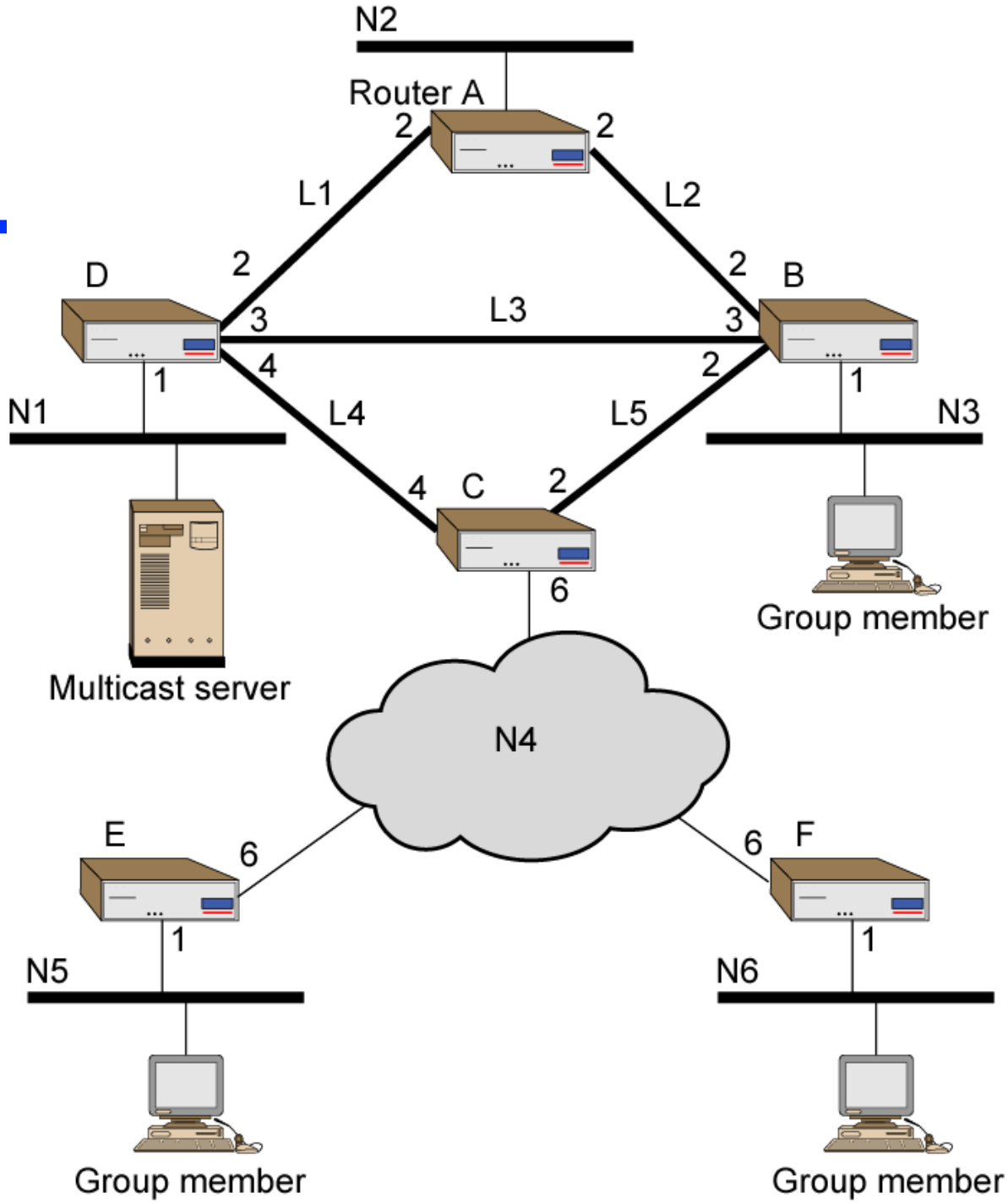
Internetwork Operation

Multicasting

- Addresses that refer to group of hosts on one or more networks
- Uses
  - —Multimedia “broadcast”
  - —Teleconferencing
  - —Database
  - —Distributed computing
  - —Real time workgroups

Example Config

Suppose N1 want to multicast to N3,N5 and N6



Broadcast and Multiple Unicast

- Broadcast a copy of packet to each network
  - —Requires 13 copies of packet
- Multiple Unicast
  - —Send packet only to networks that have hosts in group
  - —11 packets

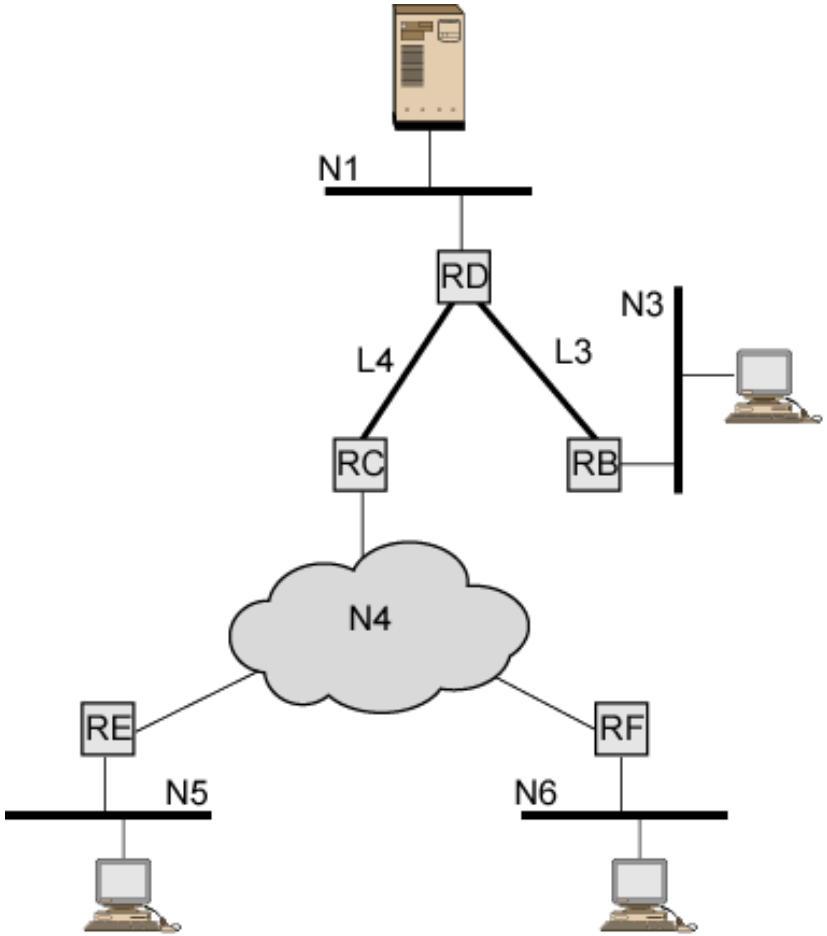
Table 19.1 Traffic Generated by Various Multicasting Strategies

