

CS3.301 Operating Systems and Networks

Networking - Network Layer

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Acknowledgement

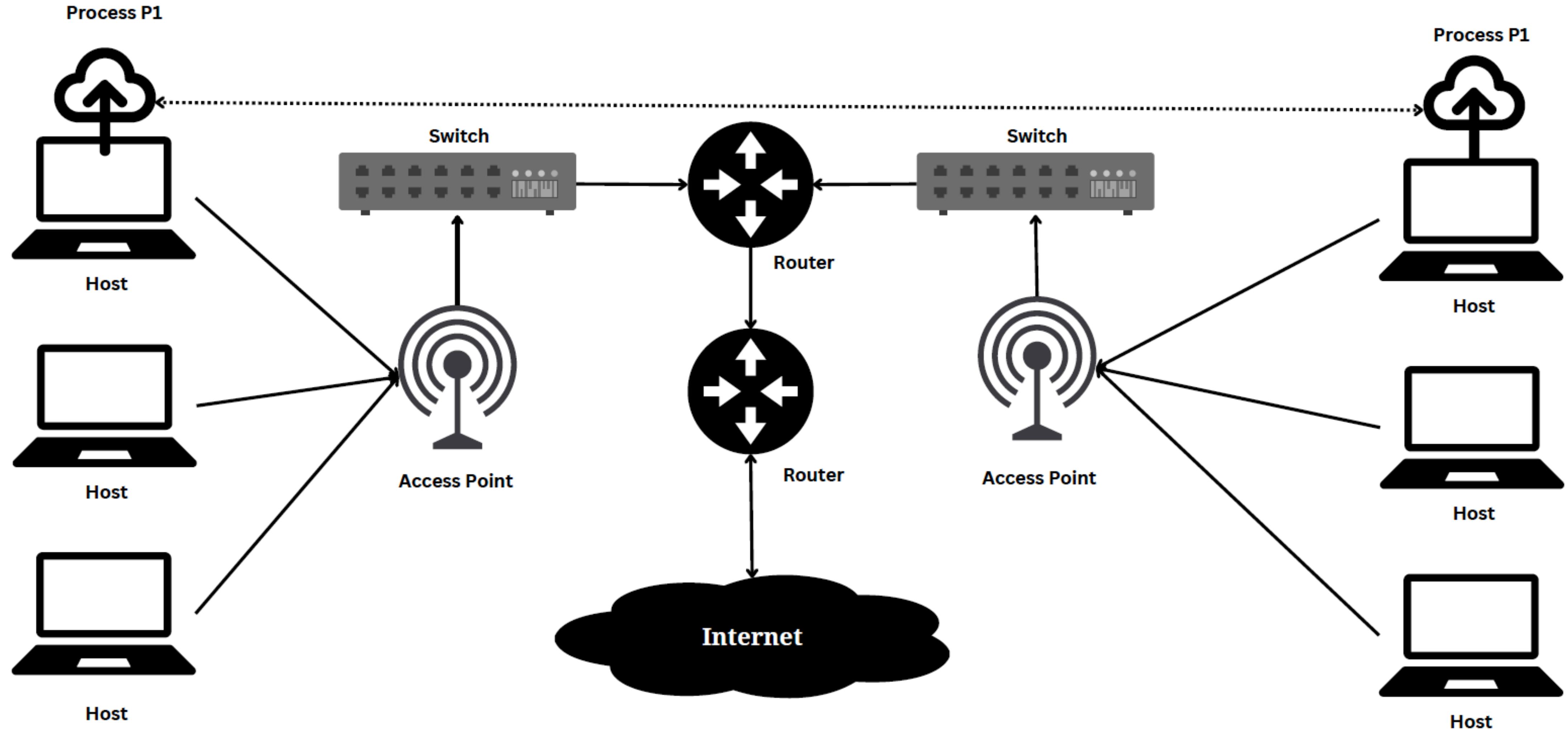
The materials used in this presentation have been gathered/adapted/generate from various sources as well as based on my own experiences and knowledge -- Karthik Vaidhyanathan

Sources:

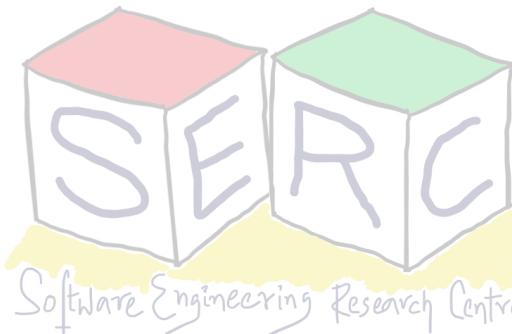
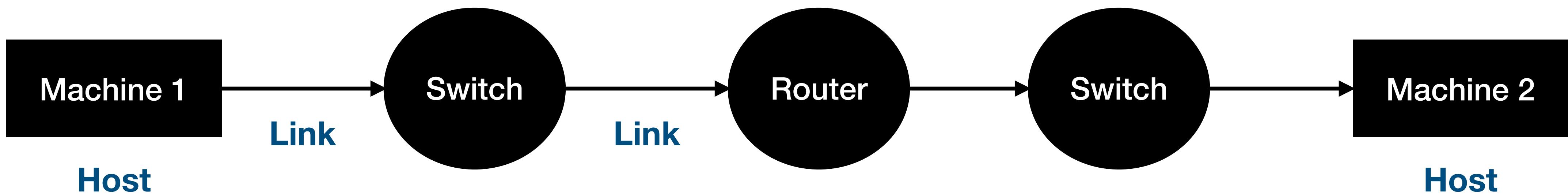
- Computer Networks, 6e by Tanbaum, Teamster and Wetherall
- Computer Networks: A Top Down Approach by Kurose and Ross
- Computer Networking essentials, Youtube Channel
- Other online sources which are duly cited



The Bigger Picture



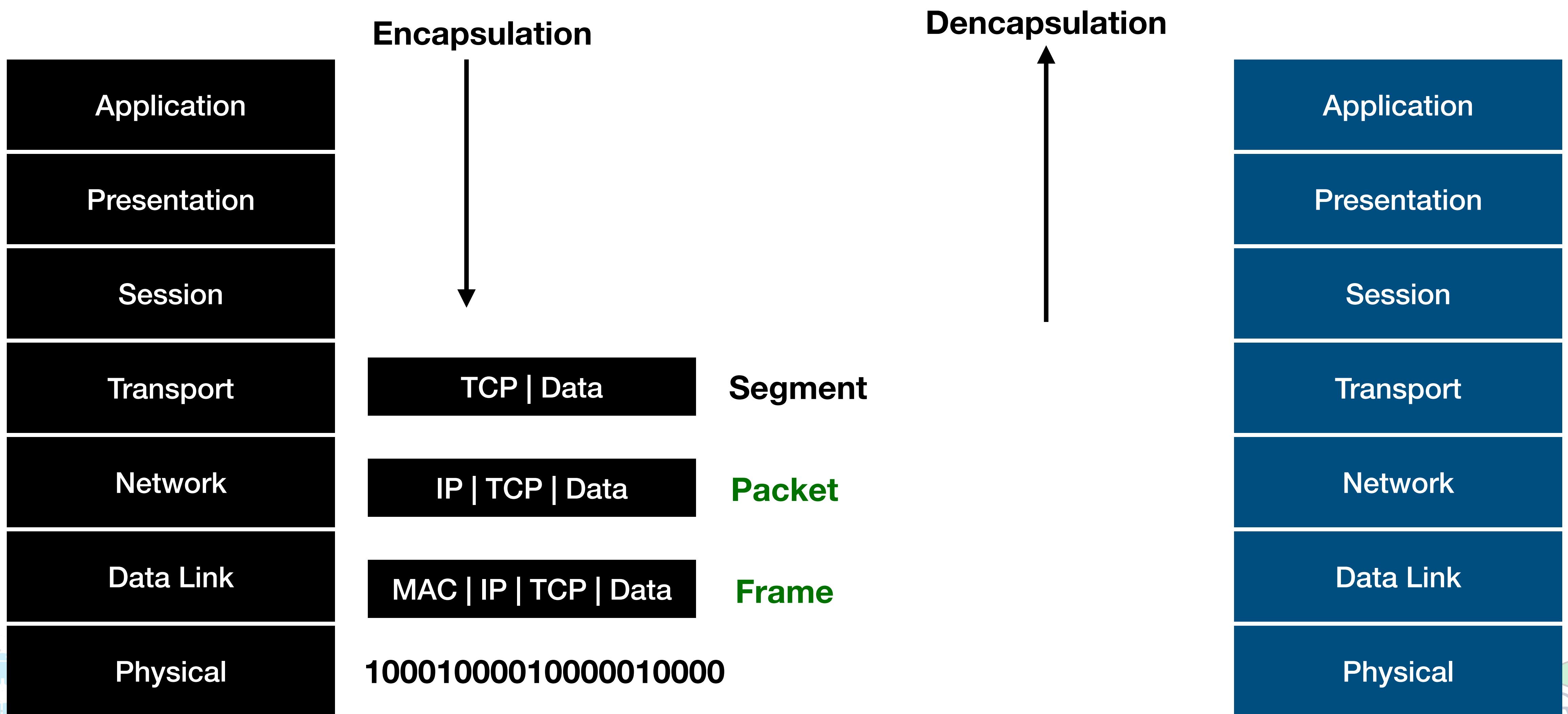
Remember the Components?



