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COMPUTER NETWORKS AND INTERNET PROTOCOLS

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IIT KHARAGPUR

SANDIP CHAKRABORTY
COMPUTER SCIENCE AND ENGINEERING,
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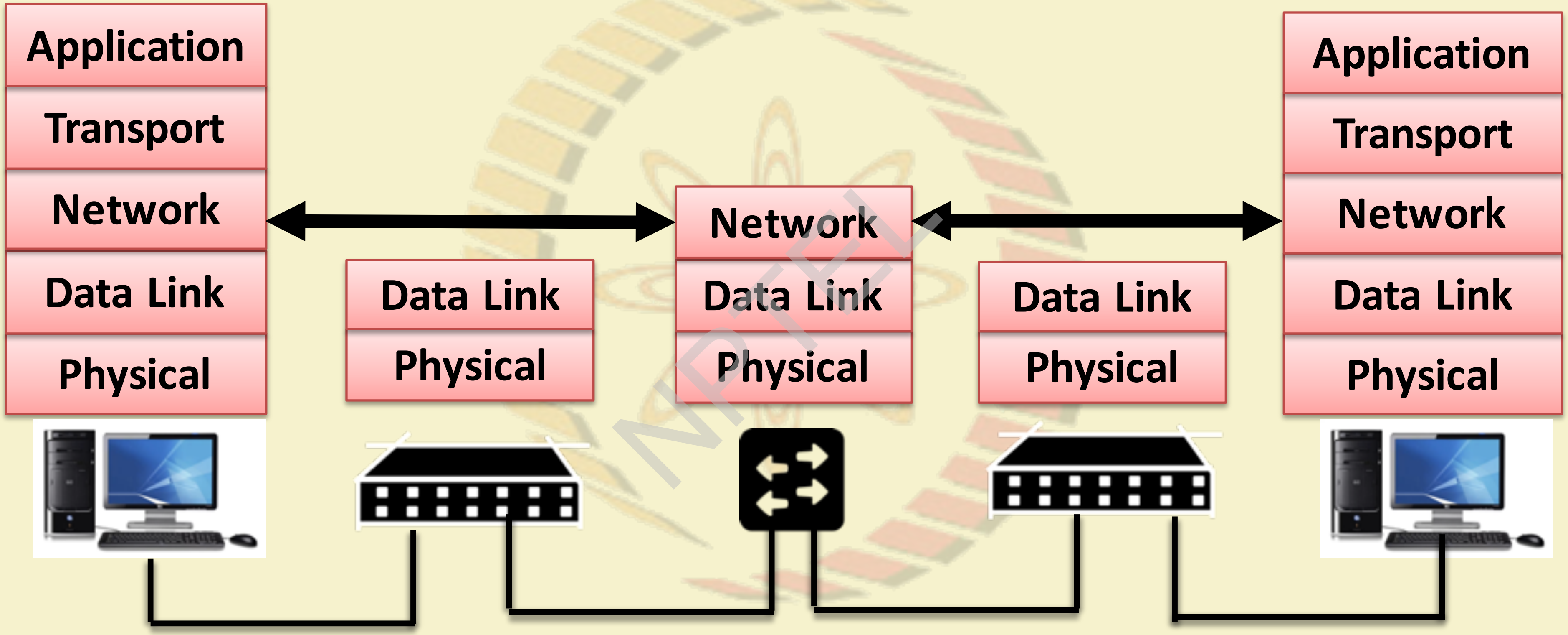
Network Layer I - Introduction



Network (Internet) Layer Services

End to end packet delivery

UDP

Connection Establishment

Reliable Data Delivery

Flow and Congestion Control

Ordered Packet Delivery

TCP

Transport

Addressing

Datagram delivery (unreliable)

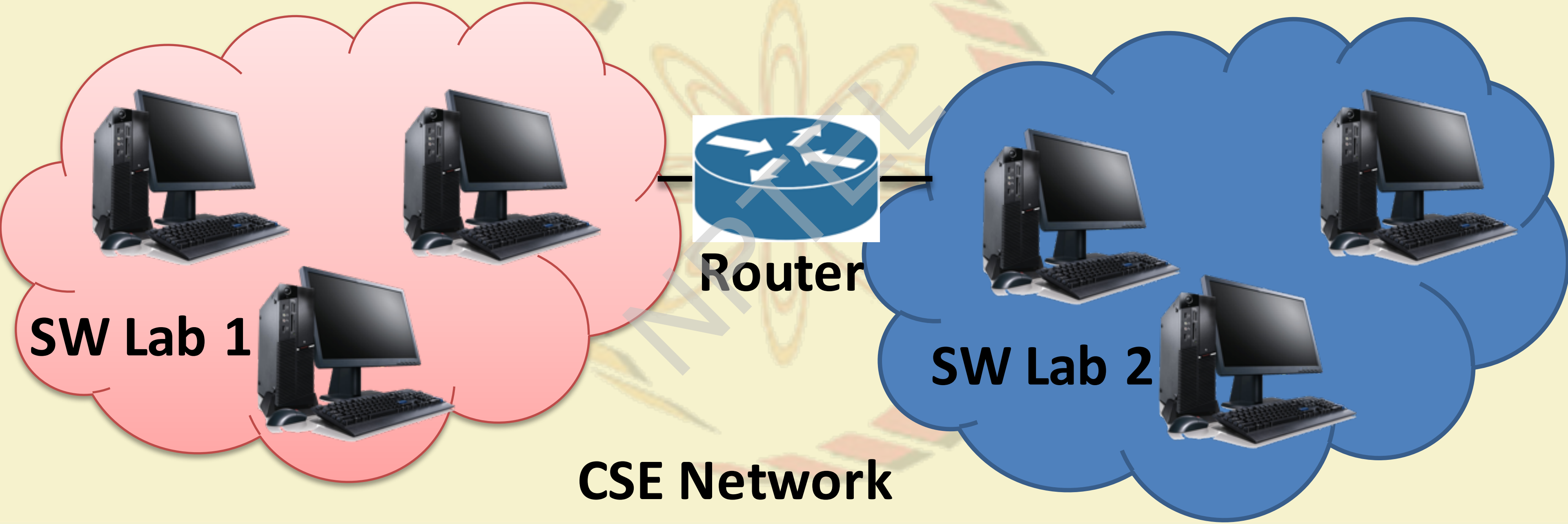
Routing

Network

Data Link

Internet Architecture – Basic Principles

- Internet is organized in a hierarchical fashion.



Internet Architecture – Basic Principles

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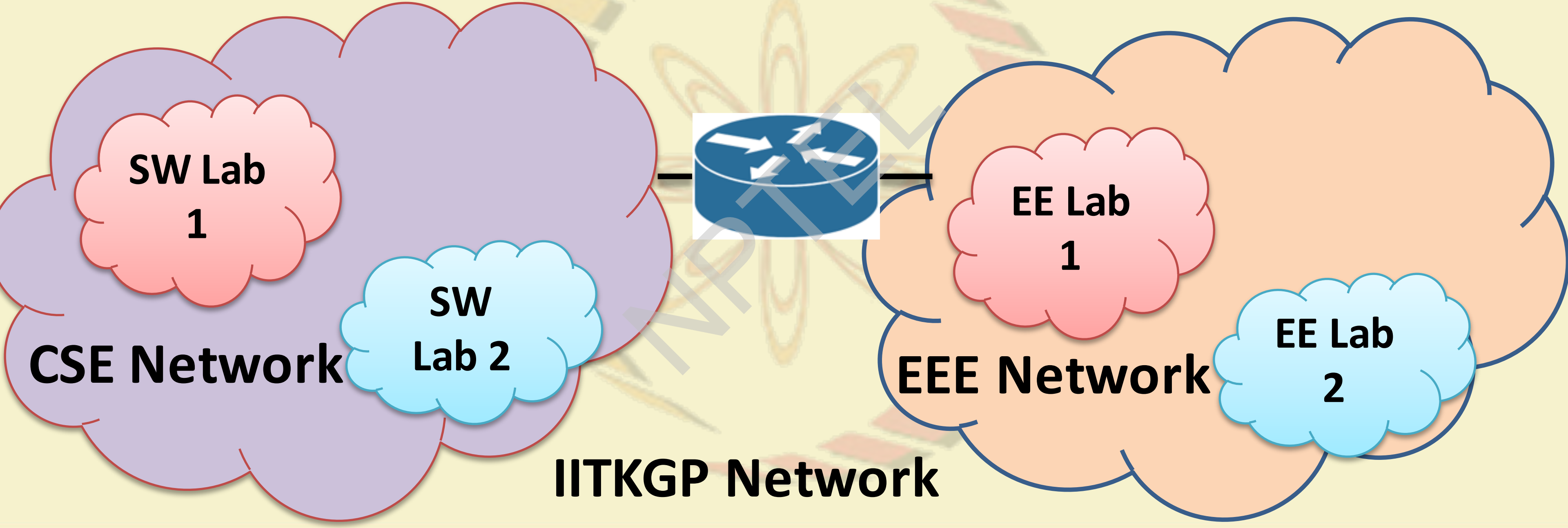
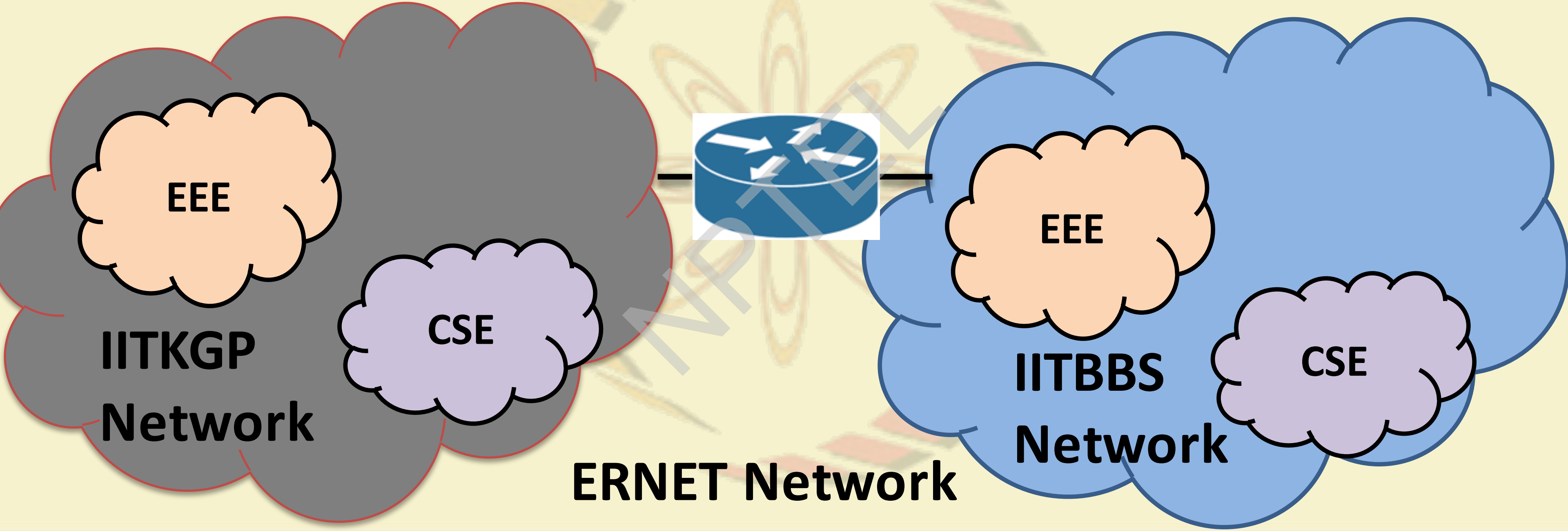