	(a) Broadcast					(b) Multiple Unicast				(c) Multicast
	S → N2	S → N3	S → N5	S → N6	Total	S → N3	S → N5	S → N6	Total	
N1	1	1	1	1	4	1	1	1	3	1
N2										
N3		1			1	1			1	1
N4			1	1	2		1	1	2	2
N5			1		1		1		1	1
N6				1	1			1	1	1
L1	1				1					
L2										
L3		1			1	1			1	1
L4			1	1	2		1	1	2	1
L5										
Total	2	3	4	4	13	3	4	4	11	8

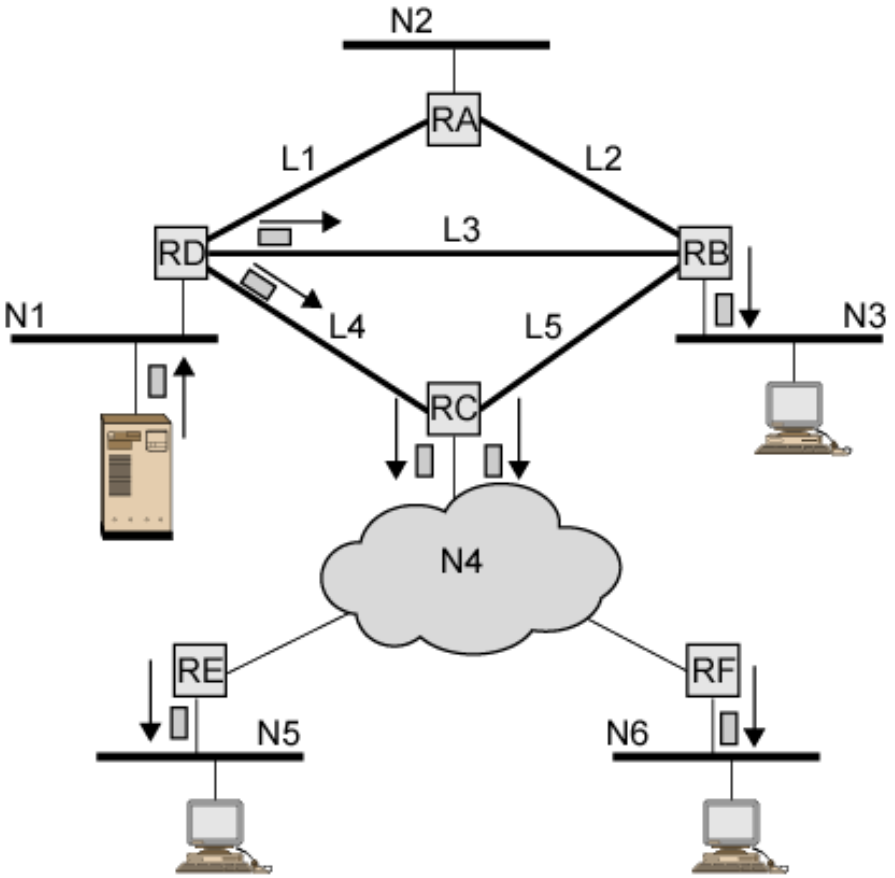
True Multicast

- Determine least cost path to each network that has host in group
  - —Gives spanning tree configuration containing networks with group members
- Transmit single packet along spanning tree
- Routers replicate packets at branch points of spanning tree
- 8 packets required

Multicast Example



(a) Spanning tree from source to multicast group



(b) Packets generated for multicast transmission

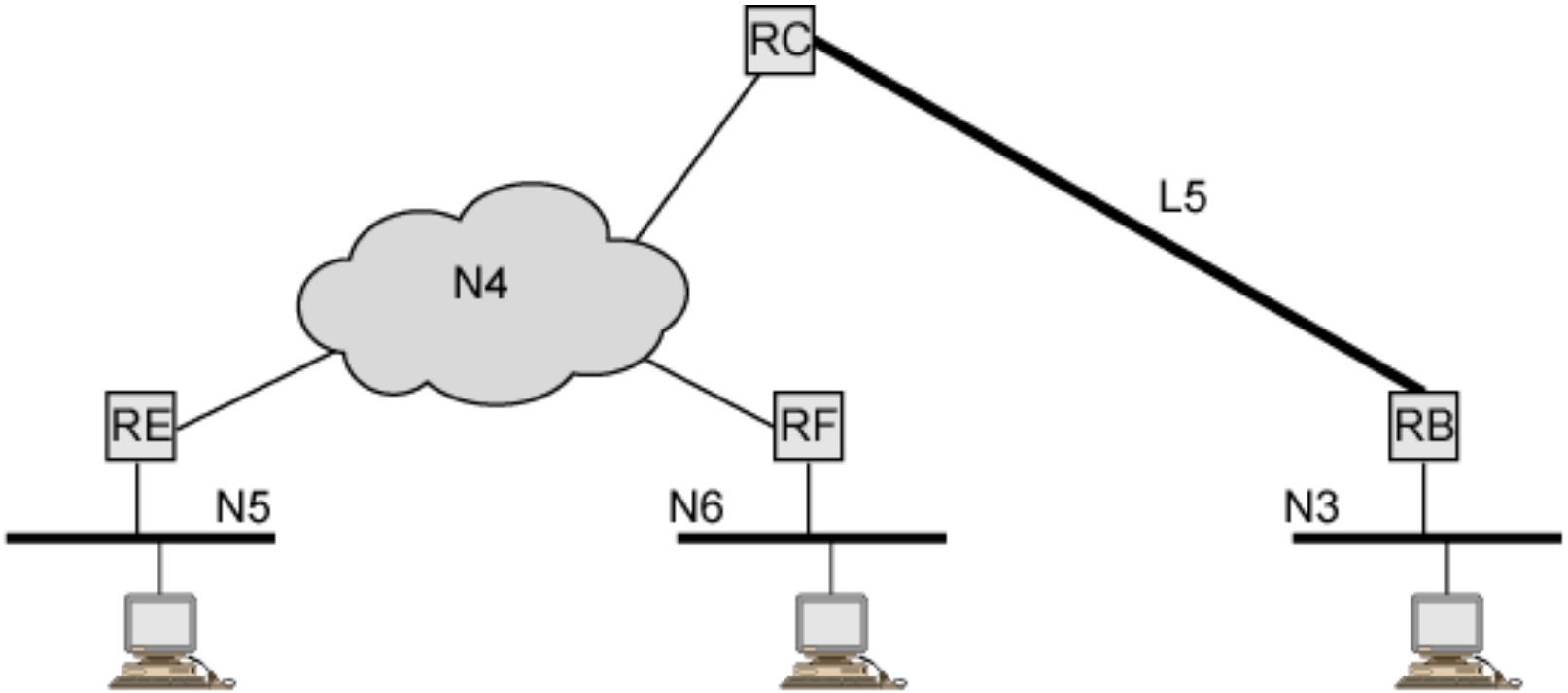
Requirements for Multicasting (1)

