Computer Networks

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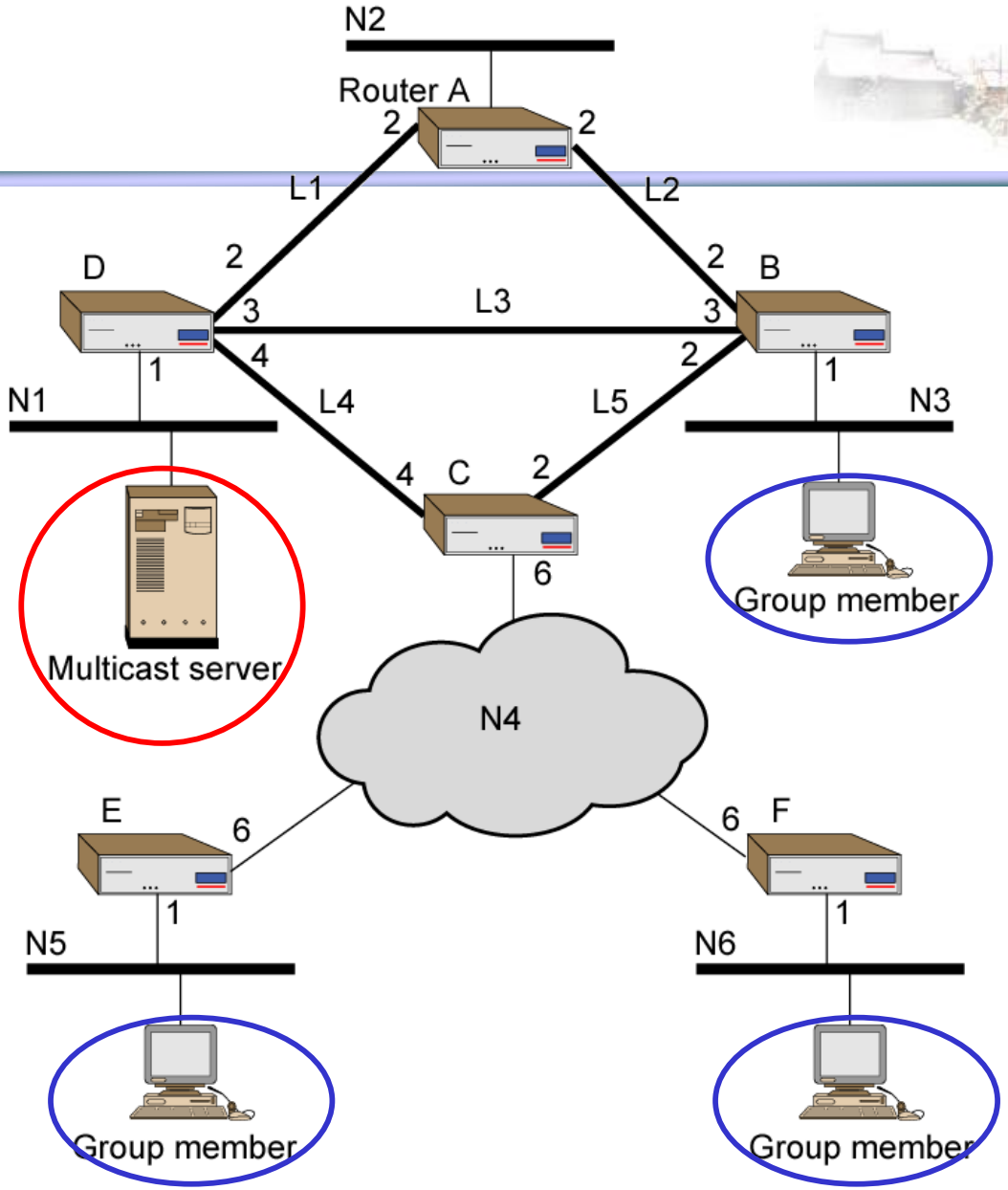
Chapter 4. Internetworking

- The Internet Protocol
- IP Address
- ARP and DHCP
- ICMP
- IPv6
- Mobile IP
- Internet Routing
- BGP and OSPF
- IP Multicasting
- Multiprotocol Label Switching (MPLS)

IP Multicasting

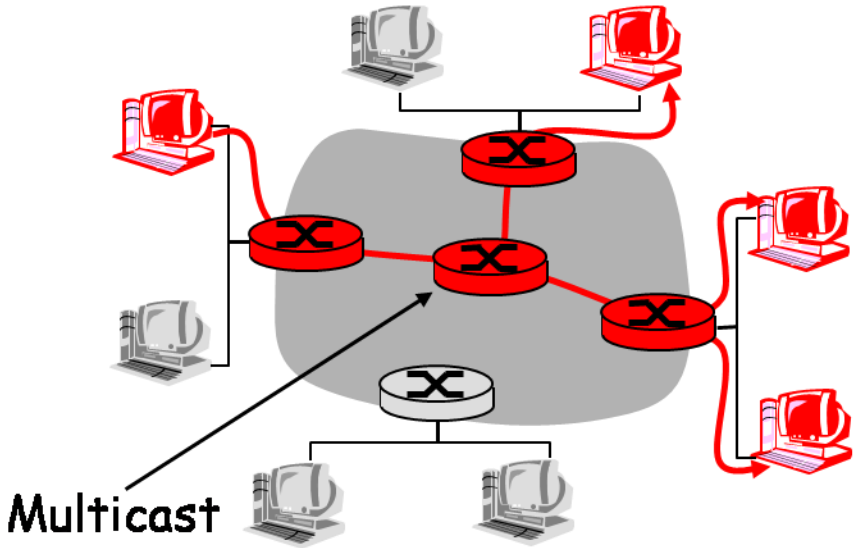
- Multicast
  - Act of sending datagram to multiple receivers (hosts) with single `transmit` operation
- Multicast address (class D in IPv4)
  - Addresses that refer to group of hosts on one or more networks
- Applications
  - Multimedia (TV) broadcast
  - Teleconferencing
  - Database replication
 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

