CS3.301 Operating Systems and Networks

Networking - Network Layer

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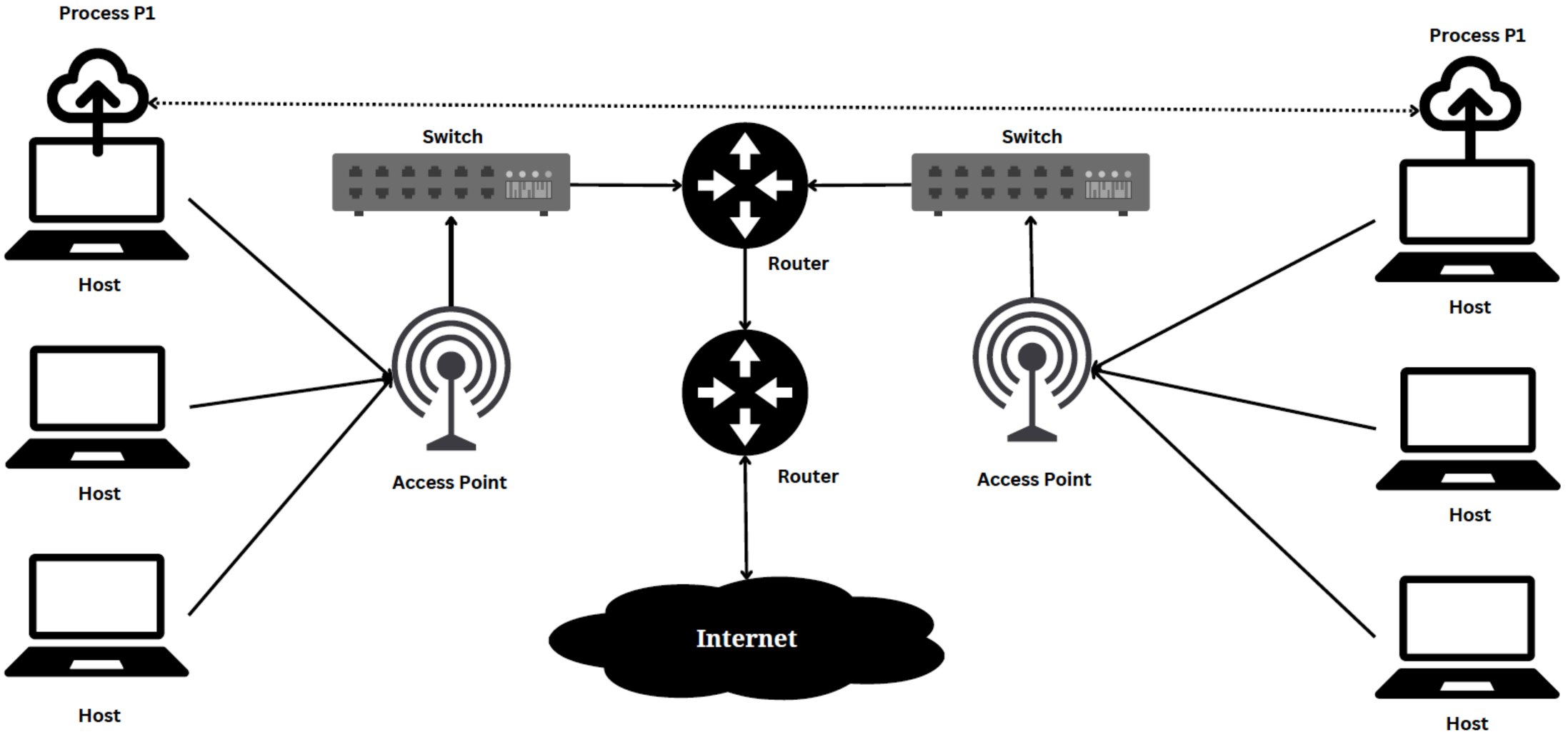
Acknowledgement

The materials used in this presentation have been gathered/adapted/generate from various sources as well as based on my own experiences and knowledge -- Karthik Vaidhyanathan

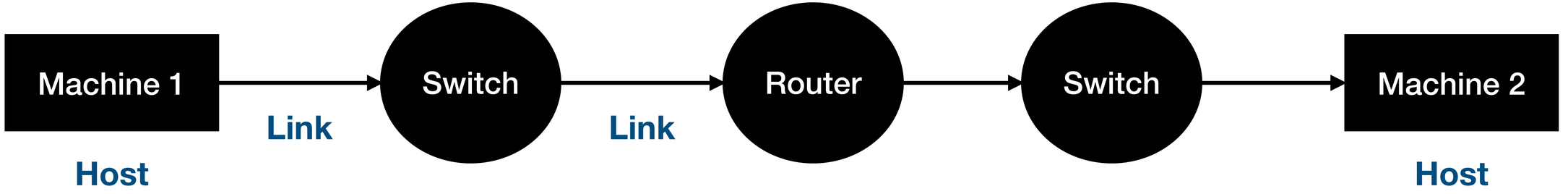
Sources:

- Computer Networks, 6e by Tanebaum, Teamster and Wetherall
- Computer Networks: A Top Down Approach by Kurose and Ross
- Computer Networking essentials, Youtube Channel
- Other online sources which are duly cited

The Bigger Picture



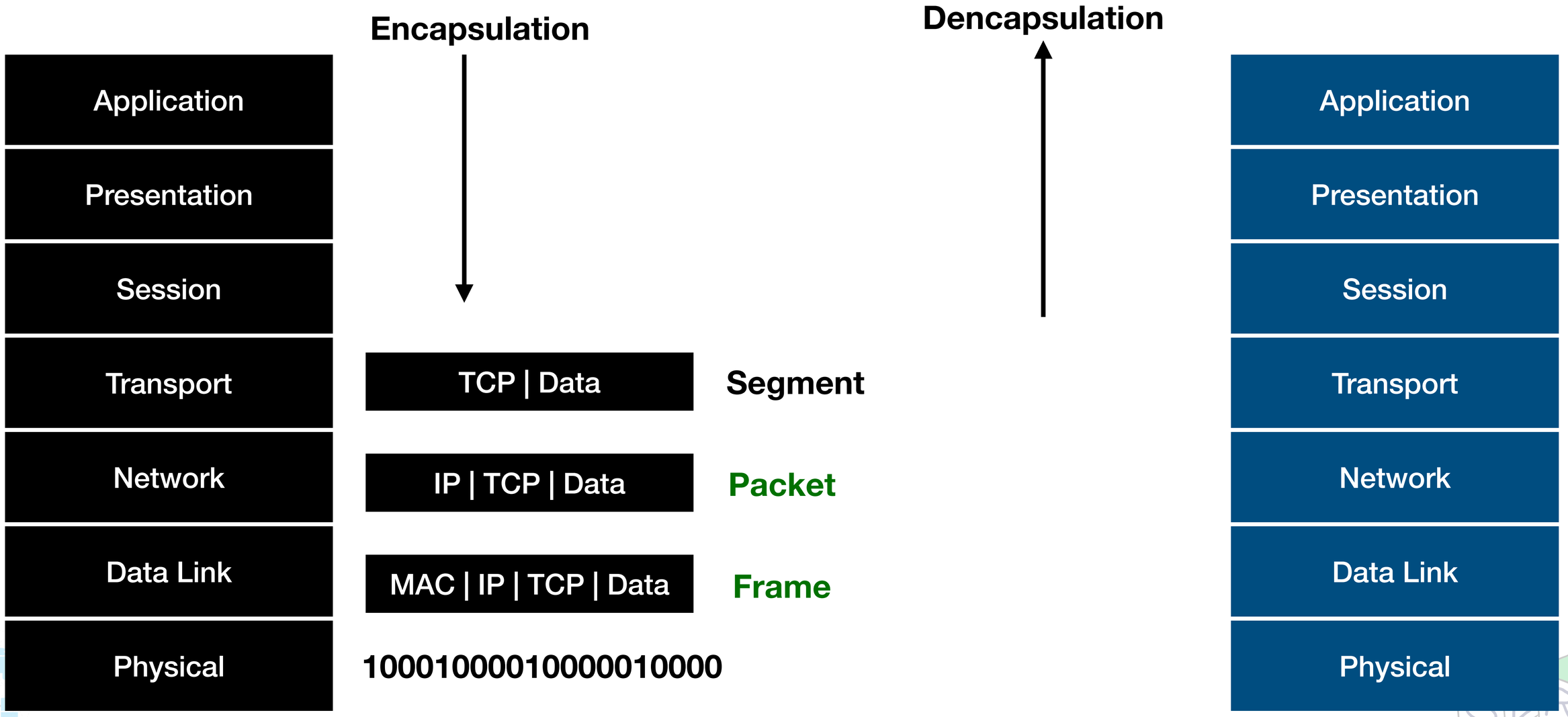
Remember the Components?



