CSE 3231
Computer Networks

Chapter 5
The Network Layer
part 5

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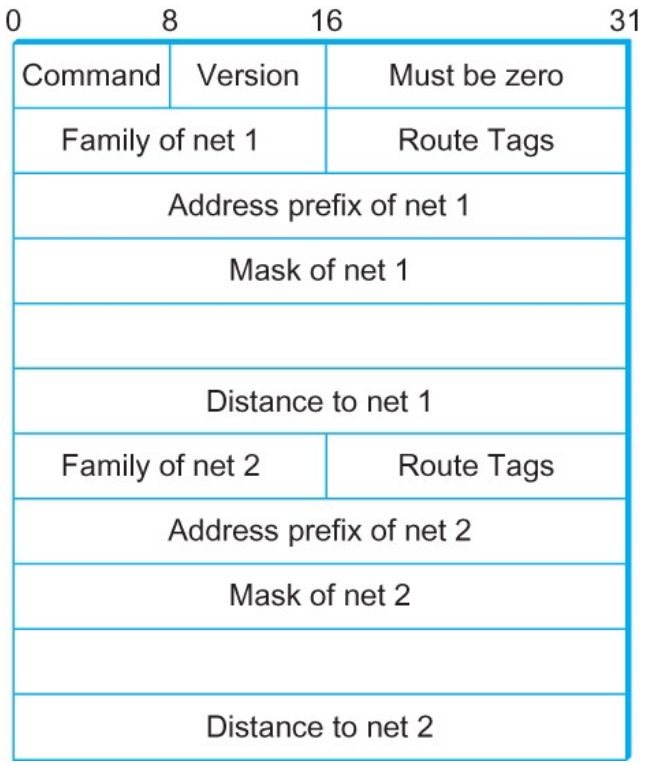
Routing Information Protocol (RIP)

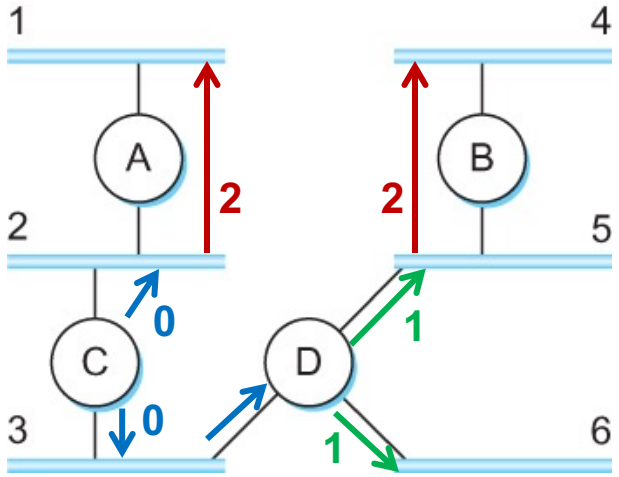
- One example of a Distance Vector protocol
  - Uses “Hop Count” as a metric for routing
- Distance Vectors are exchanged frequently
  - contained in “advertisement” messages
  - If no advertisement after a timeout period, routes are marked as invalid and new advertisements are sent out to neighbors
- Advantage:
  - Link failure updates spread quickly across network
- Disadvantage:
  - Exchanges many messages with other routers

Routing Information Protocol (RIP)



RIP version 2 supports CIDR

RIPv2 Packet Format



Router C advertises it can reach

LAN:	**Cost:**
1	2
2	0
3	0
4	2
5	1
6	1

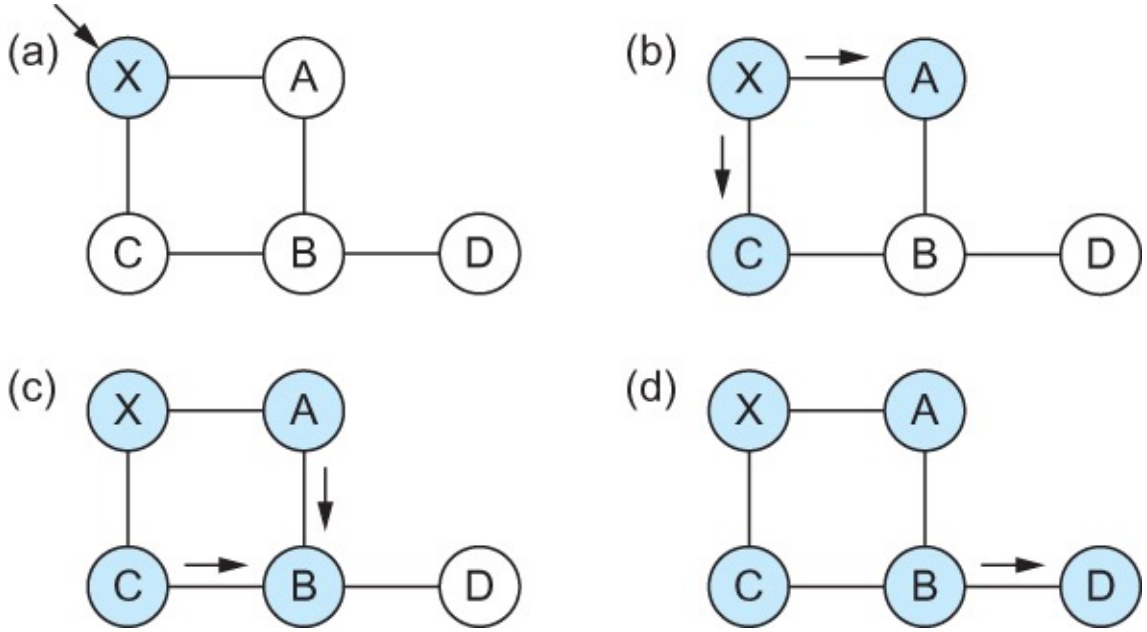
Link State Routing

Send information about directly connected links (not entire routing table) to all nodes

- Link State Packet (LSP) contains:
  - ID of the node that created the LSP
  - cost of the link to each directly connected neighbor
  - sequence number (SEQNO)
    - start SEQNO at 0 when router reboots
  - time-to-live (TTL) for this packet
- Reliable Flooding
  - router stores most recent LSP from each node
  - router forwards LSP to all nodes but the one that sent it
  - generates new LSP periodically; increments SEQNO each time
  - decrement TTL of each stored LSP; discard when TTL=0

Link State

Reliable Flooding



Flooding of link-state packets.

(a) Link State Packet (LSP) arrives at node X

(b) X floods LSP to A and C

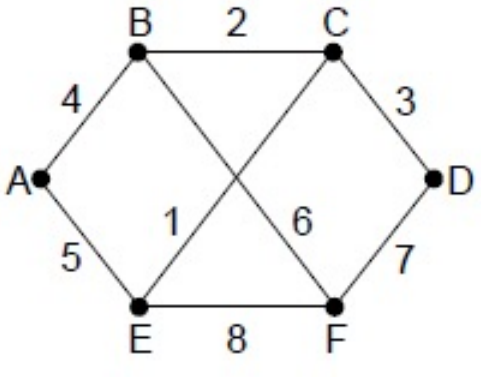
(c) A and C flood LSP to B (but not X)

(d) flooding is complete

Link State Packets

All nodes in a network send out a Link State Packet (LSP) describing each neighboring node

- sequence number
  - when a higher number arrives, discard lower numbers
- LSP's age (decrement each second, discard at 0)
- also contains the link cost to reach each neighbor