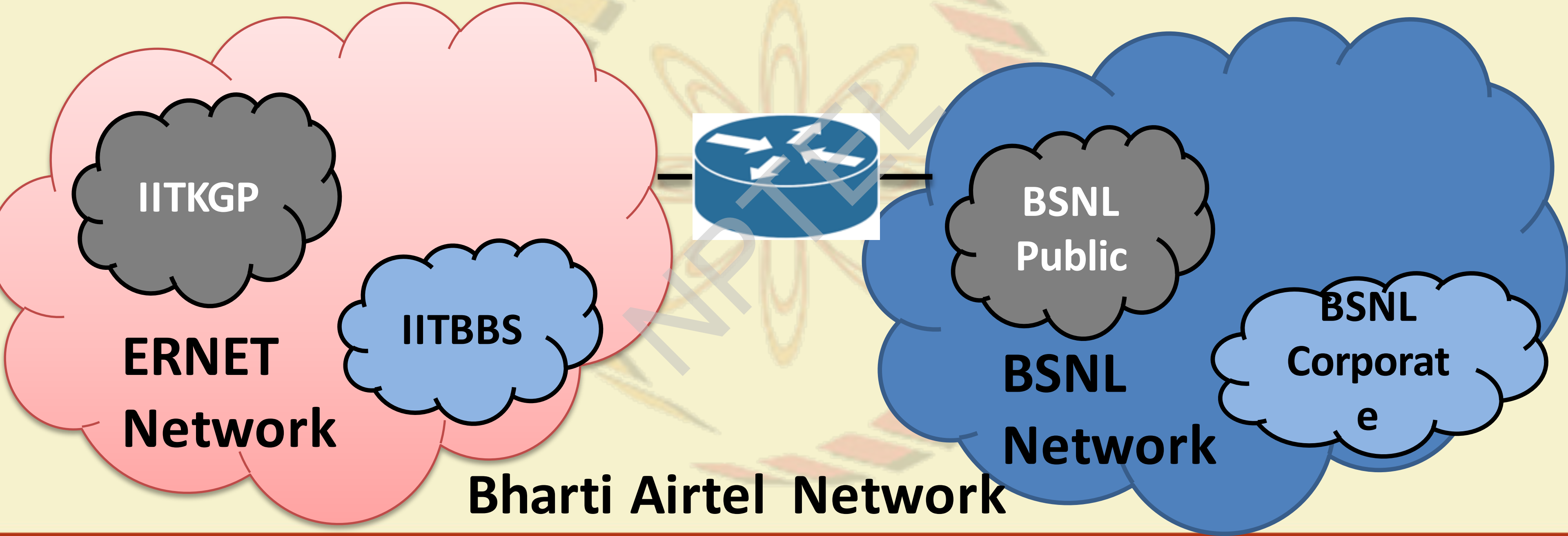
Internet Architecture – Basic Principles

- Internet is organized in a hierarchical fashion.



Internet Architecture – Basic Principles

- Internet is organized in a hierarchical fashion.



Internet Architecture

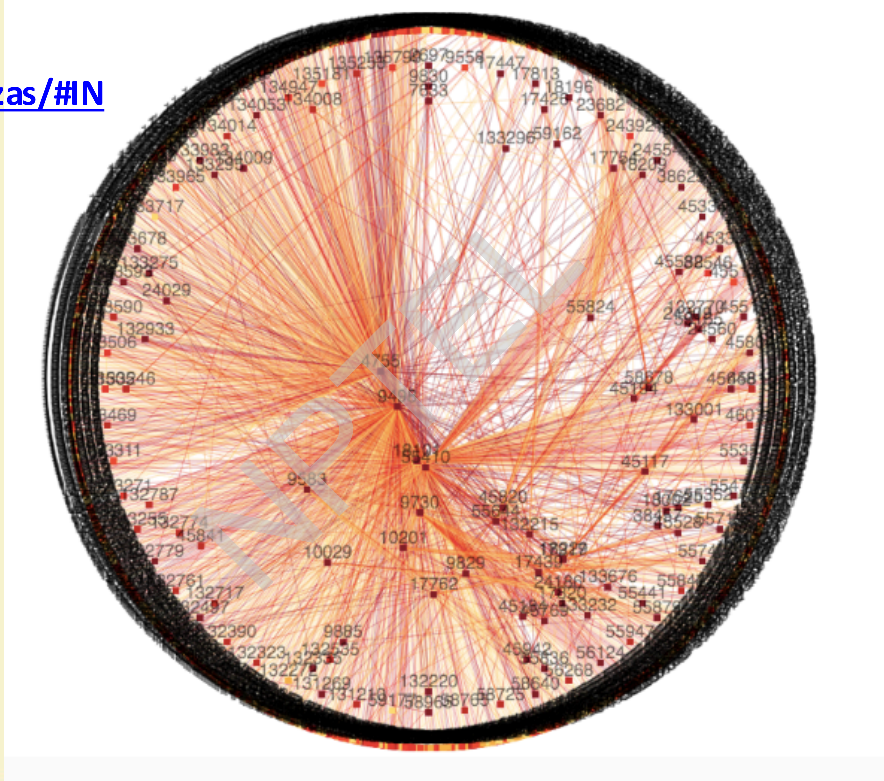
Autonomous Systems (AS) – A set of LANs for an administrative domain, identified by a unique AS number, and the routing policies are controlled by a single administrator.

