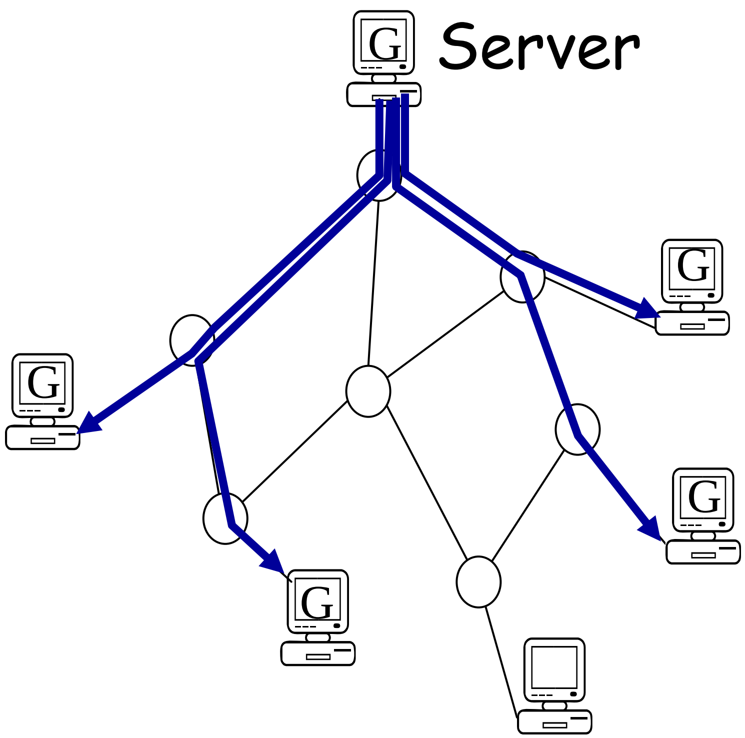
Multicast and Scribe

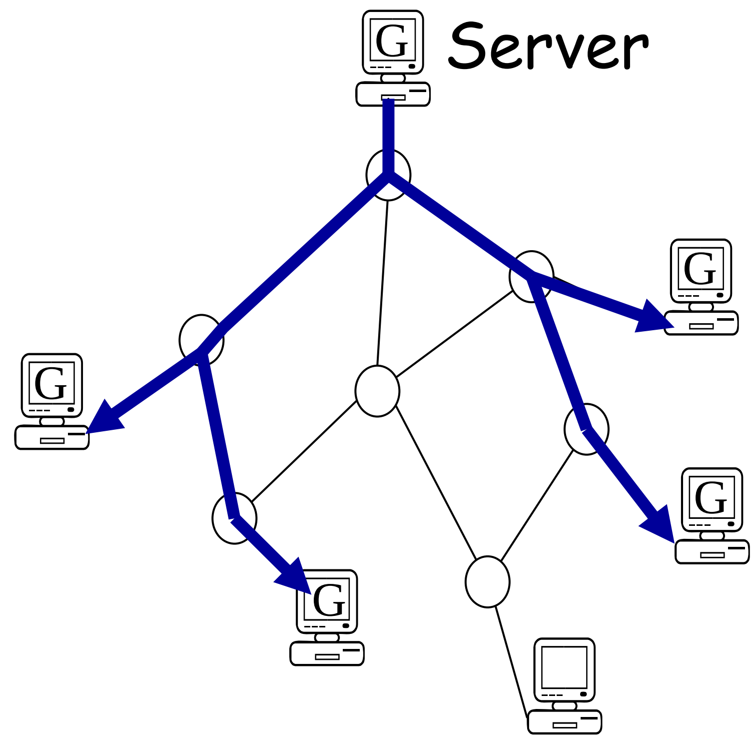
Jeff Chase
Duke University
(Thanks to Adolfo Rodriguez and Ben Zhao)

Multicast Trees

The basic idea



Multiple unicasts



Single multicast

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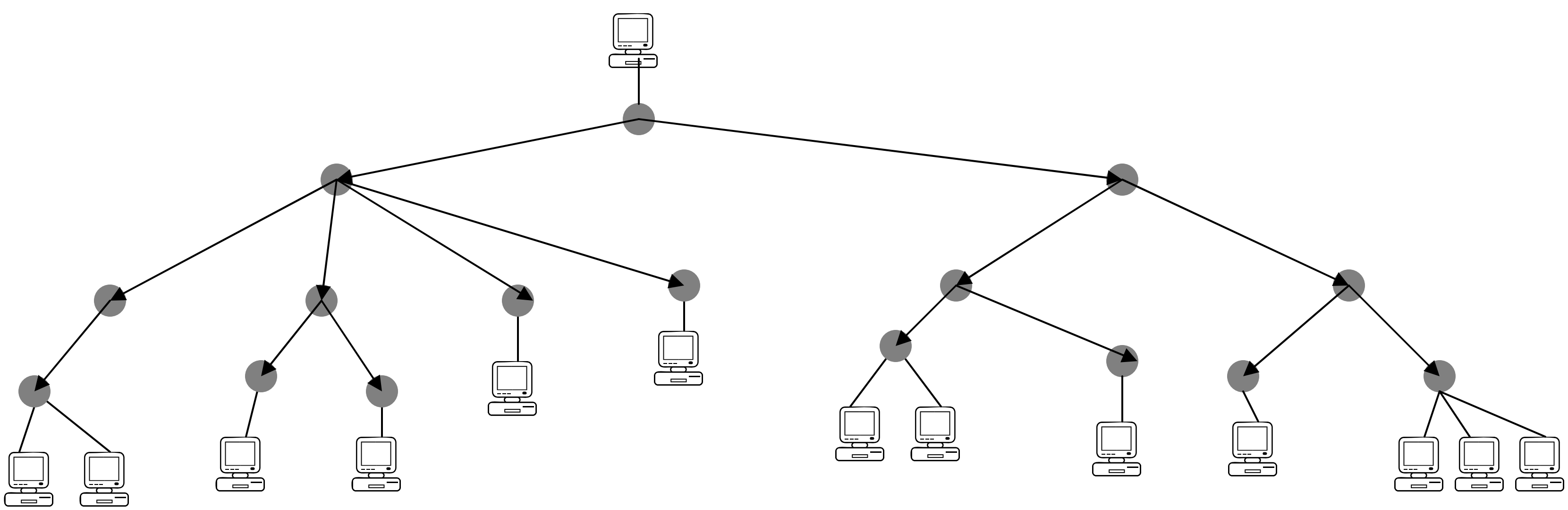
Applications that need multicast

- One way, single sender: "one-to-many"
  - TV – streaming apps (NCAA games)
  - Non-interactive learning
  - Database update
  - Information dissemination

- Two way, interactive, multiple sender: "many-to-many"
  - Teleconference
  - Interactive learning

Multicast Routing

- Naïve approach: flooding (controlled broadcast)
- Better: form a *spanning tree* with the sender at the root, spanning all the members of a multicast group.



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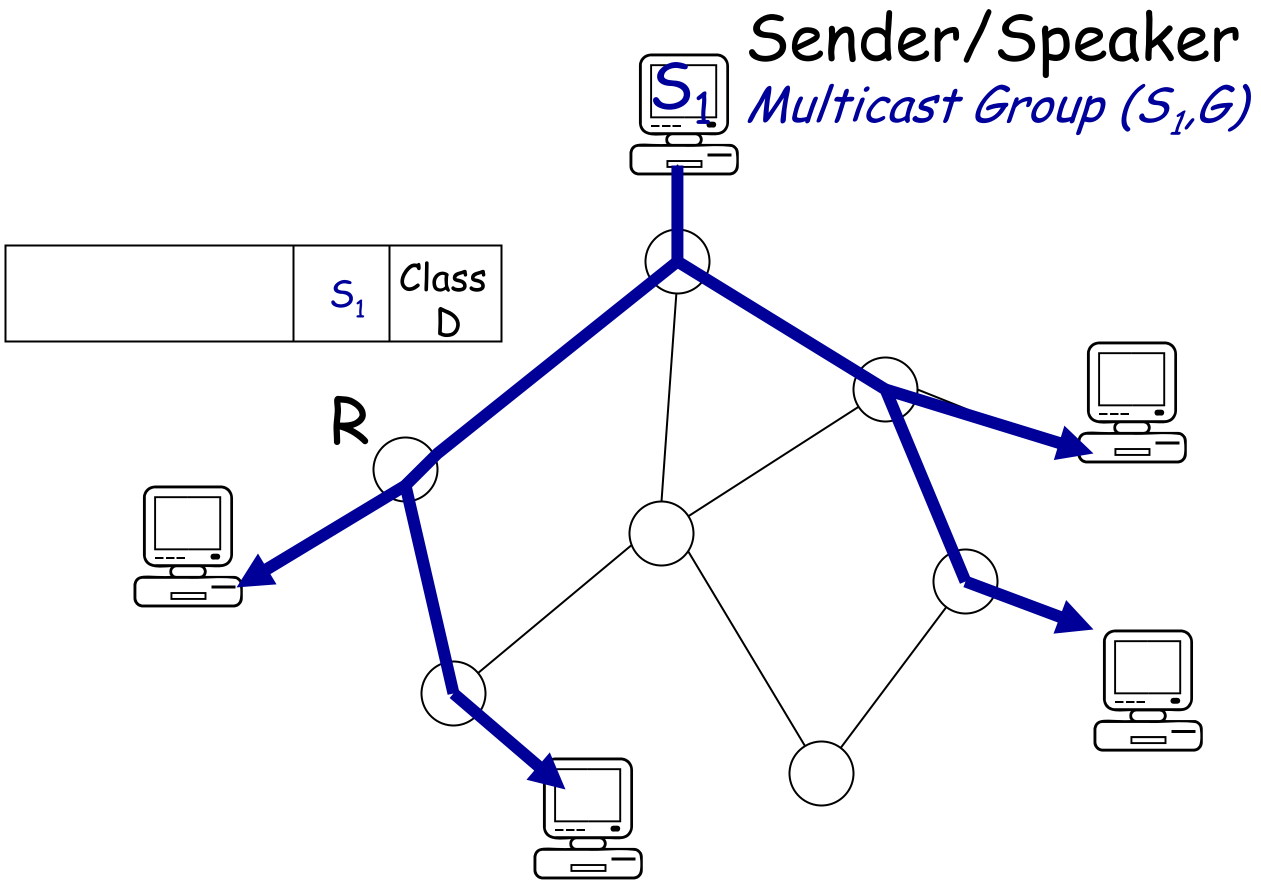
Multicast Trees