What we have seen so far

- **Application layer**
  - Provides support for end applications to format and manage data
  - HTTP, DNS, SMTP, etc.
  - In turn they make use of transport layer protocols
- **Transport layer**
  - Provides support for communication between services
  - TCP, UDP
  - Ports helps in identifying the right services/process
  - But transport layer by itself is not enough! - **Requires underlying support - Why?**

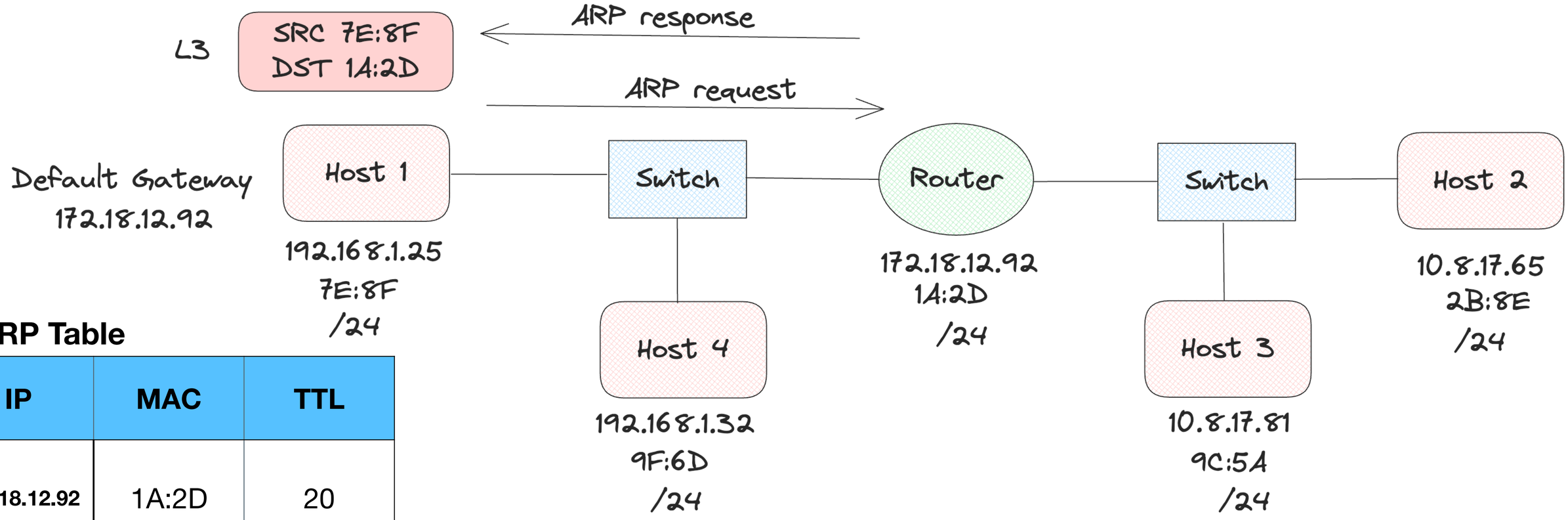
Putting It Together



Subnets

- Practice of dividing a network into one or more networks is subnetting
- Allows to create hierarchy within an organisation
  - Think about 172.18.21.x (country.organization.department.machine)
  - Another set of IP within organisations 172.18.y.x
- Consider an IP address 172.18.21.0 with a subnet mask of 255.255.255.0 or /24
  - Implies one network that can contain 254 host addresses (only the last one can change)
  - /24 - CIDR Notation (Classless Inter domain routing) - Number of 1s in the address
  - **What about subnet mask 255.255.0.0? Or /16?**

Link Layer Working



ARP Table

IP	MAC	TTL
172.18.12.92	1A:2D	20

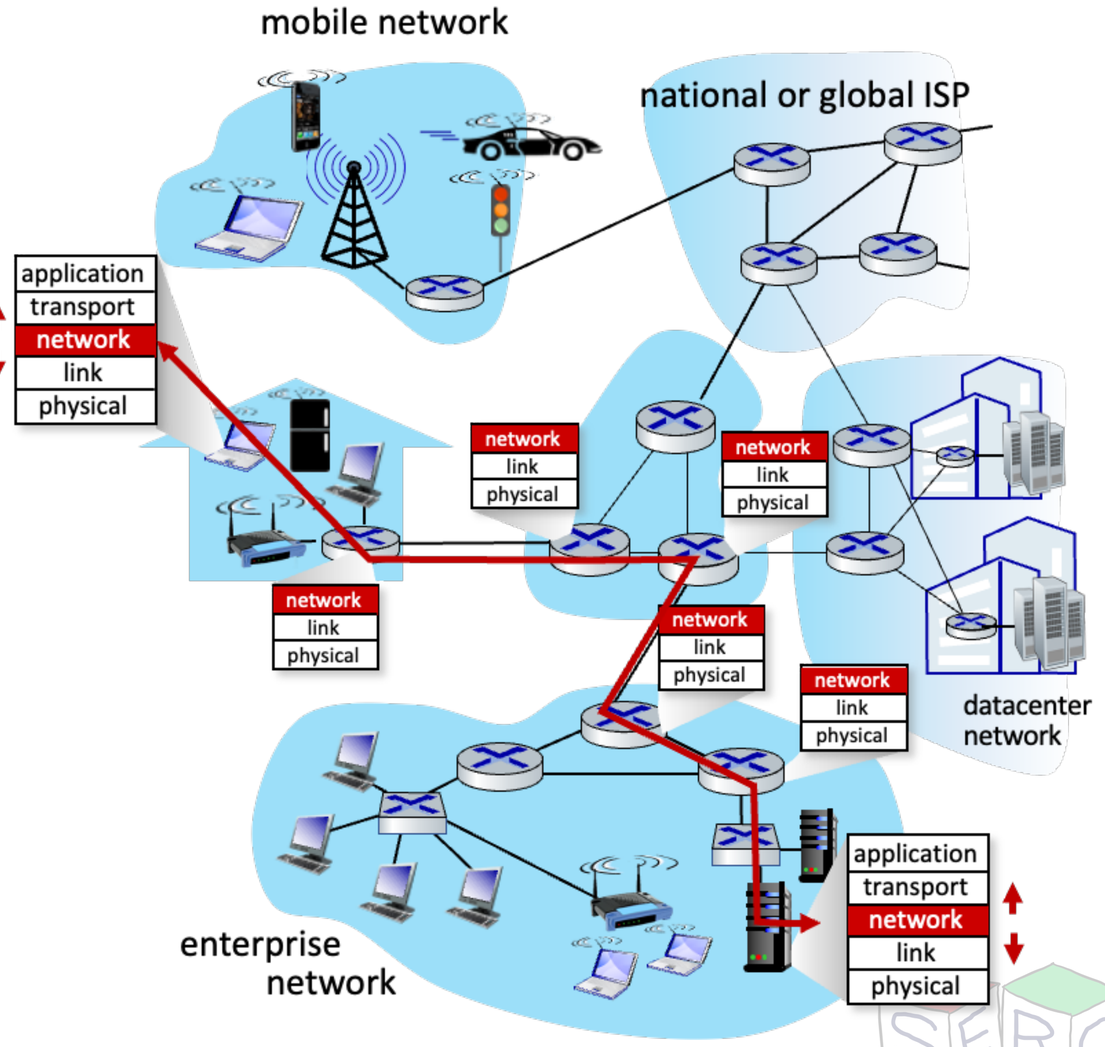
- The ARP process needs to happen only once, since router is the gateway
- First step - Check if the IP of the receiver is in the same or different network
- If different network => Send ARP to gateway else, send ARP to all nodes in the network (FF:FF….:FF)

How does end-to-end communication work?

