CSE 123A
Computer Networks

Winter 2005

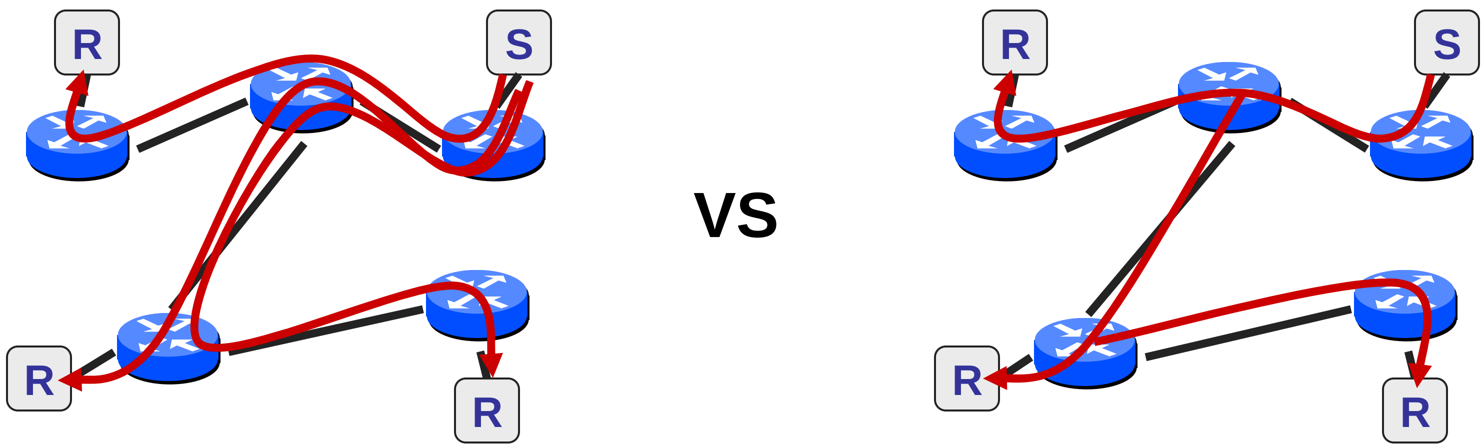
Lecture 12
Internet Routing:
Multicast

Today: Multicast routing

- Multicast service model
- Host interface
- Host-router interactions (IGMP)
- Multicast Routing
  - Distance Vector
  - Link State
  - Shared tree
- Limiters
  - Deployment issues
  - Inter-domain routing
  - Operational/Economic issues (SSM)

Motivation

- Efficient delivery to multiple destinations (e.g. video broadcast)



- Network-layer support for one-to-many addressing
  - Publish/subscribe communications model
  - Don’t need to know destinations

IP Multicast service model

- **Communications based on groups**
  - Special IP addresses represent “multicast groups”
  - Anyone can join group to receive
  - Anyone can send to group
    - » Sender need not be part of group
  - Dynamic group membership – can join and leave at will
- **Unreliable datagram service**
  - Extension to unicast IP
  - Group membership not visible to hosts
  - No synchronization
- **Explicit scoping to limit spread of packets**

Elements of IP Multicast

- **Host interface**
  - Application visible multicast API
  - Multicast addressing
  - Link-layer mapping
- **Host-Router interface**
  - IGMP
- **Router-Router interface**
  - Multicast routing protocols

Host interface

- Senders (not much new)
  - Set TTL on multicast packets to limit “scope”
    - Scope can be administratively limited on per-group basis
  - Send packets to *multicast address*, represents a group
  - Unreliable transport (no acknowledgements)
- Receivers (two new interfaces)
  - Join multicast group (group address)
  - Leave multicast group(group address)
  - Typically implemented as a socket option in most networking API

Multicast addressing

- Special address range:
  - Class D (3 MSBs set to 1) 224.0.01-239.255.255.255
  - Reserved by IANA for multicast
- Which address to use for a new group?
  - No standard
  - Global random selection
  - Per-domain addressing (MASC, GLOP)
- Which address to use to join an existing group?
  - No standard
  - Separate address distribution protocol (may use multicast)

