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Computer Networks

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Material with thanks to James F. Kurose, Mosharaf Chowdhury, and other colleagues.

Chapter 3. Network Layer

- Network Layer Functions
- IP Protocol Basic
- IP Protocol Suit
- Routing Fundamentals
- Internet Routing Protocols
- IP Multicasting

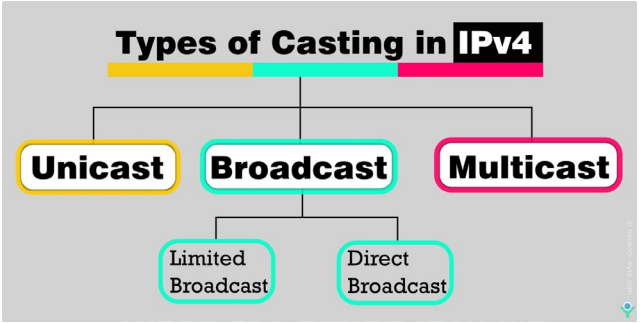
Chapter 3. Network Layer

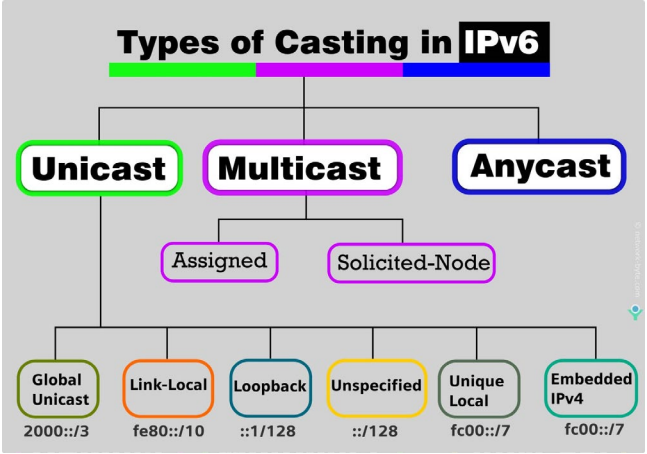
- Basic of IP Multicast
- IGMP: Internet Group Management Protocol
- Multicast Routing
- Application-level Multicast

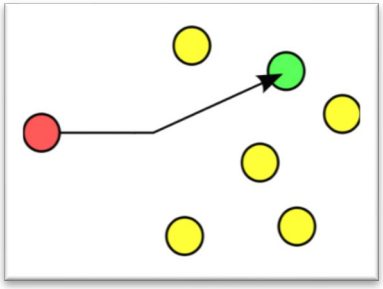
Basic of IP Multicast

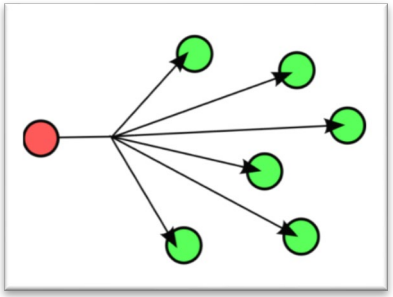
Related Concepts

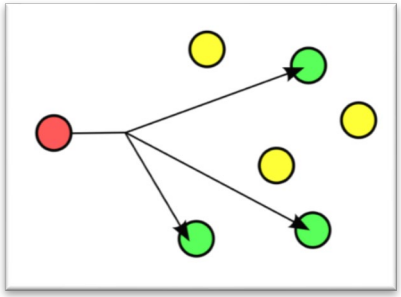
- Unicast: one-to-one transfer
- Broadcast: one-to-all transfer
- Multicast: one-to-many transfer
- Anycast: one-to-many, but only deliver to one random host
  - Anycast address in IPv6 is an address that is assigned to more than one interface in different hosts.
  - A packet that is sent to an anycast address is routed to the nearest interface that has that address.

