SECTION – C

Introduction to Routing

Routing

- The job of the network layer is to carry data "end to end", i.e. from the source to destination perhaps through a number of intermediate subnets.
- Depending on whether connection oriented or connectionless services are used, other functionalities may be incorporated at this layer.

Basic Routing Problem

- At a particular subnet node, given a packet with a particular final destination, determine the next subnet node (or the outgoing link)
  - In datagram network, this is determined for individual packets.
  - In VC network, this is determined only for setup packet for each session.

Routing Basics

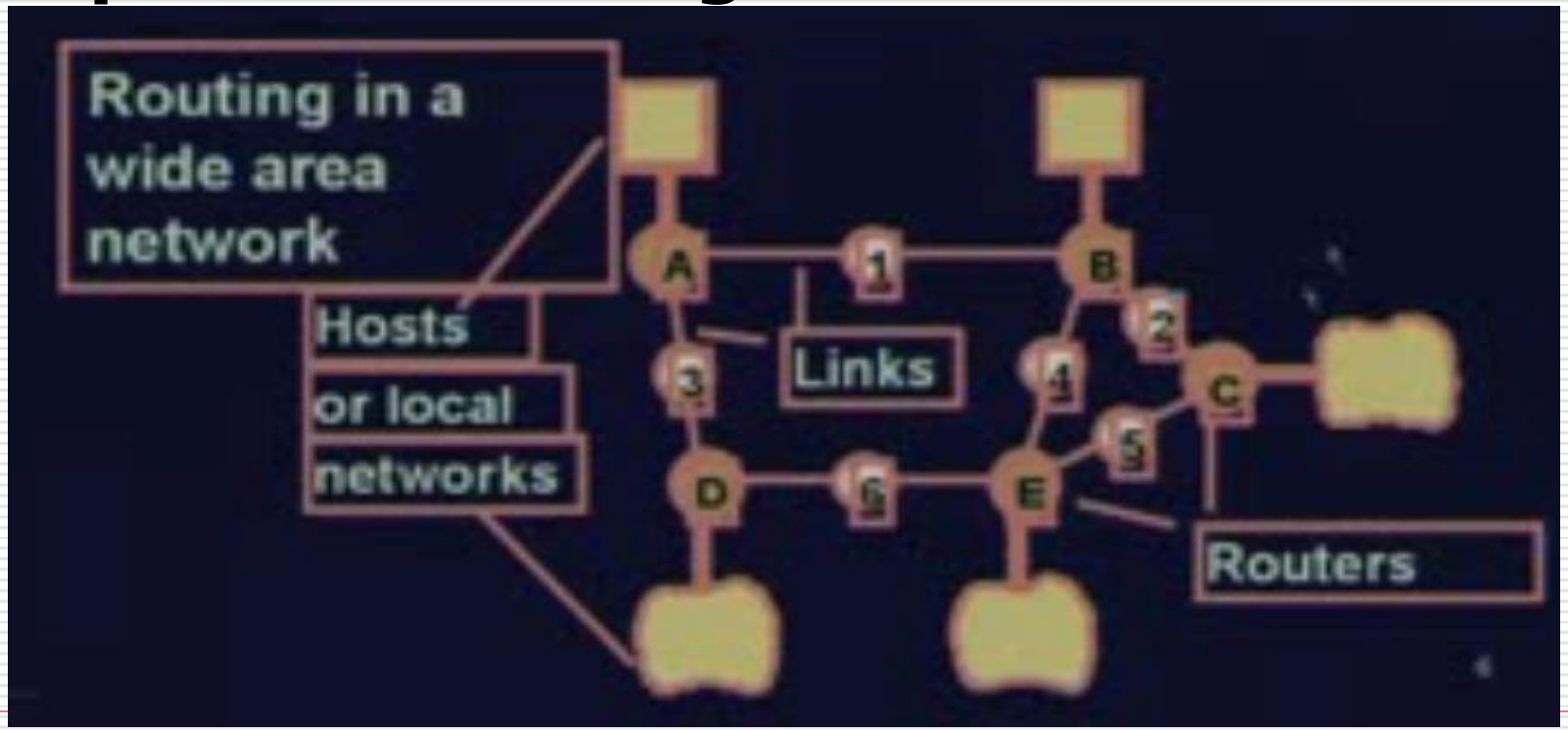
- Objective
  - Consider a router X
  - X may not know the topology of the entire internetwork
  - X needs to determine the "next-hop" router for every other network in the internet.
  - This information is structured as the routing table of router X.