Local Area Network (LAN) – A set of devices with a common layer 3 gateway

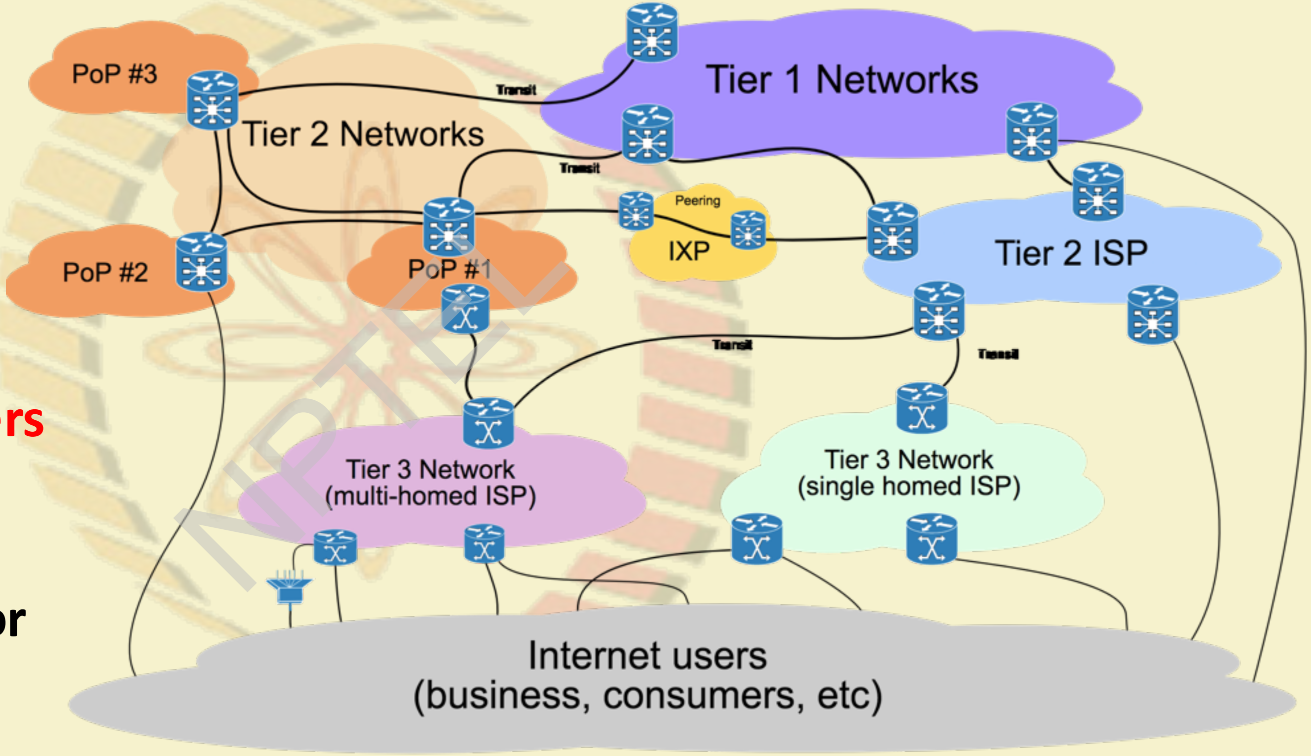
Internet Service Provider Hierarchy

Autonomous System Graph for India

Source: https://labs.apnic.net/vizas/#IN

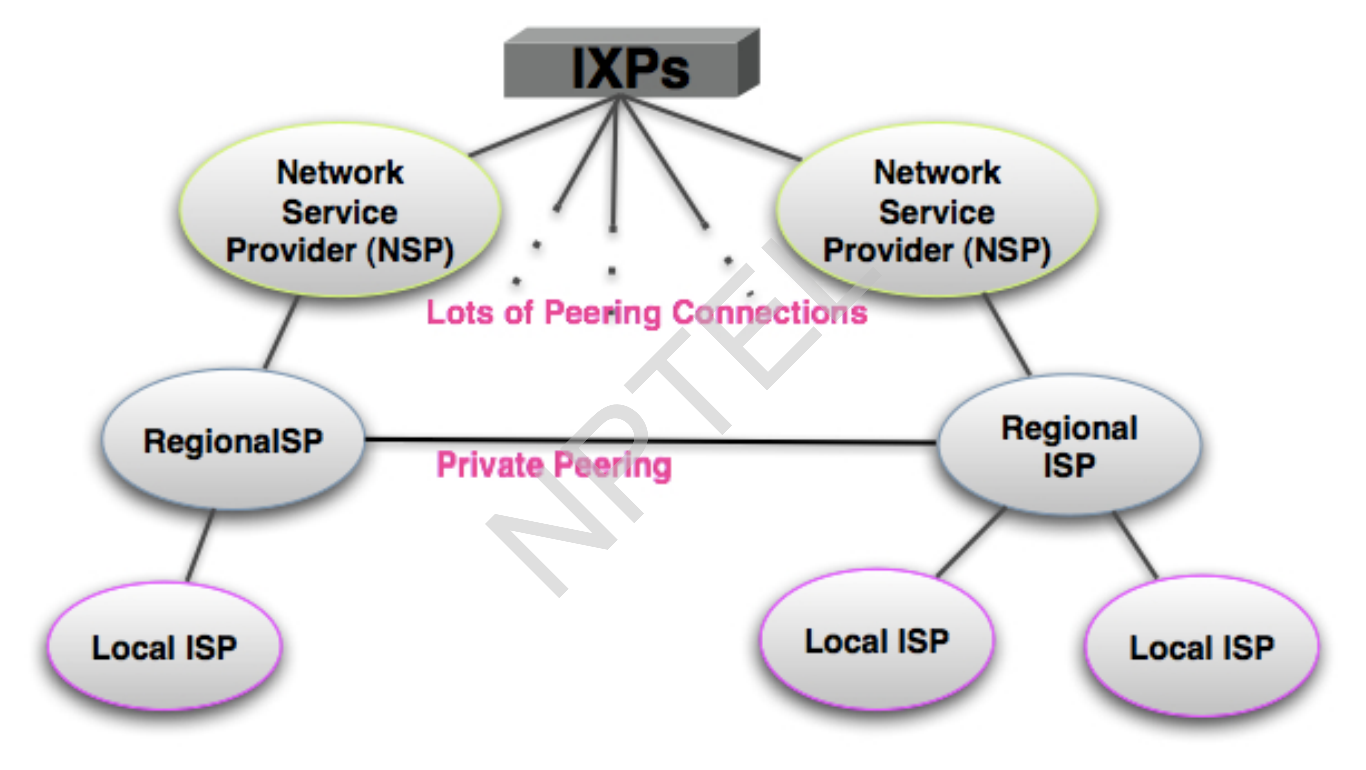


Internet Architecture

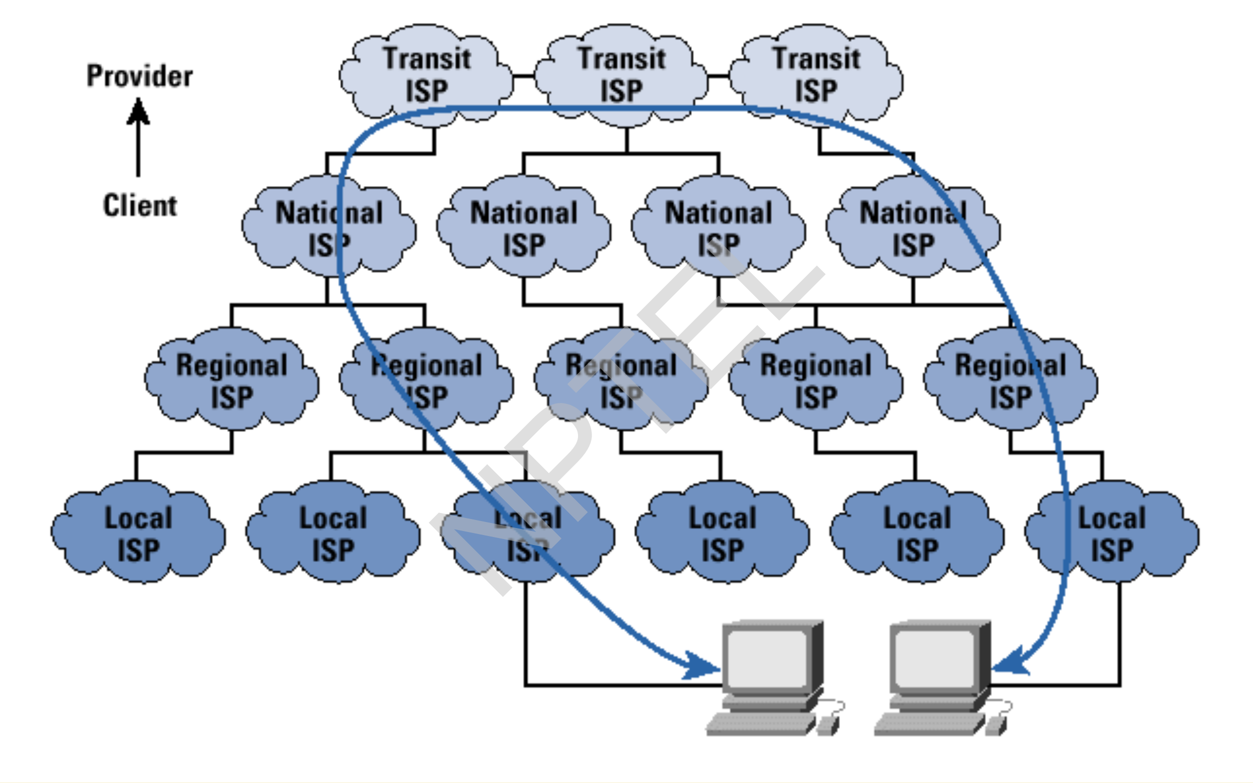


Internet Service Providers (ISP) – An AS provides Internet connectivity to another group of ASes or end users

Peering between ISPs

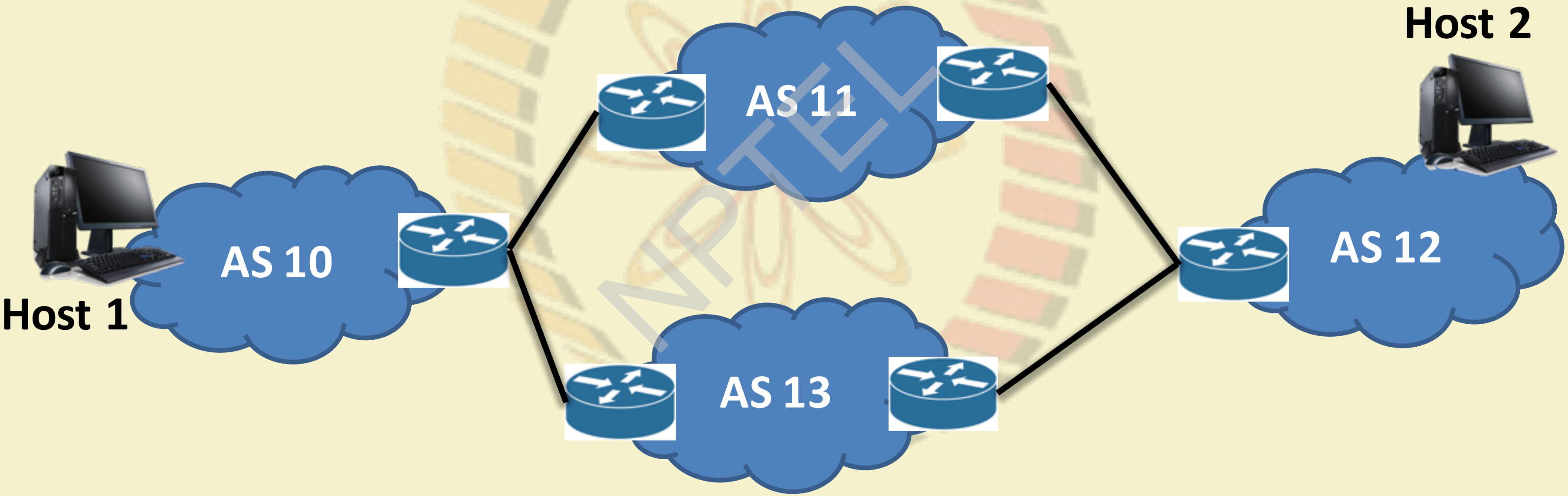


Communication between Two Nodes over ISPs



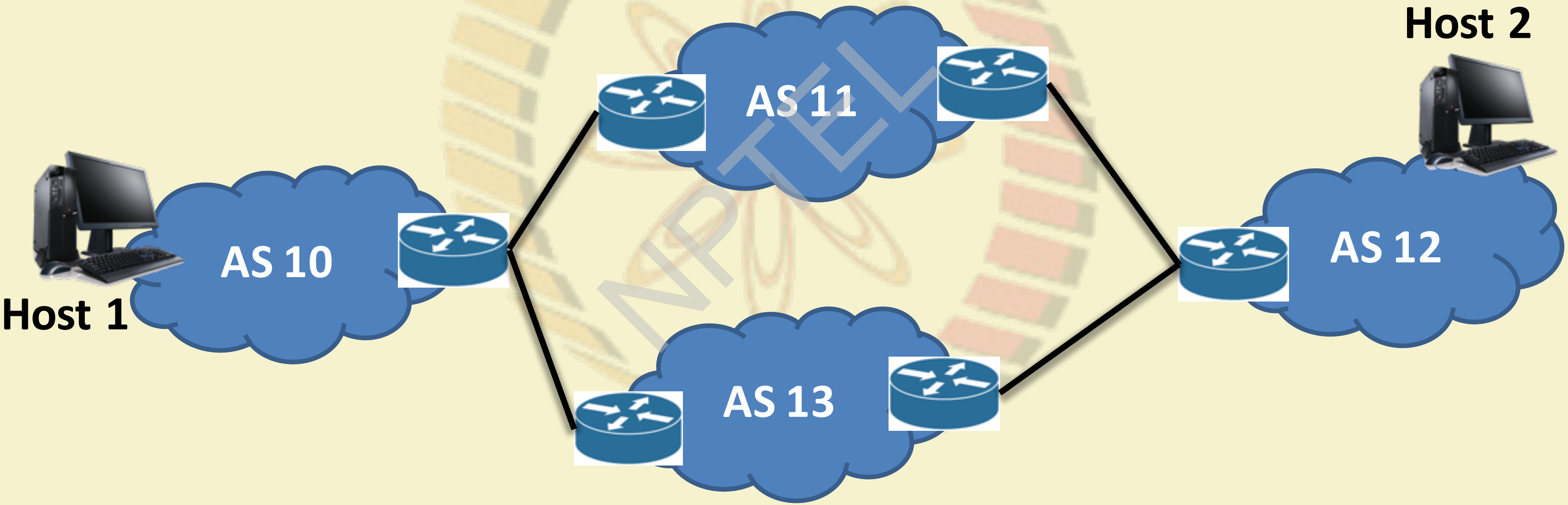
IP Addressing – Basic Principles

- We need to forward data packets from one network to another network via different intermediate networks.



IP Addressing – Basic Principles

- The address should identify a network as well as a host inside a network



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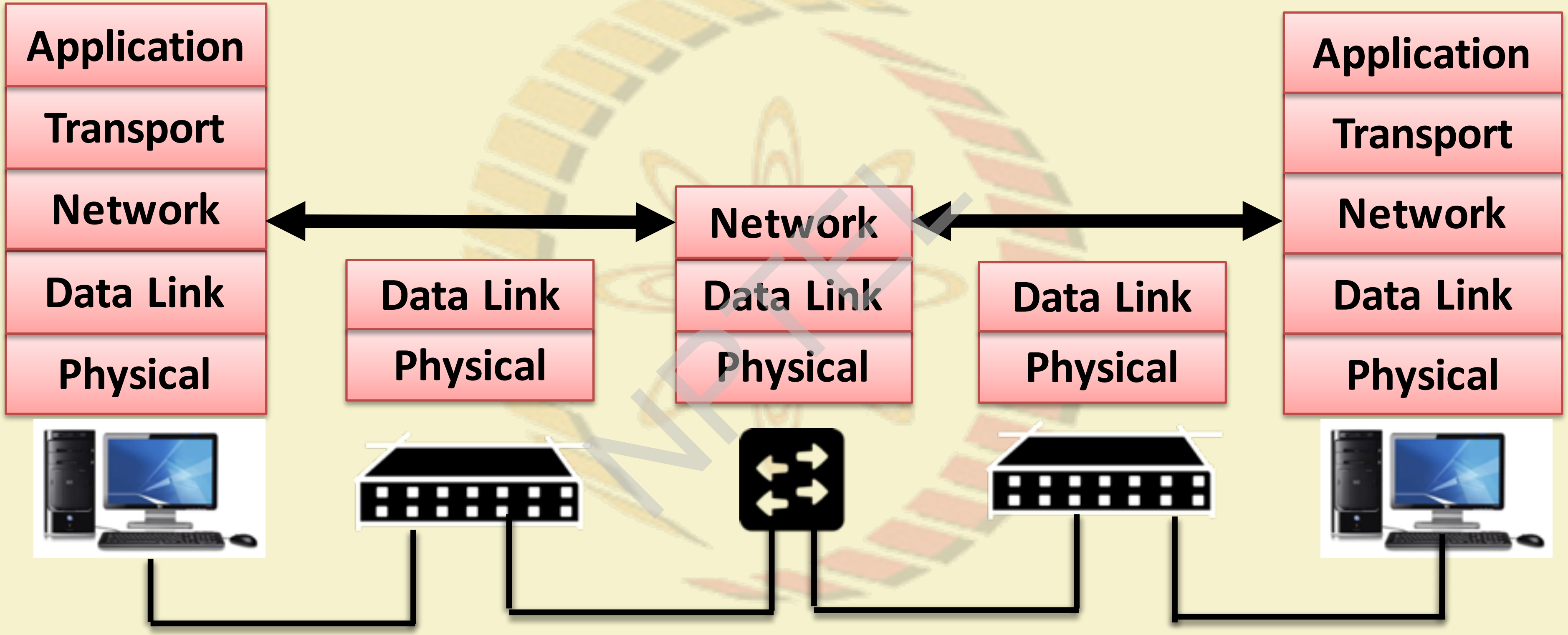
Network Layer II - IPv4 Addressing (Classful Addresses)



