Inter-networking

COS 460 & 540


CAPTAIN JAMES T. KIRK
I'M SORRY, I CAN'T HEAR YOU OVER THE
SOUND OF HOW AWESOME I AM.

Problem

LAN's are great… but…

We want to connect them together

...across the world

Inter-networking

- Internet Protocol (IP)
- Routing
- The Internet
- Multicast*
- Multi-protocol Label Switching*

Internet Protocol (IP)

- What is an Internetwork
- Service Model
  - Datagrams, Packet Format, …
- Addressing
- Datagram Forwarding
- ARP, DHCP, ICMP, ...

What?

- “internet” vs “Internet”
- “network” vs “subnetwork”
- physical vs logical networks

Bridge, Router, Switch

- repeater & hub - physical
- bridge - link
- switch - network
- router - internet
- gateway - application

Alternatives?

- Novell’s IPX

Internet Protocol (IP)

✓What is an Internetwork

- Service Model
  - Datagrams, Packet Format, …
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Service Model

- Datagram Delivery
- Packet Format
- Fragmentation and Reassembly

Datagram Delivery

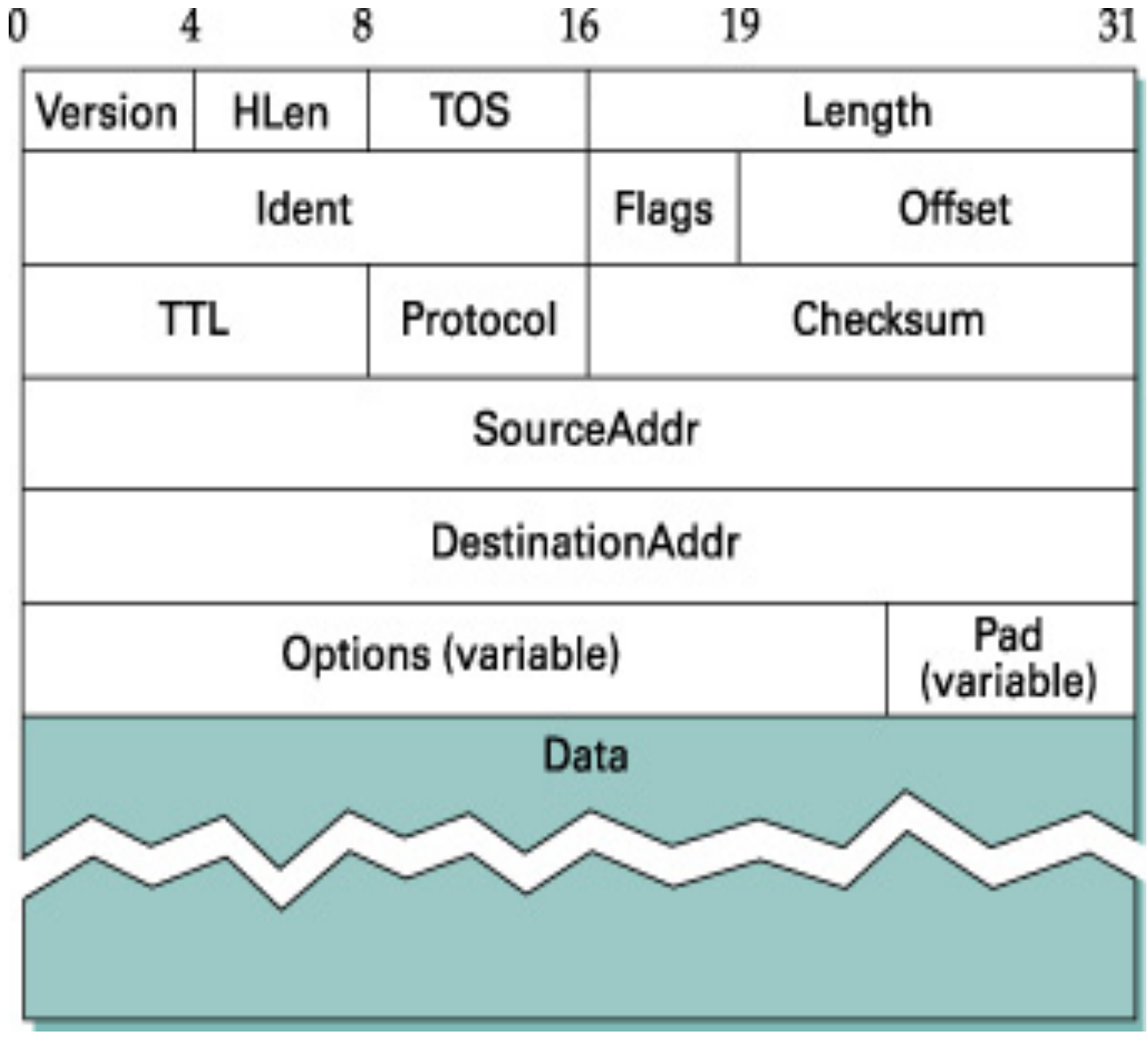
Underlying network is..

- reliable or unreliable
- connection-oriented or connectionless
- small or large packet/frame sized
- physical, logical, wireless, ...

Datagram Delivery

- IP **Datagram** is basis of protocol
- Provides a “**best-effort**” or unreliable service
- May be **out of order**
- **Connectionless**

Packet Format



Fragmentation

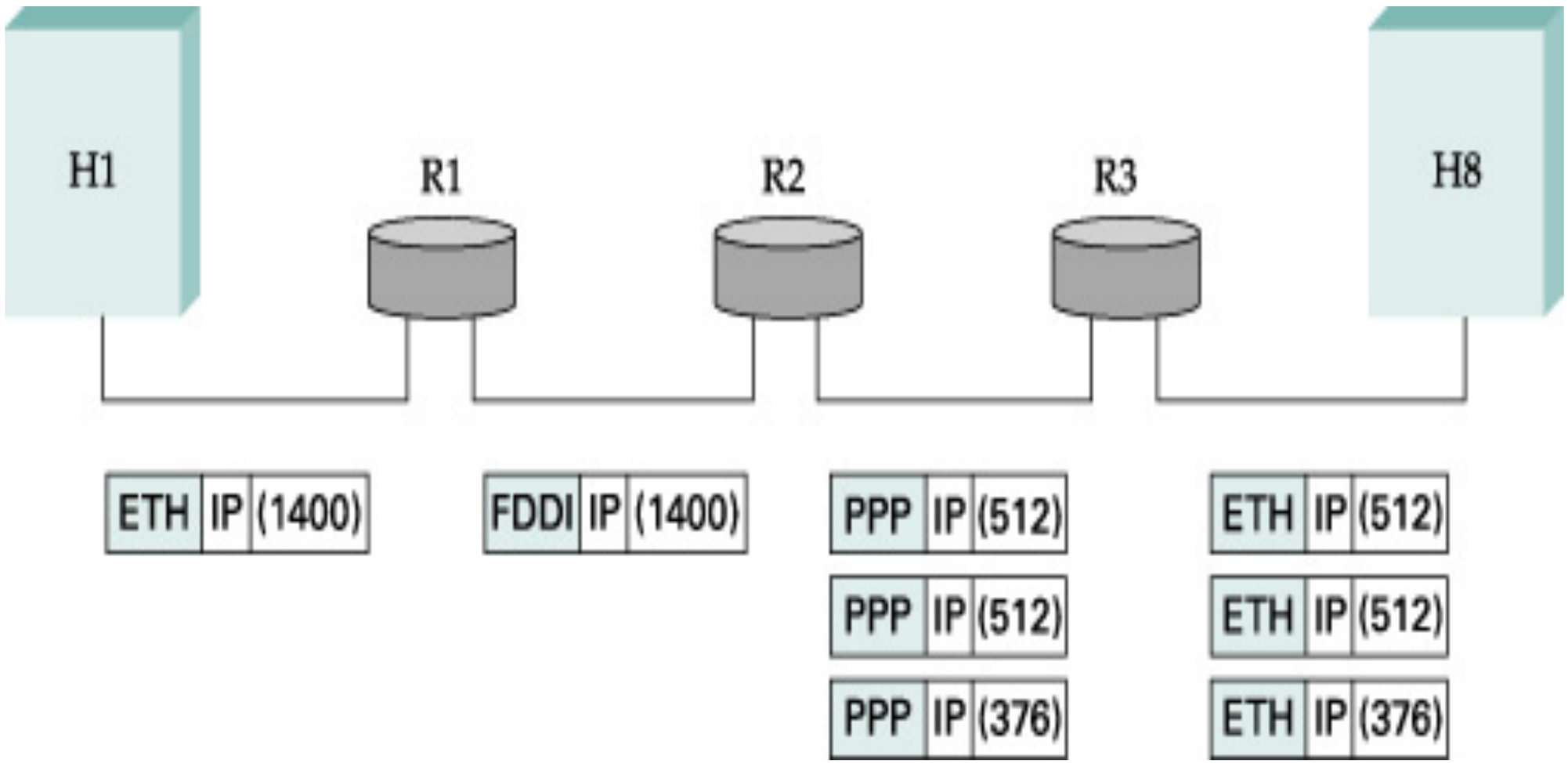
Problem:

- IP datagrams can be 64 kB
- The underlying network may have 512 Byte MTU

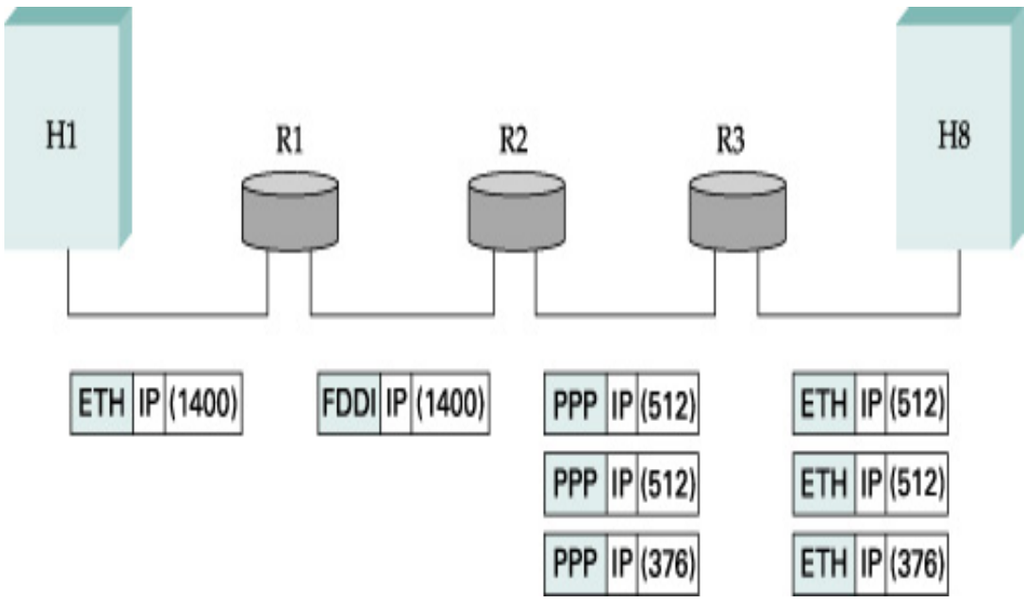
Solution:

- Each fragment is an IP datagram
- Each IP datagram is rebuilt for each network

Fragmentation



Fragmentation



(a)

Start of header				
Ident = x			0	Offset = 0
Rest of header				
1400 data bytes				

(b)

Start of header				
Ident = x			1	Offset = 0
Rest of header				
512 data bytes				

Start of header				
Ident = x			1	Offset = 64
Rest of header				
512 data bytes				

Start of header				
Ident = x			0	Offset = 128
Rest of header				
376 data bytes				

Internet Protocol (IP)

✓What is an Internetwork

✓Service Model

✓Datagrams, Packet Format, …

- Addressing
- Datagram Forwarding
- ARP, DHCP, ICMP, ...