Link-layer multicast

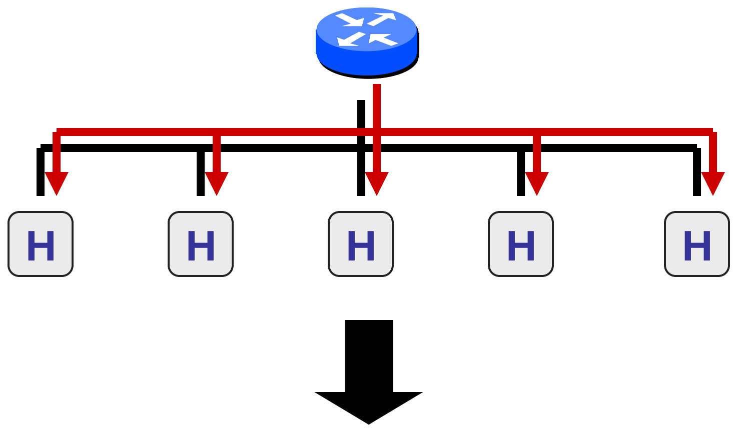
- Many link-layers protocols have multicast capability
  - Ethernet, FDDI

- Translate IP Multicast address into LL address
  - E.g. Map 28 bits of IP MC address in 23bit Ethernet MC addresses
  - Senders send and receive on link-layer MC addresses
  - Routers must listen on all possible LL MC addresses

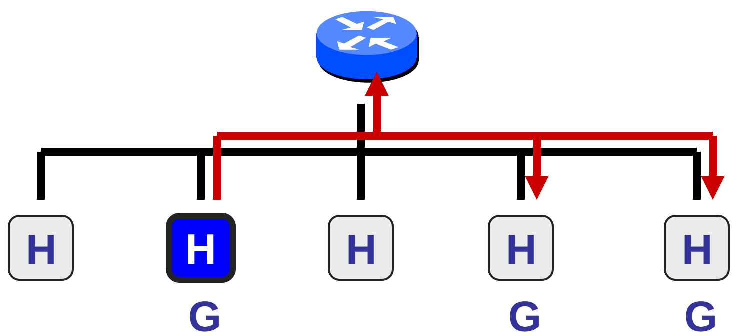
Internet Group Management Protocol (IGMP)

- **Goal: communicate group membership between hosts and routers**
- Soft-state protocol
  - Hosts explicitly inform their router about membership
  - Must periodically refresh membership report
  - Routers implicitly timeout groups that aren't refreshed
  - Why isn't explicit "leave group" message sufficient?
- Implemented in most of today's routers and switches

How IGMP works (roughly)



- Router broadcasts *membership query* to 224.0.01 (all-systems group) with ttl=1
- Hosts start random timer (0-10 sec) or each group they have joined



- When a host's timer expires for group G, send *membership report* to group G, with ttl=1
- When a member of G hears a report, they reset their timer for G
- Router times out groups that are not "refreshed" by some host's report

Multicast routing

- **Goal: build distribution tree for multicast packets**
  - Efficient tree (ideally, shortest path)
  - Low join/leave latency

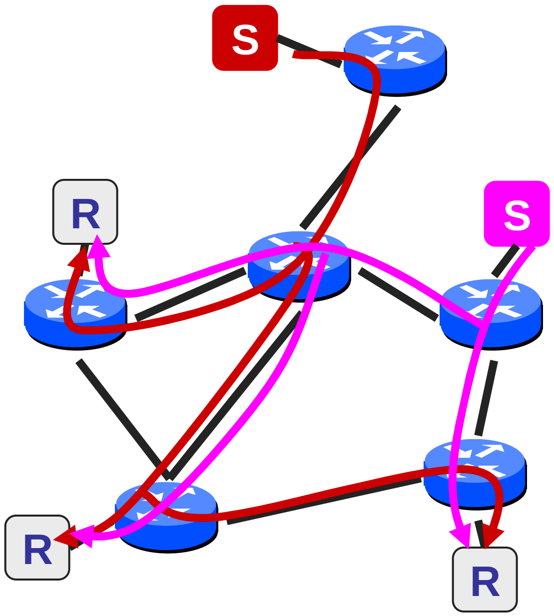
- Several approaches
  - Distance Vector/Link State
    - » Leverage existing unicast routing protocols
  - Shared tree
    - » Unicast/multicast hybrids

