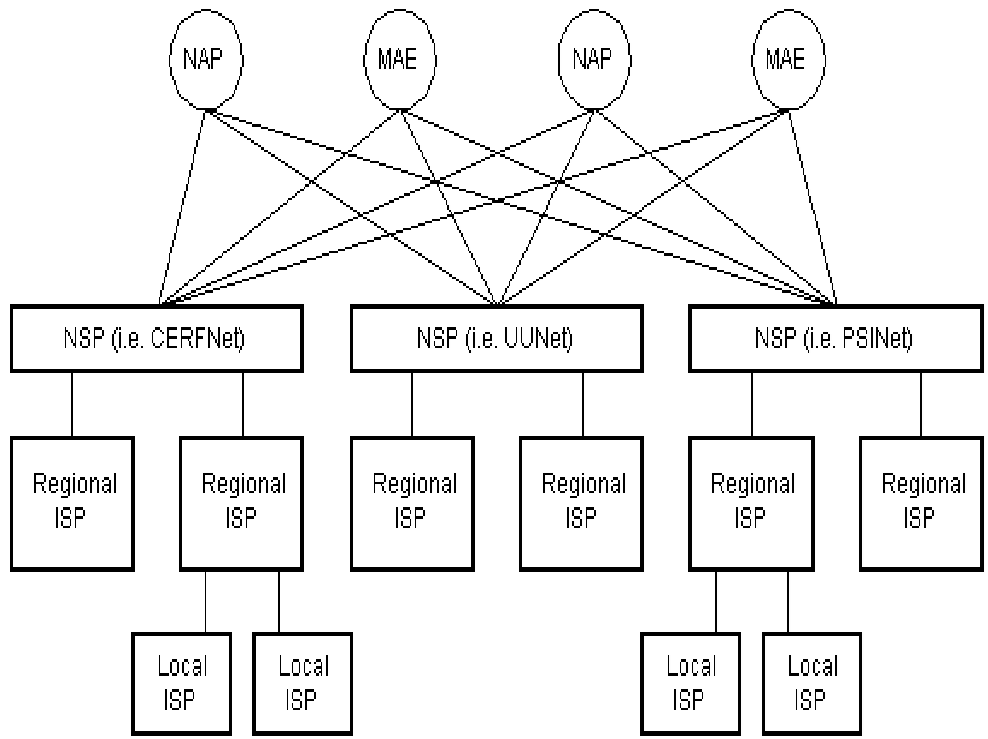
# Network Layer
# Part 1

# Services provided by Network Layer

- Logical Address to the nodes in the network.
- Packet Switching data delivery services.
- Connection less services.
- Best effort data delivery services (Unreliable).
  - Packets may be lost in the network.
  - Packets may be delivered out of order at the destination.
  - Duplicate packets may arrive at the destination.
  - Packet may delayed too long to reach to the destination.
- Congestion Control

# Global Internet Architecture

- The Internet backbone is made up of many large networks which interconnect with each other.
- These large networks are known as **Network Service Providers** or **NSP**s. Some of the large NSPs are UUNet, CerfNet, IBM, BBN Planet, SprintNet, PSINet, as well as others.
- Each NSP is required to connect to three **Network Access Points** or **NAP**s.
- NSPs also interconnect at **Metropolitan Area Exchanges** or **MAE**s.
- Both NAPs and MAEs are referred to as Internet Exchange Points or **IX**s.
- NSPs also sell bandwidth to smaller networks, such as ISPs and smaller bandwidth providers.



# Packet Switching

- Switches need to address three problems:
  - Forwarding
    - Directing input packet to correct output interface
  - Routing
    - Knowing which is the correct output interface
  - Contention
    - Buffering of packets (needs queue of storage)

- Approach of Network Layer: Store and Forward
- Packet reaches to the destination using packet switching

# Network Level Address

- Two issued must be handled when we are connecting two networks:
  - Heterogeneity
  - Scalability
- Routers are interfacing components to connect multiple networks.
- Lower layers define maximum transfer unit (MTU) for the network layer.
- Heterogeneity and scalability issues can be addressed by the following protocols:
  - IPv4 (RFC 791)
  - IPv6(RFC 2460)
- They also provide logical address to the nodes in the network.