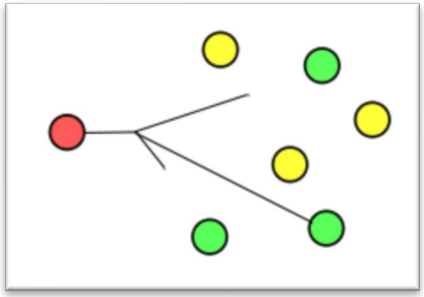




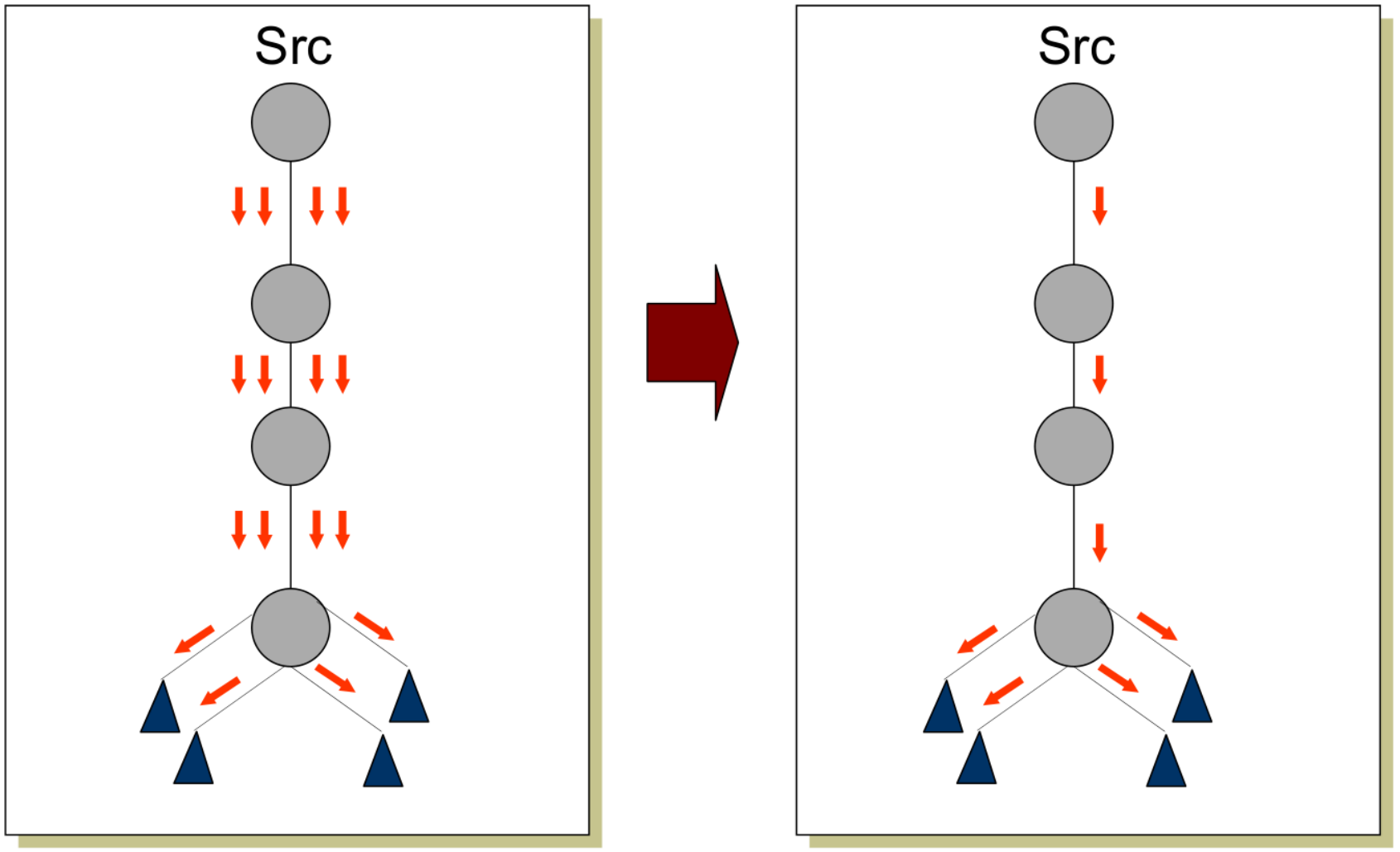

Unicast


Broadcast


Multicast


Anycast

Multicast – Efficient Data Distribution



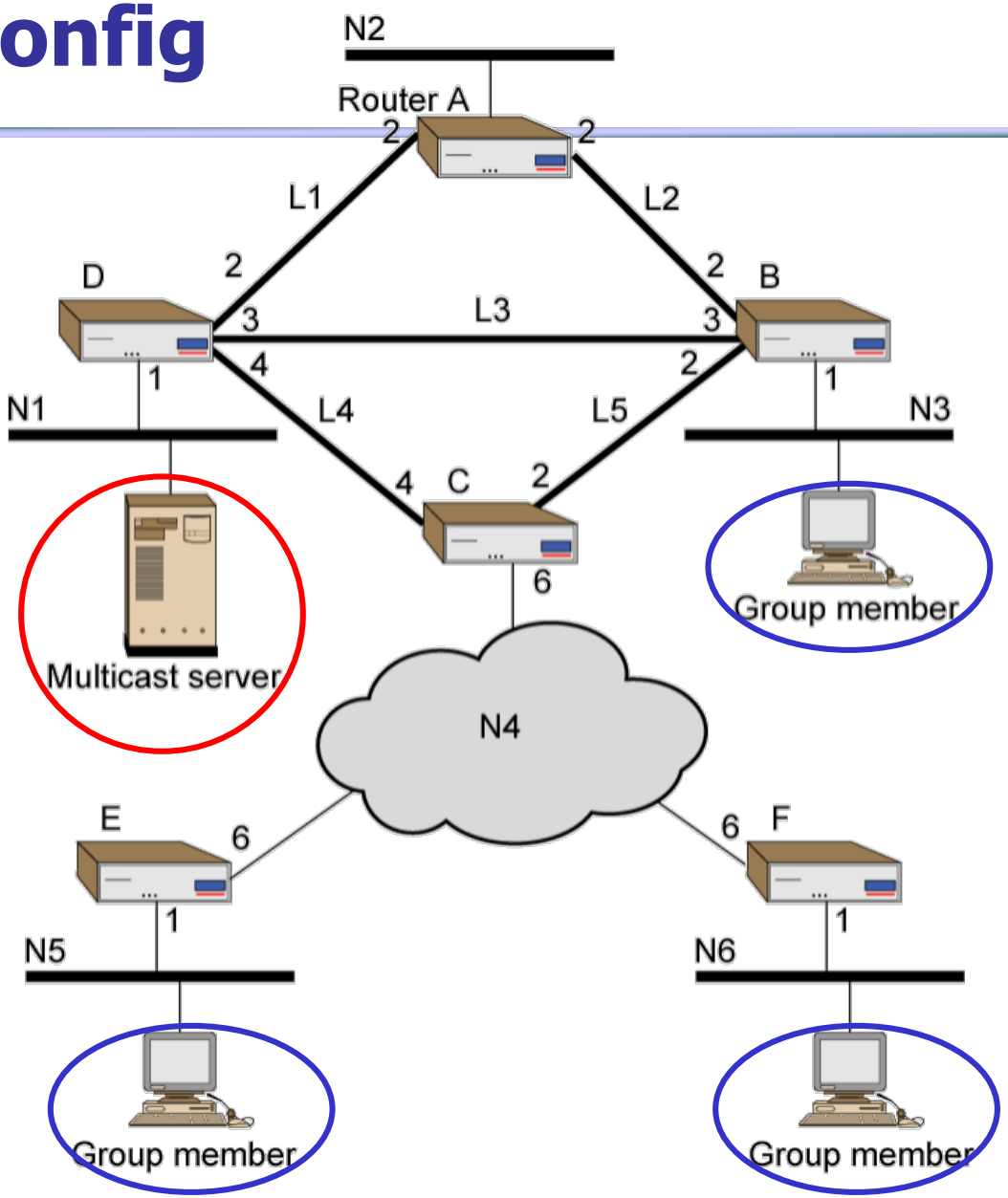
IP Multicasting

- Multicast
  - Act of sending datagram to multiple receivers (hosts) with single transmit operation
- Multicast address (class D in IPv4)
  - Addresses that refer to group of hosts on one or more networks
- Applications
  - Multimedia (TV) broadcast
  - Teleconferencing
  - Database replication
  - Distributed computing, …

Definitions

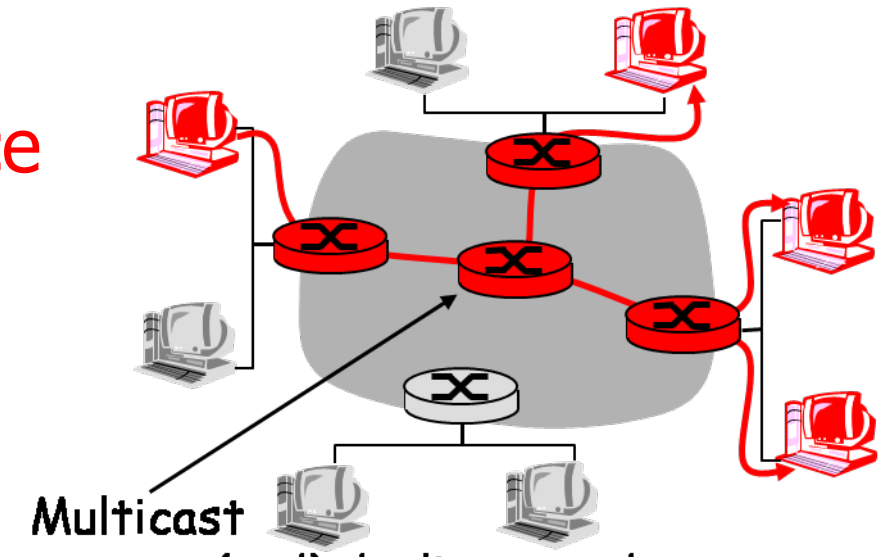
- A multicast group is a set of receivers with a common interest.
- A source is an end user that originates a data stream.
- A receiver is an end user wishing to receive a data stream.

Example Config



Handling IP Multicast

- Multicast (Spanning) Tree
  - Build a (least cost) tree connecting routers having local mcast group members
  - Nodes (routers) forward copies only along spanning tree
- Sender only sends once

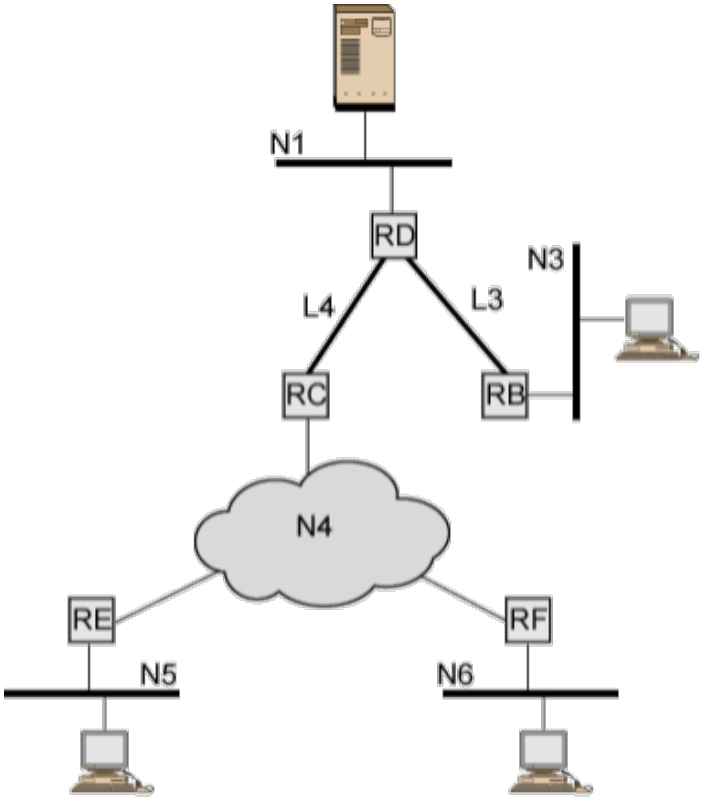


Multicast Router Responsibilities

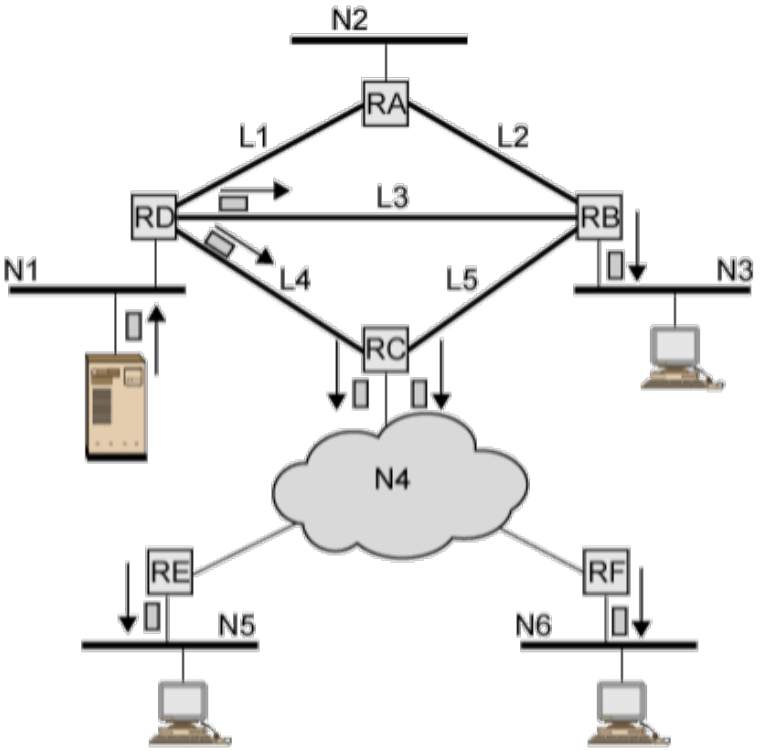
- Learn of the existence of multicast groups (through advertisement)
- Identify links with group members
- Establish state to route packets
  - Replicate packets on appropriate interfaces
  - Routing entry:

Src, incoming interface	List of outgoing interfaces

Multicast Example



(a) Spanning tree from source to multicast group



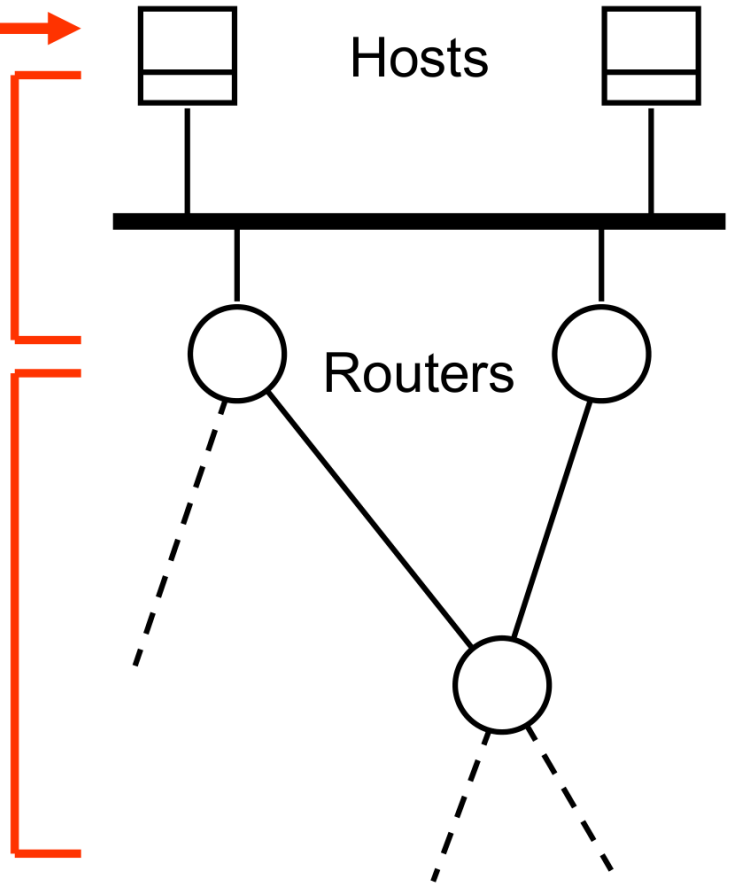
(b) Packets generated for multicast transmission

IP Multicast Architecture

Service model

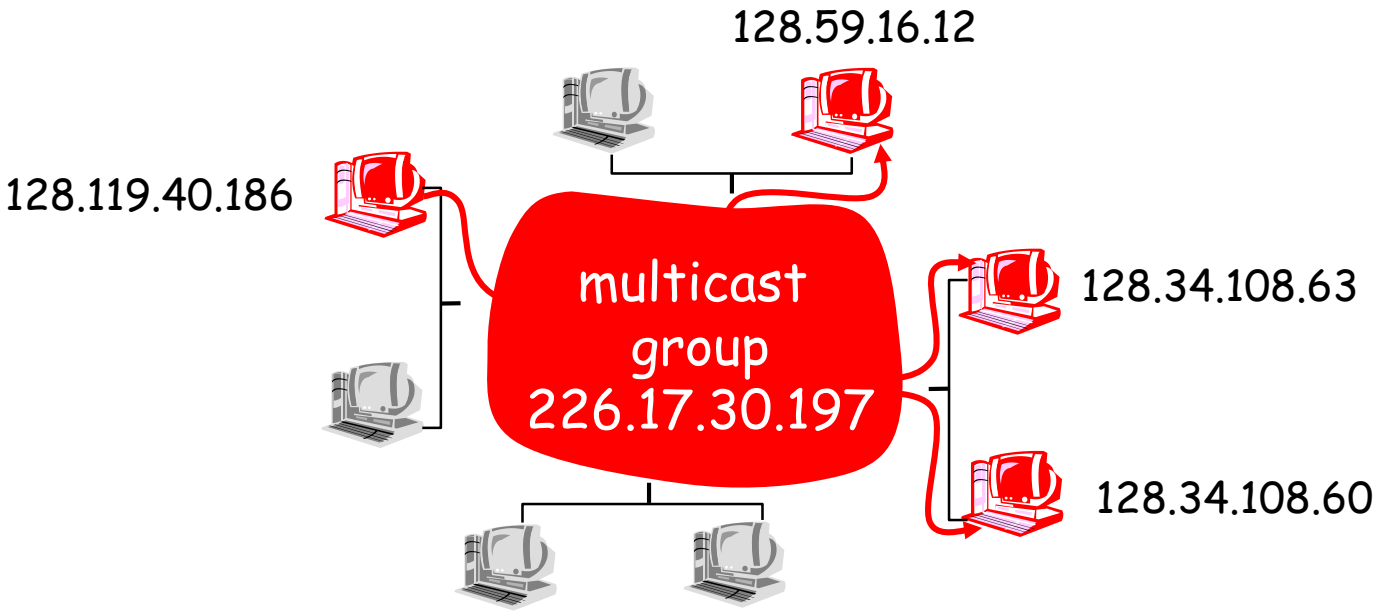
Host-to-router protocol
(IGMP)

Multicast routing protocols
(various)



IP Multicast Service Model

- Multicast group concept: use of indirection
  - Hosts address IP datagram to a multicast group
  - Routers forward multicast datagrams to hosts that have joined that multicast group



Multicast Address

- Convention needed to identify multicast addresses
  - IPv4: Class D, start with 1110

  - IPv6: 8 bit prefix, 4 bit flags, 4 bit scope, 112 bit group identifier

- 224.0.0.0～224.0.0.255为预留的组播地址（永久组地址），地址224.0.0.0保留不做分配；
- 224.0.1.0～224.0.1.255是公用组播地址，可以用于Internet；
- 224.0.2.0～238.255.255.255为用户可用的组播地址（临时组地址），全网范围内有效；
- 239.0.0.0～239.255.255.255为本地管理组播地址，仅在特定的本地范围内有效。

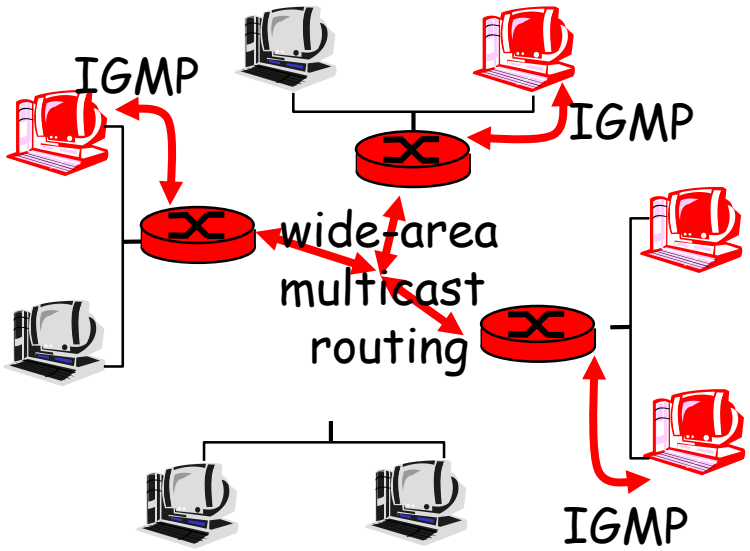
- Address translation
  - IP: translate between IP multicast addresses and lists of networks containing group members
  - Malticast MAC: translate between IP multicast address and multicast MAC address

组播mac地址的高24bit为0x01005e，mac 地址的低23bit为组播ip地址的低23bit。

IGMP: Internet Group Management Protocol

Maintain a Multicast Group

- Local network
  - Host informs local mcast router of desire to join a group
  - IGMP (Internet Group Management Protocol) used
- Wide area
  - Mcast routers interact with each other to build spanning tree, and interchange mcast datagrams
  - Many protocols (e.g. DVMRP, MOSPF, PIM)

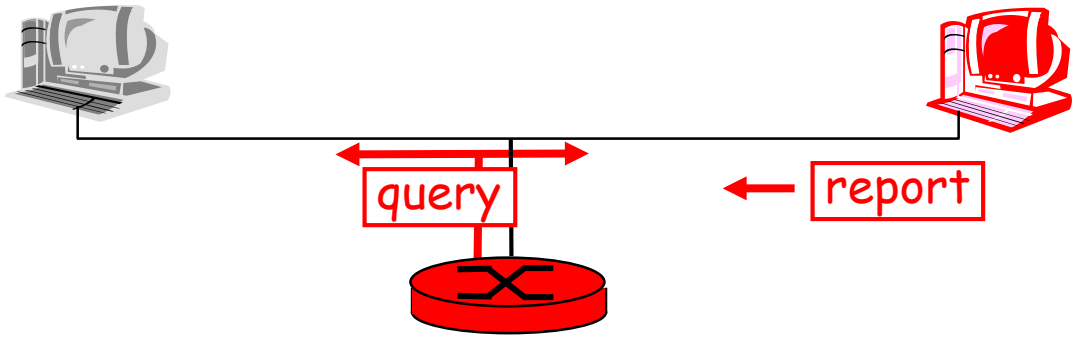


IGMP

- RFC 3376
- Host and router exchange of multicast group info on local net
- Can use broadcast LAN to transfer info among multiple hosts and routers

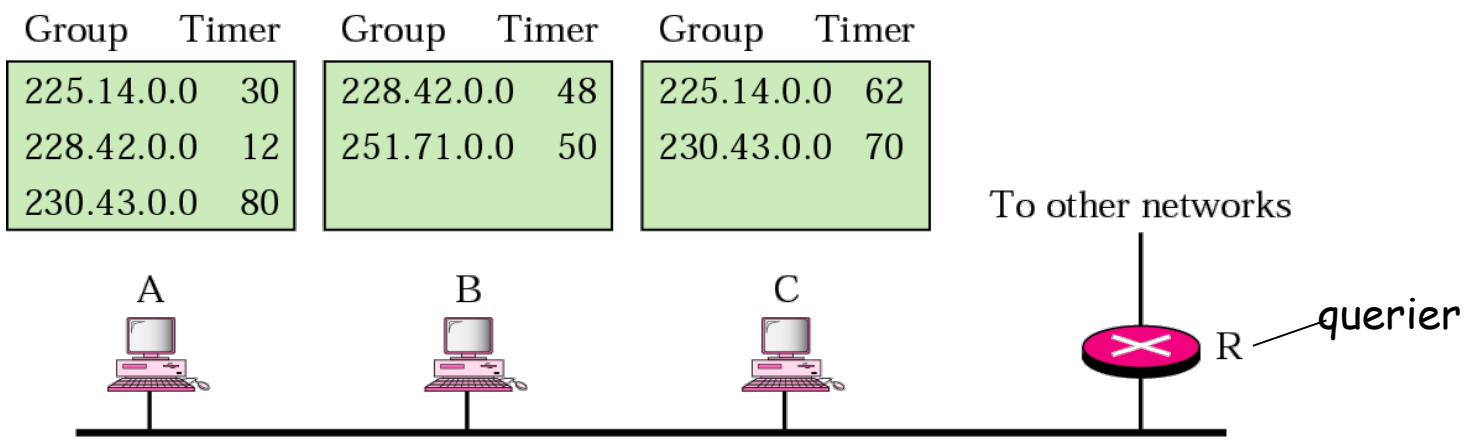
Principle Operations

- Hosts
  - Send reports to routers to subscribe to (join) and unsubscribe from (unjoin) multicast group
  - Host need not explicitly unjoin group when leaving
- Routers
  - Sends query info at regular intervals
  - Host belonging to a mcast group must reply to query