What is the role of the network layer?

Network Layer - Functionalities

- Plays key role in end-to-end communication
  - Link layer is concerned about just hop to hop
- Transport segment from sending to receiving host
  - **Sender:** Encapsulates segments into datagrams, passes to Link layer
  - **Receiver:** Delivers segments to transport layer protocol
- Network layer protocols in every internet device
  - Hosts and routers



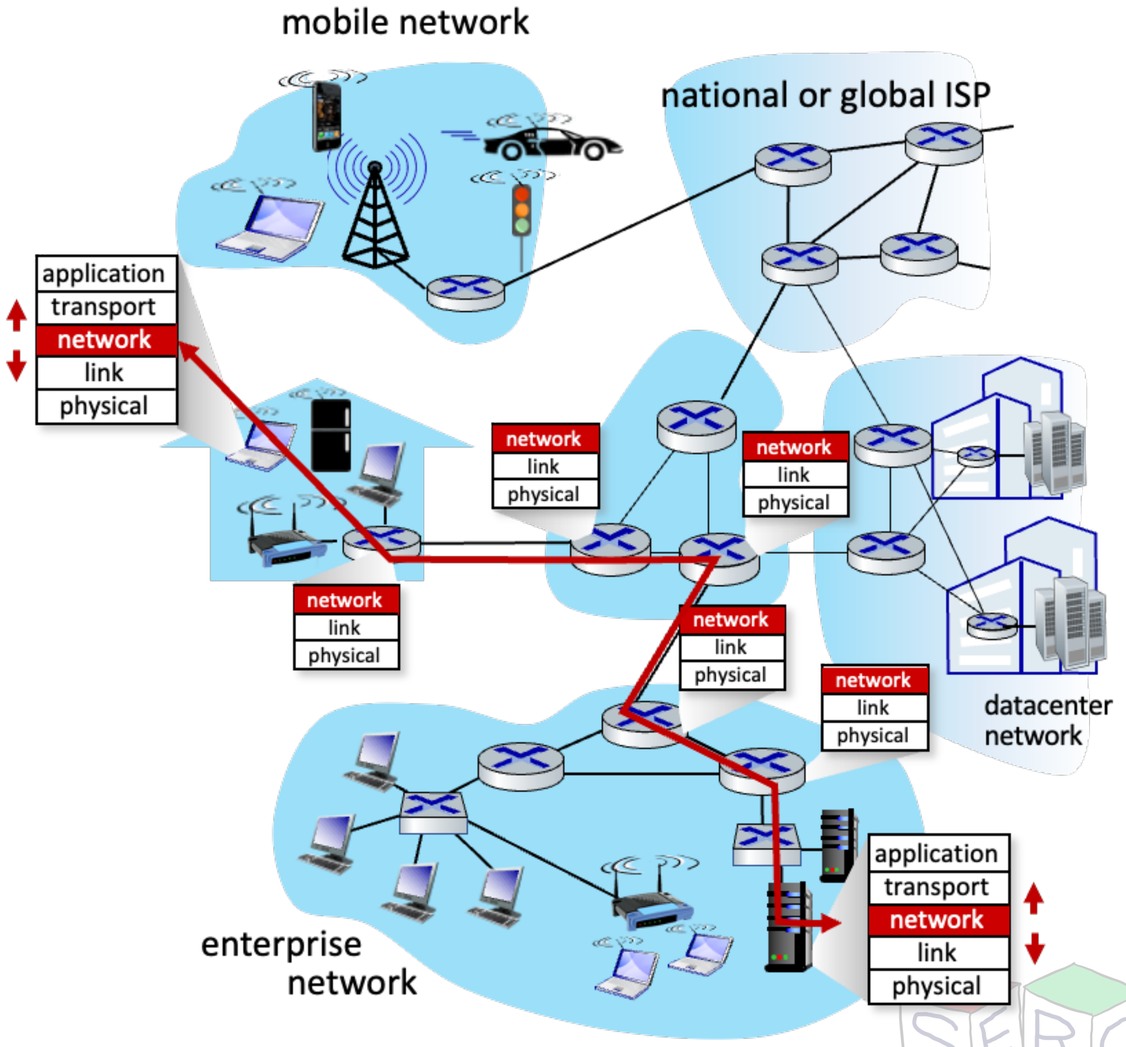
Network Layer - Functionalities

Addressing

- Devices in network are assigned logical address for unique identification - IP
- Network layer uses IP to forward packets to the intended destinations

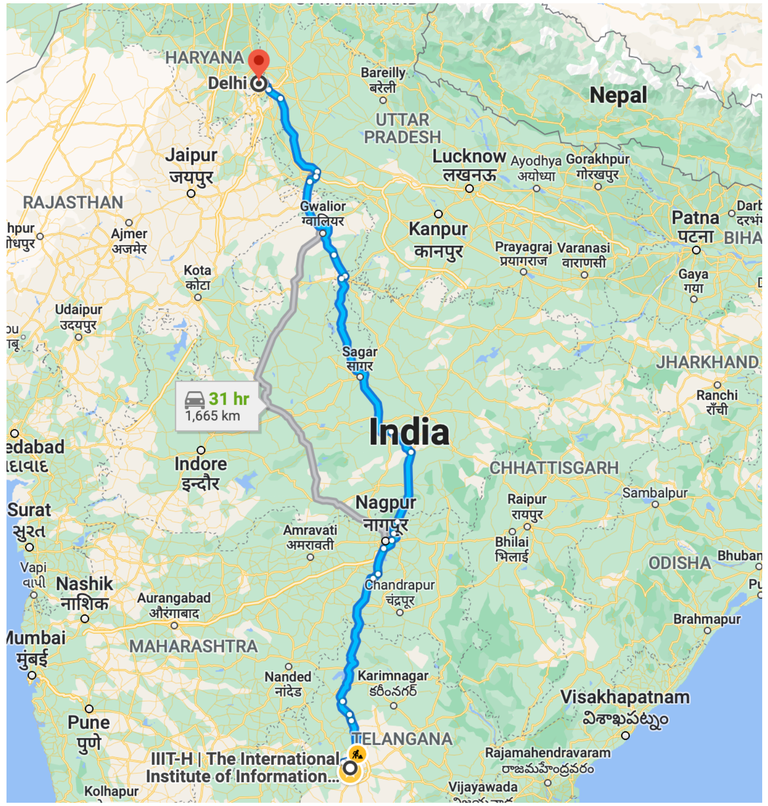
Route Determination

- Identifies best path for packets to reach to destination
- This process is dynamic and changes based on network conditions



Two Key Network Layer Functions

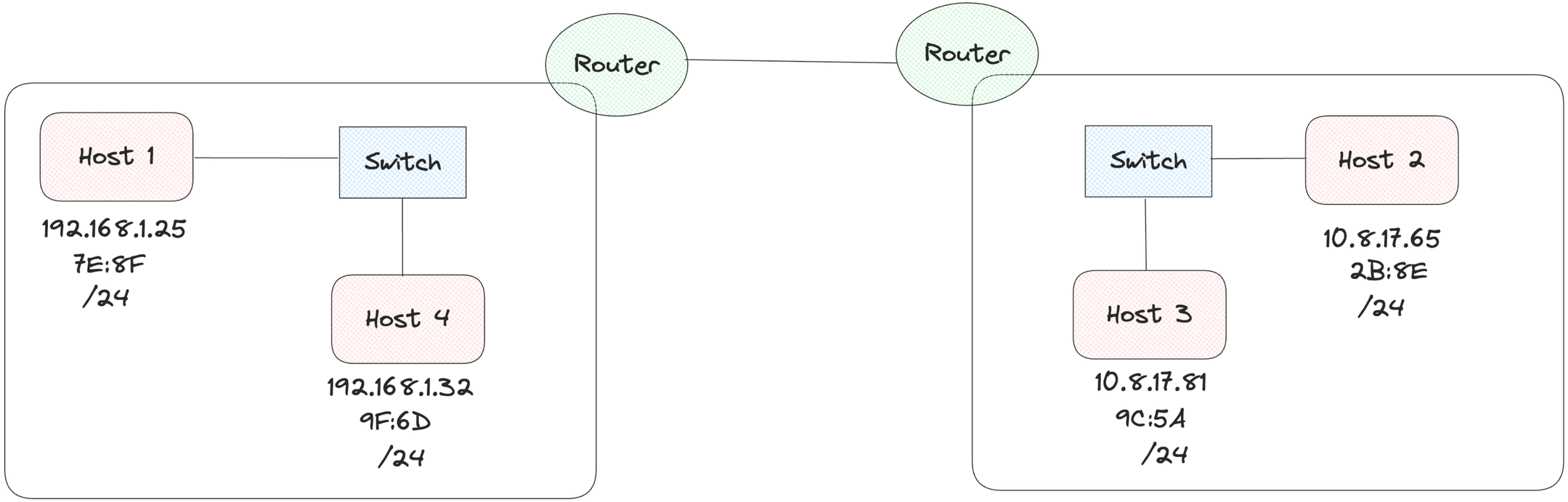
Forwarding (Interchanges)