# Example

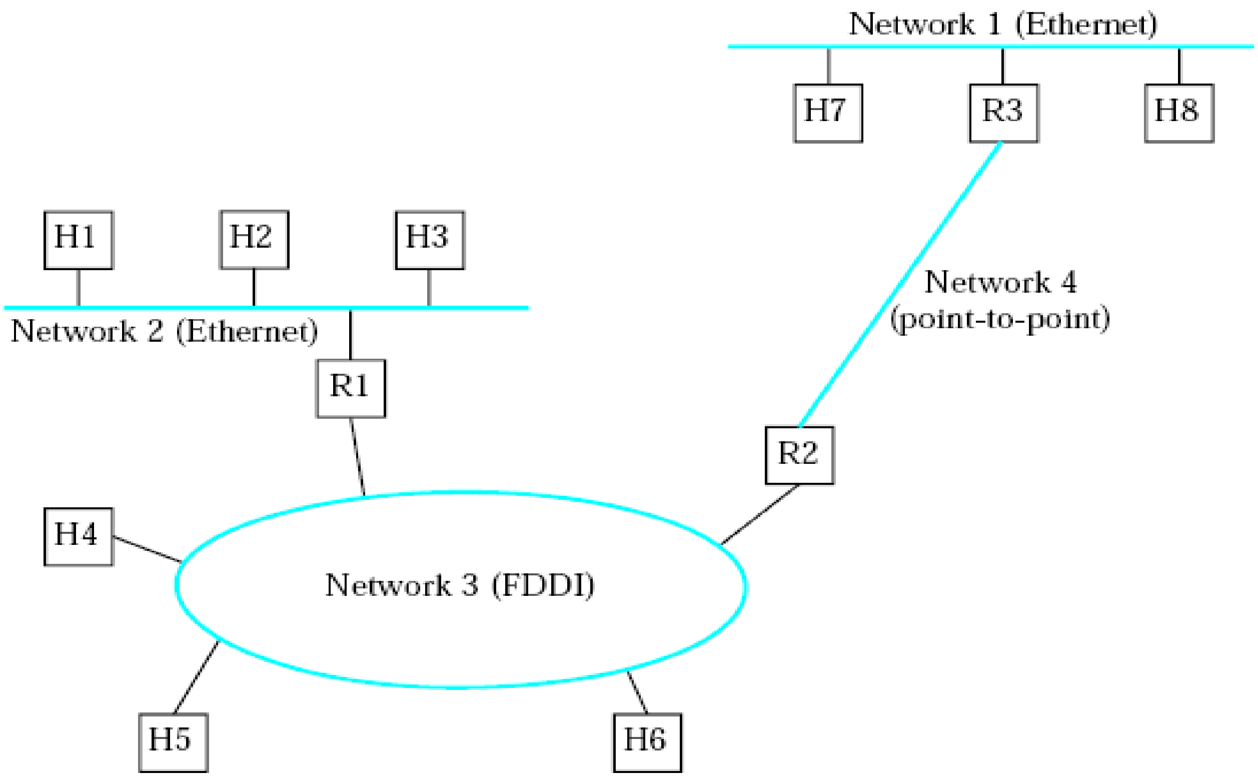
