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CHAPTER # 04

Network Layer

→ Forwarding refers to router-local action of transferring a pkt from an input link interface to appropriate output link inter. (implement on hardware)
↳ short timescale

→ Routing refers to network wide process that determines the end-to-end path that pkt takes place from src → dest. (implemented on software)
↳ long timescale

↳ The algo that calculate these path is known as routing algo.

→ Forwarding Table tells a router which output interface to use to send a packet based on the incoming packets header fields.
↳ local, per router function → determines how datagram arriving on router input port is forwarded to router output port

→ Data Plane : Forwards data pkts based on existing routing table

→ Control Plane : Makes decision about where traffic should go
↳ network wide logic
determines how datagram is routed among routers along end-end path from src host to dest host

Date ~~Two central~~ plane approaches Day

- Traditional Control Plane Approach (Implemented on routers)
  - → Forwarding and routing are in the same router
  - → Each router runs its own routing algo and maintains its own forwarding table.
  - → Routers exchange routing info with each other using some protocols.
  - → Control is distributed ; every router is both a decision-maker and a packet forwarder
  - → complex, hard to manage.

→ software defined networking

- SDN Control Plane Approach (Implemented on server (remote))
  - → Seperation of concerns : Routing (decision-making) is moved to a central controller
  - → Routers only perform forwarding based on tables given by the controller
  - → Controller = brain ; routers = hands
  - → Control is centralized & programmable
  - → Easier management.

Date Day

SUBNETTING

octet

172 . 16 . 254 . 1 (dotted decimal notation)

10101100 00010000 11111110 00000001

8 bits

32 bit (4 bytes)

CLASSFULL ADDRESSING

→ 32-bit address divided into 2 parts.

→ |← 32-bits →|

prefix	suffix
n bit	32-n bits
Network ID	Host ID

→ In classfull addressing the address space is divided into 5 classes: A, B, C, D & E.

→ Each class occupies some part of address space.

→ To accomodate small & large network fixed length prefixes were designed.

→ Jese jese classes badhengi Net ID shrinks & Host ID expands

• CLASS A

Net ID = 8 bits   Host ID = 24 bits

→ 1^{st} bit of IP Address is reserved to 0

→ Range of 1^{st} Octet [0, 127] in dotted decimal notation.

→ total 255 mein se half i.e 128 class A ko milgaya.

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→ Agr 1st Octet ki phele bit '0' hai to hum max 127 tak hi jaa skte hai. (agr 1st bit k ilawa sab 1 kerdein)

0 1111111 → 127 class A

→ It means now 7 bits left.

→ $2^7 = 128$ → 128 Network ID can be there in class A.

→ Lekin 0.0.0.0 or 127.0.0.1 reserved hai

→ means hum 1st Octet mein 00000000 (0) & 01111111 (127) nhi rakh sakte.

→ 128 − 2 (reserved ones) = 126

→ So total Network ID's in class $\boxed{A \to 126}$

→ HOST ID bit are 24 so 2^{24} no. of host can be connected in class A

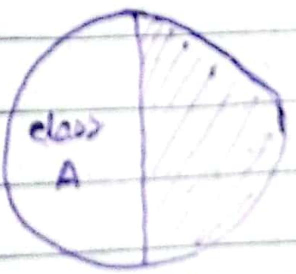
→ But no. of Host is always 2 less because of 2 reserved IP addresses.

↳ when all Host bits are 0, it represents Network ID for the network

↳ when all host bits are 1, it rep Broadcast Address.

→ So total Host ID = $2^{24} - 2$

↳ iska matlab har ek Network ID k liye $2^{24} - 2$ host ID hongi.