IP Addressing

- Need to identify any host on the network
- Globally **unique**
- **Hierarchal** (not flat like Ethernet)
  - for easier routing
  - represents a network of networks

IP Addressing

- 32 bit addresses
- “Dotted Decimal” format
  - 130.111.135.26
- Contains two parts
  - **Network**
  - **Host**

IP Addressing

IP Addressing

- Network portion
  - specifies a unique physical* network
  - used for routing
- Host portion
  - specifies a unique host on the network
  - local delivery

Internet Protocol (IP)

✓What is an Internetwork

✓Service Model

- ✓Datagrams, Packet Format, …

✓Addressing

- Datagram Forwarding

- ARP, DHCP, ICMP, ...

Datagram Forwarding

How do datagrams traverse the internetwork

Forwarding vs Routing

- ***forwarding*** is taking an input packet and sending it out the appropriate port

- ***routing*** is the process of building forwarding tables.

Datagram Forwarding

- Every datagram has **destination** IP
- Network part **uniquely identifies** a physical network
    - All **hosts/routers** on network can **communicate** with all others
- Every network has a **router** on the net

Datagram Forwarding

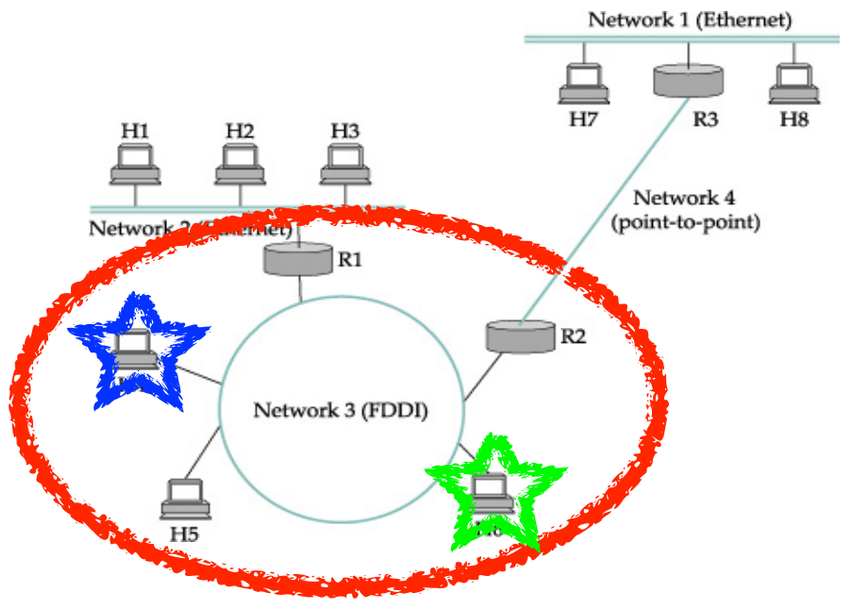
Each host and router maintains a forwarding table

Network	Next-hop
1 130.111	R1 130.111.32.1
2 141.114	R2 141.114.1.1
default	R2 76.5.4.3

Datagram Forwarding

If destination network == source network

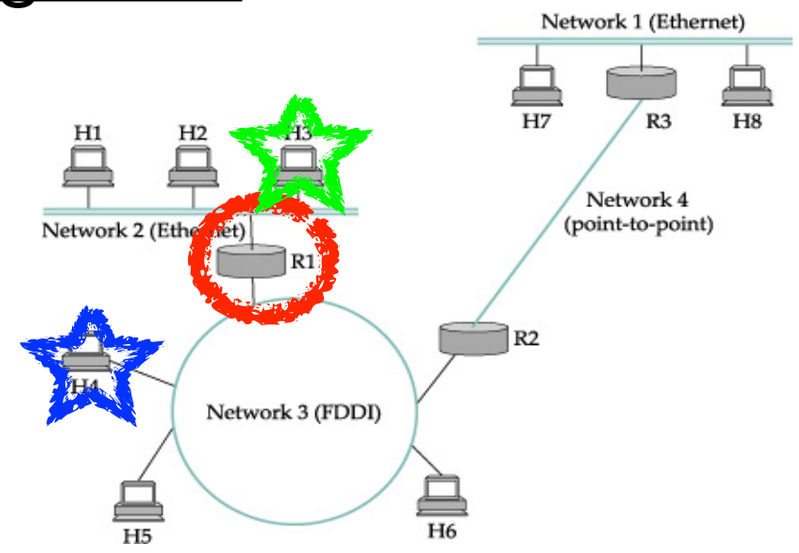
deliver locally



Datagram Forwarding

if destination network in forwarding table

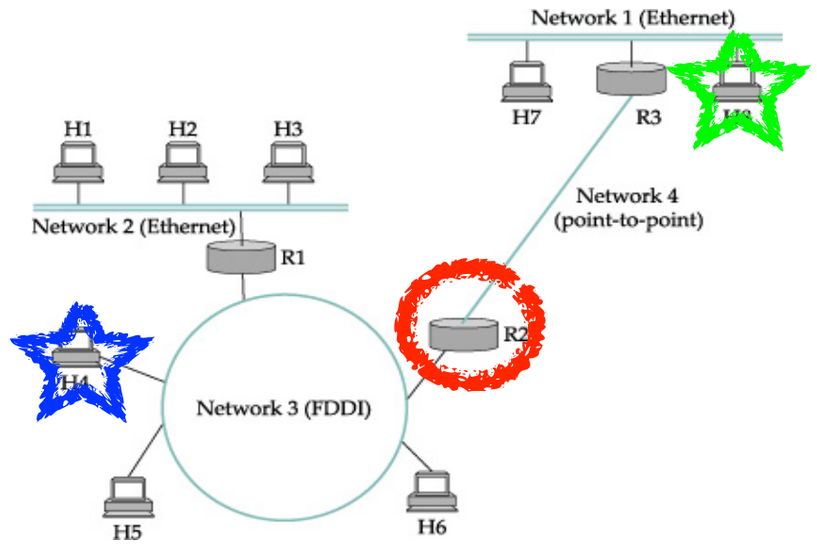
deliver to next-hop



Datagram Forwarding

if destination network unknown

deliver to default



Datagram Forwarding

- Local delivery for local datagrams

- Routers forward datagrams towards the physical network

Internet Protocol (IP)

✓What is an Internetwork

✓Service Model

- ✓Datagrams, Packet Format, …

✓Addressing

✓Datagram Forwarding

- ARP, DHCP, ICMP, ...

Address Resolution Protocol (ARP)

Local delivery

it’s not that simple

IP Address != Ethernet Address

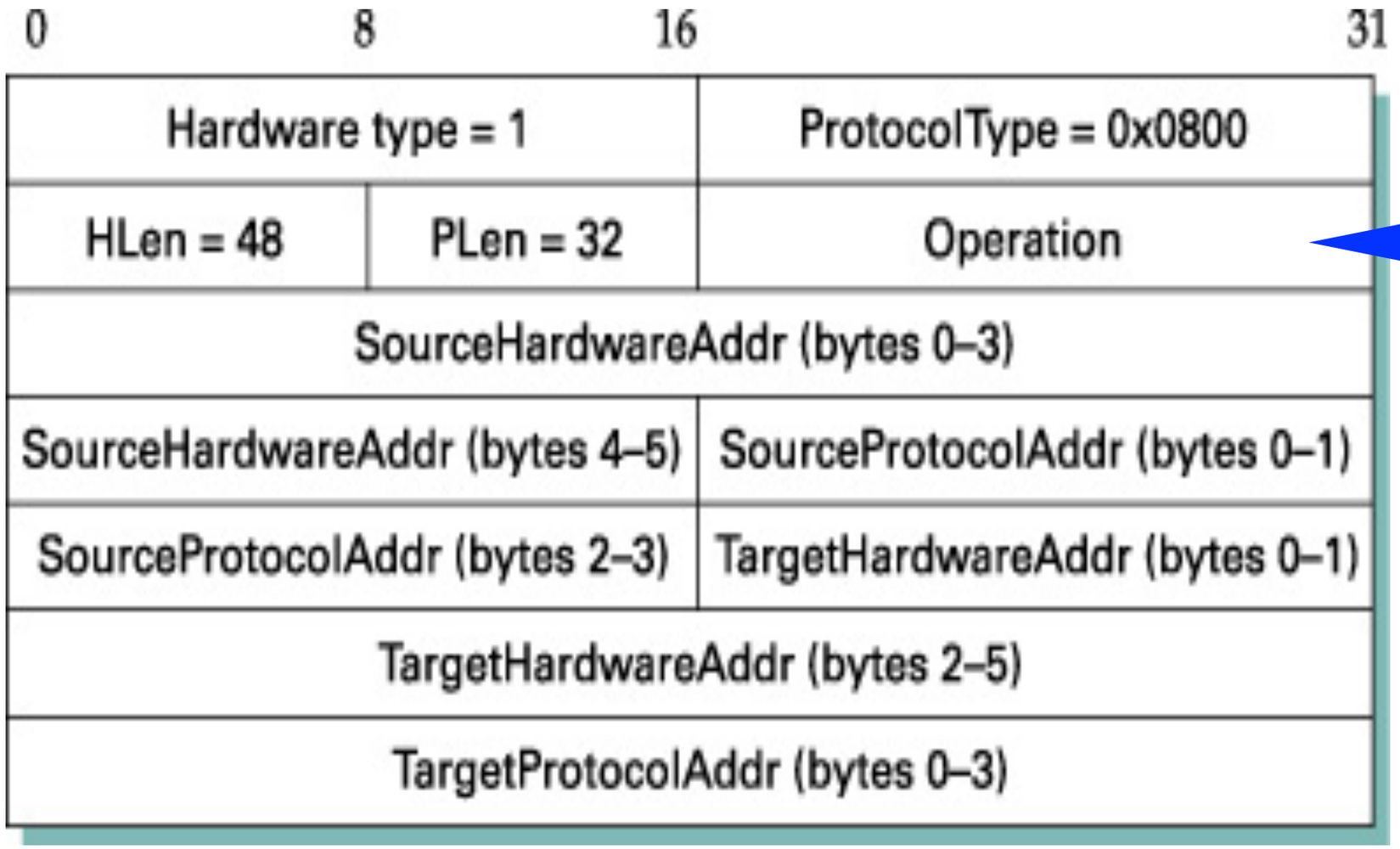
Address Resolution

- Finds **local** or **link-level** address for an **IP** address
  - Both hosts on the same IP Network
  - Discover / Dynamic
- Uses *broadcast* feature of link-level