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

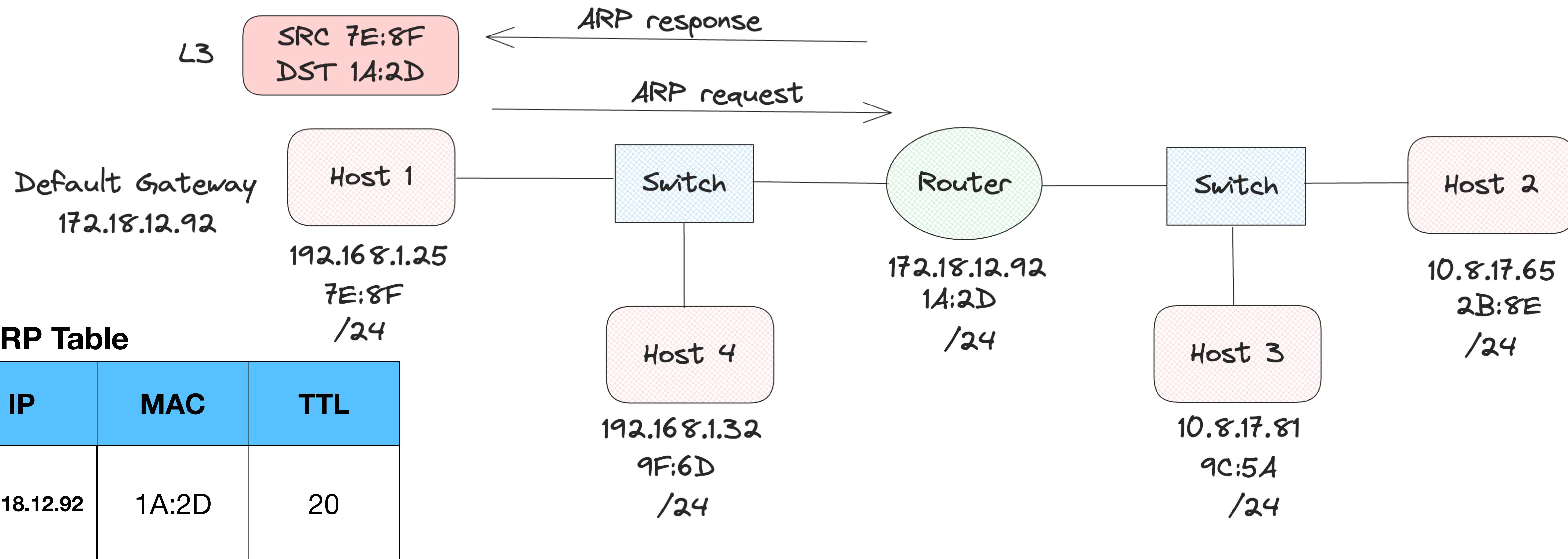


Subnets

- 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



- 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)



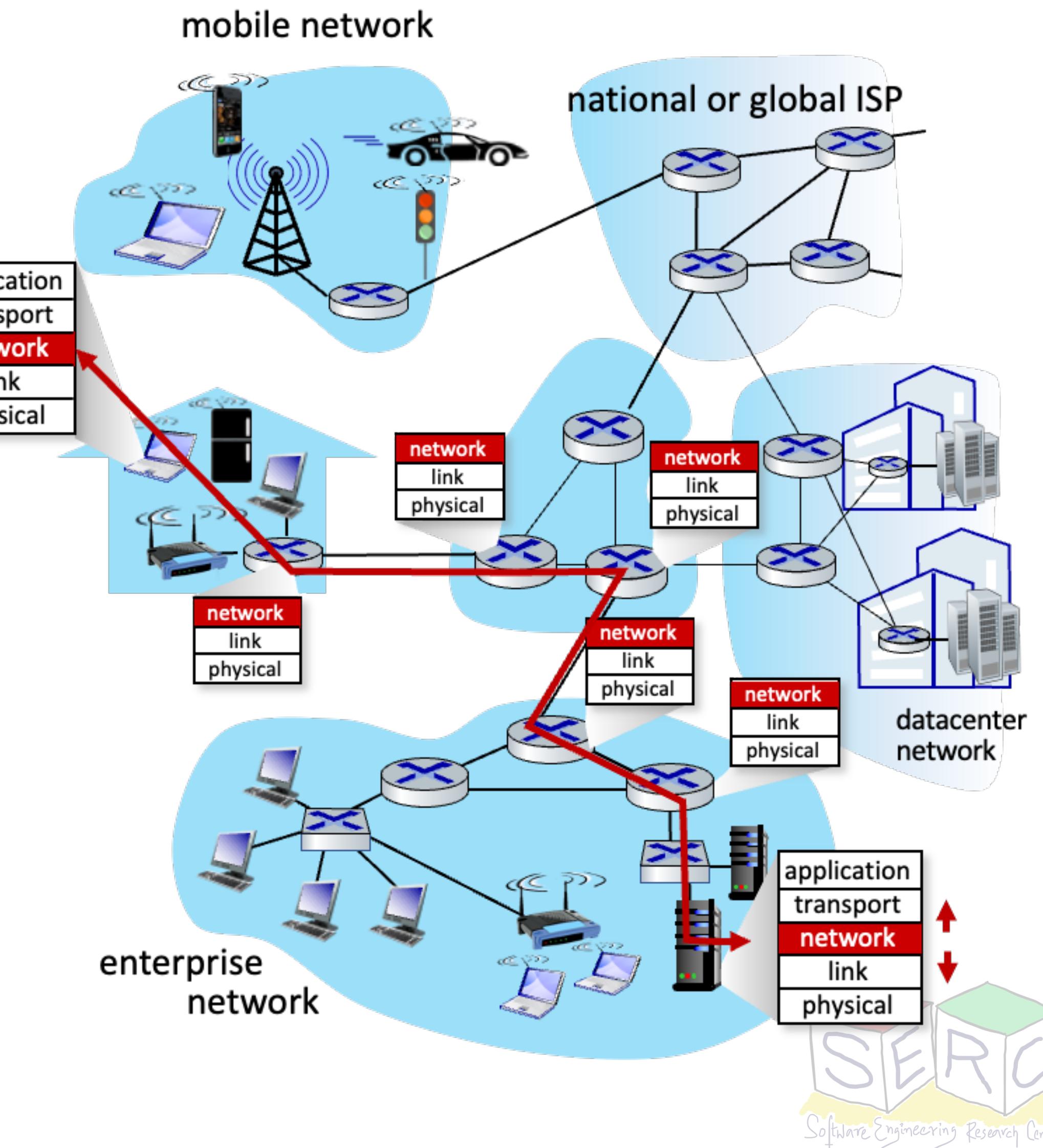
How does end-to-end communication work?