All IP Addresses

Date Day

- Class B

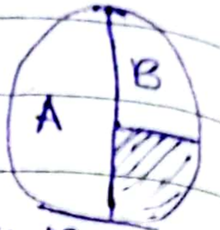
Net ID = 16 bits Host ID = 16 bit

→ 1st two bits will always be 10

→ Range of 1st Octet [128 - 191]

→ Jo 128 beche usmein se adhe

i.e 64 wo B ko milgaye 128+64 = 192



- Total Net IDs

$\overbrace{10\underbrace{\_\_\_\_\_\_\_}_{14\text{ bits}}\ldots}^{16\text{ bits}}$

↳ 1st two bits reserved

$\boxed{\text{↳ Total Net IDs} = 2^{14}}$

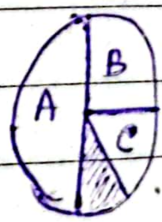
↳ ya koi reserved IP address nhi to minus 2 nhi hoga

- Total Host IDs

↳ Total 16 bits

↳ but here also there will be Network & Broadcast address therefore

$\boxed{\text{↳ Total Host IDs} = 2^{16} - 2}$



- Class C

Net ID = 24 bits Host ID = ~~8~~ 8 bit

→ 1st three bits will be 110

→ Range of 1st Octet [192, 223]

- Total Net IDs

$\overbrace{\underbrace{110}_{3}\underbrace{\_\_\_\_\ldots}_{21\text{ bits}}}^{24\text{ bits}}$

↳ 1st 3 bits reserved.

↳ Total Net IDs = 2^{21}

Day

- Total Host IDs → $2^8 - 2$

reserved for multicasting

- Class D & E (16 for each class)

Class D 1st 4 bits 1110 [224, 239]

class E 1st 4 bits 1111 [240, 255]

reserved for future use

→ Advantages of Subnetting
↳ It improves security
↳ The mentainance and administration of subnet is easy.

→ TYPES OF SUBNETTING
1. Fixed Length Subnetting
2. Variable Length Subnetting

1. Fixed Length Subnetting

→ Fixed Length Subnetting (classfull subnetting) divides the network into subnets such that:
↳ All the subnets are of same size
↳ All the subnets have equal no. of hosts
↳ All the subnets have same subnet masks

Date

Q: Consider the network having IP Addr 200.1.2.0
Divide this network into two subnets.

→ 1st Octet is 200 so class C
↳ Which means 1st 24 bits Network ID & last 8 bits Host ID

→ Net ID to same hi rhegi sabki.
→ Host ID change hogi sabki.

Subnet - 1	Subnet - 2
iski pehli 0 kradi 200.1.2.0 _ _ _ _ _ _ _ ye bit ab ek taraeqe se NetID mein include hogai	iski pehli 1 fix kradi 200.1.2.1 _ _ _ _ _ _ _ The no. of bits borrowed depends on no. of subnets created

→ Subnetting mein bit host ID se Net ID mein jaata hai

→ Agr 4 subnets banane hote to 2 bits transfer krte netID mein. bcz $4 = 2^{2}$

→ Agr 8 subnets banane hote to 3 bits.

→ Ab host ID ki range bani [0 - 127] 0 0000000 0 1111111	→ Host ID range bcms. [128 - 255] 1 0000000 1 1111111

is range mein se 2 minus krege ek Network address or doosra broadcast Address.

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Broadcast Address	Broadcast Address
= 200.1.2.01111111 = 200.1.2.127	= 200.1.2.11111111 = 200.1.2.255
Network Addr.	Network Add
= 200.1.2.0000000 = 200.1.2.0	= 200.1.2.1000000 = 200.1.2.128

Total No. of host

$= 2^8 - 2 = 128 - 2 = 126$

Fixed length tha is wajah se dono subnets ko 126 mile

[200.1.2.1, 200.1.2.126]	[200.1.2.129, 200.1.2.254]

→ Agr 4 subnets krne hote to sabko 62, 62 milte.

