Application-Level Multicast Routing

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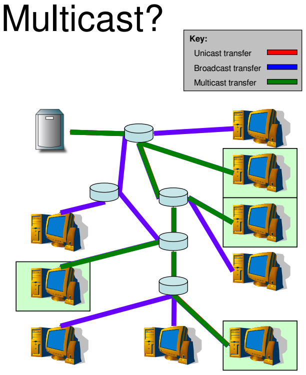
A few slides are borrowed from Swati Agarwal, CS 614, Fall 2005.

What Is Multicast?

- Unicast
  - One-to-one
  - Destination – unique receiver host address
- Broadcast
  - One-to-all
  - Destination – address of network
- Multicast
  - One-to-many
  - Multicast group must be identified
  - Destination – address of group



Few slides are based on slides originally developed by (1) L. Armstrong, Univ of Delaware, (2) Rao - www.ibr.cs.tu-bs.de/events/netgames2002/presentations/rao.pdf

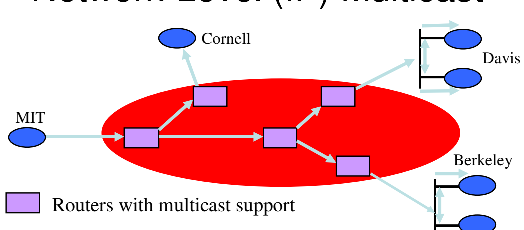
Some Applications…

- Streaming broadcast media
  - Radio
  - Television
- Live events involving multiple parties
  - Video conferencing
  - Distance learning
- Content distribution
  - Software
  - Movies
- All of these involve one-to-many communication

Why Multicast?

- Traditional mechanisms for one-to-one communication do not scale
  - Overloading a single source
  - Network links carry the same traffic separately for each receiver
- Multicasting solves both problems. In the ideal case:
  - Source only needs to transmit one or a few copies of the data
  - Each link only caries one copy of the data

Network-Level (IP) Multicast

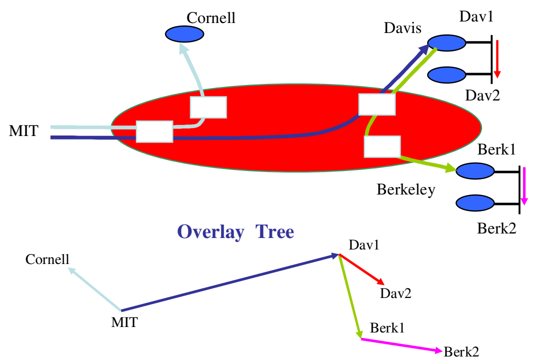


- Reserved a portion of the address space
- Route packets to the group identified by the class D destination IP address
- "You put packets in at one end, and the network conspires to deliver them to anyone who asks." – David Clark

Problems with IP Multicast

- Deployment is difficult
  - Requires support from routers
- Scalability
  - Routers maintain per-group state
- Difficult to support higher level functionality
  - Reliability, congestion control
- Billing issues
- As a result, barely anybody uses it

Application layer multicast



Benefits

- Scalability
  - Routers do not maintain per group state
- Easy to deploy
  - No change to network infrastructure
  - Just another application
- Simplifies support for higher level functionality
  - Can utilize existing solutions for unicast congestion control

Application-Level Multicast

- Two basic architectures are possible
  - Proxy-based
    - Dedicated server nodes exchange content among themselves
    - End clients download from one of the servers and do not share their data
  - Peer to peer
    - All participating nodes share the load
    - “End clients” also act as servers and relay data to other nodes

A few concerns…

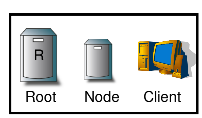
- Performance penalty
  - Redundant traffic on physical links
    - stress = number of times a semantically identical packet traverses a given link
  - Increase in latency
    - stretch = ratio of latency in an overlay network compared to a baseline such as unicast or IP multicast
- Constructing efficient overlays
  - Application needs differ
- Adapting to changes
  - Network dynamics
  - Group membership – members can join and leave
  - Both of these contribute to churn

Overcast

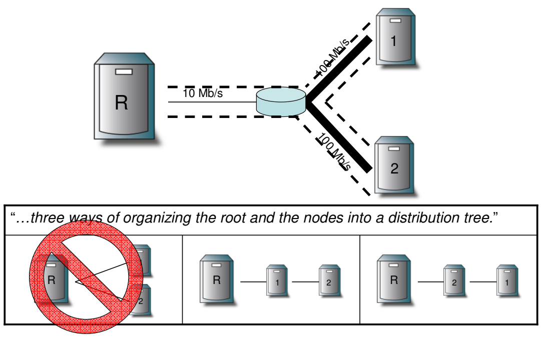
- Single source multicast
- Proxy-based architecture
  - Assumes nodes are well-provisioned
- Reliable delivery
  - Software or video distribution
  - Buffered streaming media
    - “Live” could mean delayed by seconds or minutes
- Long term storage at each node
- Easily deployable, seeks to minimize human intervention
- Works in the presence of NATs and firewalls