e.g. a teleconference



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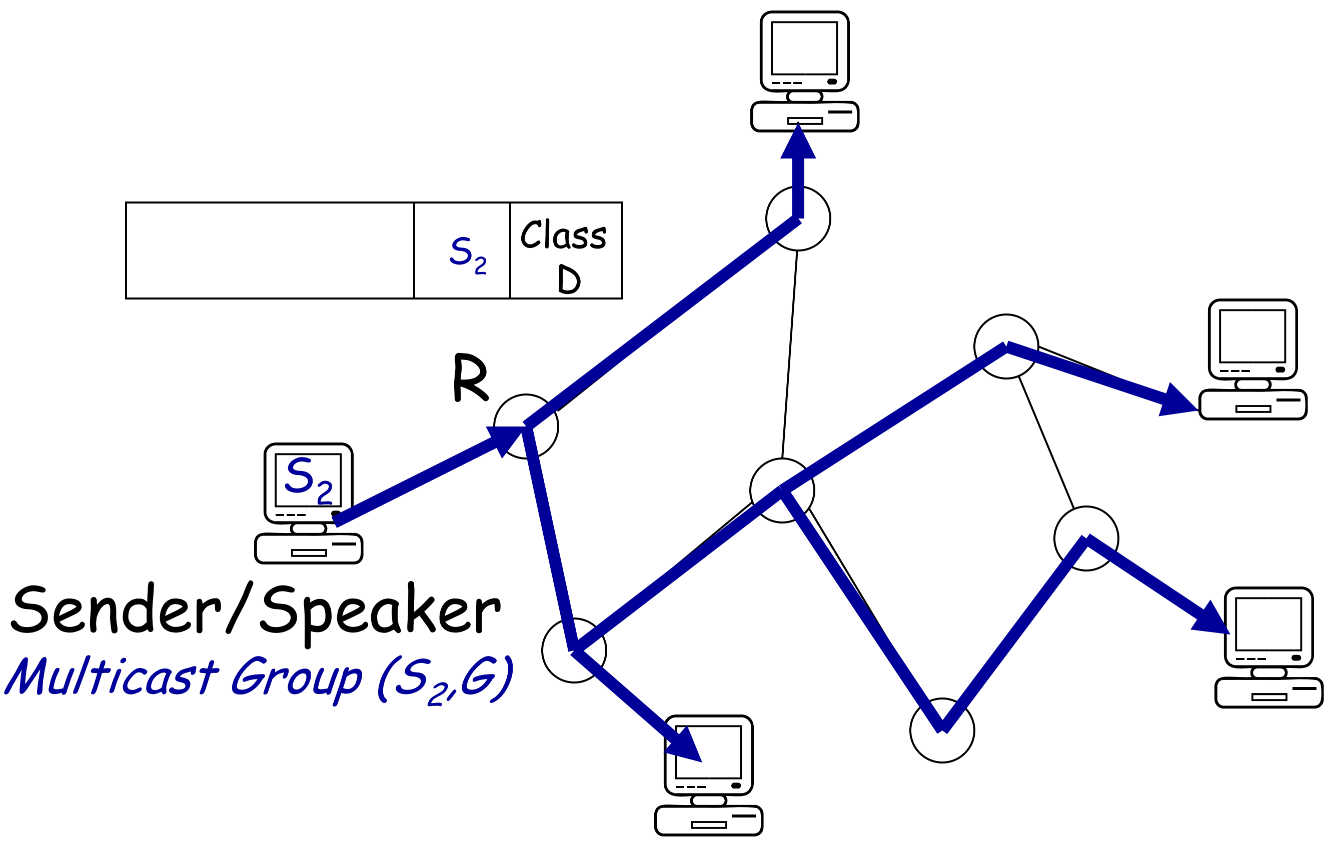
Multicast Trees

Multiple source trees



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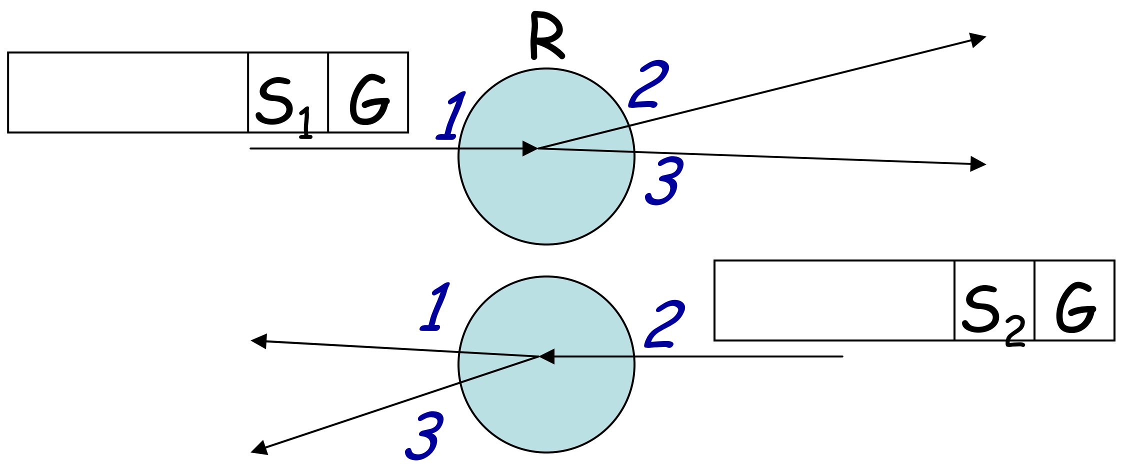
Multicast Forwarding is Sender-specific

Group Address	Src Address	Src Interface	Dst Interface
G	S_1 S_2	1 2	2,3 1,3
⋮	⋮	⋮	⋮