Routing basics

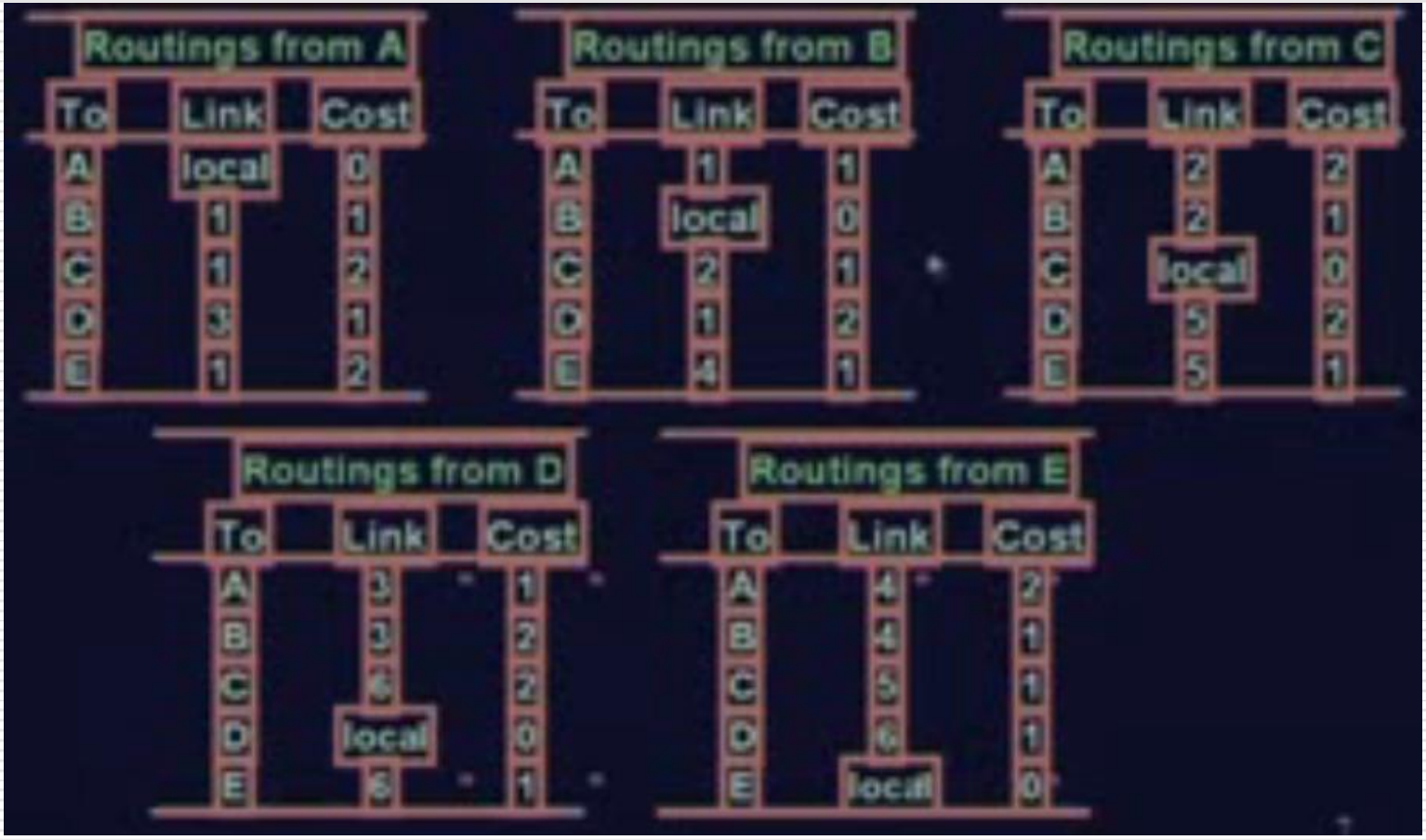
- **Major issues in routing:**
  - **Topology changes affect convergence delay and stability. (may change path)**
  - **Scalability to large number of interconnected networks / routers/ links**
  - **What is the best path from X to Y?**
    - **Minimum number of hops?**
    - **Minimum delay?**
    - **Maximum capacity?**

Routing

- Decides the route for each packet.
- Update knowledge of the network.