② Variable Length Subnetting

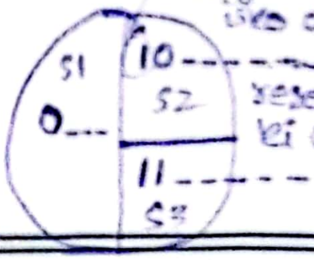
→ All subnets donot have same size

→ " " " " equal no. of host

→ " " " " same subnet mask

Q. Consider we have a big single network having IP Addr 200.1.2.0. We want to do subnetting and divide this network into 3 subnets, such that first contains 126 hosts, and other two 62 hosts each.

subnet#1 mein 0 hai to yaha 1. Ab mazeed isko divide krne kei 2nd bit reserve kardenge. ki 0 daare ki 1.



Date ________ Day

• Subnet#1 :

→ As it is of class C so host bits will be 8.

→ We will reserve the 1st bit

→ 200.1.2.0_ _ _ _ _ _ _   } 0 krne se 50% address space milgaya.

→ Broadcast Address 200.1.2.0 1111111

200.1.2.127

→ Network Address 200.1.2.0 0000000

200.1.2.0

[200.1.2.1 , 200.1.2.126] Host ID range

Subnet mask 255.255.255.128 → 25 bits reserved for NetID
10000000

• Subnet#2 :

→ Yaha par bhi 8 bits hai lekin 1st reserved hai S1 ki wajah se.

→ Ab mazeed divide krne kliye 2nd bhi reserve krdenge.

→ 200.1.2.10_ _ _ _ _ _

→ Broadcast 200.1.2.10111111 = 200.1.2.191

→ Network 200.1.2.10000000 = 200.1.2.128

[200.1.2.129, 200.1.2.190]

Subnet mask 255.255.255.192   26 bit for NetID
11000000

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- Subnet #03

→ Yaha par bhi 8 bits

200.1.2.11 _ _ _ _ _ _

→ Broadcast 200.1.2.11111111 = 200.1.2.255

→ Network 200.1.2.11000000 = 200.1.2.192

[200.1.2.193, 200.1.2.254]

- Subnet Mask

→ Classfull Addressing mein humein clearcut pta hai k kitne bit ka NetID hai or kitne bit ka Host ID.

→ Leken Subnetting k baad NetID change hojata hai.

→ Jitne bits bi NetID uthne 1's baaqi sab 0's

→ Agr 25 bit is Net ID then

1111111111111111111111111 0000000

$\underbrace{255.255.255.128}_{\text{Subnet mask.}}$

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▷ CIDR (Classless Addressing)

→ No classes.
→ Only Blocks

28	4
Block ID	Host ID

←32→

x.y.z.w/n

200.10.20.40/28 → Iska mtlab 1st 28 bits represent Net ID / Block ID

11111111.11111111.11111111.11110000
255 . 255 . 255 . 240

Iska network address nikalne k liye Subnet mask ko AND kodo with IP Address

we get 200.10.20.32/28 → Net/Blk ID

→ VLSM in CIDR
→ 245.248.128.0/20

S1	S2
	S3

Subnet #01

→ 245.248.1000|0|00.00000000

Net ID — Host ID

isko fix kardeg

~~New Net ID~~
New Net ID

245.248.128.0 — 245.248.135.255 /21

245.248.10000|11.11111111

fixed

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→ Two devices can communicate each other if they have same Net ID.

- 10.10.10.1 255.0.0.0
  10.10.20.16
  ↳ indono ki NetID 10.0.0.0 (so belong to same network)

- 10.10.10.1 255.255.255.0
  10.10.20.16
  ↳ 10.10.10.0
  ↳ 10.10.20.0 > diff NetID (so belong to diff netw)

→ STEPS FOR SUBNETTING

1. Identify the class of IP Addr & note the default subnet Mask
2. Convert default subnet mask into binary
3. Note the no. of hosts req/ per subnet & find the subnet generator (SG) & octet position
4. Generate new subnet mask
5. Use the SG & generate the network ranges in appropriate octet position.