Routing (Source to destination route)

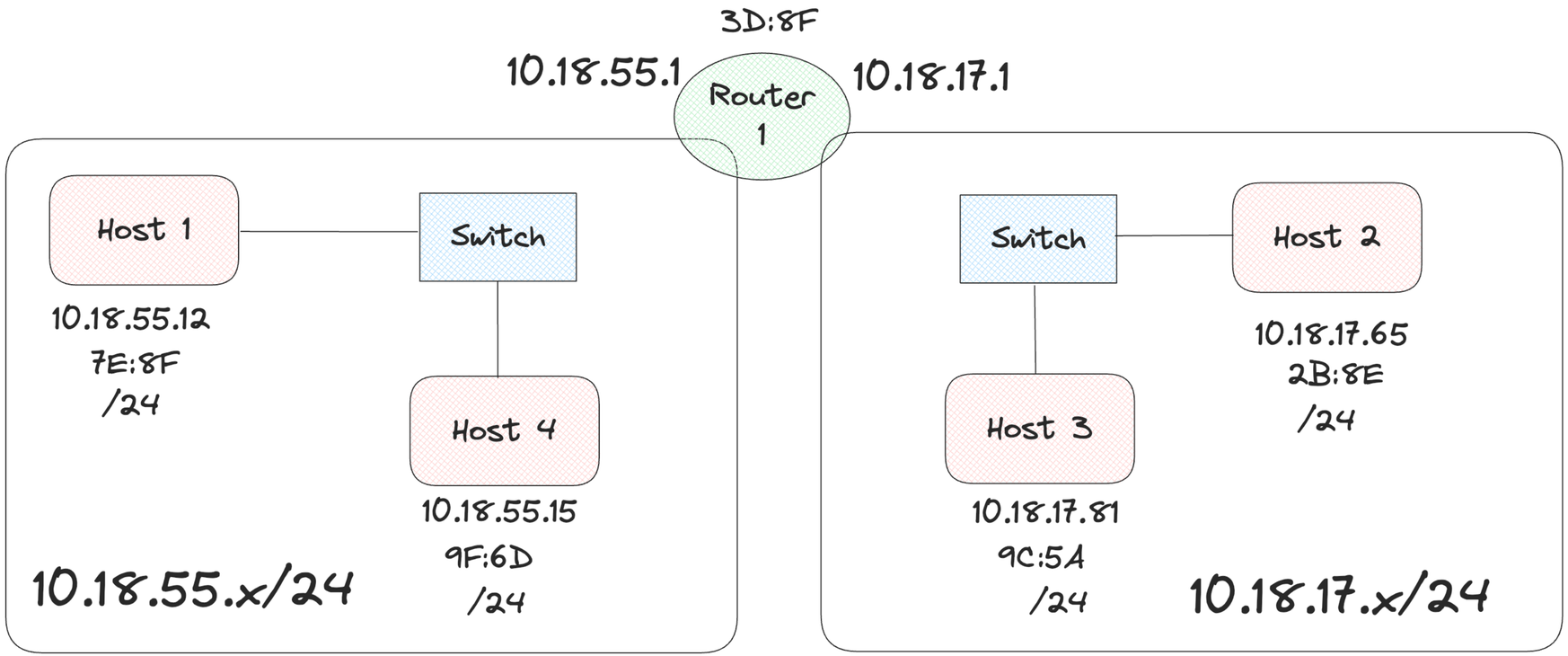
- **Forwarding**
  - Move packets from routers input link to output link
- **Routing**
  - Determine route to be taken by packets from source to destination

Routers - Devices in L3 that makes things happen



- Routers are connected to a network (have IP and MAC)
- Routers are node that **forwards packets** not explicitly addressed to itself
- Hosts are any nodes that are not a router (RFC 2460, IPV6) - They can discard packets

More about Routers

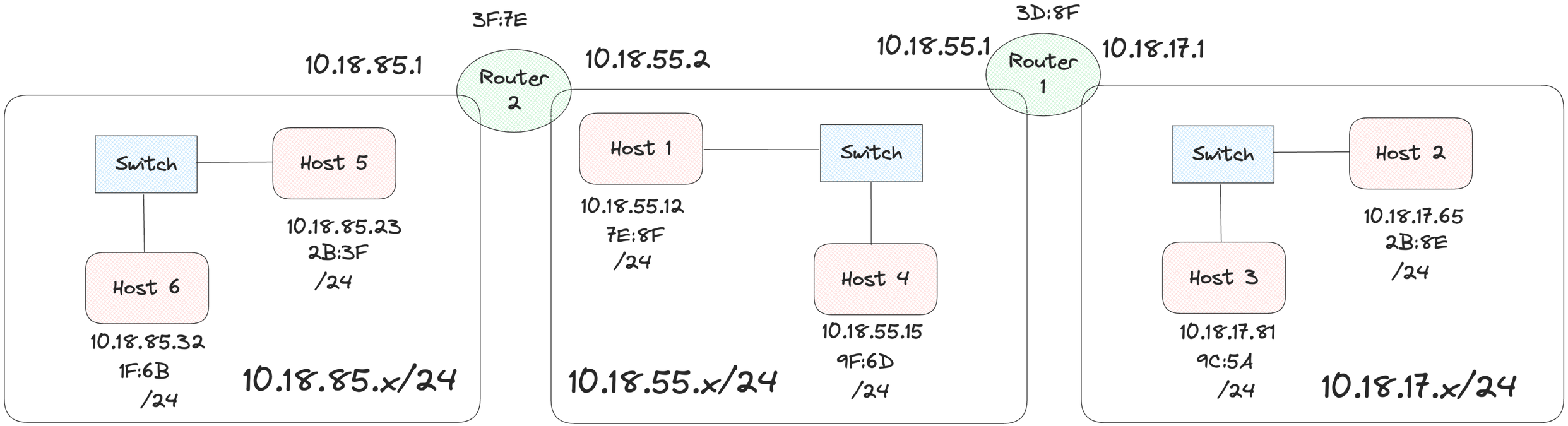


Router 1 routing table

Destination	Interface
10.18.55.x/24	Left
10.18.17.x/24	Right

- Routers maintain a map of all networks they know about
  - **Routing Table**: Used by routers as a map to connect to the networks they know about given the destination IP
  - **Note** the table is just a sample, in reality instead of left and right it can be eth/0, eth/1, etc.

