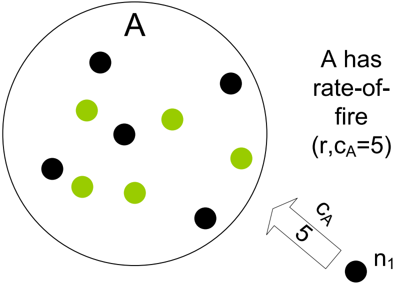
Nodes and Intersections



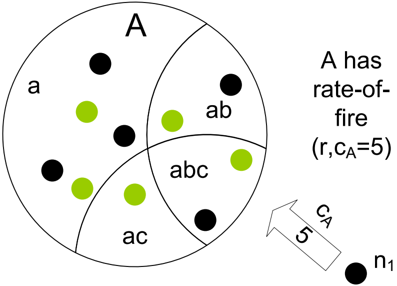
- Node n_1 belongs to groups A, B, and C
- Divides groups into disjoint intersections
- Is unaware of groups it does not belong to (D)

Regional Selection



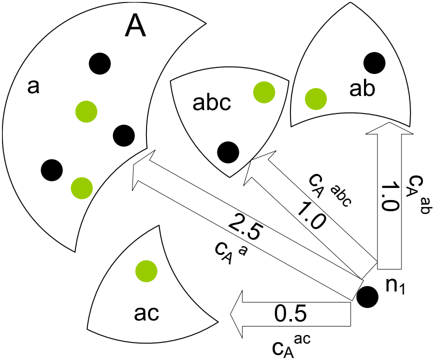
A has rate-of-fire $(r, c_A = 5)$

Regional Selection



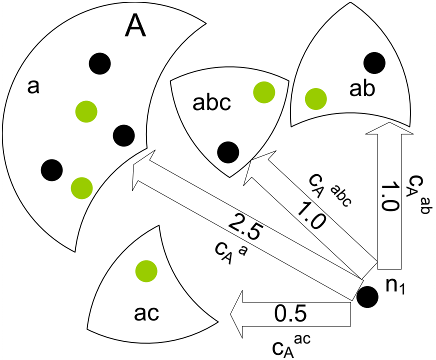
- Select targets for repairs from *intersections*, not groups

Regional Selection



- Select targets for repairs from *intersections*, not groups
- From each intersection, select proportional fraction of c_A:
  $c_A^x = \frac{|x|}{|A|} \cdot c_A$

Regional Selection



- Select targets for repairs from *intersections*, not groups
- From each intersection, select proportional fraction of c_A: $c_A^x = \frac{|x|}{|A|} \cdot c_A$

$$latency \propto \frac{1}{\sum_s \sum_g datarate}$$

data rate: across all senders, in intersections of groups

Systems Issues

- Overheads:
  - Membership State:
    # of intersections $<$ # of known nodes.
  - Computational:
    XORs are fast... 150-300 ms per packet.
  - Bandwidth:
    $(r, c) \implies \frac{c}{r+c}$ repair overhead.
- Group Membership Service: Any old one works.

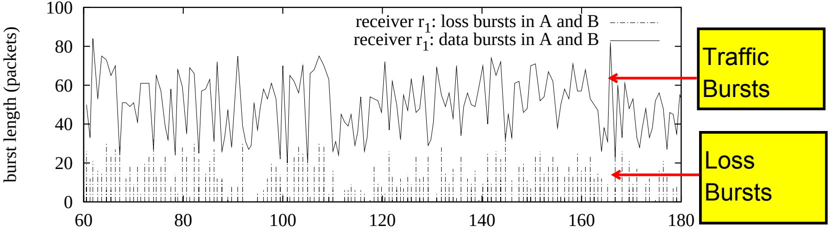
Experimental Evaluation

- Cornell Cluster: 64 1.3 Ghz nodes
- Java Implementation running on Linux 2.6.12
- Three Loss Models: {Uniform, Burst, Markov}
- Grouping Parameters: $g * s = d * n$
  - g: Number of Groups in System
  - s: Average Size of Group
  - d: Groups joined by each Node
  - n: Number of Nodes in System
- Each node joins d randomly selected groups from g groups

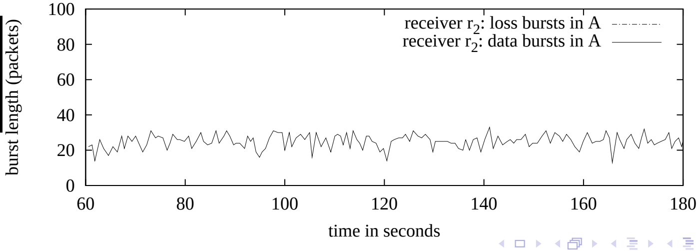
Where does loss occur in a Datacenter?