IGMP Operations (1)

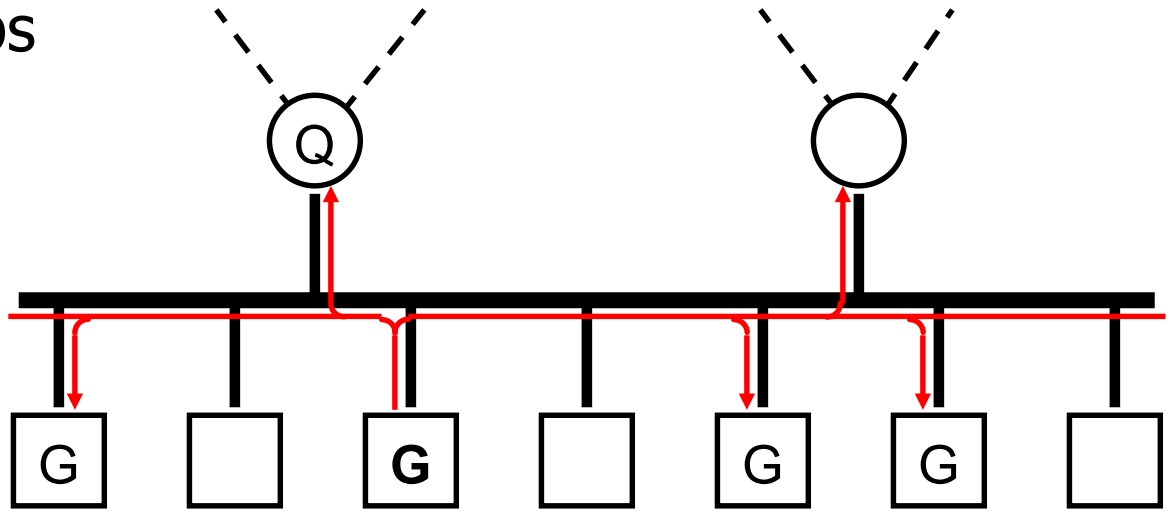
- 2 special multicast address
  - 224.0.0.1: all multicast groups on subnet
  - 224.0.0.2: all routers on subnet
- On each LAN, one router is elected as the querier
  - Querier periodically sends a Membership Query message to 224.0.0.1 with TTL = 1
- On receipt, hosts start random timers (0~10s) for each multicast group to which they belong



IGMP Operations (2)

- When a host's timer for group *G* expires, it sends a Membership Report to group *G*, with TTL = 1
- Other members of *G* hear the report and stop their timers

- Routers hear all reports, and time out non-responding groups



IGMP Versions

- IGMP v1
  - Routers: "Host Membership Query" broadcast on LAN to all hosts
  - Use timer to unsubscribe members
  - Hosts: explicitly issues "Host Membership Report" to indicate group membership (join a group)
  - Implicit leave via no reply to Query
- IGMP v2
  - Routers can use group-specific Query
  - Host replying to Query can send explicit "Leave Group" message

IGMP v1 & v2

- Operations
  - Sources do not have to subscribe to groups
  - Any host can send traffic to any multicast group
- Problems
  - Location of sources is not known
  - Establishment of distribution trees is problematic (not optimistic)
  - Spamming of multicast groups consume valuable resources
  - Finding globally unique multicast addresses difficult

IGMP v3

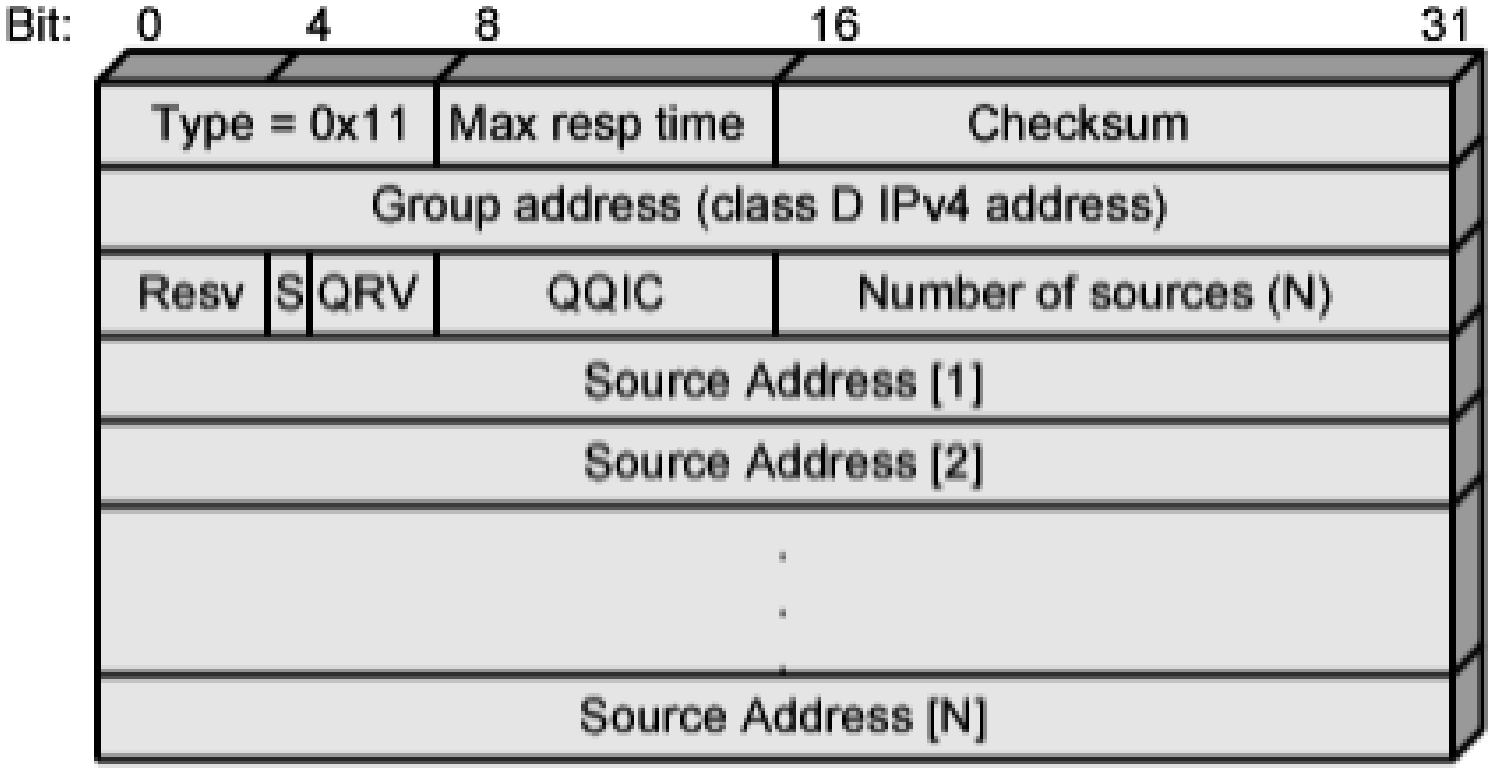
- Allows hosts to specify source list from which they want to receive traffic
  - Traffic from other hosts blocked at routers

- Allows hosts to block packets from sources that send unwanted traffic

Membership Query

- Sent by multicast router
- General query
  - Which groups have members on attached network
- Group-specific query
  - Does specified group have members on attached network
- Group-and-source specific query
  - Do attached hosts want packets sent to specified multicast address from any of specified list of sources