Routing tables



Routing vs Forwarding

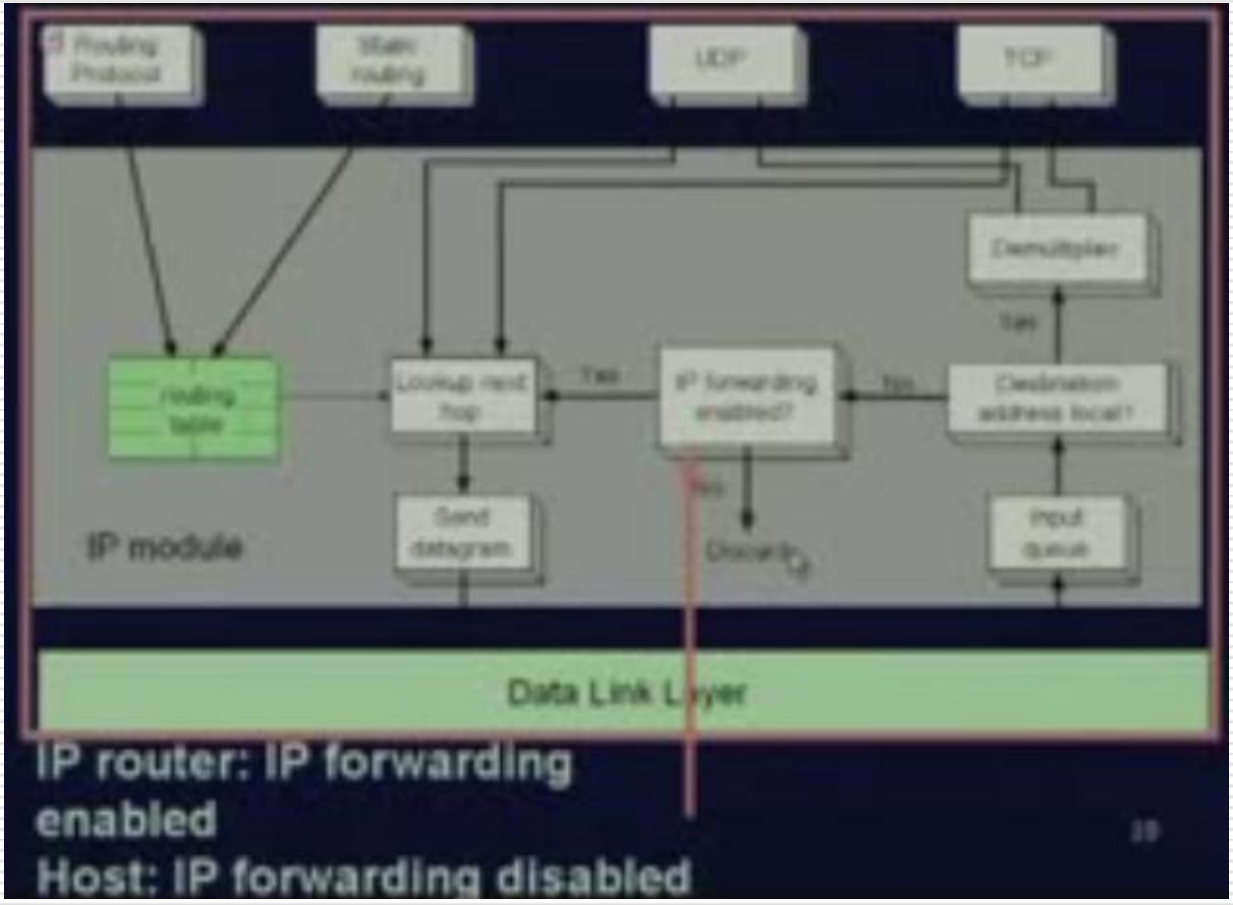
- **Routing: process of building routing tables at each router**
- **Forwarding: process of looking at the destination address of a packet, and sending it to appropriate next-hop interface of a router.**
- **Forwarding requires access to local routing table.**
- **Sometimes, forwarding table is structured in a different manner than routing table.**

- **Forwarding table: optimize for packet lookups**
- **Routing table: optimize for routing changes, topology changes, etc**

Net #	Next hop	Link Cost
10	171.69.245.10	2

Net #	Interface	MAC Address
10	if1	8:0:2b:e4:b:1:2

Processing of an IP datagram in IP



Processing of an IP datagram in IP

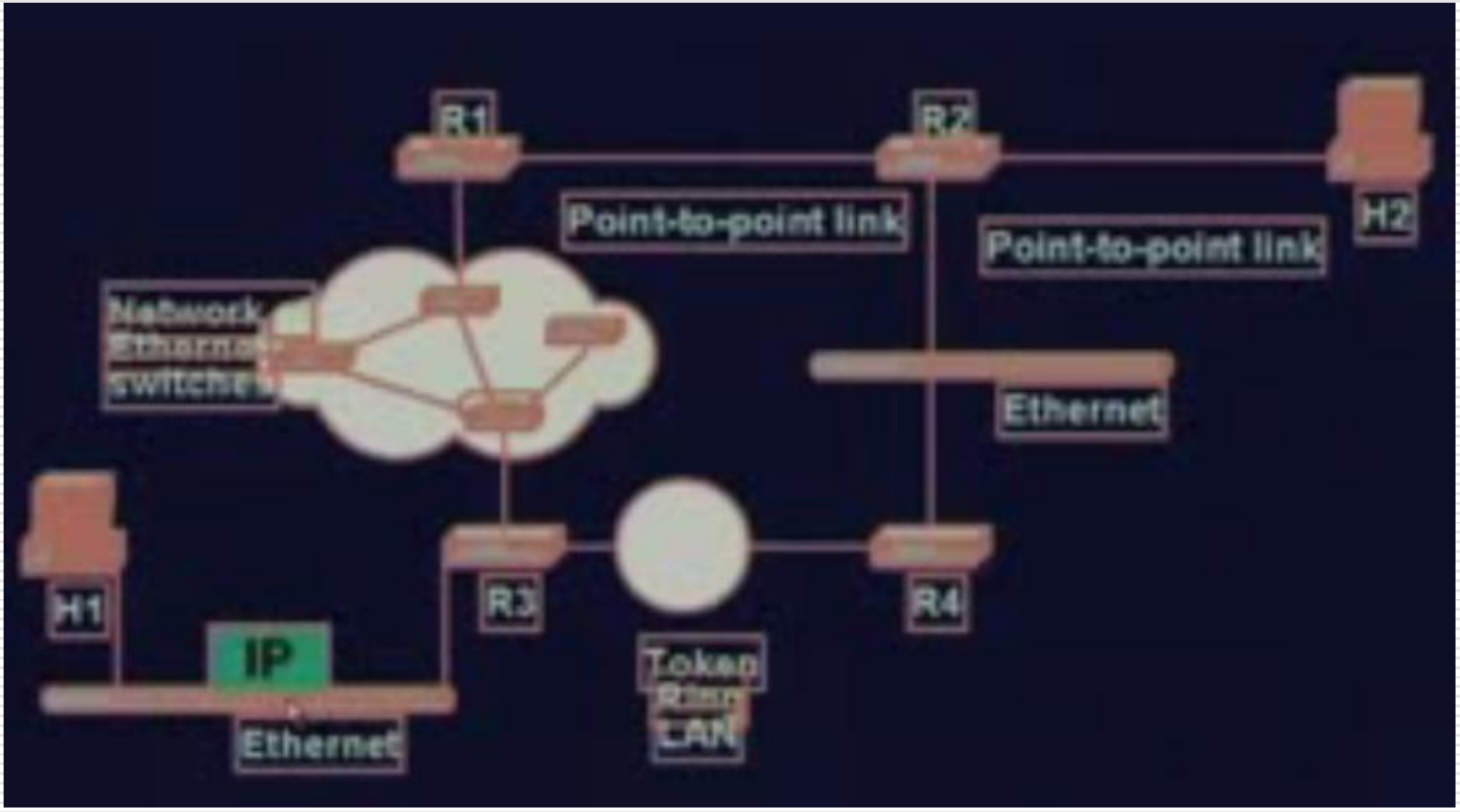
- Processing of IP datagrams is very similar on an IP router and a host
- Main difference:
  - " IP forwarding" is enabled on router and disabled on host.