Simple Example



Destination	Interface
10.18.85.x/24	Left
10.18.55.x/24	Right

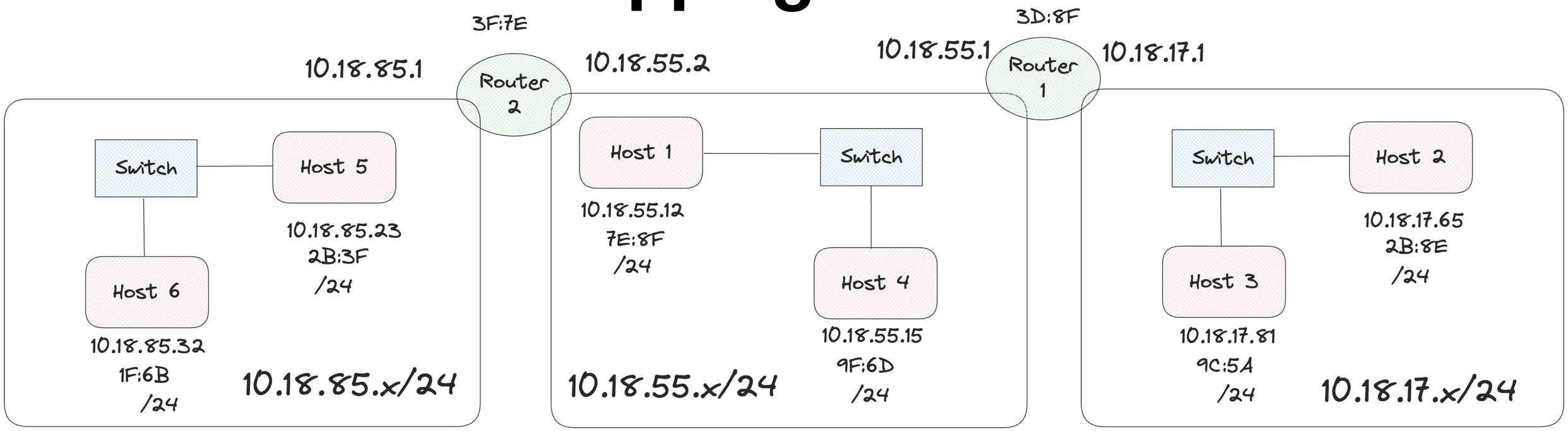
Router 2 routing table

Destination	Interface
10.18.55.x/24	Left
10.18.17.x/24	Right

Router 1 routing table

How can Host 6 communicate with Host 2?

Admin can add mappings to table!



Type	Destination	Interface
DC	**10.18.85.x/24**	Left
DC	**10.18.55.x/24**	Right
Static	**10.18.17.x/24**	10.18.55.1

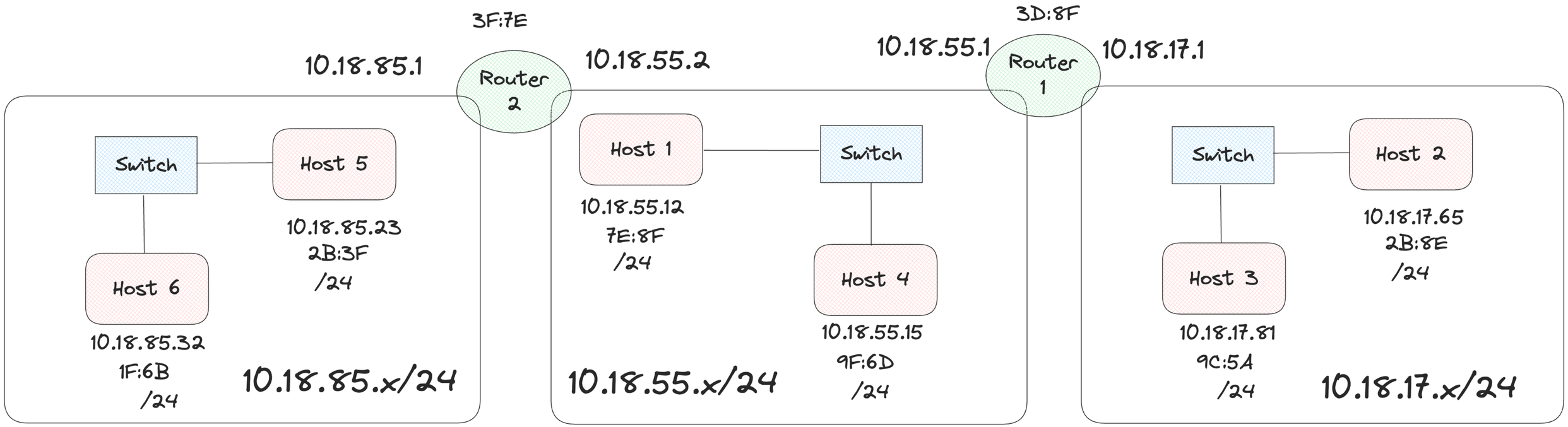
Router 2 routing table

Type	Destination	Interface
DC	**10.18.55.x/24**	Left
DC	**10.18.17.x/24**	Right
Static	**10.18.85.x/24**	10.18.55.2

Router 1 routing table

Admin can add it!!

What if Routers can learn by themselves?



Type	Destination	Interface
DC	**10.18.85.x/24**	Left
DC	**10.18.55.x/24**	Right
Dyn	**10.18.17.x/24**	10.18.55.1

Router 2 routing table

Type	Destination	Interface
DC	**10.18.55.x/24**	Left
DC	**10.18.17.x/24**	Right
Dyn	**10.18.85.x/24**	10.18.55.2

Router 1 routing table

Dynamic discovery And addition

But how to send data to the host

- Routers have an IP and MAC
- Routers have routing tables - Map to every network
- Routers also have ARP tables
  - Mapping of L3 address to L2 address
  - Anything in network with IP will have an ARP table
  - ARP table is populated on the fly - Why?
  - Routing tables needs to be ready apriori - Routers may drop packets if IP is not known