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



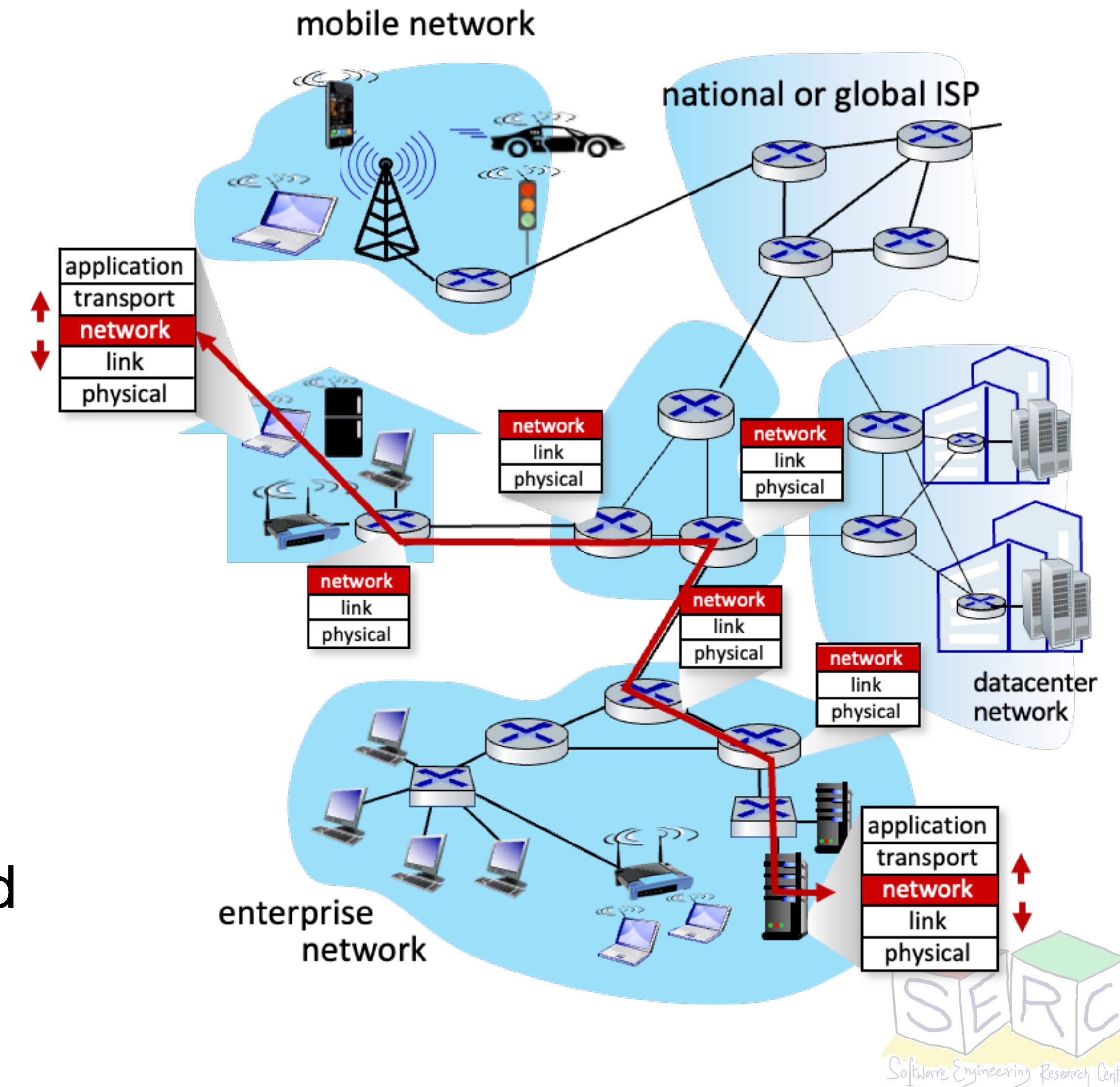
Network Layer - Functionalities

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

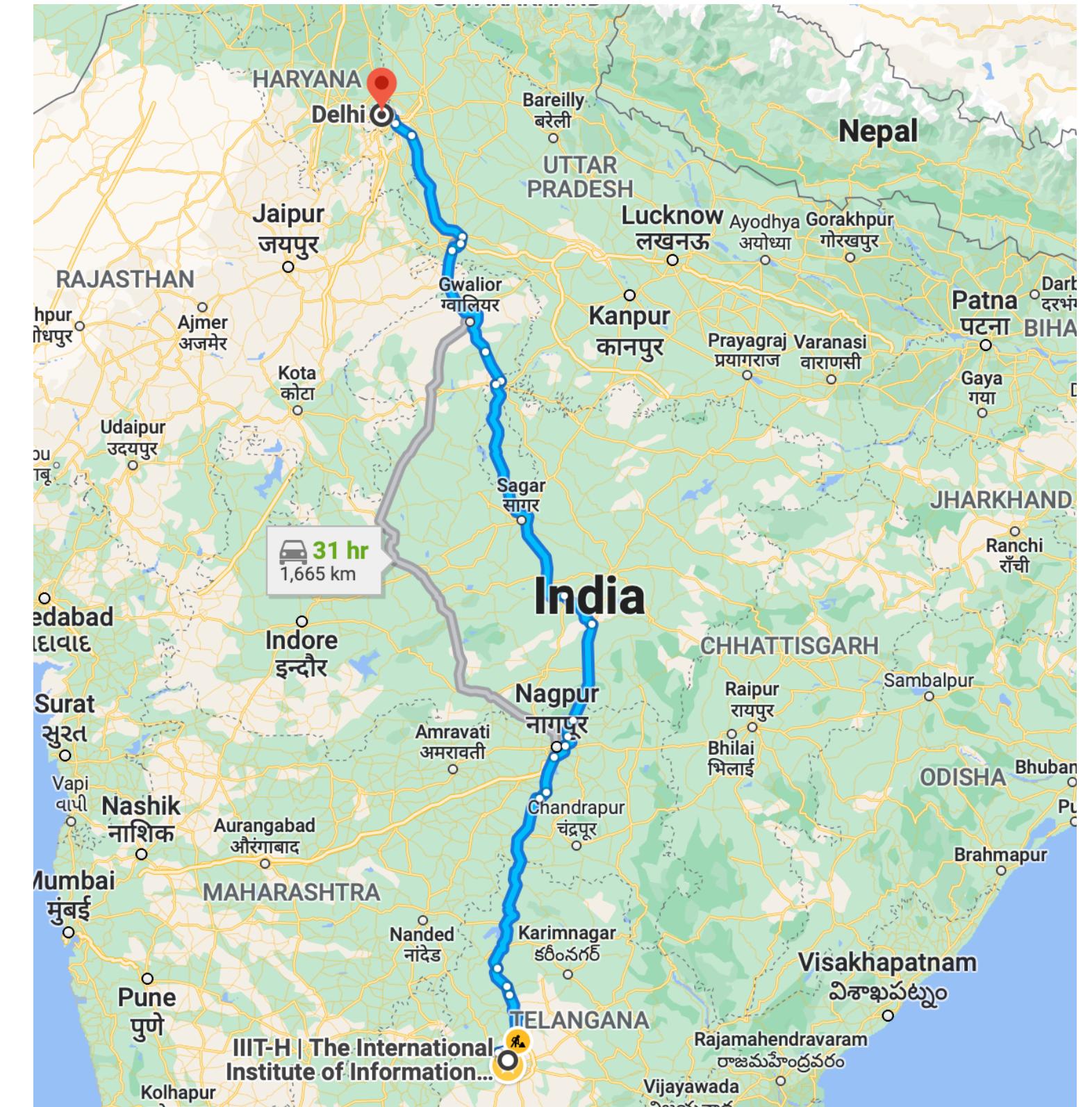


Two Key Network Layer Functions