Example Config

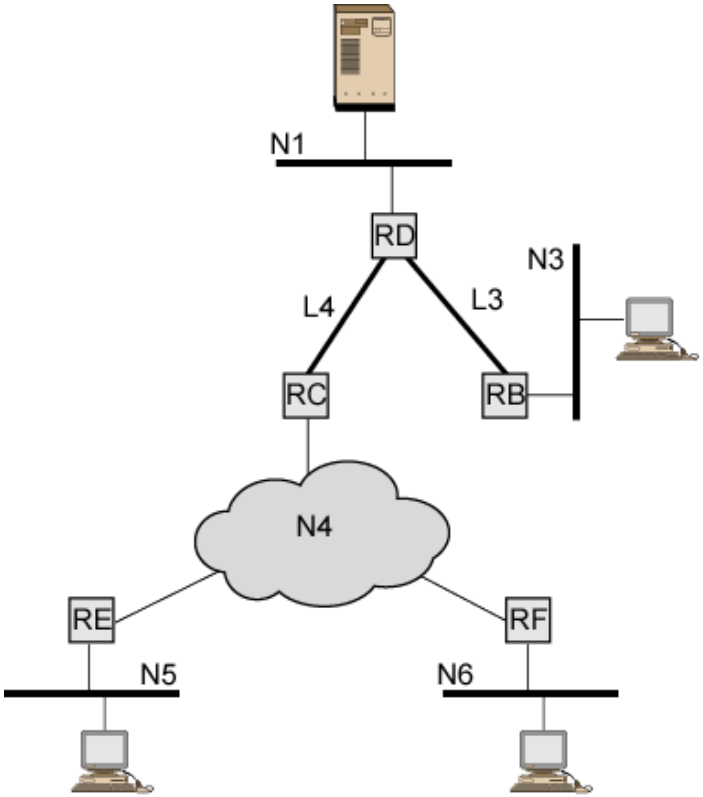


Handling IP Multicast

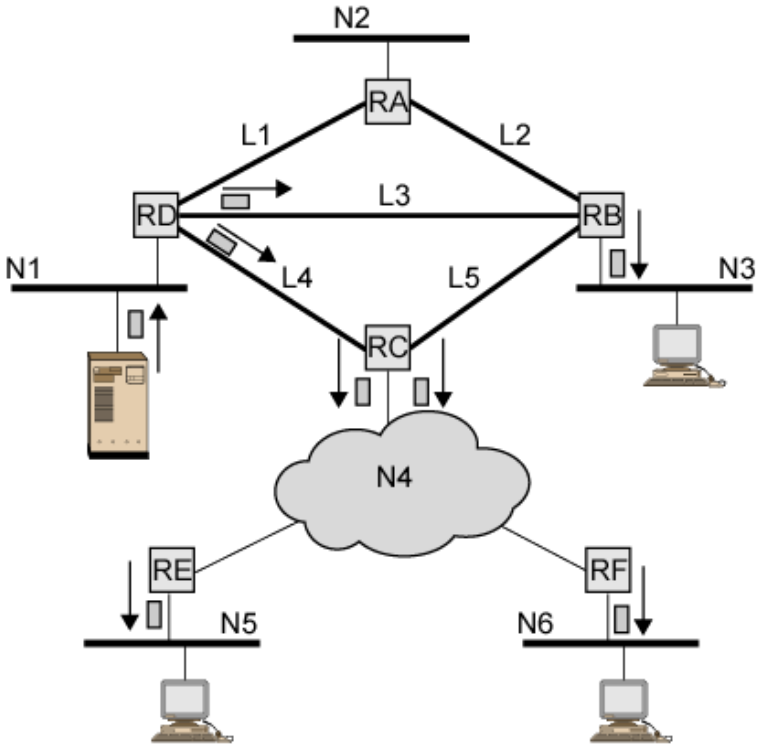
- Multicast (Spanning) Tree
  - Build a (least cost) tree connecting routers having local mcast group members
  - Nodes (routers) forward copies only along spanning tree
- Sender only sends once



Multicast Example



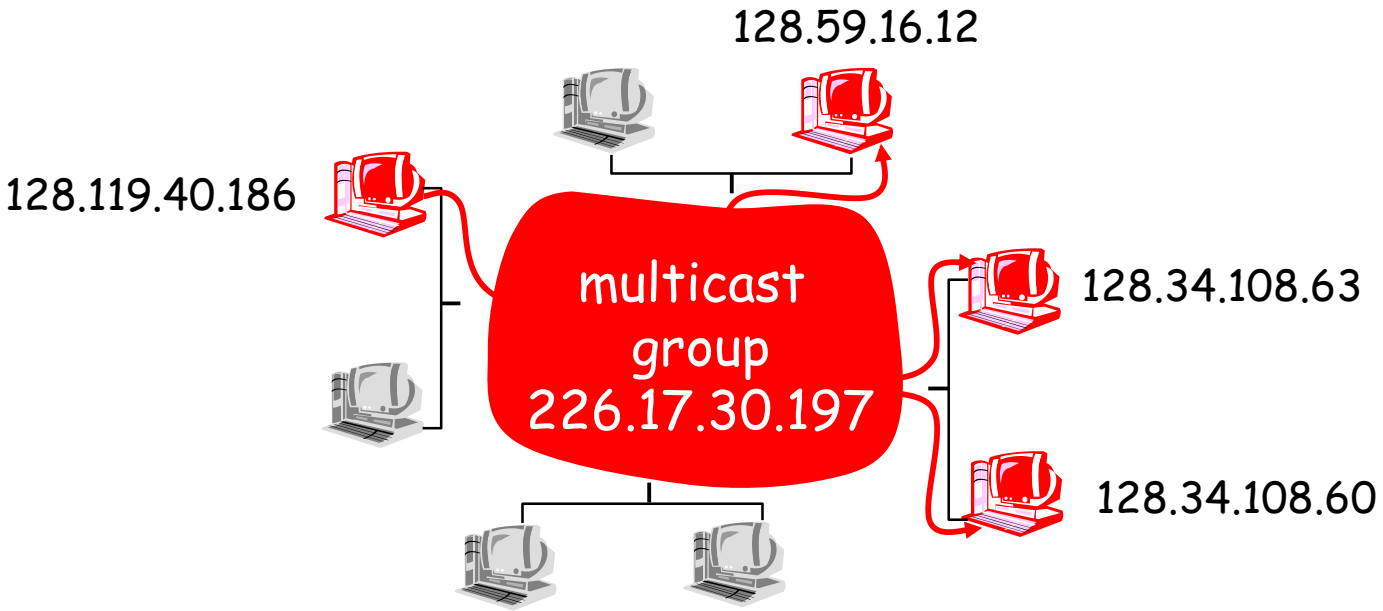
(a) Spanning tree from source to multicast group



(b) Packets generated for multicast transmission

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

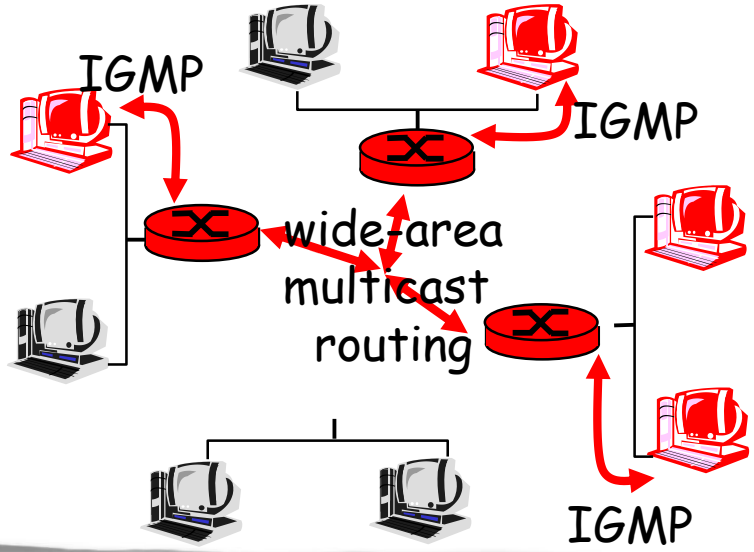
- Convention needed to identify multicast addresses
  - IPv4: Class D, start with 1110

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

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

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)