Address Resolution

1. Do we have the IP-MAC addresses cached?
2. Send out broadcast query
3. Look for response, and fill in cache

ARP Packet



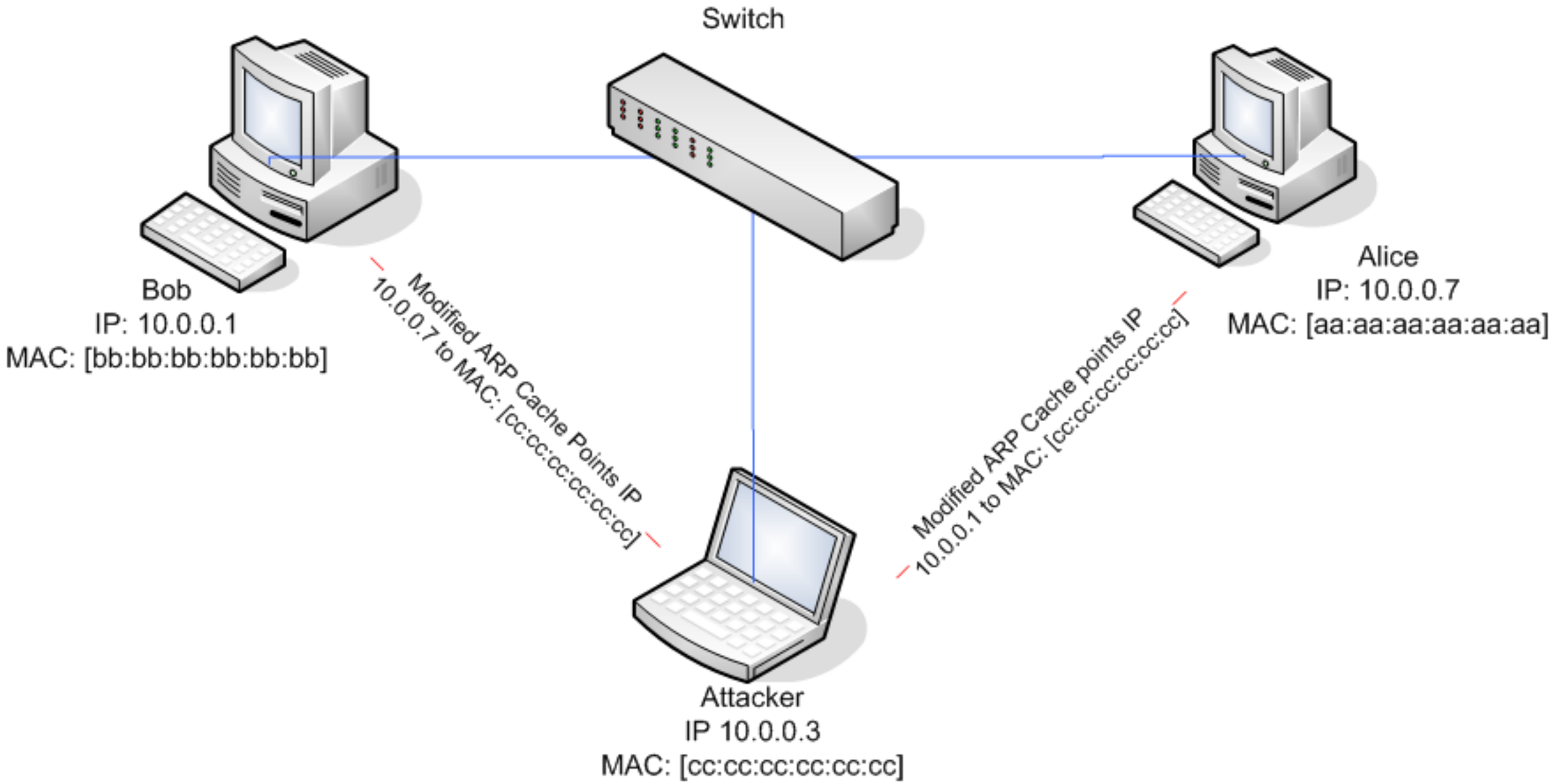
Request
or
Response

ARP

- Problems?

- ARP Spoofing (http://en.wikipedia.org/wiki/ARP_spoofing)

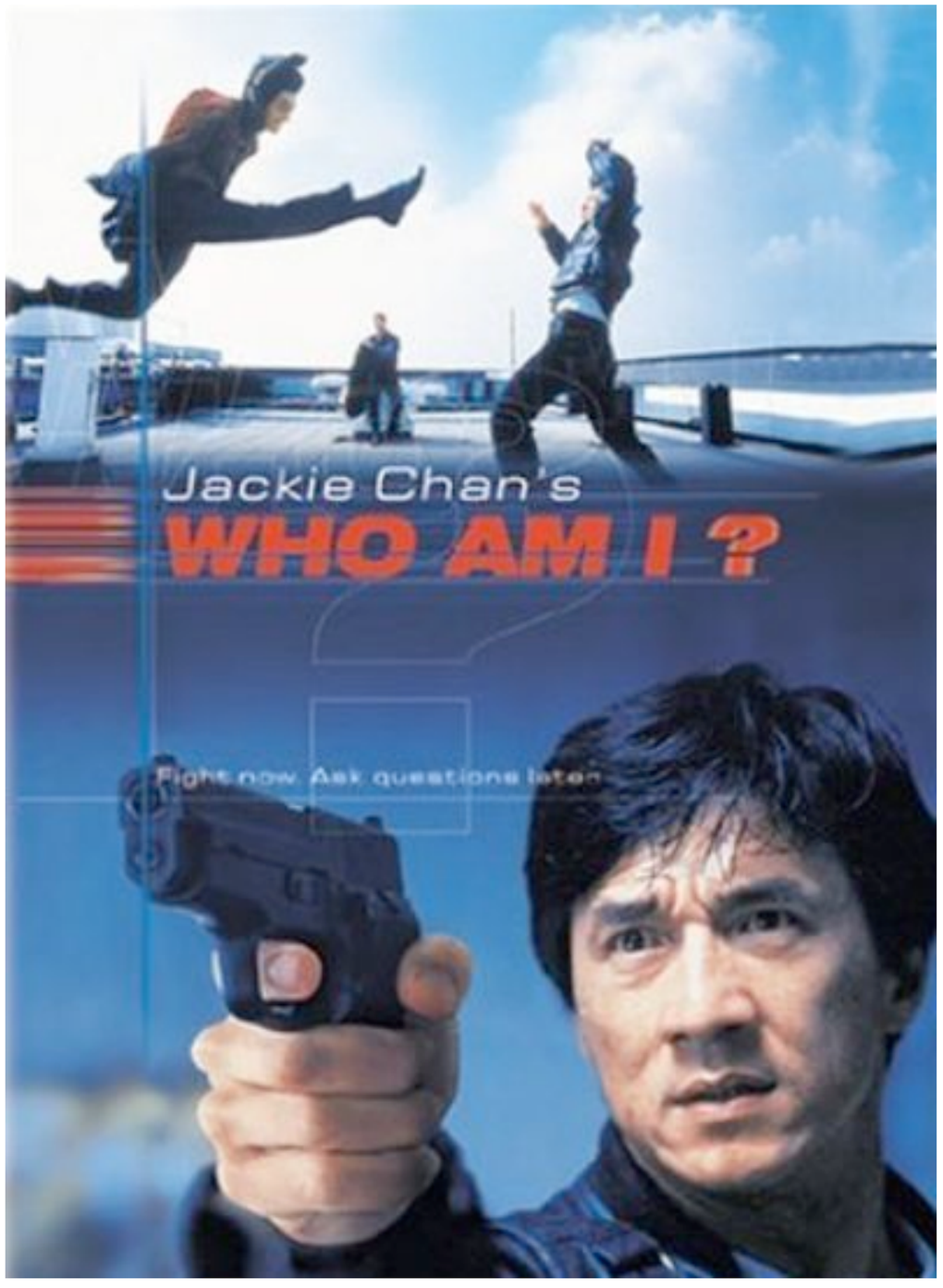
ARP Spoofing



DHCP

Dynamic Host Configuration Protocol

Who Am I?



DHCP

- Static configuration of hosts
  - not flexible or adaptable to changes
  - cumbersome
- Dynamic configuration
  - provide host with an IP address
  - additional information: router, boot info...

DHCP

1. Broadcast request: DHCPDISCOVER
2. Look for responses: DHCPOFFERs
3. Pick one and DHCPREQUEST
4. Wait for DHCPACK

DHCP

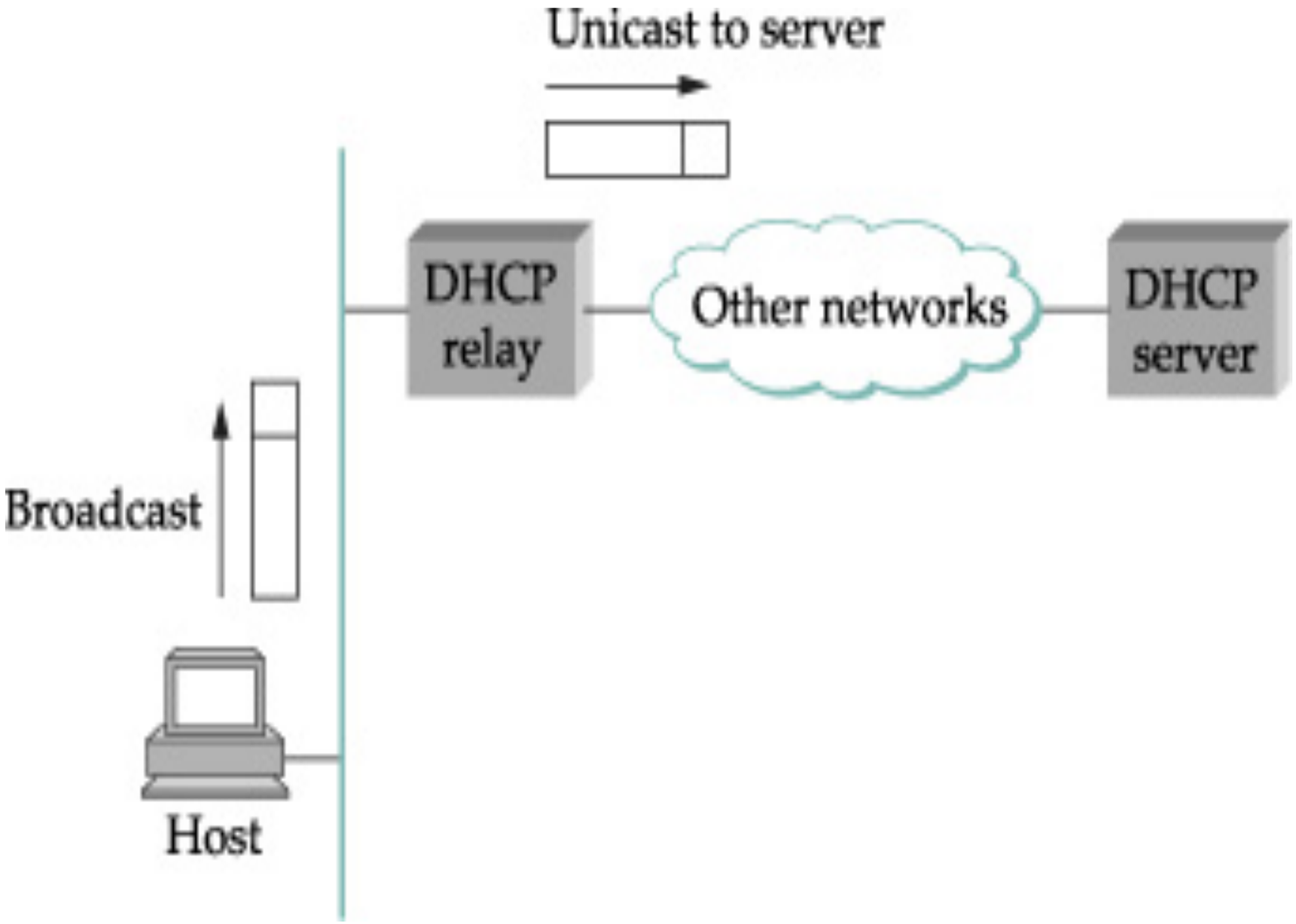
Problem:

Broadcast means you need a DHCP server on every network.