Packet Loss occurs at end-hosts: independent and bursty

Overloaded Node

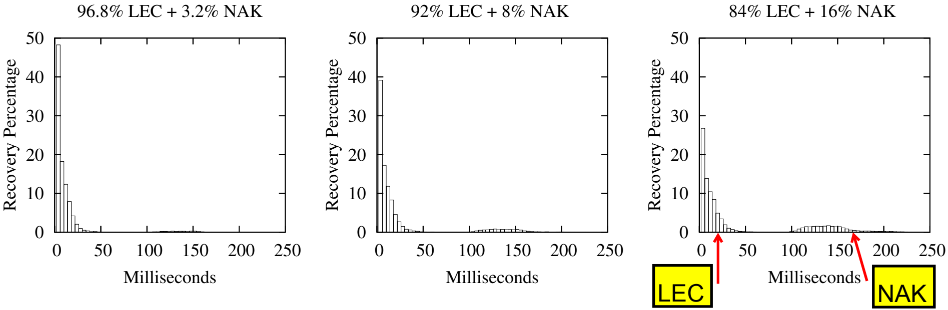


Lightly Loaded Node



Distribution of Recovery Latency

16 Nodes, 128 groups per node, 10 nodes per group, Uniform *% Loss



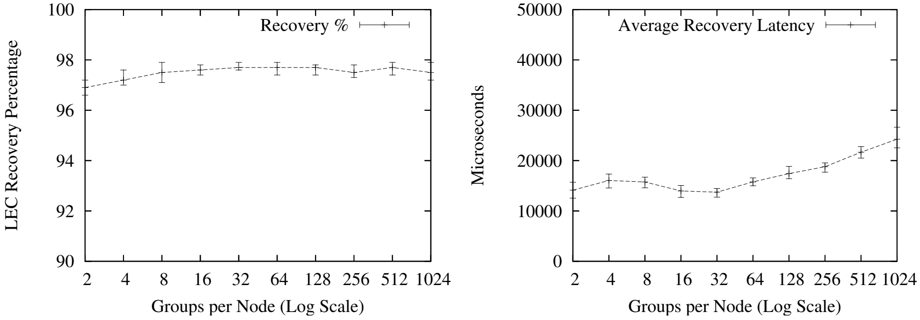
(a) 10% Loss Rate **(b) 15% Loss Rate** **(c) 20% Loss Rate**

Most lost packets recovered $<$ 50ms by LEC.
Remainder via reactive NAKs.

Claim: Ricochet is *reliable* and *time-critical*.

Scalability in Groups

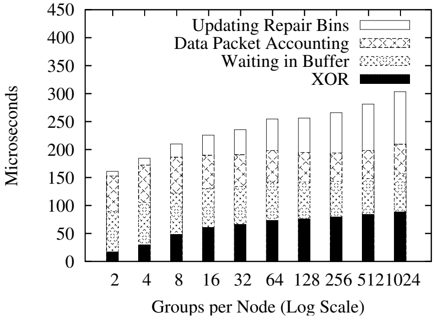
64 nodes, * groups per node, 10 nodes per group, Loss Model: Uniform 1%

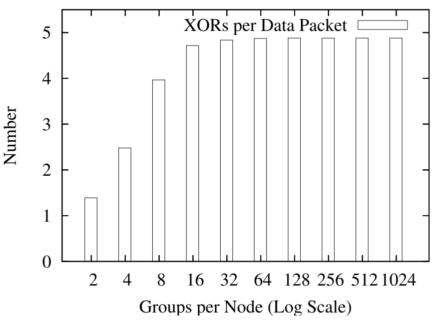


Claim: Ricochet *scales* to hundreds of groups. Comparison: at 128 groups, SRM latency was 8 seconds. 400 times slower!