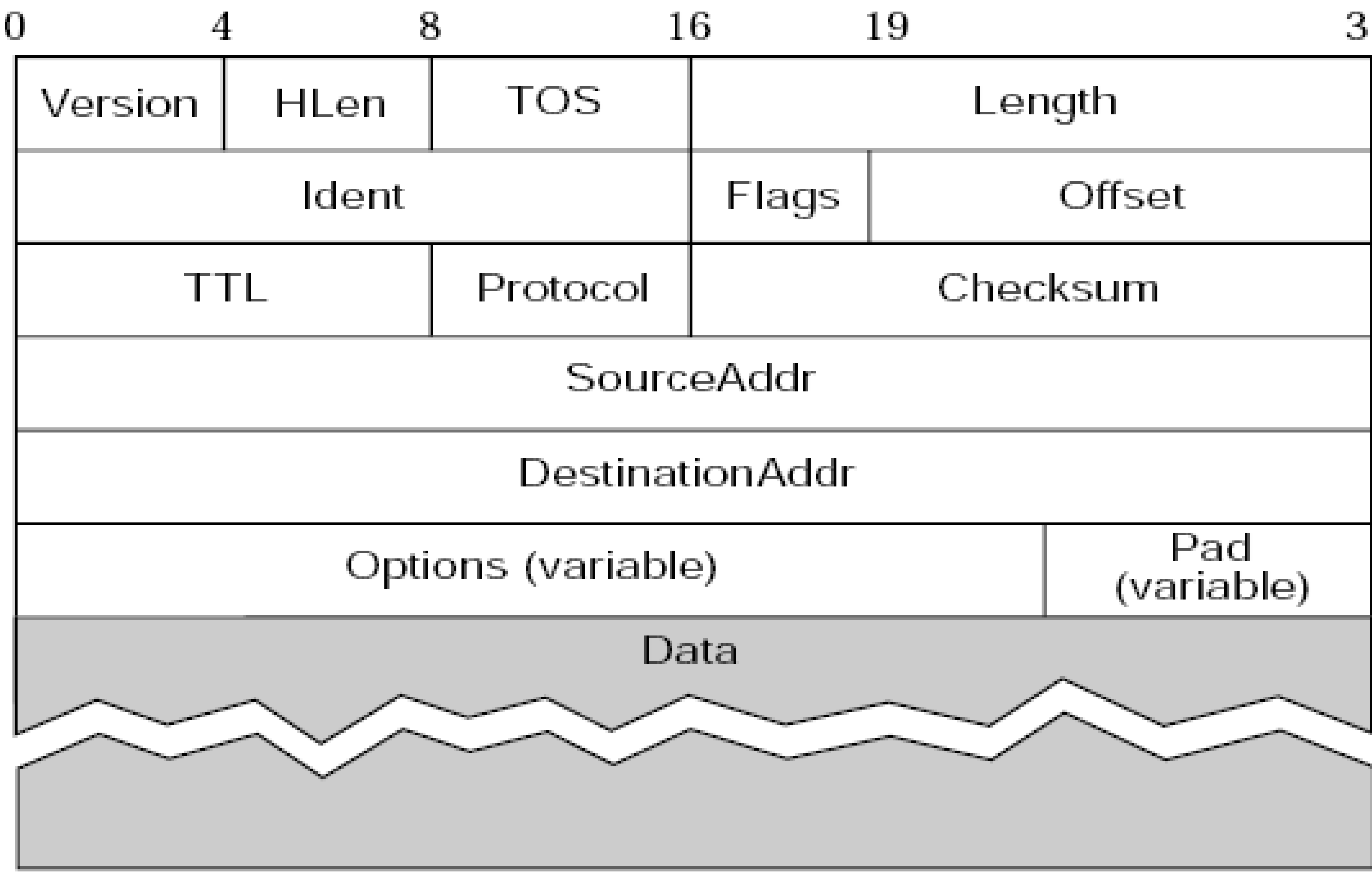