IGMP Message – Membership Query



(a) Membership query message

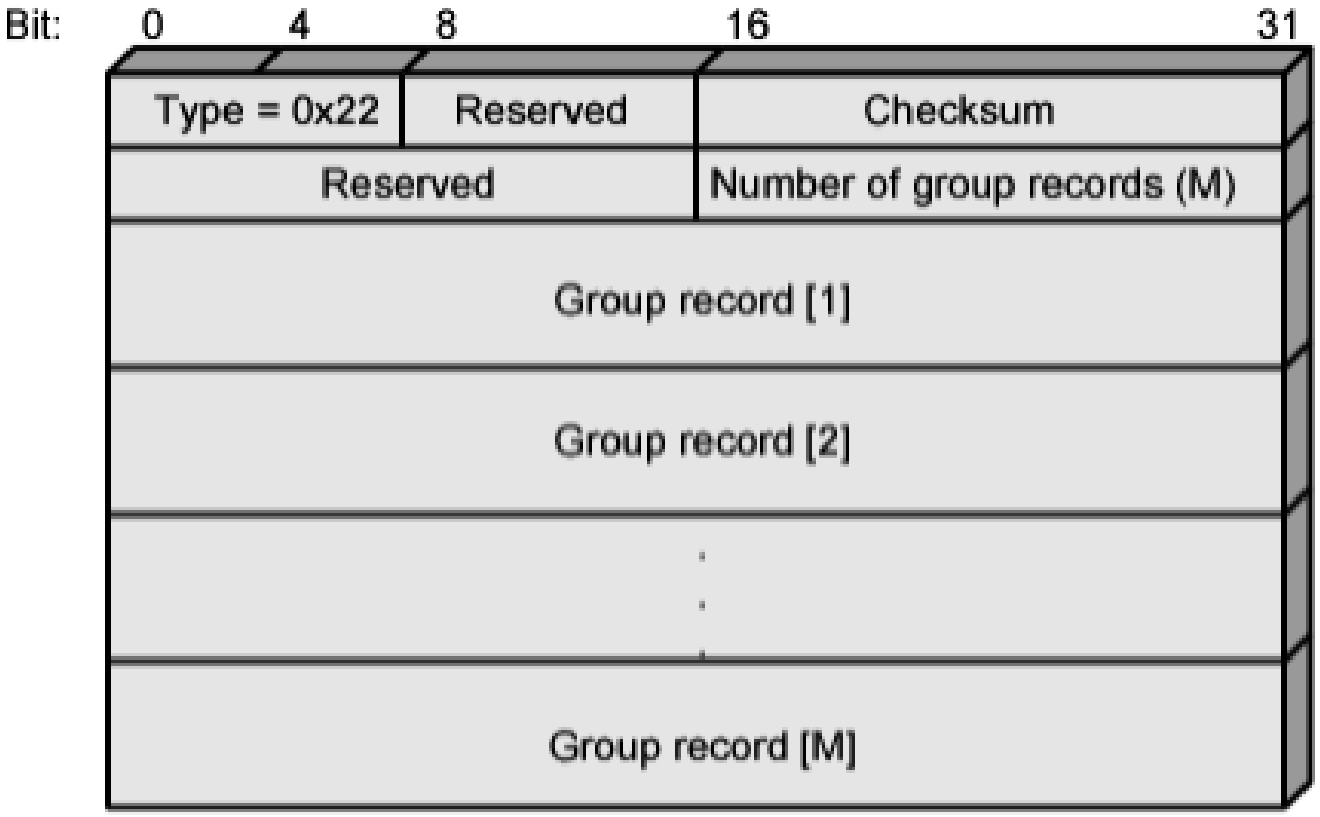
Membership Query Fields (1)

- Type (8 bits): 0x11, means Query
- Max Response Time (8 bits)
  - Max time before host sending report in units of 1/10 second
- Checksum (16 bits): Same algorithm as IPv4
- Group Address (32 bits)
  - Zero for general query message
  - Multicast group address for group-specific or group-and-source
- S Flag (1 bit)
  - 1 indicates that receiving routers should suppress normal timer updates done on hearing query

Membership Query Fields (2)

- QRV (querier's robustness variable) (3 bits)
  - RV dictates number of retransmissions to assure report not missed
  - Other routers can adopt value from most recently received query
- QQIC (querier's querier interval code) (8 bits)
  - QI dictates timer for sending multiple queries
  - Routers not current querier adopt most recently received QI
- Number of Sources (16 bits)
- Source addresses
  - One 32 bit unicast address for each source

IGMP Message – Membership Report



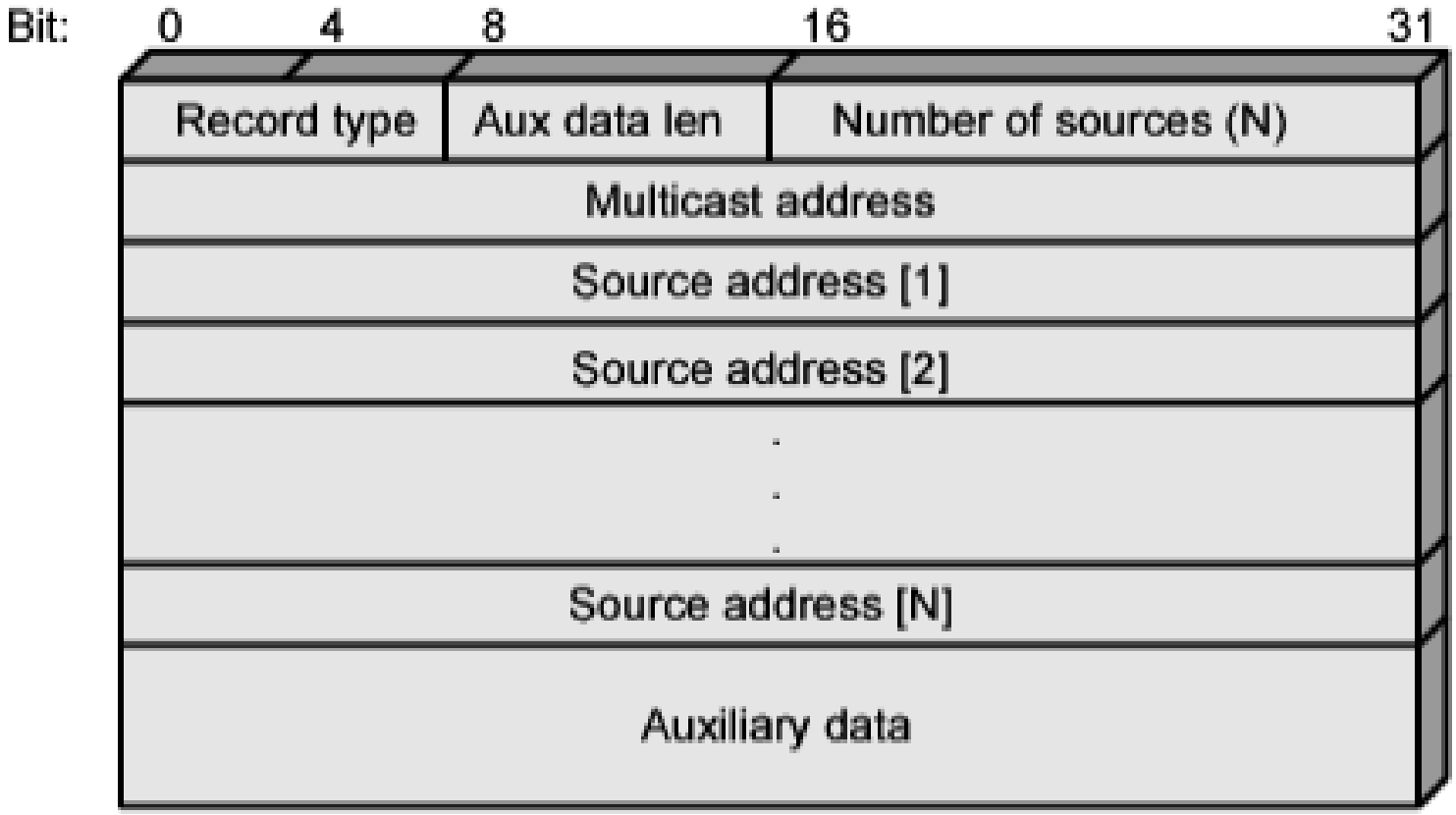
(b) Membership report message

Membership Reports Fields

- Type (8 bits)
  - 0x22, means Report
- Checksum (16 bits)
  - Same algorithm as IPv4

- Number of Group Records
- Group Records
  - One record for each group attended

IGMP Message – Group Record



(c) Group record

Group Record

- Multicast Address (32 bits)
  - Identify the group attended
- Record Type (8 bits)
  - EXCLUDE or INCLUDE mode (6 modes defined)
- Number of Sources (16 bits)
- Source Addresses
- Aux Data Length (8 bits)
  - Length of Auxiliary Data, in 32-bit words
- Auxiliary Data
  - Currently, no auxiliary data values defined

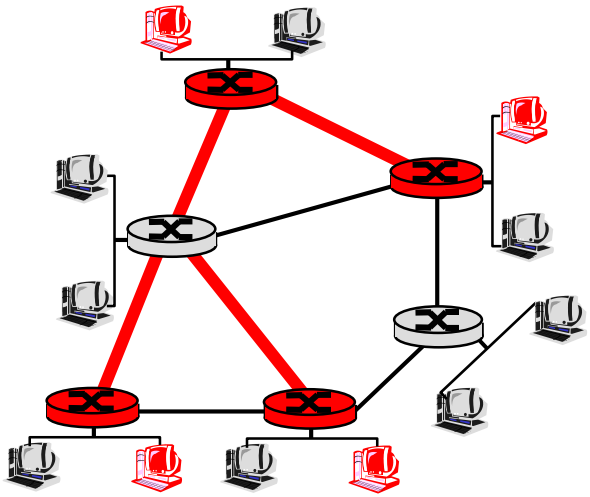
Group Membership with IPv6

- IPv6 internets need same functionality
- IGMP functions incorporated into Internet Control Message Protocol version 6 (ICMP v6)
  - ICMPv6 includes all of functionalities of ICMPv4 and IGMP
- ICMPv6 includes Group-membership Query and Group-membership Report message
  - Used in the same fashion as in IGMP v3

