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COMPUTER NETWORKS AND INTERNET PROTOCOLS

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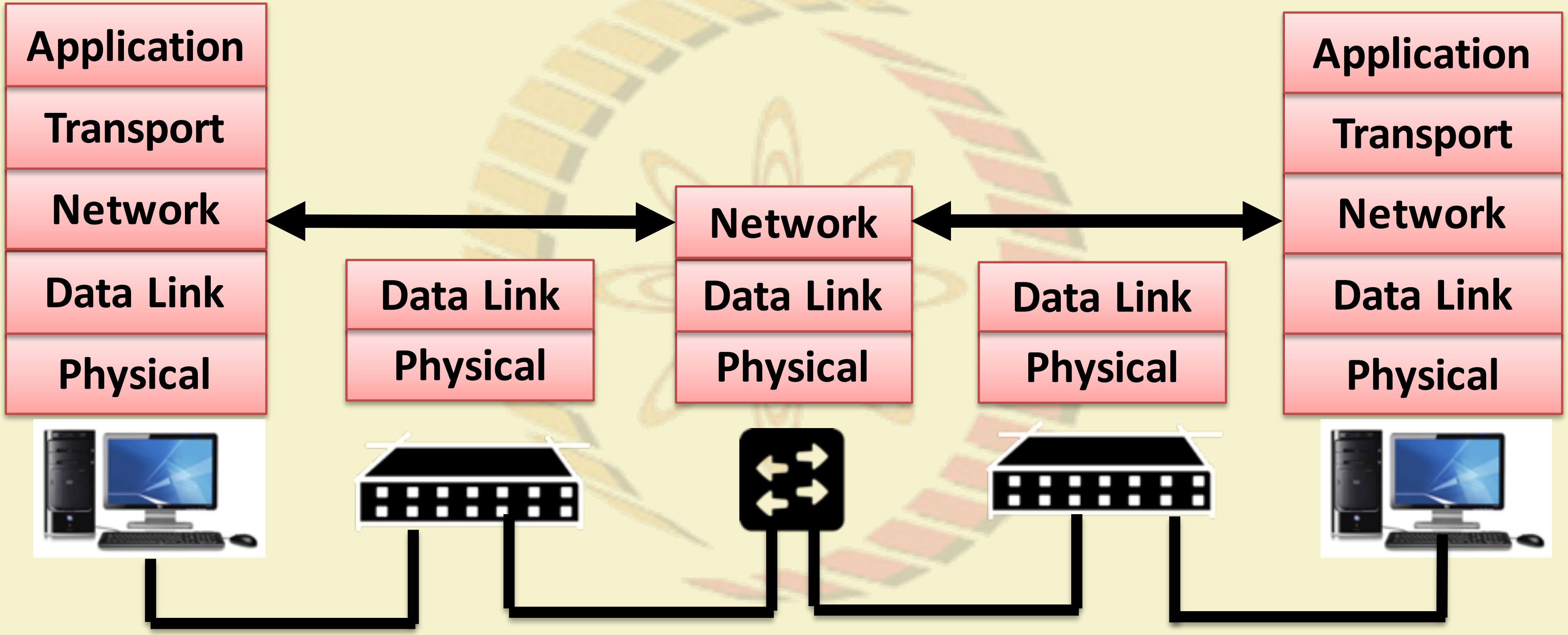
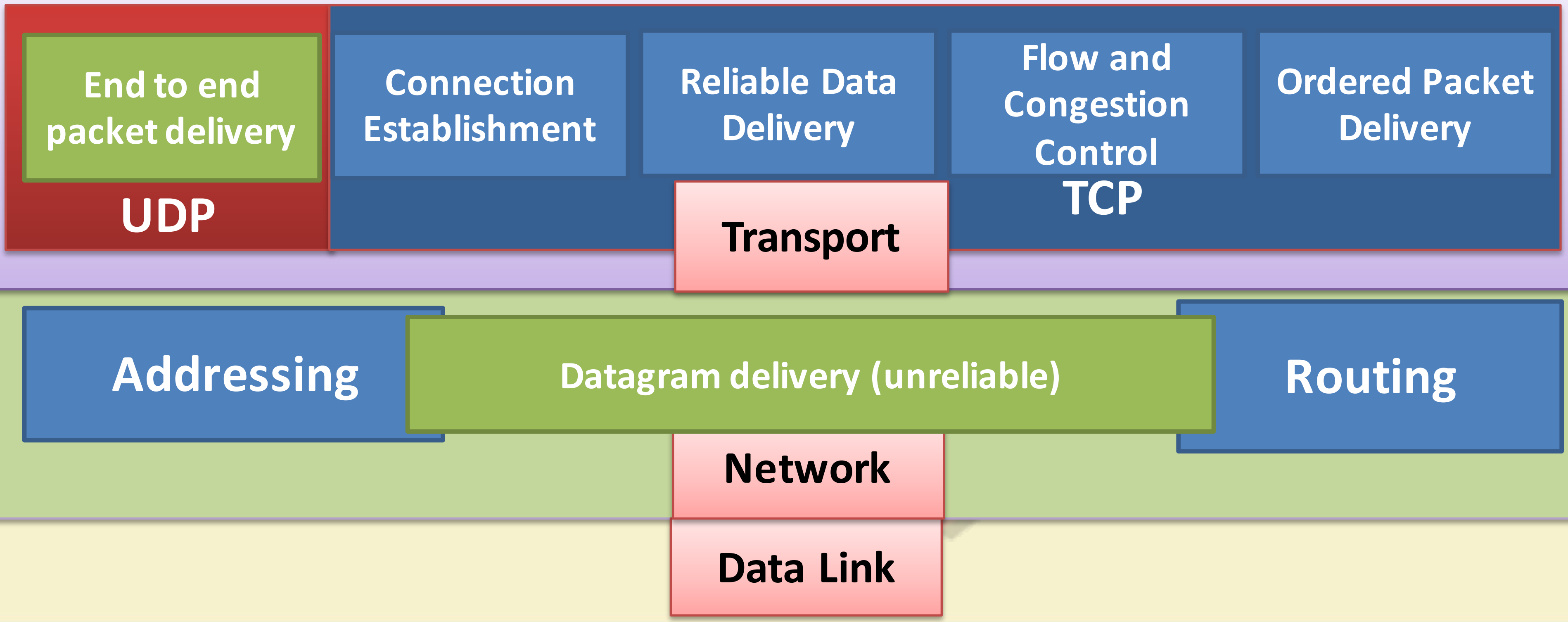
Network Layer I - Introduction

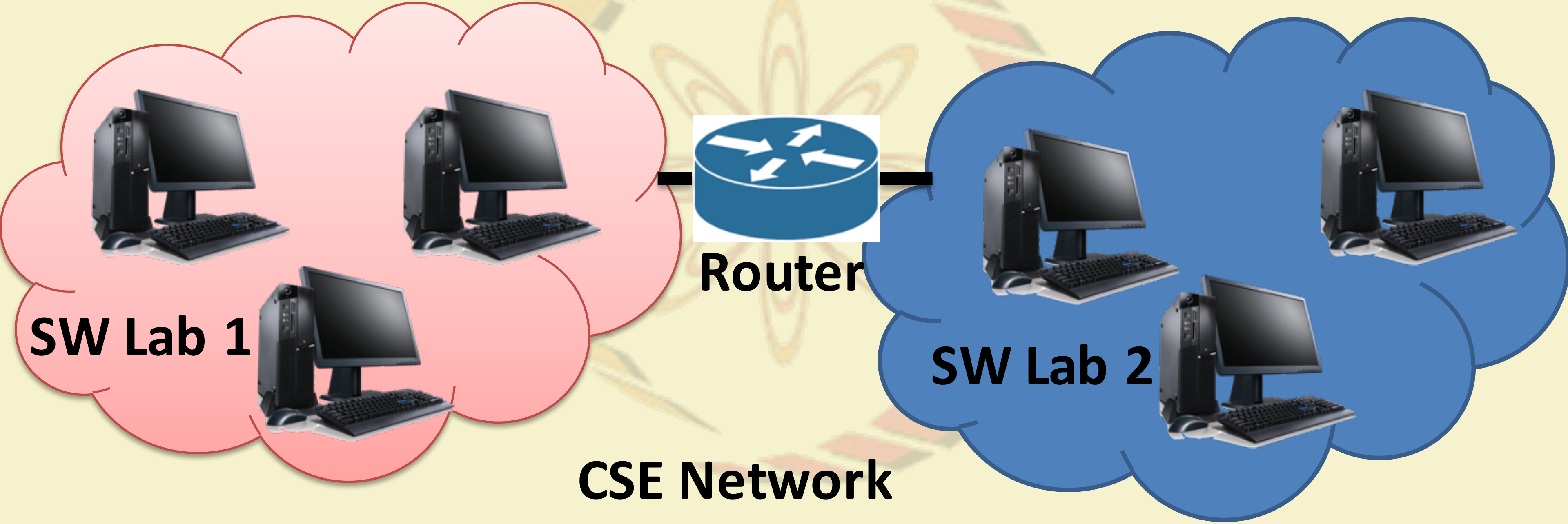


Network (Internet) Layer Services



Internet Architecture – Basic Principles

- Internet is organized in a hierarchical fashion.



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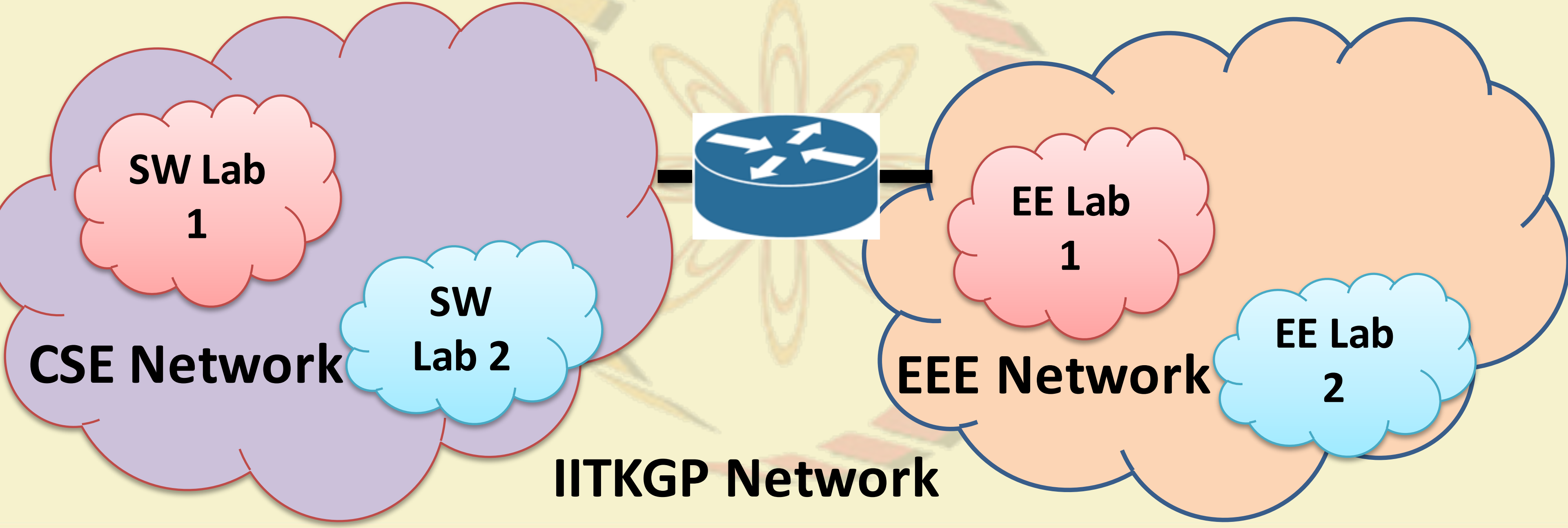