Figure 1: A simple Internetwork. Hn = Host; Rn = Router

# IPv4 Header


0
4
8
16
19
31
Version
HLen
TOS
Length
Ident
Flags
Offset
TTL
Protocol
Checksum
SourceAddr
DestinationAddr
Options (variable)
Pad (variable)
Data

# IPv4 Header (Contd.)

- Version: Version Number (4/6)
- Internet Header Length (IHL): Number of 32 byte words in the IP header
- Type of Service (TOS): Define the type of processing at intermediary node. (Shortest Path, Minimum Delay etc.)
- Length: Total number of bytes in IP packet including header.
- Identifier, Flag and Fragment offset are used for fragmentation and reassembly of IP packet.

# IPv4 Header (Contd.)

- Fragmentation and Reassembly example:
- Fragment the packet if packet sixe >MTU of the link.
- Identifier: Define a unique id for every fragment of the same datagram.
- Flag: Three flags bits are defined with the following usage:
  - First bit: Reserved (must be zero)
  - Second bit: Don’t Fragment (DF)
  - Third bit : More fragment (MF)
- Fragment offset are used for reassembly of fragmentations and mark the offset from the starting byte of the IP packet.

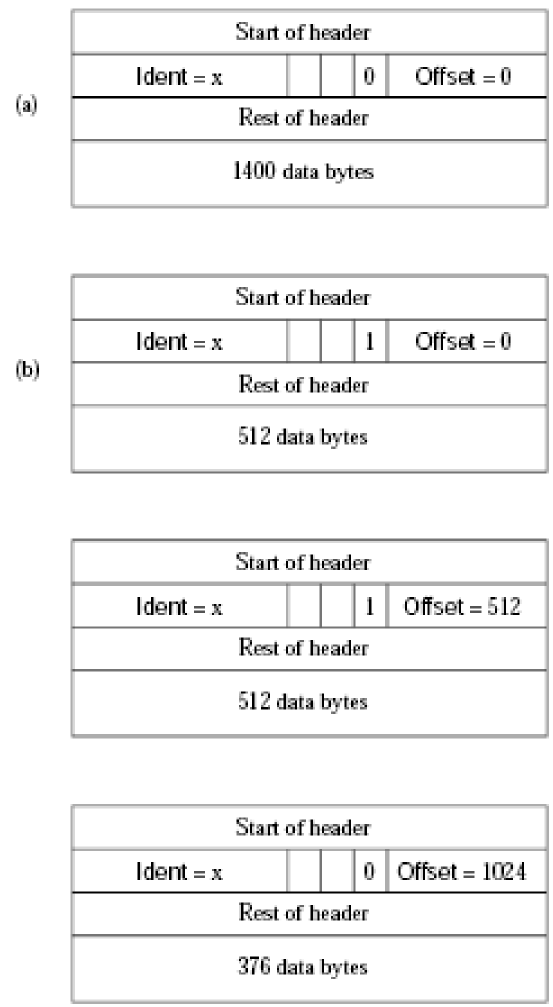
# IPv4 Header (Contd.)
# Fragmentation and Reassembly Example

- Suppose an IP packet contains 1400 bytes of data but the MTU of the outgoing link is 512 Bytes.
- Then 1400 bytes will be divided into smaller chunks: 512, 512, 376

| | | |
|---|---|---|
| The first packet will have the following parameters:<br>• Id: x<br>• MF: 1<br>• Offset: 0<br>• Date: 512 bytes | The second packet will have the following parameters: | The thirst packet will have the following parameters:<br>Id: x<br>MF: 0<br>Offset: 1024<br>Date: 376 bytes |

- After receiving all the chunks, the receiver will assemble the data and forward it to the upper layer protocol.
- Receiver gives up reassembly if all data segments do not receive at the receiver.

# IPv4 Header (Contd.)
# Fragmentation and Reassembly Example



# IPv4 Header (Contd.)

- TTL: number of hops after which the network will discard the packet. Hop count is decremented on each hop (forwarding).
- Protocol: The IP packet is containing data of which upper layer protocol. (TCP:6) (UDP:17)
- Header Checksum: Used for error detection
- Source Address: 32 bit IP address of source node.
- Destination Address: 32 bit IP address of destination node.

# IPv4 Address

- 32 bits long
- Identifier for host, router *interface*
- Notation:
  - Each byte is written in decimal in MSB order, separated by dots
  - Example: 128.195.1.80 stands for the 32-bit IP address

**10000000 11000011 00000001 01010000**

# Types of IPv4 Addresses

- Unicast Address
  - Destination is a single host
- Multicast address
  - Destination is a group of hosts
- Broadcast address
  - 255.255.255.255
  - Destination is all hosts

# Types of IPv4 Addresses

- IPv4 address are divided into classes
- IPv4 Address has an hierarchical structure.
- IP address can be divided into the following:
  - Net Id
  - Host ID
- IP address has the notion of subnet mask which helps to determine class of IP address and Net Id.

# Class A IP Addresses

| Class | 32 bits | | |
|---|---|---|---|
| A | 0 | Net Id (8 Bits) | Host ID (24 Bits) |

- Default subnet mask: 255.0.0.0
- Address range:
  - 0.0.0.0 – 127.255.255.255
- First 8 bits represent Net ID
- Rest 24 bits represent Host Id.
- For very large organizations
- 16 million hosts allowed in one network.
- Eg. 69.25.36.21 → Net ID: 64.0.0.0; Host ID: 0.25.36.21

# Class B IP Addresses

| Class | ← 32 bits → | | |
|---|---|---|---|
| B | 10 | Net Id (16 Bits) | Host ID (16 Bits) |