Network

A	
Seq.	
Age	
B	4
E	5

B	
Seq.	
Age	
A	4
C	2
F	6

C	
Seq.	
Age	
B	2
D	3
E	1

D	
Seq.	
Age	
C	3
F	7

E	
Seq.	
Age	
A	5
C	1
F	8

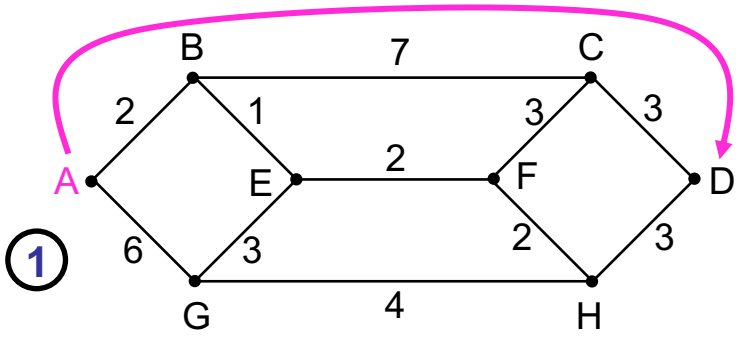
F	
Seq.	
Age	
B	6
D	7
E	8

LSP for each node in the network

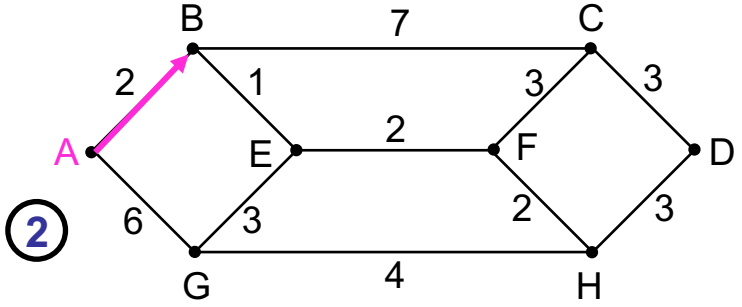
Shortest Path Routing

- In practice, each switch computes its routing table directly from the LSP's it has collected by using a version of Dijkstra's algorithm called the *forward search algorithm*
- Algorithm:
  1. Set the cost value at all nodes to infinity
  2. Set the source node as the root of the tree
  3. Calculate the distance from the current node to neighbors that have a path to the destination
  4. Pick the neighbor node with the lowest cost that is not already in the tree and add it to the tree
  5. Make that neighbor the current node and *repeat from step 3* until all nodes are in the tree