CPU time and XORs per data packet

64 nodes, * groups per node, 10 nodes per group, Loss Model: Uniform 1%



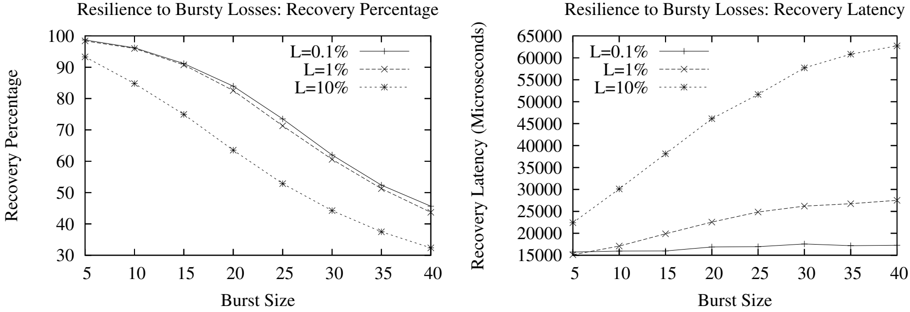


Claim: Ricochet is *lightweight*

$\Longrightarrow$ Time-Critical Apps can run over it

Resilience to Burstiness

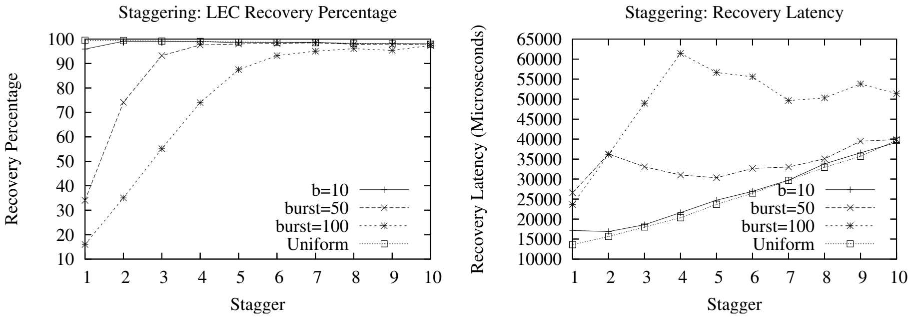
64 nodes, 128 groups per node, 10 nodes per group, Loss Model: Bursty 1%



... can handle short bursts (5-10 packets) well. Good enough?

Staggering

64 nodes, 128 groups per node, 10 nodes per group, Loss Model: Bursty 1%



Stagger of *i*: Encode every *i*th packet

Stagger 6, burst of 100 packets $\Longrightarrow$ 90% recovered at 50 ms!

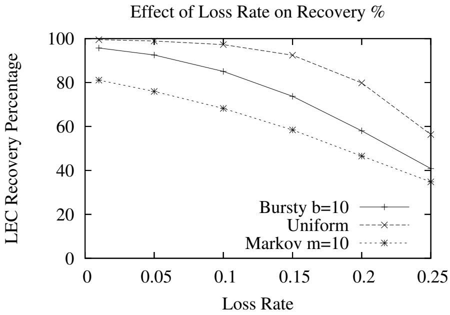
Conclusion

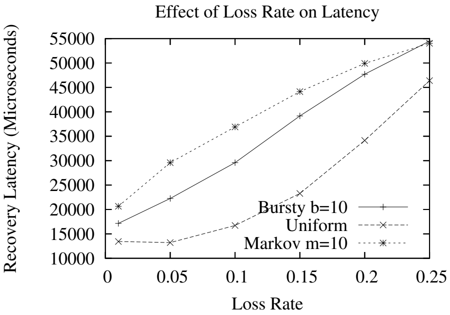
- Multicast in Datacenters:
  - large numbers of low-rate groups
  - aggregate load can be high, causing packet loss
- Ricochet is the first protocol to scale in the *number of groups* in the system
- Layered under high-level platforms: Tempest, Axis2
- Available for download: http://www.cs.cornell.edu/projects/quicksilver/Ricochet.html

Overflow

Impact of Loss Rate on LEC

64 nodes, 128 groups per node, 10 nodes per group, Loss Model: *





Works well at typical datacenter loss rates: 1-5%