Solution:

DHCP forwarding

DHCP Forwarding



DHCP

- IP Address is ***leased*** for a given amount of time.
- Host must ***renew*** the lease with the server.
- Server can deny renewal
    - Can request a new lease

ICMP

When things don’t go as planned.

ICMP

Remember: Best-effort service

- Diagnostic purposes (ping)
- TTL (hops) reaches 0 at a router
- Host not reachable (network error)
- Network redirection

ARP, DHCP, ICMP

These protocols are at the edge between the Network and IP layers

- Address Resolution Protocol (ARP)
- Dynamic Host Configuration Protocol (DHCP)
- Internet Control Message Protocol (ICMP)

Internet Protocol (IP)

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- ✓ Datagram Forwarding
- ✓ ARP, DHCP, ICMP, ...

Internet Protocol (IP)

- ✓ What is an Internetwork
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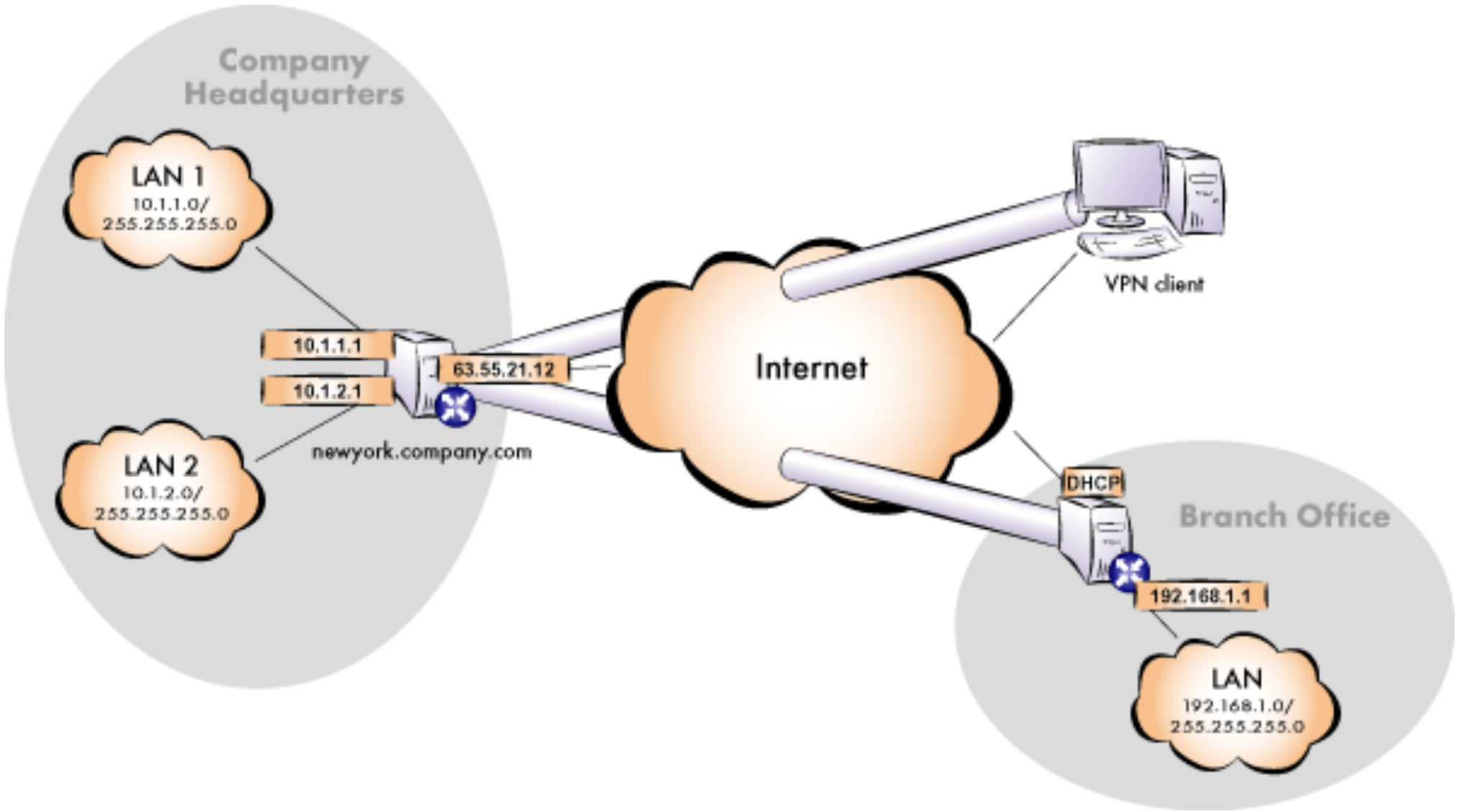
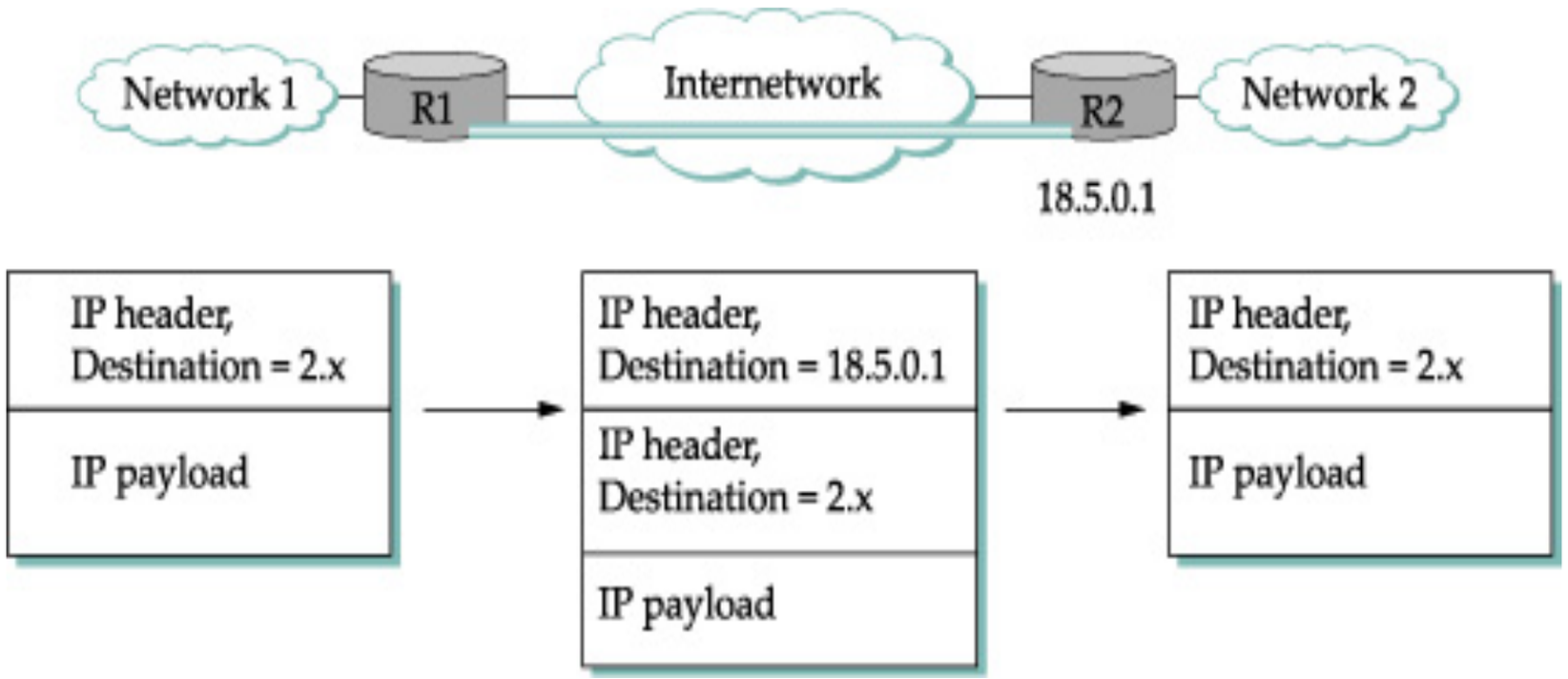
Virtual Networks (VPN)



VPN


Network 1
R1
Internetwork
R2
Network 2
18.5.0.1
IP header,
Destination = 2.x
IP payload
IP header,
Destination = 18.5.0.1
IP header,
Destination = 2.x
IP payload
IP header,
Destination = 2.x
IP payload

Inter-networking

✓Internet Protocol (IP)

★Routing

- The Internet
- Multicast*
- Multi-protocol Label Switching*

Routing

- Network as a graph
- Distance Vector (RIP)
- Link State
  - Open Shortest Path First (OSPF)
- Mobile Routing

Forwarding vs Routing

- ***forwarding*** is taking an input packet and sending it out the appropriate port

- ***routing*** is the process of building forwarding tables.