- Router may have to forward more than one copy of packet
- Convention needed to identify multicast addresses
  - IPv4 - Class D - start 1110
  - IPv6 - 8 bit prefix, all 1, 4 bit flags field, 4 bit scope field, 112 bit group identifier
- Nodes must translate between IP multicast addresses and list of networks containing group members
- Router must translate between IP multicast address and network multicast address

Requirements for Multicasting (2)

- Mechanism required for hosts to join and leave multicast group
- Routers must exchange info
  - —Which networks include members of given group
  - —Sufficient info to work out shortest path to each network
  - —Routing algorithm to work out shortest path
  - —Routers must determine routing paths based on source and destination addresses

Spanning Tree from Router C to Multicast Group



Internet Group Management Protocol (IGMP)

- RFC 3376
- Host and router exchange of multicast group info
- Use broadcast LAN to transfer info among multiple hosts and routers

Principle Operations

- Hosts send messages to routers to subscribe to and unsubscribe from multicast group
  - —Group defined by multicast address
- Routers check which multicast groups are of interest to which hosts
- IGMP currently version 3
- IGMPv1
  - —Hosts could join group
  - —Routers used timer to unsubscribe members

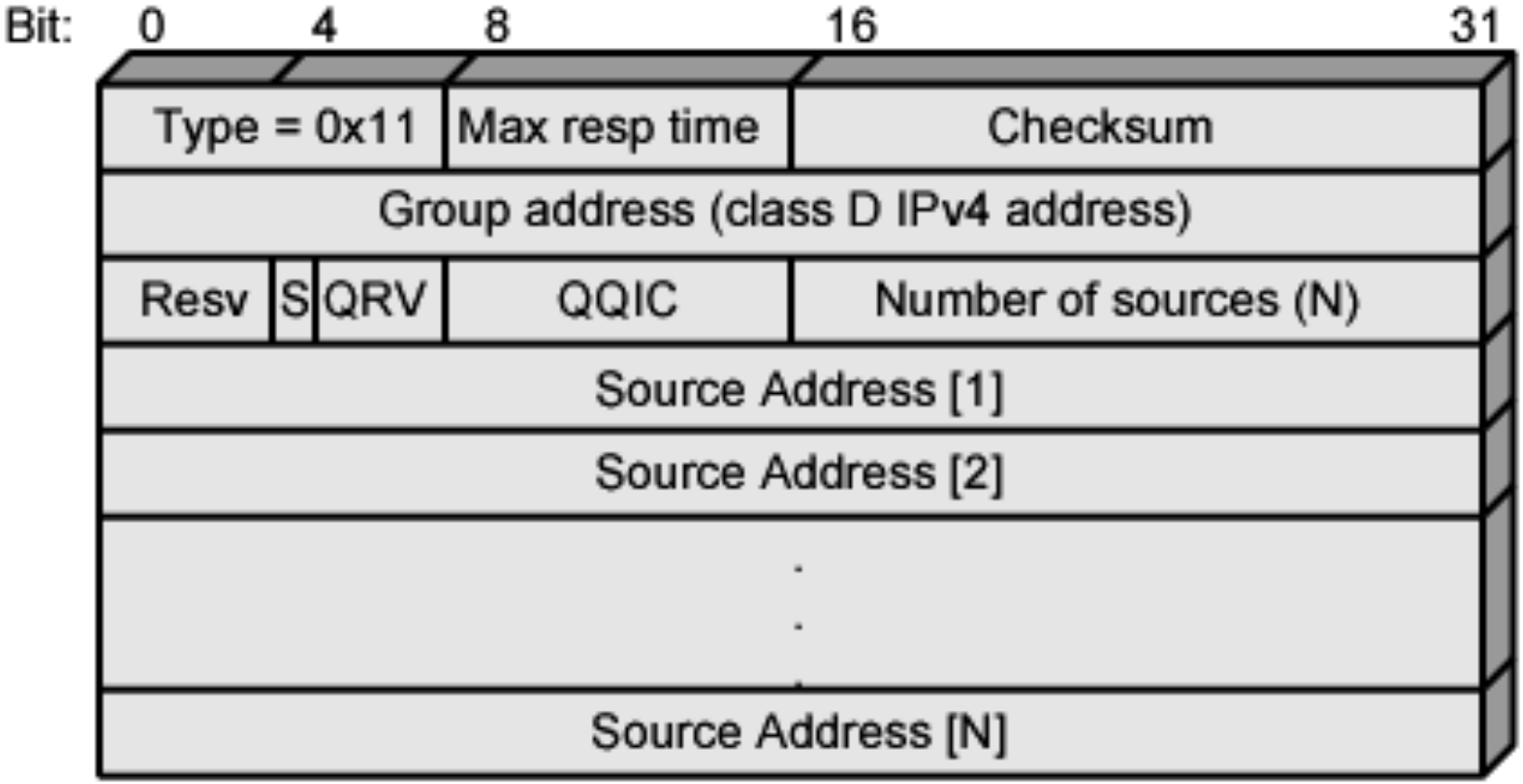
Operation of IGMPv1 & v2

- Receivers have to subscribe to groups
- Sources do not have to subscribe to groups
- Any host can send traffic to any multicast group
- Problems:
  - —Spamming of multicast groups
  - —Even if application level filters drop unwanted packets, they consume valuable resources
  - —Establishment of distribution trees is problematic
  - —Location of sources is not known
  - —Finding globally unique multicast addresses difficult