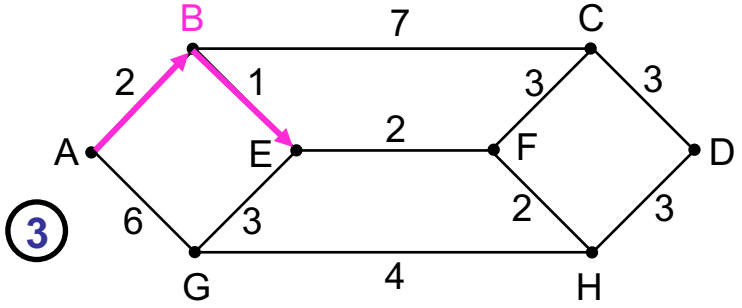
Find the shortest path from A to D



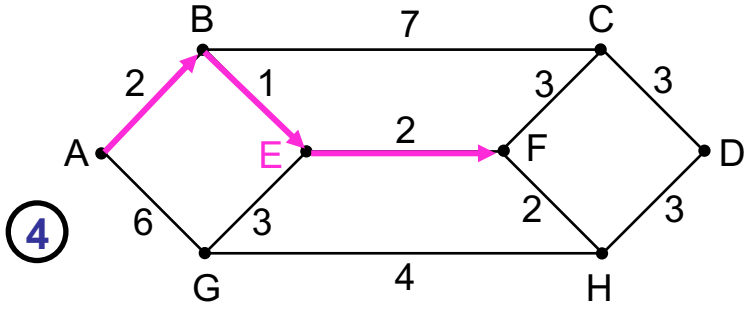
B has lowest cost link from A



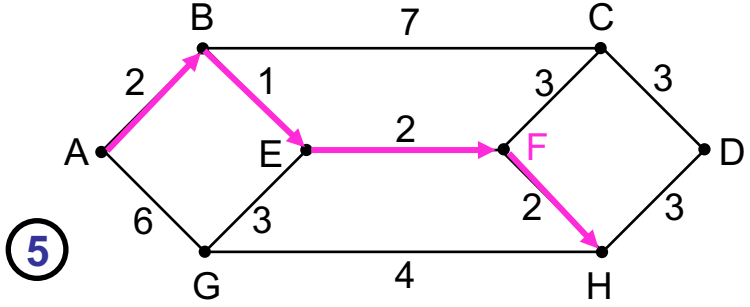
E has lowest cost link from B



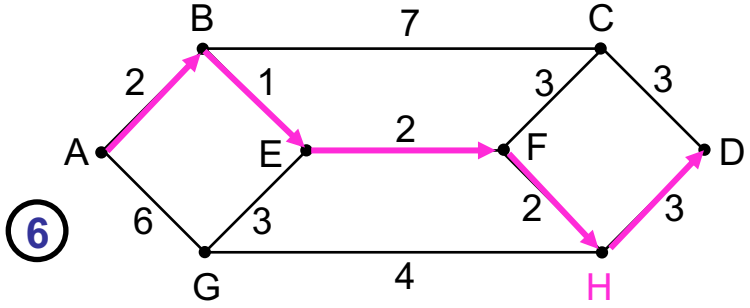
F has lowest cost link from E



H has lowest cost link from F



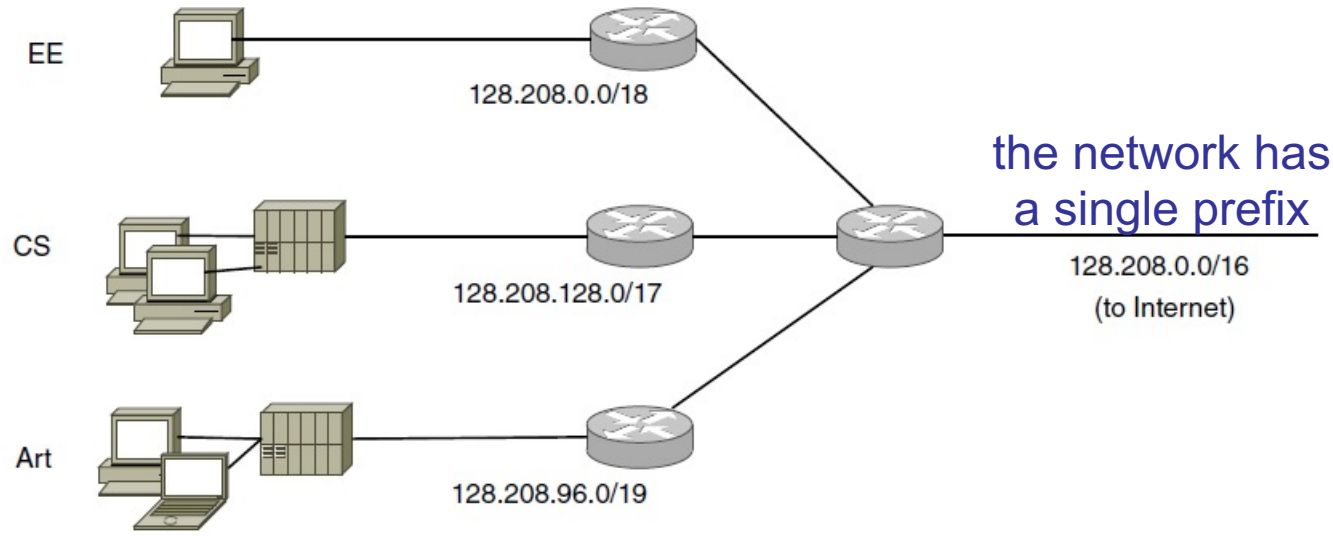
D is the destination



IP Addresses – Subnets

Subnetting splits up an IP prefix to help manage large networks

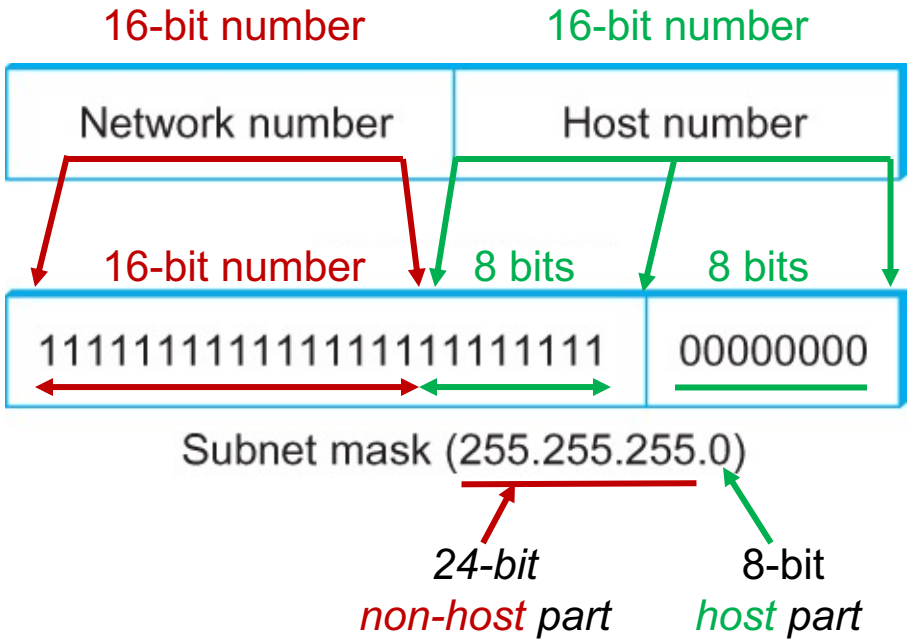
- Outside the network there is a single prefix for all subnets, but inside routers can isolate traffic



Network is divided into subnets internally

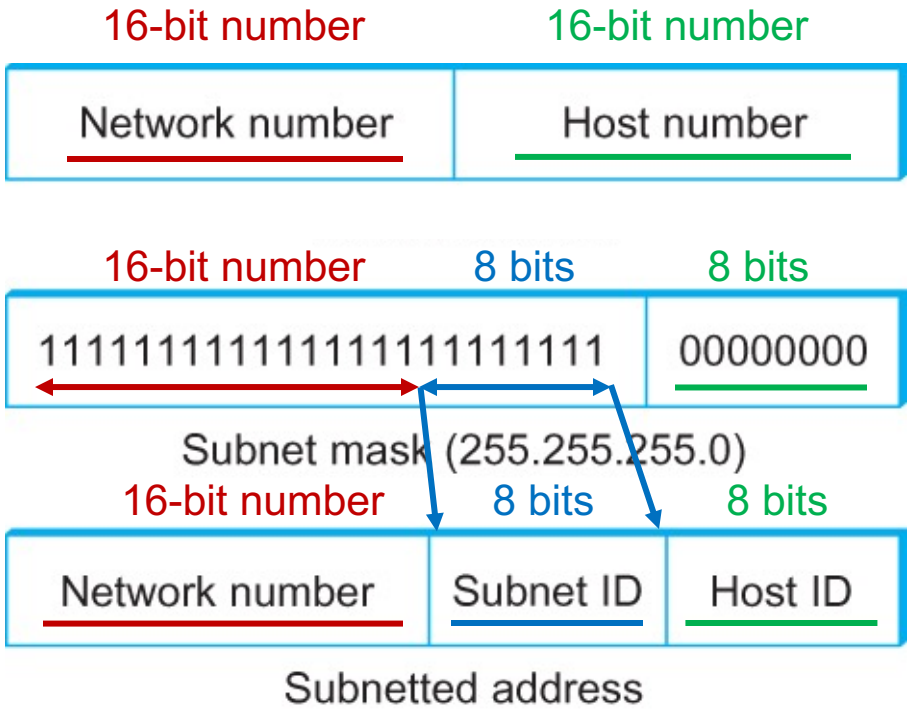
Subnetting

- From outside the network, it appears to be another Class B
- The host part is divided into subnets
- *Subnet masks* define the size of a partition of the **host part** of the Class B addresses