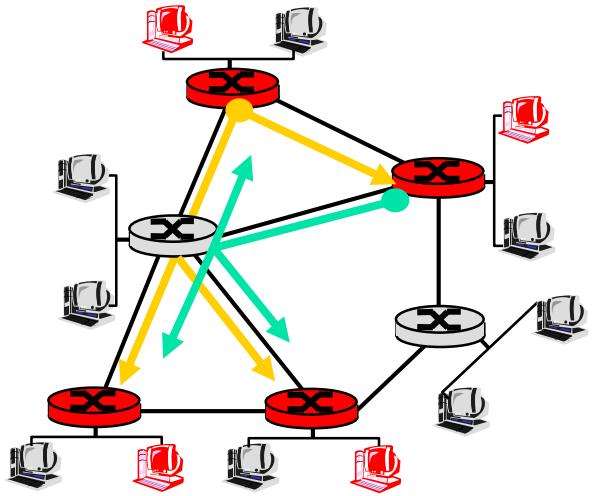
Multicast Routing

Multicast Routing

- Find a spanning tree (or trees) connecting routers having local mcast group members
- Shared-tree
  - Same tree used by all group members
- Source-based
  - Different tree from each sender to receivers



Shared tree



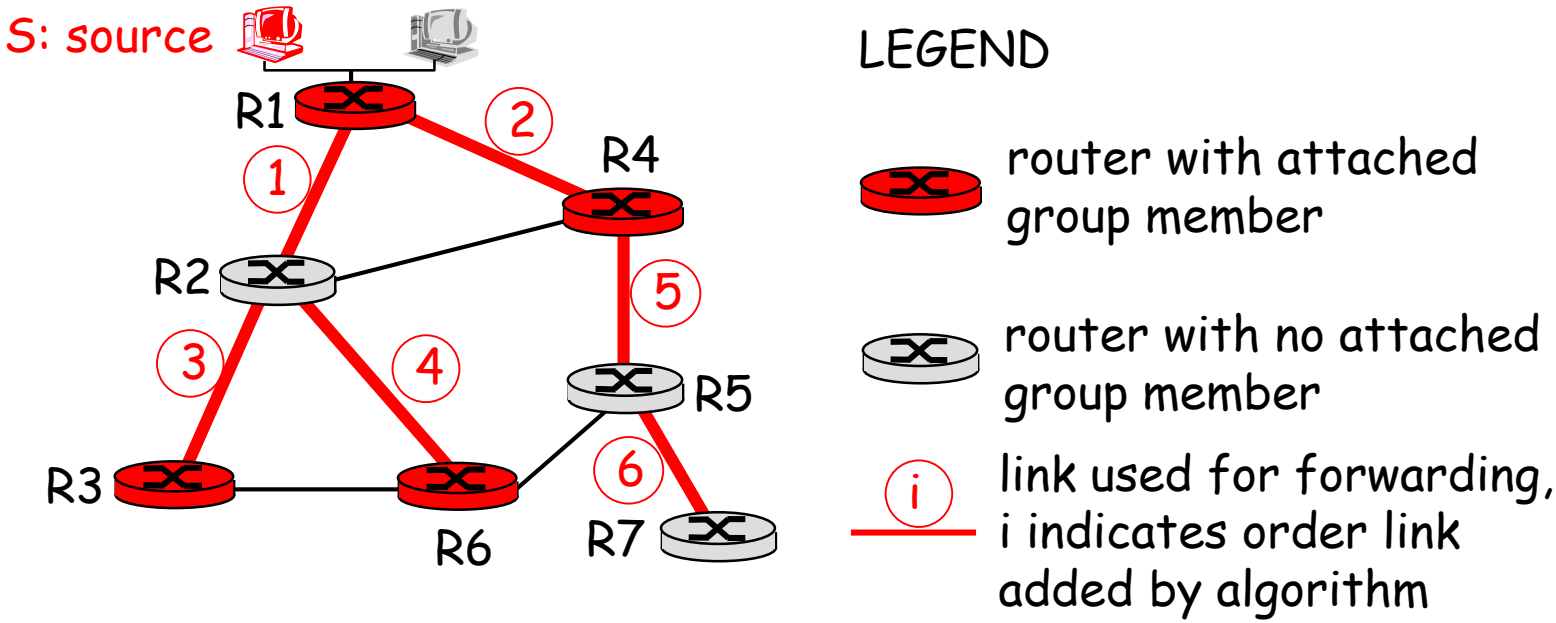
Source-based trees

Approaches for Multicast Trees

- Source-based tree: one tree per source
  - Shortest path trees
  - Reverse path forwarding
- Group-shared tree: group uses one tree
  - Minimal spanning (Steiner)
  - Center-based trees

Shortest Path Trees

- Multicast forwarding tree
  - Tree of shortest path routes from source to all receivers
  - Use Dijkstra's algorithm, used with OSPF

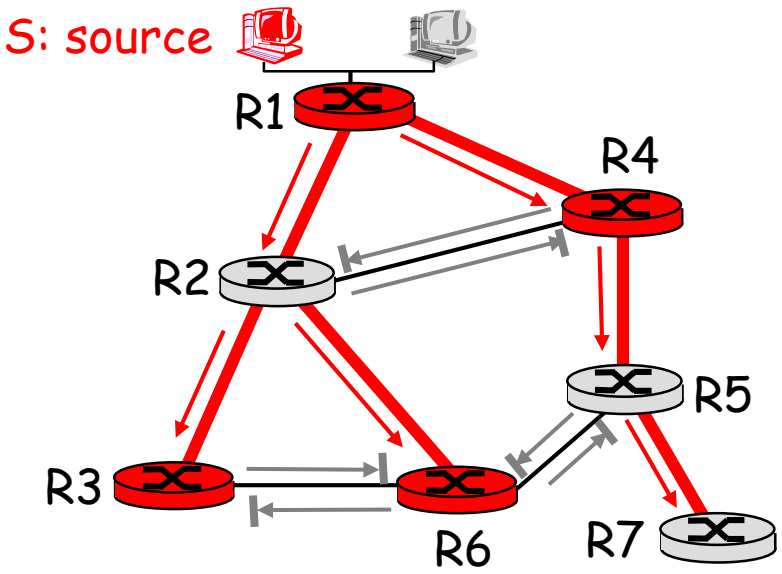


Reverse Path Forwarding

- Rely on router's knowledge of unicast shortest path from it to sender
- Each router has simple forwarding behavior:
- Used with RIP

if (mcast datagram received on incoming link on shortest path back to sender)
  then flood datagram onto all outgoing links
  else ignore datagram

Reverse Path Forwarding: Example



LEGEND

router with attached group member

router with no attached group member

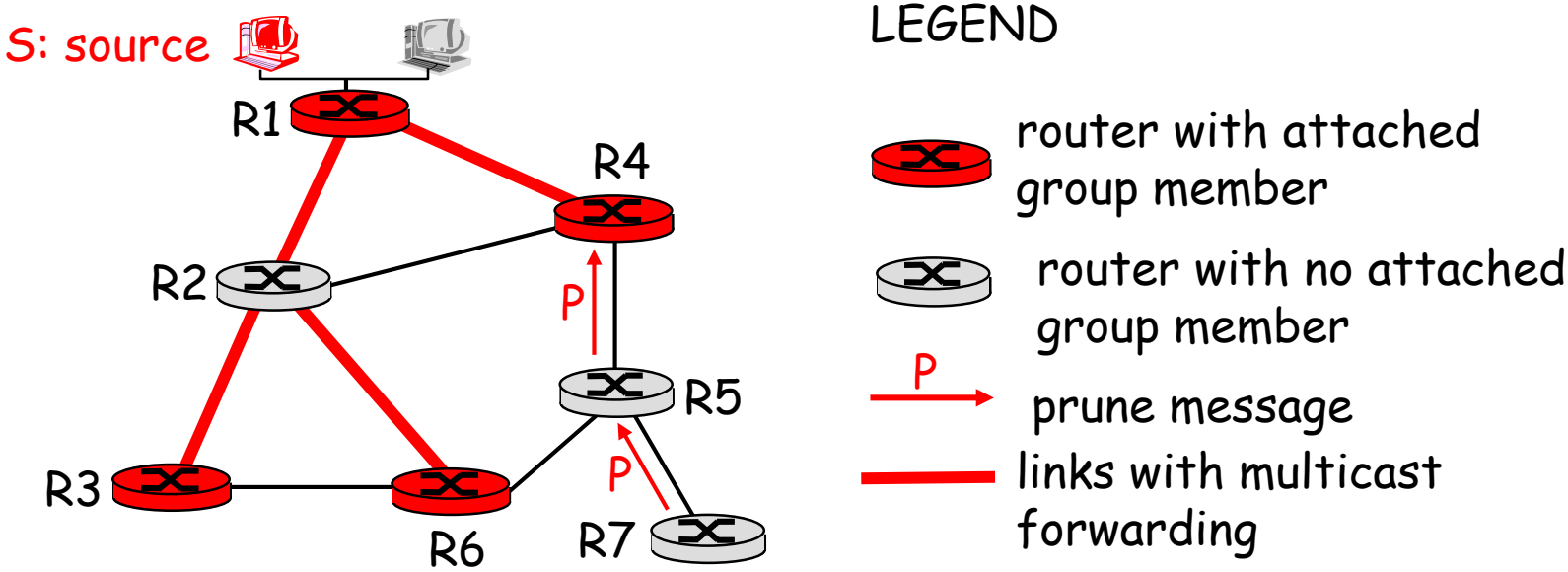
datagram will be forwarded

datagram will not be forwarded

- The result is a source-specific reverse SPT
  - May be a bad choice with asymmetric links