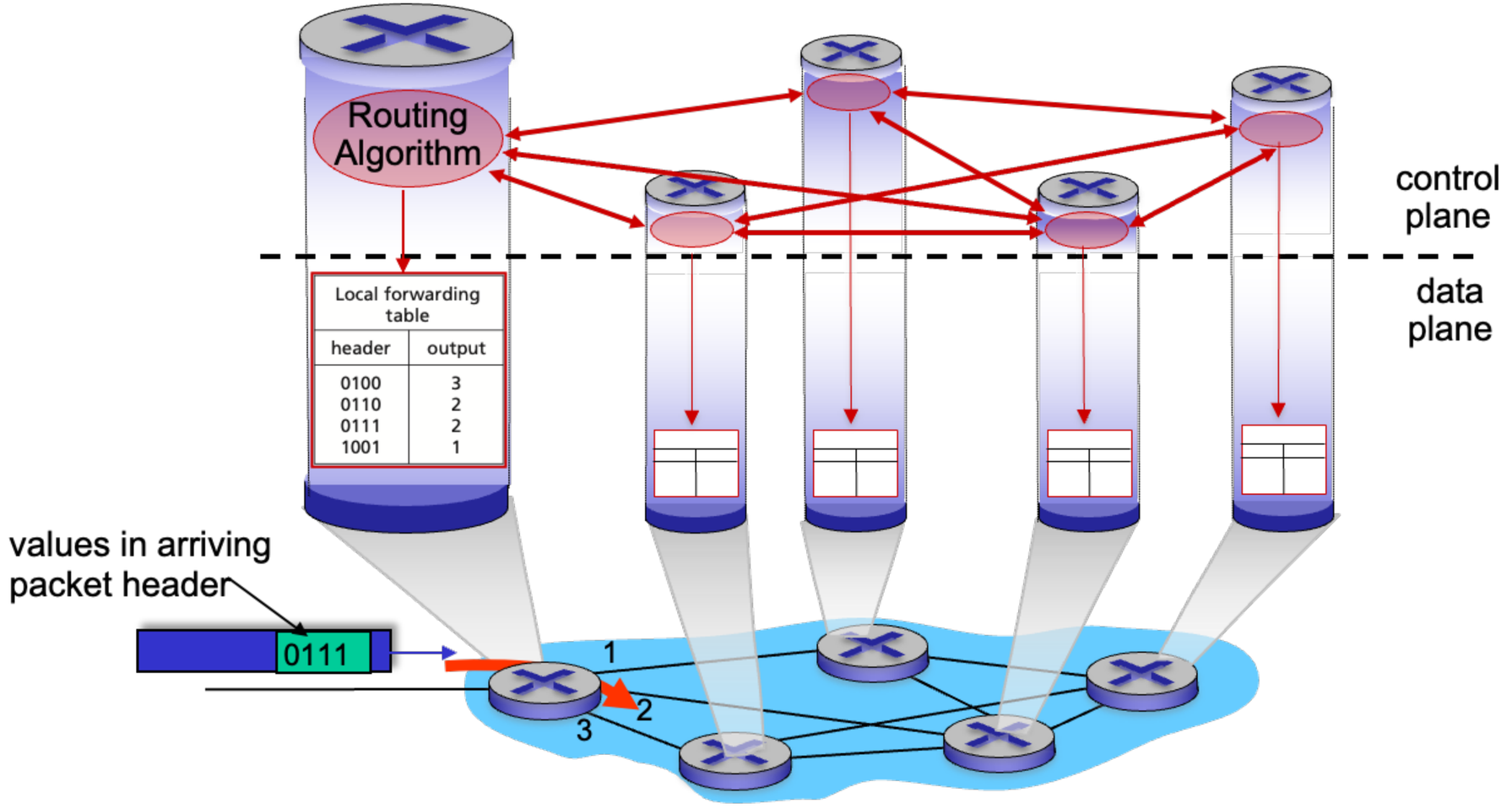
Routing Table

- Three methods to populate routing table
  - **Directly connected:** Networks to which the router is directly attached to
  - **Static routes:** Routes manually provided by an administrator
  - **Dynamic routes:** Routes automatically learned from other routers
    - Routers communicate with each other to know about different networks
    - Different protocols: OSPF, BGP, EIGRP, IS-IS
    - Used by routers to inform about the different networks they are connected to

Network Layer: Data Plane and Control Plane

- One can divide network layer functions into two planes: Data and control
- **Data plane:** Local per router function
  - Determines how datagram arriving on router input port is forwarded to router output port
- **Control plane:** Network wide logic
  - Determine how datagram is routed along end to end path form source to destination
  - Two approaches: Traditional routing algorithms, or Software defined networking (SDN)

Traditional Control Plane Approach

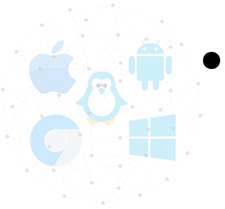


How does one router know whom to send to?

- Routers have forwarding table consisting of routes
- But there are **billions of destinations** - Not everything can be stored in each router!!!
- Sending so many links with each other can itself bring down the network
- There are two parts to it:
  - Internet: network of networks
  - Each network admin may want to control routing in its own network

Protocols used in routing

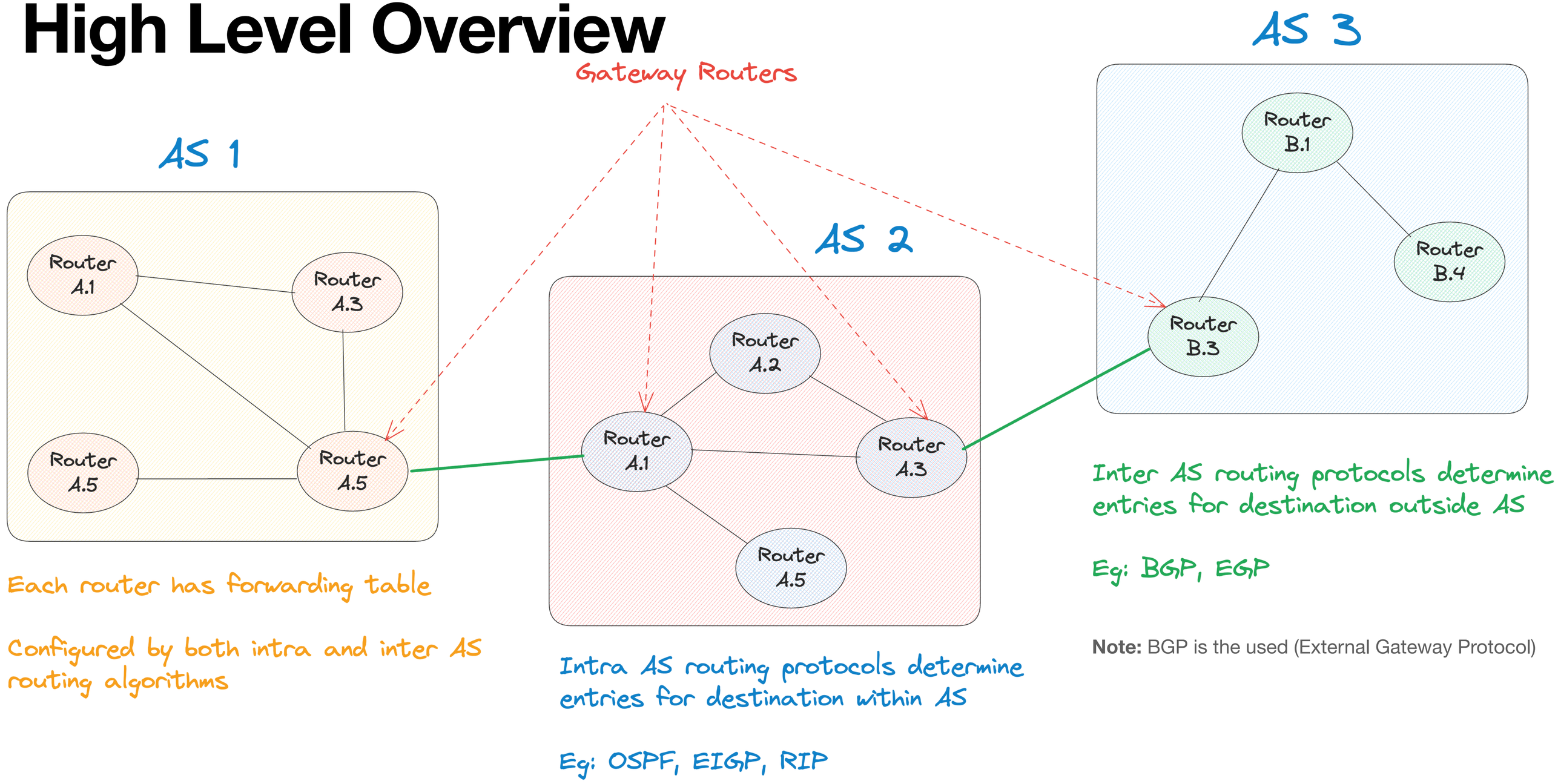
- Intra-AS routing protocols:
  - **OSPF (Open Shortest Path First) Protocol**
    - Classic link state routing (Dijkstra's algorithm)
  - Others include: RIP, EIGRP (RIP: Routing Information Protocol)
- Inter-AS routing protocols:
  - **BGP (Broader Gateway protocol)**
    - Path vector protocol
  - Considered as "glue that holds internet together"



Internet approach to scalable routing

- Aggregate routers into regions known as **“Autonomous Systems” (AS)** a.k.a “domains”
  - Total of around 70,000 AS’s have been assigned not all are active
- There are mechanisms for handling routing within the domain and across AS
- **Intra-AS or Intra-domain**
  - All routers in AS must run the same intra-domain protocol
  - There is a **gateway router** at the edge of each AS which connects with router in another AS
- **Inter-AS or Inter-domain**
  - Routing among AS’s
  - Gateways perform inter-domain as well as intra-domain within their network