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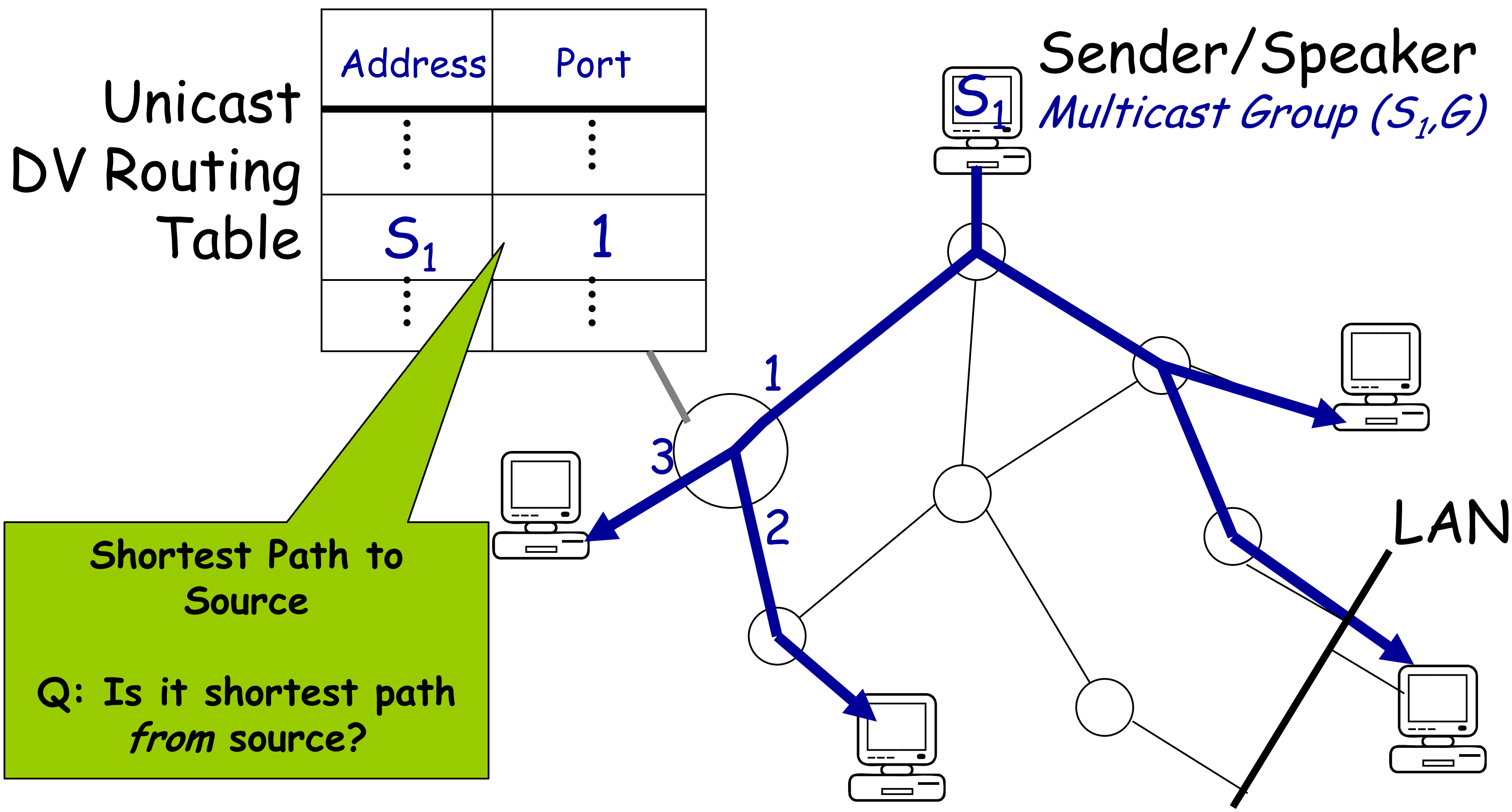
Distance-vector Multicast

RPB: Reverse-Path Broadcast

- Uses existing unicast shortest path routing table.
- If packet arrived through interface that is the shortest path to the packet's SA, then forward packet to all interfaces.
- Else drop packet.

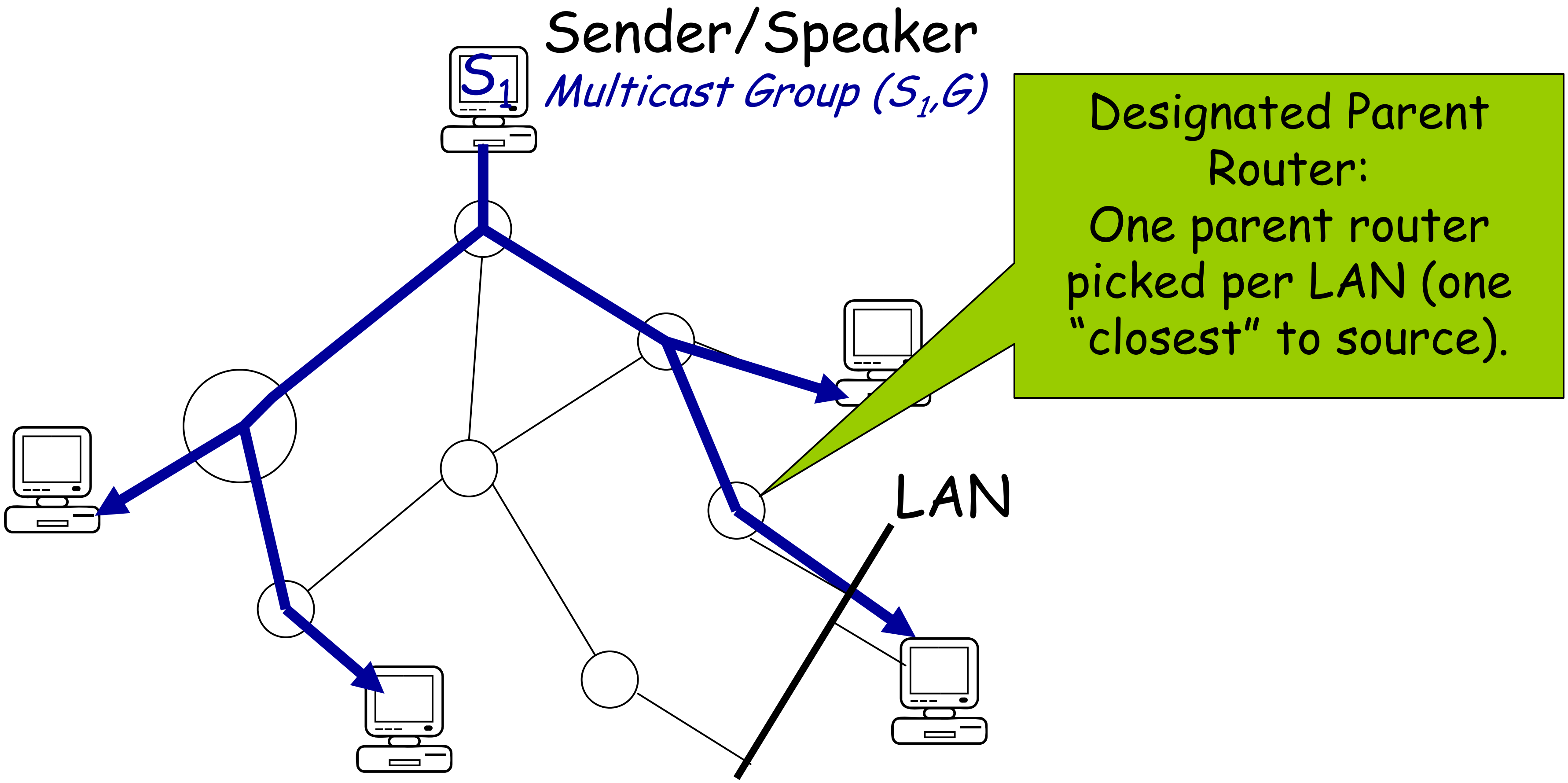
Distance-vector Multicast

RPB: Reverse-Path Broadcast



Distance-vector Multicast

RPB: Reverse-Path Broadcast



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Distance-vector Multicast

RPM: Reverse-Path Multicast

- RPM = RPB + Prune
- RPB used when a source starts to send to a new group address.
- Routers that are not interested in a group send prune messages up the tree towards source.
- Prunes sent implicitly by not indicating interest in a group.
- DVMRP works this way.

IP Multicast: Trees and Addressing

- All members of the group share the same "Class D" Group Address.
- An end-station "joins" a multicast group by (periodically) telling its nearest router that it wishes to join (uses IGMP – Internet Group Management Protocol).
  - An end station may join multiple groups.
- Routers maintain "soft state" indicating which end-stations have subscribed to which groups.
- IGMP itself does not deal with the multicast routing problem.
  - DVMRP, PIM

Link State Multicast

- MOSPF (Multicast OSPF)
- Use IGMP to determine LAN members
- Flood topology/group changes
- Each router gets complete topology, group membership
  - Compute shortest path spanning tree
  - Recompute tree every time topology changes
  - Add/delete links if membership changes
- Scalability concerns similar to OSPF
  - Overhead of flooding

Protocol Independent Multicast

- PIM-DM (Dense Mode) uses RPM.
- PIM-SM (Sparse Mode) designed to be more efficient that DVMRP.
  - Routers explicitly join multicast tree by sending unicast Join and Prune messages.
  - Routers join a multicast tree via a RP (rendezvous point) for each group.
  - Several RPs per domain (picked in a complex way).
  - Provides either:
    - Shared tree for all senders (default).
    - Source-specific tree.

Multicast: Issues

- How to make multicast reliable?
- What service model, e.g., delivery ordering?
  - Much work in group communication (CATOCS)
- How to implement flow control?
- How to support/provide different rates for different end users?
- How to secure a multicast conversation?
- What does end-to-end mean here?
- Will IP multicast become widespread?

The End-to-end Challenge

- Keep the network simple & robust
- Rely upon end-to-end adaptation
- Layer reliability on top of IP multicast…or not
- Unlike TCP, RM has to cope with
  - Scale
  - Heterogeneity among receivers
- Been trying for a decade
  - This is a HARD problem

Application-Layer Multicast

- IP multicast is not enough.
  - Inter-domain multicast routing not widely deployed.
  - Topology-aware, but not reliable.
  - No success in deploying Reliable Internet Multicast
- Interest in overlay multicast began with Hui Zhang@CMU, and a few others, in late 1990s.
  - Conference telecasts, etc.
  - Now dozens of papers
- Several deployed systems and broadcast/multicast services offered by CDNs.
- Single-source, multi-source, meshes, speed differences, reliability, resource management, etc.
- How to structure the overlay?