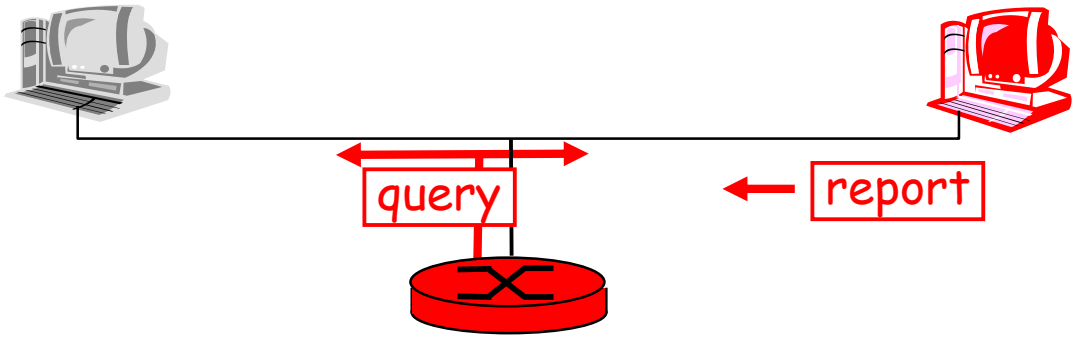


IGMP

- 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

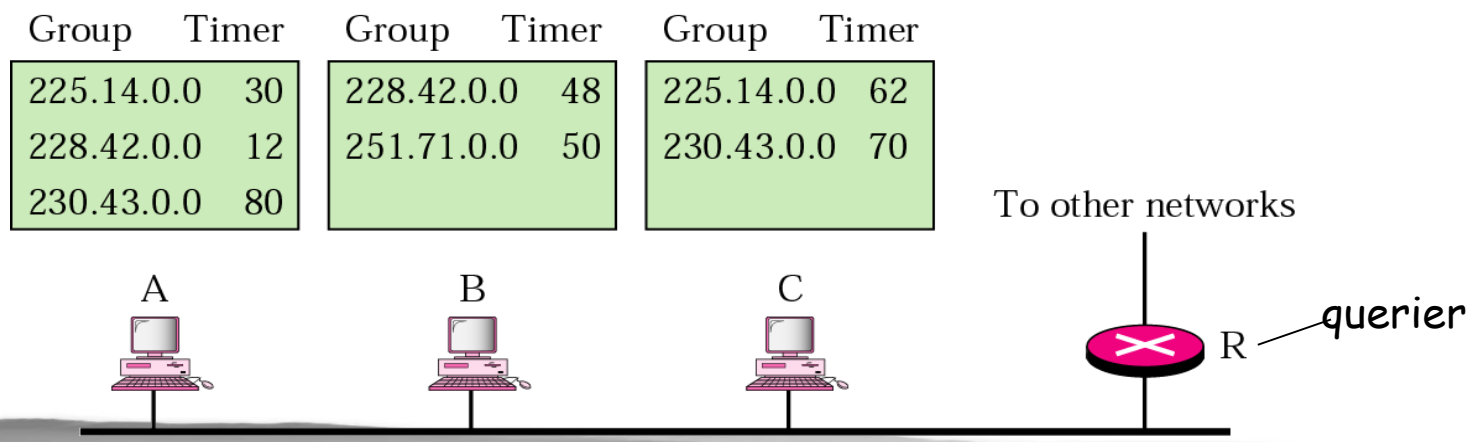
Principle Operations

- 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)

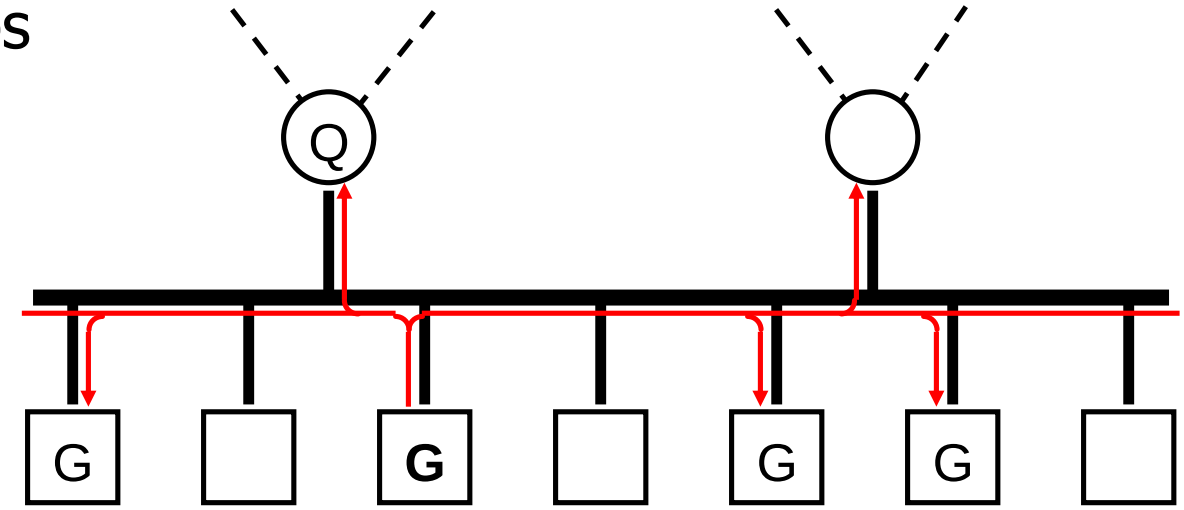
- 2 special multicast address
  - 224.0.0.1: all multicast groups on subnet
  - 224.0.0.2: all routers on subnet
- On each LAN, one router is elected as the querier
  - Querier periodically sends a Membership Query message to 224.0.0.1 with TTL = 1
- On receipt, hosts start random timers (0~10s) for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