Multicast routing taxonomy

- **Source-based tree**
  - *Separate shortest path tree for each source*
  - **Flood and prune** (DVMRP, PIM-DM)
    - » Send multicast traffic everywhere
    - » Prune edges that are not actively subscribed to group
  - **Link-state** (MOSPF)
    - » Routers flood groups they would like to receive
    - » Compute shortest-path trees on demand
- **Shared tree** (CBT, PIM-SM)
  - *Single distributed tree shared among all sources*
  - Specify rendezvous point (RP) for group
  - Senders send packets to RP, receivers join at RP
  - RP multicasts to receivers; Fix-up tree for optimization

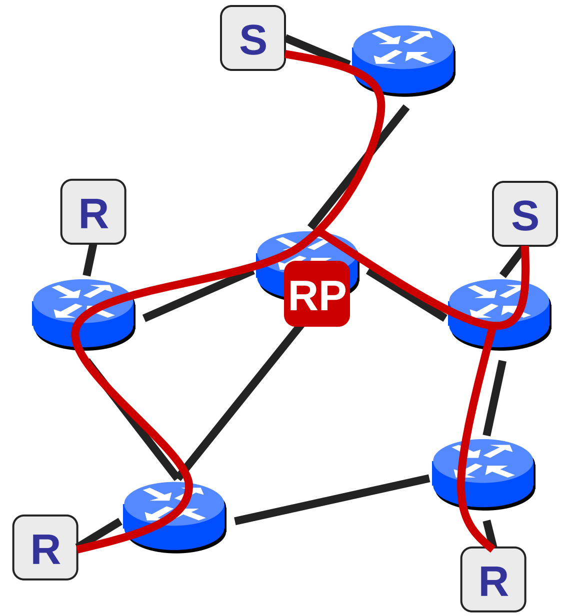
Source-based vs Shared

Source-based tree



- Efficient trees; low delay, even load
- Per-source state in routers (S,G)
- Good for dense-area multicast

Shared-tree



- Higher delay, skewed load
- Per-group state only (G)
- Efficient for sparse-area multicast

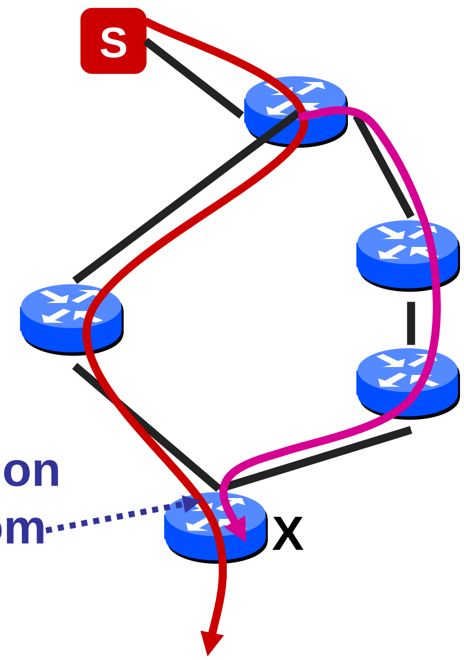
Flood and Prune (DV)

- Extensions to unicast distance vector algorithm
- Goal
  - Multicast packets delivered along shortest-path tree from sender to members of the multicast group
  - Likely have different tree for different senders
- Distance Vector Multicast Routing (DVMRP) developed as a progression of algorithms
  - Reverse Path Flooding (RPF)
  - Reverse Path Broadcast (RPB)
  - Reverse Path Multicast (RPM)