128 64 32
1 1 1 0 0

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Q: Subnet the IP Addr 196.10.20.0 into 52 host in each subnet

(1) Class C → 255.255.255.0

(2) 255.255.255.00000000

(3) No. of host / subnet = 52 (110100 – 6 bits)

↳ Now reserve 6 0's from LSB

.11000000

remaining will be 1's

SG → 64 (value of 1st one encountered from left to right)

octet → Jaha SG occur hoga i.e $\boxed{\text{4th octet}}$

(4) 255.255.255.192 or /26 → 2 extra 1's reserve krdie

(5) Network ranges

196.10.20.0 – 196.10.20.63
2+SG
196.10.20.64 – 196.10.20.127
2+SG
196.10.20.128 – 196.10.20.255

~~[illegible]~~

hamari octet position 4 hai to SG bhi 4 mein add hoga.

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Q: Subnet the IP Addr 150.15.0.0 int 500 host in each subnet.

① class B → 255.255.0.0
255.255.00000000.00000000

② No. of host / subnet = 500 (111110100 – 9 bits)

③ 255.255.1111111**1**0.00000000

SG → 2 , octet → 3
↳ woe agr Left to right krein to 512 hai but it is not a valid IP. to humne new octet se start kraa.

④ 255.255.254.0 or /23

⑤ Network Ranges.

150.15.0.0 – 150.15.1.255
150.15.2.0 – 150.15.3.255
150.15.4.0 – 150.15.5.255
150.15.6.0
⋮

2^9 = 512-2 Host / Subnet
2^7 = 128 Subnets

.11110000
01000001
010
.64

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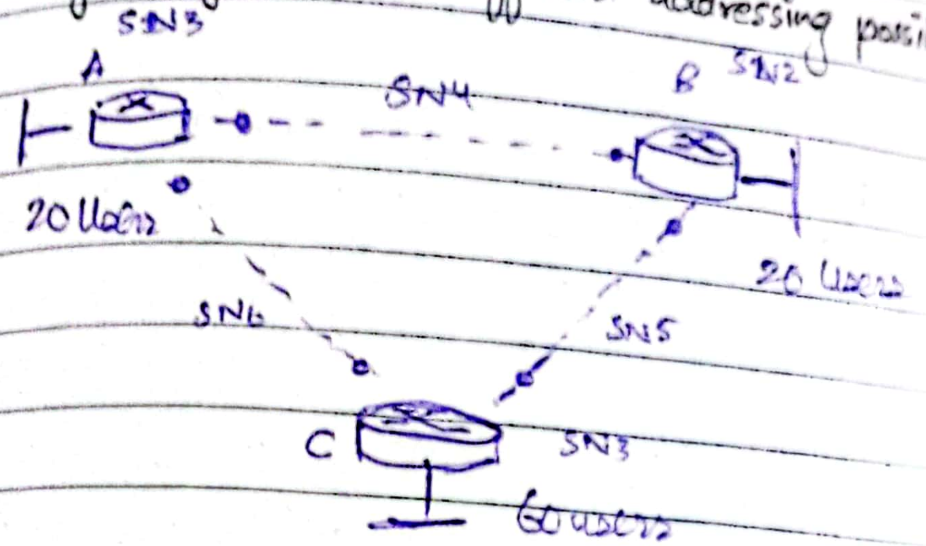
VLSM Questions :

Q: Subnet 192.168.10.0/24 to address the network by using the most efficent addressing possible



→ There are total 6 Network
→ Start with largest subnet. i.e C

① Class C → 255.255.255.0
② 255.255.255.00000000
③ No. of host / subnet → 60 (111100 - 6 bits)
255.255.255.11000000
SG = 64 , Octet = 4
④ 255.255.255.192 or /26 (Only For C)

⑤ Network ranges
192.168.10.0 — 192.168.10.63 /26 (C)
192.168.10.64 → Starting address of A

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Now for A

No. of host / subnet → 20 (11000 – 5 bits)

255 . 255 . 255 . 11100000

SG = 32   Octet = 4

192.168.10.64 – 192.168.10.95 /27 (A)

192.168.10.96 – Starting of B

Now for B

→ It also has same host req.