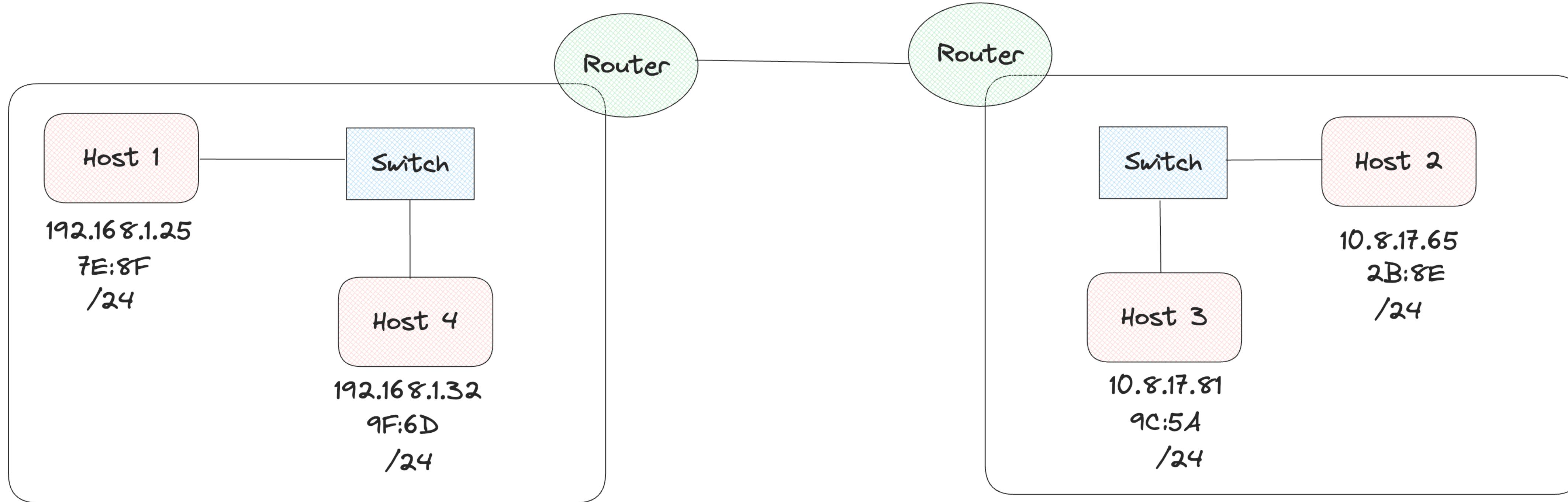
Forwarding (Interchanges)

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



Routing (Source to destination route)

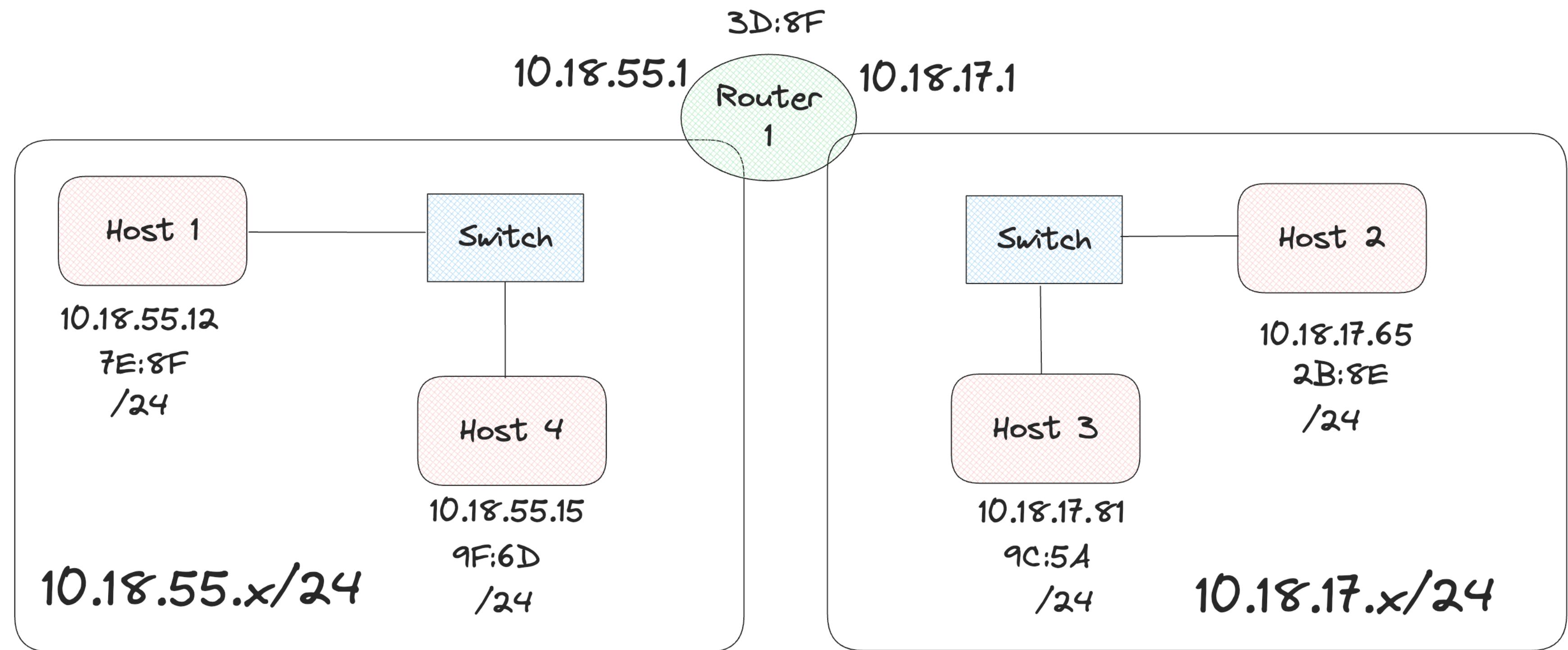
Routers - Devices in L3 that makes things happen