IP Addressing – Basic Principles

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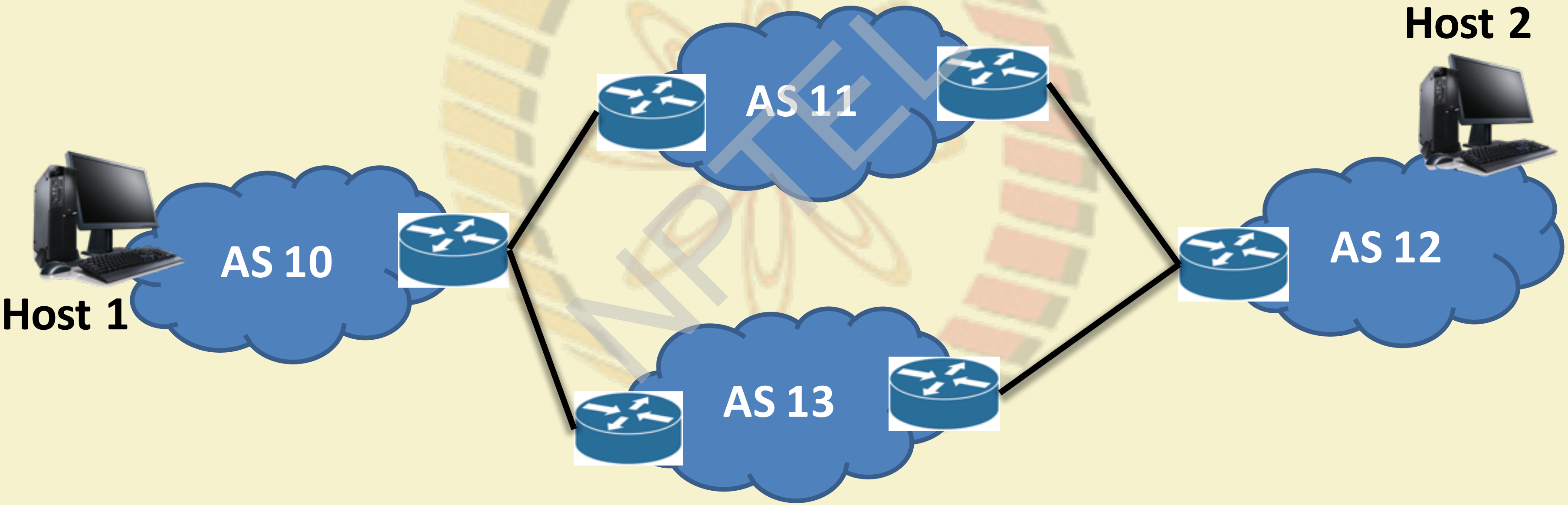
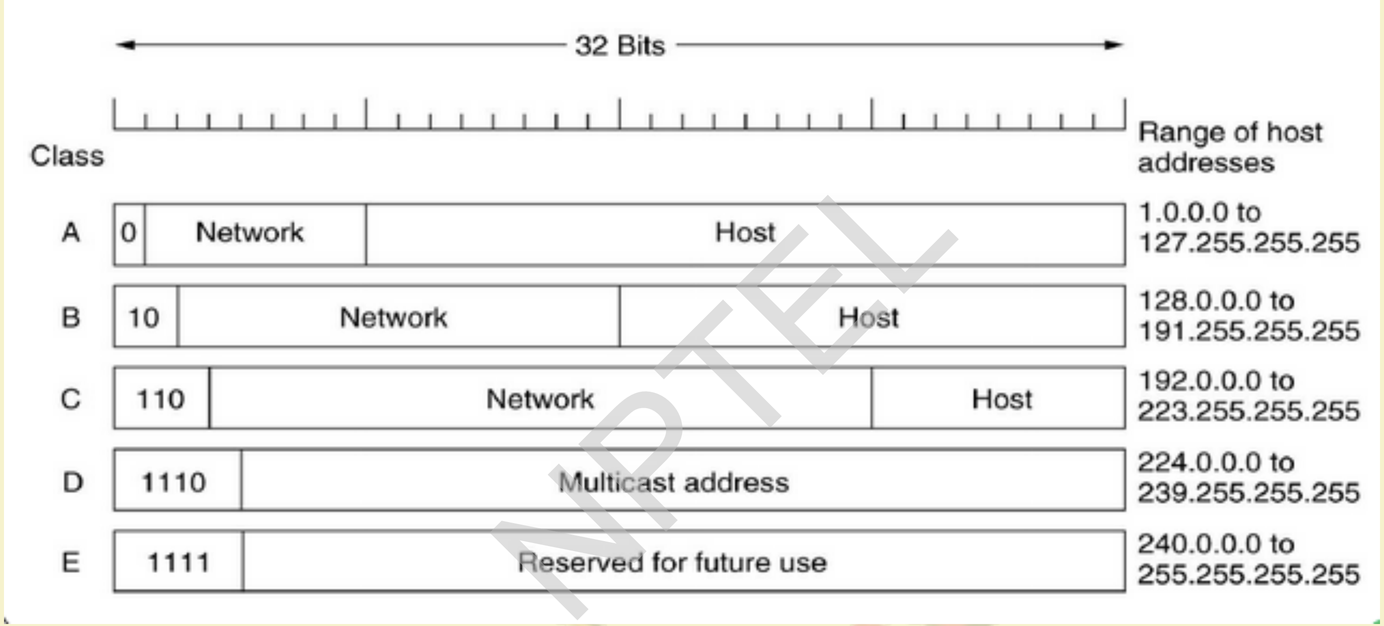


IP Addressing

Network address	Host address

- Divide the address space (32 bit in IPv4) among network address and host address
- **The old age – Classful addressing:** Fixed number of bits for network address and host address

Classful Addressing



- **How to identify a class –** use the first few bits
  - **0 – Class A, 10 – Class B, 110 – Class C, 1110 – Class D, 1111 – Class E**

Network Address and Broadcast Address

- **Network address –** identify a network
  - All 0's in the host address part
  - **Ex-1 (Class A):** 01111110.00000000.00000000.00000000 (126.0.0.0)
  - **Ex-2 (Class B):** 10111101.11101001.00000000.00000000 (189.233.0.0)

- **Broadcast address –** send the data to **all the hosts** of a network
  - All 1's in the host address part
  - **Ex-1 (Class A)**: 01111110.11111111.11111111.11111111 (126.255.255.255)
  - **Ex-2 (Class B):** 10111101.11101001.11111111.11111111 (189.233.255.255)

- **How many valid hosts can be there in a Class A, in a Class B and in a Class C IP address?**

Subnetting and Supernetting – Classless Inter-domain Routing (CIDR)

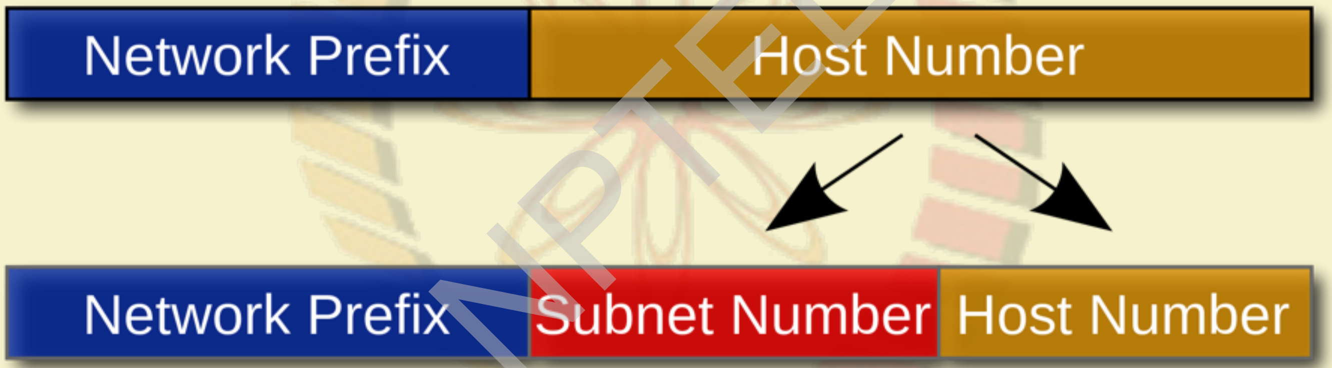
- **You have 255 hosts in a network. Which IPv4 address class will you use – Class C or Class B ?**
  - Class C – not possible
  - Class B – huge address space is lost (using only 255 addresses out of possible 2^{16}-2 addresses)

Subnetting and Supernetting – Classless Inter-domain Routing (CIDR)

- Split a large network or combine multiple small networks for efficient use of address space
  - **Subnetting** – divide a large network into multiple small networks
  - **Supernetting** – combine multiple small networks into a single large network

- **Subnet mask –** denote the number of bits in the network address field

Divide a Network into Subnets



CIDR – Addressing Format

IP Address	10111111	10110100	01010011	11101011
Netmask	11111111	11110000	00000000	00000000

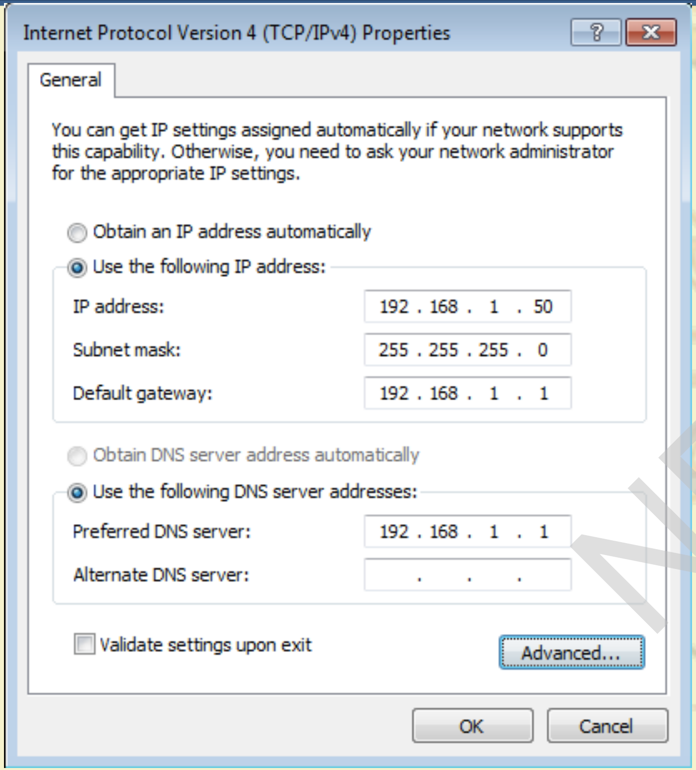
Subnet Address | Host Address

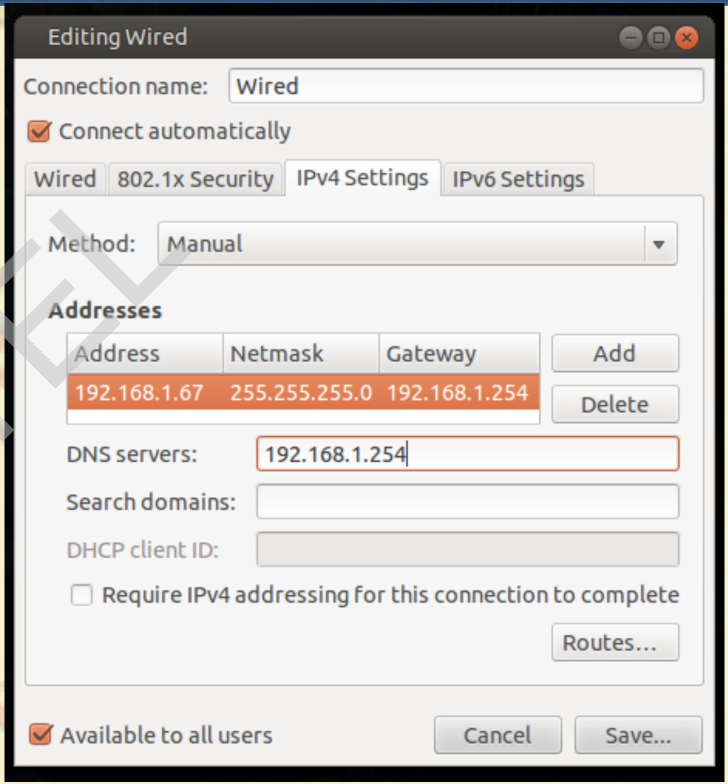
CIDR – Addressing Format

- We write the IP address as 191.180.83.235/12 in CIDR notation
  – The first 12 bits are the network address and rest (32-12)=20 bits are for host address