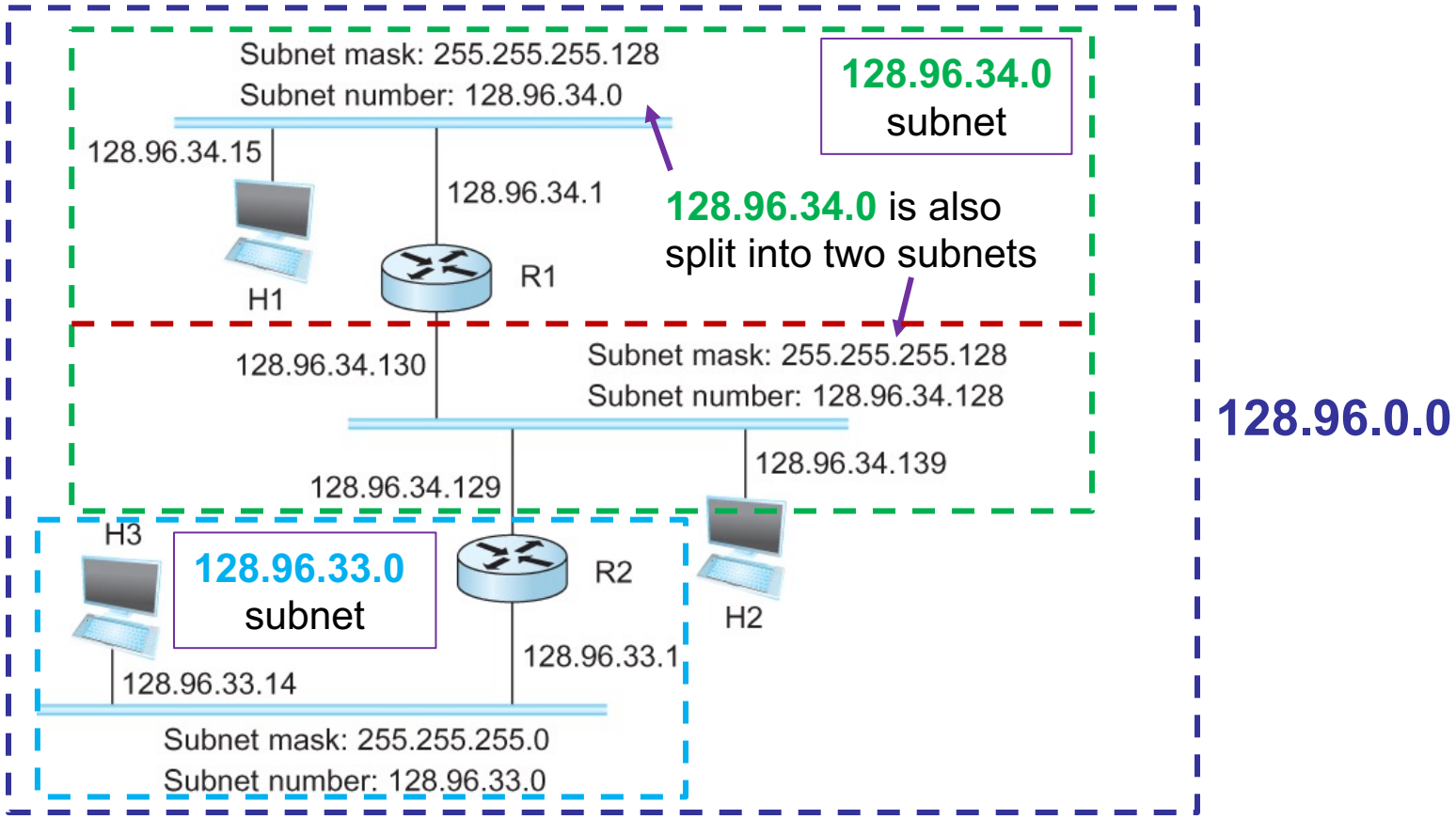
Subnetting

- From outside the network, it appears to be another Class B
- The host part is divided into subnets
- *Subnet masks* define the size of a partition of the **host part** of the Class B addresses
  - Example: 16-bit network, 16-bit host, subnet splits the host part into 256 subnets (8-bits)



Outside routers only use the Class B part

Subnetting

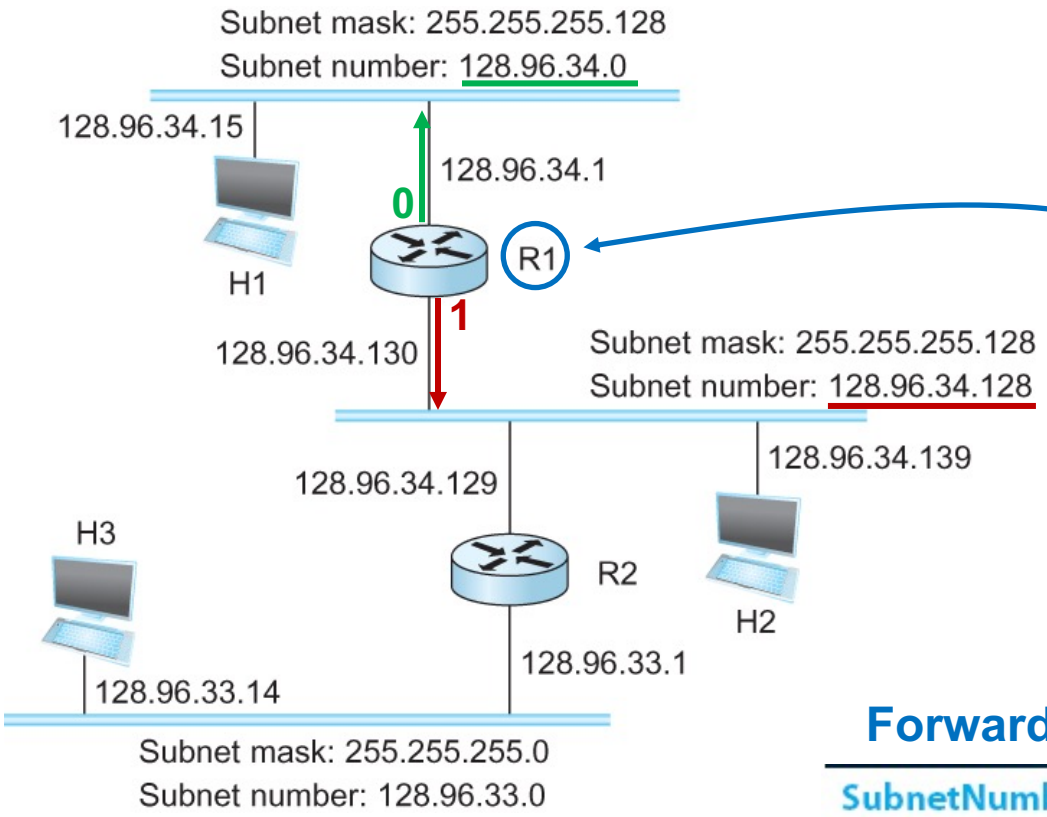


- **128.96.0.0** is a class B network
- It has been split into *subnets*

Routing with Subnets

- Routers have one or more interfaces (ports) and can direct packets out the interface that is connected to the appropriate subnet
  - Routers use the subnet part of the IP address to determine which port should be used to deliver the packet to the correct subnet
  - Routers have a table of subnet addresses and port numbers in their *forwarding table*

Subnetting

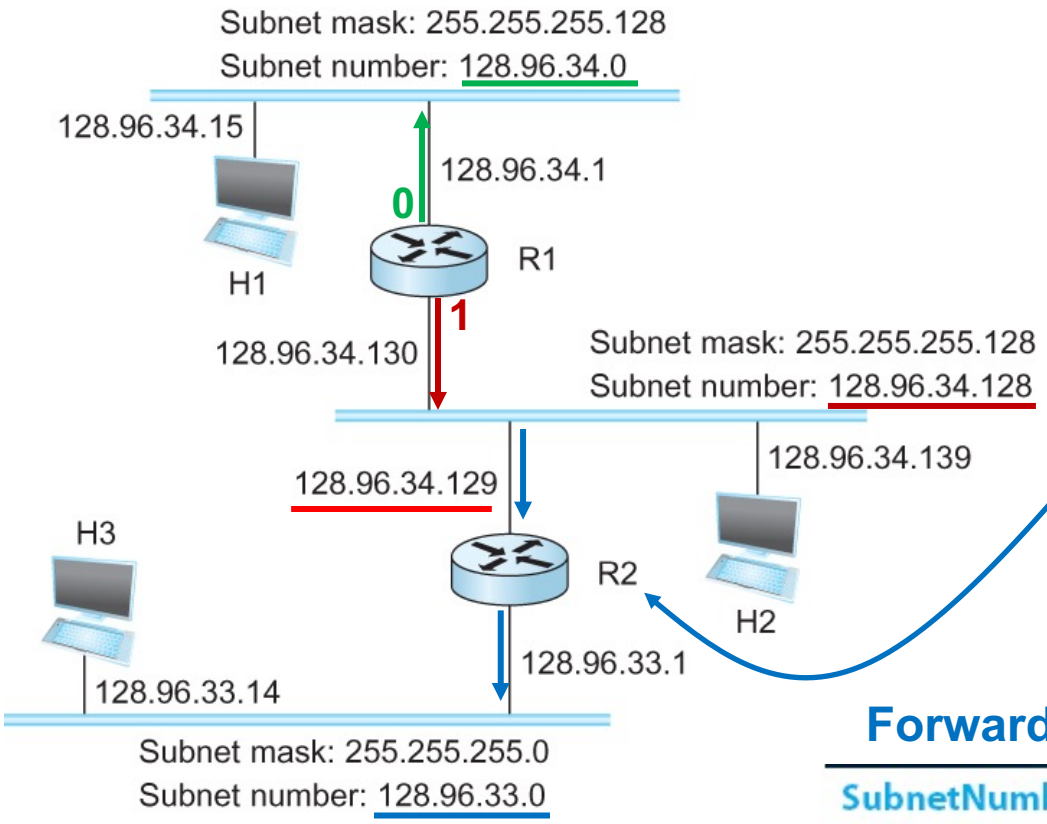


128.96.0.0 is a class B network and has been split into several *subnets*

Forwarding Table at Router R1

SubnetNumber	SubnetMask	NextHop
128.96.34.0	255.255.255.128	Interface 0
128.96.34.128	255.255.255.128	Interface 1
128.96.33.0	255.255.255.0	R2