Components

- Root : central source (may be replicated)
- Node : internal overcast nodes with permanent storage
  - Organized into distribution tree
- Client : final consumers (HTTP clients)



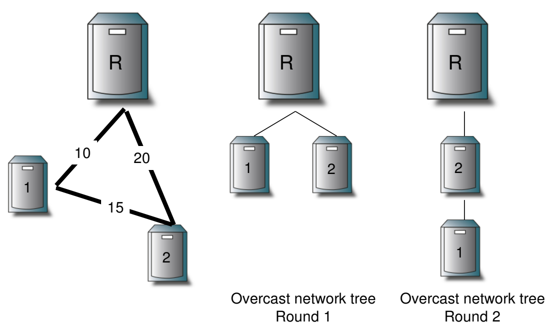
Bandwidth Efficient Overlay Trees



Self-Organizing Algorithm

- A new server initially joins at the root
- Iteratively moves farther down the tree
  - Relocate under a sibling if doing so does not sacrifice bandwidth back to the root
  - This results in a deep tree with high bandwidth to every node
- A node periodically reevaluates its position
  - May relocate under a sibling
  - May become a sibling of its parent
- Fault tolerant
  - If parent fails, relocate under grandparent

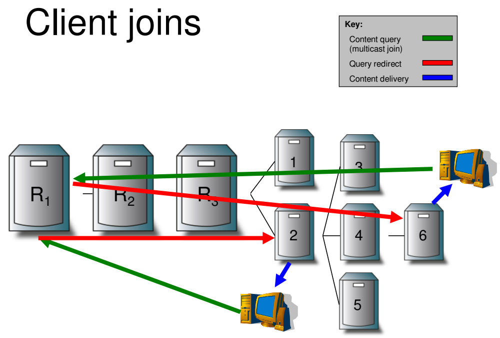
Self-Organizing Algorithm



Connecting Clients

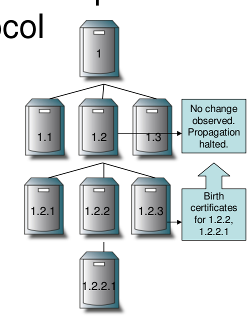
- Client contacts the root via an HTTP request
  - Allows unmodified clients to connect
  - URLs provide flexible addressing
    - Hostname identifies the root
    - Pathname identifies the multicast group
- Root redirects the client to a node which is geographically close to the client
  - Root must be aware of all nodes

Client joins



State Tracking – the Up/Down protocol

- Each node maintains state about all nodes in its subtree
  - Reports the "births" and "deaths" among its children
  - Information is aggregated on its way up the tree
- Each child periodically checks in with its parent
  - Support NATs/firewalls



Is The Root Node A Single Point Of Failure?

- Root is responsible for handling all join requests from clients
  - Note: root does not deliver content
- Root's Up/Down protocol functionality can not be easily distributed
  - Root maintains state for all Overcast nodes
- Solution: configure a set of nodes linearly from root before splitting into multiple branches
  - Each node in the linear chain has sufficient information to assume root responsibilities
  - Natural side effect of Up/Down protocol

Evaluation

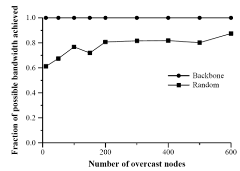


Figure 3: Fraction of potential bandwidth provided by Overcast.

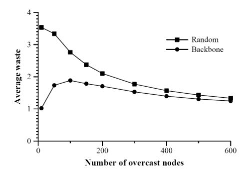


Figure 4: Ratio of the number of times a packet must "hit the wire" to be propagated through an Overcast network to a lower bound estimate of the same measure for IP Multicast.

Evaluation

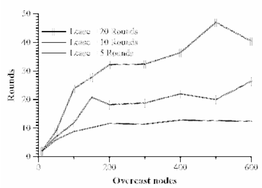


Figure 5: Number of rounds to reach a stable distribution tree as a function of the number of overcast nodes and the length of the lease period.

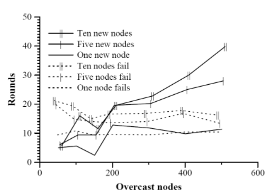


Figure 6: Number of rounds to recover a stable distribution tree as a function of the number of nodes that change state and the number of nodes in the network.