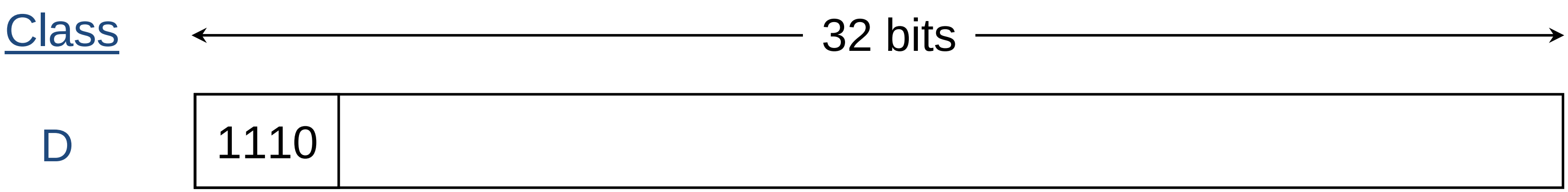
- Default subnet mask: 255.255.0.0
- Address range:
  - 128.0.0.0 – 191.255.255.255
- First 16 bits represent Net ID
- Rest 16 bits represent Host Id.
- For large organizations
- 65 thousand hosts allowed in one network.
- Eg. 169.25.36.21 → Net ID: 169.25.0.0; Host ID: 0.0.36.21

# Class C IP Addresses

| Class | 32 bits | | |
|---|---|---|---|
| C | 110 | Net Id (24 Bits) | Host ID (8 Bits) |

- Default subnet mask: 255.255.255.0
- Address range:
  - 192.0.0.0 – 223.255.255.255
- First 24 bits represent Net ID
- Rest 8 bits represent Host Id.
- For small organizations
- 255 hosts allowed in one network.
- Eg. 194.25.36.21 → Net ID: 194.25.36.0; Host ID: 0.0.0.21

# Class D IP Addresses




- No default subnet mask
- Address range:
  - 224.0.0.0 – 239.255.255.255
- Known as multicast address which means one address can represent a group of hosts.

# Class E IP Addresses

| Class | 32 bits | |
|---|---|---|
| E | 1111 | |

- Reserved Addresses
- No default subnet mask
- Address range:
  - 240.0.0.0 – 255.255.255.255
- Not usable for any one.

# Special Addresses

- 127.x.y.z: Loopback Address
- 255.255.255.255: Limited Broadcast Address

# Subnetting

- Add another level to address/routing hierarchy: *subnet*
- Subnet masks define variable partition of host part
- Subnets visible only within site

| Network number | Host number |
| --- | --- |

Class B address

| 111111111111111111111111 | 00000000 |
| --- | --- |

Subnet mask (255.255.255.0)

| Network number | Subnet ID | Host ID |
| --- | --- | --- |

Subnetted address

# Subnetting

Example: Class B address with 8-bit subnetting.
Now IP address will have Net ID, Subnet ID and Host ID

| | 16 bits | 8 bits | 8 bits |
|---|---|---|---|
| | Network id | Subnet id | Host id |
| Example Address: | 165.230 | .24 | .8 |

# Subnet Masks

Subnet masks allow hosts to determine if another IP address is on the same subnet or the same network

| | 16 bits | 8 bits | 8 bits |
|---|---|---|---|
| | Network id | Subnet id | Host id |
| Mask: | 1111111111111111 | 11111111 | 00000000 |
| | 255.255 | .255 | .0 |

# Problems with Class-based Addressing

- Too many small networks requiring multiple class C addresses.

- Running out of class B addresses, not enough nets in class A.

- Addressing strategy must allow for greater diversity of network sizes.

- IPv4 address space is running out, therefore, IPv6 came into existence with 128 bit address space.

# Subnet Mask

Assume IP addresses A and B share subnet mask M.

Are IP addresses A and B on the same subnet?

1. Compute logical AND (A & M).
2. Compute logical AND (B & M).
3. If (A & M) == (B & M) then A and B are on the same subnet.