- IP forwarding enabled
  - If a datagram is received, but it is not for the local system, the datagram will be sent to a different system.
- IP forwarding disabled
  - If a datagram is received, but it is not for the local system, the datagram will be sent to a different system.

Delivery of an IP datagram

- View at the data link layer layer:
  - Internetwork is a collection of LANs or point-to-point links or switched networks that are connected by routers.

Delivery of an IP datagram



Delivery of an IP datagram

- View at the IP layer:
  - An IP network is a logical entity with a network number
  - We represent an IP network as a “cloud”
  - The IP deliver service takes the view of clouds, and ignores the data link layer view.

Delivery of an IP datagram

End-to-end delivery of datagrams

The following conditions must hold so that an IP datagram can be successfully delivered.

1. The network prefix of an IP destination address must correspond to a unique data link layer network(=LAN or point-to-point link or switched network).

   (The reverse need not be true!)

End-to-end delivery of datagrams

1. Routers and hosts that have a common network prefix must be able to exchange IP dagrams using a data link protocol (e.g., Ethernet, PPP)
2. Every data link layer network must be connected to at least one other data link layer network via a router.

Routing tables

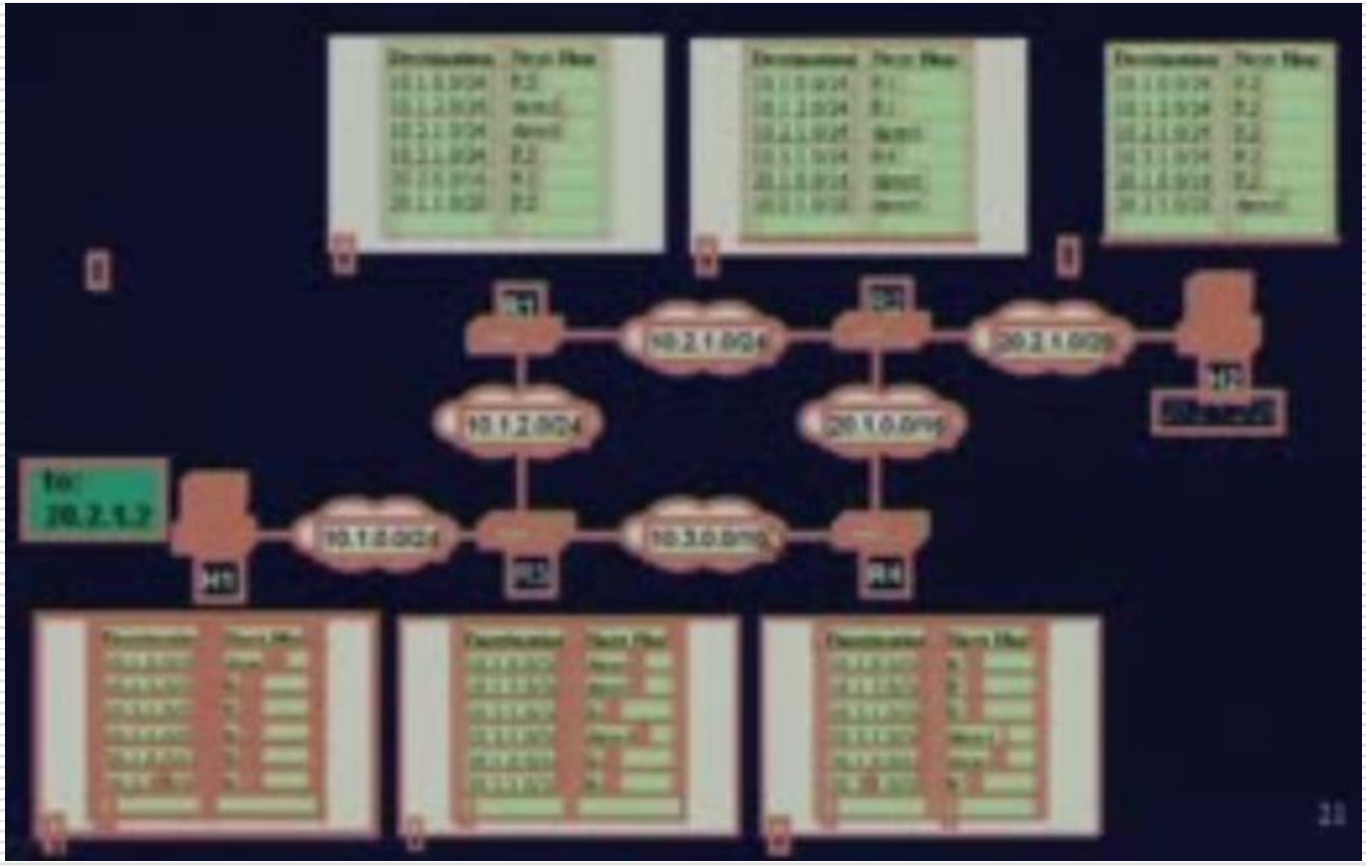
- Each router and each host keeps a routing table which tells the router how to process an outgoing packet.
- Main columns:
  1. Destination address: where is the IP datagram going to?
  2. Next hop: how to send the IP datagram?
  3. Interface: what is the output port?
- Next hop and interface column can often be summarized as one column.
- Routing tables are set so that datagrams gets closer to the its destination.