IGMP v3

- Allows hosts to specify 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

IGMP Message Formats
Membership Query



(a) Membership query message

Membership Query

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

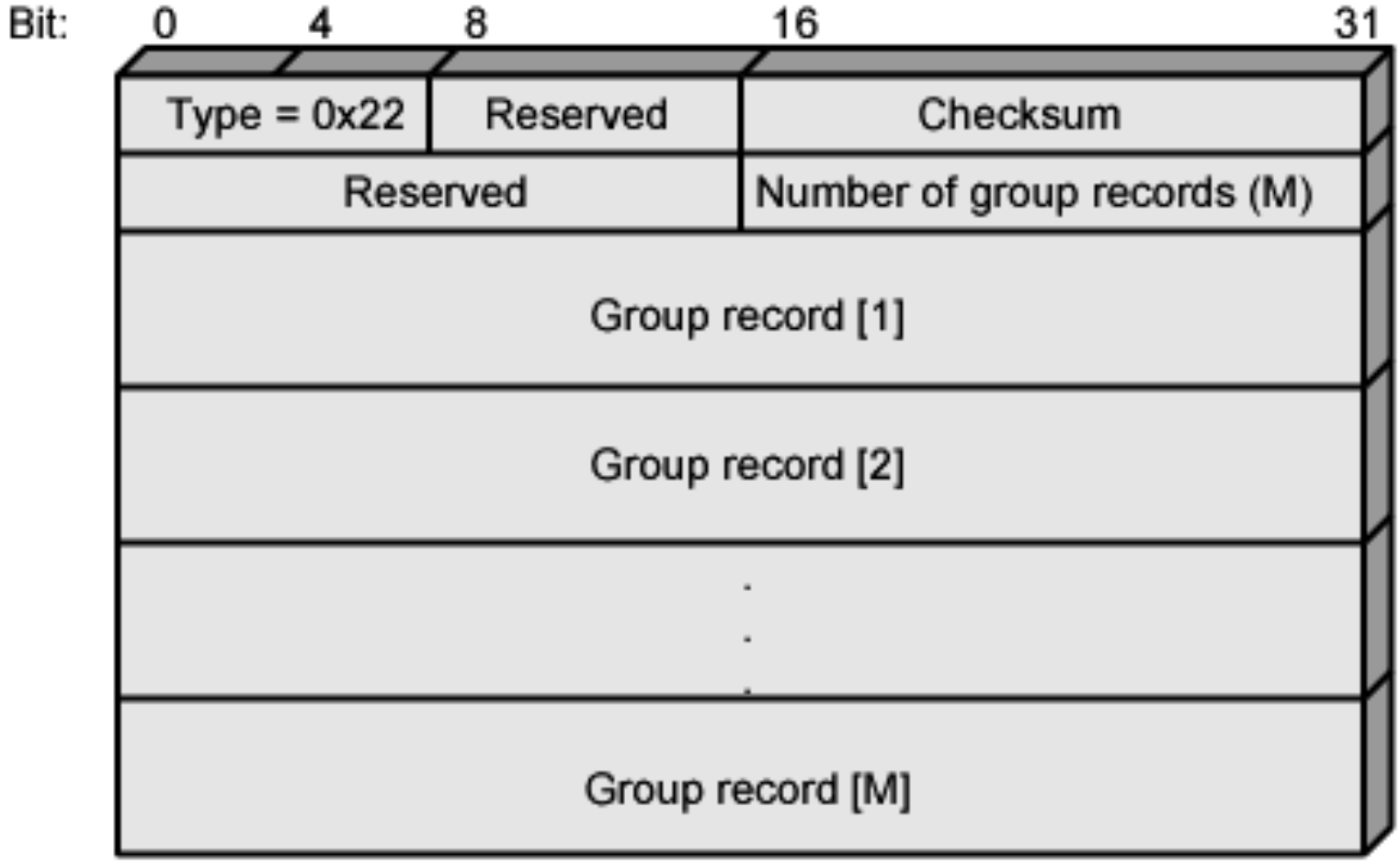
Membership Query Fields (1)

- Type
- Max Response Time
  - Max time before sending report in units of 1/10 second
- Checksum
  - Same algorithm as IPv4
- Group Address
  - Zero for general query message
  - Multicast group address for group-specific or group-and-source
- S Flag
  - 1 indicates that receiving routers should suppress normal timer updates done on hearing query

Membership Query Fields (2)

- QRV (querier's robustness variable)
  - RV value used by sender of query
  - Routers adopt value from most recently received query
  - Unless RV was zero, when default or statically configured value used
  - RV dictates number of retransmissions to assure report not missed
- QQIC (querier's querier interval code)
  - QI value used by querier
  - Timer for sending multiple queries
  - Routers not current querier adopt most recently received QI
  - Unless QI was zero, when default QI value used
- Number of Sources
- Source addresses
  - One 32 bit unicast address for each source