192.168.10.96 – 192.168.10.127 /27 (B)

128

Now for links (unke sibke liye 2,2 IP chahiye)

No. of hosts → 2 (10 – 2 bits)

~~SG~~ — .11111100

SG = 4 , Octet = 4

192.168.10.128 – 192.168.10.131 /30

192.168.10.132 – 192.168.10.135 /30

192.168.10.136 – 192.168.10.139 /30

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Q: There are 3 departments.

- Development — 120 PC's
- Finance — 35 PC's
- HR — 10 PC's

SG

Network Address → 200.16.100.0/24

For Development:

→ Subnet 255.255.255.00000000

→ No.of Hosts → 120 (1111000 – 7 bits)

255.255.255.10000000

SG = 128 G = 4

Network range

[200.16.100.0 – 200.16.100.127/25]

- Network Add = 200.16.100.0/25
- Broad cast Add = 200.16.100.127/25
- Usable Host [200.16.100.1/25, 200.16.100.126/25]

For Finance:

→ No.of Host → 35 (100011 – 6 bits)

----- .11000000 SG = 64, G = 4

Network range

[200.16.100.128 – 200.16.100.192] /26

- Network Add = 200.16.100.128/26
- Broad cast Add = 200.16.100.192/26
- Usable Host [200.16.100.129/26, 200.16.100.190/26]

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For HR:

No. of Host → 10 (1010 - 4 bits)

------ .11110000   86 = 16

Network Ranges

[200.16.100.192 - 200.16.100.207] /28

- Network Addr = 200.16.100.192 /28
- Broadcast Addr = 200.16.100.207 /28
- Usable Host [200.16.100.193 /28 , 200.16.100.206 /28]

Q: No. of Departments → 3

- CS — 90 PC's
- EE — 50 PC's
- BBA — 20 PC's

Network Addr 195.168.10.0 /24

- For CS

No. of host = 90 (1011010) - 7 bits

Network range

[195.168.10.0 - 195.168.10.127] /25

For EE

No. of host = 50 (110010) - 6 bits

[195.168.10.1...

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▸ Network Service Model

↳ Internet "best effort" service model

↳ No guarantees on:

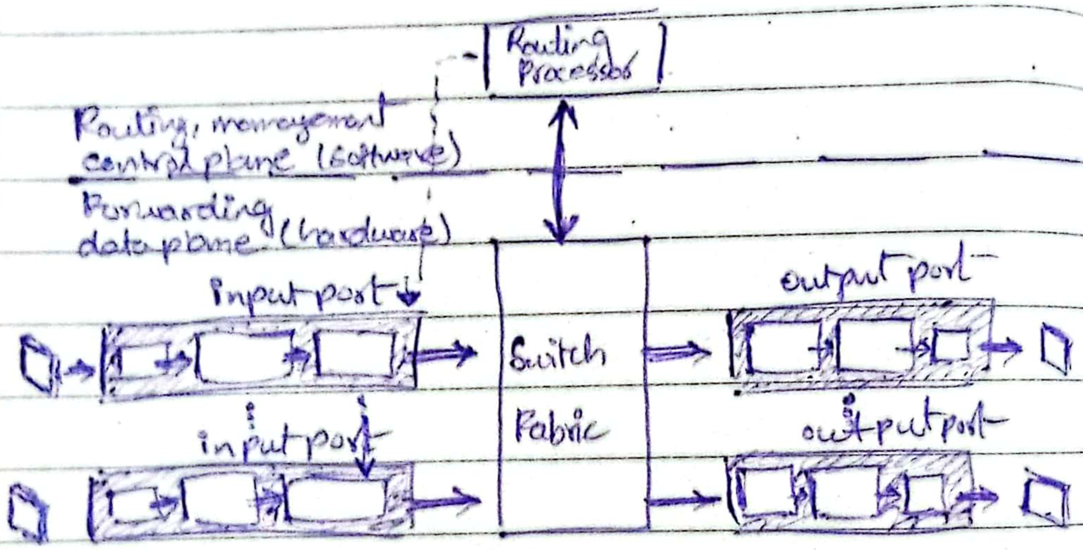
i- Successful datagram delivery to destination