Reverse Path Forwarding: Pruning

- Forwarding tree contains subtrees with no mcast group members
  - No need to forward datagrams down subtree
  - "Prune" msgs sent upstream by router with no downstream group members



Shared-Tree: Steiner Tree

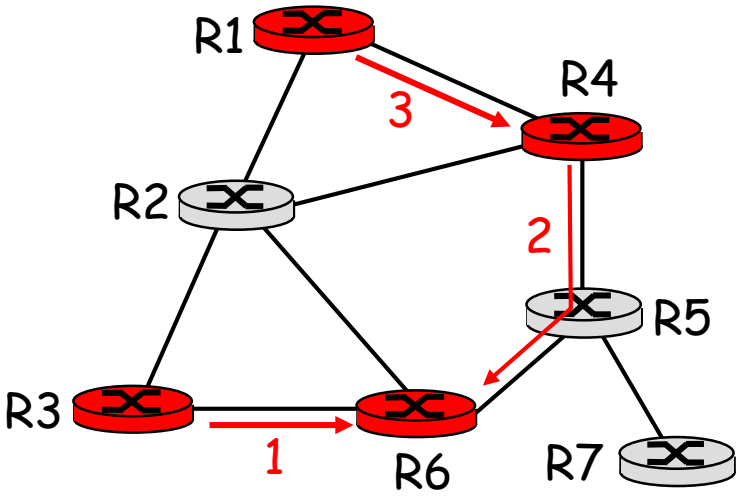
- Steiner Tree
  - Minimum cost tree connecting all routers with attached group members
  - Problem is NP-complete, but excellent heuristics exists
- Not used in practice
  - Computational complexity
  - Information about entire network needed
  - Monolithic: rerun whenever a router needs to join/leave

Center-based Trees

- Single delivery tree shared by all
  - One router identified as center of tree
- Other routers to join:
  - Edge router sends unicast join-msg addressed to center router
  - join-msg processed by intermediate routers and forwarded towards center
  - join-msg either hits existing tree branch for this center, or arrives at center
  - Path taken by join-msg becomes new branch of tree for this router

Center-based Trees: Example

Suppose R6 chosen as center:



LEGEND

router with attached group member

router with no attached group member

1 path order in which join messages generated

Multicasting Routing Protocols

- DVMRP
  - Distance Vector Multicast Routing Protocol, RFC1075
  - Based on RIP
  - Flood and prune: source-based tree, reverse path forwarding
- Soft state
  - DVMRP router periodically (1 min) "forgets" branches are pruned
  - Mcast data again flows down unpruned branch
  - Downstream router: reprune or else continue to receive data
- Does not scale well
  - All routers in the network need global information about all multicast groups and their sources.

Multicasting Routing Protocols

- MOSPF
  - RFC 1584 defines Multicast Extensions to OSPF
  - Link State
  - For a given multicast datagram, all routers calculate an identical shortest-path tree. There is a single path between the datagram's source and any particular destination group member.

- Not widely deployed

Multicasting Routing Protocols

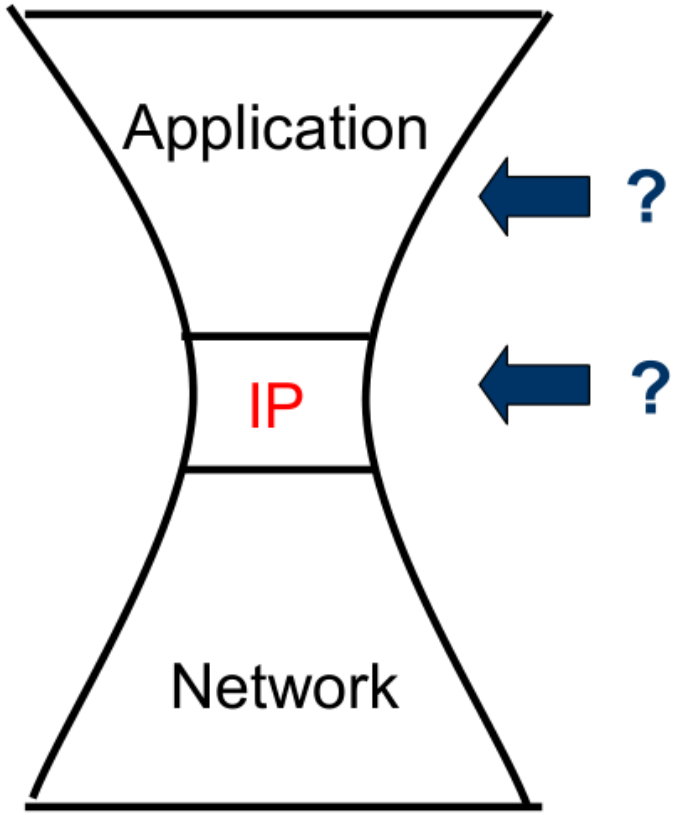
- PIM: Protocol Independent Multicast
  - Not dependent on any specific underlying unicast routing algorithm (works with all)
- Sparse mode
  - Group-shared tree, use center-based approach
  - Group members widely dispersed, bandwidth not plentiful
- Dense mode
  - Flood and prune: source-based tree, reverse path forwarding (Nearly same as DVMRP)
  - group members densely packed, bandwidth more plentiful

Application-level Multicast

Failure of IP Multicast

- Not widely deployed even after 15 years!
  - Use carefully – e.g., on LAN or campus, rarely over WAN
- Various failings
  - Scalability of routing protocols
  - Hard to manage
  - Hard to implement TCP equivalent
  - Hard to get applications to use IP Multicast without existing wide deployment
  - Hard to get router vendors to support functionality and hard to get ISPs to configure routers to enable
- Can we achieve efficient multi-point delivery without IP-layer support?