Scribe

- Scribe is a scalable application-level multicast infrastructure built on top of Pastry
- Provides topic based publish-subscribe service.
  - Provides best-effort delivery of multicast messages
  - Fully decentralized
  - Supports large number of groups
  - Supports groups with a wide range of size
  - High rate of membership turnover (churn?)

API's for Scribe

Pastry's API

- Pastry exports
  - Route(msg, key)
  - Send(msg, IPAddr)
- Application's build on Pastry must exports
  - Deliver(msg, key)
  - Forward(msg, key, nextid)

Scribe's API

- Create(credentials, topicId)
- Subscribe(credentials, topicId, evtHandler)
- Unsubscribe(credentials, topicId)
- Publish(credentials, topicId, event)

Scribe API

- *create (credentials, group-id)*
  - create a group with the group-id
- *join (credentials, group-id, message-handler)*
  - join a group with group-id.
  - Published messages for the group are passed to the message handler
- *leave (credentials, group-id)*
  - leave a group with group-id
- *multicast (credentials, group-id, message)*
  - publish the message within the group with group-id

credentials are used throughout for access control.

The Pastry API

- Operations exported by Pastry
  - nodeId = pastryInit(Credentials,Application)
  - route(msg,key)
- Operations exported by the application working above Pastry
  - deliver(msg,key)
  - forward(msg,key,nextId)
  - newLeafs(leafSet)

Scribe on Pastry

- Use Pastry to manage topic/group creation, subscription, and to build a per-topic multicast tree used to disseminate the events published in the topic.
- topicId = hash(topic name + creator name). Hash function should be collision resistant. E.g., SHA-1
- Each topic will have a rendezvous point, which is a node with nodeid closest to the topicId.
  - Replicate across the leaf set
- Multicast tree is rooted at the rendezvous point.
  - Union of all Pastry/DHT paths from group members to the rendezvous point.
  - Do DHT/Pastry proximity heuristics result in an efficient multicast tree?

Pastry

- Routes based on 'digits'
- Similar to Chord, CAN, and Tapestry
- Each hop takes you one digit closer to your destination
- Improves on locality by finding the 'closest' node to you with the same prefix
- Number of nodes from which decreases exponentially as you get closers to the destination

Pastry: Properties

- *NodeId* randomly assigned from $\{0, .., 2^{128}-1\}$
- *b*, |*L*| are configuration parameters

Under normal conditions:

1. *A* pastry node can route to the numerically closest node to a given key in less than $\boldsymbol{log_{2^b} N}$ steps
2. Despite concurrent node failures, delivery is guaranteed unless more than ***|L|/2*** nodes with adjacent NodeIds fail simultaneously
3. Each node join triggers $\boldsymbol{O(log_{2^b} N)}$ messages

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Pastry Node State

Leaf set

	SMALLER	LARGER	
10233033	10233021	10233120	10233122
10233001	10233000	10233230	10233232

Set of nodes with |L|/2 smaller and |L|/2 larger numerically closest NodeIds

Routing table

-0-2212102	1	-2-2301203	-3-1203203
0	1-1-301233	1-2-230203	1-3-021022
10-0-31203	10-1-32102	2	10-3-23302
102-0-0230	102-1-1302	102-2-2302	3
1023-0-322	1023-1-000	1023-2-121	3
10233-0-01	1	10233-2-32	
0		102331-2-0	
		2	

Prefix-based routing entries

Neighborhood set

13021022	10200230	11301233	31301233
02212102	22301203	31203203	33213321

|M| “physically” closest nodes

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Pastry: Routing Table

- *NodeIds* are in base 2^b
- Several rows – one for each prefix of local NodeId ($Log_{2^b} N$ populated on average)
- 2^b – 1 columns – one for each possible digit in the NodeId representation

b defines the tradeoff:

$(Log_{2^b} N) \times (2^b - 1)$ entries Vs. $Log_{2^b} N$ routing hops

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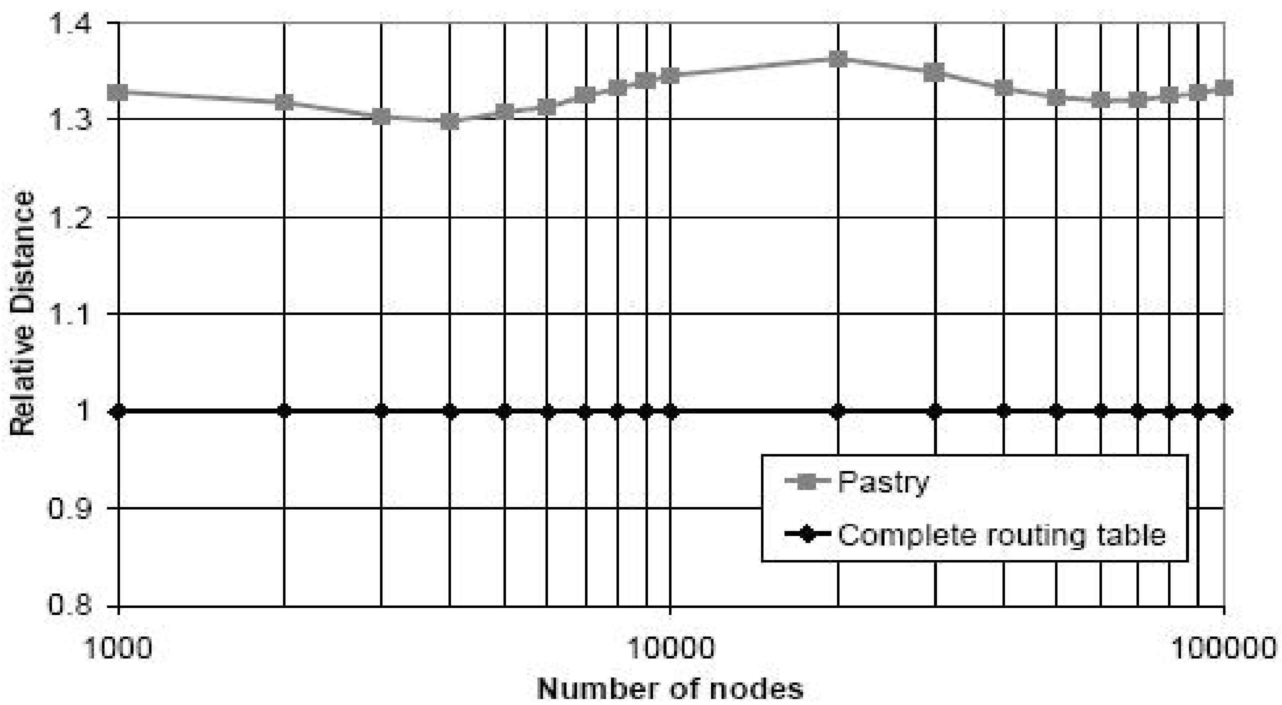
Pastry Proximity

- Application provides the “distance” function
- Invariant: “All routing table entries refer to a node that is near the present node, according to the proximity metric, among all live nodes with an appropriate prefix”
- Invariant maintained on self-organization

Messaging Distance



b=4; |L|=16; |M|=32; 200,000 lookups; Random end points

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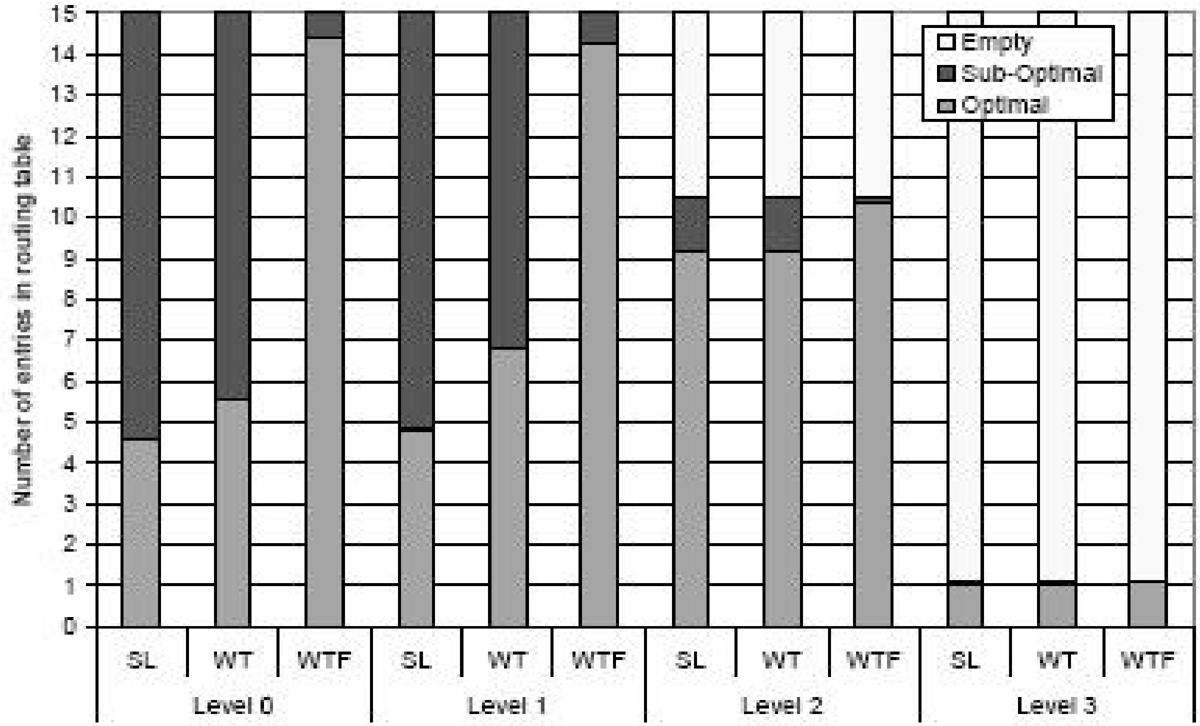
Quality of Routing Tables