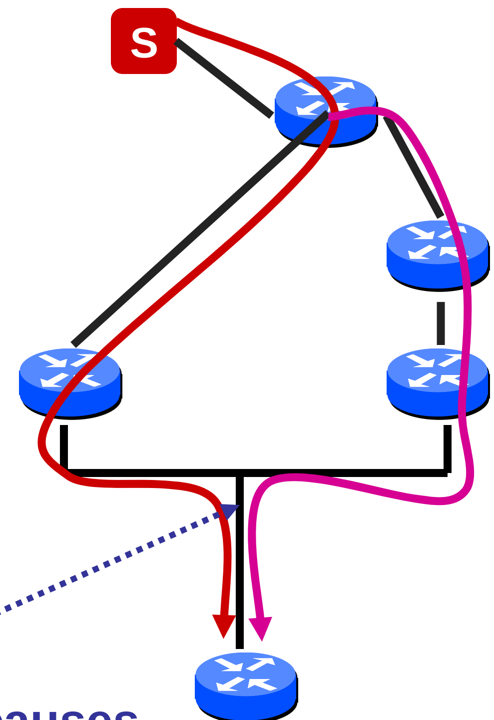
Reverse Path Flooding (RPF)

- Observation: Shortest-path multicast tree is subtree of shortest-path broadcast tree
- Approach: Use shortest-path broadcast tree
- Use reverse path to determine shortest path
  - Router forwards a packet from S iff received from the shortest-path link to S
  - Exactly what is in entry in forwarding table
    - » To reach S along shortest path, use link L
    - » If received packet from S on L, it came along shortest path
- How are packets forwarded?
  - Flooding – forward packets to multicast address out to all links except incoming link (hence reverse path flooding)

Example: Reverse Path Forwarding



Forward packets on shortest path from X to S

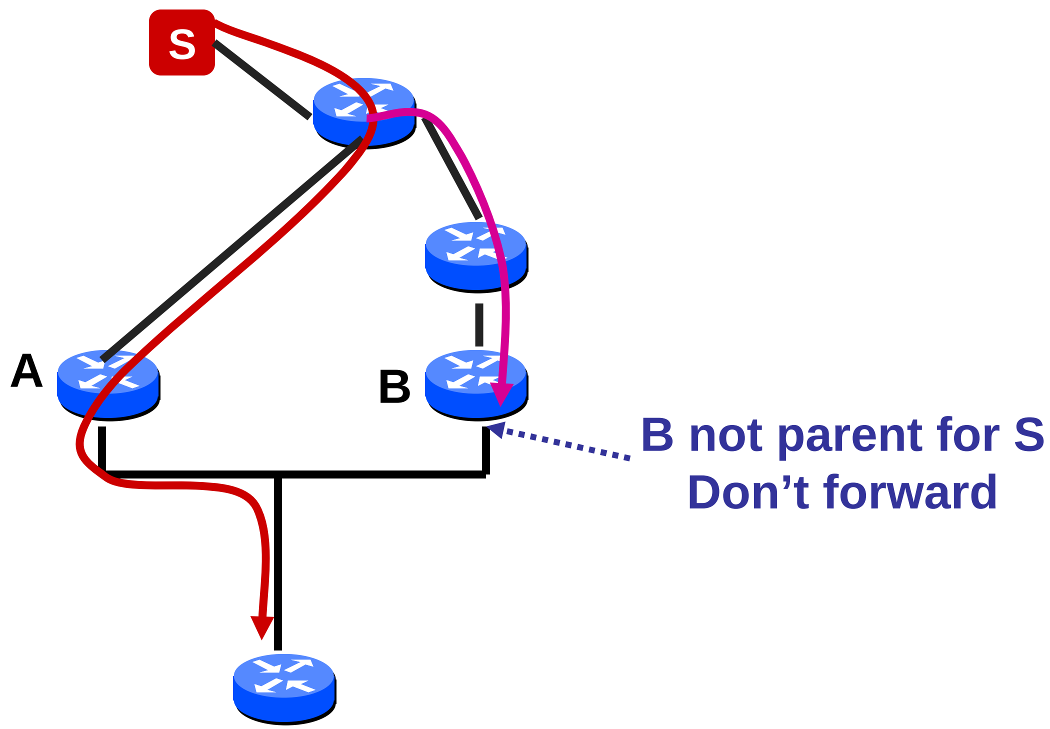


Problem: Flooding causes duplicate packets to be sent on LANs

Solution: Reverse Path Broadcast (RPB)