ii- timing or order of delivery

iii- bandwidth available to end-end flow.

↳ Simplicity of mechanism has allowed internet to be widely deployed adopted.

▷ ROUTER :



▲ Router's architecture

Routing Processor: It performs control plane function

↳ Traditional Routers: Executes routing protocols, maintains routing table and computes forwarding table for router

↳ SDN Router: Responsible for communicating with remote controller in order to receive forwarding table enteries computed by

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remote controller and install these entries in router's input port.

→ Longest Prefix matching

↳ When looking for forwarding table entry for given destination address, use longest address prefix that matches destination address

"THE INTERNET PROTOCOL (IP)"

▷ IPV4 Datagram Structure

32-bit

Version	Header length	Type of Service	Datagram length	
16-bit Identifier			Flags	13-bit fragmentation offset
TTL		Upper layer protocol	Header Checksum	
32-bit source IP Addr				
32-bit Destination IP Add				
Options (if any)				
Data				

Maximum length 64KB
Typically: 1500 bytes or less

- Version: Specifies the IP protocol version (like 4 or 6)
- Header Length: Indicates where payload starts
- Type of Service: Suggests priority & handling of pkts
- Total length: Specifies total size of the IP datagram
- Identification: Helps in reassembling fragmented datagm.

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- Flags : Controls & identifies datagram fragments.
- Fragment offset : Indicates position of the fragment in original datagram
- Time To Live (TTL): limits datagram lifespan to avoid infinite loops
- Protocol : Indicates which transport layer protocol to deliver
- Options : Allows for special control and testing feature

Overhead —
20 bytes TCP + 20 bytes IP = 40 bytes + application layer overhead

▷ Hierarchical Addressing :
The ability to use single prefix to advertise multiple networks is often reffered to as address aggregation (route aggregation or route summarization)

→ ISPs advertises a single larger block (eg: 200.23.1… that represents multiple smaller networks to reduce routing table size
→ 200.23.16.0/20 will then contain multiple organi…
→ When an organization moves from one ISP …

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another ISP ken there is problem. As each ISP have different network bits.

→ ISP1 (200.23.16.0/20) ← Org 0 (200.23.16.0/23)
← Org 1 (200.23.~~20~~.0/23)

→ ISP2 (199.31.0.0/16) ←

Ab jab Org1 ISP2 mein jayega to ISP2 (199.31.0.0/16) or (200.23.20.0/23) dono ko advertise krega.

→ To longest prefix matching se pkts ISP2 mein aaj aajyenge.

- Broadcast Address:

→ Every subnet or network has a broadcast Address in which all host bits are 1.

→ Agr kisi subnet k tamam host ko msg bhejna ho to we use broadcast addr.