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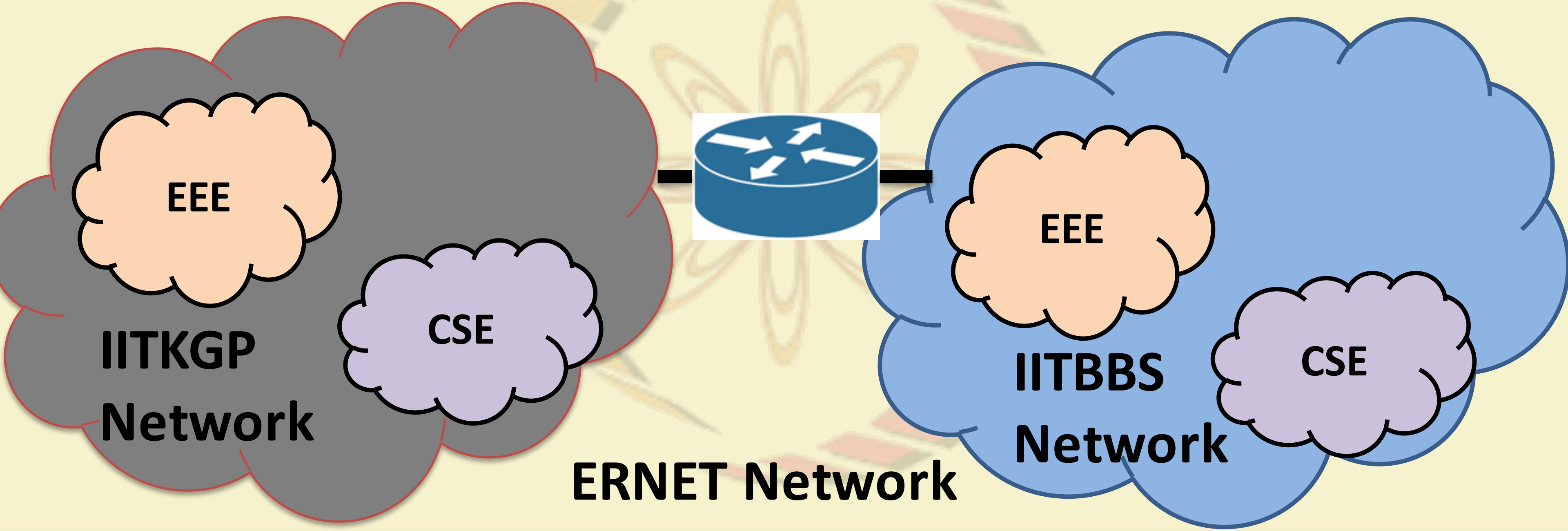

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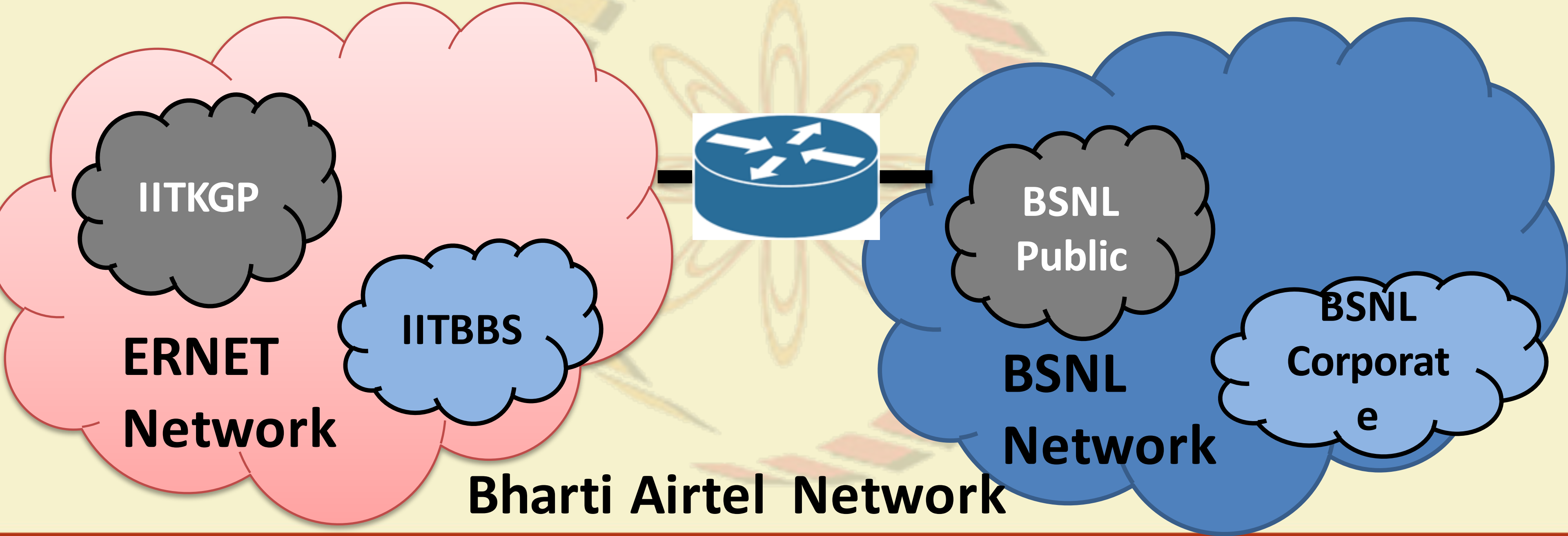


Internet Architecture

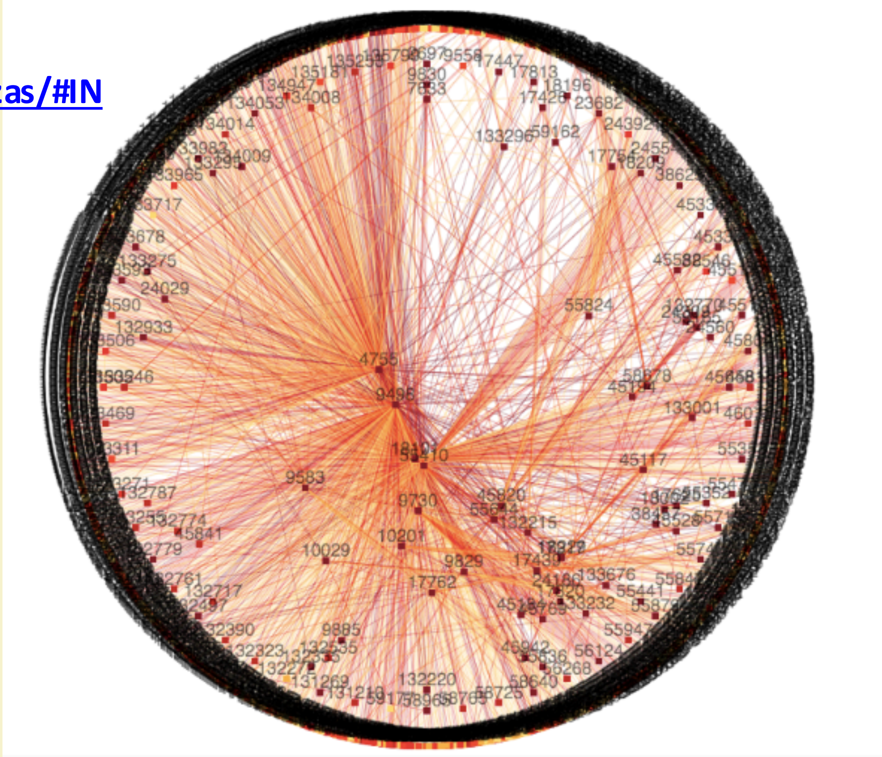
Autonomous Systems (AS) – A set of LANs for an administrative domain, identified by a unique AS number, and the routing policies are controlled by a single administrator.

