15-744 Computer Networking

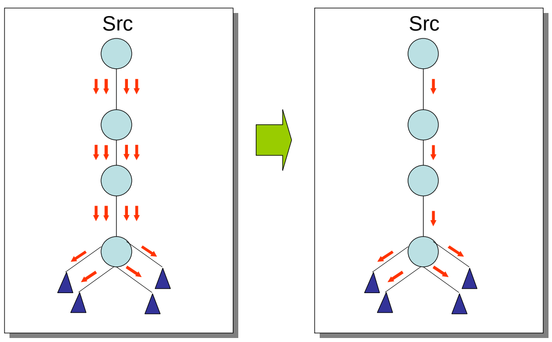
Multicast

(some slides borrowed from Srini Seshan)

Multicast Routing

- Unicast: one source to one destination
- Multicast: one source to many destinations
- Main goal: efficient data distribution
  - Avoid data duplication within network

Multicast – Efficient Data Distribution



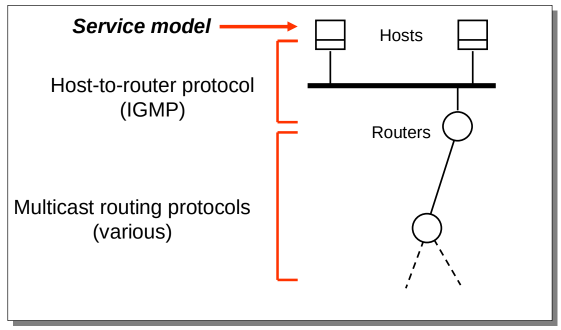
Overview

- IP Multicast Service Basics
- Routing: MOSPF/DVMRP
- Reliability: SRM
- Overlay Multicast

Example Applications

- Broadcast audio/video
- Push-based systems (e.g., BGP updates)
- Software distribution
- Web-cache updates
- Teleconferencing (audio, video, shared whiteboard, text editor)
- Multi-player games
- Other distributed applications

IP Multicast Architecture



IP Multicast Service Model

- Each group identified by a single IP address
- Variable Size:
  - Groups of any size; sparse or dense
- Variable Location:
  - Members may be located anywhere on Internet
- Dynamic membership:
  - Members can join and leave at will
- Many-to-many
  - Not only one-to-many
- No central state
  - Group membership not known explicitly
- Analogy:
  - Each multicast address is like a radio frequency, on which anyone can transmit, and to which anyone can tune-in.

IP Multicast Addresses

- Class D IP addresses
  - 224.0.0.0 – 239.255.255.255

1 1 1 0	Group ID

- How to allocate these addresses?
  - Well-known addresses: IANA
  - Transient addresses: e.g., by "SDR" program
    - Assigned and reclaimed dynamically,

IP Multicast API

- Sending – same as before
- Receiving – two new operations
  - Join(group)
  - Leave(group)
  - Receive multicast packets for joined groups via normal IP-Receive operation
  - Implemented using socket options

Multicast Router Responsibilities

- Learn of the existence of multicast groups
  - (through advertisement)
- Identify links with group members
- Establish state to route packets
  - Replicate packets on appropriate interfaces
  - Routing entry:

Src, incoming interface	List of outgoing interfaces

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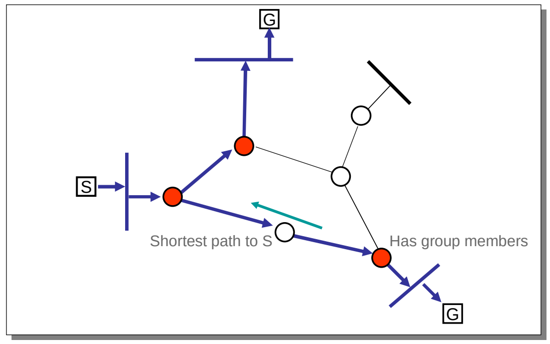
Routing Techniques

- Basic objective – build distribution tree for multicast packets
- Link-state multicast protocols
  - Routers advertise groups for which they have receivers to entire network
  - Compute trees on demand
  - Example: MOSPF
- Flood and prune
  - Begin by flooding traffic to entire network
  - Prune branches with no receivers
  - Example: DVMRP

Multicast OSPF (MOSPF)

- Add-on to OSPF
  - Recall: flood routing announcements, each node gets entire topology
  - Now each router also keeps track of multicast group members
  - Routers mark link-state advertisement with groups that it has members for
- Source-based trees
  - Shortest paths to a node form a spanning tree
  - Routing algorithm augmented to compute shortest-path distribution tree from a source to any set of destinations
  - Packets from each source are forwarded on this tree