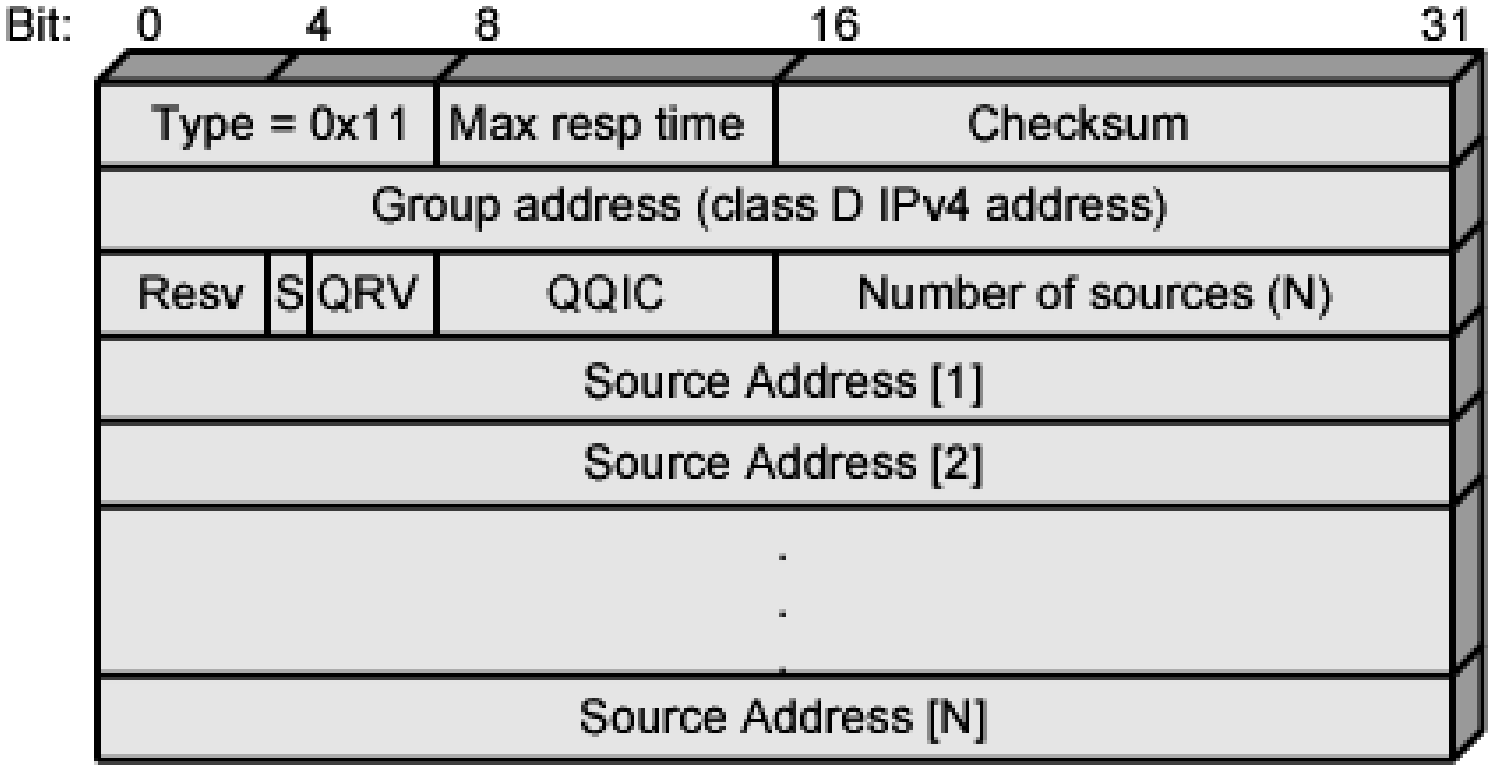
IGMP v3

- 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

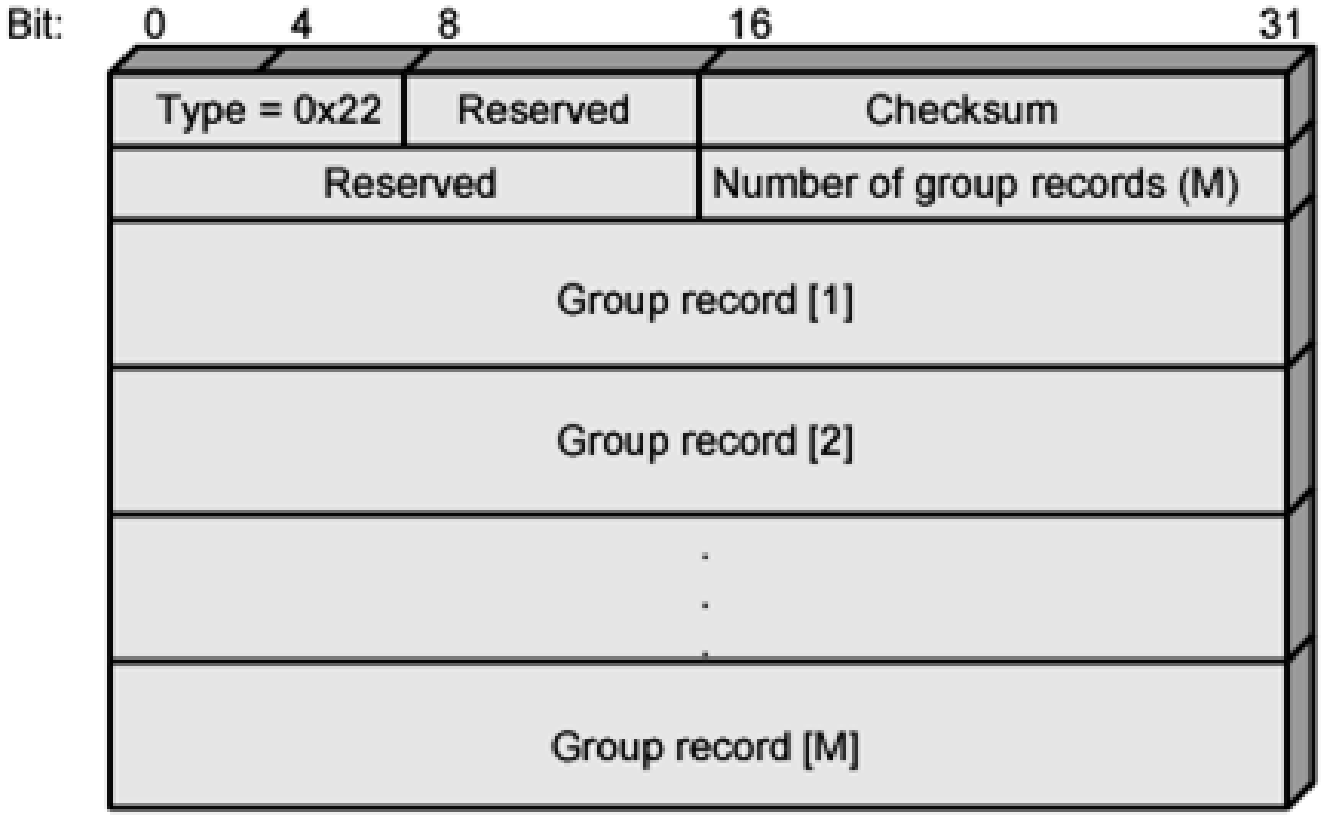
Membership Query Fields (1)