- The subnet mask is 255.240.0.0

CIDR - Manual IP Setting in the OS





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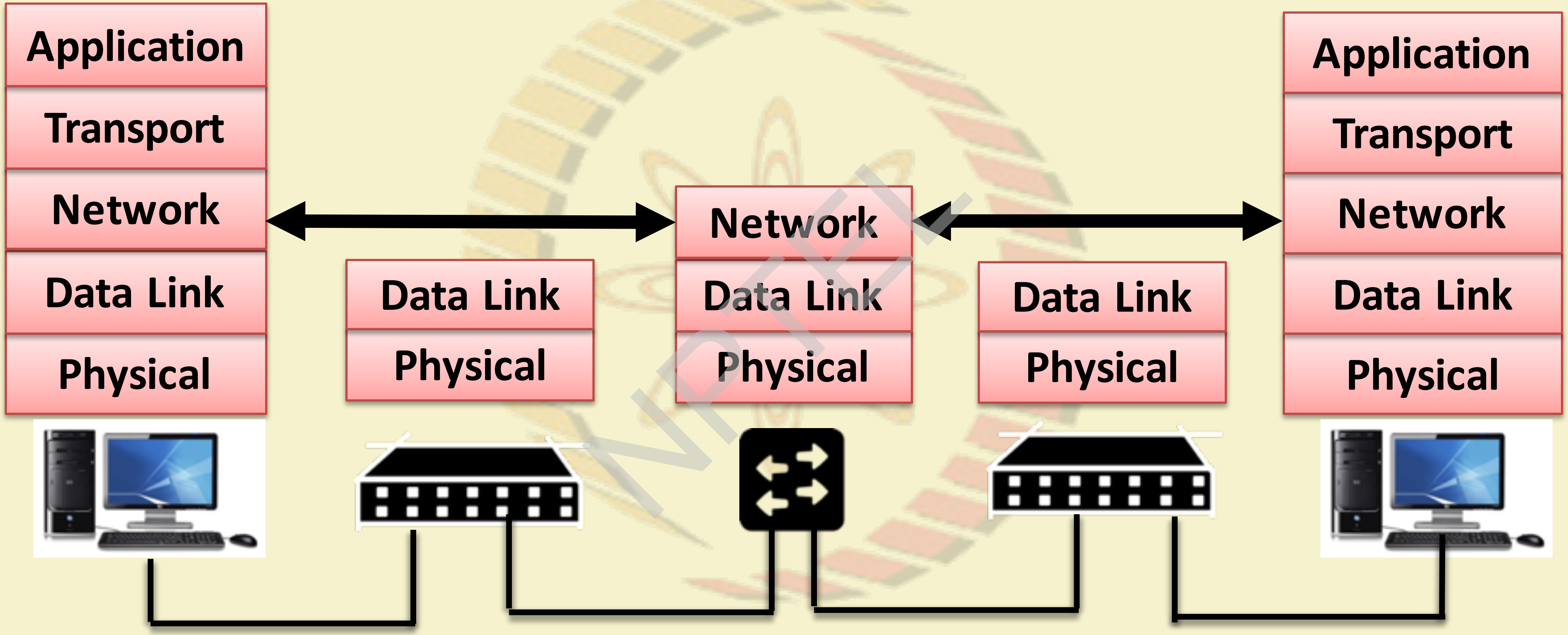
Network Layer III - IPv4 Addressing (CIDR)



CIDR – Addressing Format

IP Address	10111111	10110100	01010011	11101011
Netmask	11111111	11110000	00000000	00000000

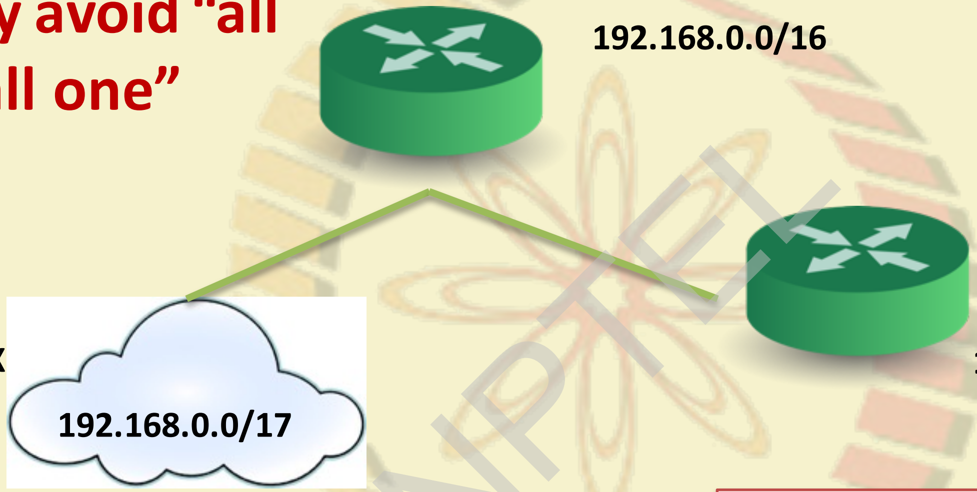
Subnet Address | Host Address

Divide a Network into Subnets

- Let the IP address of a network is 203.110.0.0/16
- We want to divide this network into three subnets
- We need 3 bits for subnets – **why not 2 bits?**
  - Subnet 1 – 100, Subnet 2– 101, Subnet 3 – 110
- Rest 13 bits are used for addressing the hosts of those subnets.
- The subnets are – 203.110.128.0/19, 203.110.160.0/19, 203.110.192.0/19

All Zero and All One Subnets

We normally avoid "all zero" and "all one" subnets.



The network address for the subnet and the original network is identical – **Subnet Zero**

Broadcast address for this subnet is 192.168.255.255, broadcast address for the original network is also 192.168.255.255 – **All-One Subnet**

CIDR Example

CIDR Example

CSE – 2000 Hosts

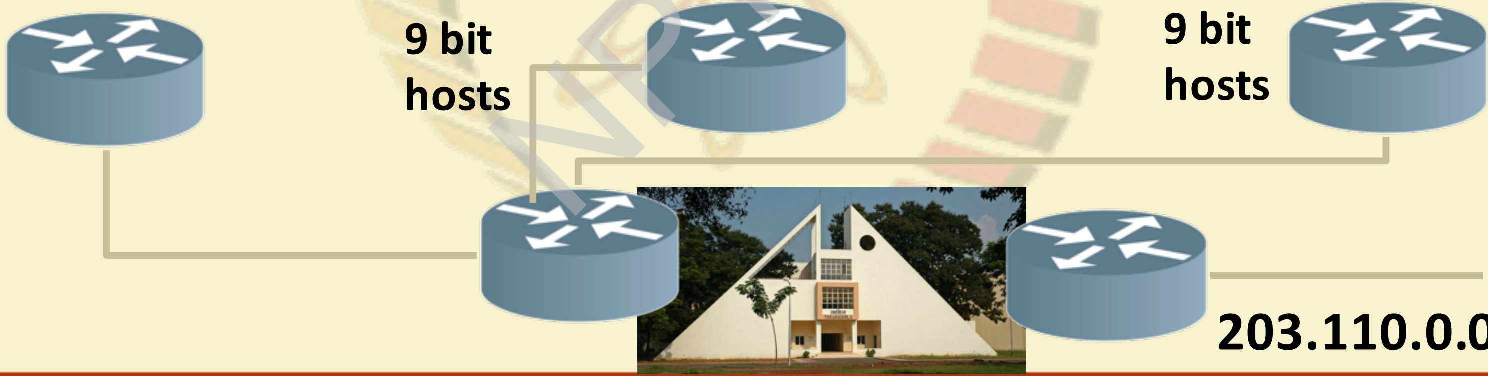
VGSOM – 500 Hosts

EE – 500 Hosts

11 bit hosts

9 bit hosts

9 bit hosts



203.110.0.0/19

CIDR Example

- Address space – 203.110.0.0/19
  - 13 bits are available to serve all the hosts of IITKGP network
  - We need to divide these address space among 3 subnets

- CSE – 11 bits, VGSOM – 9 bits, EE – 9 bits for host address

- We have 2 bits left for identifying three subnets **– Is this possible?**
  - Avoid “all zero” and ”all one” subnets

- Let us apply CIDR – Combine VGSOM and EE Networks together

CIDR Example

CIDR Example

CSE – 11 bits, VGSOM+EE – 10 bits

- Network address – 203.110.0.0/19, 203.110.000**XX**XXX.XXXXXXXX
- CSE network address 203.110.00010XXX.XXXXXXXX (203.110.16.0/21)
- VGSOM+EE network address 203.110.00001XXX.XXXXXXXX (203.110.8.0/21)

CIDR Example

CIDR Example

VGSOM – 9 bits, EE – 9 bits

- Network address – 203.110.8.0/21, 203.110.00001XXX.XXXXXXXX
- VGSOM network address 203.110.0000110X.XXXXXXXX (203.110.12.0/23)
- EE network address 203.110.0000101X.XXXXXXXX (203.110.10.0/23)

CIDR Example

thank you!

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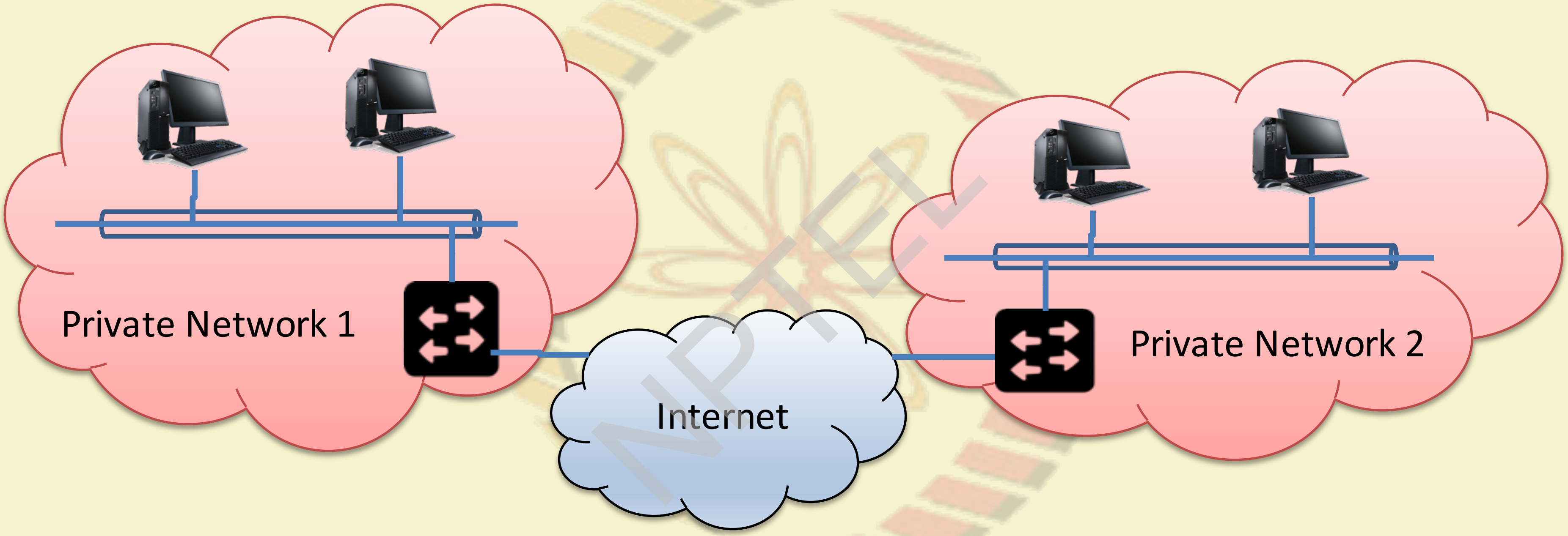
Network Address Translation (NAT)



Issues with IPv4 Addressing

- The address space is limited - number of devices (networking equipment) are increasing exponentially.