b=4; |L|=16; |M|=32; 5000 New Nodes

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Scribe Node

A Scribe node

- May create a group
- May join a group
- May be the root of a multicast tree
- May act as a multicast source

Scribe messages

- Scribe messages
  - CREATE
    - create a group
  - JOIN
    - join a group
  - LEAVE
    - leave a group
  - MULTICAST
    - publish a message to the group

Scribe Group

- A Scribe group
  - Has a unique group-id
  - Has a multicast tree associated with it for dissemination of messages
  - Has a rendezvous point which is the root of the multicast tree
  - May have multiple sources of multicast messages

Scribe Multicast Tree

- Scribe creates a per-group multicast tree rooted at the rendezvous point for message dissemination
- Nodes in a multicast tree can be
  - Forwarders
    - Non-members that forward messages
    - Maintain a children table for a group which contains IP address and corresponding node-id of children
  - Members
    - They act as forwarders and are also members of the group

Create Group

- Create Group
  - Scribe node sends a CREATE message with the group-id as the key
  - Pastry delivers the message to the node with node-id numerically closest to group-id, using *deliver* method
  - This node becomes the rendezvous point
  - *deliver* method checks and stores credentials and also updates the list of groups

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GroupID

- Is the hash of the group's textual name concatenated with its creator's name
- Making creator the Rendez-Vous point
  - Pastry nodeID be the hash of the textual name of the node and a groupID can be the concatenation of the nodeID of the creator and the hash of the textual name of the group
- They claim this improves performance with good choice of creator

Join Group

- Join Group
  - Scribe node sends a JOIN message with the group-id as the key
  - Pastry routes this message to the rendezvous point using *forward* method
    - If an intermediate node is already a forwarder
      - adds the node as a child
    - If an intermediate node is not a forwarder
      - creates a child table for the group, and adds the node
      - sends a JOIN towards the rendezvous point.
    - terminates the JOIN message from the child

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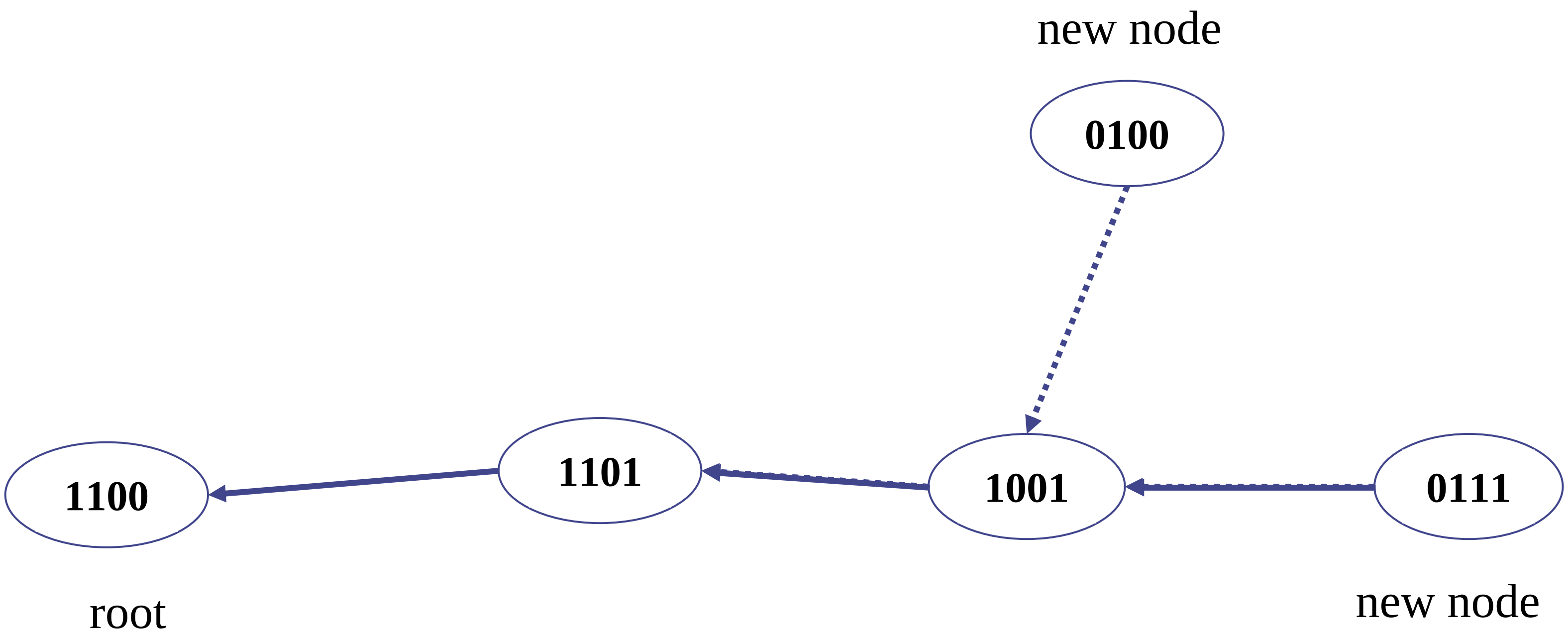
Join group



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Leave Group

- Leave Group
  - Scribe node records locally that it left the group
  - If the node has no children in its table, it sends a LEAVE message to its parent
    - The message travels recursively up the multicast tree
    - The message stops at a node which has children after removing the departing node

```
forward(msg, key, nextID)
    switch msg.type is
        JOIN: if !(msg.group in groups)
                    group = groups U msg.group
                    route(msg,msg.group)
              groups[msg.group].children U msg.source
              nextId = null // Stop routing original message
```

```
deliver(msg, key)
    switch msg.type is
        CREATE:  groups = groups U msg.group
        JOIN: groups[msg.group].children U msg.source
        MULTICAST: ∀ node in groups[msg.group].children
                   send(msg, node)
                   if memberOf(msg.group)
                        invokeMsgHandler(msg.group, msg)
        LEAVE:     groups[msg.group].children -= msg.source
                   if (|groups[msg.group].children| = 0)
                        send(msg.groups[msg.group].parent
```