Subnetting



128.96.0.0 is a class B network and has been split into several *subnets*

R2 will be specified by its address on the 128.96.34.0 subnet

128.96.34.129

R2 will handle routing within the subnet

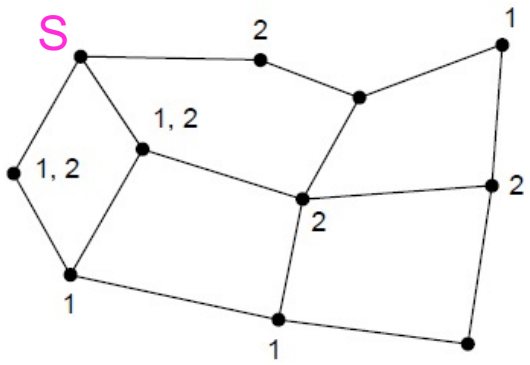
Forwarding Table at Router R1

SubnetNumber	SubnetMask	NextHop
128.96.34.0	255.255.255.128	Interface 0
128.96.34.128	255.255.255.128	Interface 1
128.96.33.0	255.255.255.0	128.96.34.129

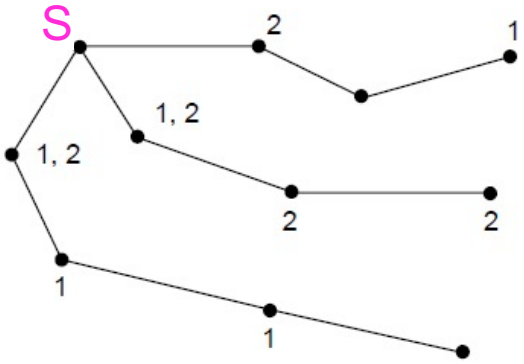
Multicast Routing

Multicast sends data to a group (subset) of the nodes

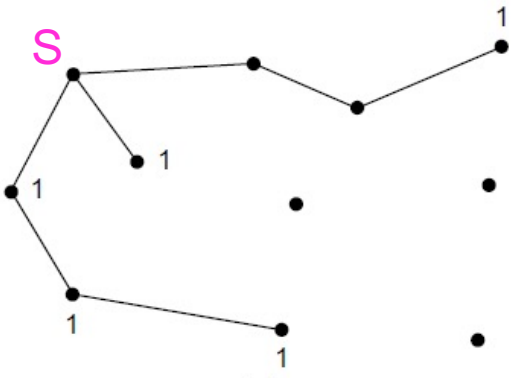
– Uses a different tree for each source and group



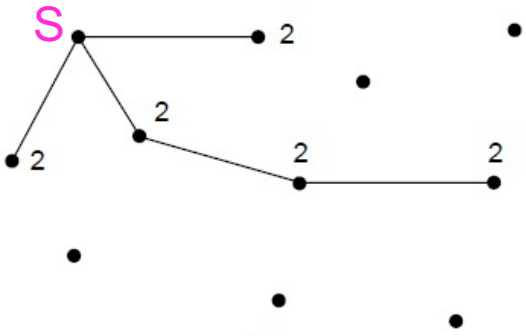
Network with groups 1 & 2



Create a spanning tree from source S



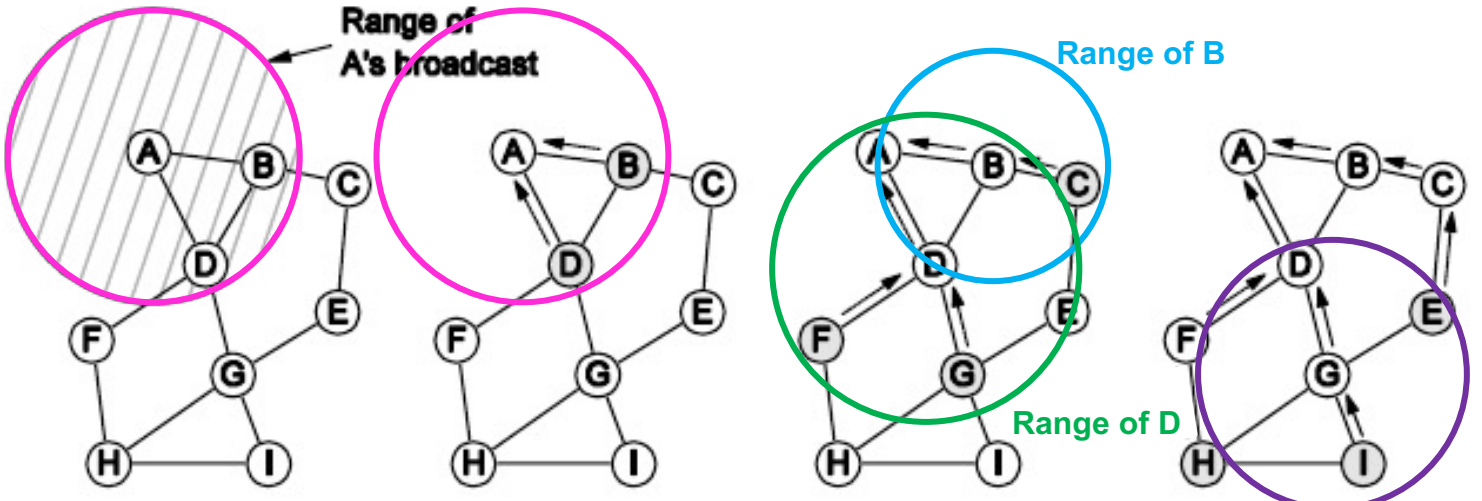
Multicast tree from S to group 1



Multicast tree from S to group 2

Routing in Ad Hoc Networks

- The network topology changes as wireless nodes move in and out of range
  - Routes are often made on demand (e.g., AODV)