Example: A and B are class B addresses

A = 165.230.82.52
B = 165.230.24.93
M = 255.255.255.0

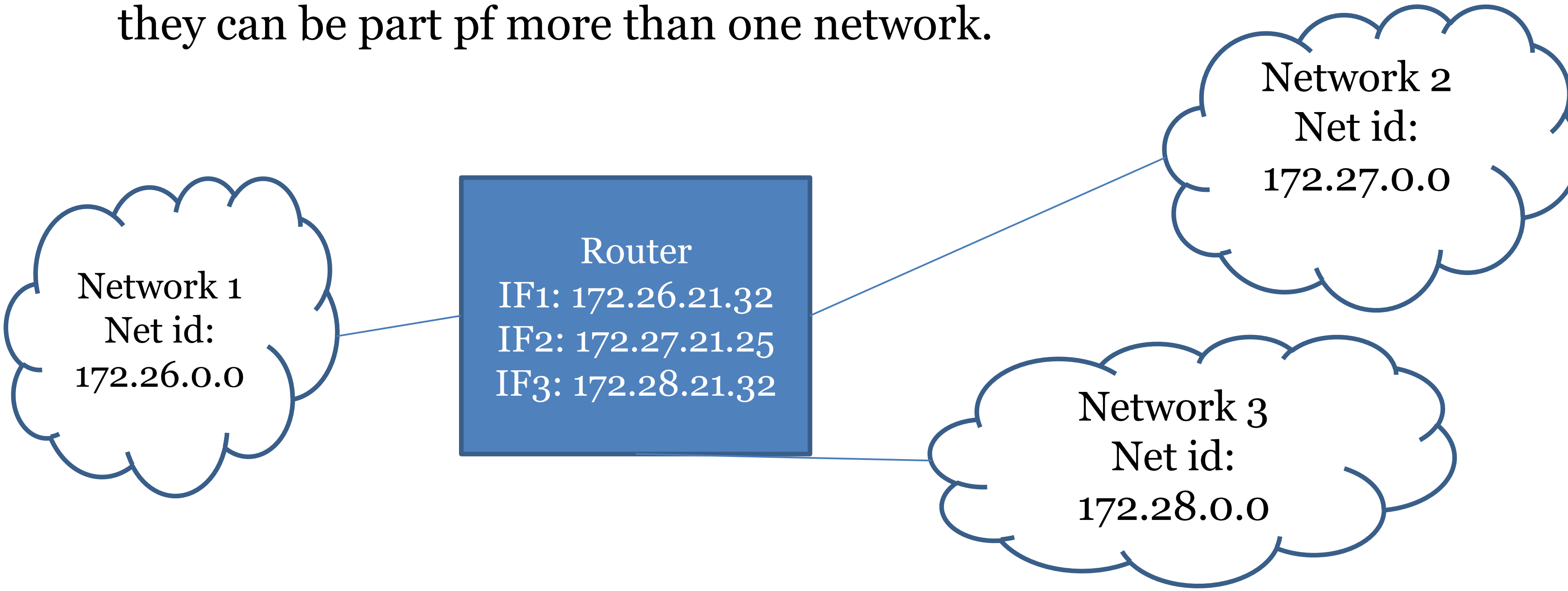
Same (classful) network?
Same subnet?

# Global Address vs Logical Address

- Global address are also known as the following names:
  - MAC address
  - Physical address
  - NIC address
  - Ethernet address etc.
  - Provided by IEEE 802.x standards where x=3, 4,….22.
- Logical addresses are provided by the following protocols:
  - IPv4
  - IPv6

# Router

- Routers are attached to two or more networks.
- Since they need to have an address on each network, therefore, they need more than one network interface (port).
- IP addressed are assigned to the interfaces rather than host so that they can be part pf more than one network.



# Routing vs Forwarding

- Forwarding is the process of taking a packet queue and forward it on a appropriate output interface.

Whereas

- Routing is the process of building and maintaining the routing /forwarding table that allows the correct output interface for the packet to be determined.

# Forwarding Algorithm

if (net id of the destination = net is of one of my interfaces)

then

deliver the packet to the destination on that interface.