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

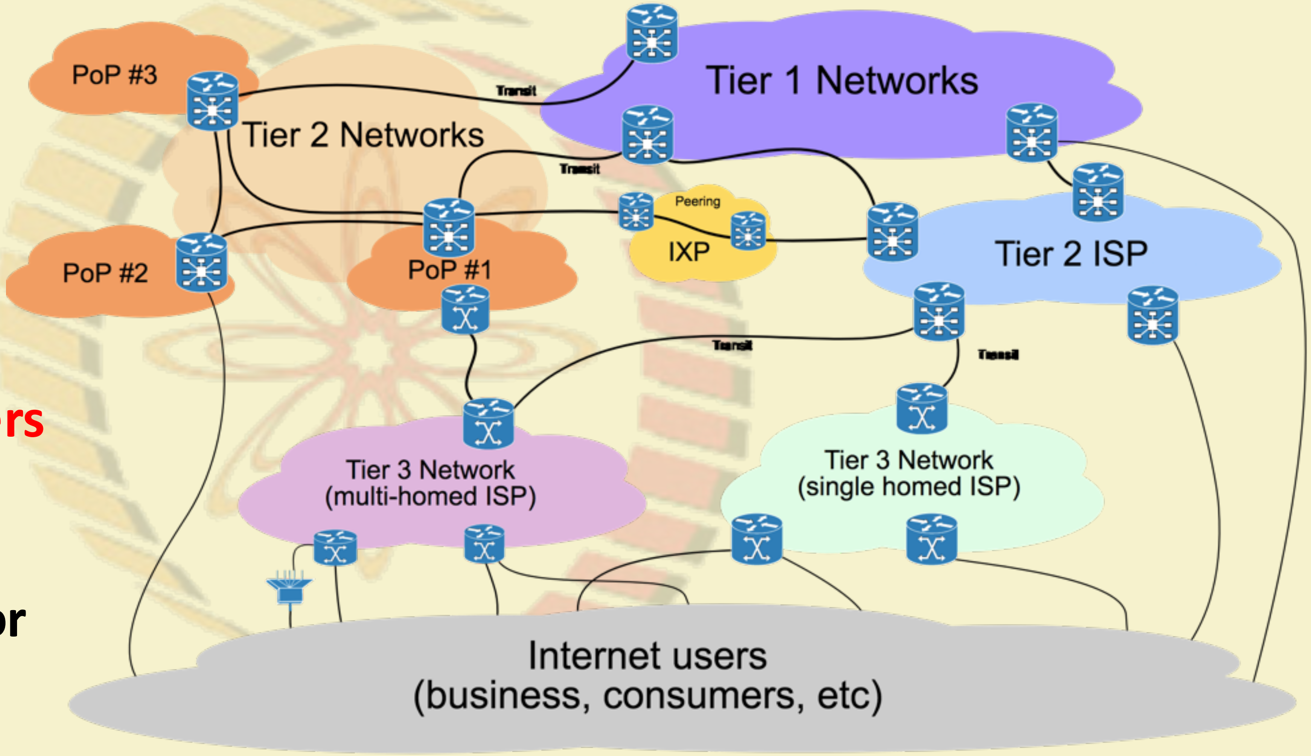
Internet Service Provider Hierarchy

Autonomous System Graph for India

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

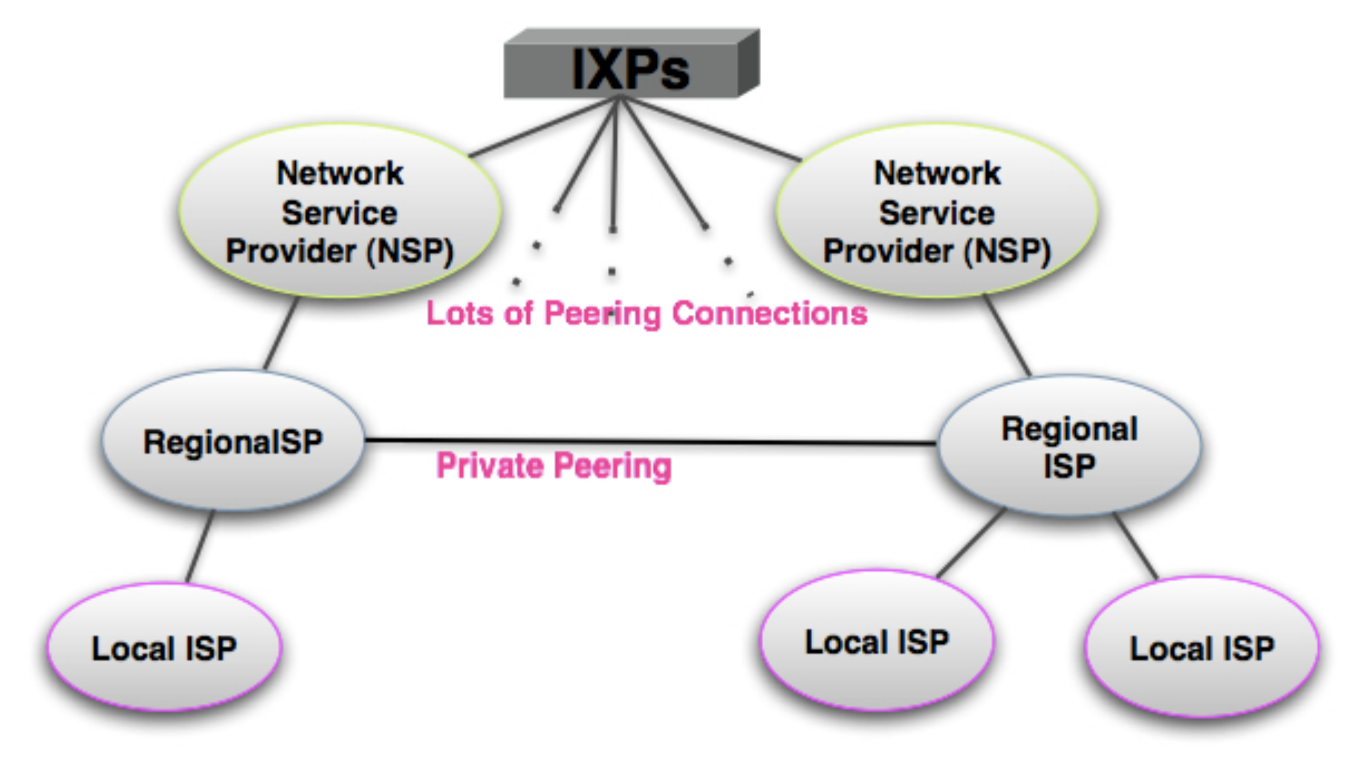


Internet Architecture

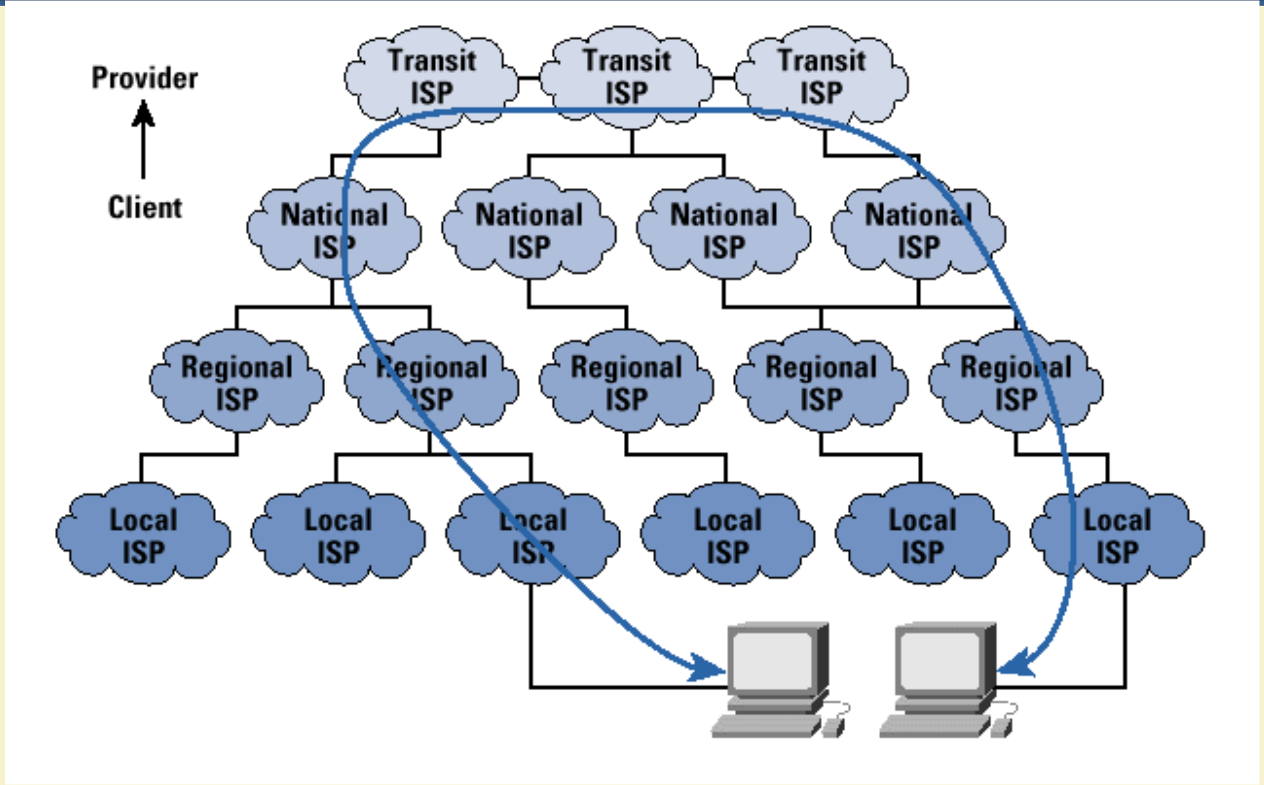


Internet Service Providers (ISP) – An AS provides Internet connectivity to another group of ASes or end users