Routing table of a host or router

IP datagrams can be directly delivered ("direct") or is sent to a router("R4")

Destination	Next Hop	Interface
10.1.0.0/24	direct	eth0
10.1.2.0/24	direct	eth0
10.2.1.0/24	R4	serial0
10.3.1.0/24	direct	eth1
20.1.0.0/16	R4	eth0
20.2.1.0/28	R4	eth0

Delivery with routing tables



Processing of an IP datagram at a router

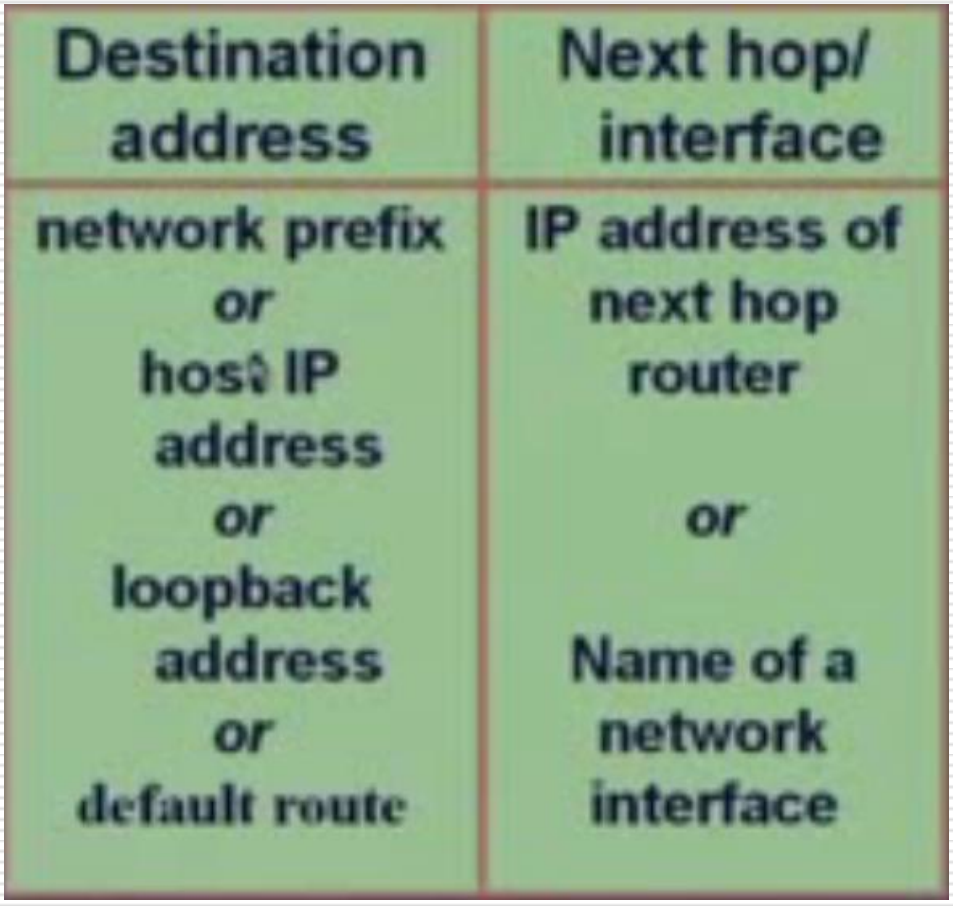
1. Receive an IP Datagram
2. IP header validation
3. Process options in IP header
4. Parsing the destination IP address
5. Routing table lookup
6. Decrement TTL

Processing of an IP datagram at a router

7. Perform fragmentation (if necessary)
8. Calculate checksum
9. Transit to next hop
10. Send ICMP packet (if necessary)

Routing table lookup

- When a router or host need to transmit an IP datagram, it performs a routing table lookup.
- Routing table lookup: Use the IP destination address as a key to search the routing table.
- Result of the lookup is the IP address of a next hop router, and/or the name of a network interface.