Tables

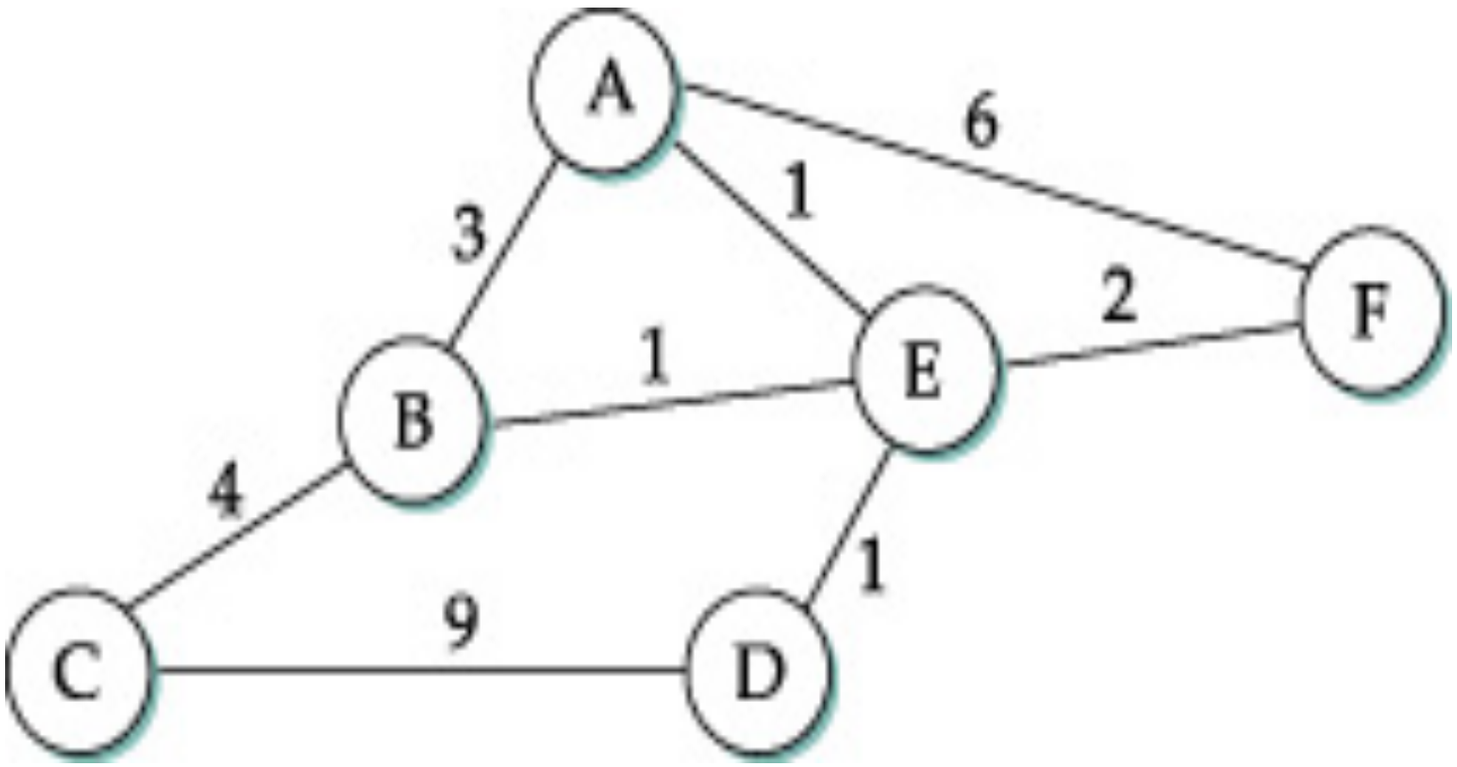
Routing Table

Network	Next Hop
42	192.168.1.1

Forwarding Table

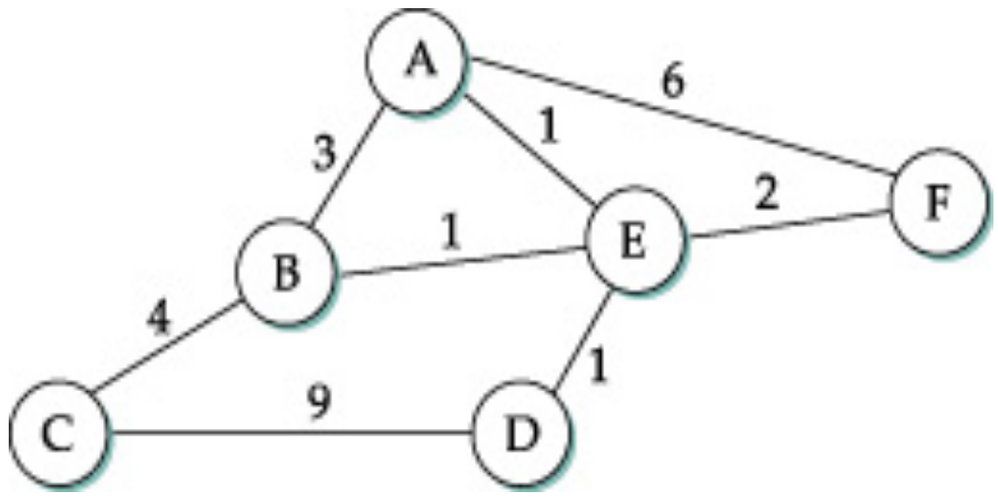
Network	Port	MAC
42	1	00:BC:D4:34:32:0B

Network Graph



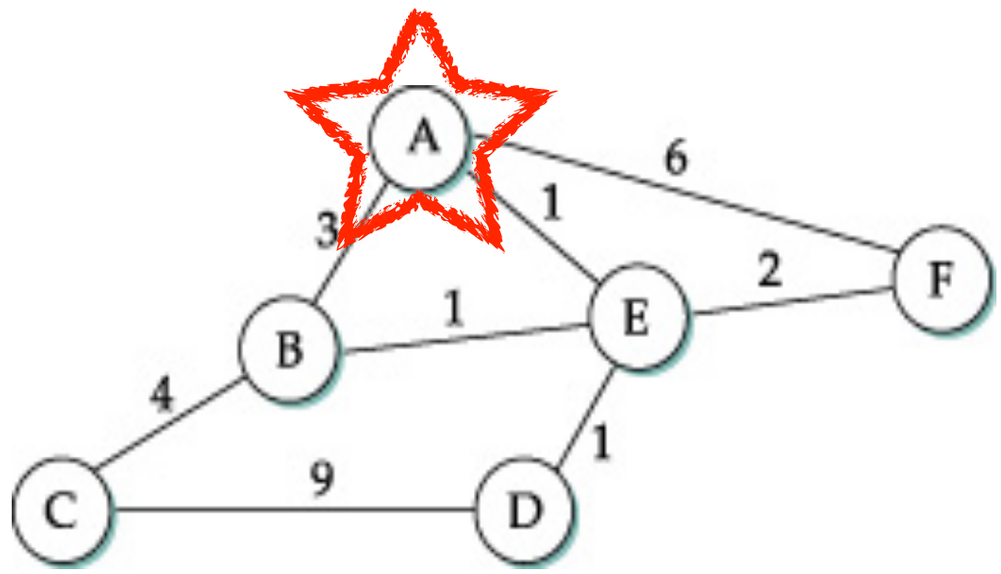
Distance Vector (RIP)

- Table of distance/cost to all nodes
- Distribute to immediate neighbors
- Link Down = ∞
- periodic & triggered



Distance Vector (RIP)

Dest	Cost	Hop
B	3	B
C	∞	-
D	∞	-
E	1	E
F	6	F

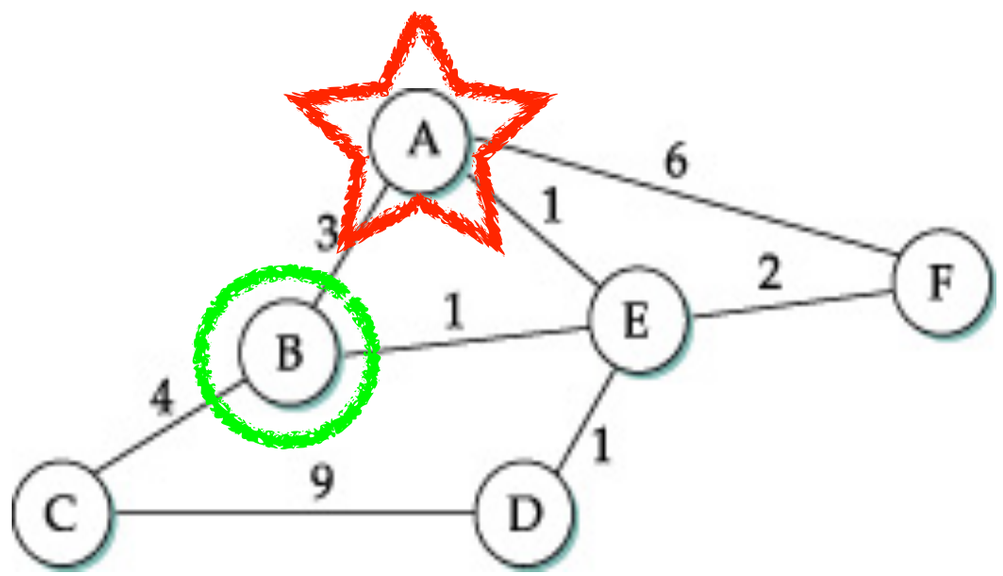


Distance Vector (RIP)

Dest	Cost	Hop
B	3	B
C	7	B
D	∞	-
E	I	E
F	6	F

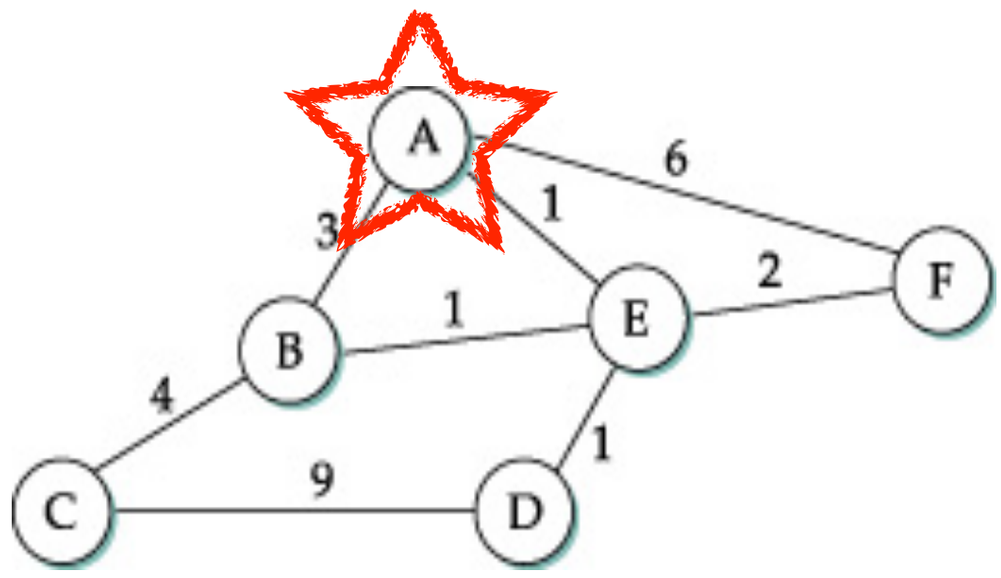
From: B

Dest	Cost	Hop
A	3	A
C	4	C
D	∞	-
E	I	E
F	∞	-



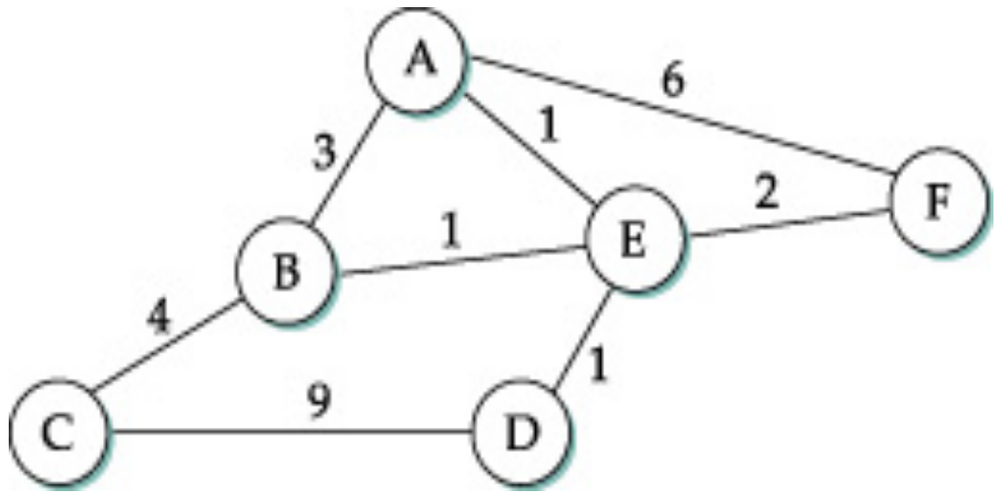
Distance Vector (RIP)

Dest	Cost	Hop
B	2	E
C	6	E
D	2	E
E	1	E
F	3	E



Distance Vector (RIP)