- 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



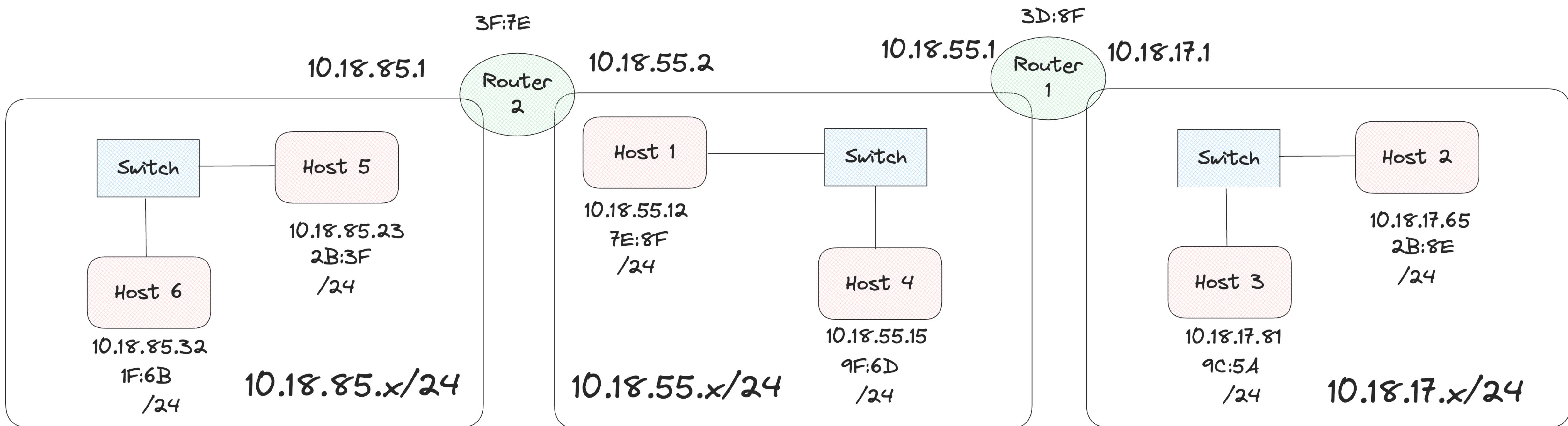
Router 1 routing table

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



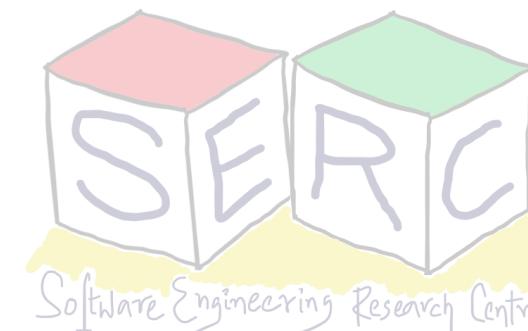
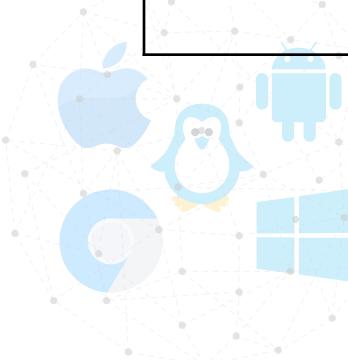
Destination	Interface
10.18.85.x/24	Left
10.18.55.x/24	Right

Router 2 routing table

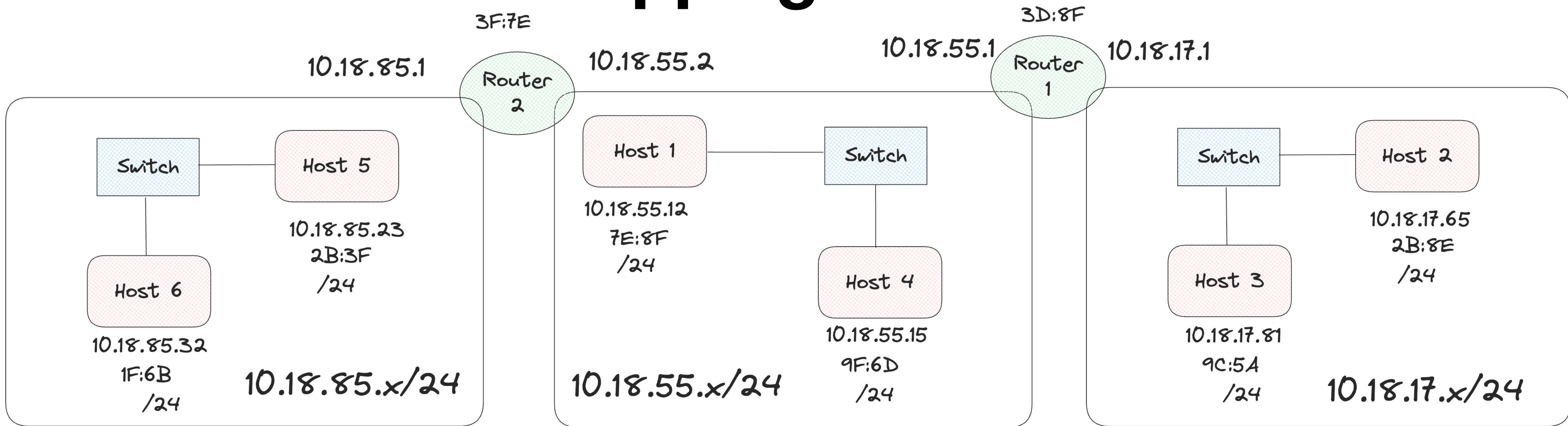
Destination	Interface
10.18.55.x/24	Left
10.18.17.x/24	Right

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

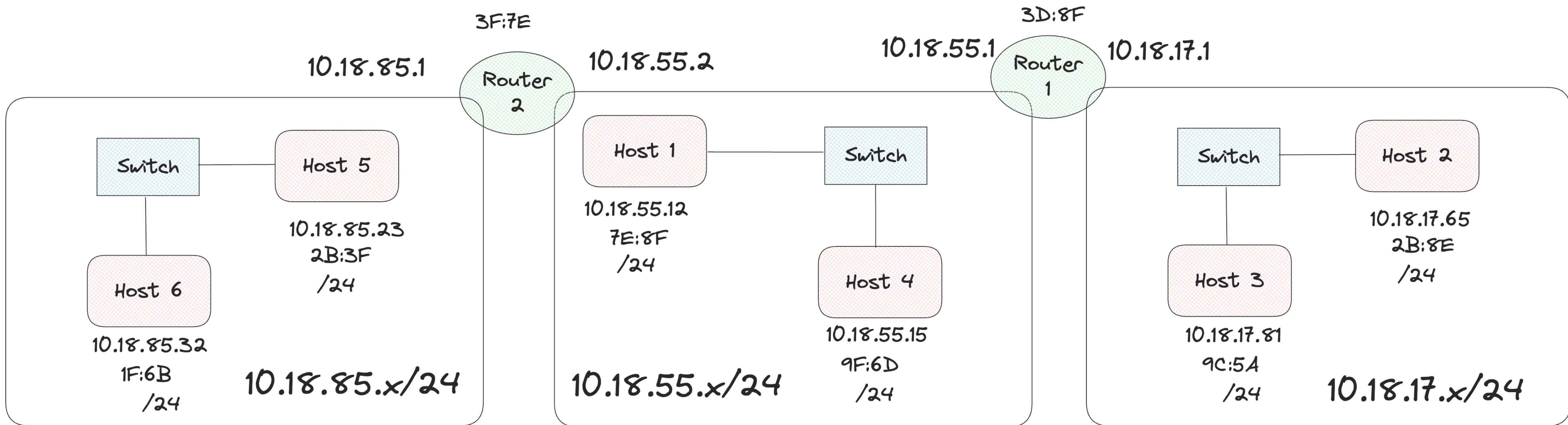
Type	Destination	Interface
DC	10.18.55.x/24	Left
DC	10.18.17.x/24	Right
Static	10.18.85.x/24	10.18.55.2