- Flooding vs. broadcast
  - With flooding, a single packet can be sent along an individual link multiple times
    - » Each router attached to link can potentially forward same packet
  - RPB sends a packet along a link at most once
- Approach: Define parent and child routers for each link
  - Relative to each link and each source S
  - Router is a parent for link if it has minimum path to S
  - All other routers on the link are children
  - Only parent router is allowed to forward multicast packets on link
- How to decide parent and children routers for link?
  - In routing updates; router determines if is parent

Example: Reverse Path Broadcasting



Reverse Path Multicast (RPM)

- Problem: Still **broadcasting** up to leaf networks
- Idea: Instead of actively building tree, use reports to actively prune tree
- Start with a full broadcast tree to all links (RPB),
- Prune (S,G) at leaf if it has no members
  - Send Non-Membership Report (NMR) to prev-hop for S
- If all children of router R prune (S,G)
  - Send NMR for (S,G) to parent of R
- Soft-state management (must refresh NMR or rejoin)
- New group member sends graft (anti-prune) message

Link State

- Use existing link-state routing algorithm (e.g. OSPF)
- Idea: include active groups in LSPs
  - Each router can compute shortest path tree from source to all destinations for any group
  - Trigger new flood on group membership change
- Performance issues
  - Expensive to precompute all (S,G) trees
  - Keep cache of trees and compute new trees on demand when new (S,G) packet arrives
  - Workload/topology dependant
- Best known example: MOSPF

Shared tree approaches

- Unicast packets to Rendezvous Point (RP), which multicasts packet on shared tree
- Tree construction
  - Receivers send join messages to RP
  - Intermediate routers install state to create per-group tree
  - Key advantage is routers only store O(G) state
  - Potential optimizations: reroute to source-specific trees for local group members or high data-rate sources
  - Example: CBT, PIM-SM
- Issues
  - Delay, fault tolerance, RP selection