High Level Overview



Each router has forwarding table

Configured by both intra and inter AS routing algorithms

Intra AS routing protocols determine entries for destination within AS

Eg: OSPF, EIGP, RIP

Inter AS routing protocols determine entries for destination outside AS

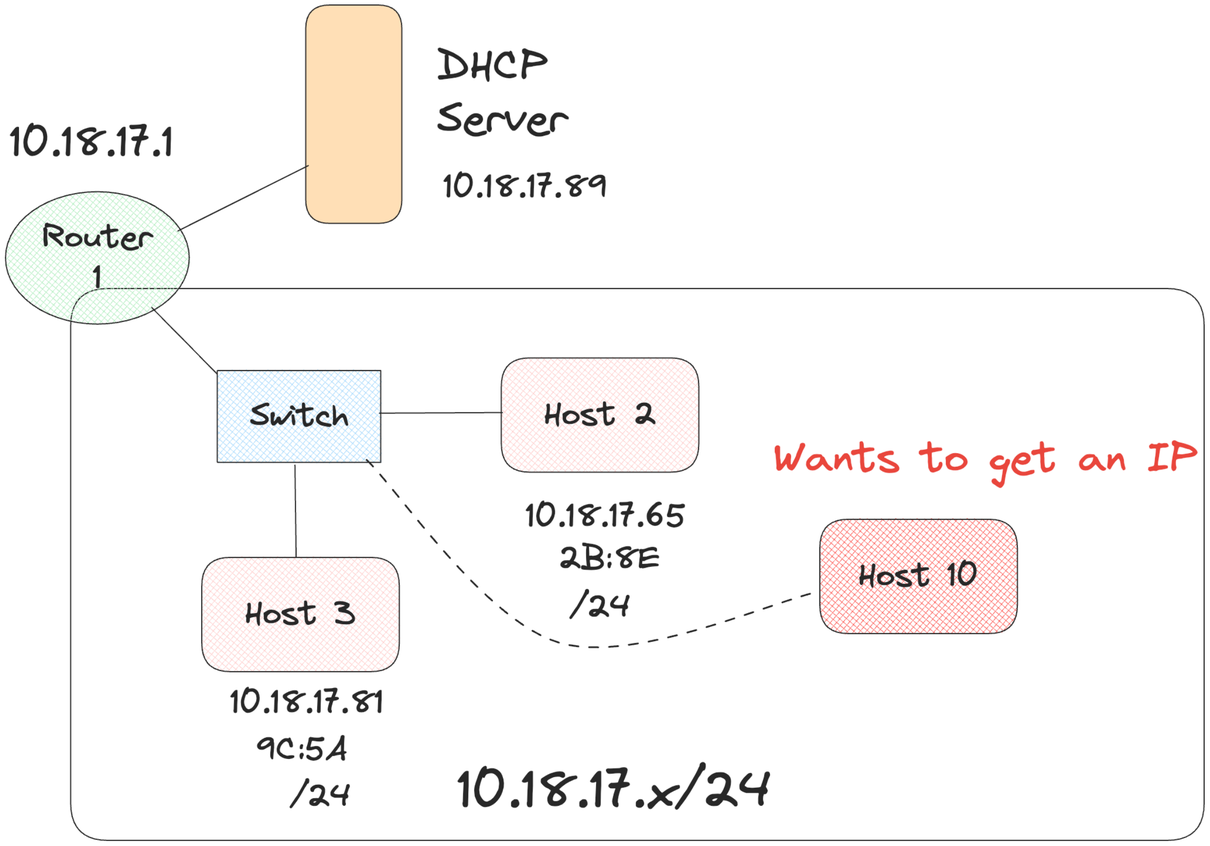
Eg: BGP, EGP

Note: BGP is the used (External Gateway Protocol)

Taking a step back: How to get IP address?

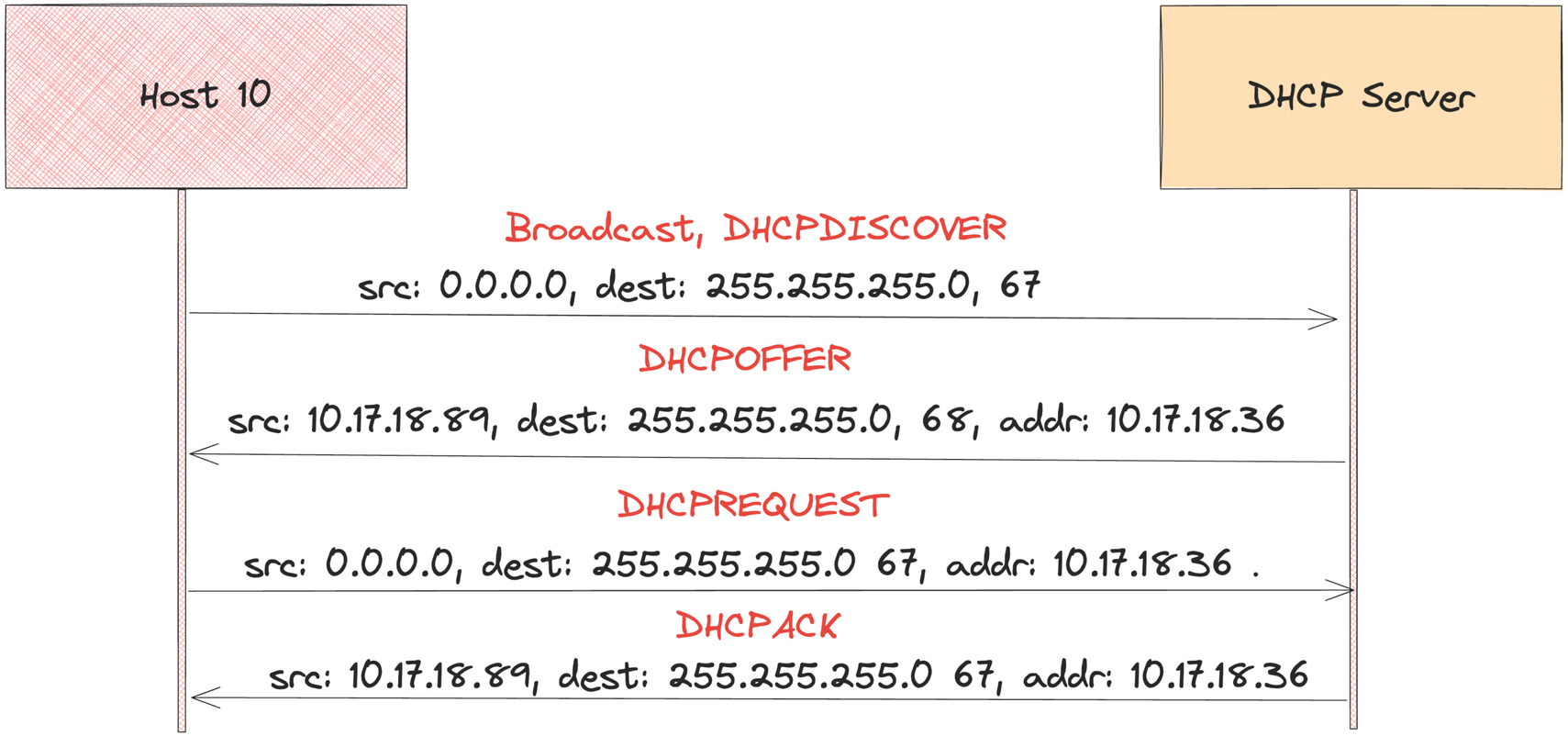
- Two questions needs to be answered:
  - How does host get IP address within its network?
  - What about the network address?
- How does host get an IP address?
  - Hard-coded by sysadmin in config file (e.g., /etc/rc.config in UNIX)
  - **DHCP:** Dynamic Host Configuration Protocol - Dynamically get IP address when joining from a server

Working of DHCP



- Host 10 is the client here
- It sends out a broadcast DHCP request to every node in the network to get DHCP server
- Every device in the network will get the request
- DHCP runs over UDP
- Client uses port 68 and server port (listens on port 67)