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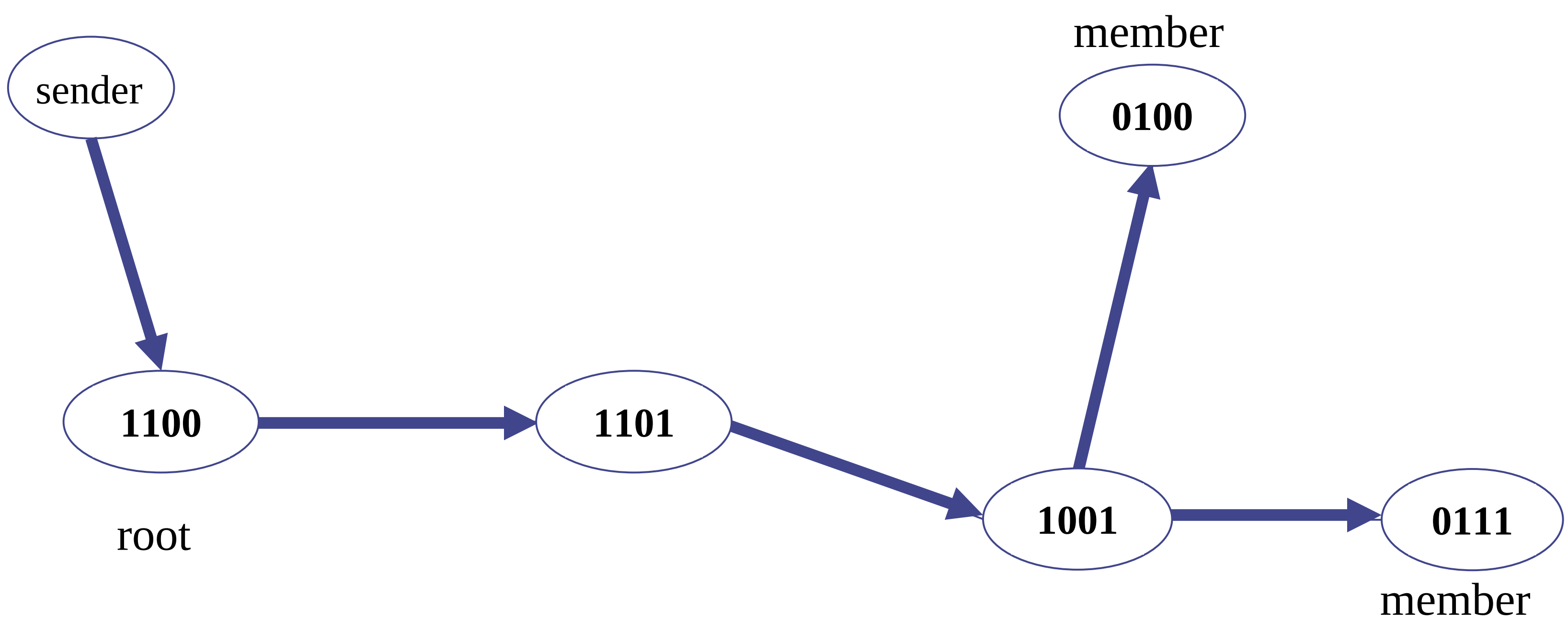
Multicast Message

- Multicast a message to the group
  - Scribe node sends MULTICAST message to the rendezvous point
  - A node caches the IP address of the rendezvous point so that it does not need Pastry for subsequent messages
  - Single multicast tree for each group
  - Access control for a message is performed at the rendezvous point

Multicast message



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Multicast Tree Repair I

- Broken link detection and repair
  - Non-leaf nodes send heartbeat message to children
  - Multicast messages serve as implicit heartbeat
  - If child does not receive heartbeat message
    - assumes that the parent has failed
    - finds a new route by sending a JOIN message to the group-id, thus finding a new parent and repairing the multicast tree

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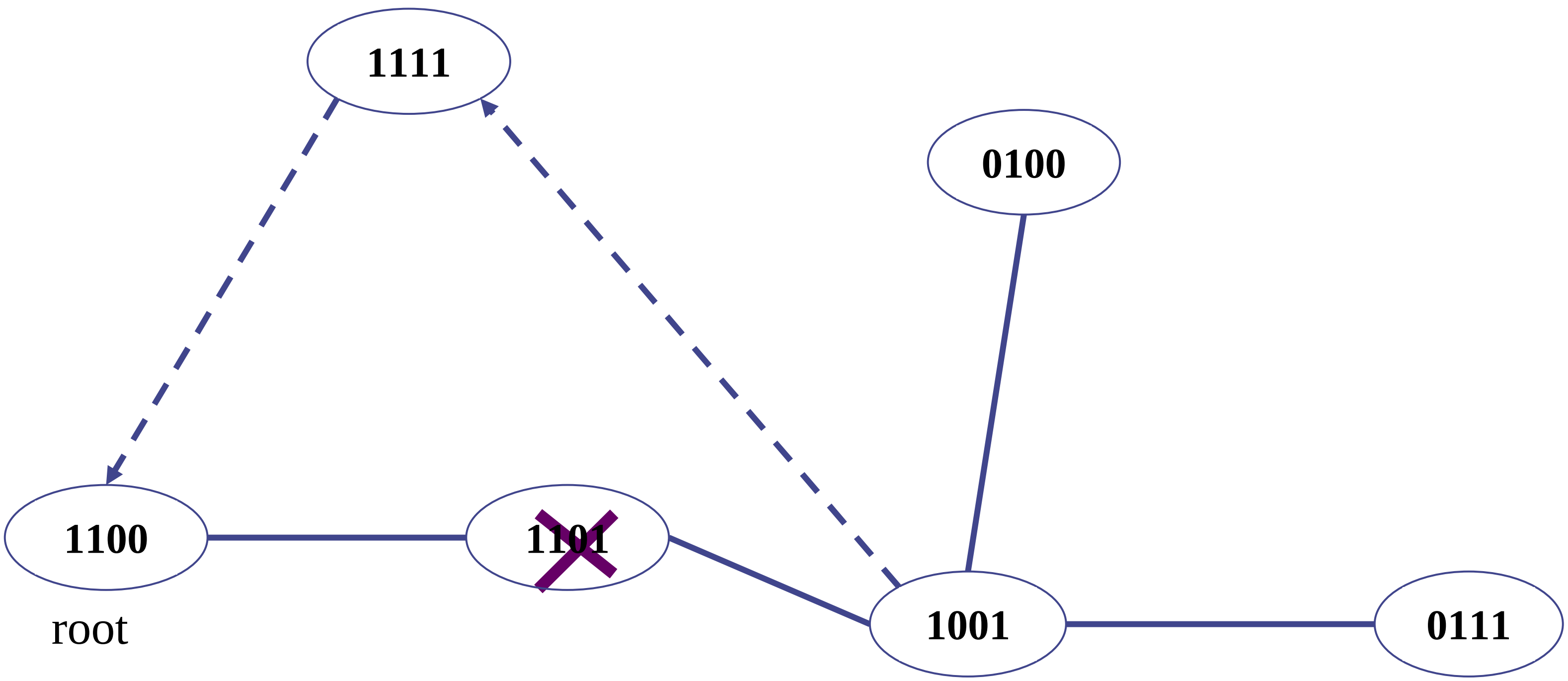
Multicast Tree Repair



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Reliablity

- Non-leaf nodes in the tree sends HeartBeat (HB) msgs to its children.
- If a node fails to receive HB msgs, it routes a (SUBSCRIBE, topicId) msg and attach to a new parent.
- Avoid root failure by replicating the topicId across k closest nodes to the root node in the nodeid space.
- Children table entries are discarded unless refresh msgs received from children periodically.
- Scribe provides best-effort service, events may be out of order. Reliable services can be built on top of Scribe.

Multicast Tree Repair II

- Rendezvous point failure
  - The state associated with a rendezvous point is replicated across *k* closest nodes
  - When the root fails, the children detect the failure and send a JOIN message which gets routed to a new node-id numerically closest to the group-id

- Fault detection and recovery is local and accomplished by sending minimal messages

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Stronger Reliability

- Scribe provides reliable, ordered delivery only if there are no faults in the multicast tree
- Scribe provides a mechanism to implement stronger reliability
  - Applications built on top of Scribe should provide implementation of certain upcall methods to implement stronger reliability…

Reliability API

- *forwardHandler(msg)*
  - invoked by Scribe before the node forwards a multicast message to its children
- *joinHandler(JOINmsg)*
  - invoked by Scribe after a new child has been added to one of the node's children tables
- *faultHandler(JOINmsg)*
  - invoked by Scribe when a node suspects that its parent is faulty

The messages can be modified or buffered in these handlers to implement reliability

Example, Reliable delivery

- *forwardHandler*
  - Root assigns a sequence number to each message, such that messages are buffered by root and nodes in multicast tree
- *faultHandler*
  - Adds the last sequence number, *n*, delivered by the node to the JOIN message
- *joinHandler*
  - Retransmits buffered messages with sequence numbers above *n* to new child

Messages must be buffered for an amount of time that exceeds the maximal time to repair the multicast tree after a TCP connection breaks.