else if (net id of the destination is in my forwarding / routing table)

then

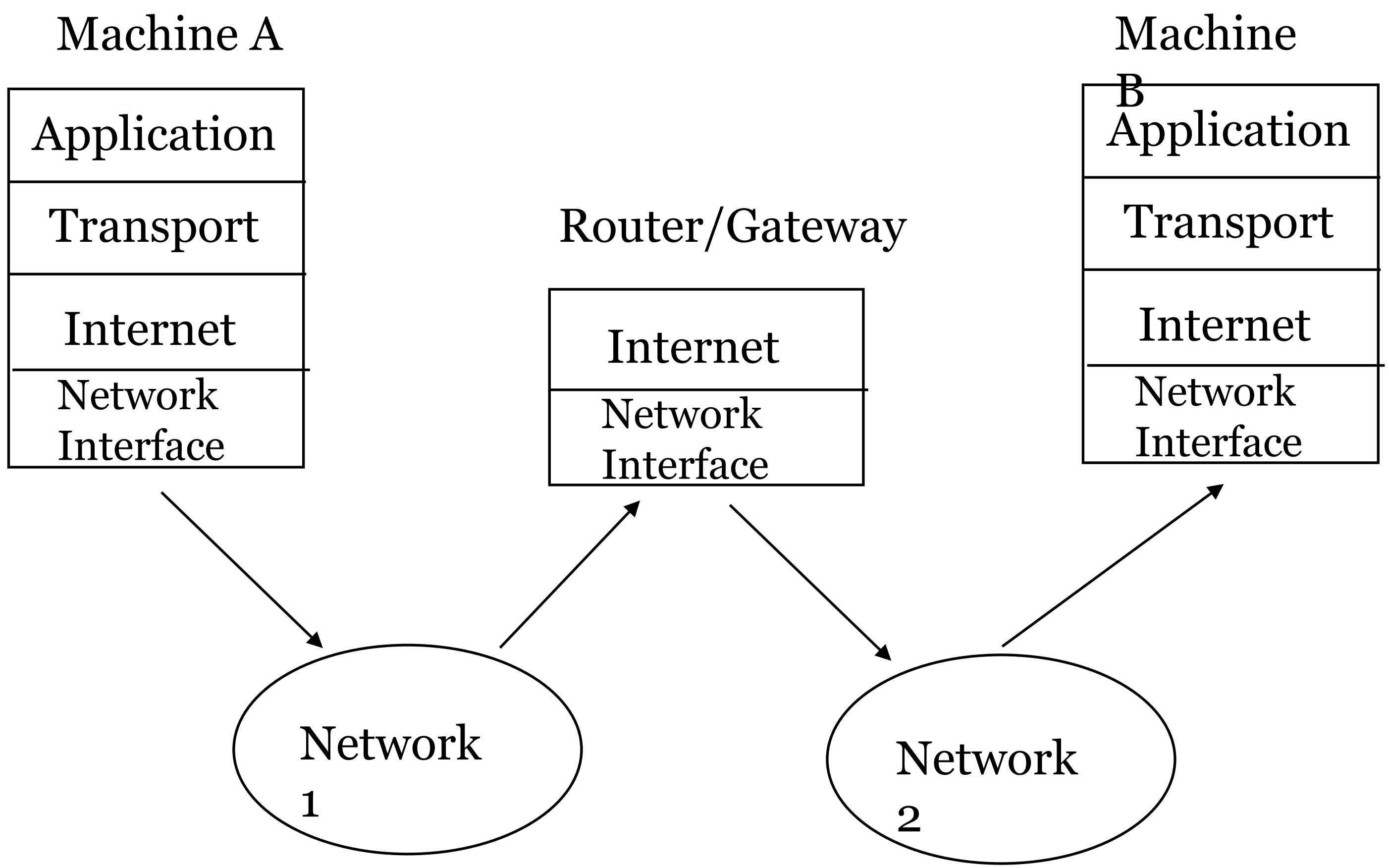
deliver the packet to next hop on the output interface.

else

deliver the packet to the default router.

# Routing Protocols

- Concerned with delivering a packets from source to destination.



# Routing Protocols (contd.)

- *Routing algorithms* are the part of the Network Layer responsible for deciding on which output interface /link to transmit an incoming packet.
- **Algorithm properties**: correctness, simplicity, robustness, stability, fairness, optimality, and scalability.
- Routing protocols visualize network as graph G (V,E) where V are the nodes of the network and E are the edges in the network representing links between the two nodes.
- V={v1, v2, v3, .....vn}
- E={(v1,v3),........}
- Autonomous system (domain): All the networks under a single administrative control.

| Routing Table | | |
|---|---|---|
| Destination Net Id | Next Hop | Cost |
| 172.23.0.0 | IF1 | 25 |
| 192.26.25.0 | IF7 | 12 |
| …. | … | … |