Lease period = how long a parent will wait to hear from a child before reporting its death

Evaluation

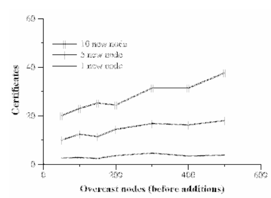


Figure 7: Certificates received at the root in response to node additions.

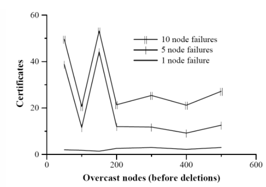


Figure 8: Certificates received at the root in response to node deletions.

Overcast Conclusion

- Designed for software, video distribution
  - Bit-for-bit integrity, not time critical
- Could fullfill a similar role as content distributions systems such as Akamai
- Also works for "live" streams, if sufficient buffering delay is used

Enabling Conferencing Applications on the Internet using an Overlay Multicast Architecture

- Latency and bandwidth are important
  - Real-time interaction between users
- Evaluates how to optimize for dual metrics
- Small-scale (10s of nodes) peer to peer architecture
  - Single source at any given time
- Gracefully degradable
  - Better to give up on lost packets than to retransmit and have them arrive too late to be useful

Self-Improving Algorithm

- Two-step tree building process (Narada)
  - Construct a *mesh*, a rich connected graph
  - Choose links from the mesh using well-known routing algorithms
- Routing chooses *shortest widest path*
  - Picks highest bandwidth, and opts for lowest latency when there are multiple choices
  - Exponential smoothing and discrete bandwidth levels are used to deal with instability due to dynamic metrics

Evaluation

- Schemes for constructing overlays
  - Sequential Unicast
    - Hypothetical construct for comparisons purposes
  - Random
    - Baseline to compare against
  - Latency-Only
  - Bandwidth-Only
  - Bandwidth-Latency

Evaluation

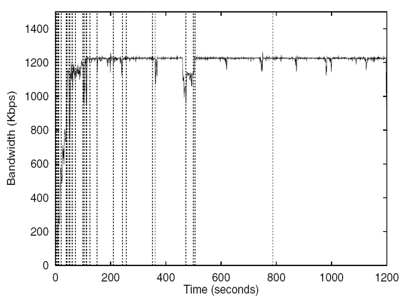


Figure 3: Mean Bandwidth averaged over all receivers as a function of time.

Comparison of schemes

- Primary Set – 1.2 Mbps
- Primary Set – 2.4 Mbps
- Extended Set – 2.4 Mbps

- Primary Set contains well connected nodes
  - North American university sites
- Extended Set – more heterogeneous environment
  - Some ADSL links, hosts in Europe and Asia

Bandwidth – primary set, 1.2 Mbps

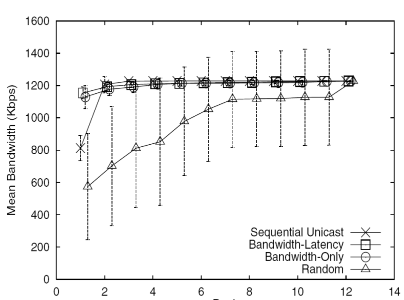


Figure 6: Mean bandwidth versus rank at 1.2 Mbps source rate for the *Primary Set* of machines

Bandwidth – extended set, 2.4 Mbps

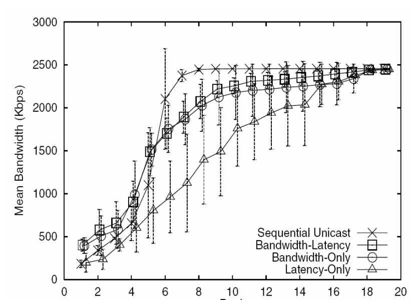


Figure 10: Mean bandwidth versus rank at 2.4 Mbps source rate for the *Extended Set* of machines

RTT – extended set, 2.4 Mbps

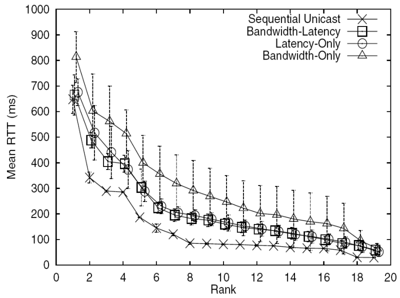


Figure 11: Mean RTT versus rank at 2.4 Mbps source rate for the *Extended Set* of machines

Conclusion

- It is possible to build overlays that optimize for both bandwidth and latency
- Unclear whether these results scale to larger group sizes

More Recent Work

- SplitStream
  - Uses multiple overlapping trees
- Various DHT-based approaches
- BitTorrent
  - Unstructured, random graphs

Discussion Questions

- Is a structured overlay the right approach, or is something more random better?
  - How much do we really care about stress or stretch?
- Both papers mainly use heuristics
  - Could a more mathematically based approach do better?