- ICANN (Internet Corporation for Assigned Names & Number)
  - ↳ allocates IP Addresses
  - ↳ manages DNS root zones

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▷ DYNAMIC HOST CONFIGURATION PROTOCOL :

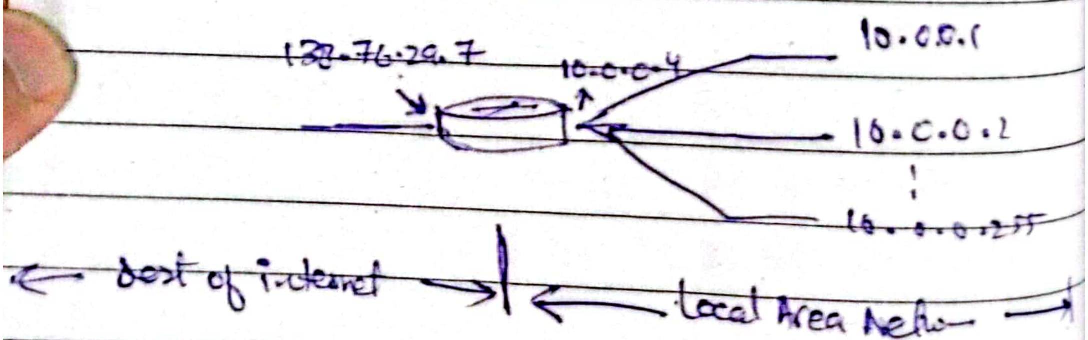
- ↳ Assigns a temporary IP Add's to each host that req an IP.
- ↳ Also tells the subnet mask, default gateway and Local DNS server.
- ↳ It is also called plug-and-play or zeroconf.
- ↳ Support for mobile users who join leave network

• Steps:

1. Host broadcast DHCP discover msg [optional]
2. DHCP server responds with DHCP offer msg [optional]
3. Host requests IP address : DHCP request msg
4. DHCP server sends address : DHCP ACK msg

↘ agr multiple DHCPOFFER ayengi to jo sabse phele receive hogi wo accept hogi by the client

▷ NETWORK ADDRESS TRANSLATION :



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→ All devices in LAN share just one IP address as far as outside world is concerned.

→ All datagram leaving local network have same source NAT IP Address 138.76.29.7, but different source port #

→ All devices in LAN have 32-bit address in a "private IP" address space that can only be used in local network

10.0.0.0 /8

172.16.0.0 /12

192.168.0.0 /16

→ ADVANTAGES:

↳ Just one IP Address needed from provider ISP for all devices

↳ can change address of host in LAN without notifying outside world

↳ can change ISP without changing addresses of devices in local network

↳ security: devices inside LAN not directly accessible

→ NAT Translation Table

NAT translation table	
(WAN IP, new PORT#)	(Private IP, orig port #)

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→ Controversies

↳ Routers should only process upto layer 3

↳ Address shortage should be solved by IPV6

↳ PORT # manipulation by Network layer

▷ IPV6

Version	Traffic Class	Flow label	
Payload length		Next Hdr	Hop limit
Src Addr (128 bit)			
dest Addr (128 bits)			
Data			

Traffic class → indicates priority or class of traffic

Flow Label → Label pkts in same flow

Next Header → Same as protocol in IPV4

Hop limit → Limits no. of hops a pkt can take
(similar to TTL)

✗ Fragmentation: handled by hosts only

✗ Header Checksum: Removed to speed up processing
↳ redundant

✗ Options field

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▷ Transitioning From IPV4 to IPV6

↳ Most of the current internet infrastructure is IPV4

↳ Old IPV4 devices can't handle IPV6 datagram

↳ ~~A complete sudden swi.~~

↳ Tunneling

↳ Encapsulates an IPV6 datagram inside the payload of an IPV4 datagram.