- Complete Map
- Exchange with immediate neighbors



Distance Vector Game

1. Make “Routing Table” of network

Destination	Cost	Next Hop

2. Send messages to neighbors with

From: _____

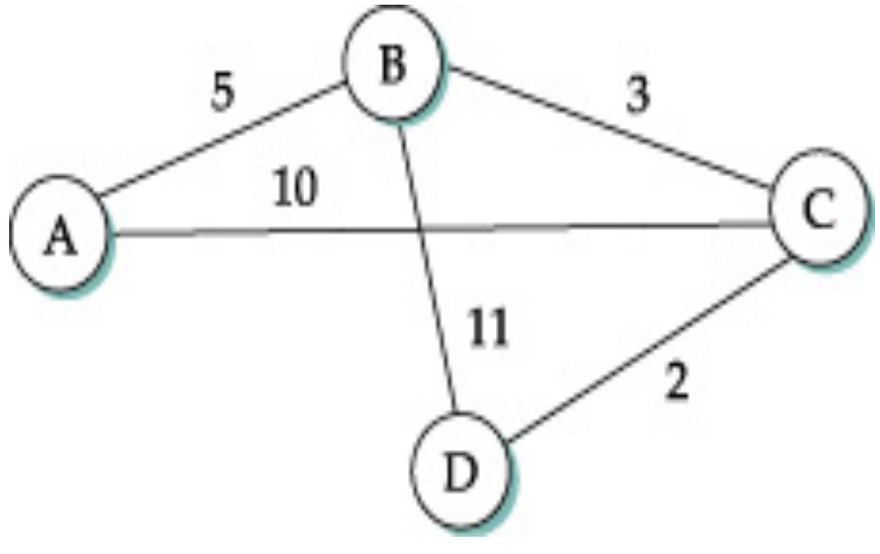
Destination	Cost

3. Use messages from neighbors and destroy

4. Repeat from step 2

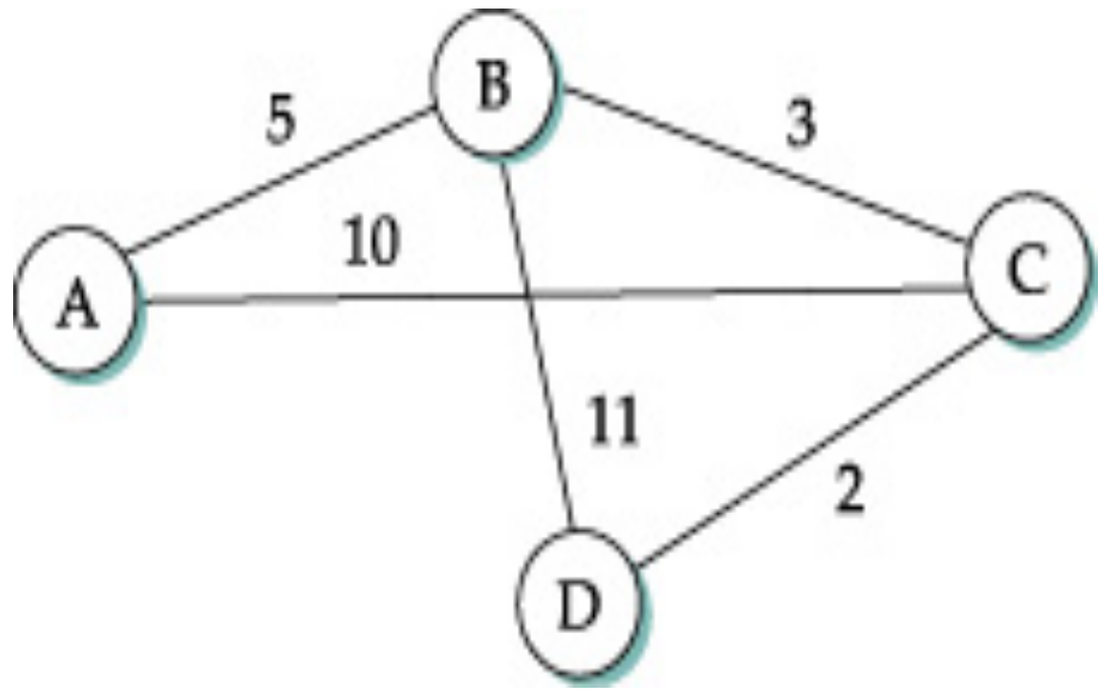
Link State

- Link State Packet (LSP)
- Distance/Cost of neighbors
- Flood to all routers



Link State

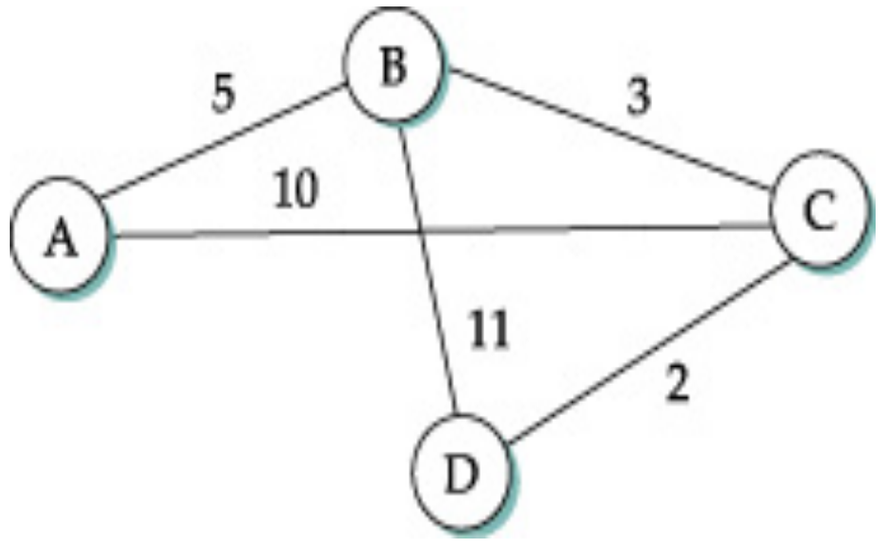
Dest	Cost	Hop
B	5	B
C	8	B
D	10	B



Link State

Step	Confirmed	Tentative	Replaced
1	(A,0,-)		
2	(A,0,-)	(B,5,B) (C,10,C)	
3	(A,0,-) (B,5,B)	(C,8,B) (D,14,B)	(C,10,C)
4	(A,0,-) (B,5,B) (C,8,B)	(D,10,B)	(D,14,B)
5	+(D,10,B)		

From: B cost 5
(A,5,A)
(C,3,C)
(D,11,D)



Link State

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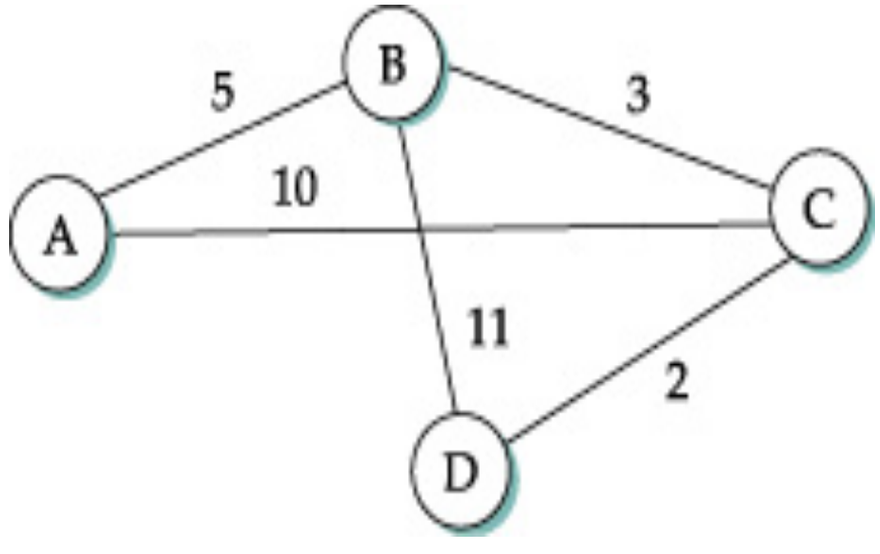


Link State Game

1. Make “Routing Table” of network

Confirmed Tentative

2. Flood messages to everyone with neighbor information only, keep your own

From: _____

Neighbor	Cost	NextHop

3. Use messages from others (Dijkstra’s Alg.)

4. Repeat from step 2, until tentative is empty

Metrics

- Bandwidth
- Latency
- “hops”
- Cost (dollars)
- Utilization
- Geo-Political boundaries

Inter-networking

✓Internet Protocol (IP)

✓Routing

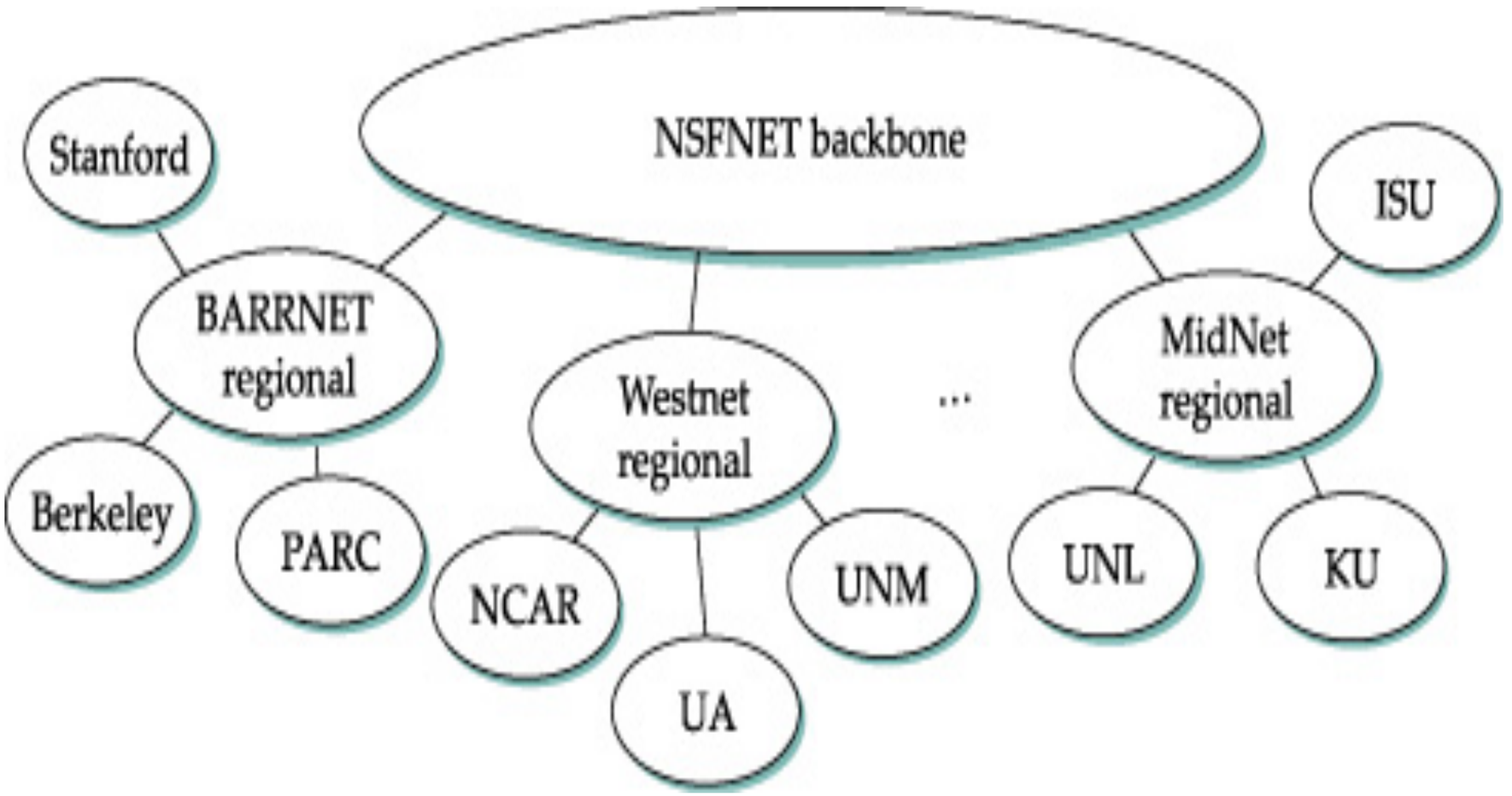
★The Internet

- Multicast*
- Multi-protocol Label Switching*

The Internet

- Construction
  - Autonomous Systems
  - Subnetting
  - Classless Routing (CIDR)
  - Border Gateway Routing (BGP)
  - IPv6