Peering between ISPs

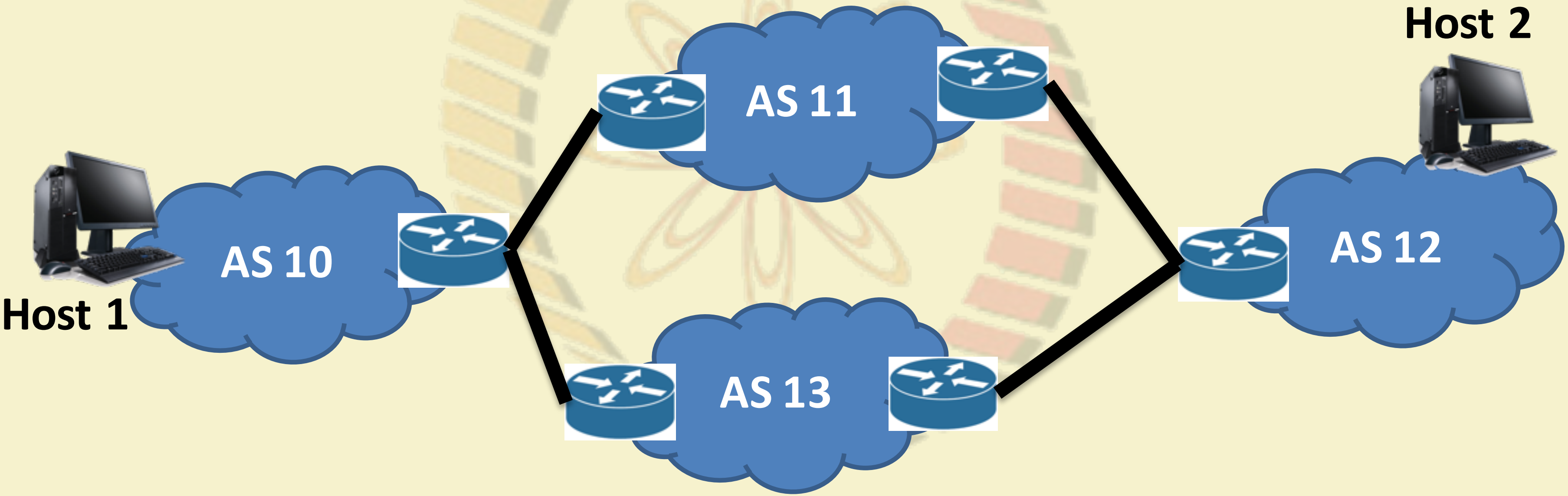


Communication between Two Nodes over ISPs



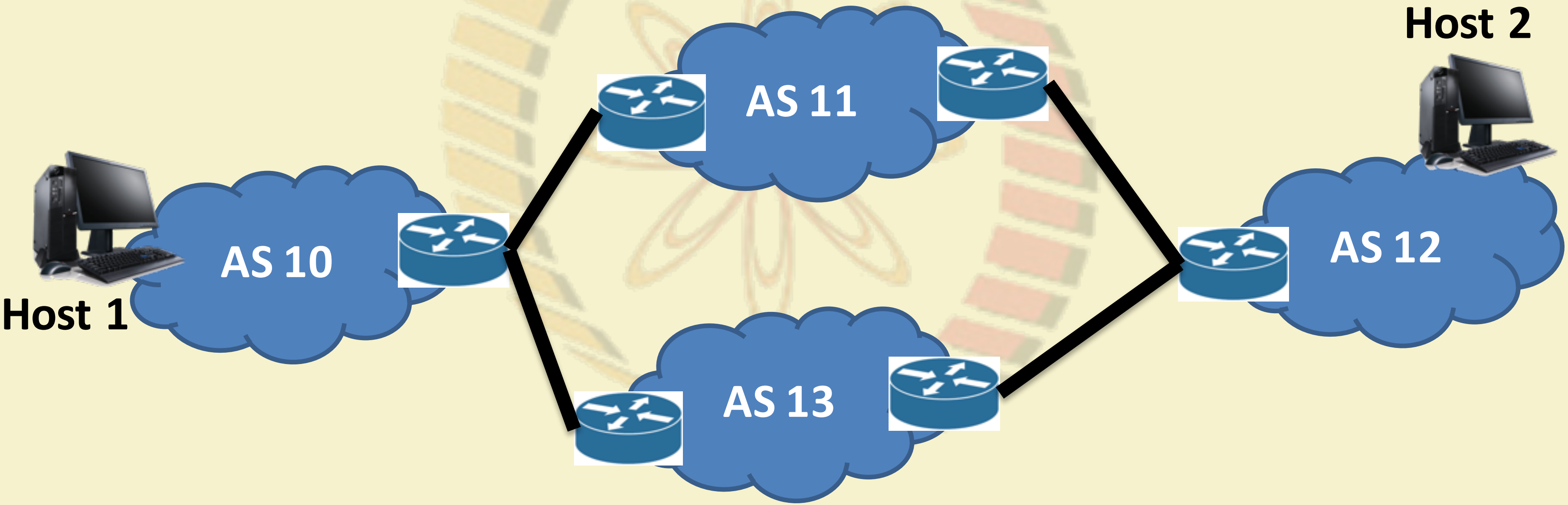
IP Addressing – Basic Principles

- 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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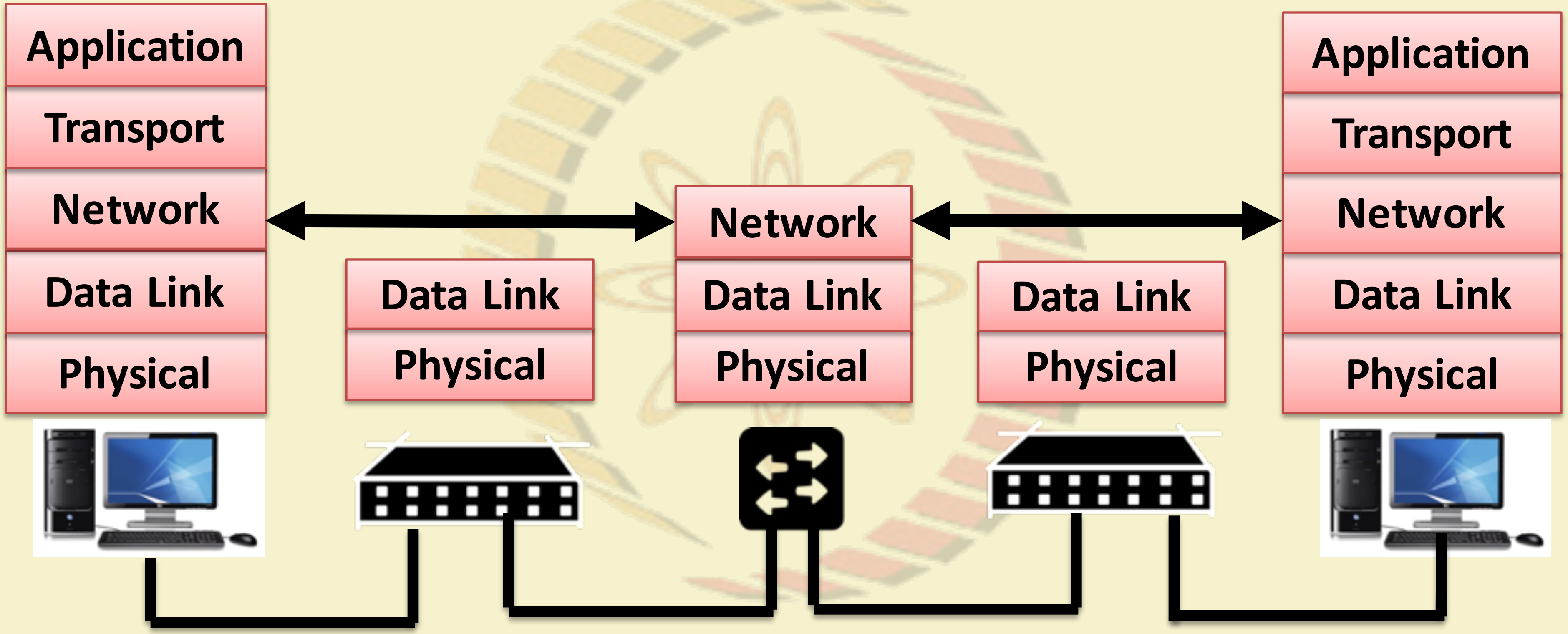
Network Layer II - IPv4 Addressing (Classful Addresses)



IP Addressing – Basic Principles

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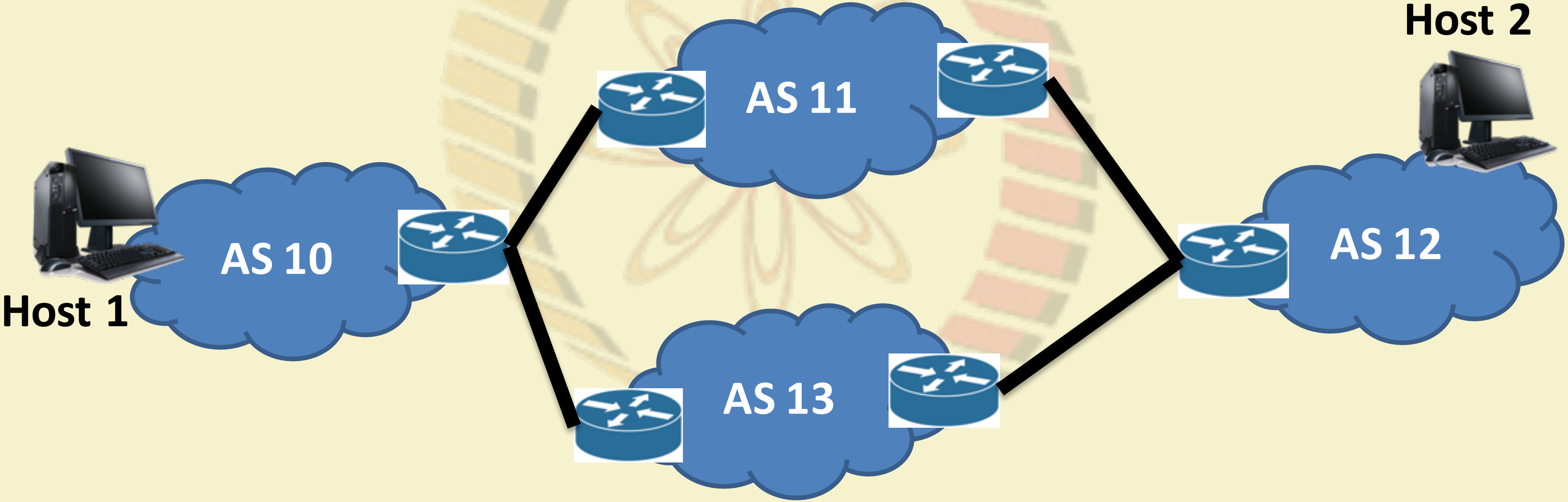


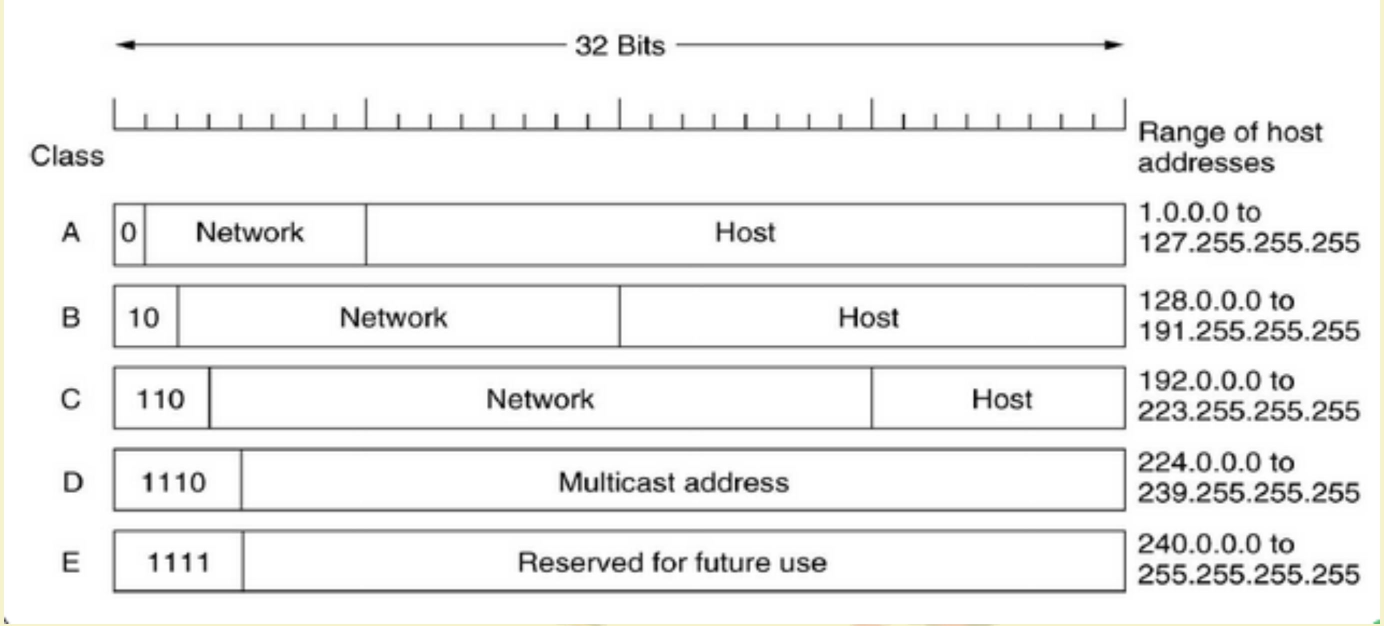
IP Addressing

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)