Source-based Tree



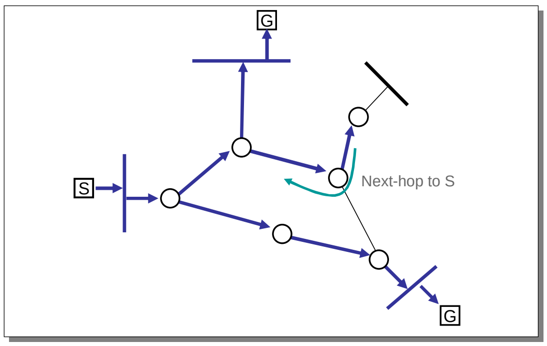
Impact on Route Computation

- Problems?
  - $O(N^2)$ state: one tree per potential sender
  - Can't pre-compute multicast trees for all possible sources
- One solution: Compute on demand
  - When first packet from a source S to a group G arrives
  - Slow if sources send infrequently
- Another solution: Shared trees
  - One tree per multicast group
  - Requires a rendezvous point
    - Unicast to RP, then RP multicasts it along tree
  - E.G., PIM Sparse Mode

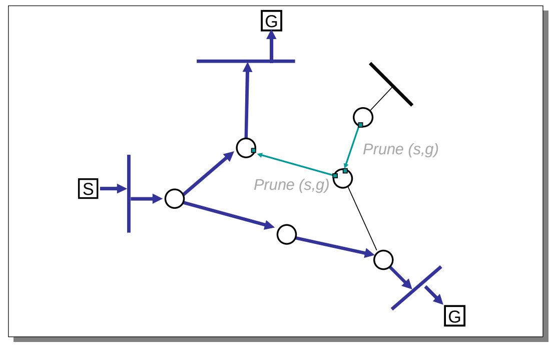
Distance-Vector Multicast Routing

- Add on to DV routing (e.g., RIP)
  - Recall: each node locally determines shortest-path "next hop" for each destination
- Router forwards a packet if
  - The packet arrived from the link used to reach the source of the packet
    - Reverse path forwarding check (RPF)
    - Shortest-paths to a source form a spanning tree
  - If downstream links have not pruned the tree
    - Initially send to all routers then prune away branches

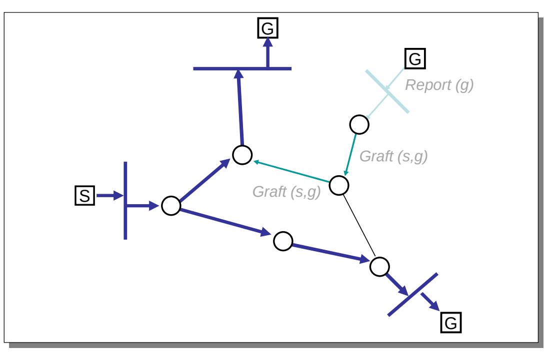
Reverse Path Forwarding



Prune



Graft



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Multicast Transport Properties

- IP Multicast service guarantees?
  - Best effort
- What other properties would applications want?
  - Reliability
  - Congestion/Flow Control
  - In-order delivery
  - Etc.
- Why doesn't IP Multicast provide these?
  - End-to-end principle: Can build other properties on top just like IP unicast
- SRM tackles reliability

Straw man Reliability Solutions

- Why not have each member ACK the sender?
  - *ACK implosion*: each packet sent generates *N* ACKs!
  - Requires sender to track all receiver state
- Why not have each member NACK the sender?
  - If data rate is slow, may not know that we're missing the last packet
  - Loss near the sender generates lots of NACKs; many receivers could share a bottleneck
  - SRM uses NACKs but in a more intelligent fashion

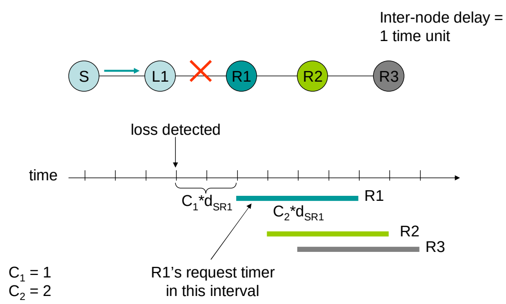
SRM Design Assumptions

- Example Application: digital whiteboard
- Many-to-many
  - Any one in the group can send
- Named data units
  - E.G., 0000 => "point (3,4)", 0001 => "line (3,4)-(1,2)"
  - Each object sent has globally unique name
- Cooperative recovery
  - Any member can supply lost data to any other member
  - E.g., each member buffers all data