Destination address
Next hop/ interface
network prefix
or
host IP address
or
loopback address
or
default route
IP address of next hop router
or
Name of a network interface

Type of routing table entries

- **Network route:**
  - **Destination addresses is a network address (e.g. 10.0.2.0/24)**
  - **Most entries are network routes**
- **Host route**
  - **Destination address is an interface address (e.g. 10.0.1.2/32)**
  - **Used to specify a separate route for certain hosts.**

Type of routing table entries

- Default route
  - Used’ when no network or host route matches.
  - The router that is listed as the next hop of the default route is the default gateway.

Type of routing table entries

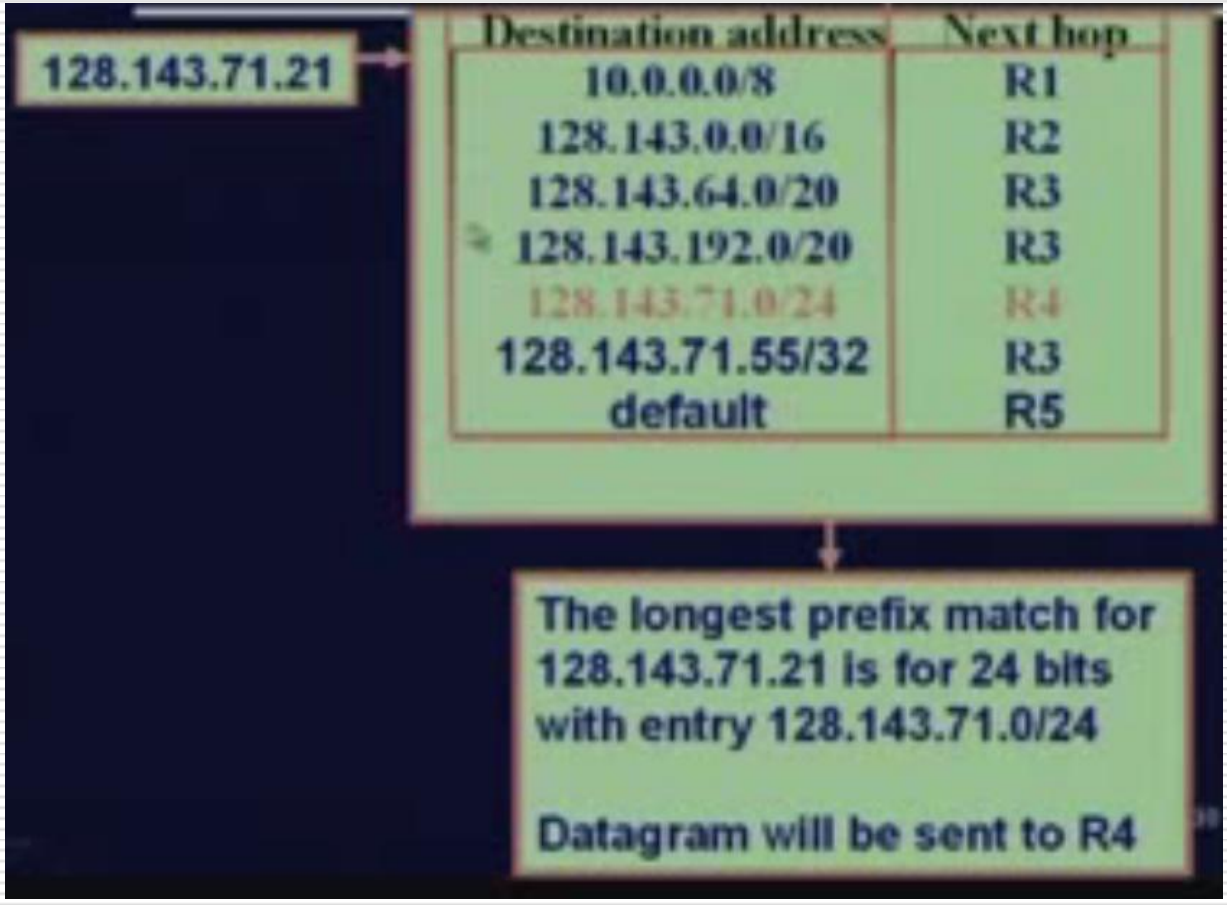
- **Loopback address**
  - **Routing table for the loopback address (127.0.0.1)**
  - **The next hop lists the loopback (lo0) interface as outgoing interface.**

Routing table lookup: Longest Prefix Match

- **Longest Prefix Match: Search for the routing table entry that has the longest match with the prefix of the destination IP address.**
- **Search for a match on all 32 bits, 31 bits… 0 bits.**
- **Host route, loopback entry**

  → 32-bit prefix match
- **Default route is represented as 0.0.0.0/0**

  → 0-bit prefix match.