A's wants to find a route to *I*

A's broadcast reaches *B* & *D*

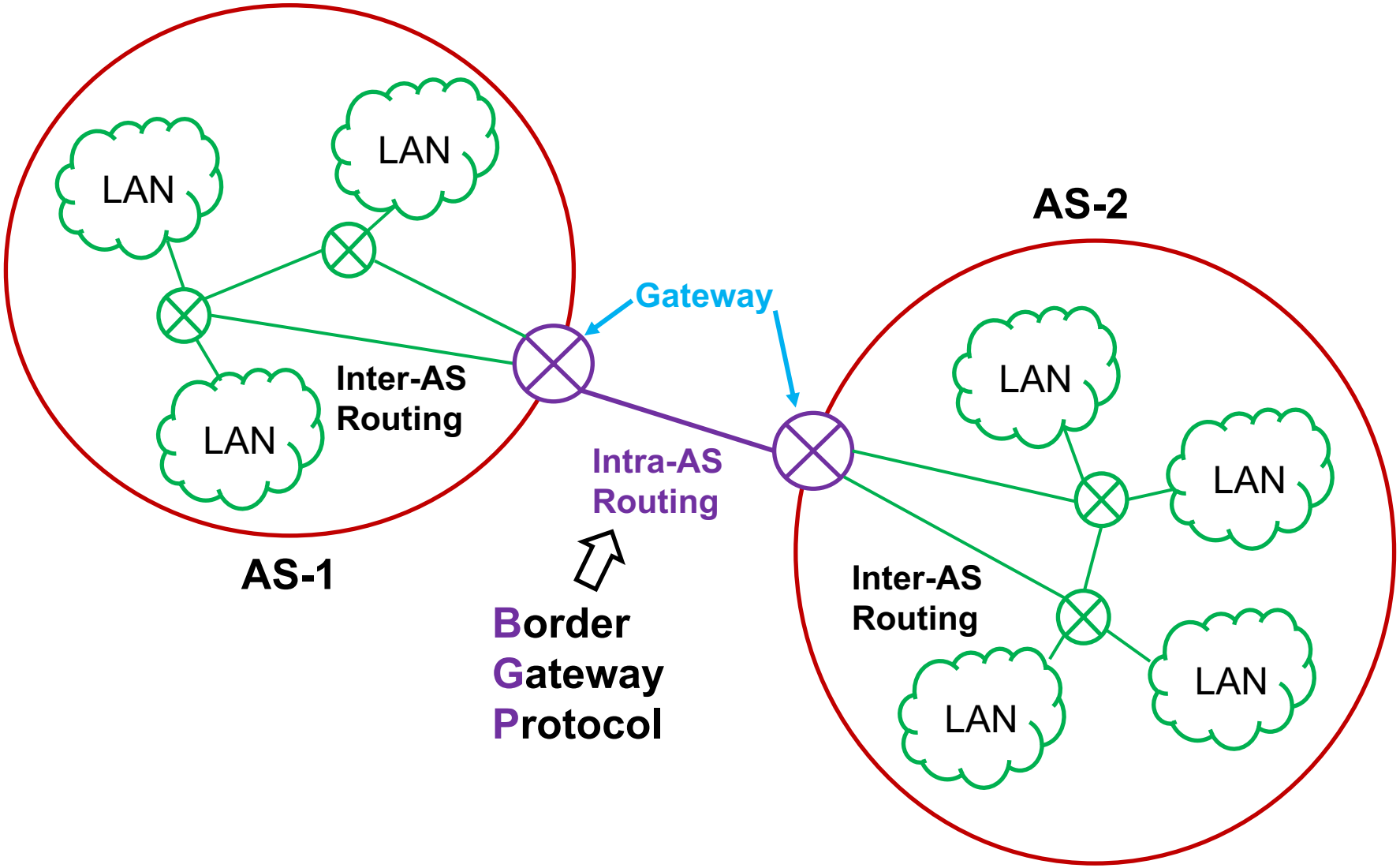
B's and *D*'s broadcast reach *C, E, F* & *G*

G's broadcast reaches *I,* and *I* replies to *A*

Internet Routing Hierarchy

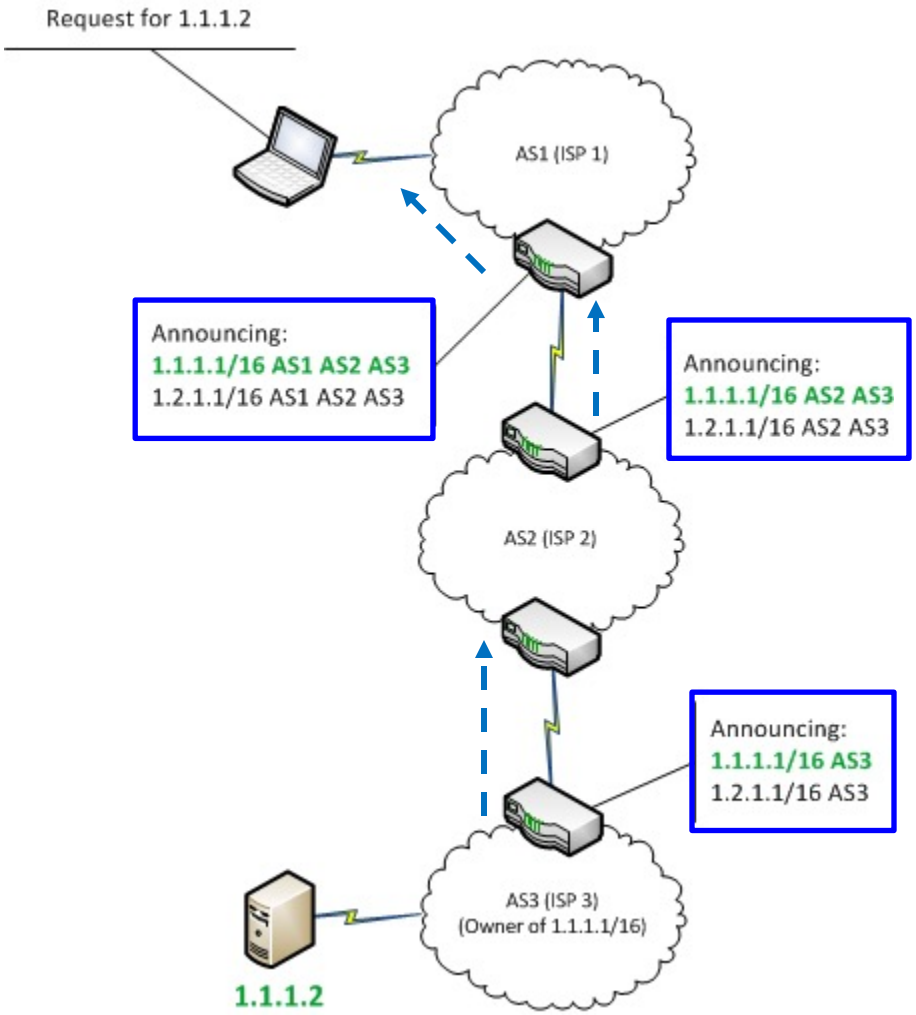
- The Internet is divided into *Autonomous Systems* (AS) which are connected by routers that are referred to as *border* or *gateway* routers
- Routing from one AS to another is handled by the *Border Gateway Protocol* (BGP)
- BGP routers exchange information with other BGP routers to learn network configurations
  - BGP uses TCP/IP to pass routing information, but there is no authentication for the author of change requests - false or incorrect updates are possible

Internet Routing Hierarchy



BGP Routing Information

- A node in *AS1* wants to know what network contains the node at 1.1.1.2
- *AS3*'s BGP router said that *AS3* has the addresses from 1.1.1.1-1.2.255.255
- *AS2*'s BGP router said, you have to go through *AS2*, *AS3* to get to nodes in the range 1.1.1.1-1.2.255.255
- *AS1*'s BGP router said, you have to go through *AS1*, *AS2*, and *AS3* to get to nodes in the range 1.1.1.1-1.2.255.255