SRM Basic Operation

- Multicast periodic *session* messages telling everyone the "latest seqno"
  - Aside: can use these to estimate RTT between members
- Loss detected (missing seqno) => multicast *repair request* (NACK)
  - Request sent after a timer with time picked from uniform distribution: $2^i[C_1*d_{SA}, (C_1+C_2)*d_{SA}]$
  - Suppress request if we see a request and i++
  - => nodes closer to loss send request sooner (on expectation)
  - => first request likely to suppress others (with reasonable C_1,C_2)
- Receive repair request && we have the data item => multicast *repair response*
  - Request sent after a timer picked from uniform distribution: $[D_1*d_{AB}, (D_1+D_2)*d_{AB}]$
  - => nodes closer to requestor will respond sooner (on expectation)
- *Goal:* Have few repair request/responses for the entire group when loss

SRM Operation Example



Adaptive Parameter Adjustment

- Can trade-off higher delay for lower request/response duplicates
- **Probabilistic Suppression**: Higher C_2 => higher expected delay, but less likely to have duplicates
  - First request will likely reach all others before other request timers expire
- **Deterministic Suppression**: Members with lower C1 will likely send requests earlier
  - Mechanism 1: reduce C_1 when send request
  - => members near persistent loss will send sooner
  - Mechanism 2: reduce C_2 when sent requests but still receive duplicate requests from members much farther from source
  - => request more likely to reach far away members first

Adaptive Adjustment Algorithm

- After sending request:
  - Decrease C_1
- Before setting timer:
  - If sent request already && seen dup requests from further away:
    - Decrease C_2
  - Dup requests > T
    - Increase C_2
  - Dup requests < T && request delay > D
    - Decrease C_2
- Converge on optimal delay-duplicate tradeoff
- Basically the same for D_1,D_2

Other Issues

- Local Recovery: Scoping recovery requests/replies
  - Basic algorithm multicast them to entire group
  - Administrative boundaries + TTLs can scope requests/replies
- Congestion control:
  - Assume fixed rate
  - Why not reduce rate to bottleneck link?
    - => one bottlenecked receiver slows down the whole group

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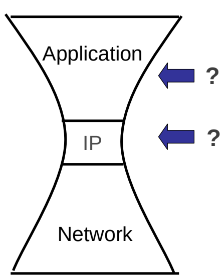
Failure of IP Multicast

- Real world:
  - Not widely deployed even after 15 years!
  - Use carefully – e.g., on LAN or campus, rarely over WAN
  - Largest deployment: MBONE, using IP-tunnels to connect domains
- IP Multicast failings
  - Scalability of routing protocols
    - Extra router state required
  - Hard to manage
    - Who gets to set up groups and when?
  - Hard to implement TCP equivalent
    - As we just saw with SRM
  - Chicken-egg: No real applications
    - Hard to get applications to use IP Multicast without existing wide deployment
  - Economics, policy: Hard to get inter-domain support
    - Who pays for packet duplication?

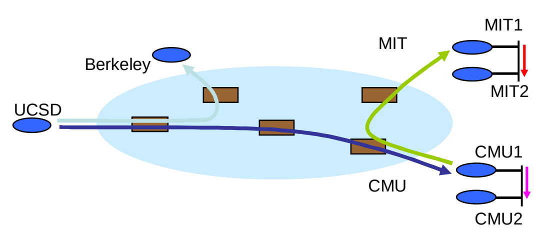
Supporting Multicast on the Internet



Internet architecture

At which layer should multicast be implemented?

End System Multicast

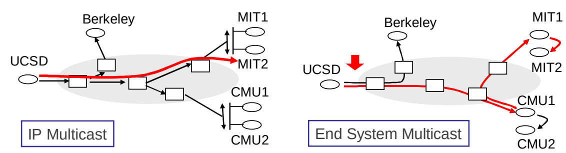


Potential Benefits Over IP Multicast

- Quick deployment
- All multicast state in end systems
- Simplifies support for higher level functionality
  - Reliability, congestion control, etc.

Concerns with End System Multicast

- Self-organize recipients into multicast delivery overlay tree
  - Must be closely matched to real network topology to be efficient
- Performance concerns compared to IP Multicast
  - Increase in delay
  - Bandwidth waste (packet duplication)
  - Not usually substantial problems



Concerns with End System Multicast

- Reality: Many users behind asymmetric DSL/Cable modems
  - Not enough upload bandwidth to forward!
  - => Must be leafs in the multicast tree
- Key Metric: Resource Index
  - forwarding capacity/total bandwidth demand
  - Measured ESM video groups have RI of 1-2…
  - => Building feasible tree is challenging (+ dealing with group dynamics, etc.)

Important Concepts

- Multicast provides support for efficient data delivery to multiple recipients
- Requirements for IP Multicast routing
  - Keeping track of interested parties
  - Building distribution tree
  - Broadcast/suppression technique
- Build reliability, congestion control, in-order delivery on top
  - Just like with TCP/IP, but harder…
- Difficult to deploy new IP-layer functionality
- End system-based techniques can provide alternative
  - Easier to deploy