- 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

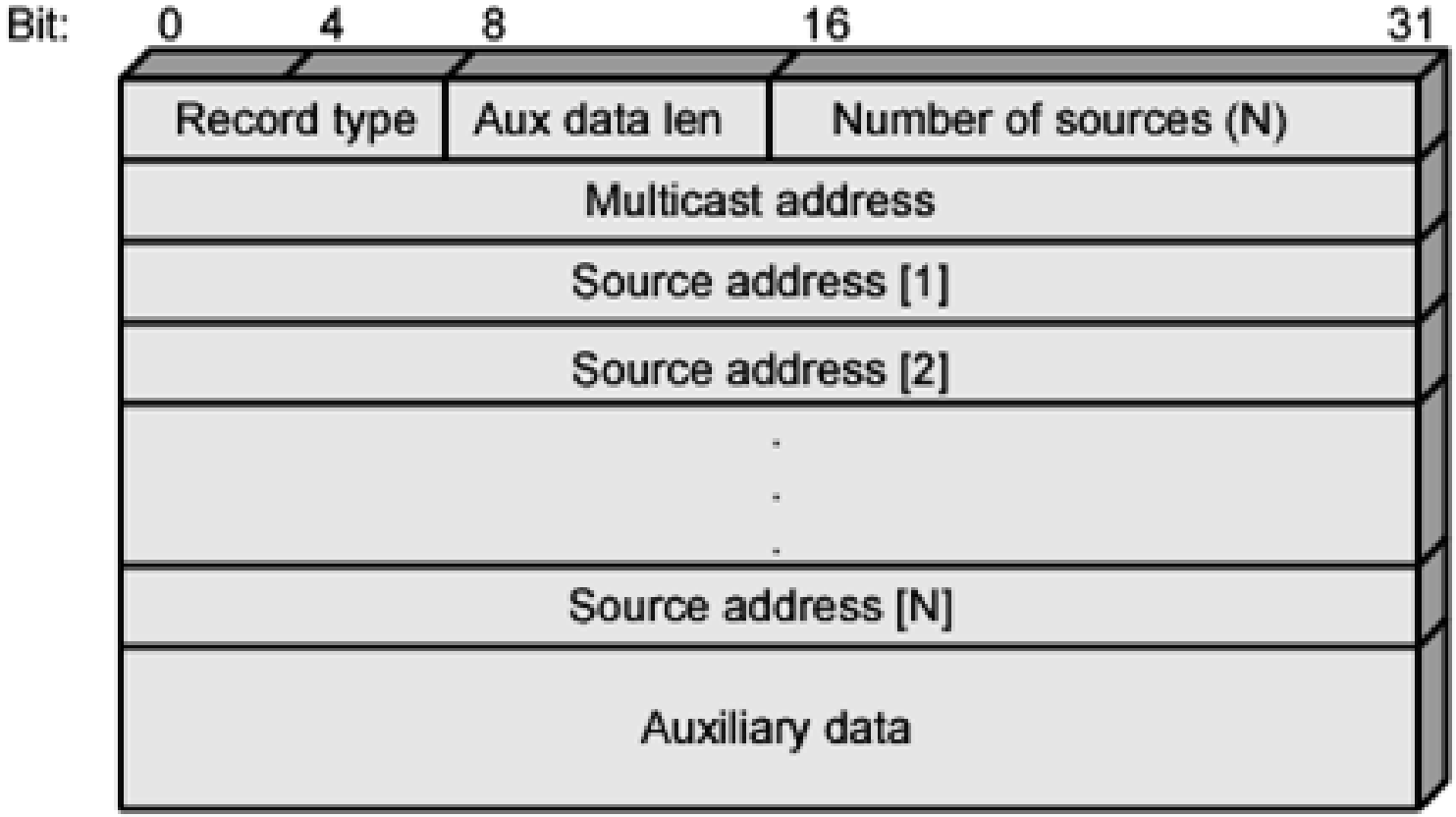


(b) Membership report message

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

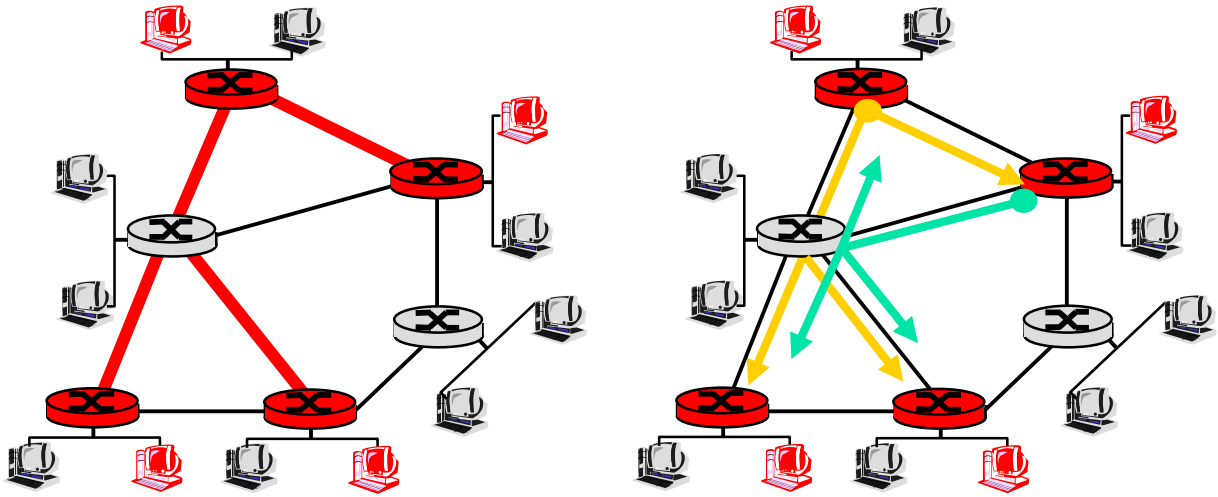
- Multicast Address (32 bits)
  - Identify the group attended
- Record Type (8 bits)
  - EXCLUDE or INCLUDE mode (6 modes defined)
- Number of Sources (16 bits)
- Source Addresses
- Aux Data Length (8 bits)
  - Length of Auxiliary Data, in 32-bit words
- Auxiliary Data
  - Currently, no auxiliary data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