IGMP Message Formats
Membership Report

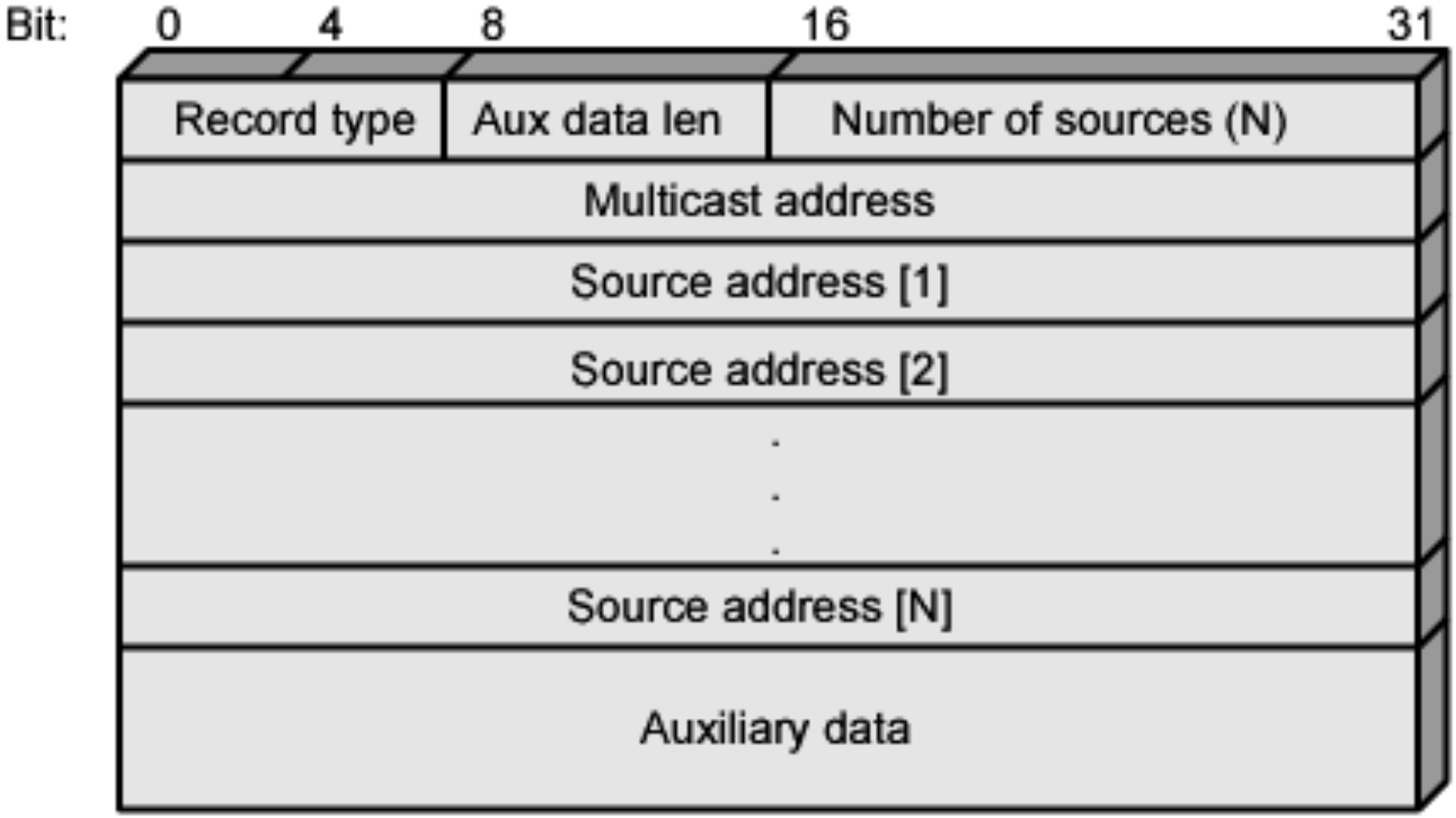


(b) Membership report message

Membership Reports

- Type
- Checksum
- Number of Group Records
- Group Records
  - One 32-bit unicast address per source

IGMP Message Formats
Group Record



(c) Group record

Group Record

- Record Type
  - See later
- Aux Data Length
  - In 32-bit words
- Number of Sources
- Multicast Address
- Source Addresses
  - One 32-bit unicast address per source
- Auxiliary Data
  - Currently, no auxiliary data values defined

IGMP Operation - Joining

- Host using IGMP wants to make itself known as group member to other hosts and routers on LAN
- IGMPv3 can signal group membership with filtering capabilities with respect to sources
  - EXCLUDE mode – all group members except those listed
  - INCLUDE mode – Only from group members listed
- To join group, host sends IGMP membership report message
  - Address field multicast address of group
  - Sent in IP datagram with Group Address field of IGMP message and Destination Address encapsulating IP header same
  - Current members of group will receive learn of new member
  - Routers listen to all IP multicast addresses to hear all reports

IGMP Operation – Keeping Lists Valid

- Routers periodically issue IGMP general query message
  - In datagram with all-hosts multicast address
  - Hosts that wish to remain in groups must read datagrams with this all-hosts address
  - Hosts respond with report message for each group to which it claims membership
- Router does not need to know every host in a group
  - Needs to know at least one group member still active
  - Each host in group sets timer with random delay
  - Host that hears another claim membership cancels own report
  - If timer expires, host sends report
  - Only one member of each group reports to router

IGMP Operation - Leaving

- Host leaves group, by sending leave group message to all-routers static multicast address
- Send membership report message with EXCLUDE option and null list of source addresses
- Router determine if there are any remaining group members using group-specific query message

Routing Protocols

- Routing Information
  - —About topology and delays in the internet
- Routing Algorithm
  - —Used to make routing decisions based on information

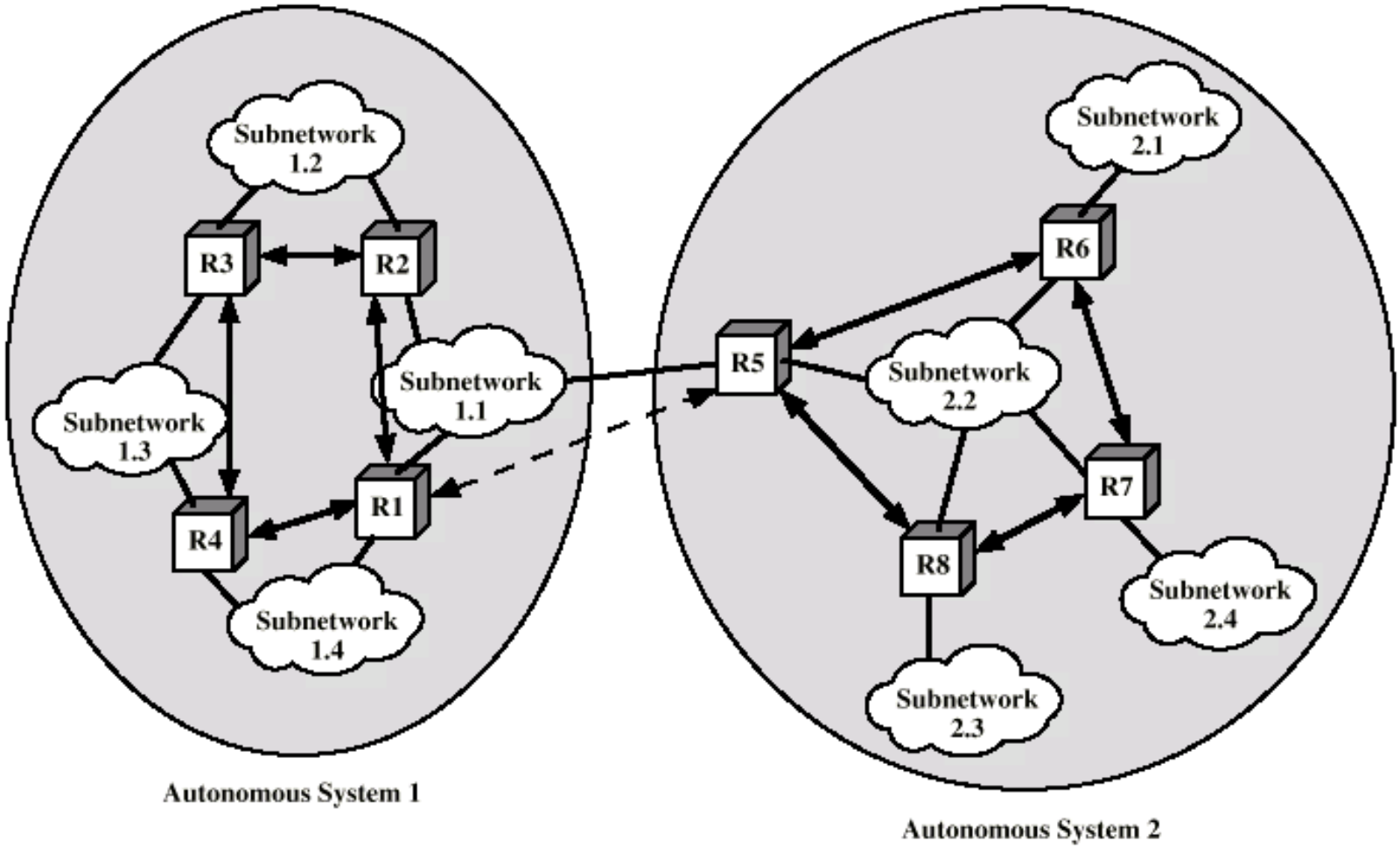
Autonomous Systems (AS)

- Group of routers
- Exchange information
- Common routing protocol
- Set of routers and networks managed by signle organization
- A connected network
  - —There is at least one route between any pair of nodes