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

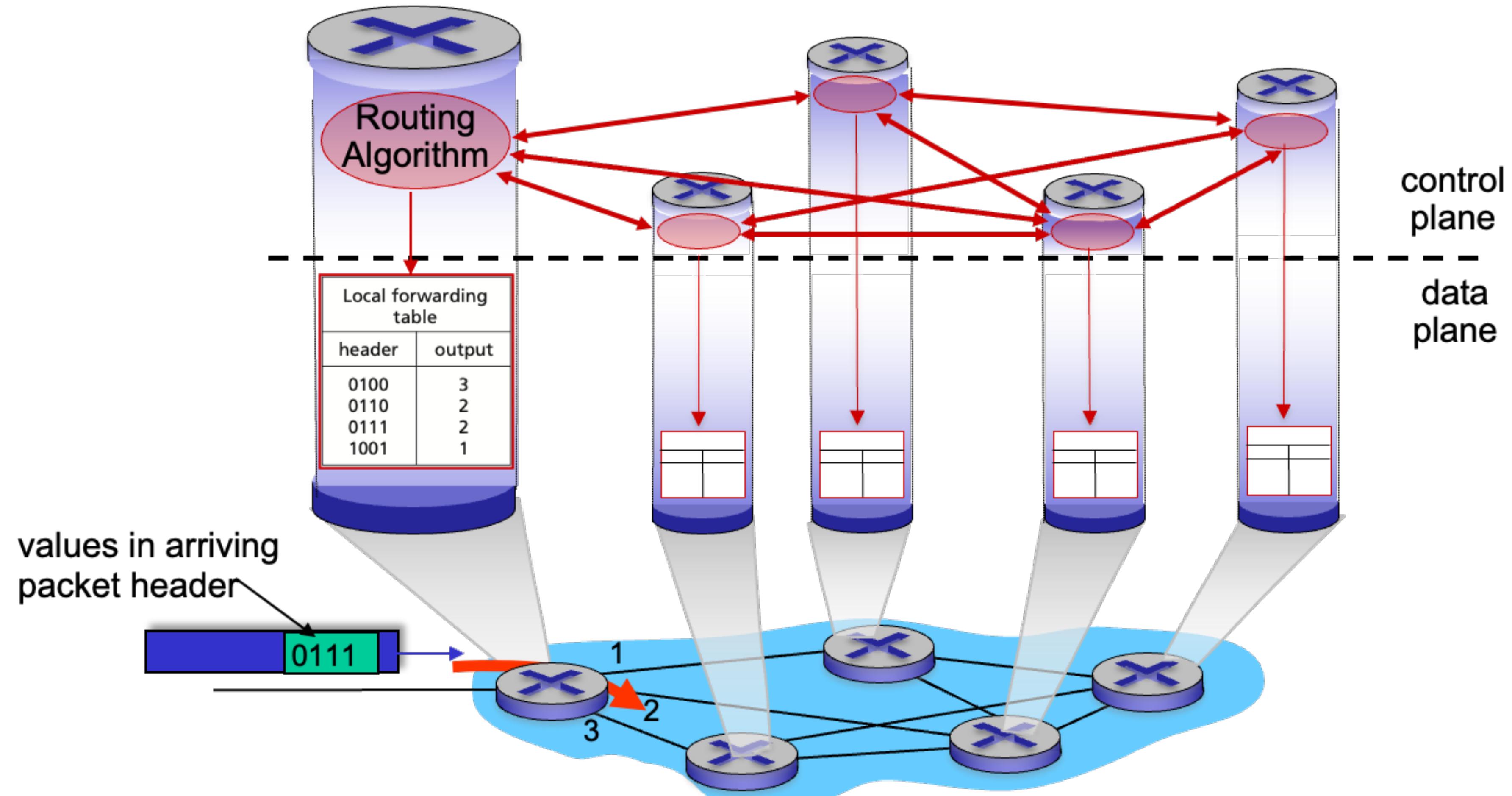


Network Layer: Data Plane and Control Plane

- 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 from 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”