- 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



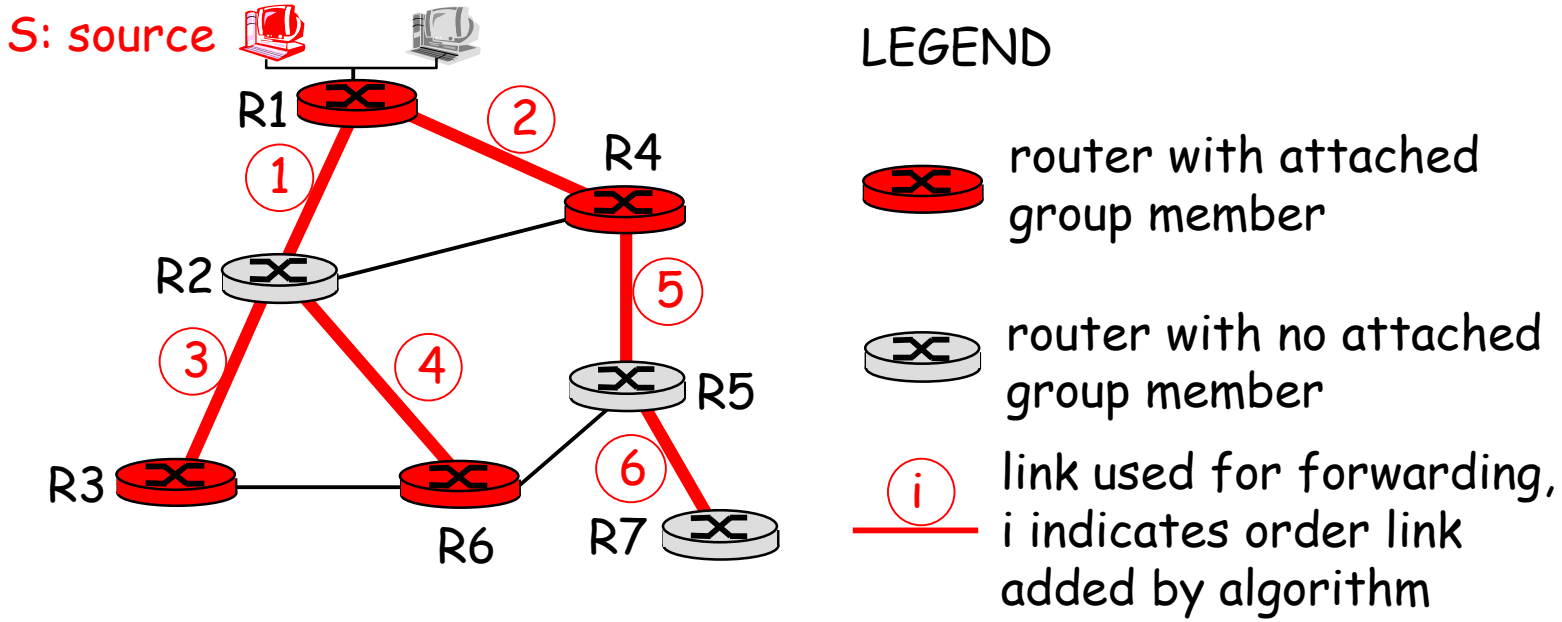
Shared tree　　Source-based trees

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

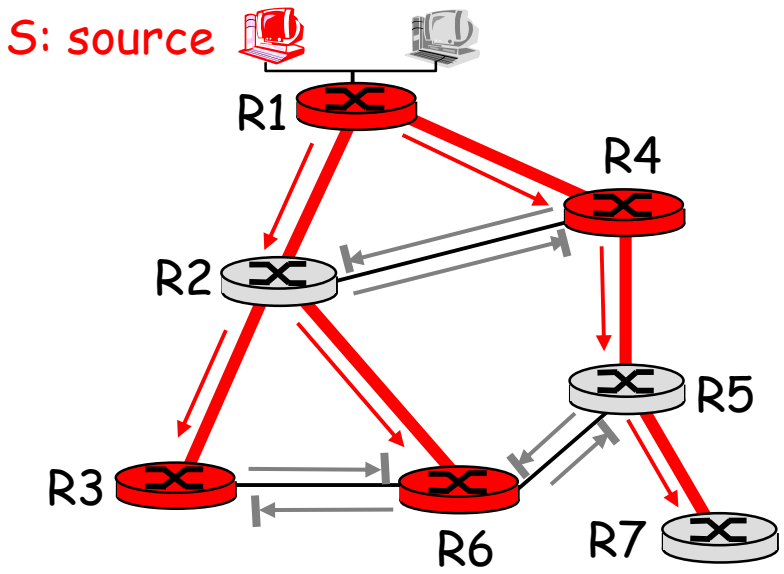


Reverse Path Forwarding

- 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



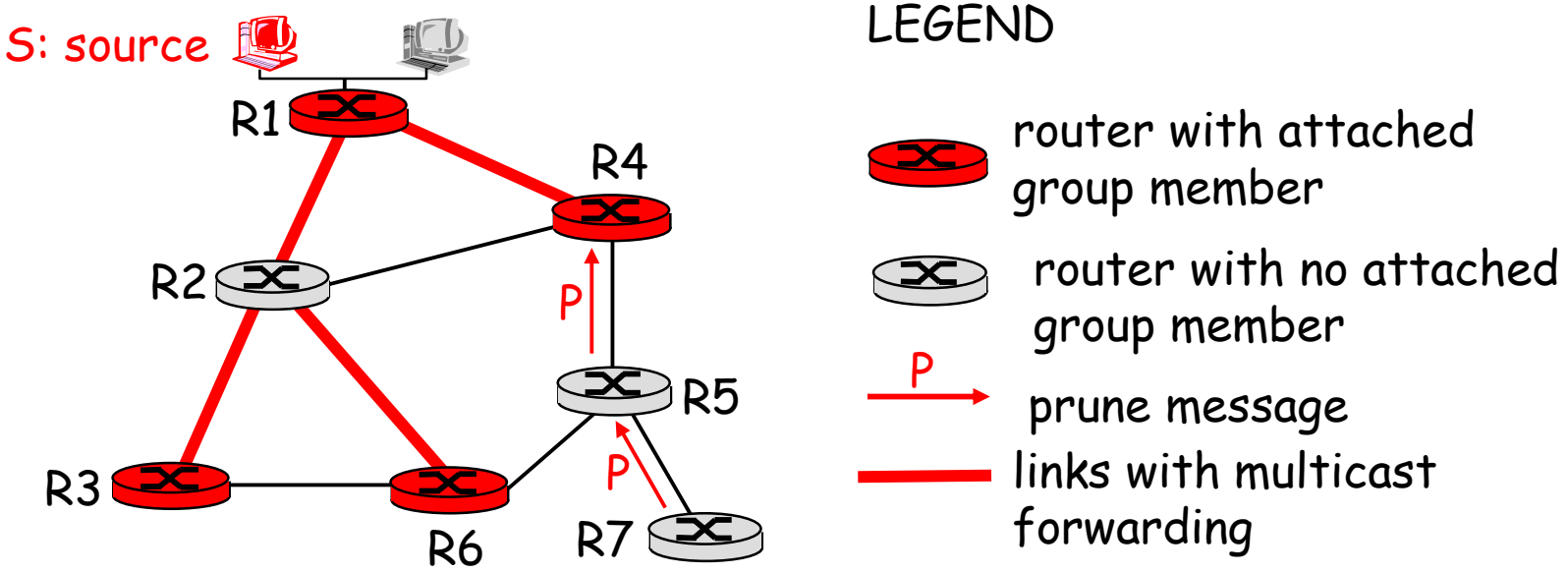
LEGEND

- 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

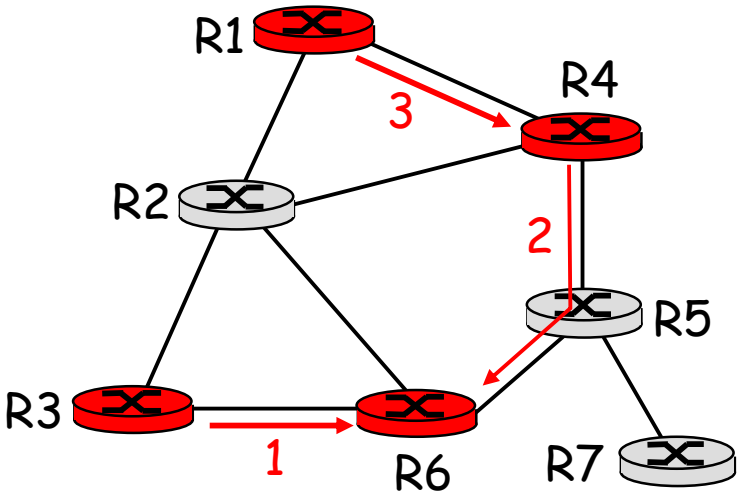
- Steiner Tree
  - Minimum cost tree connecting all routers with attached group members
  - Problem is NP-complete, but excellent heuristics exists
- Not used in practice
  - Computational complexity
  - Information about entire network needed
  - Monolithic: rerun whenever a router needs to join/leave

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
  - 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

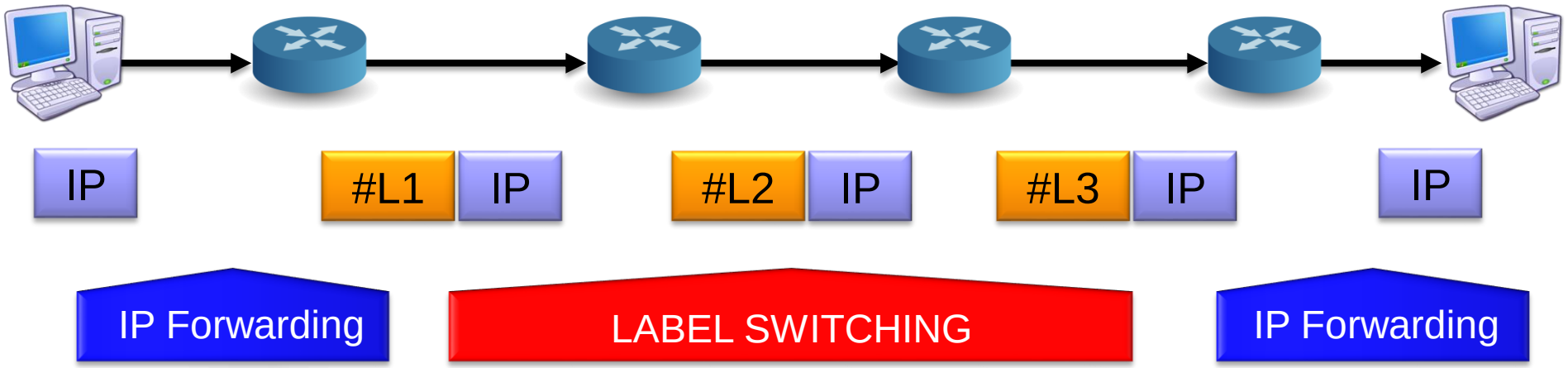
Multicasting Routing Protocols

- PIM: Protocol Independent Multicast
  - 2 different multicast distribution scenarios
  - Sparse: group members widely dispersed, bandwidth not plentiful
  - Dense: group members densely packed, bandwidth more plentiful
- Sparse mode
  - Group-shared tree, use center-based approach
- Dense mode
  - Nearly same as DVMRP