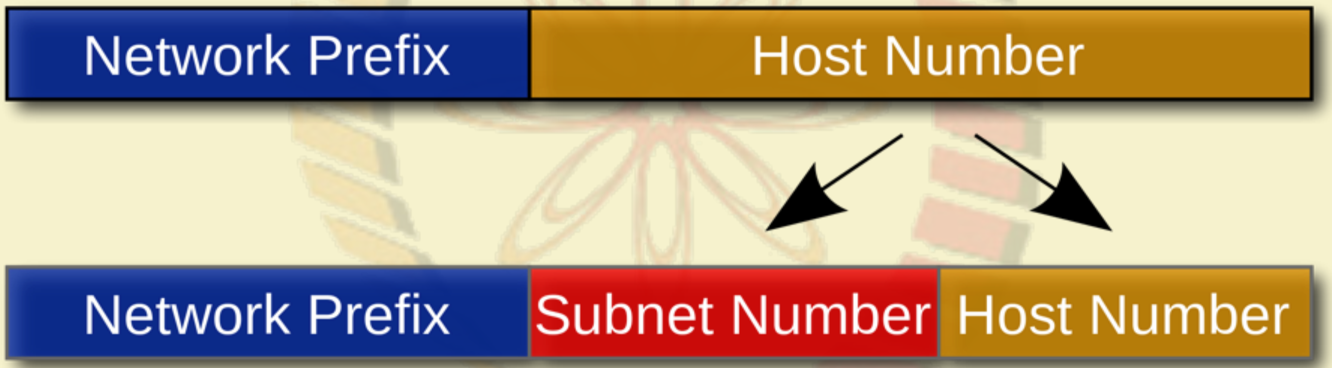
- **You have 255 hosts in a network. Which IPv4 address class will you use – Class C or Class B ?**
  - Class C – not possible
  - Class B – huge address space is lost (using only 255 addresses out of possible 2^{16}-2 addresses)

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

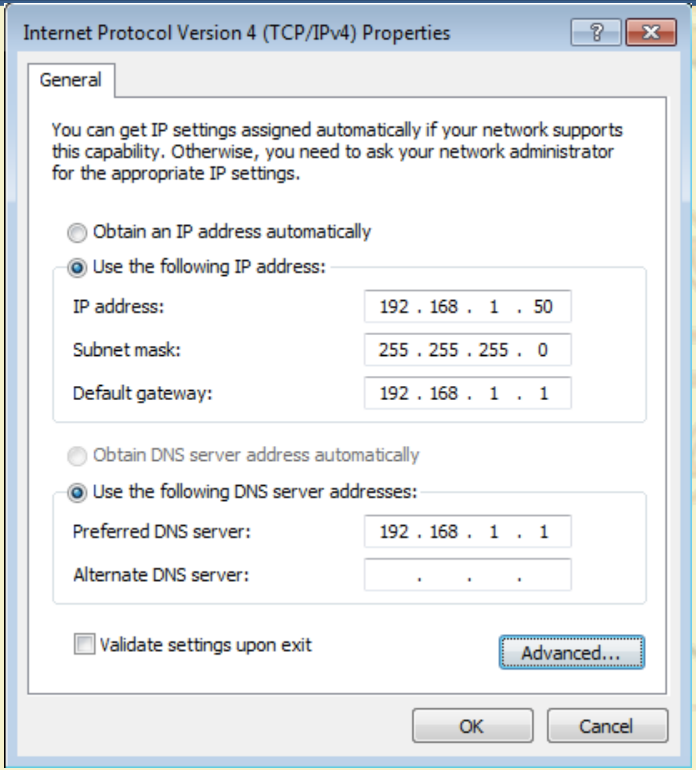
Host Address

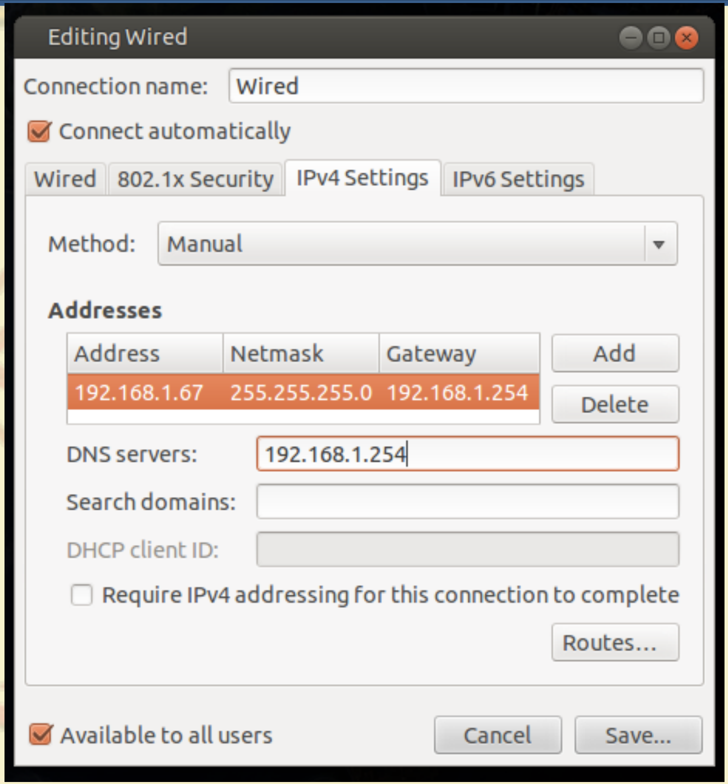
CIDR – Addressing Format

- 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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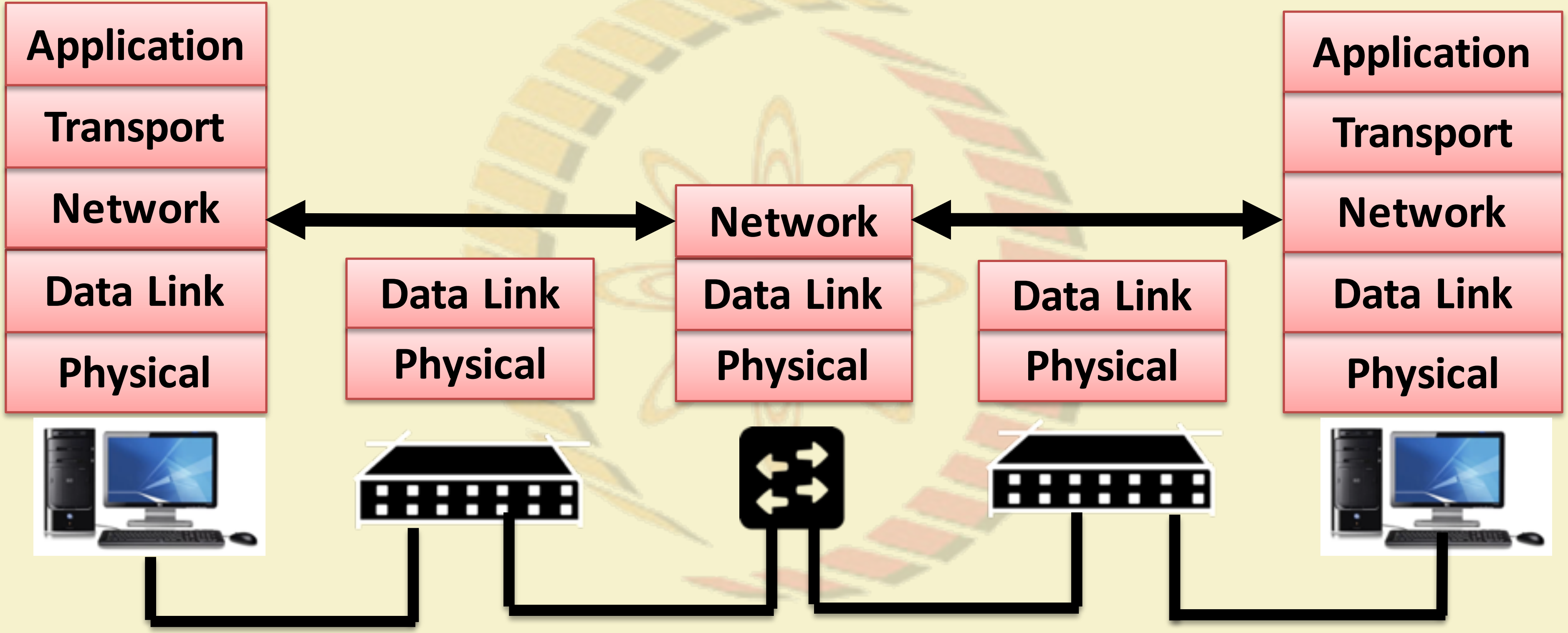
Network Layer III - IPv4 Addressing (CIDR)



CIDR – Addressing Format

IP Address	10111111	10110100	01010011	11101011
Netmask	11111111	11110000	00000000	00000000