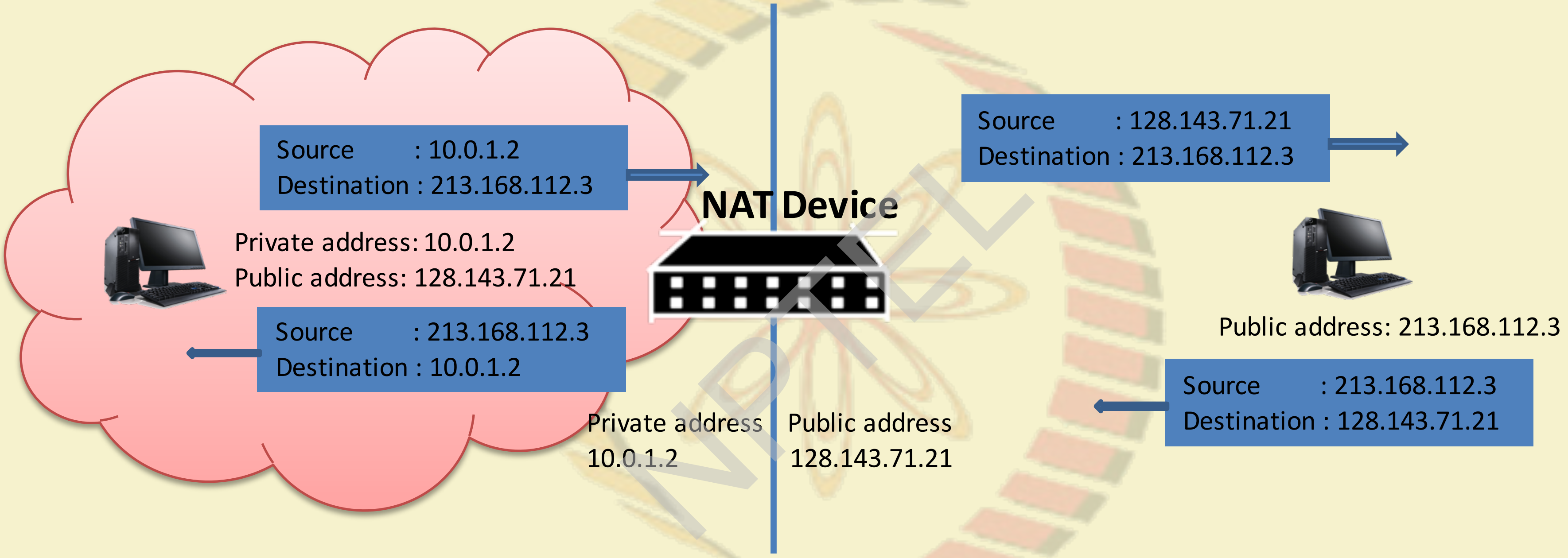
- A large number of addresses are wasted or remain unutilized (Class D or Class E).

- **Solution:** Make the address reusable, leveraging on the fact that not all users or all devices will connect to the Internet at the same time.

Network Address Translation (NAT)

- Divide addresses into reusable (private) and non-reusable (public) blocks
- Translate internal (private) addresses to external (public) addresses
- Hide internal machines from external devices
- Allow Internet access to large number of users via few public addresses
  - IPv4 private address
    - 10.0.0.0-10.255.255.255
    - 172.16.0.0-172.32.255.255
    - 192.168.0.0-192.168.255.255

Basic Operation of NAT



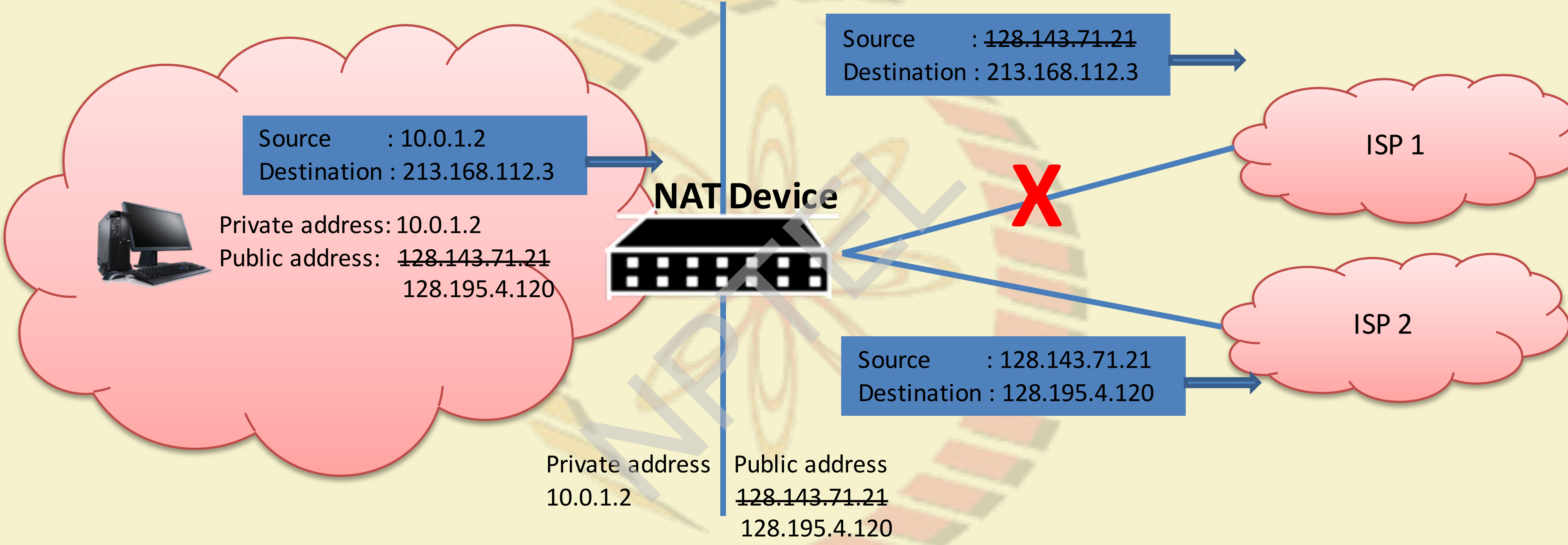
Working Principles of NAT

- Organizations manages internal private network
- NAT boxes manages a pool of public IP address
- For outgoing connections, NAT boxes selects one of the IP address from its pool, and forward packet from that IP

Migration between ISPs

- An organization can connect to multiple ISPs for better reliability
- NAT allow easy interchange between ISPs by changing IP addresses in NAT boxes
  - Without NAT, every internal system address need to be changed to reflect the network IP of the ISP
- NAT box can be configured to use alternative ISPs in case of a failure

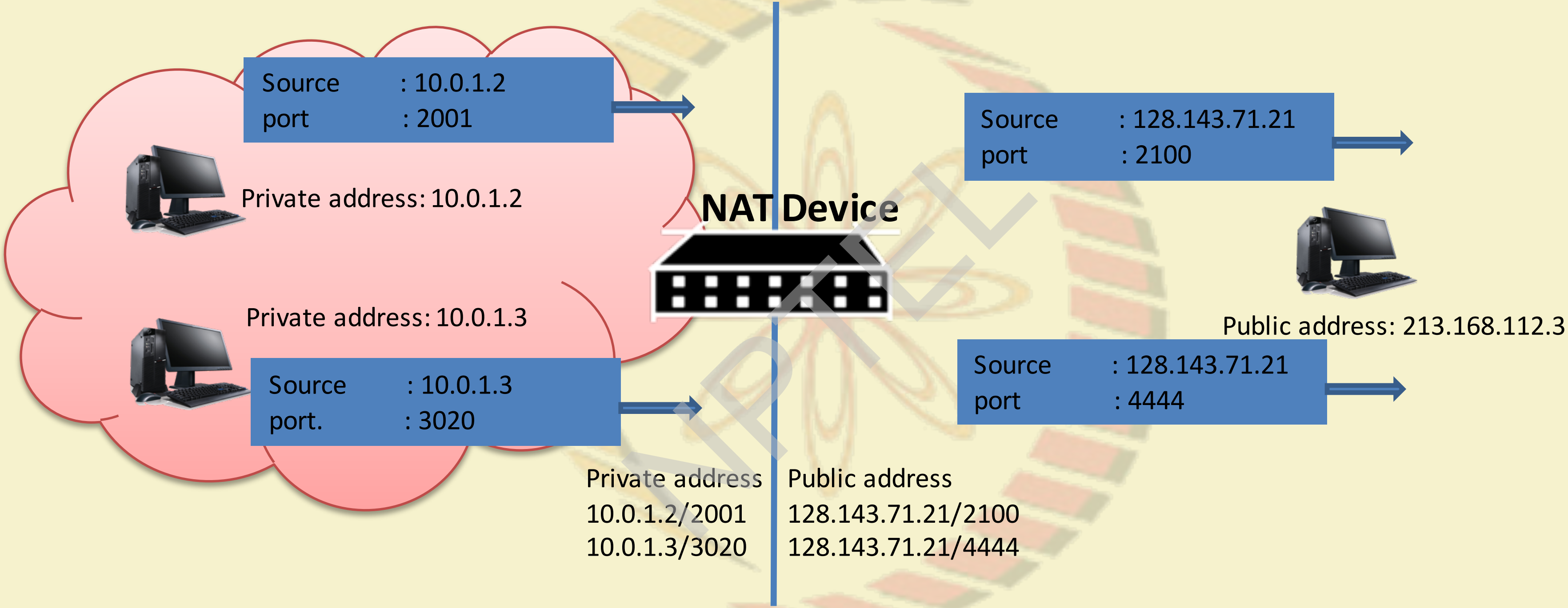
Migration between Network Service Provider



IP Masquerading

- Single public IP address is mapped to multiple hosts
- NAT box modify port address and replace private IP address to public IP address
  - Keep mapping in a table to forward incoming packet to proper internal host

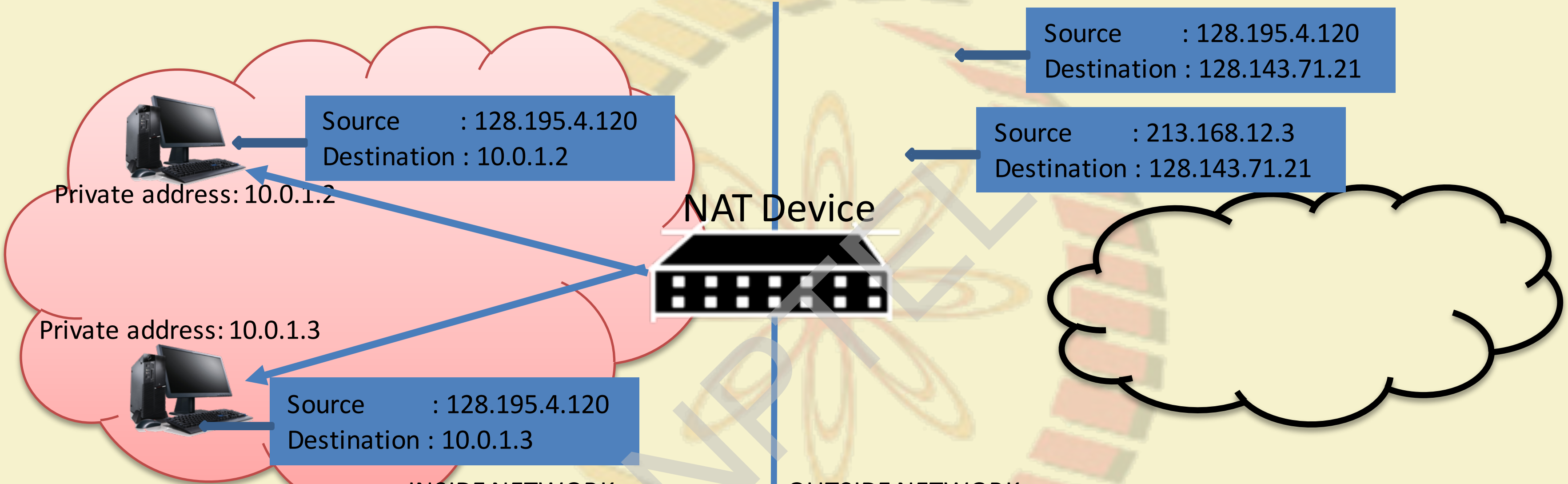
IP Masquerading



Load Balancing of Servers

- Balance the load of multiple identical server accessible from a single IP address
- NAT box translate different incoming connection to different internal IP address to balance load between server
- Internal systems are configured with private addresses

Load Balancing of Servers



INSIDE NETWORK		OUTSIDE NETWORK
Private address	Public address	Public address
10.0.1.2	128.143.71.21	128.195.4.120
10.0.1.3	128.143.71.21	213.168.12.3