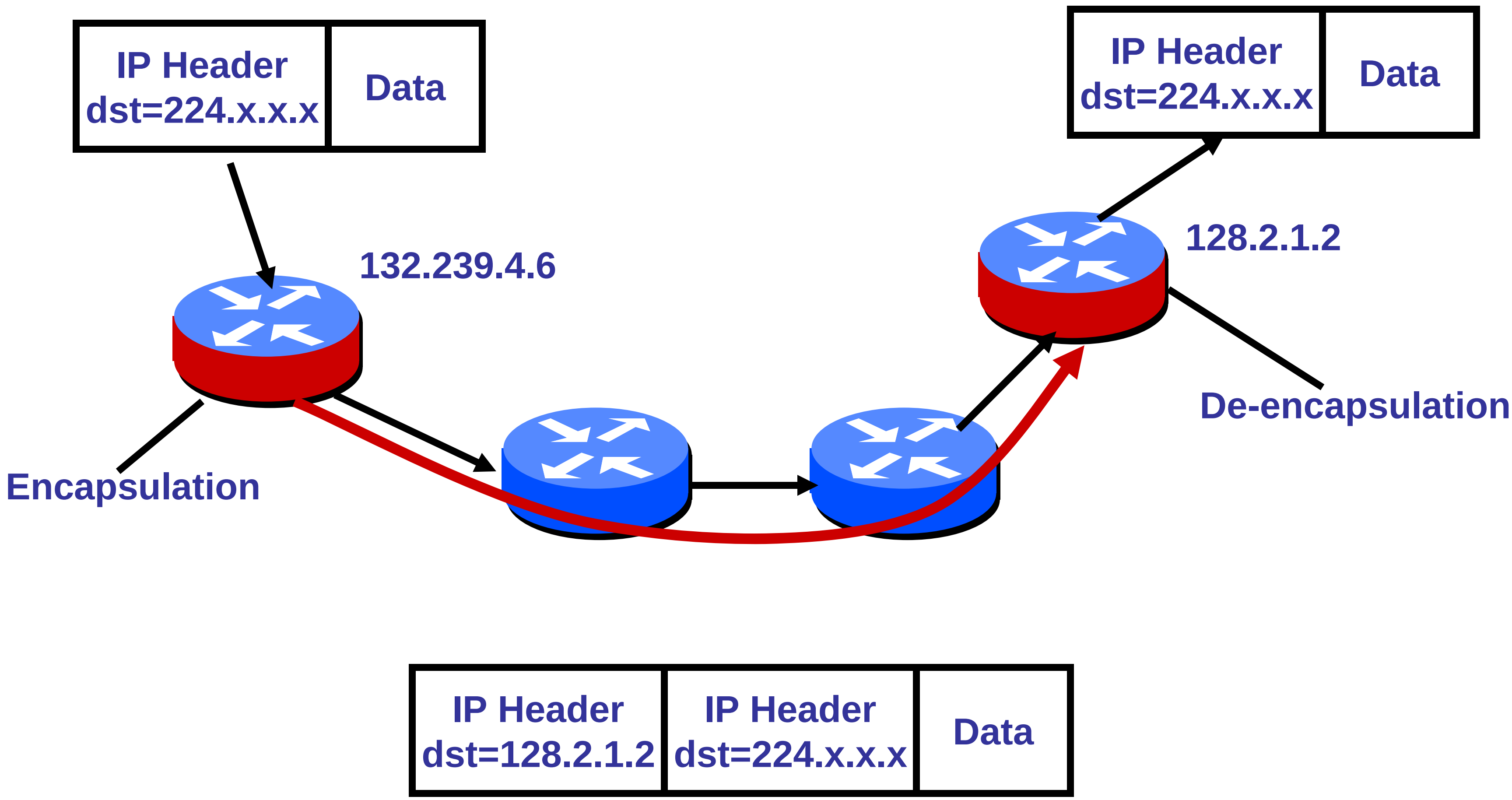
IP Multicast today

- IP Multicast has generated 1000s of papers, but has not been widely deployed in the Internet…
- Why?
  - General deployment difficulties (Mbone)
  - Inter-domain multicast complexity
  - Economics of multi-source multicast