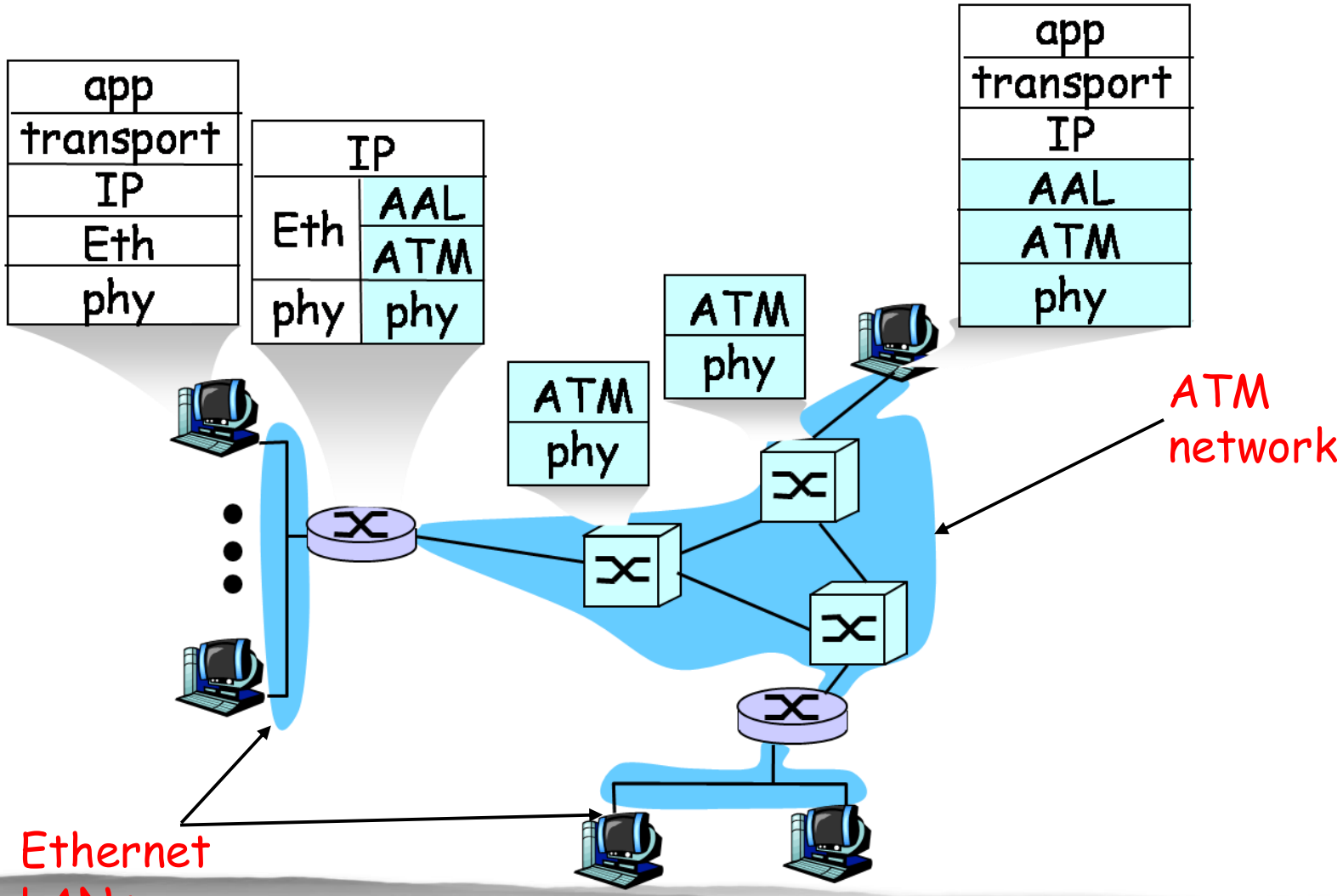
MPLS

Multiprotocol Label Switching

- Speed up IP forwarding by using fixed length label to do VC-like routing
  - Called IP traffic engineering
  - Leverage existing ATM hardware
  - Better supporting Virtual Private Networks
  - QoS support – for Voice/Video on IP



IP-Over-ATM

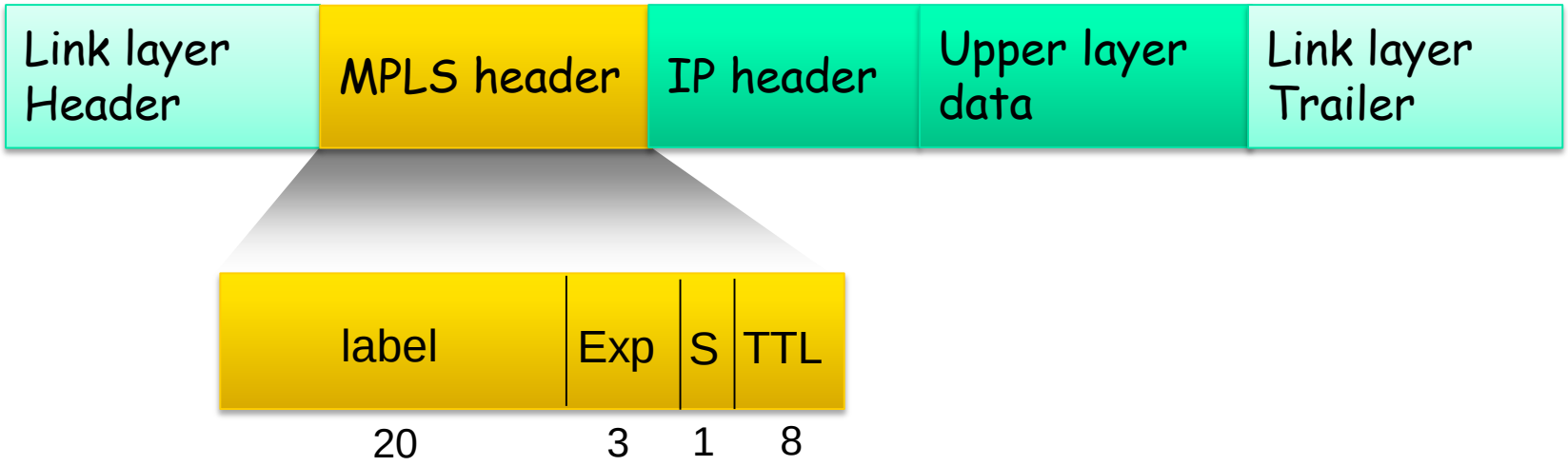

app
transport
IP
Eth
phy
IP
Eth
AAL
ATM
phy
phy
ATM
phy
ATM
phy
app
transport
IP
AAL
ATM
phy
ATM network
Ethernet LANs

IP-Over-ATM

- Boundary router at source LAN
  - IP layer maps between IP, ATM dest address
  - Passes datagram to AAL5
  - AAL5 encapsulates data, segments cells, passes to ATM layer
- ATM network: moves cell along VC to destination LAN
- Boundary router at dest LAN
  - AAL5 reassembles cells into original datagram
  - If CRC OK, datagram is passed to IP

MPLS

- Capable of providing a connection oriented Inter-networks
  - Makes full use of VC networks such as ATM or Frame Relay



MPLS Header

- Contains one or more "labels", called a label stack

Each label contains 4 fields

- Label value, 20-bit VC number
- Experimental traffic class, 3 bit, for priority and Explicit Congestion Notification

- Bottom of stack, 1 bit, means the last "label"
- Time to Live, 8 bit, same as IP TTL