Interior Router Protocol (IRP) Exterior Routing Protocol (ERP)

- Passes routing information between routers within AS
- May be more than one AS in internet
- Routing algorithms and tables may differ between different AS
- Routers need some info about networks outside their AS
- Used exterior router protocol (ERP)
- IRP needs detailed model
- ERP supports summary information on reachability

Application of IRP and ERP



Approaches to Routing – Distance-vector

- Each node (router or host) exchange information with neighboring nodes
  - Neighbors are both directly connected to same network
- First generation routing algorithm for ARPANET
- Node maintains vector of link costs for each directly attached network and distance and next-hop vectors for each destination
- Used by Routing Information Protocol (RIP)
- Requires transmission of lots of information by each router
  - Distance vector to all neighbors
  - Contains estimated path cost to all networks in configuration
  - Changes take long time to propagate

Approaches to Routing – Link-state

- Designed to overcome drawbacks of distance-vector
- When router initialized, it determines link cost on each interface
- Advertises set of link costs to all other routers in topology
  - Not just neighboring routers
- From then on, monitor link costs
  - If significant change, router advertises new set of link costs
- Each router can construct topology of entire configuration
  - Can calculate shortest path to each destination network
- Router constructs routing table, listing first hop to each destination
- Router does not use distributed routing algorithm
  - Use any routing algorithm to determine shortest paths
  - In practice, Dijkstra's algorithm
- Open shortest path first (OSPF) protocol uses link-state routing.
- Also second generation routing algorithm for ARPANET

Exterior Router Protocols – Not Distance-vector

- Link-state and distance-vector not effective for exterior router protocol
- Distance-vector assumes routers share common distance metric
- ASs may have different priorities
  - —May have restrictions that prohibit use of certain other AS
  - —Distance-vector gives no information about ASs visited on route

Exterior Router Protocols – Not Link-state

- Different ASs may use different metrics and have different restrictions
  - —Impossible to perform a consistent routing algorithm.
- Flooding of link state information to all routers unmanageable

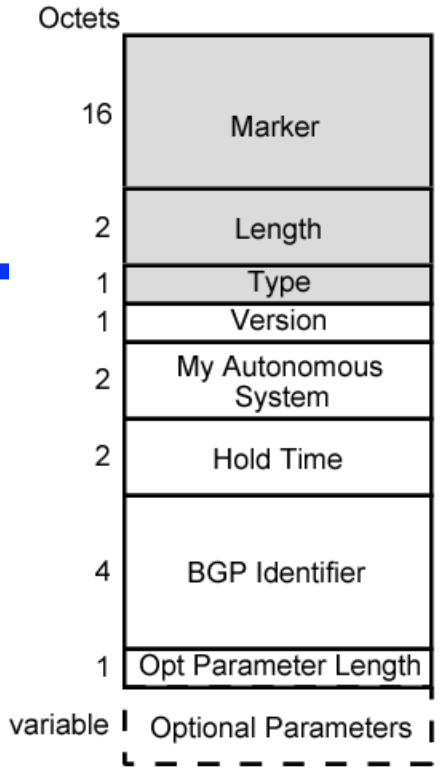
Exterior Router Protocols – Path-vector

- Dispense with routing metrics
- Provide information about which networks can be reached by a given router and ASs crossed to get there
  - Does not include distance or cost estimate
- Each block of information lists all ASs visited on this route
  - Enables router to perform policy routing
  - E.g. avoid path to avoid transiting particular AS
  - E.g. link speed, capacity, tendency to become congested, and overall quality of operation, security
  - E.g. minimizing number of transit ASs

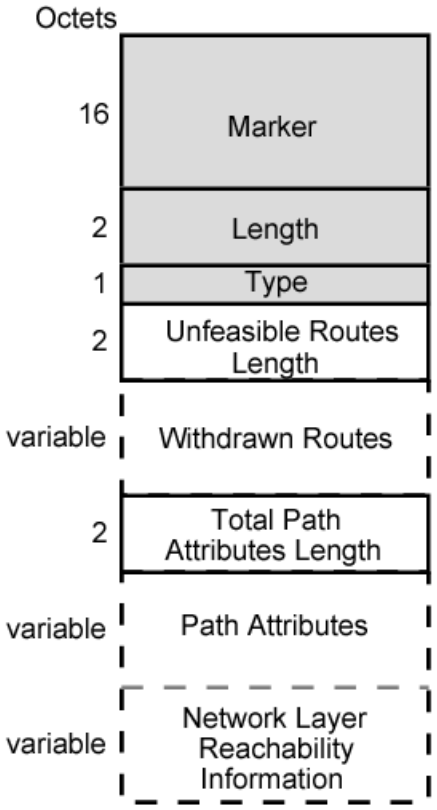
Border Gateway Protocol (BGP)

- For use with TCP/IP internets
- Preferred EGP of the Internet
- Messages sent over TCP connections
  - Open
  - Update
  - Keep alive
  - Notification
- Procedures
  - Neighbor acquisition
  - Neighbor reachability
  - Network reachability

BGP Messages

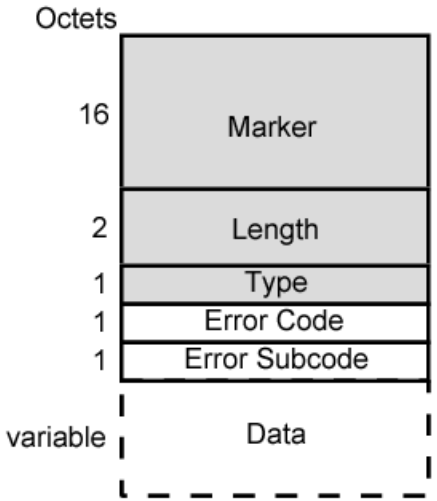


(a) Open Message



(b) Update Message

(c) Keepalive Message



(d) Notification Message

BGP Procedure

- Open TCP connection
- Send Open message
  - —Includes proposed hold time
- Receiver selects minimum of its hold time and that sent
  - —Max time between Keep alive and/or update messages

Message Types

- Keep Alive
  - To tell other routers that this router is still here
- Update
  - Info about single routes through internet
  - List of routes being withdrawn
  - Includes path info
    - Origin (IGP or EGP)
    - AS_Path (list of AS traversed)
    - Next_hop (IP address of boarder router)
    - Multi_Exit_Disc (Info about routers internal to AS)
    - Local_pref (Inform other routers within AS)
    - Atomic_Aggregate, Aggregator (Uses address tree structure to reduce amount of info needed)

Uses of AS_Path and Next_Hop

- AS_Path
  - —Enables routing policy
    - Avoid a particular AS
    - Security
    - Performance
    - Quality
    - Number of AS crossed
- Next_Hop
  - —Only a few routers implement BGP
    - Responsible for informing outside routers of routes to other networks in AS