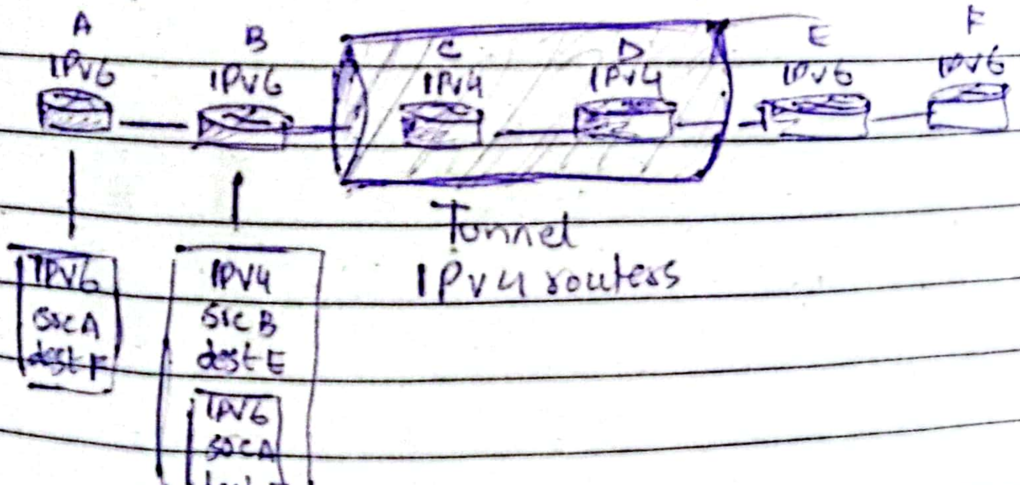
↳ How it work?

1. The sender IPv6 node encapsulates the IPV6 datagram in an IPV4 datagram

2. This IPv4 datagram is sent accross a tunnel (a path of IPV4 routers) to the receiver IPV6 node

3. The receiver extracts the original IPv6 datagram and process it normally

↳ IPv4 protocol field: set to 41 indicating the payload is an IPV6 datagram.



▷ Middle boxes

↳ Any intermediary box performing funcs apart from normal, std func of an IP router on the data path b/w src & dest

▷ GENERALIZED FORWARDING

→ Jese tradional routing mein forwarding table hota hai, yaha par flow table hota hai.

→ Structure of table

Rule	Action	Stats
:	:	:
:		

• Rule: Har table mein kuch predefined rules honge agr wo rules match kr jaate hai to wo action perform hojayega.
Gye rules Header fields ko dekh kr bante hai

Ingress port	src MAC	dest MAC	Eth Type	VLAN ID	VLAN Pri	IP src	IP dest	IP Proto	IP ToS	TCP sport	TCP dest Port
input port of router	Link layer					Network layer				Transport layer	

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- Action:
  - ↳ Forward packet to port(s)
  - ↳ Drop packet
  - ↳ Modify field in headers
  - ↳ Encapsulate & forward to controller

- Stats
  Packet + byte counter

→ Ek priority bhi set hoti hai har entry ke liye of the flow table
  ↳ Agr ek header multiple rule se match hoga, to priority high wala execute hoga.

→ This structure can emulate different kind of devices

① Router
  ↳ match: longest destination IP prefix
  ↳ action: forward out a link

② Switch:
  ↳ match: destination MAC addr
  ↳ action: forward

③ Firewall:
  ↳ match: IP address or PORT #
  ↳ action: permit or deny.

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- NAT :
  - ↳ match : IP Addr & PoRT
  - ↳ action : Rewrite addr & port

See example from slide pg # 64.

→ Ye flow table OpenFlow protocols k thru R. ek (or more) ~~[illegible]~~ remote controllers k zariye routers mein install kiye jate hai.

▷ IP Fragmentation / Reassembly

→ Network links have MTU (largest possible link layer frame

→ Agr Datagram ko size MTU se zyada hojaye toh Datagram is divided into small parts.

→ Then it is reassemble at destination only.

4000 byte datagram < ~~3980 data~~ / 20 bytes header

MTU = 1500 bytes

→ The 1st fragments carries bytes 0 to 1479.
  ↳ Offset → 0/8 = 0, frag flag = 1

→ 2nd fragment 1480 to (1480+1480) = 2959
  ↳ Offset 1480/8 = 185, frag flag = 1

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→ 3rd fragment carries 2960 to 2999.
↳ Offset 2960/8 = 370, frag flag = 0

if it's zero means
it is last fragment