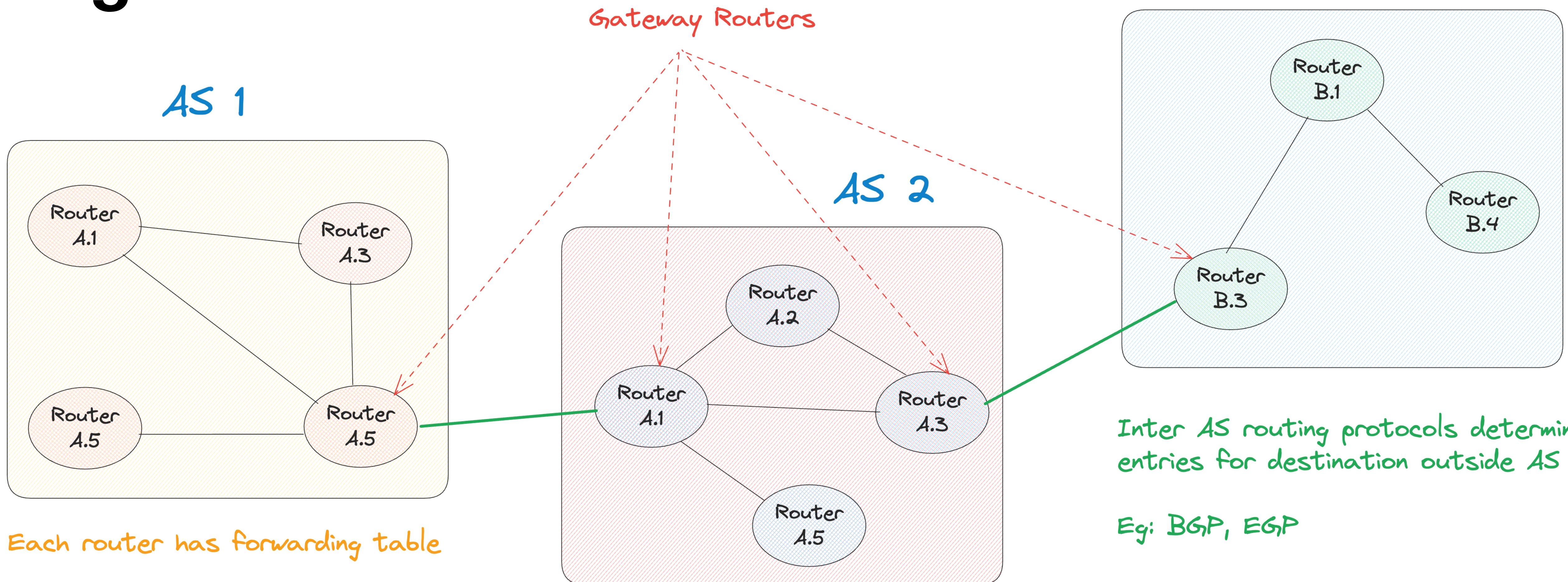


Internet approach to scalable routing

- 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

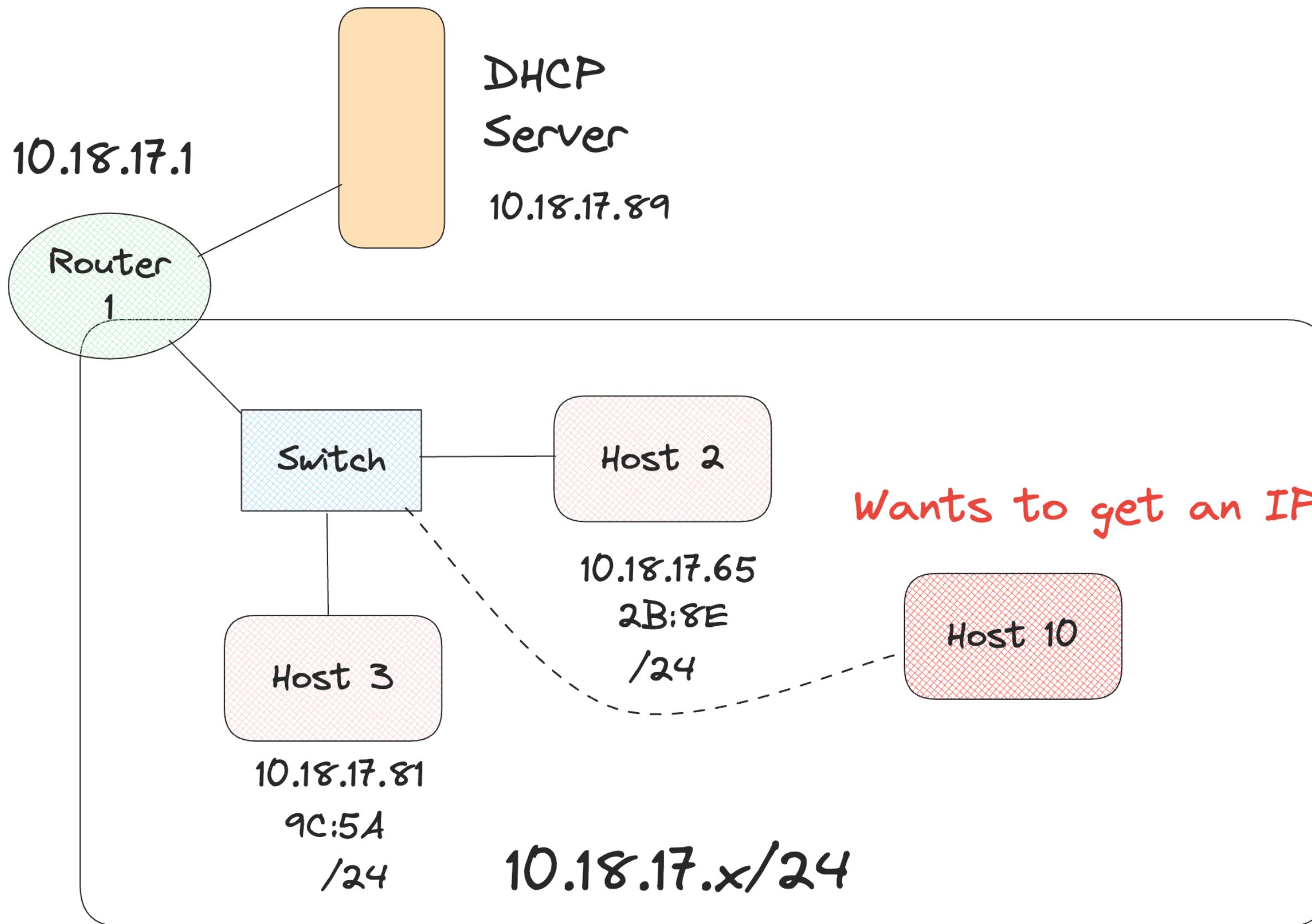


Taking a step back: How to get IP address?

- 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



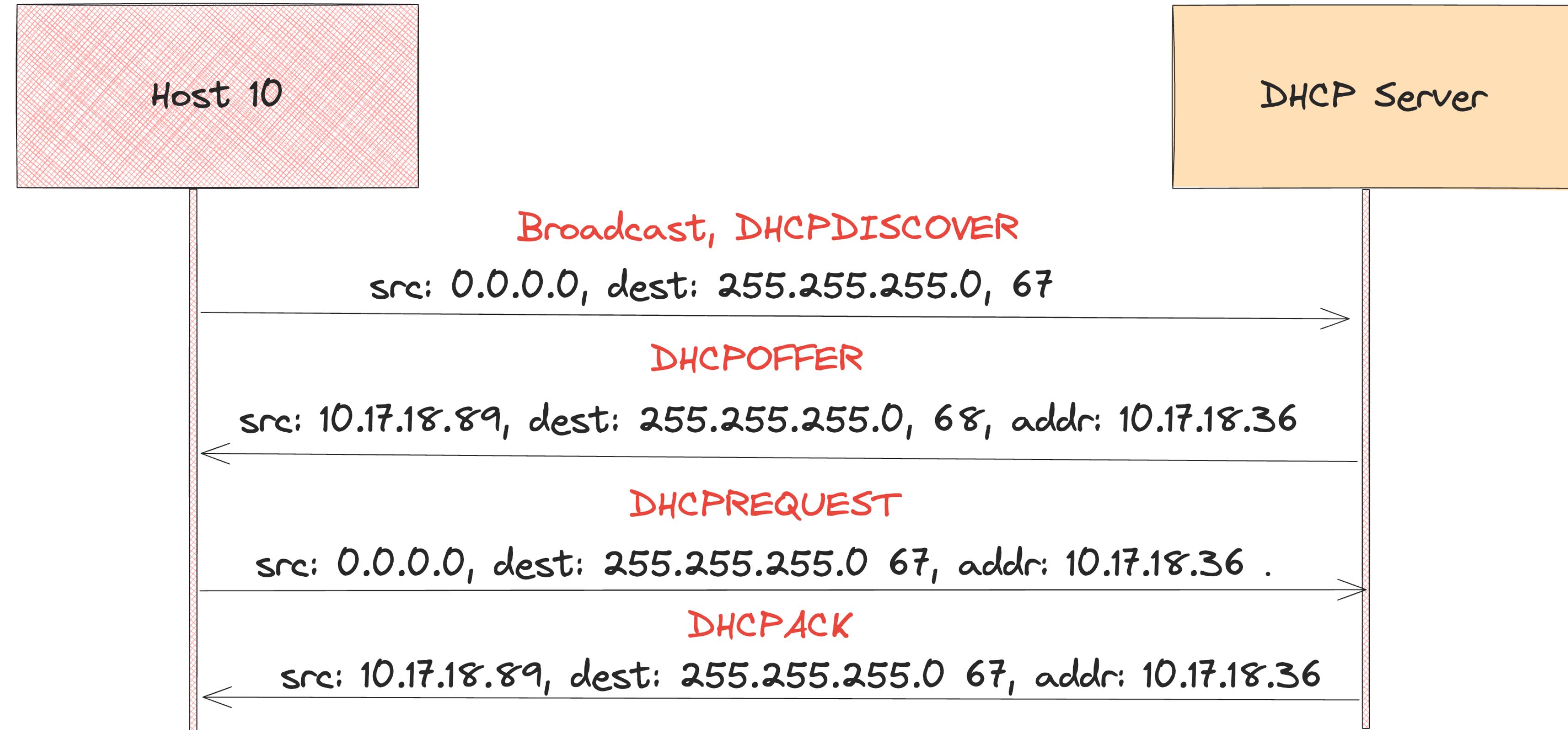
Working of DHCP



- 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.