Notification Message

- Message header error
  - Authentication and syntax
- Open message error
  - Syntax and option not recognized
  - Unacceptable hold time
- Update message error
  - Syntax and validity errors
- Hold time expired
  - Connection is closed
- Finite state machine error
- Cease
  - Used to close a connection when there is no error

BGP Routing Information Exchange

- Within AS, router builds topology picture using IGP
- Router issues Update message to other routers outside AS using BGP
- These routers exchange info with other routers in other AS
- Routers must then decide best routes

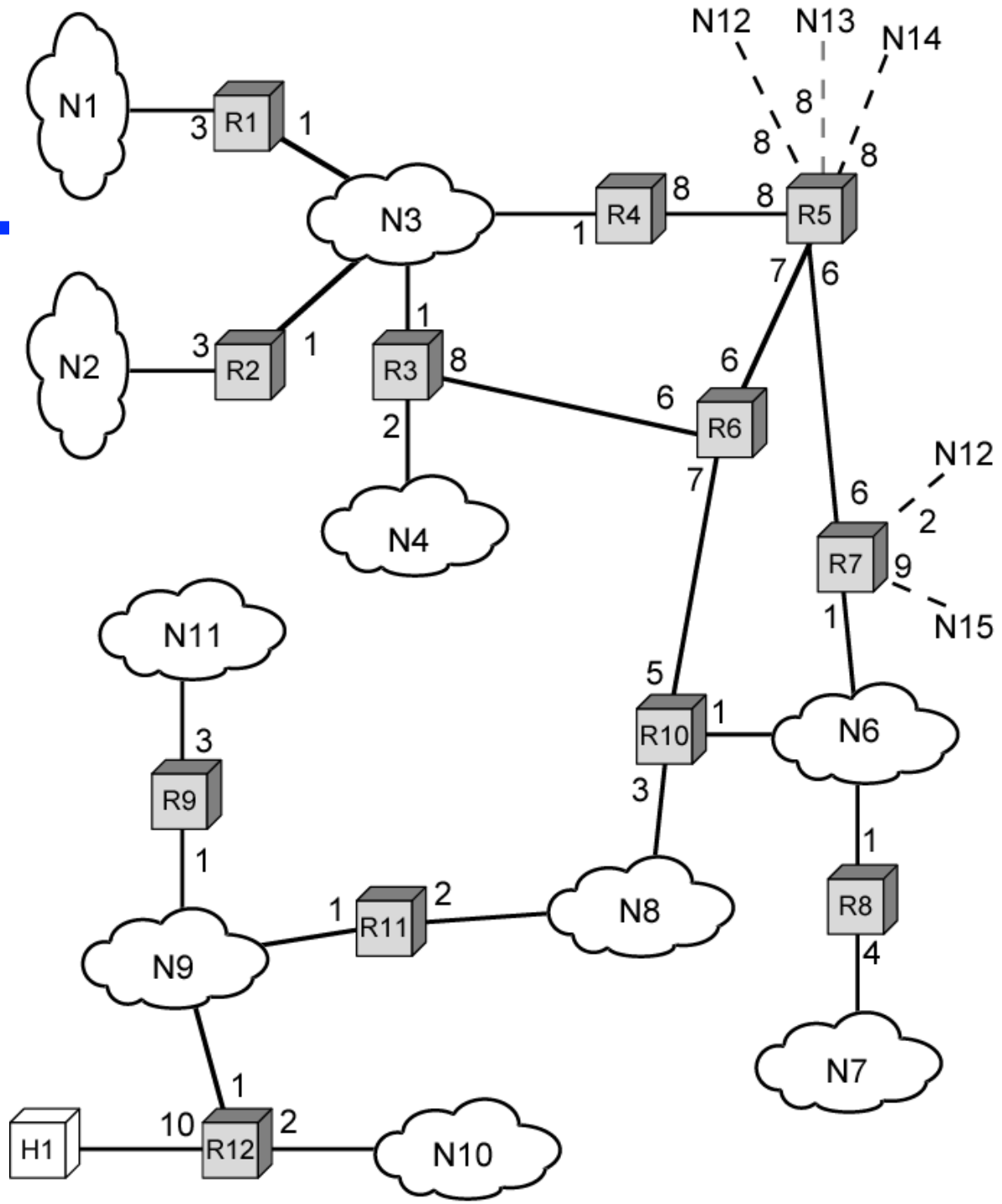
Open Shortest Path First (1)

- OSPF
- IGP of Internet
- Replaced Routing Information Protocol (RIP)
- Uses Link State Routing Algorithm
  - Each router keeps list of state of local links to network
  - Transmits update state info
  - Little traffic as messages are small and not sent often
  - RFC 2328
- Route computed on least cost based on user cost metric

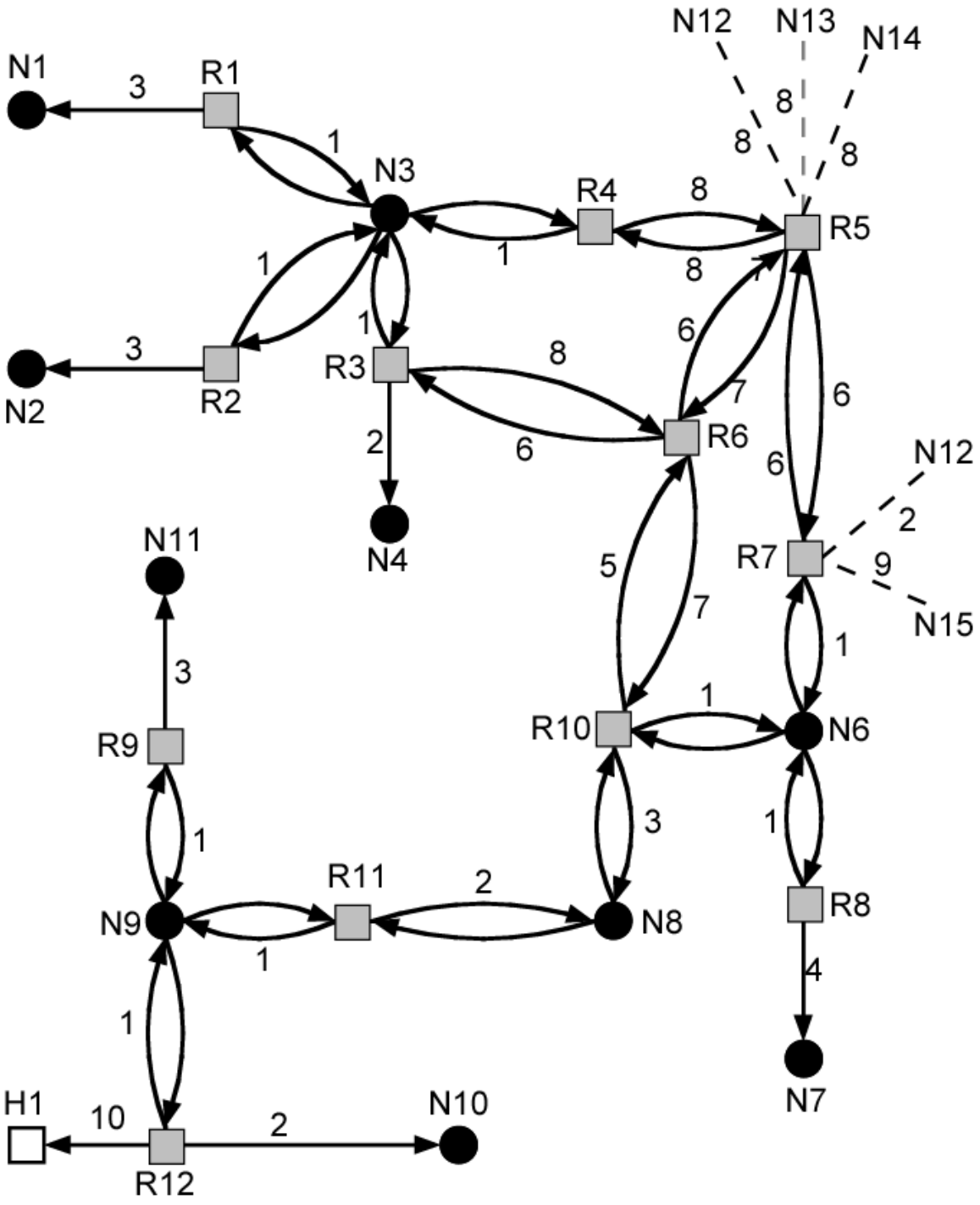
Open Shortest Path First (2)