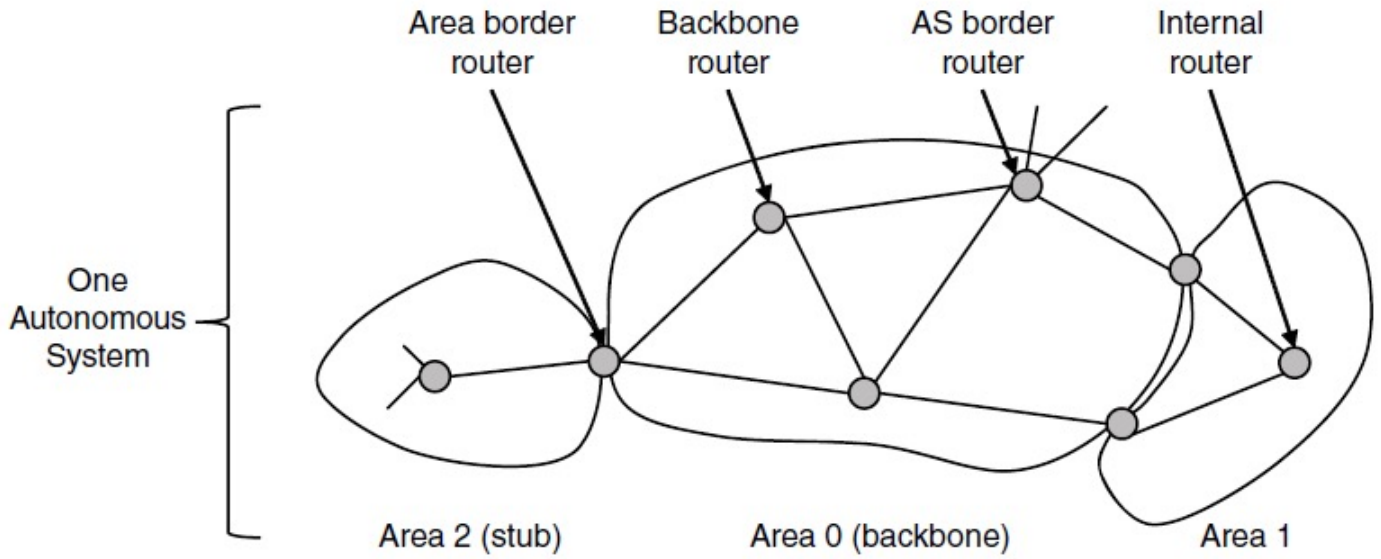
Open Shortest Path First (OSPF)

- Routing protocol based on Link State approach
- Focuses on routing between networks, not inside LANs
- OSPF Provides:
  - Authentication of routing messages
  - Scalable Hierarchy (domains divided into *Areas*)
  - Load Balancing - splitting traffic over multiple paths
  - Is supposed to support routing based on Type of Service, including real-time traffic, but not often used
  - OSPF supports most LAN protocols and also can provide routing for SONET and similar networks

OSPF— Interior Routing Protocol

OSPF divides an Autonomous System into *areas* connected through a *backbone* area

- Area Border Routers connect two areas
- Backbone Routers forward traffic between areas



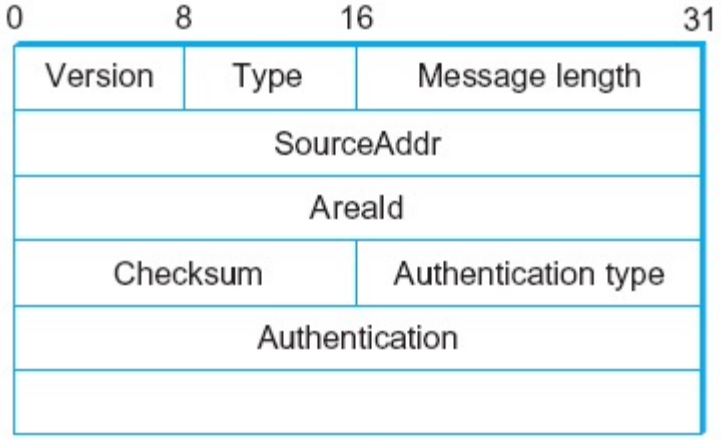
OSPF— Interior Routing Protocol

OSPF (Open Shortest Path First) is a special type of link-state routing:

- Not all routers contribute to the link state tree, selected routers are designated to exchange data
- Uses messages (below) get link information
- When done, runs Dijkstra to compute routes

Message type	Description
Hello	Used to discover who the neighbors are
Link state update	Provides the sender's costs to its neighbors
Link state ack	Acknowledges link state update
Database description	Announces which updates the sender has
Link state request	Requests information from the partner

Open Shortest Path First (OSPF)



OSPF Header Format

LS Age		Options	Type = 1
Link-state ID			
Advertising router			
LS sequence number			
LS checksum		Length	
0	Flags	0	Number of links
Link ID			
Link data			
Link type	Num_TOS	Metric	
Optional TOS information			
More links			

OSPF Link State Advertisement

Packet Scheduling

How does a router decide which packet (in a buffer full of packets) to send next?

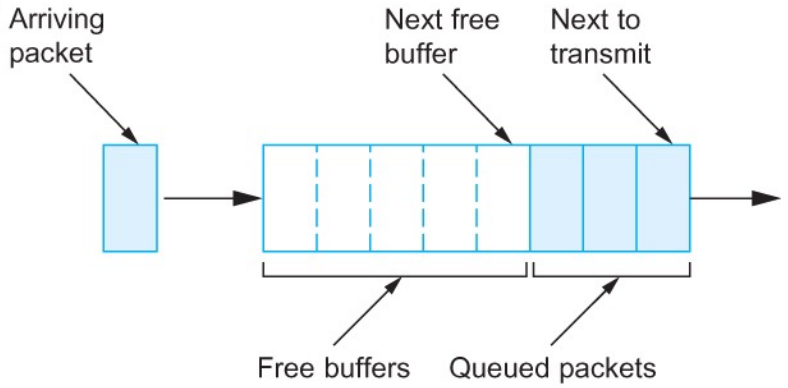
The term *packet scheduling* refers to the process of selecting which packet to send

- Newly arriving packets are put in queues and then selected according to an algorithm
  - First-In-First-Out (FIFO) queues
  - Priority queues
  - Round Robin queues

FIFO Queuing

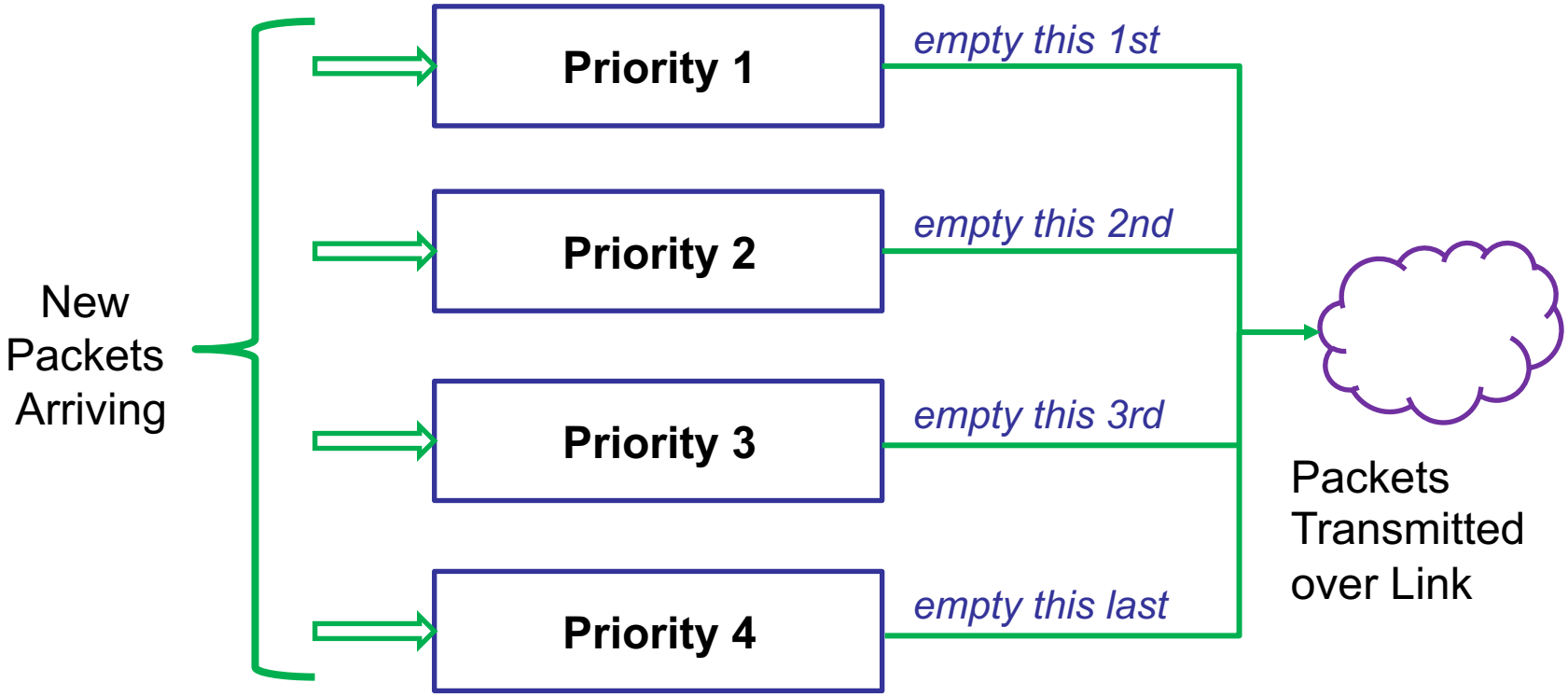
First-In-First-Out (FIFO) queuing is simple:

- The first packet that arrives at a router is the first packet to be transmitted
- The amount of buffer space at each router is finite:
  - if the queue (buffer space) is full when a packet arrives, then the router discards that packet, otherwise it adds it to the queue



Priority Queues

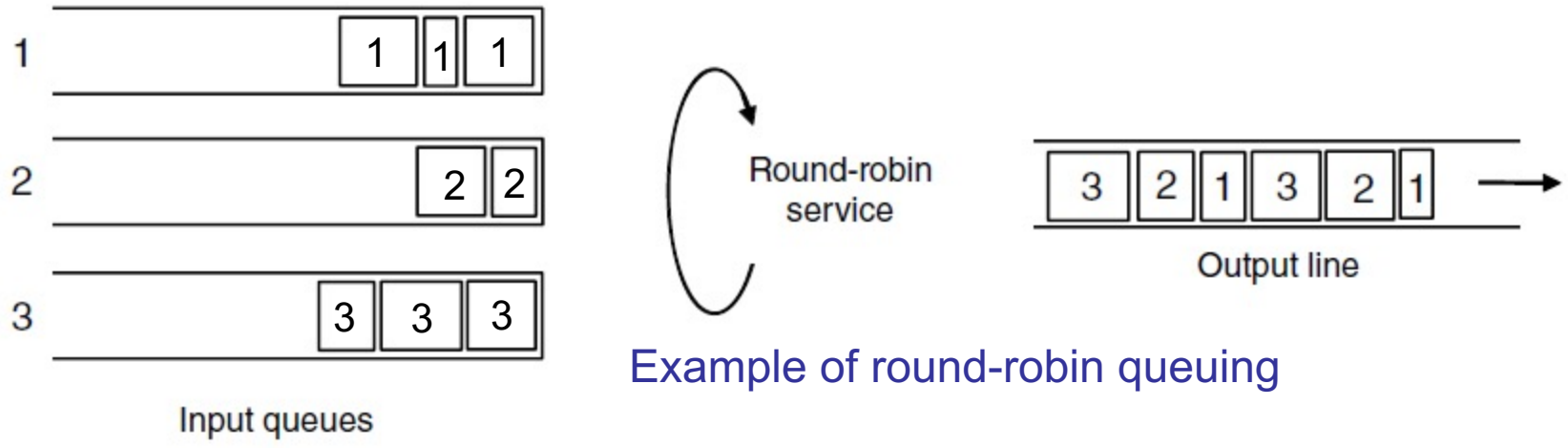
Each priority level has its own queue and all packets are selected from Priority 1 queue first, then all from Priority 2 queue, etc.



Round Robin

Packets of varying size are entered into queues based on some factor and selected according to a round-robin approach

- queues are usually grouped by the flow between source and destination nodes



Example of round-robin queuing

IP Version 6

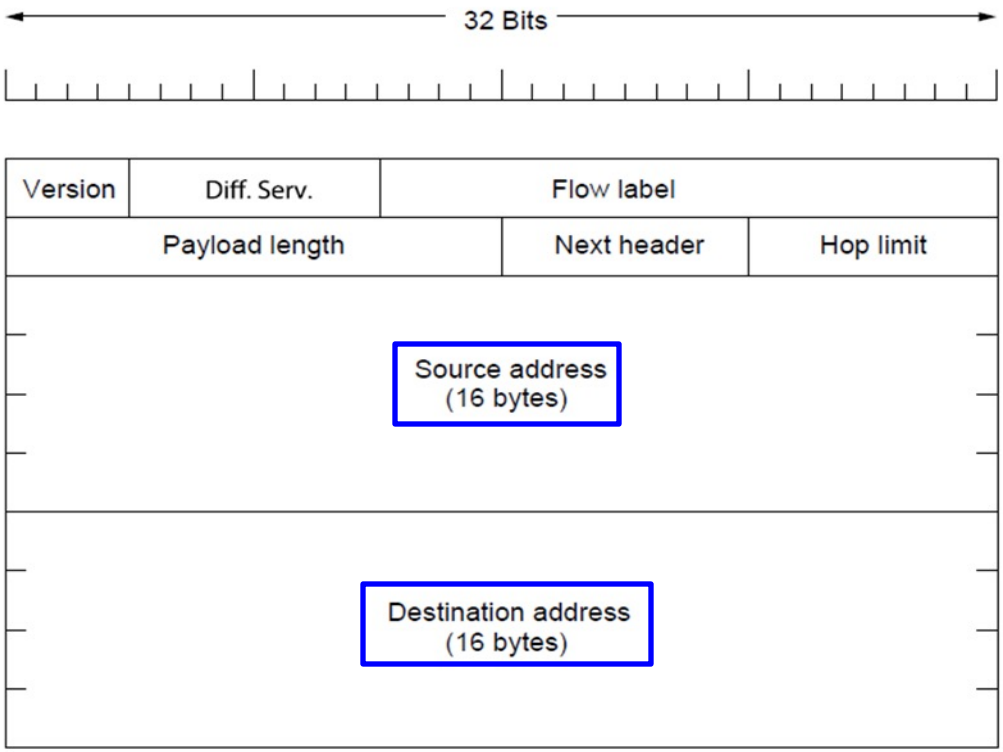
Major upgrade in the 1990s due to impending address exhaustion, with various other goals:

- Support billions of hosts
- Reduce routing table size
- Simplify protocol
- Better security
- Attention to type of service
- Aid multicasting
- Roaming host without changing address
- Allow future protocol evolution
- Permit coexistence of old, new protocols, …

IP Version 6

IPv6 header has longer address fields (128 bits)

- header size is reduced by providing optional headers for specific purposes (called *extension headers*)



No checksum field
Improves performance in routers and takes advantage of increased reliability in networks

Source and destination addresses are 16 bytes giving 2^{128} addresses

IP Version 6

IPv6 extension headers support optional features

- examples: support for packets larger than 64k bytes, fragmentation header is only included if needed, authentication of sender's identity can be included

Extension header	Description
Hop-by-hop options	Miscellaneous information for routers
Destination options	Additional information for the destination
Routing	Loose list of routers to visit
Fragmentation	Management of datagram fragments
Authentication	Verification of the sender's identity
Encrypted security payload	Information about the encrypted contents