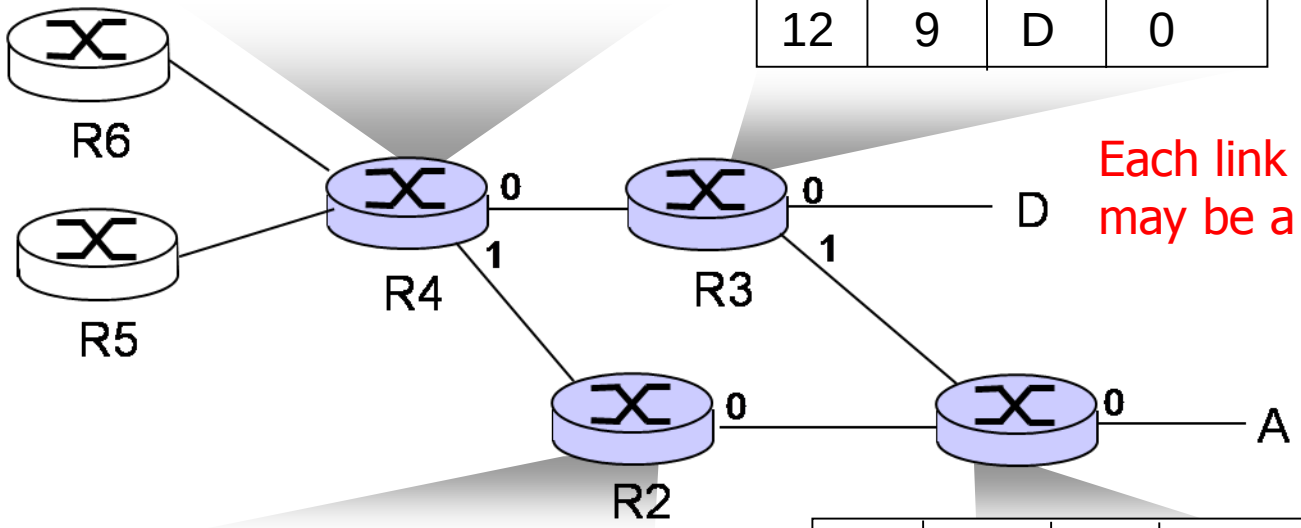
MPLS Forwarding

- By MPLS capable routers, must co-exist with IP-only routers
- Forwards packets to outgoing interface based only on label value
  - MPLS forwarding table distinct from IP forwarding tables
- Signaling protocol needed to set up forwarding table
  - Support hop-by-hop and source routing
  - RSVP-TE, an extension of the Resource Reservation Protocol (RSVP) for traffic engineering

MPLS Forwarding Tables

in label	out label	dest	out interface
	10	A	0
	12	D	0
	8	A	1

in label	out label	dest	out interface
10	6	A	1
12	9	D	0

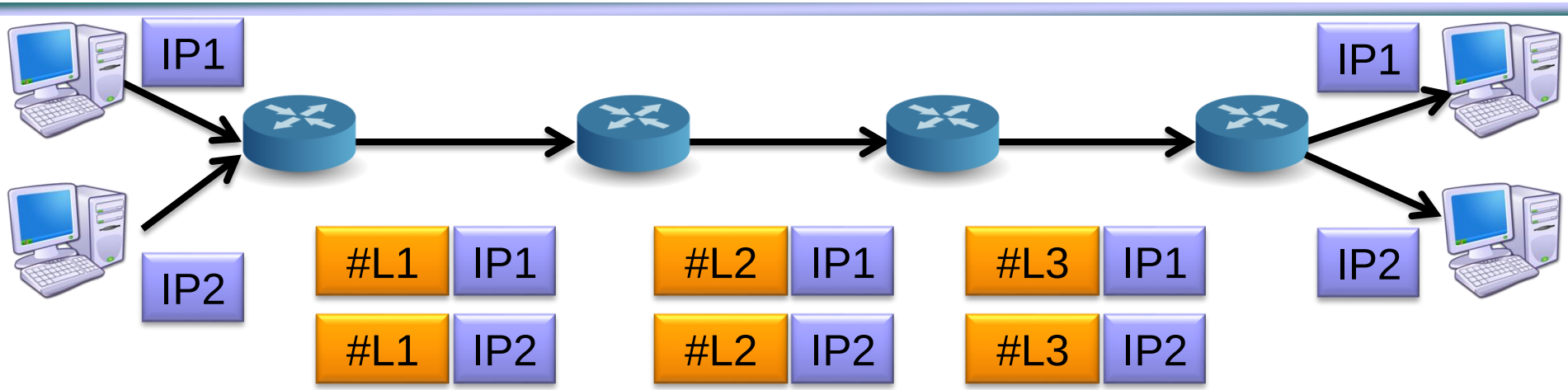


Each link in a MPLS path may be a VC in local net

in label	out label	dest	out interface
8	6	A	0

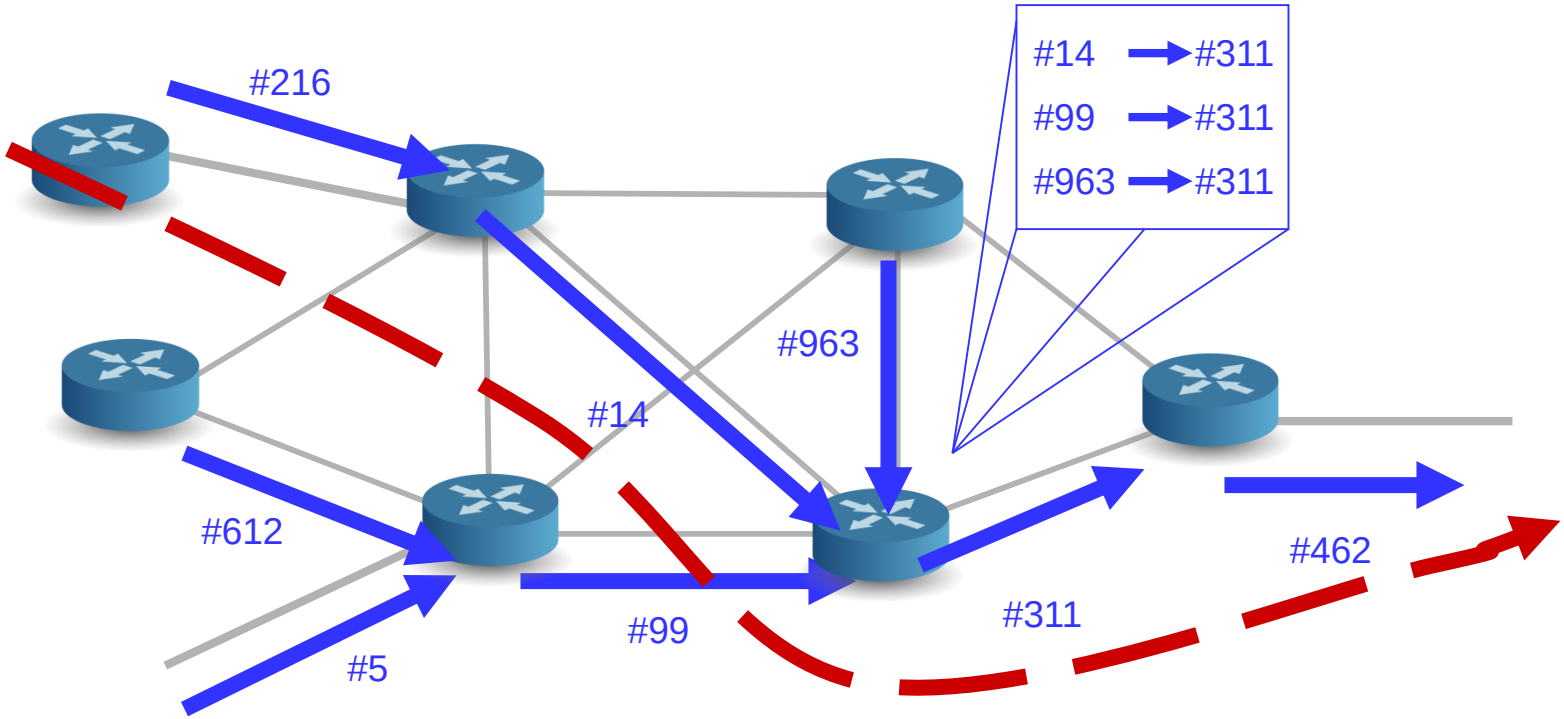
in label	out label	dest	out interface
6	-	A	0

More than VC



- Forwarding Equivalence Class
  - A subset of packets or flows that are all treated the same way by a MPLS router
  - Provides for a great deal of flexibility and scalability

Traffic Engineering



- IP multicast can be supported in likely way