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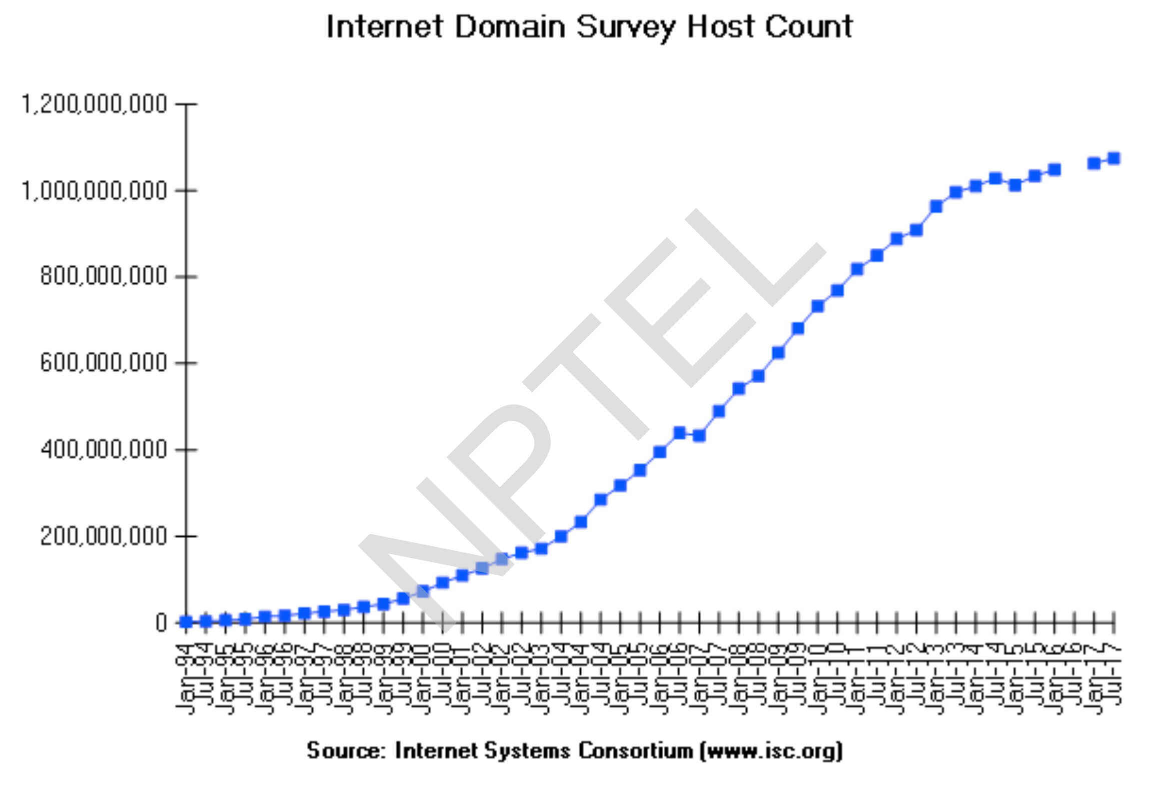
Internet Protocol Version 6 (IPv6)



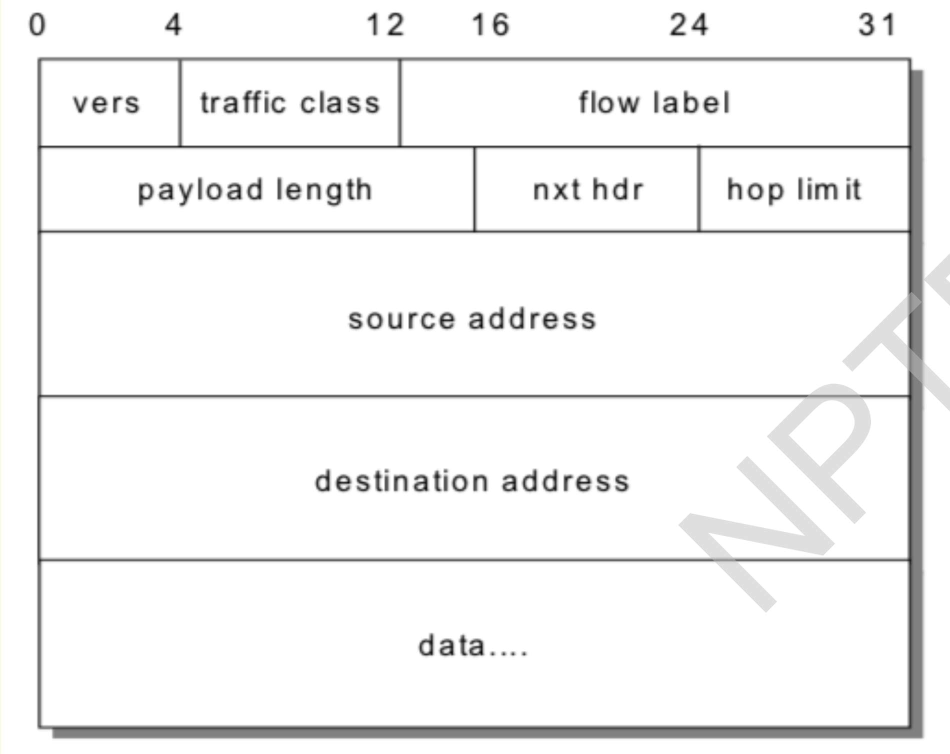
Why do We Need a New IP Structure?

- Address space is not sufficient even with CIDR.
- QoS is vaguely defined - need real time service support for modern-day applications
- Mobile applications are unmanageable
- There is no direct security support in IPv4

IPv6 Features

- Larger address space
- Globally unique and hierarchical addressing
- Optimized routing table using prefixes rather than address classes
- Auto-configuration of network interfaces
- Support for encapsulation
- Service class support to manage QoS classes
- Built-in authentication and encryption
- Compatibility with IPv4

IPv6 Header Format



- 128 bit source address and destination address

Image Source: IBM Redbook, TCP/IP Protocols and Technical Overview

Extension Headers

- Additional information are transmitted through the extension headers.
- The base header points to the extension headers

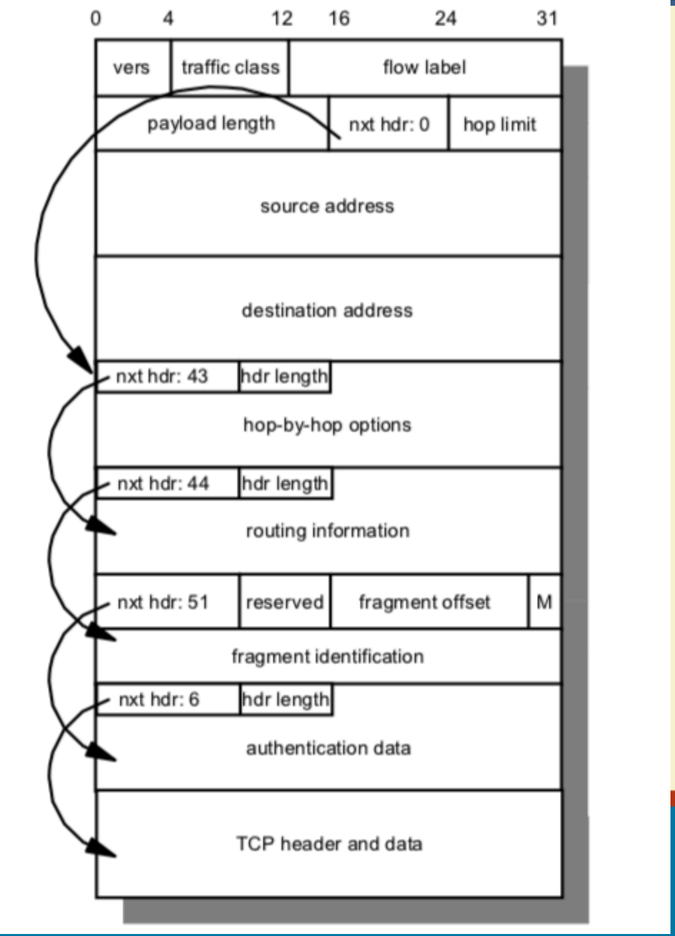


Image Source: IBM Redbook, TCP/IP Protocols and Technical Overview

IPv6 Addressing

- 128 bit addresses - represented in 8 hexadecimal numbers FE80:0000:0000:0000:0001:0800:23E:F5DB

- Leading zeros can be omitted - FE80:0:0:0:1:800:23E7:F5DB

- A group of zeros can be replaced by a double colon - FE80::1:800:23E7:F5DB (Can be used only once)

Address Space Allocation based on Prefix

Allocation	Prefix (bin)	Start of address range (hex)	Mask length (bits)	Fraction of address space
Reserved	0000 0000	0:: /8	8	1/256
Reserved for NSAP	0000 001	200:: /7	7	1/128
Reserved for IPX	0000 010	400:: /7	7	1/128
Aggregatable global unicast addresses	001	2000:: /3	3	1/8

Image Source: IBM Redbook, TCP/IP Protocols and Technical Overview

Address Space Allocation based on Prefix

Allocation	Prefix (bin)	Start of address range (hex)	Mask length (bits)	Fraction of address space
Link-local unicast	1111 1110 10	FE80:: /10	10	1/1024
Site-local unicast	1111 1110 11	FEC0:: /10	10	1/1024
Multicast	1111 1111	FF00:: /8	8	1/256
Total allocation				15%

Image Source: IBM Redbook, TCP/IP Protocols and Technical Overview

Global Unicast Address Format

- **Global routing prefix:** A value assigned to a site for a cluster of subnets/links. The global routing prefix is designed to be structured hierarchically

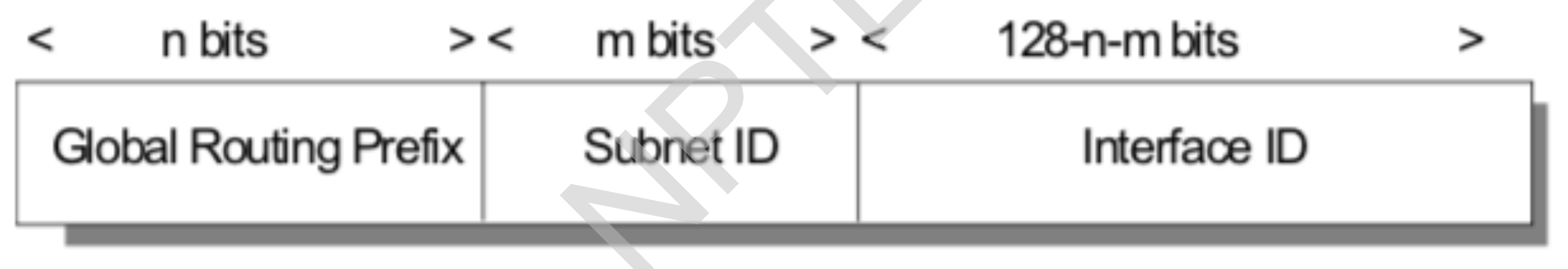
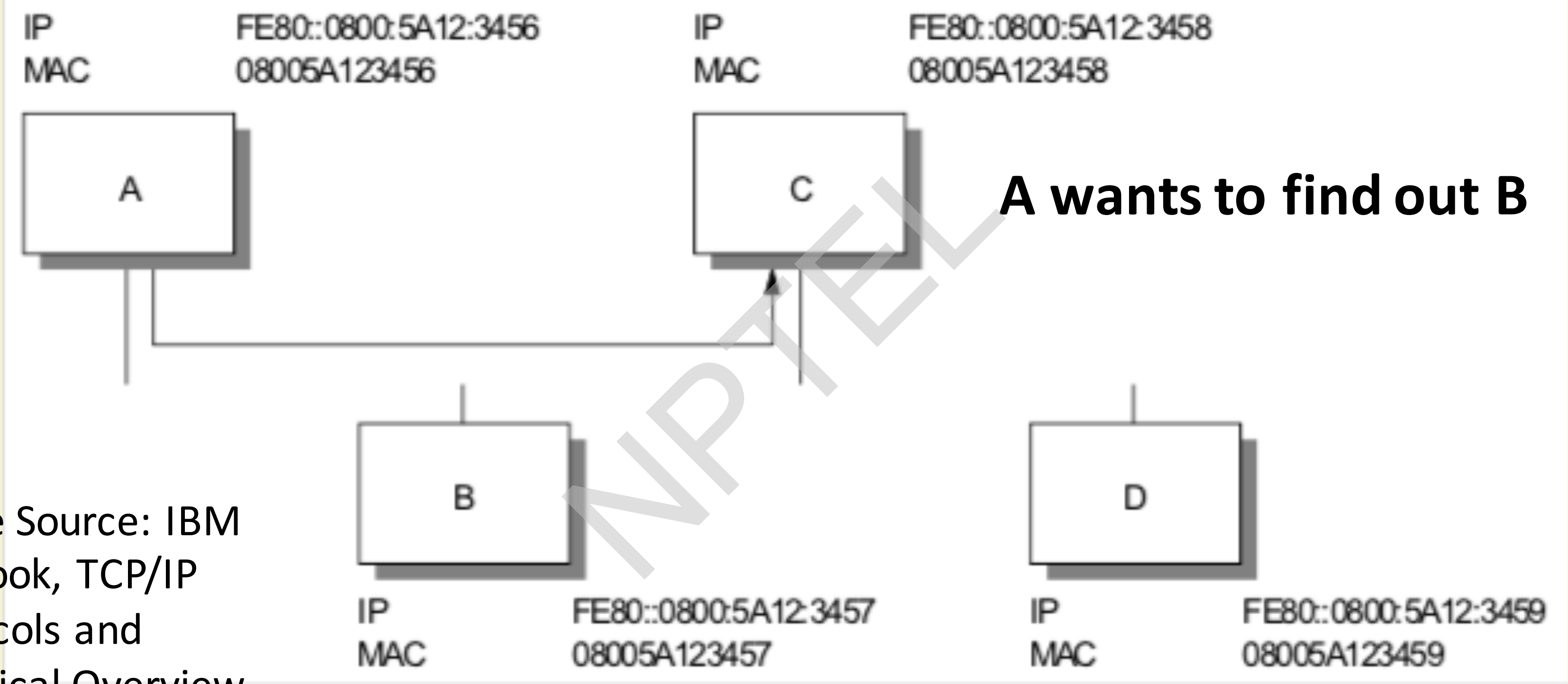