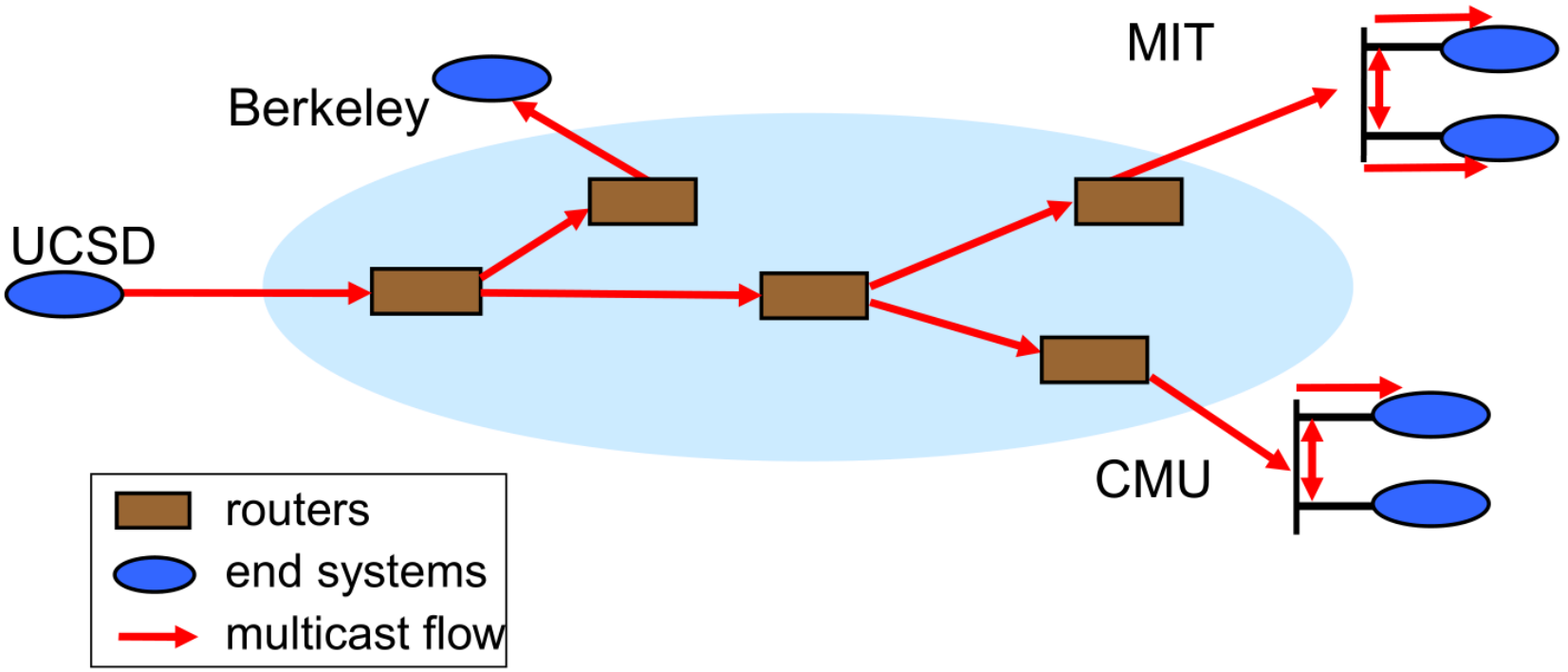
Supporting Multicast on the Internet



Internet architecture

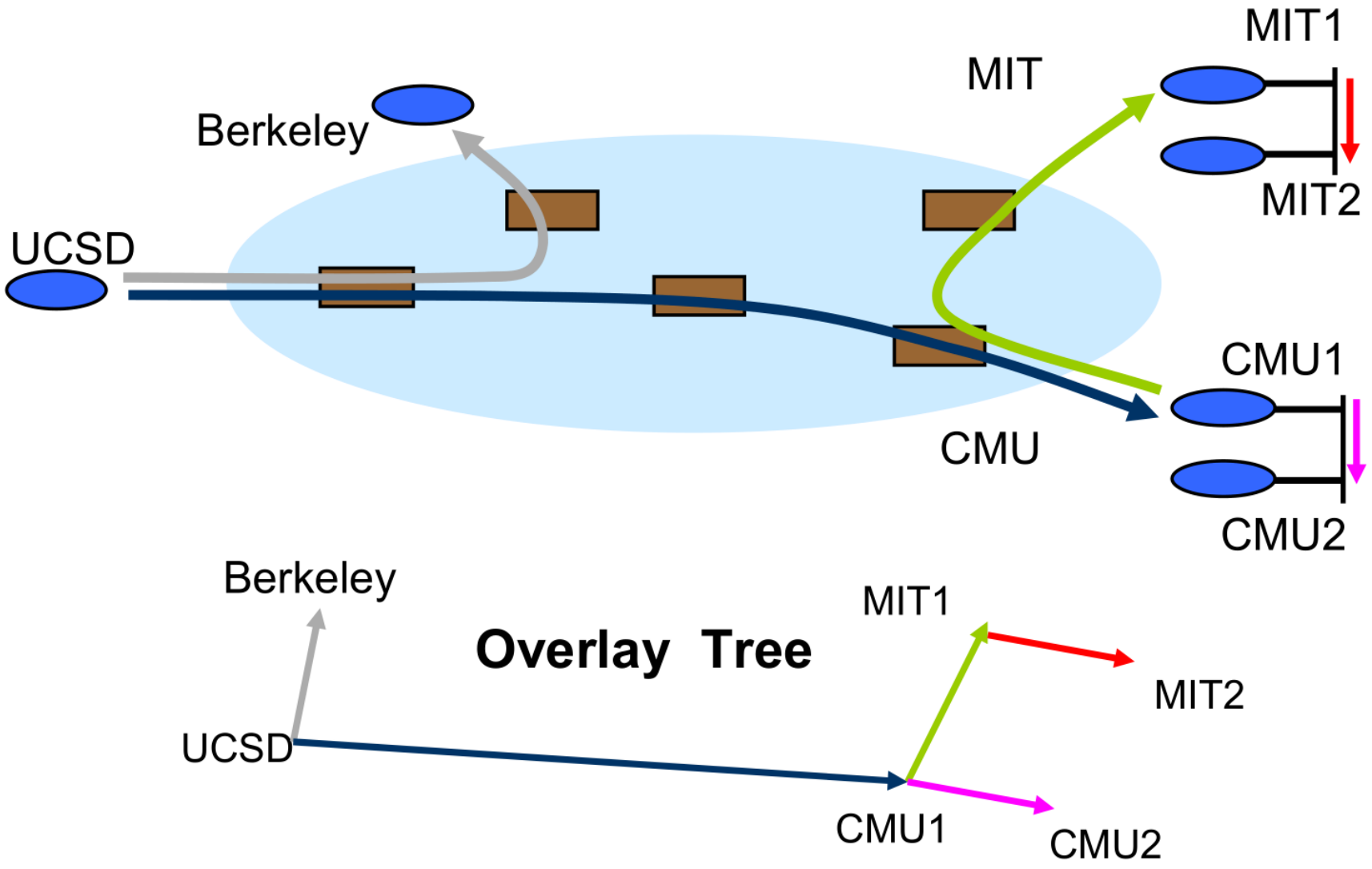
At which layer should multicast be implemented?

IP Multicast



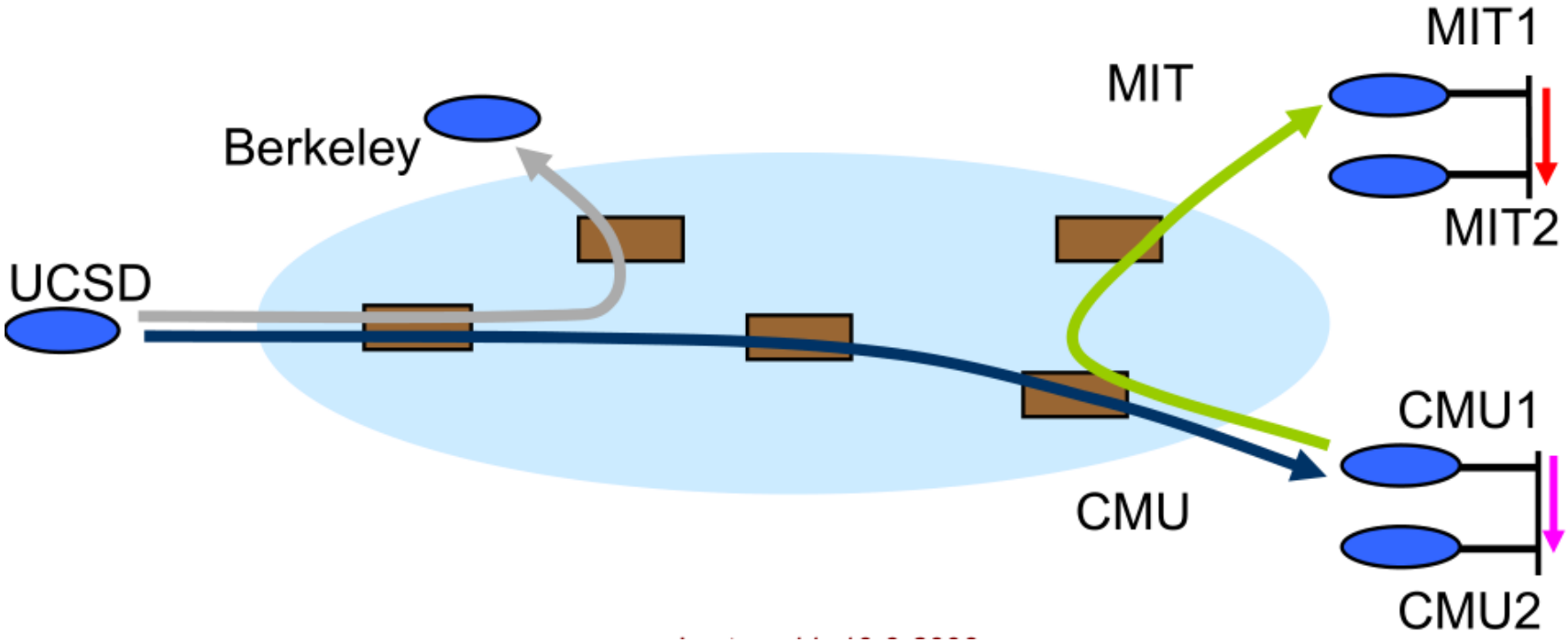
- Highly efficient
- Good delay

End System (App-layer) Multicast



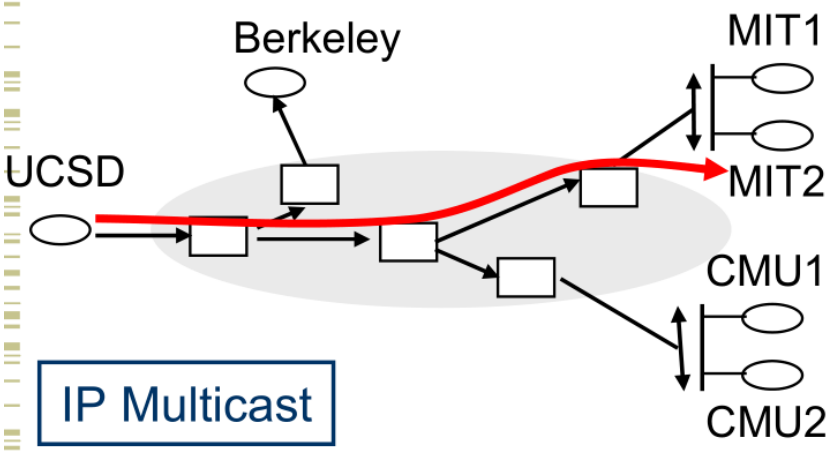
Potential Benefits

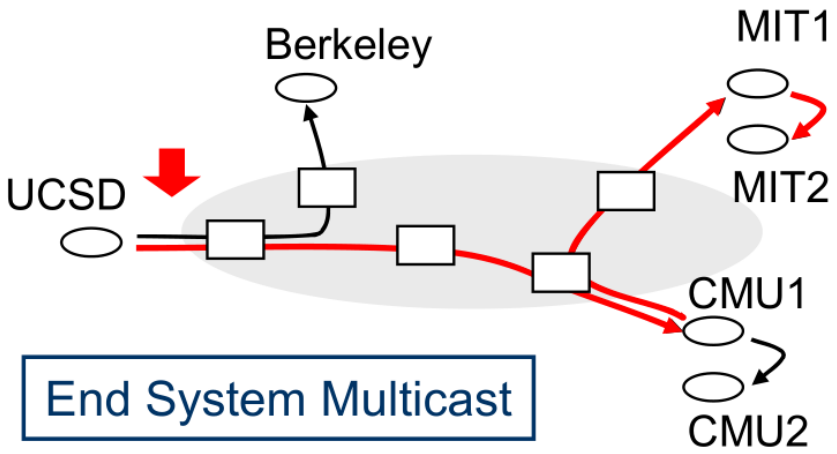
- Quick deployment
- All multicast state in end systems
- Computation at forwarding points simplifies support for higher level functionality



Concerns

- 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)
  - Penalty can be kept small in practice





Summary

- IP Multicast
  - 组播地址
  - 组管理：IGMP
  - 组播路由机制及协议

Homework

- 第四章：R35, R36, P45