Subnet Address

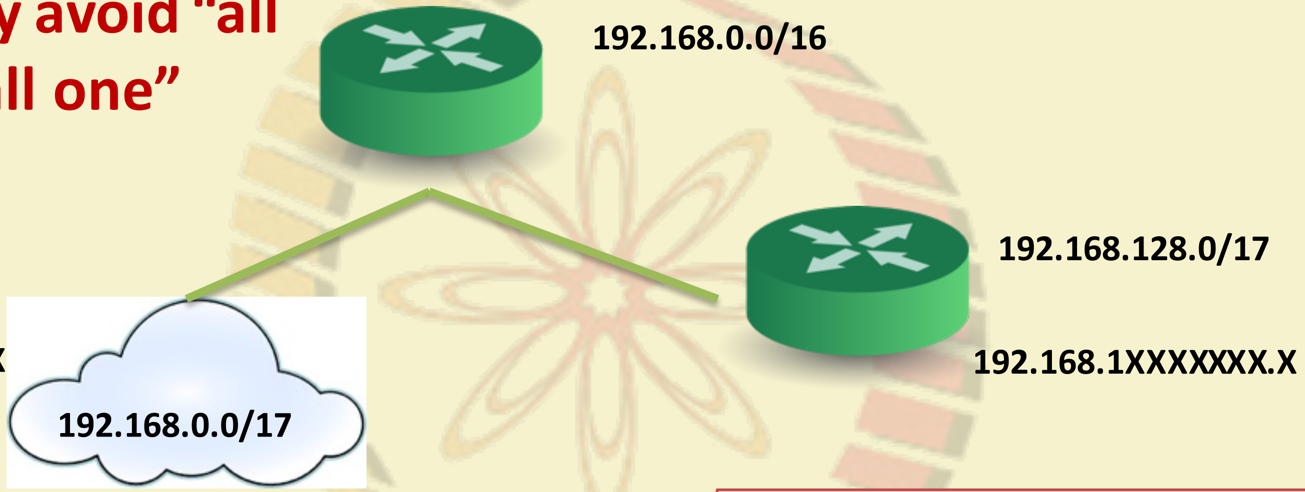
Host Address

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

CSE – 2000 Hosts

VGSOM – 500 Hosts

EE – 500 Hosts

203.110.0.0/19

CIDR Example

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

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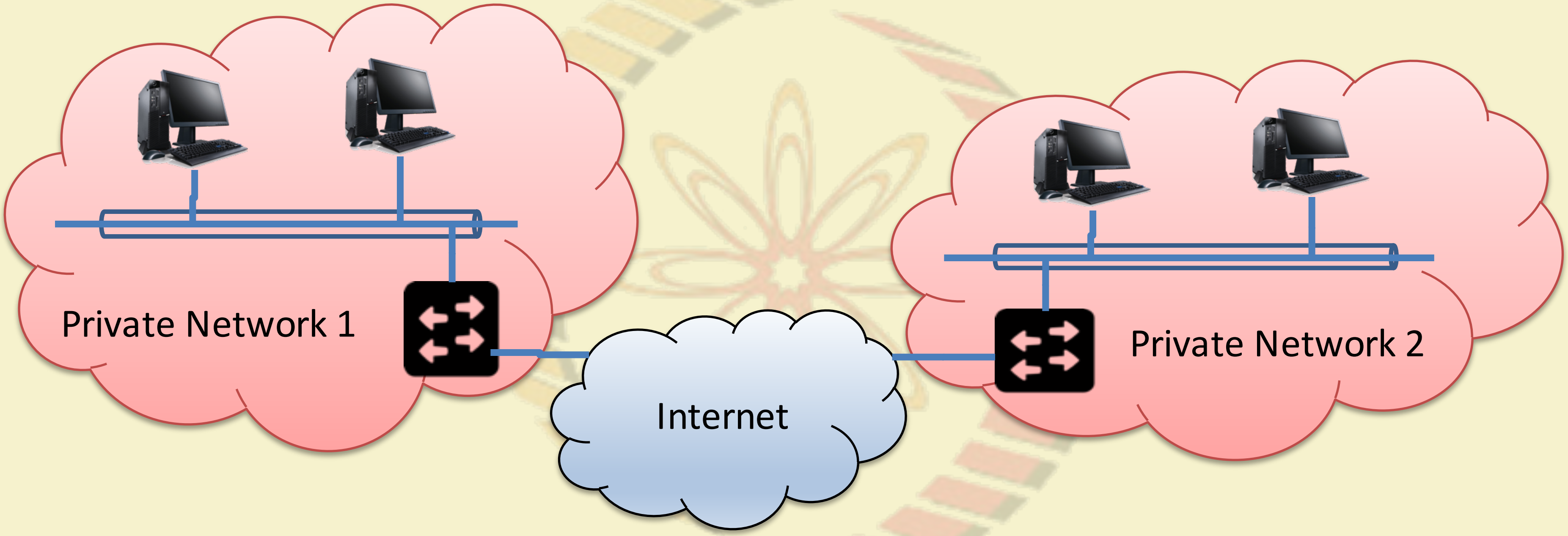
Network Address Translation (NAT)



Issues with IPv4 Addressing

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

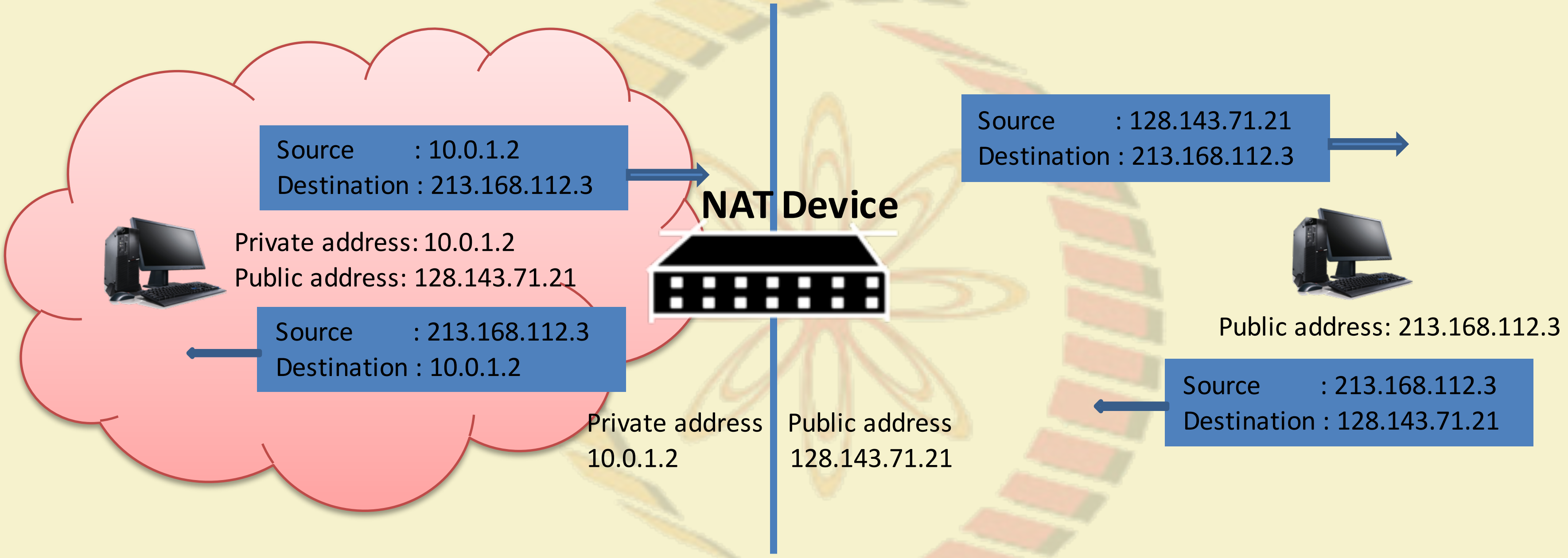
- A large number of addresses are wasted or remain unutilized (Class D or Class E).

- **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



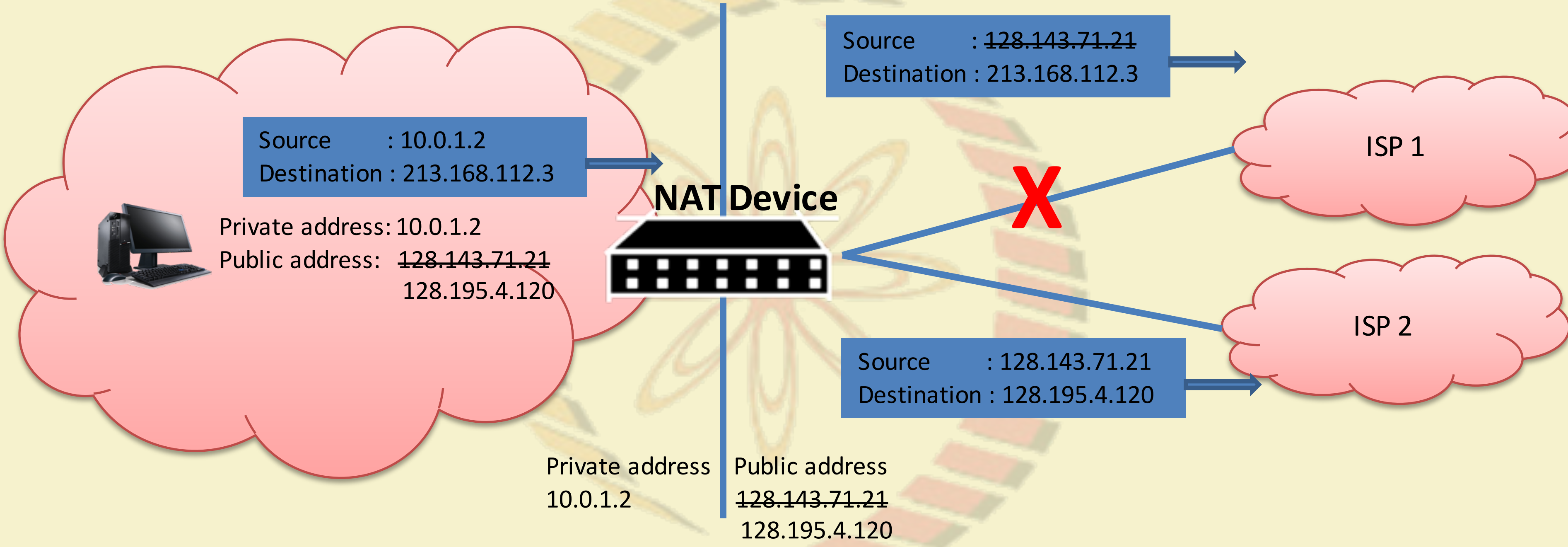
Working Principles of NAT

- 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

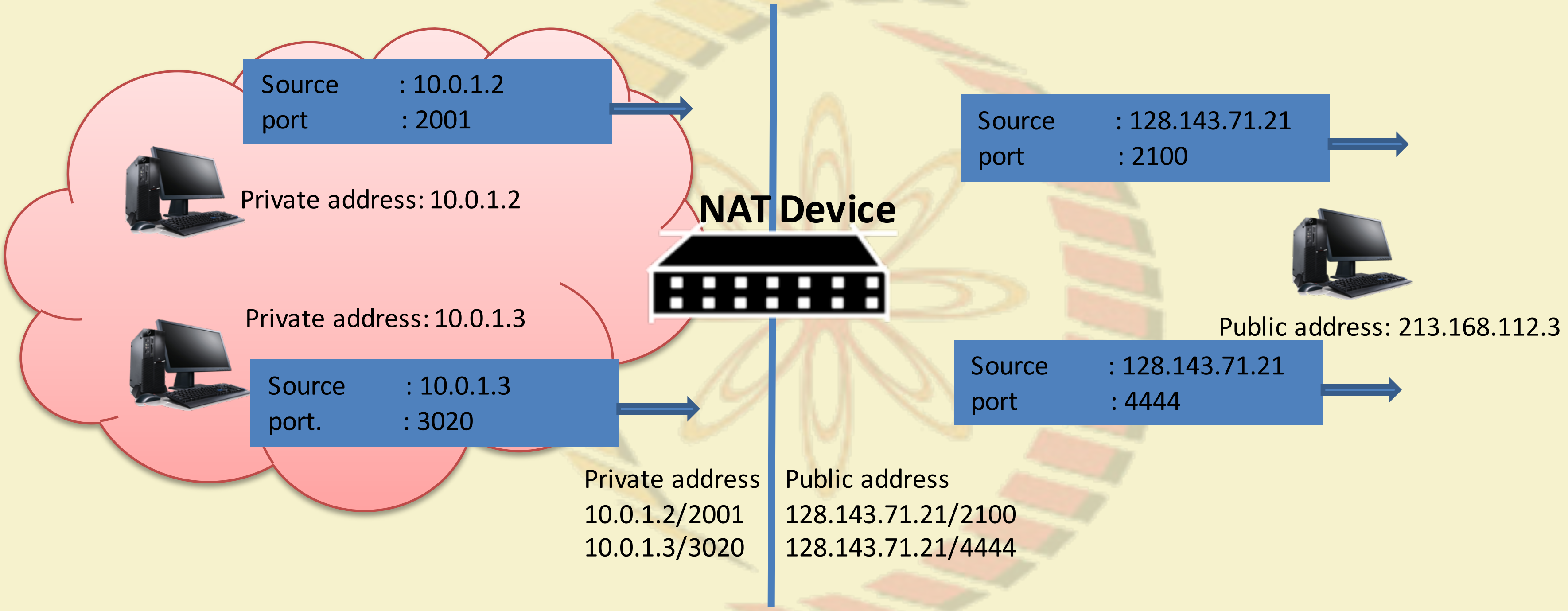
Migration between Network Service Provider