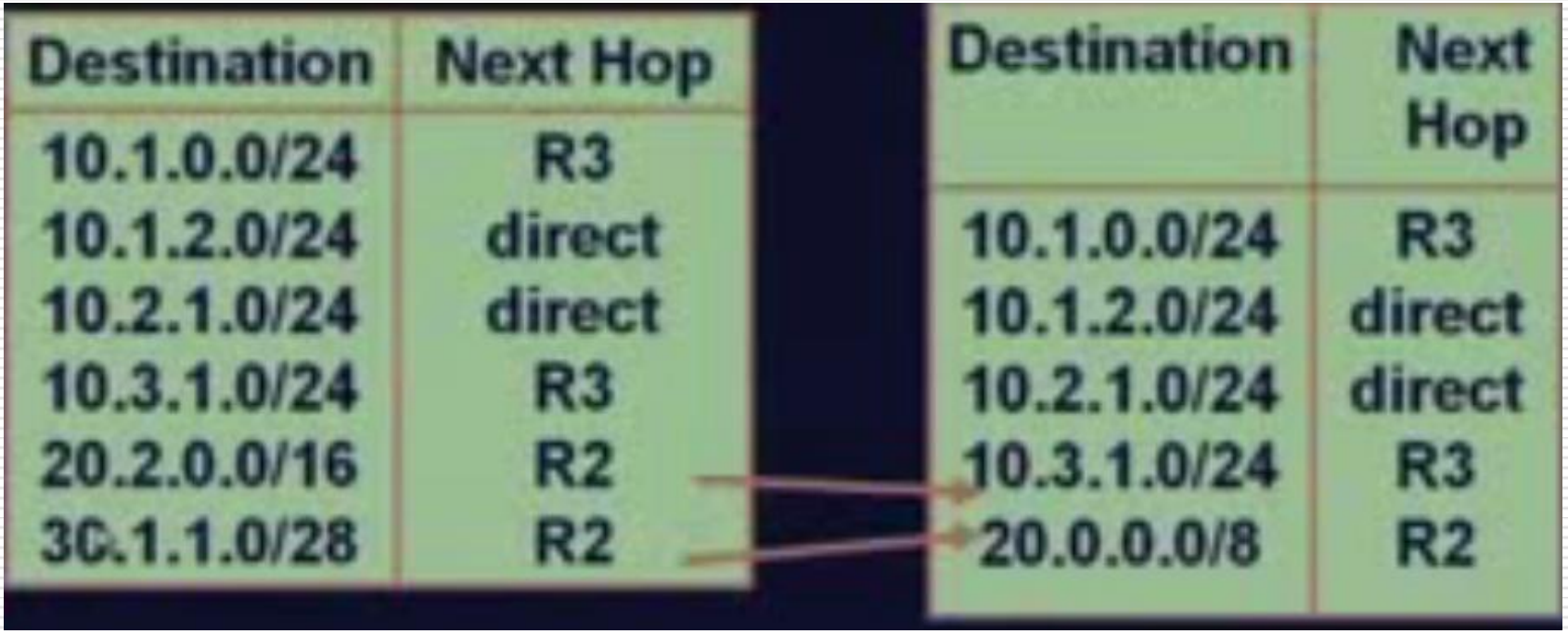

128.143.71.21
Destination address
Next hop
10.0.0.0/8
R1
128.143.0.0/16
R2
128.143.64.0/20
R3
128.143.192.0/20
R3
128.143.71.0/24
R4
128.143.71.55/32
R3
default
R5
The longest prefix match for 128.143.71.21 is for 24 bits with entry 128.143.71.0/24
Datagram will be sent to R4

Route Aggregation

- Longest prefix match algorithm permits to aggregate prefixes with identical next hop address to a single entry.

- This contributes significantly to reducing the size of routing tables of internet routers.

Route Aggregation



Destination	Next Hop
10.1.0.0/24	R3
10.1.2.0/24	direct
10.2.1.0/24	direct
10.3.1.0/24	R3
20.2.0.0/16	R2
30.1.1.0/28	R2

Destination	Next Hop
10.1.0.0/24	R3
10.1.2.0/24	direct
10.2.1.0/24	direct
10.3.1.0/24	R3
20.0.0.0/8	R2

How do routing table get updated?

- **Adding an interface:**
  - **Configuring an interface eth2 with 10.0.2.3/24 adds a routing table entry:**

Destination	Next Hop/ interface
10.0.2.3/24	eth2

- **Adding a default gateway:**
  - **Configuring 10.0.2.1 as the default gateway adds the entry:**

Destination	Next Hop/ interface
0.0.0.0/0	10.0.2.1

Updating Routing Tables

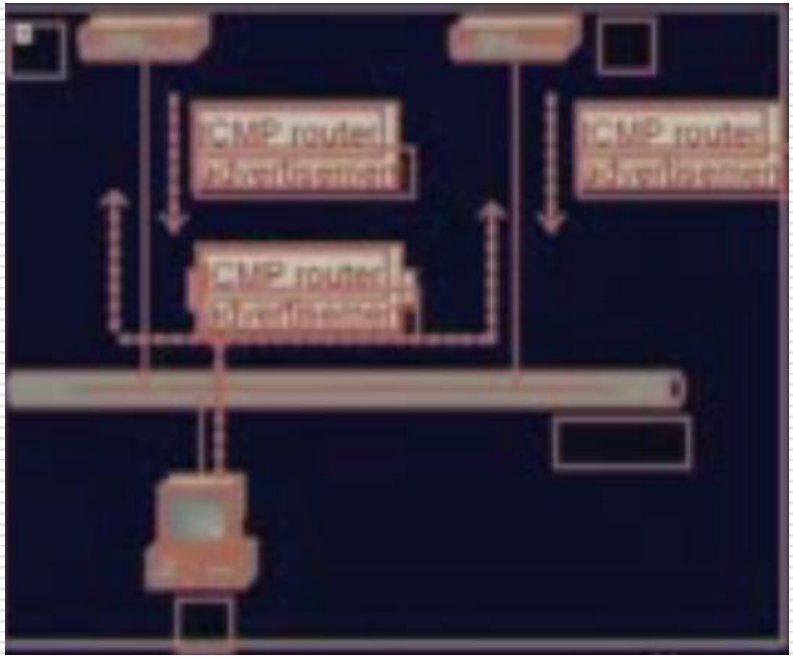
- Static configuration of network routes or host routes.
- Update of routing tables through routing protocols.
- ICMP messages

Routing table manipulations with ICMP

- When a router detects that an IP datagram should have gone to a different router, the router (here R2)
  - Forwards the IP datagram to the correct router.
  - Sends an ICMP redirect message to the host.
- Host uses ICMP message to update its routing table.