- Topology stored as directed graph
- Vertices or nodes
  - —Router
  - —Network
    - Transit
    - Stub
- Edges
  - —Graph edge
    - Connect two router
    - Connect router to network

Sample AS


N1
R1
N2
R2
N3
R3
R4
R5
R6
N4
R7
N12
N13
N14
N15
N11
R9
R10
N6
N8
R11
N9
R8
N7
H1
R12
N10

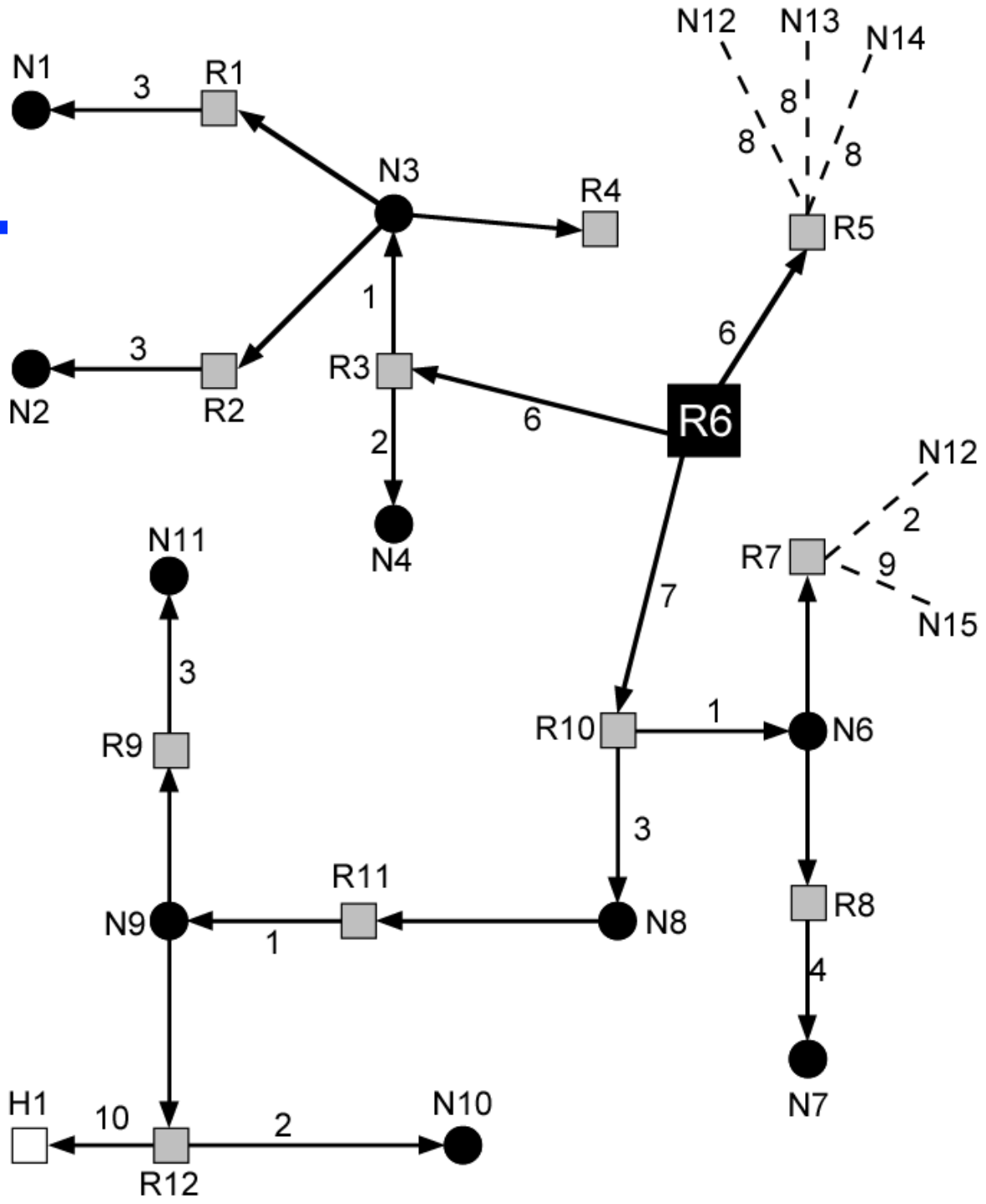
Directed Graph of AS



Operation

- Dijkstra's algorithm used to find least cost path to all other networks
- Next hop used in routing packets

SPF Tree for Router 6



Integrates Services Architecture

- Changes in traffic demands require variety of quality of service
- Internet phone, multimedia, multicast
- New functionality required in routers
- New means of requesting QoS
- ISA
- RFC 1633

Internet Traffic

- Elastic
  - —Can cope with wide changes in delay and/or throughput
    - FTP sensitive to throughput
    - E-Mail insensitive to delay
    - Network Management sensitive to delay in times of heavy congestion
    - Web sensitive to delay
- Inelastic
  - —Does not easily adapt to variations
  - —e.g. real time traffic

Internet Traffic

- we will skip the rest of this chapter