Image Source: IBM Redbook, TCP/IP Protocols and Technical Overview

ICMPv6 - Neighbor Discovery

- Enables a node to identify other hosts and routers on its links
- The node needs to know of at least one router so that it knows where to forward packets if a target node is not on its local link
- ARP request/response in IPv4

Neighbor Discovery Example



A wants to find out B

Image Source: IBM Redbook, TCP/IP Protocols and Technical Overview

Neighbor Discovery - Neighbor Solicitation

- The destination address is the address of the *solicitated node*
- An improvement over ARP broadcast

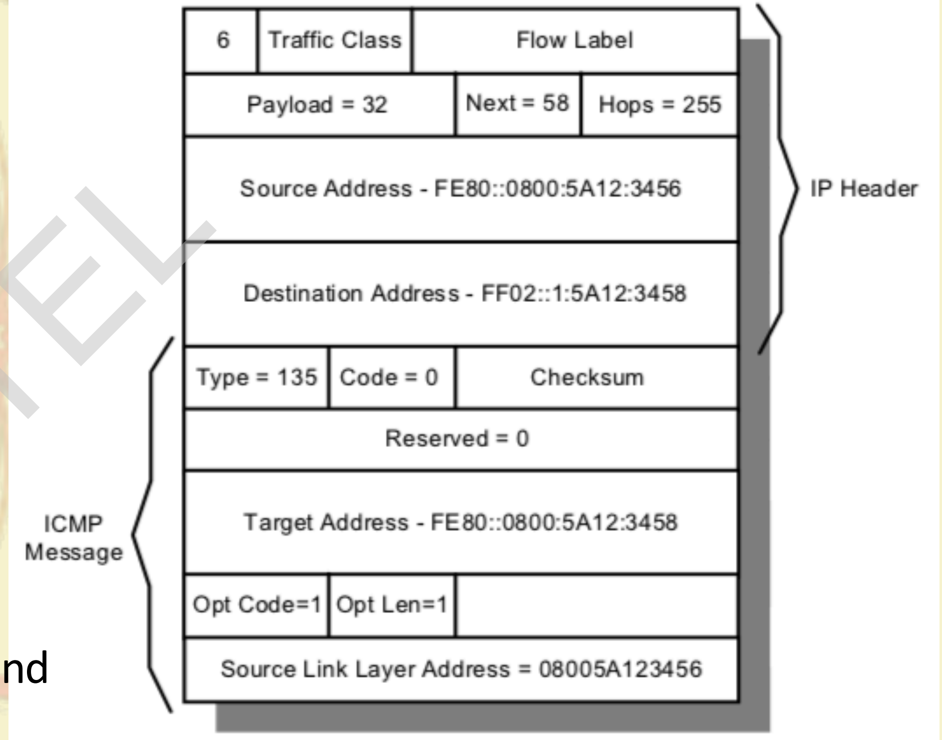


Image Source: IBM Redbook, TCP/IP Protocols and Technical Overview

Neighbor Discovery - Neighbor Advertisement

- Response of the *neighbor solicitation*
- Three flags
  - **R**: Sender of the advertisement is a router
  - **S**: Advertisement is a response to a solicitation
  - **O**: Override, must update a cached information

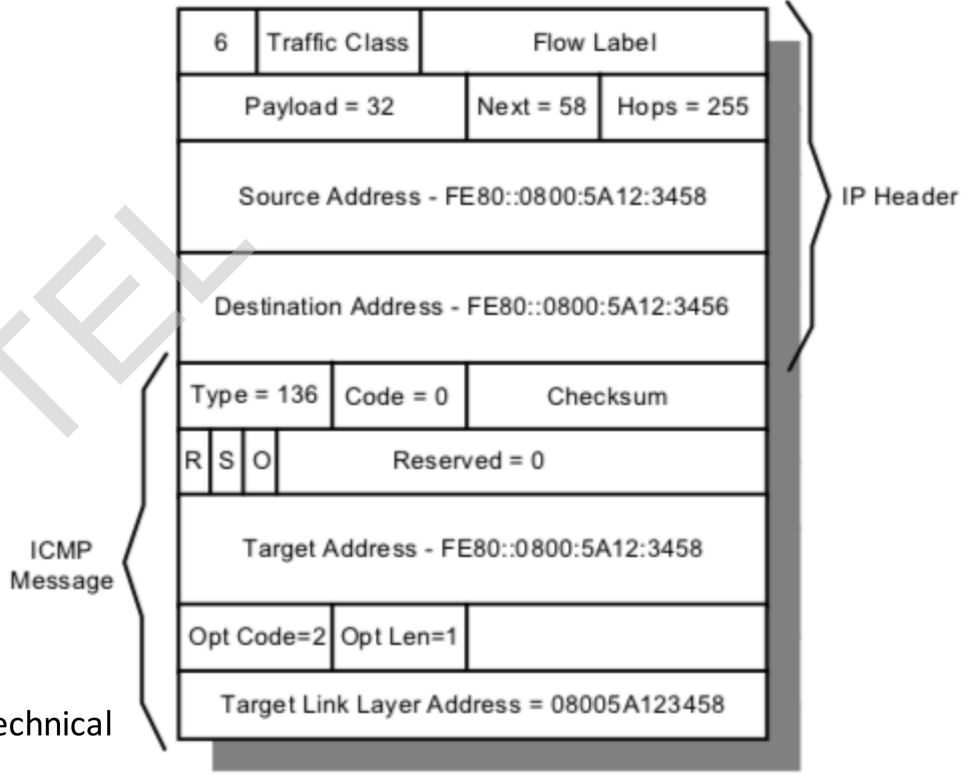


Image Source: IBM Redbook, TCP/IP Protocols and Technical Overview

IPv6 Mobility Support

- A mobile node uses a temporary address when it is away from the home location
  - Use IPv6 Destination Optional header to store its home address
- A mobile station can list the all routing header for the packets to follow a particular path for establishing connection with a service provider network
- Packets sent to a mobile node can be tunneled by IPv6 routing headers
- Do not require *foreign agents* like IPv4 - *neighbor discovery* and *address autoconfiguration* can be used to connect a node with any network

Migrating from IPv4 to IPv6

- **Dual stack IP implementations**

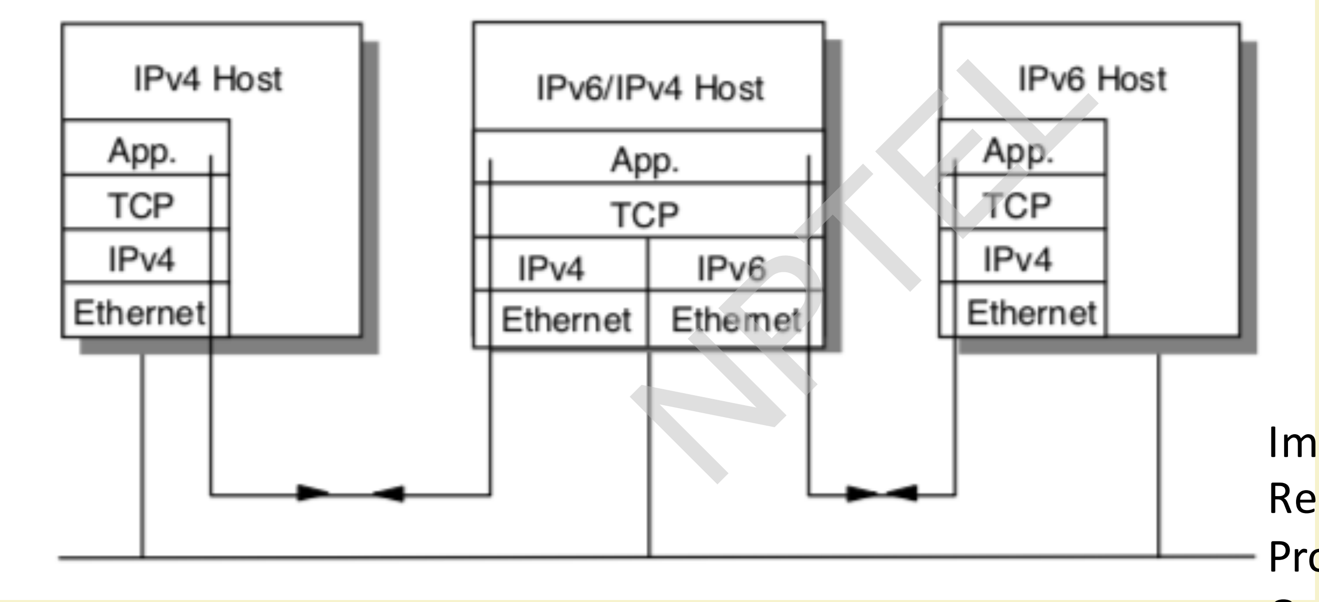


Image Source: IBM Redbook, TCP/IP Protocols and Technical Overview

Migrating from IPv4 to IPv6

- **Tunneling:** Tunnel IPv4 headers through IPv6 headers and vice-versa
- **Header Translation:** Translate a IPv4 header to a IPv6 header and vice-versa
  - Address must be translated as well
  - Take low order 32 bits for IPv6 to IPv4
  - Append ::FFFF/96 prefix for IPv4 to IPv6

Address Translation

- IPv4 Address: 202.141.80.20
- IPv6 Address: CA8D:5014::FFFF

- IPv6 Address: FE80:2381:0000:0000:0001:0800:23E:F5DB
- IPv4 Address: 254.128.35.129

Interesting Reads

- RFC 2460 – Internet Protocol, Version 6 (IPv6) (December 1998)
- RFC 4291 – IP Version 6 Addressing Architecture (February 2006)
- RFC 3587 – IPv6 Global Unicast Address Format (August 2003)
- IANA Assignment Documentation: INTERNET PROTOCOL VERSION 6 MULTICAST ADDRESSES, June 2006 http://www.iana.org/assignments/ipv6-multicast-addresses
- 6NET http://www.6net.org

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