Working of DHCP

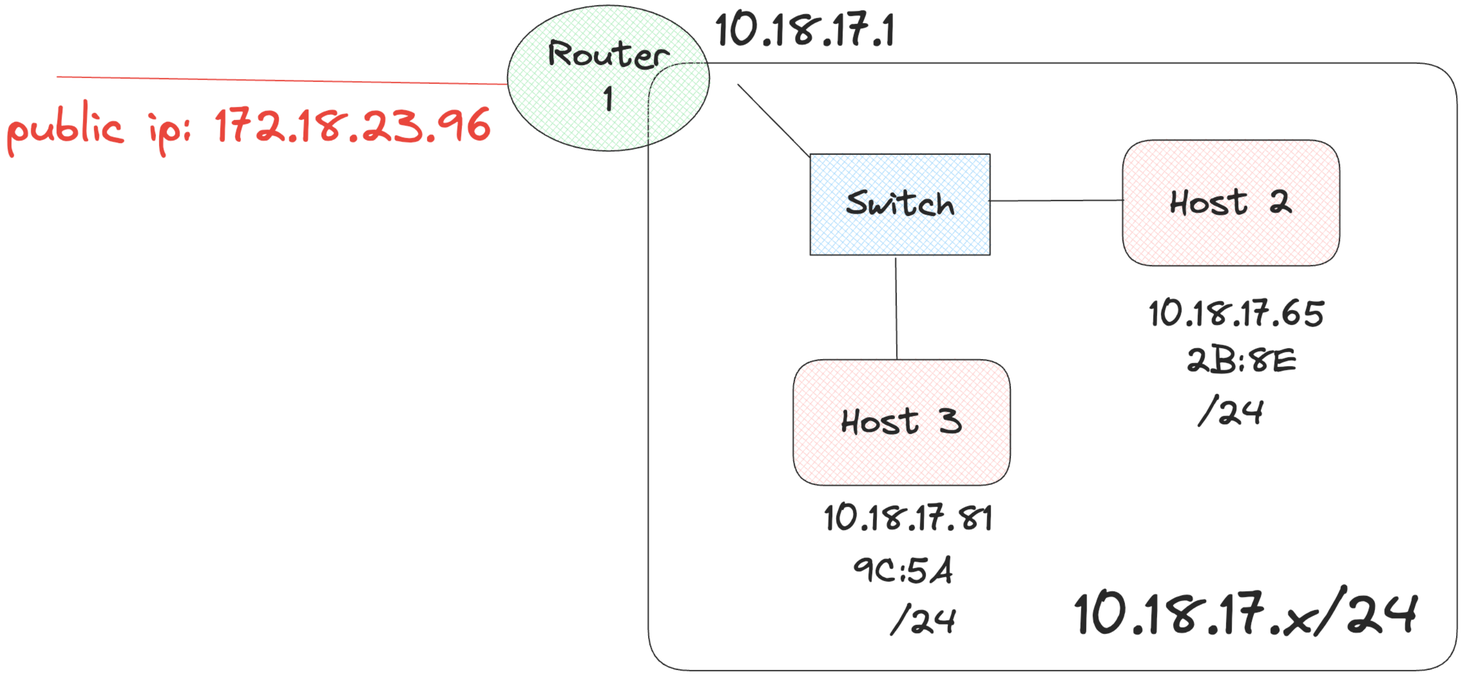


- DHCPDISCOVER will be broadcasted to all the DHCP servers
- The IP address offer will be given by multiple DHCP servers, client chooses one (first response) and broadcasts the acceptance
- DHCP server can also give details like address of DNS server, address of first hop router, network mask, etc.

How to get IP Address

- ISP gets IP address block from ICANN (Internet Corporation for Assigned Names and Numbers) - http://ican.org
  - Allocates IP addresses through 5 regional registries (RRs)
  - There are not enough IPV4 addresses - Last chunk was allocated to RRs in 2011
  - IPV6 - 128 bit address space
- We are still able to function with IPV4 due to NAT (Network Address Translation)

Network Address Translation (NAT)

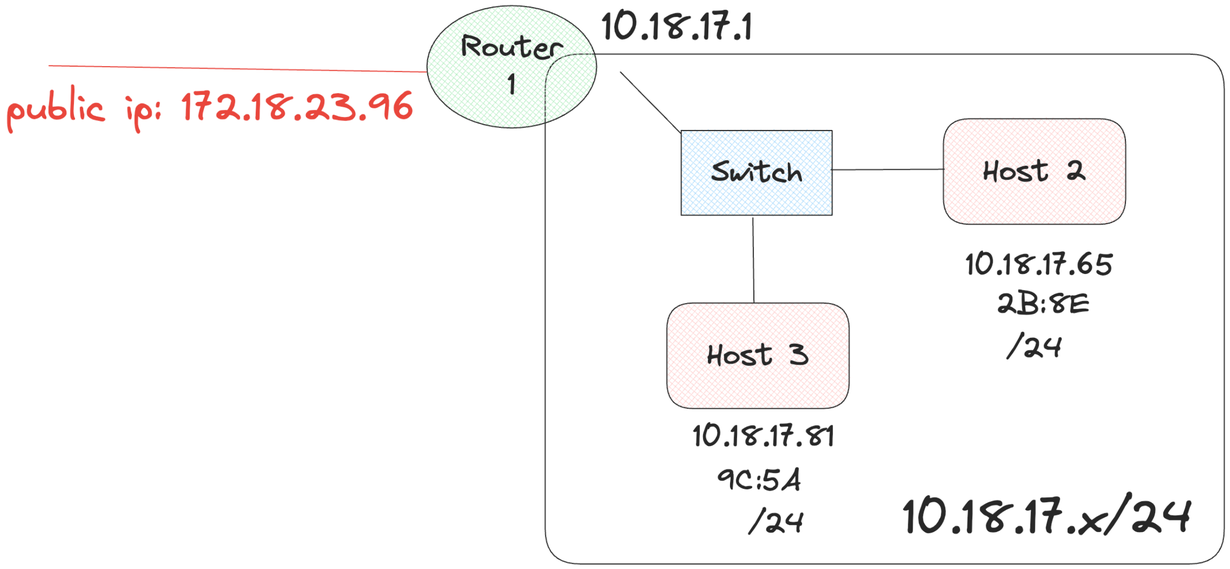


- All devices in the network share just one IPV4 address as far as the outside world is concerned
  - They can still communicate with different hosts outside the network with one public IP
  - How is that possible and how to make this work?

Network Address Translation (NAT)

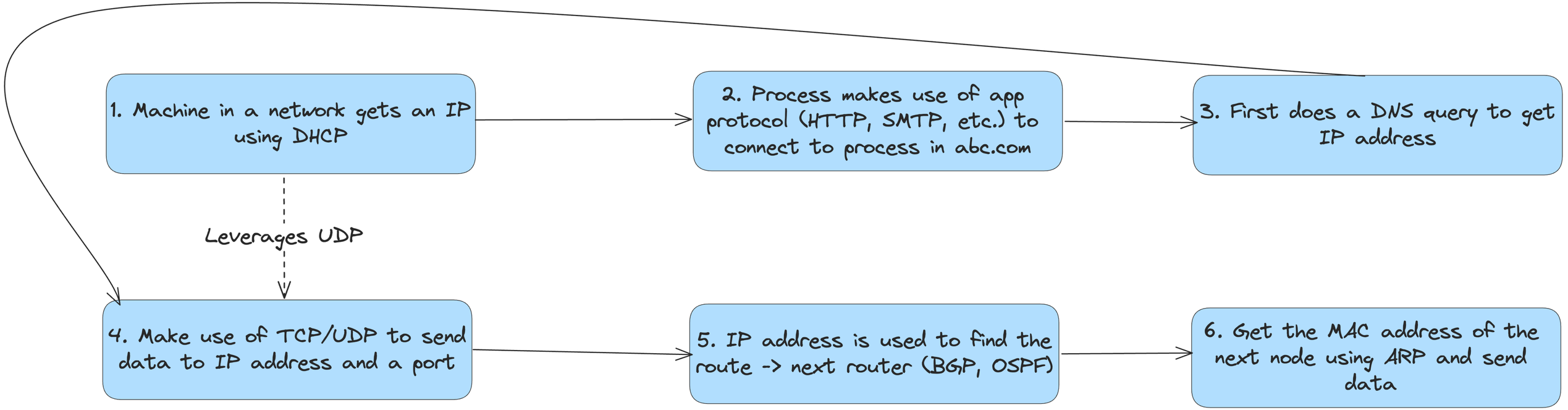
NAT Translation Table

WAN side address	LAN side address
172.18.23.96 5501	10.18.17.81 3801
....	.....



- NAT allows a router (similar device) to translate private IP addresses to its own public IP address
- When devices from network wants to communicate with outside network:
  - NAT modifies the source IP to make it appear that communication is from the larger public IP
  - A translation table is used for managing the translations
- **Multiple types:** Static NAT, Dynamic NAT, Port Address Translation or NAT Overload

Putting it together



Thank you

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