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Scribe Results

- Experiments
  - Compare the delay, node and link load with IP multicast
  - Scalability test with large number of small groups
- Setup
  - Network topology with 5050 routers GaTech random graph generator using transit-stub model
  - Number of scribe nodes: 100,000
  - Number of groups: 1500
  - Group Size: minimum 11 maximum 100,000

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Methodological Issues

- Simulation via their own packet-level simulator
- Only considers propagation delay
- Does not take into account queuing delay or packet losses!
- 100,000 nodes!
- Created 1,500 with very varied group sizes

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Delay Penalty

- Delay Penalty
  - Measured the distribution of delays to deliver a message to each member of a group using both Scribe and IP multicast
  - Measure Ratio of Average Delay (RAD)
    - 50% groups 1.68
    - max: 2
  - Measure Ratio of Maximum Delay (RMD)
    - 50% of groups: 1.69
    - Max: 4.26
- The message delivery delay is more in Scribe compared to IP Multicast
  - Only in 2.2% of groups it is lower

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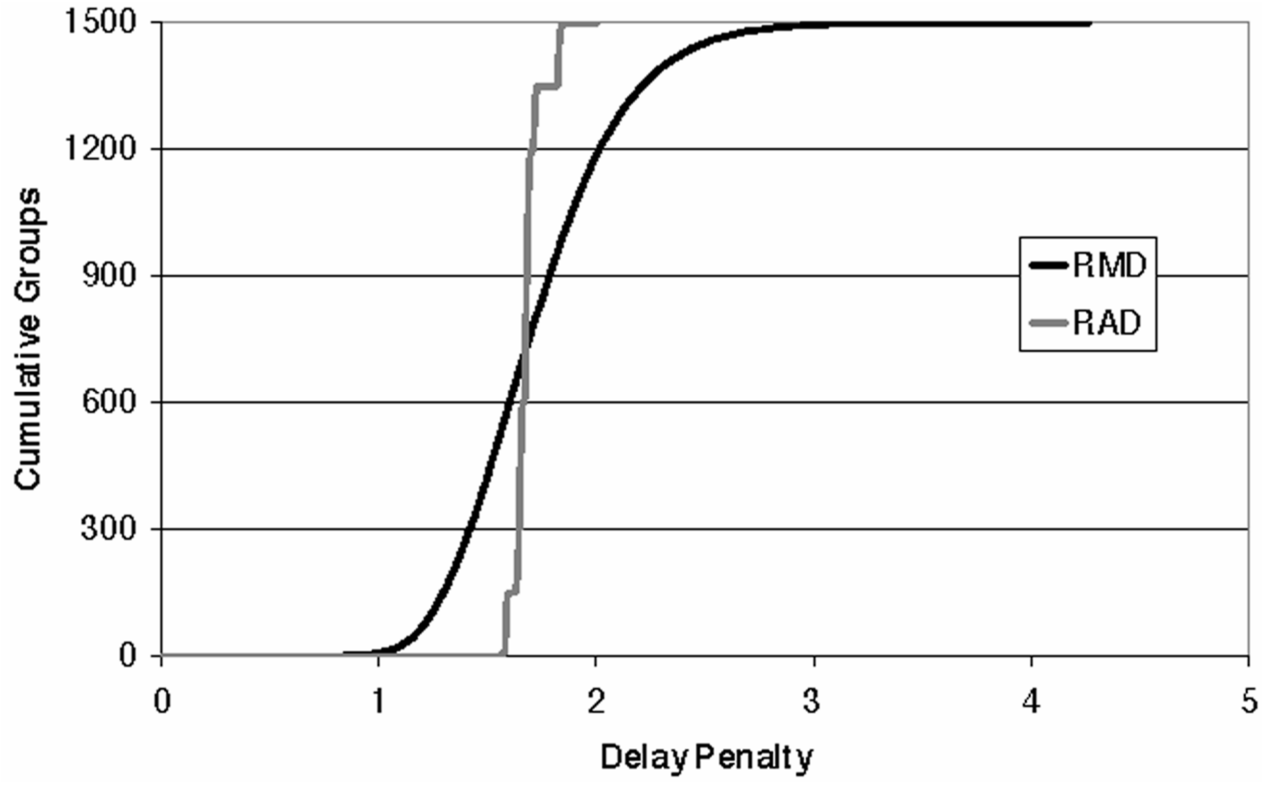
Delay Penalty



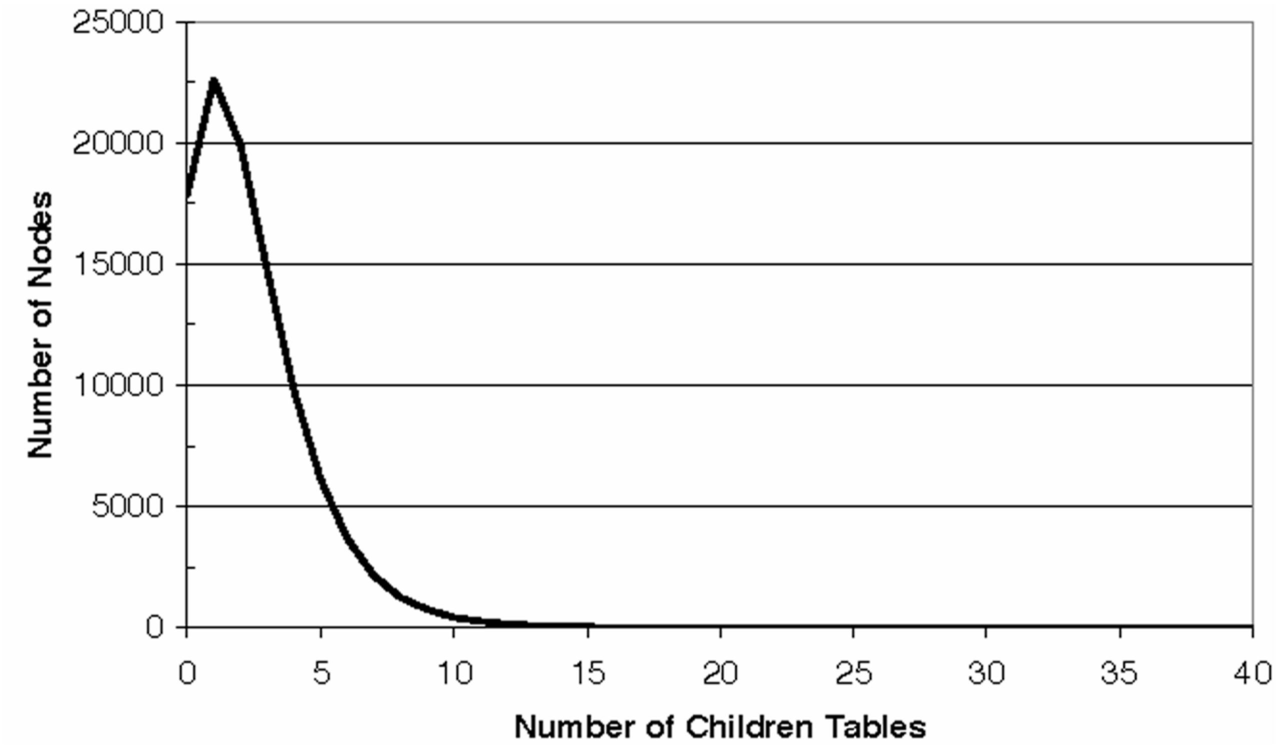
Cumulative distribution delay penalty relative to IP multicast per group
(standard deviation was 62 for RAD and 21 for RMD)

Node Stress

- Node Stress
  - Measure the number of groups with non-empty children tables for each node
  - Measure the number of entries in the children table in each node

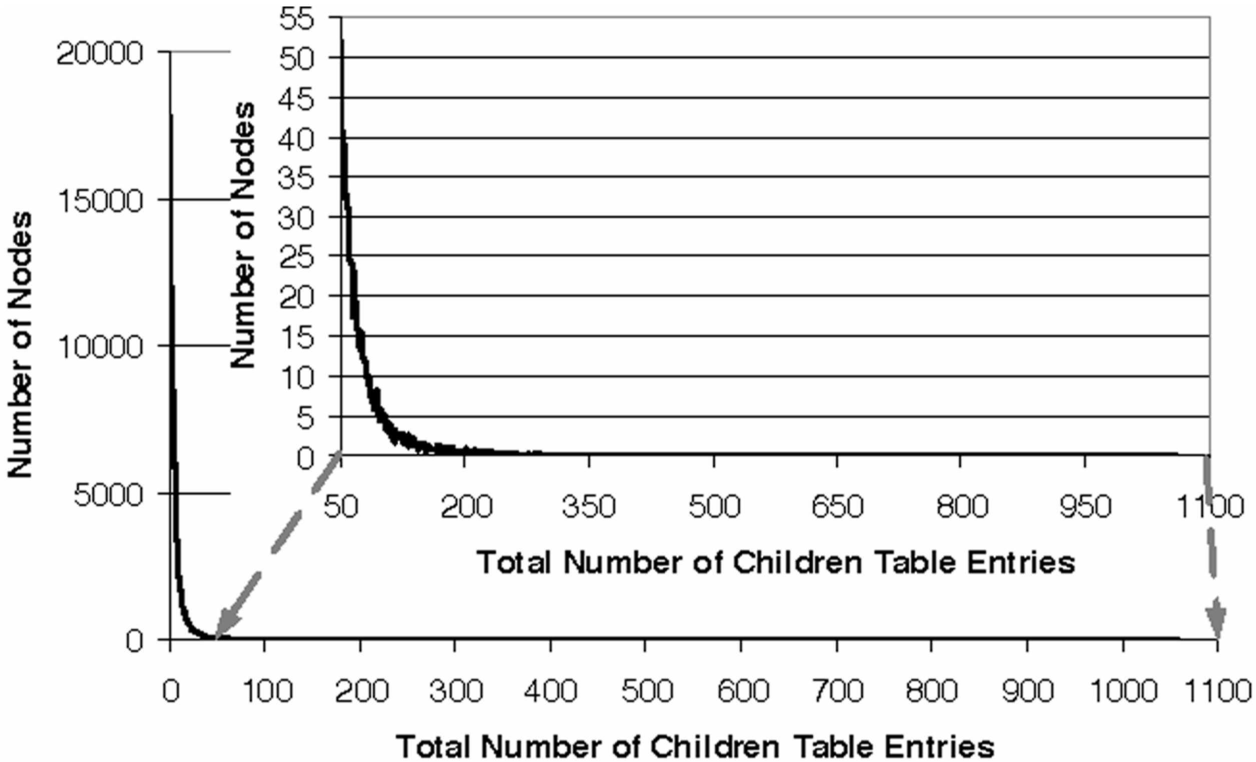
  The mean number of non-empty children tables per node is only 2.4 although there are 1500 groups, median is 2
- Results indicate Scribe does a good job of partitioning and distributing the load. This is one of the factors that ensures scalability.