What does it look like

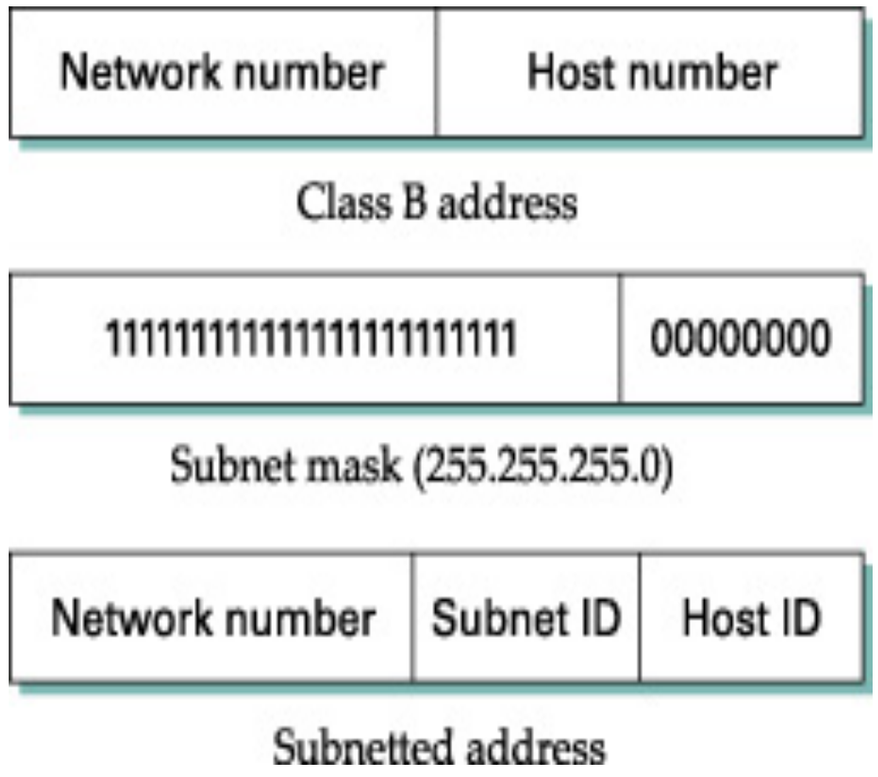


Subnetting

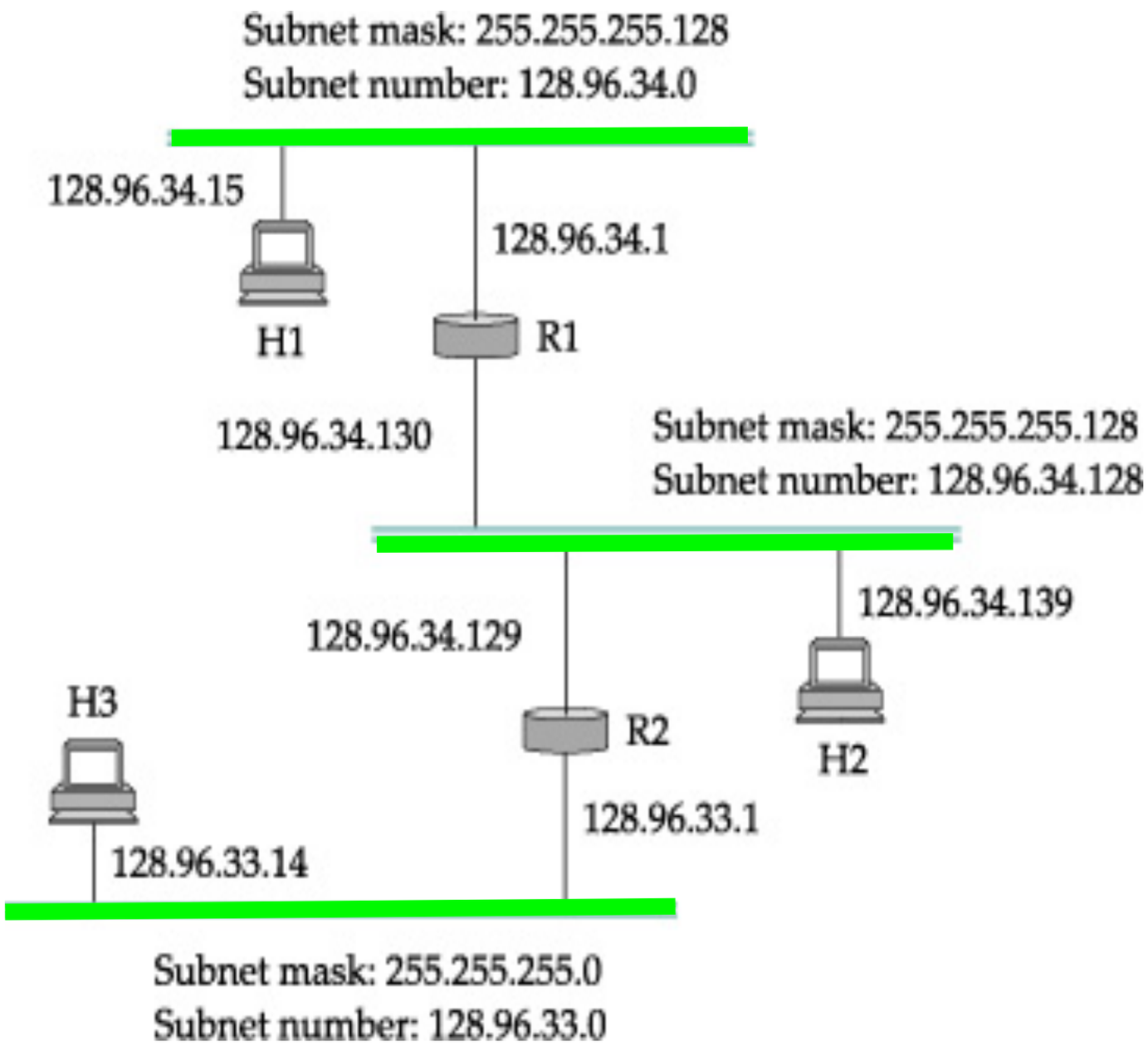
- Network part of address uniquely identifies a physical network
- Class B network (16 & 16 bits) - unused
- Class C network (24& 8 bits) - too small

Subnetting

- Allocate one “network” to several physical networks
  - internal to network
  - outside routes same



Subnetting


Subnet mask: 255.255.255.128
Subnet number: 128.96.34.0
128.96.34.15
128.96.34.1
H1
R1
128.96.34.130
Subnet mask: 255.255.255.128
Subnet number: 128.96.34.128
128.96.34.129
128.96.34.139
H3
R2
H2
128.96.33.1
128.96.33.14
Subnet mask: 255.255.255.0
Subnet number: 128.96.33.0

Subnetting

- Solves scalability problem
- improve address assignment efficiency
- aggregates information, from a distance

Classless Routing (CIDR)

- Scalability problems in the backbone
  - Single location with multiple C nets
  - Lots of entries to maintain outside
  - Assignment of Class B wastes

CIDR

- Solution: aggregate routes
  - 192.4.16/20 = 192.4.16 to 192.4.31
  - 192.4.16/24 = 192.4.16

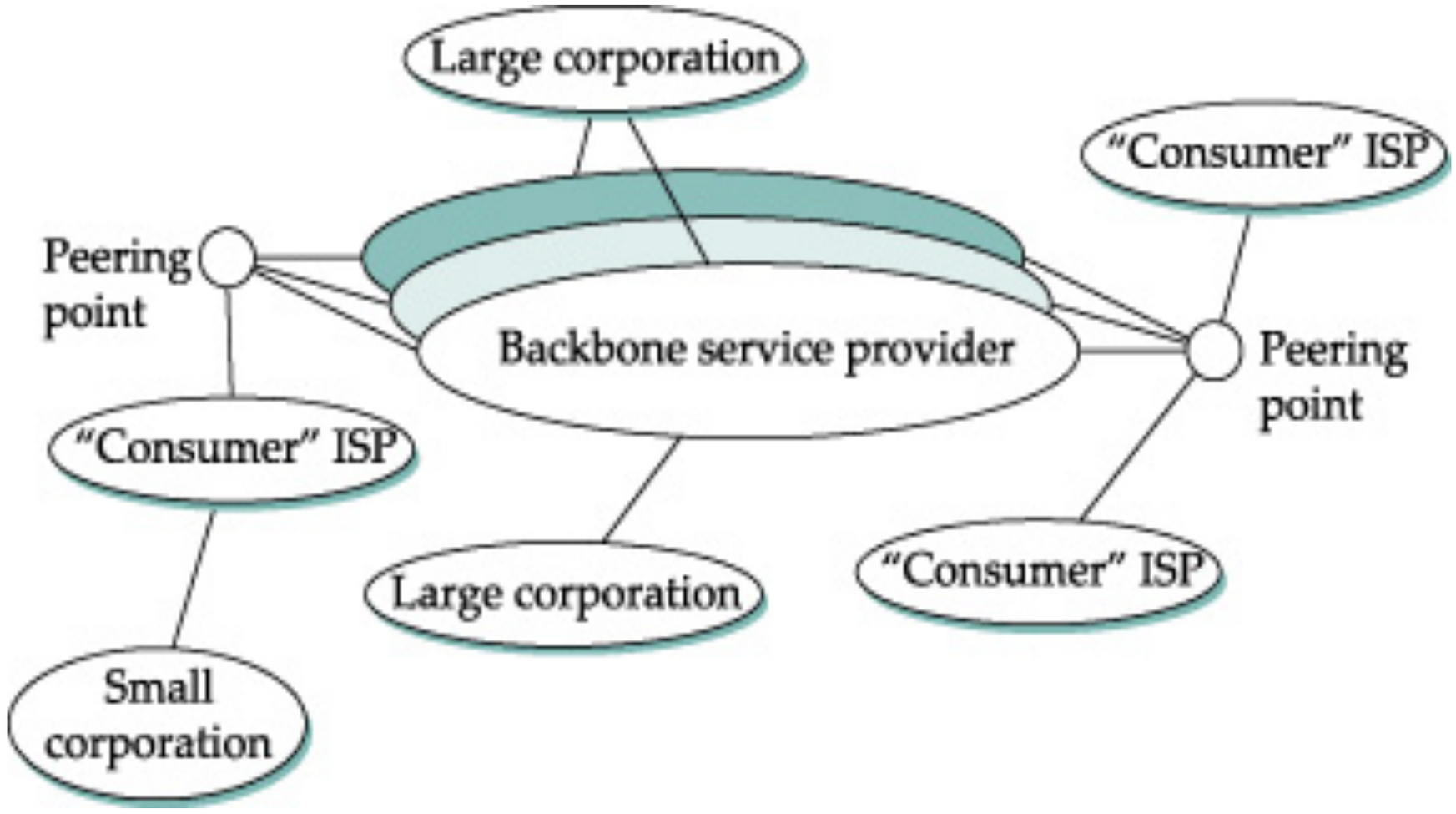
CIDR

- Solution: Assign **<u>blocks</u>** of Class C addresses
  - creates aggregate routes to AS