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

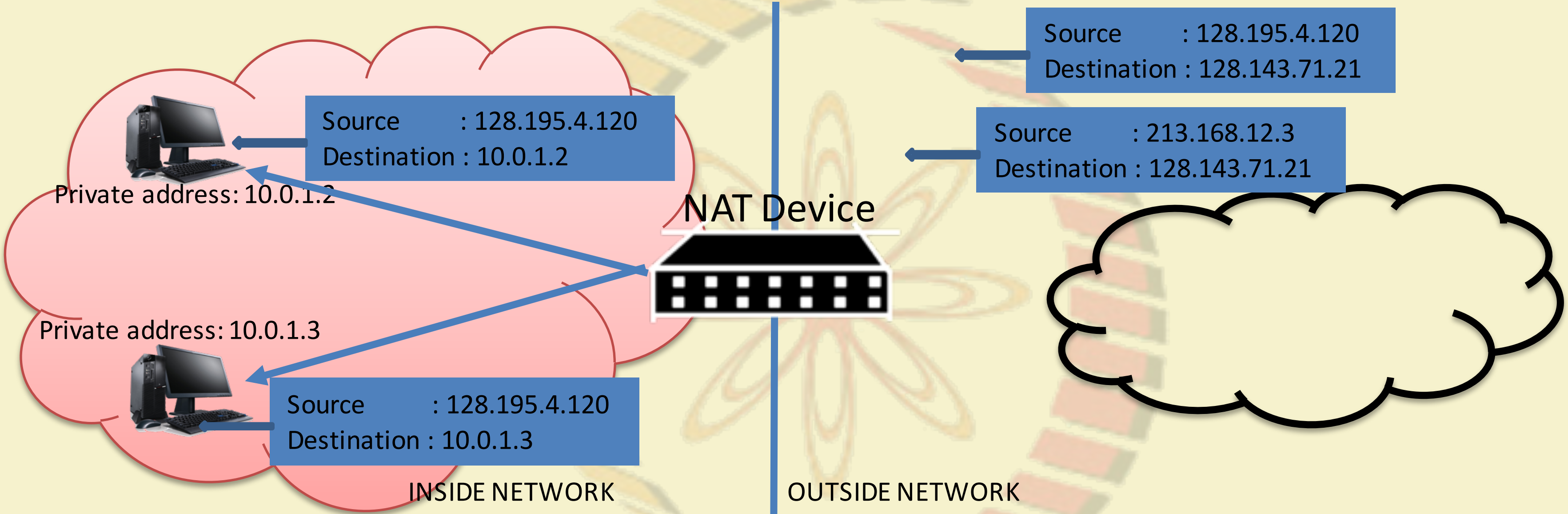
IP Masquerading



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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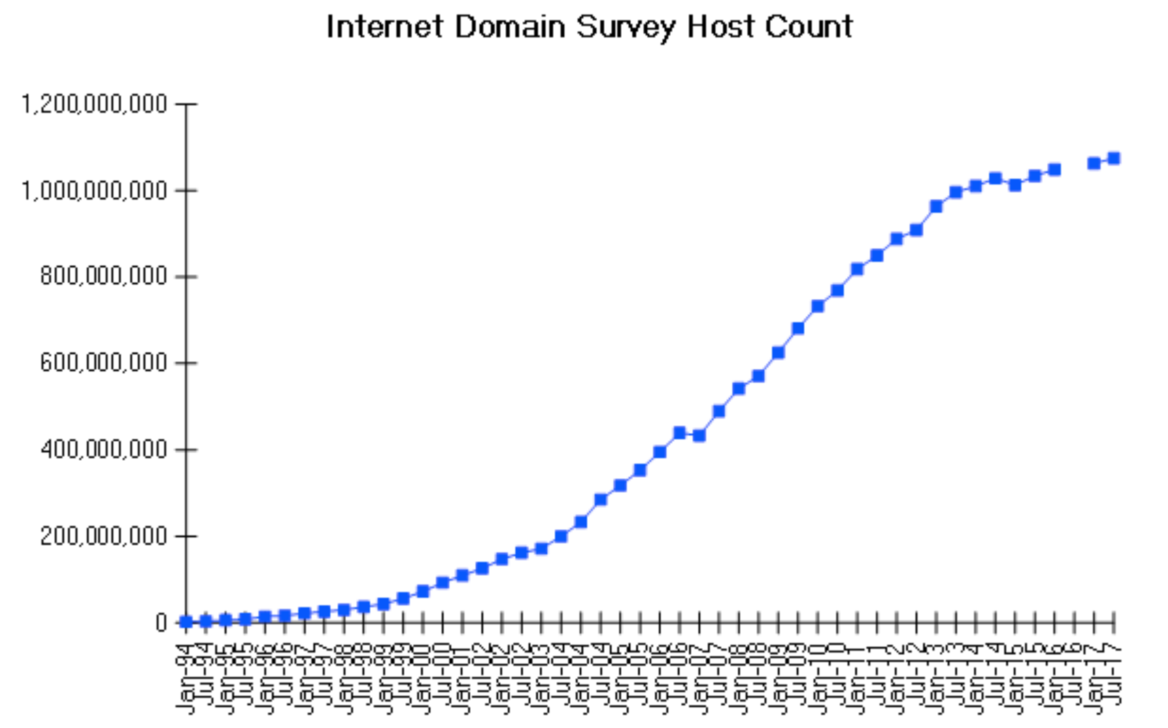
Internet Protocol Version 6 (IPv6)



Source: Internet Systems Consortium (www.isc.org)

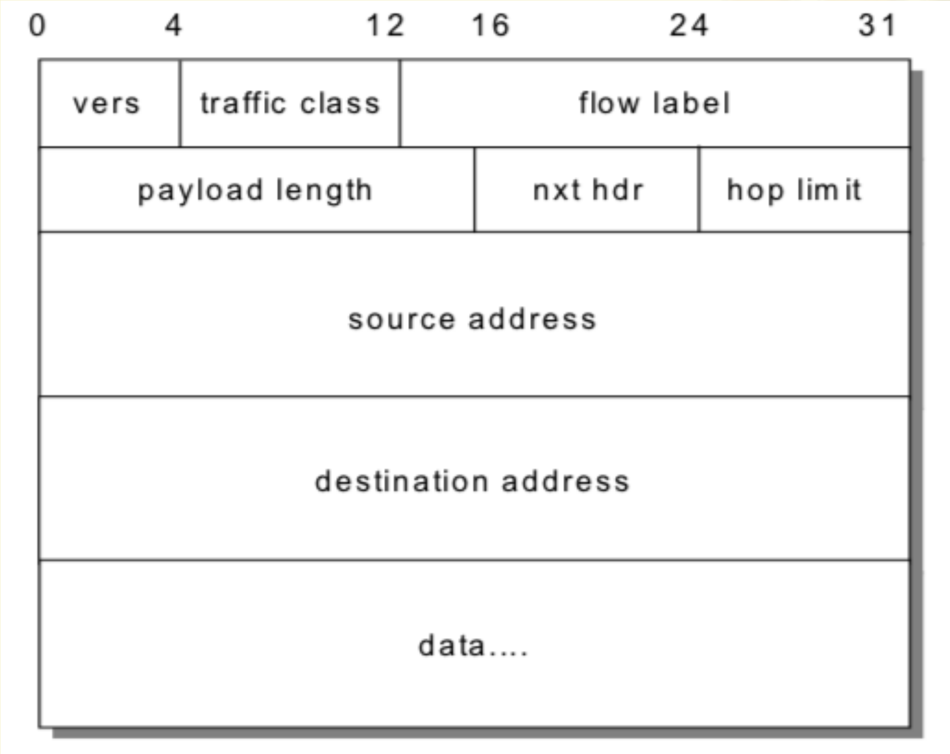
Why do We Need a New IP Structure?