Node Stress I



Number of children pre Scribe node
(average standard deviation was 58)

Node Stress II



Number of table entries per Scribe node
(average standard deviation was 3.2)

Link Stress

- Link Stress
  - Measure the number of packets that are sent over each link when a message is multicast to each of the 1500 groups

  Measured mean number of messages per link

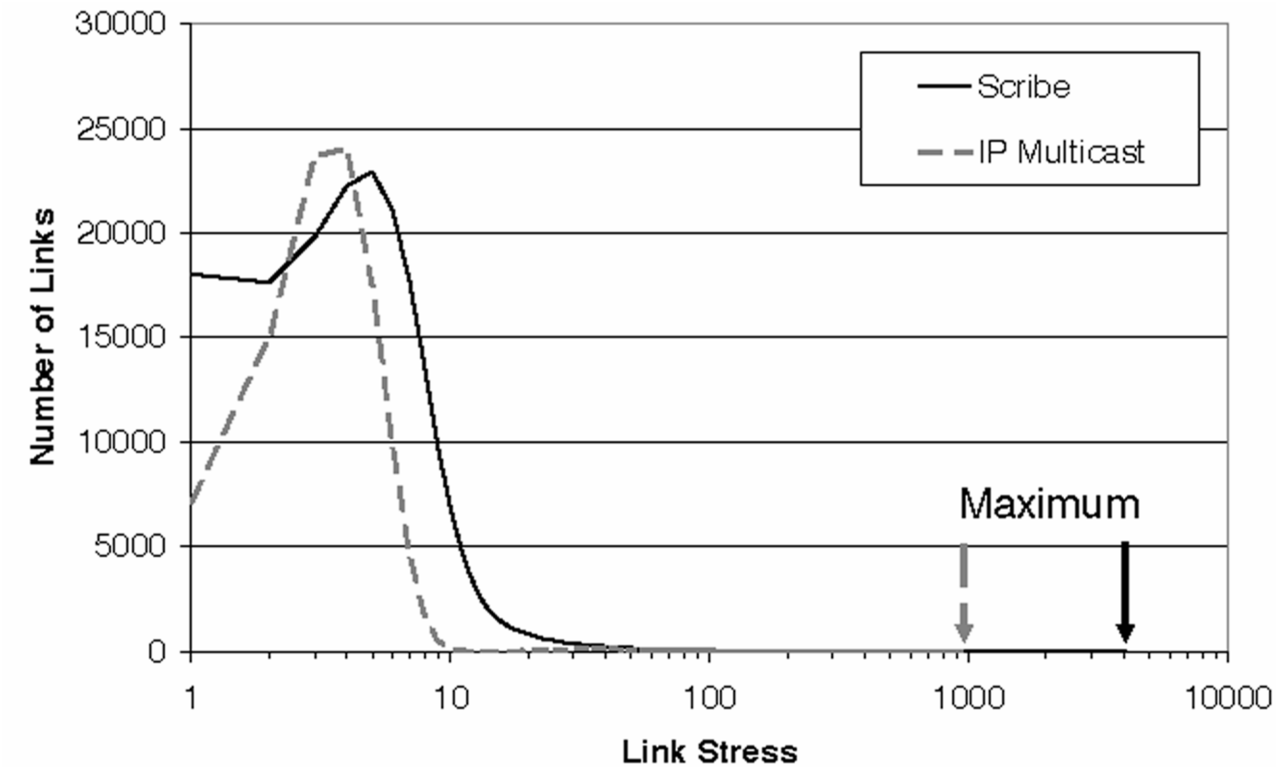
    - Scribe : 2.4
    - IP Multicast : 0.7

  Maximum link stress

    - Scribe: 4031
    - IP multicast: 950

  Scribe Link stress = 4 x IP Multicast Stress

Link Stress

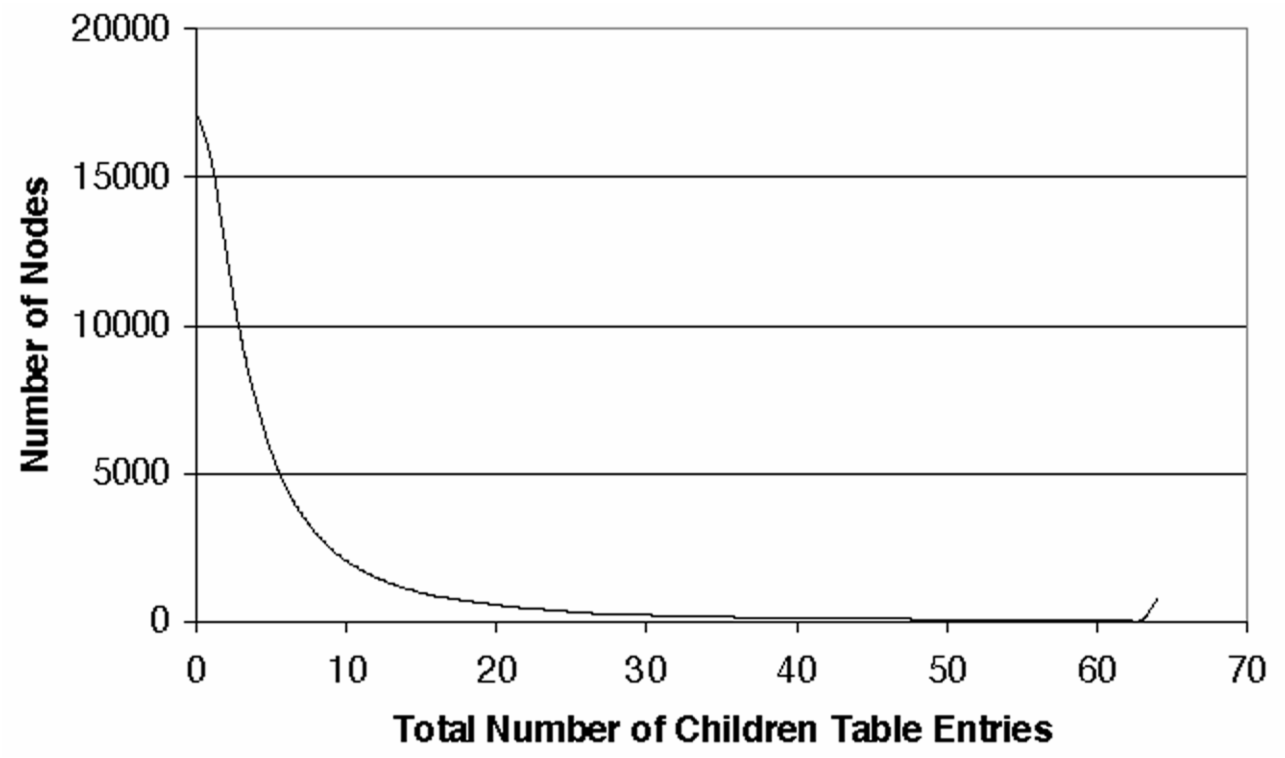


Link stress for multicasting a message to each of 1,500 groups
(average standard deviation was 1.4 for Scribe and 1.9 for IP multicast)

Bottleneck Remover

- All nodes may not have equal capacity in terms of computational power and bandwidth
- Under high load conditions, the lower capacity nodes become bottlenecks
- Solution: Offload children to other nodes
  - Choose the group that uses the most resources
  - Choose a child of this group that is farthest away
  - Ask the child to join its sibling which is closest in terms of delay
- This gives an improved performance
- Increases link stress for joining

Bottleneck Remover



Number of children table entries per Scribe node with the bottleneck remover
(average standard deviation was 57)

Scalability Test

- Scalability test with many small groups
  - 30000 groups with 11 members
  - 50000 groups with 11 members
- Scribe Multicast Trees are not efficient for small groups because it creates trees with long paths with no branching
- Scribe Collapse algorithm
  - Collapses paths by removing nodes
    - not members of the group
    - only have one entry in the group's children table
  - Reduce average link stress from 6.1 to 3.3, average number of children per node from 21.2 to 8.5