Interdomain Routing

- Each Autonomous System (AS)
  - Has a “border”
  - Handles its own internal routing
  - Has its own policies for in & out

Interdomain Routing



Interdomain Routing

- Find *some* path to destination
- Avoid *loops*
- Compliant with *policies* of ASs

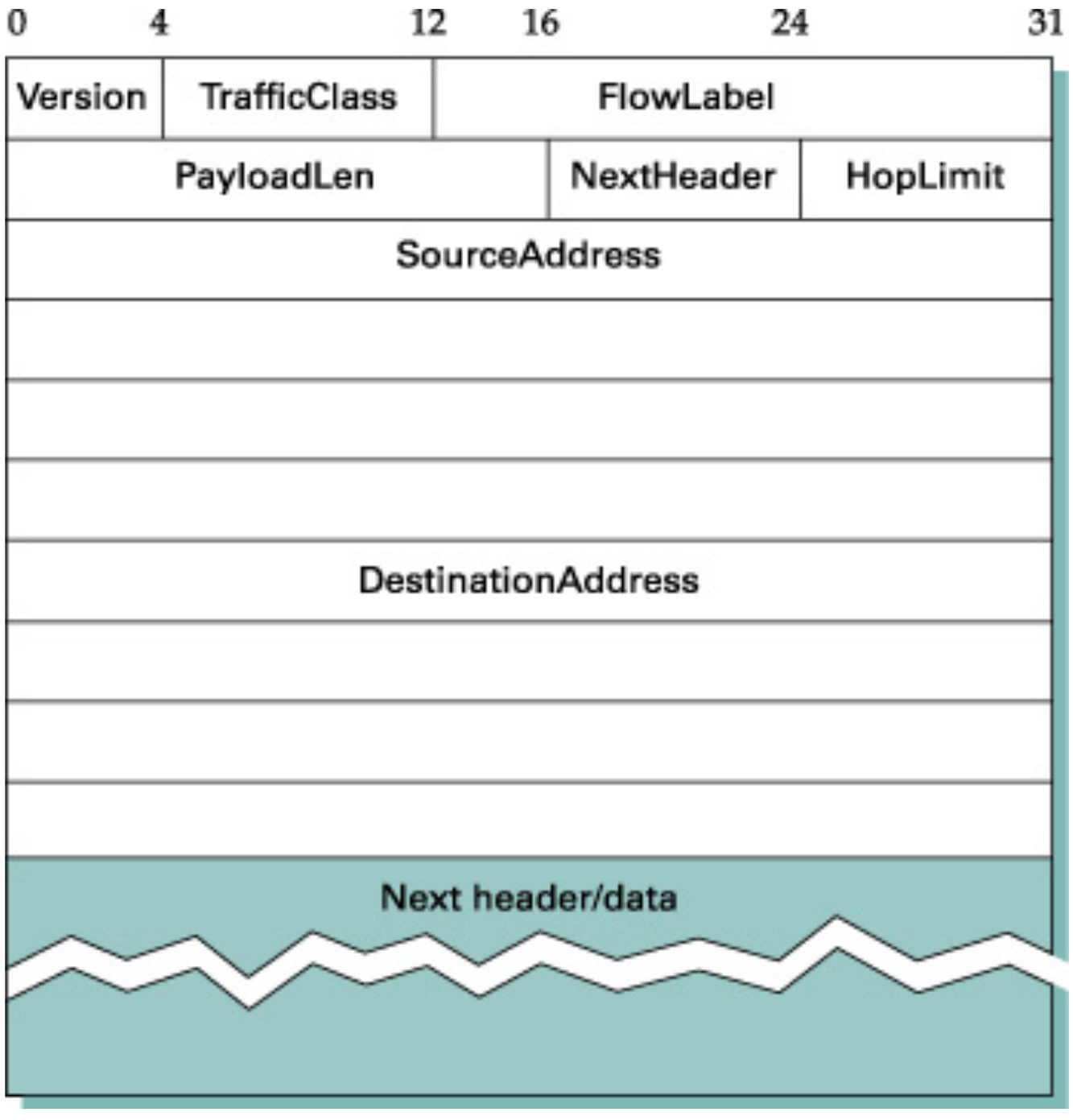
Interdomain Routing

- Border Gateway Protocol (BGP)
  - AS numbers are *unique*
  - One node is the *speaker* for the network
  - Advertises *complete paths* to networks
  - Prevent *loops*
  - Path *withdrawn* messages

Interdomain Routing

- Scalable (by hierarchy)
  - AS has own internal policies and routing
  - Only AS borders run BGP on backbone
  - Aggregate networks
  - Only need to find path to border

IPv6


0
4
12
16
24
31
Version
TrafficClass
FlowLabel
PayloadLen
NextHeader
HopLimit
SourceAddress
DestinationAddress
Next header/data

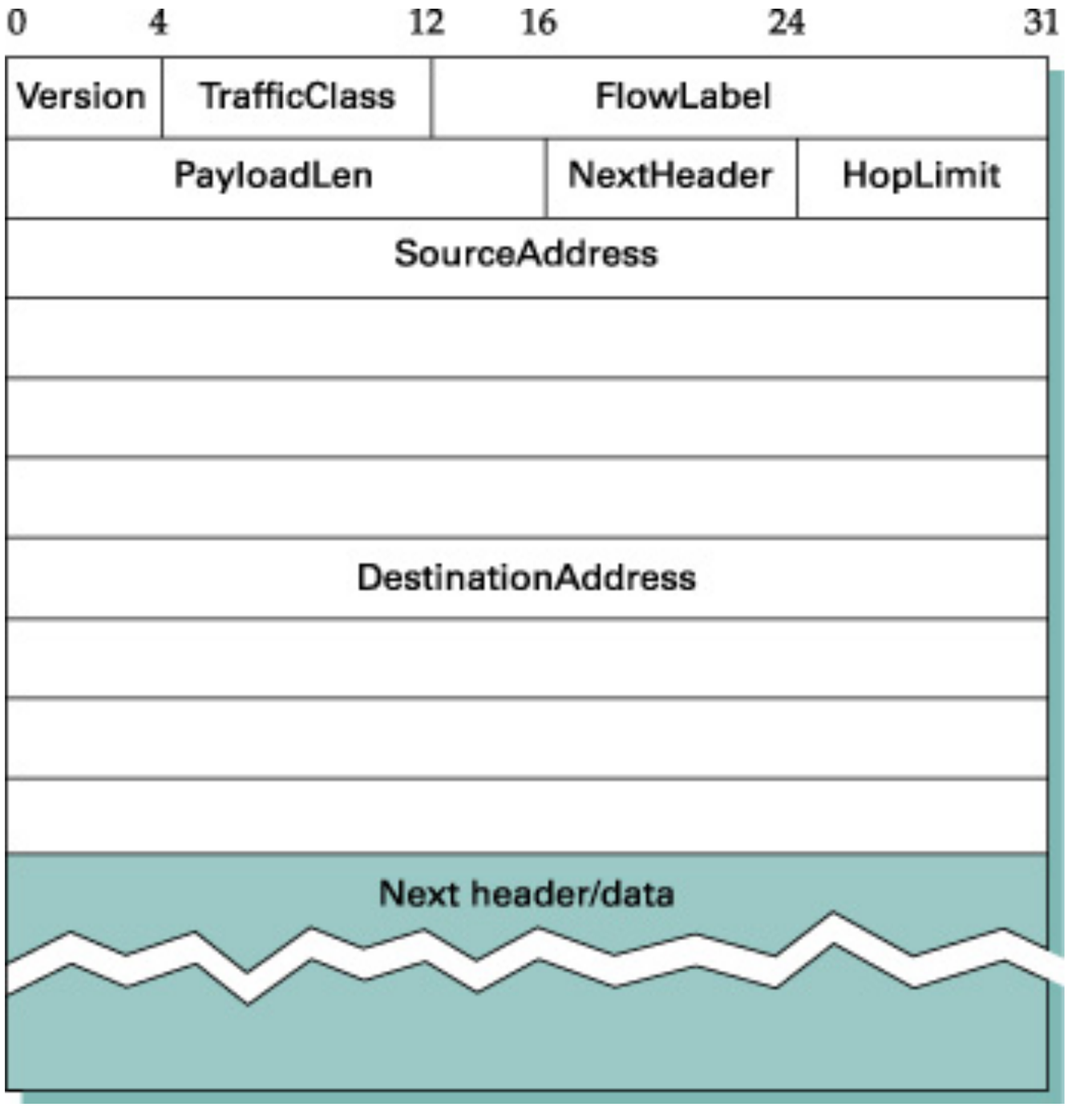
IPv6 - Why?

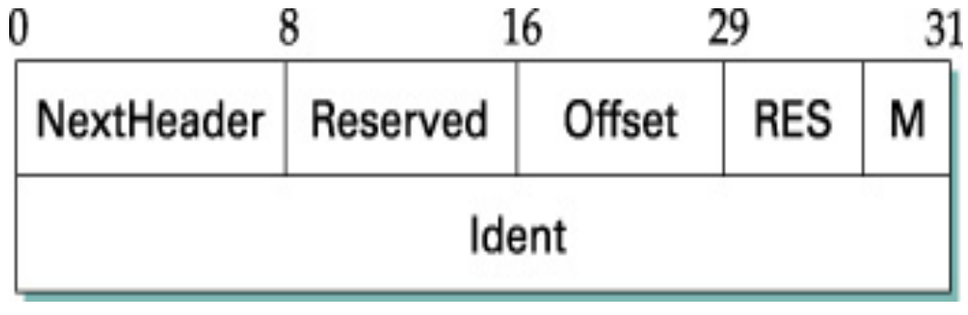
- Address exhaustion (really Class B)
- Real-time services
- Security
- Configuration
- Routing - mobile hosts
- Jumbograms

Addresses

- 128 bits = 3.4 x 10^{38} nodes
- Notation = x:x:x:x:x:x:x:x
  - :: = zeros; 45de:1230:FG::11:12
  - IPv4 (zero extended) ::FFFF:128.96.33.81

Packet Format





Configuration

- No more DHCP servers...
- Prefixes are assigned to networks (at AS)
    - Obtain interface ID
    - Obtain address prefix for subnet
        - local link only (1111 1110 10)
        - routers periodically advertise prefix
- Temporary addresses for mobile and privacy

Inter-networking

✓Internet Protocol (IP)

✓Routing

✓The Internet

- Multicast*

- Multi-protocol Label Switching*

Inter-networking

fin