- After bootstrapping a router broadcasts an ICMP router solicitation.
- In response, routers send an ICMP router advertisement message.
- Also, routers periodically broadcast ICMP router advertisement

  This is sometimes called the Router Discovery Protocol.



Routing as Graph Theory Problem

- **Nodes: routers of a single administrative domain (intradomain routing), or different networks (interdomain routing)**
- **Edges: interconnection links**
- **Link costs: related to physical distance, capacity, delay, etc.**
- **Objective: determine minimum-cost path (based on certain cost metric) from each node to every other node.**

Routing as a Graph Theory Problem

- **Constraint-1: Solve the minimum-cost path problem in a distributed (rather than centralized)manner**
- **Constraint-2: react quickly and robustly to topology changes.**

Routing Protocol Requirements

- Minimizing routing table space: this makes the routers smaller/cheaper/ faster.

  Exchange overhead is also lower.
- Minimize control messages.
- Robustness: routers should not misroute packets. Loops and oscillations is also to be avoided.
- Use Optimal paths.

Centralized vs. Distributed

- In centralized routing, one central processor collects information about the status of each link, computes the routing table for each node and distributes it.

- In distributed routing, routers cooperate to run a distributed protocol to create mutually consistent routing tables.

Source Based vs Hop by Hop

- In source based routing, the packet header contains the entire route. If a link or a router along the path goes down, a source routed packet will not reach the destination.
- In hop by hop, the packet contains only the destination address and each router chooses the next hop.
- Loose Source Route is an intermediate solution.

Stochastic vs. Deterministic

- **In stochastic routing, each router maintains more than one next hop for each possible destination. One of these is randomly chosen. The load is distributed along the links. On the other hand, packets may get out of order because of this.**

Single vs Multiple Paths

- Each router maintains one primary and some alternate paths. Single path routing is used in internet to reduce routing table size. Multiple paths are used by telephone networks as routes can easily be deciphered from the address (telephone number)

State Dependent vs. State Independent

- State Independent or Static routing precomputes the routes ignoring the network state.

- State Dependent or Dynamic routing uses the current measured network state(like loading or health of a link) to determine the current route. It requires more overhead but can usually find better routes.

Routing in Telephone Network

- Under the same exchange, there is no routing.
- Under the same SDCA, a central switch sets up the connection with the destination exchange.
- For trunk calls, the central switch forwards the setup request to TAX who maintains a primary and an alternate path to destination LDCA.

Flooding

- Every incoming packet is sent out through every outgoing line except the one it arrived on.
- A hop count or keeping track of previously flooded packets may be used to avoid generating infinite no. of packets.
- Gives shortest route and is very robust but hardly practical otherwise.

Flow Based Routing I

- A static algorithm that uses both topology and load for routing.
- The traffic matrix, the capacity matrix and a routing algo is assumed to be given
- The mean delay time for the entire network is calculated from this.
- Different routs from different algorithms (or all possible routs) can be evaluated.

Flow Based Routing II

- Given a particular set of routing entries, the net average traffic in each link is calculated.
- The mean delay of each line is calculated from queuing theory as $T = 1/(\lambda C-k)$ where $1/\lambda$ is mean bits/packet and k is the mean flow in packets/second.
- The mean delay for the entire network is the weighted sum of individual link delays.

Multipath Routing

- At router, given packet with particular final destination, several choices for next router are enumerated.
  - Each choice is assigned routing probabilty.
  - For given packet, actual routing choice is made by sampling corresponding pmf.
- Applicable to VC networks as well as datagram networks
  - In VC network, path of setup packet is determined stochastically.

Multipath routing cont.

- **Alternative routes can be determined by other means than stochastic sampling**
  - **E.g. assign traffic to routes based on priorities.**
  - **Example: an interactive connection between terminal and remote computer could be routed over fiber to minimize delay, while file transfer between same host and destination could be routed via satellite.**

Dynamic Routing

- Centralized routing
  - Single computer computes all new routing tables.
- Advantages
  - Since algorithm has complete information, can yield globally optimal routes.
  - Reduces computational burden at individual nodes.

- **Disadvantages**
  - **Lacks fault tolerance if routing computer goes down or network connectivity is lost.**
  - **Can result in network congestion around site containing routing computer.**

Distributed Routing

- Distributed Bellman-Ford
- Each router maintains routing table with entry for every other destination router in subnet.
  - Indicates preferred outgoing link for destination.
  - Indicates current estimate of ‘distance’ to destination.
- ‘distance’ can be any metric such as hops, time delay, total number of queued packets along path, etc..