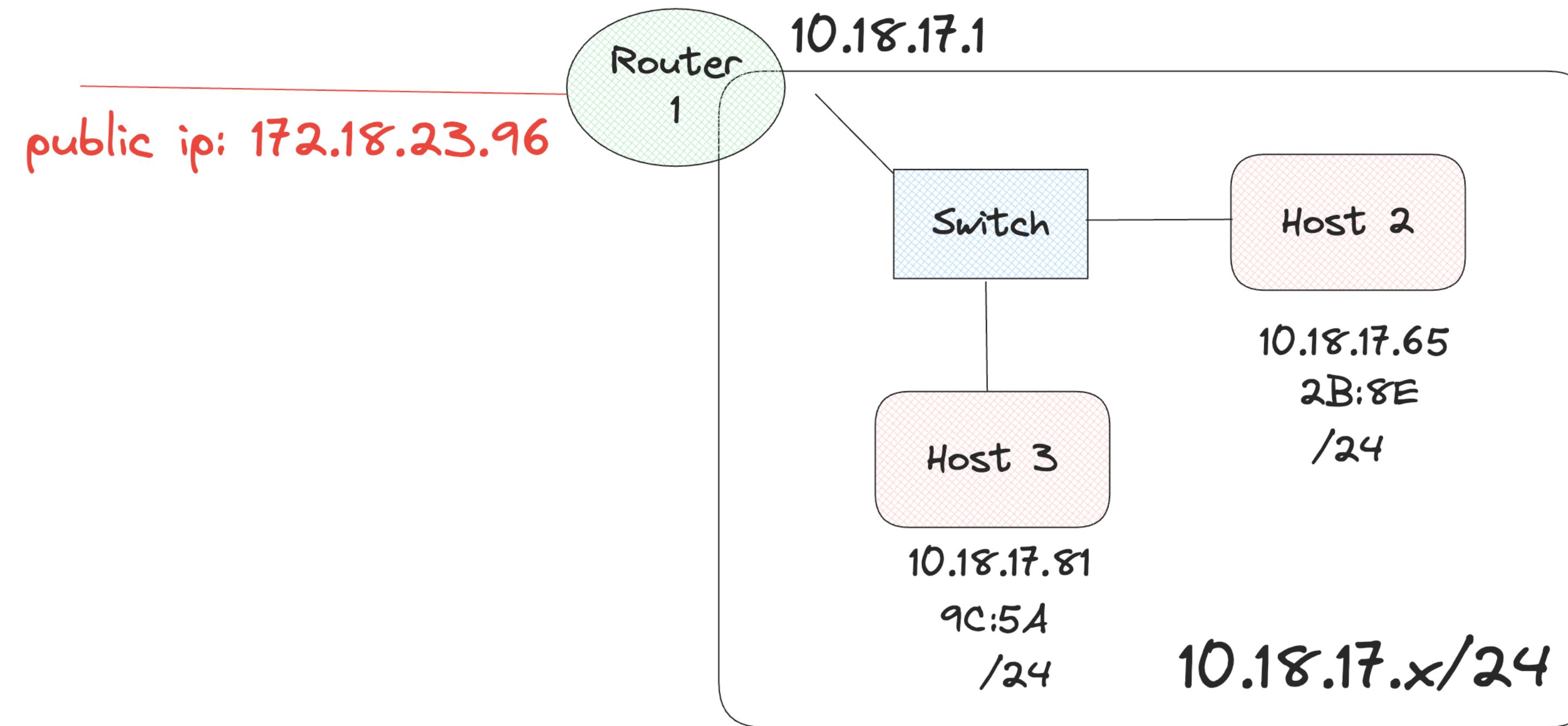


How to get IP Address

- 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)



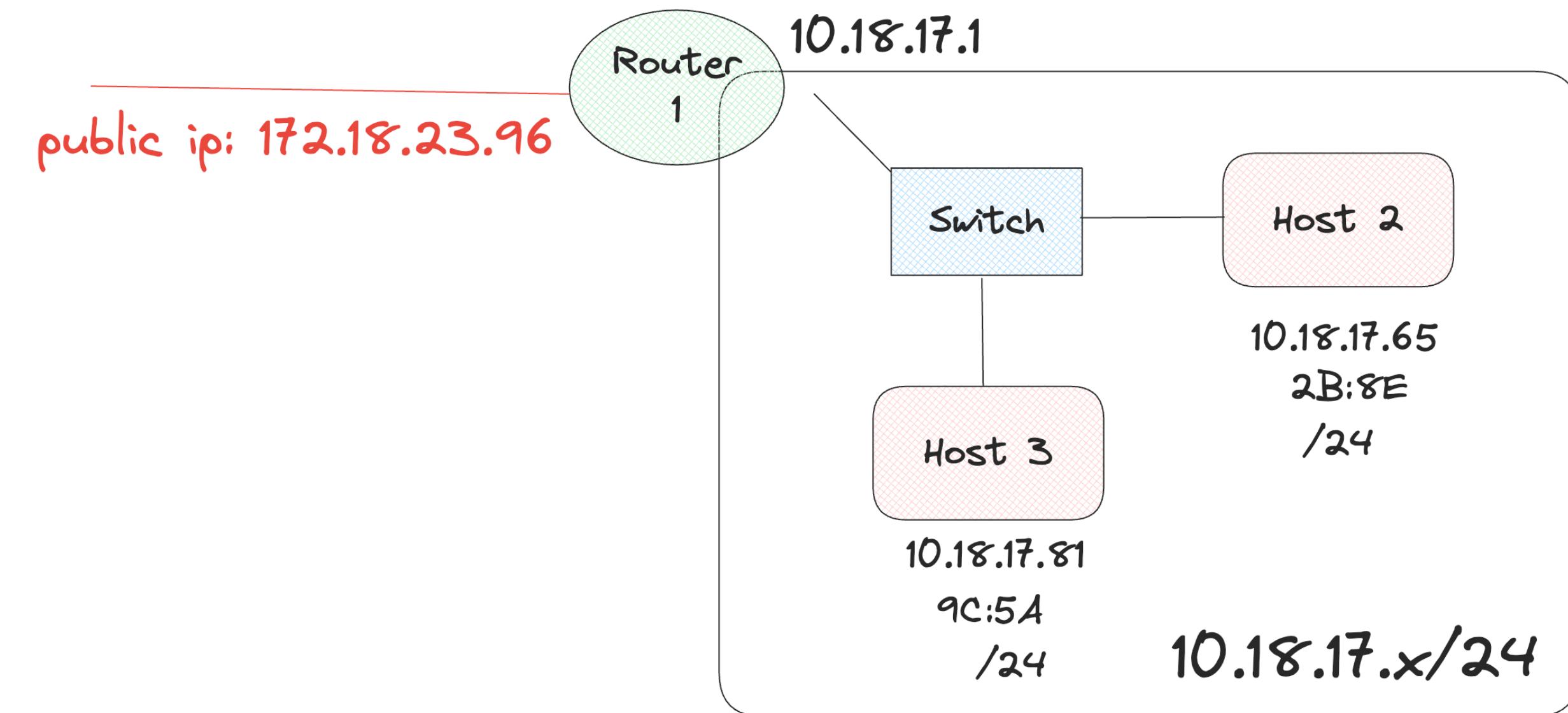
- All devices in the network share just one IPv4 address as far as the outside world is concerned
 - They can still communicate with different hosts outside the network with one public IP
 - How is that possible and how to make this work?



Network Address Translation (NAT)

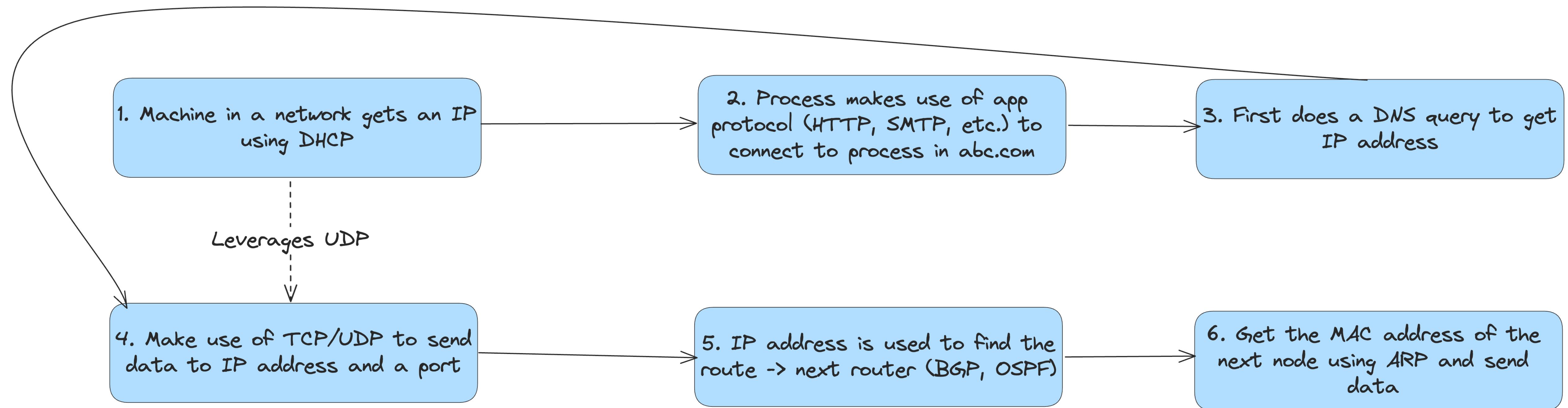
NAT Translation Table

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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