- 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

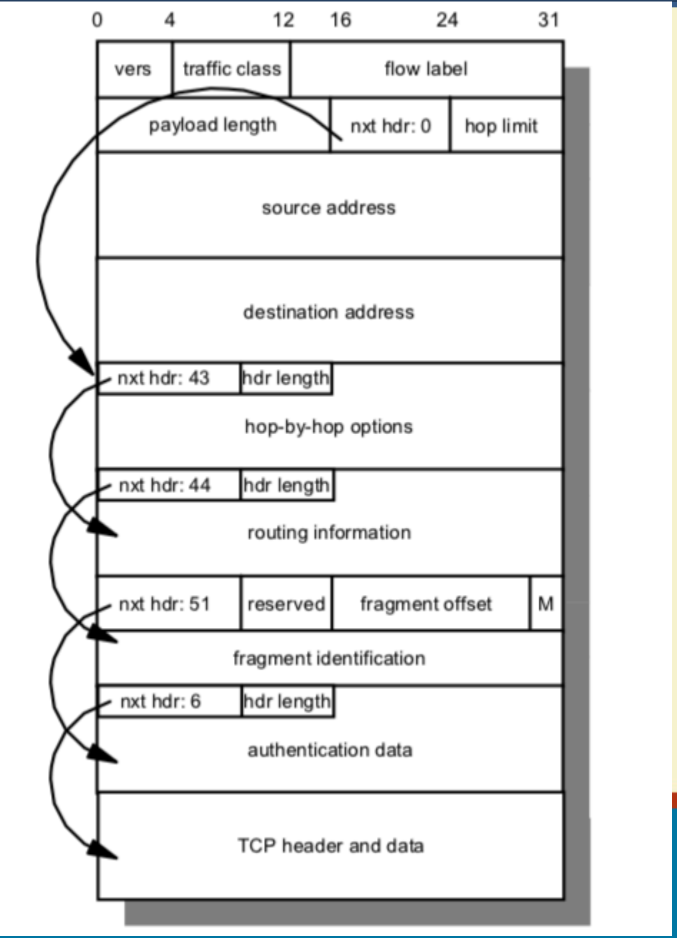


Image Source: IBM Redbook, TCP/IP Protocols and Technical Overview

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

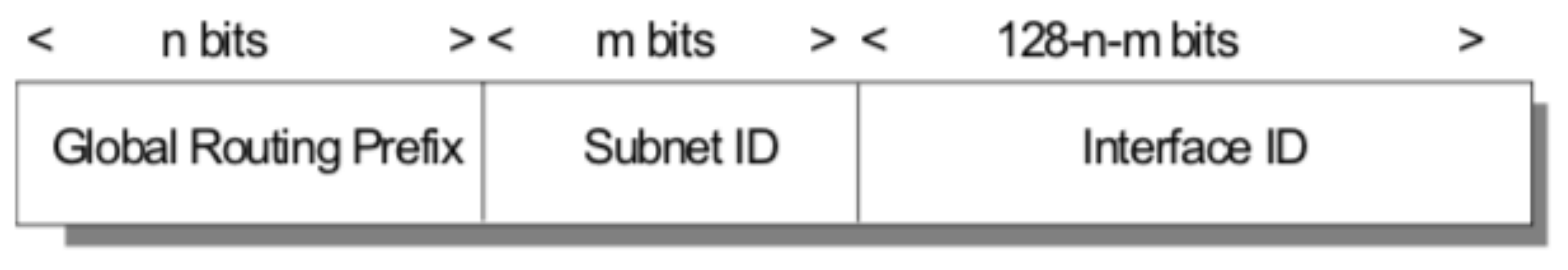
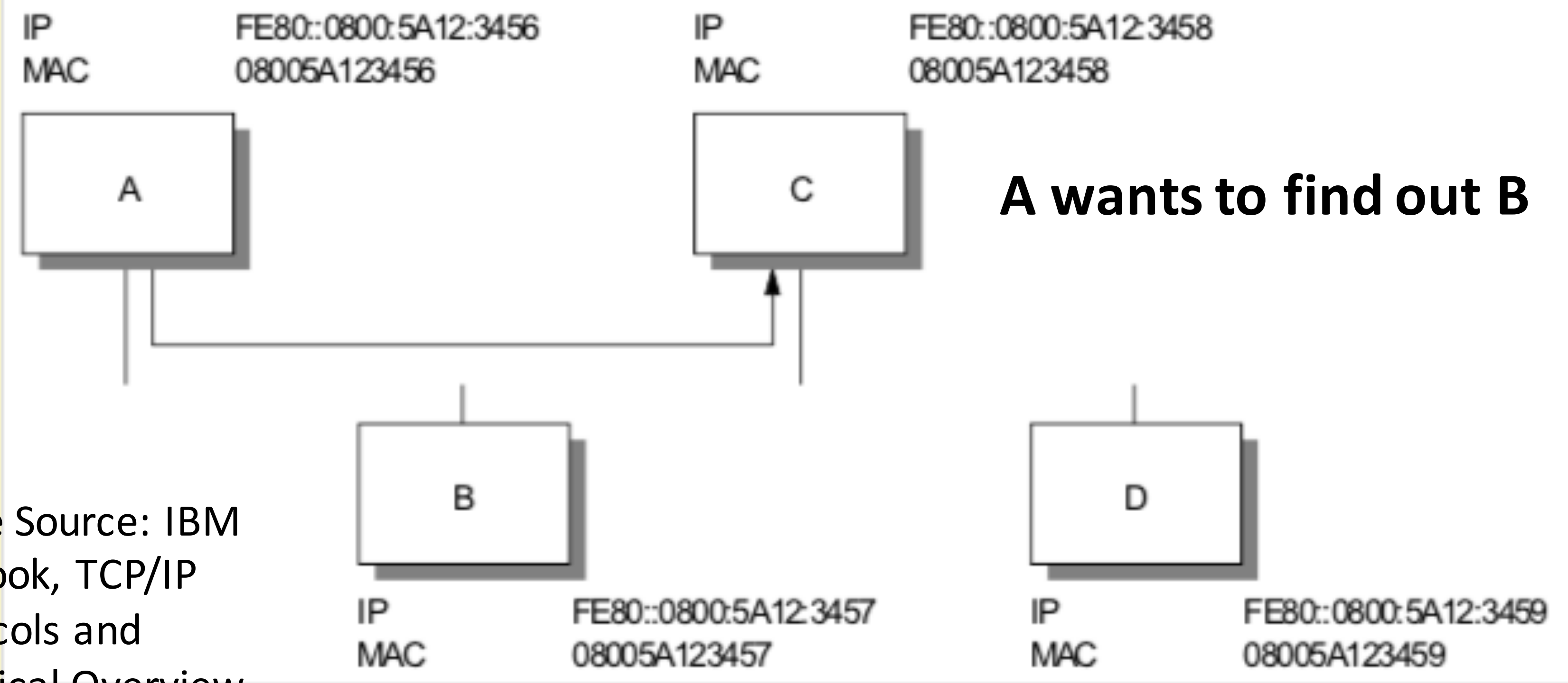


Image Source: IBM Redbook, TCP/IP Protocols and Technical Overview

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

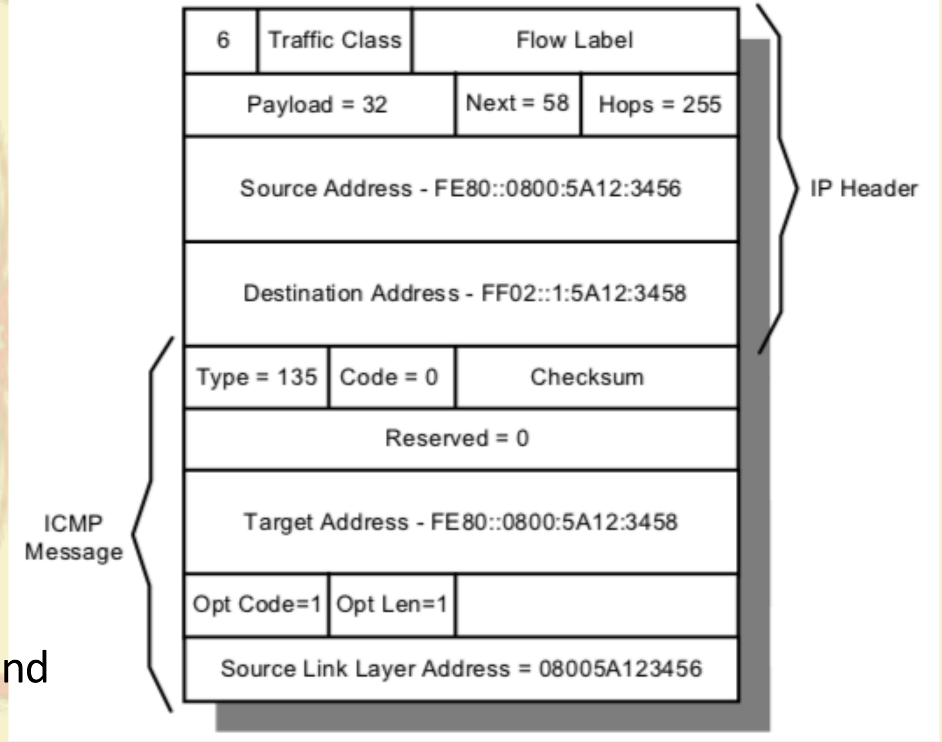


Image Source: IBM Redbook, TCP/IP Protocols and Technical Overview

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

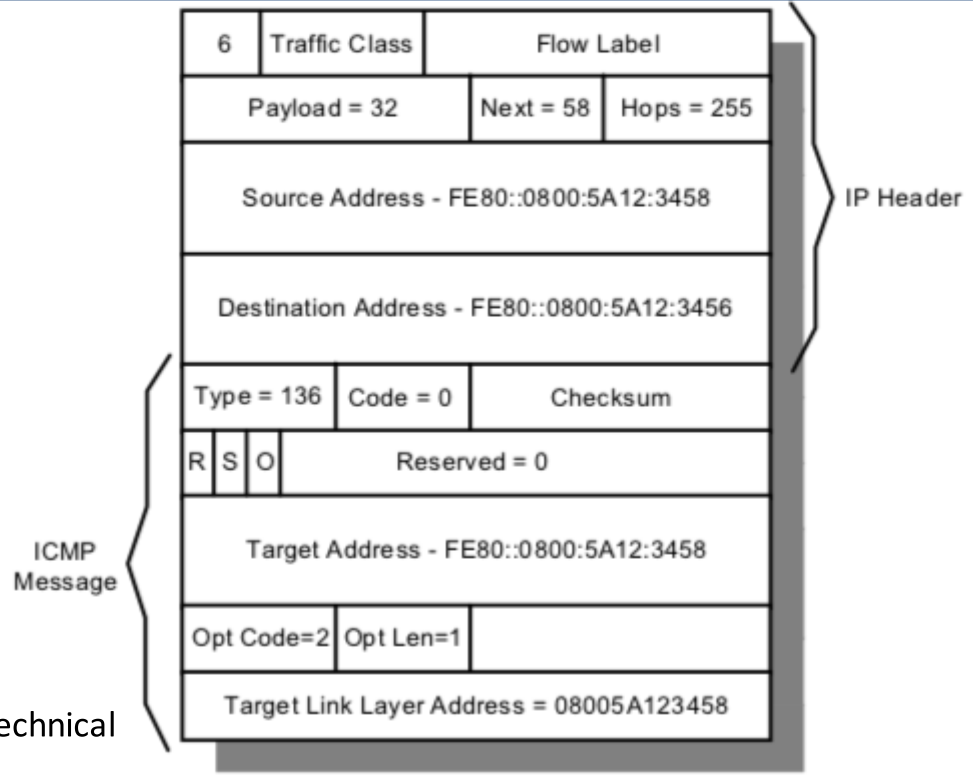


Image Source: IBM Redbook, TCP/IP Protocols and Technical Overview

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**

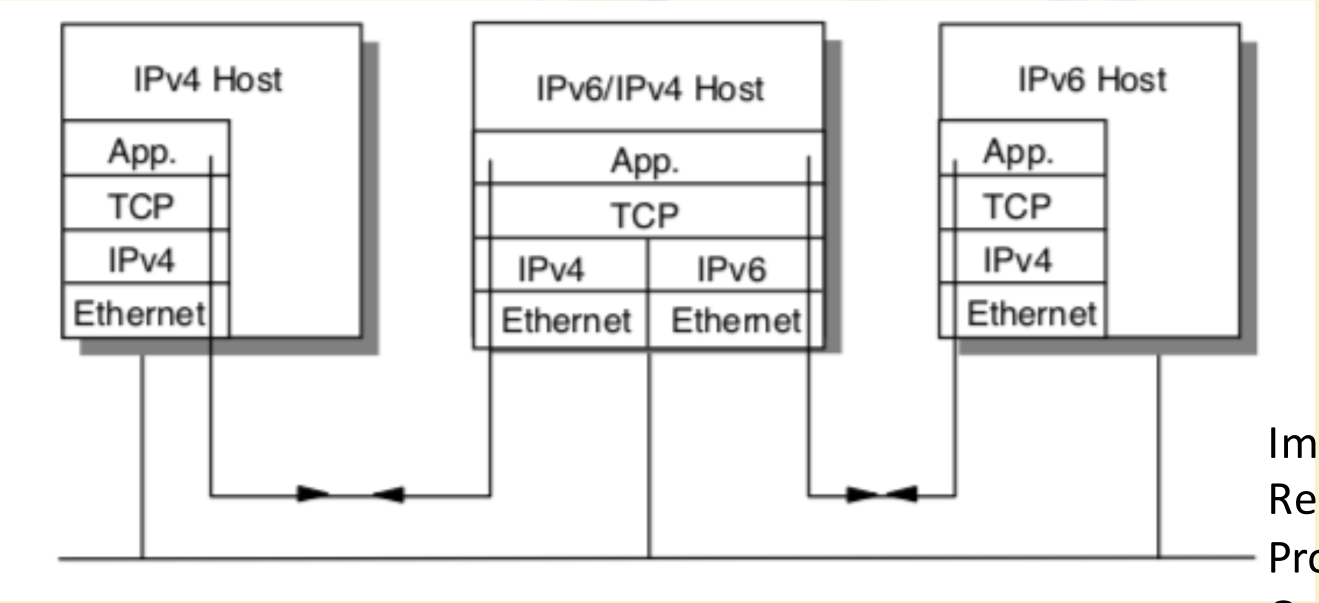


Image Source: IBM Redbook, TCP/IP Protocols and Technical Overview

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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