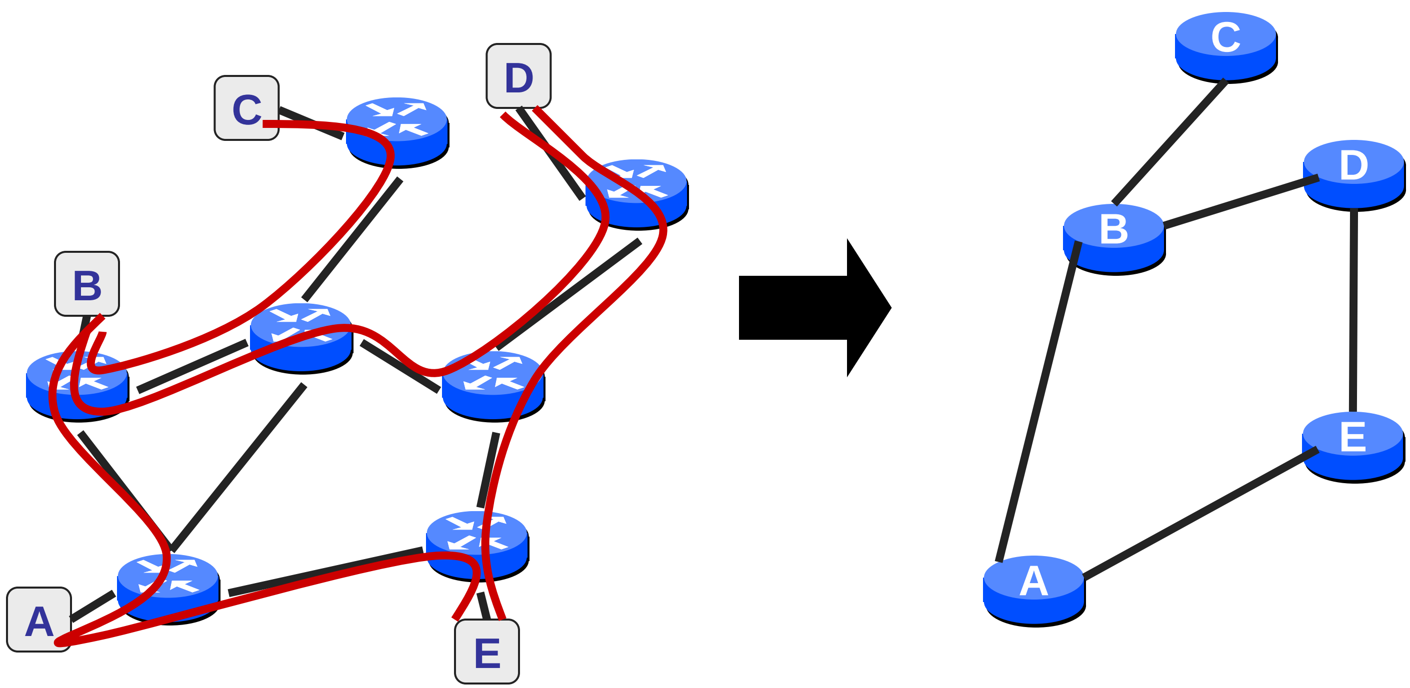
Multicast evolution

- How to deploy a new network-layer service?
  - Difficult to change router software
  - Difficult to change all routers
- Mbone (tunneling)
  - Special multicast routers (built from PCs/Workstations)
  - Construct virtual topology between them (overlay)
  - Run routing protocol over virtual topology
  - Virtual point-to-point links called ***tunnels***
    - » Multicast traffic encapsulated in IP datagrams
    - » Multicast routers forward over tunnels according to computed virtual next-hop

Tunnelling


IP Header
dst=224.x.x.x
Data
132.239.4.6
Encapsulation
128.2.1.2
IP Header
dst=224.x.x.x
Data
De-encapsulation
IP Header
dst=128.2.1.2
IP Header
dst=224.x.x.x
Data

Virtual overlay network



Real topology with tunnels **Virtual overlay topology**

Mbone Pro/Con

- Success story
  - Multicast video to 20 sites in 1992
  - Easy to deploy, no explicit router support
  - Ran DVMRP and had 100s of routers
- Drawbacks
  - Manual tunnel creation/maintenance
  - Inefficient
  - No routing policy (single tree)
  - Why would an ISP deploy a new mbone node?

Inter-domain multicast routing

- Technical issues
  - How to exchange reachability information?
  - How to construct trees?
  - Who controls RP in shared tree?
- MBGP: reachability to multicast sources per prefix
- PIM-SM: shared tree multicast protocol
- MSDP: RP per group per AS, communication presence of group sources between RPs
- BGMP: alternative proposal, single shared tree with group addresses owned by individual ASs

Economic issues

- ISP router migration cycle
  - Can't afford new routers on edge
- Domain independence
  - Do I want my customers MC controlled by an RP in a competitors domain?
  - Why run an RP for which I have no senders or receivers?
- Billing model
  - Inconsistent with input-rate-based billing
  - No group management (how big is group?)
- Group management
  - Who is in the group? Who can send? Security
- Network management
- Limited Multicast addresses

Summary

- Multicast service model
  - One-to-many, anonymous communication
  - Simple host interface
- Per-source tree routing
  - Efficient trees, S*G state explosion for large networks/groups
- Shared tree
  - More complex, fragile, hard to manage
  - Trees inefficient by as much as 2x
  - Only requires G state on routers
- Operational and Economic issues matter in deployment
- Killer app not found

For next time…

- Routing is over… transport protocols next!
- Reliable communication…
  - Read 2.5 and Chapter 5 up to (but not including 5.3)