Routing Table and Routing Protocols

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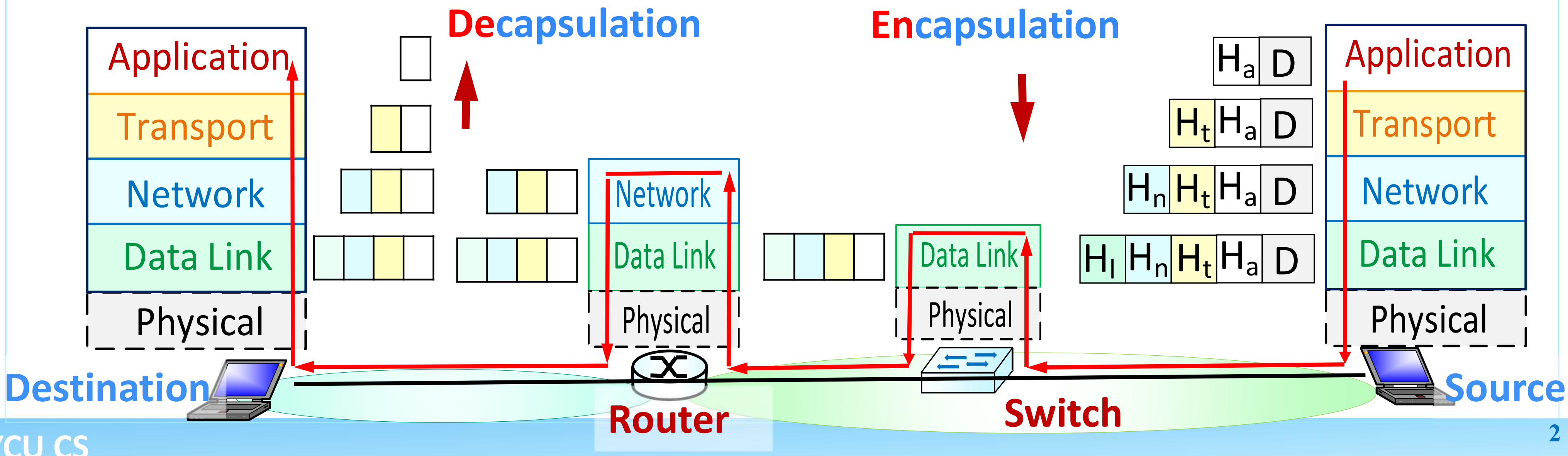
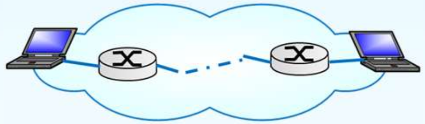
References: Cisco CCNA

Switches vs. Routers

- Both are store-and-forward:
  - *Routers:* NW-layer devices, examine NW-layer headers
  - *Switches:* Link-layer devices, examine link-layer headers
- Both have forwarding tables:
  - *Routers:* compute forwarding tables, using routing algorithms, IP addresses
  - *Switches:* learn forwarding table, using flooding, learning, MAC addresses



Two Main Functions of IP Layer



1) Routing: **control plane**
   determines the source-destination route for packets
   - Manual (**static**) configuration or
   - Dynamic methods (Routing Algorithms)
   - **Slow** time-scales (**per control event**)

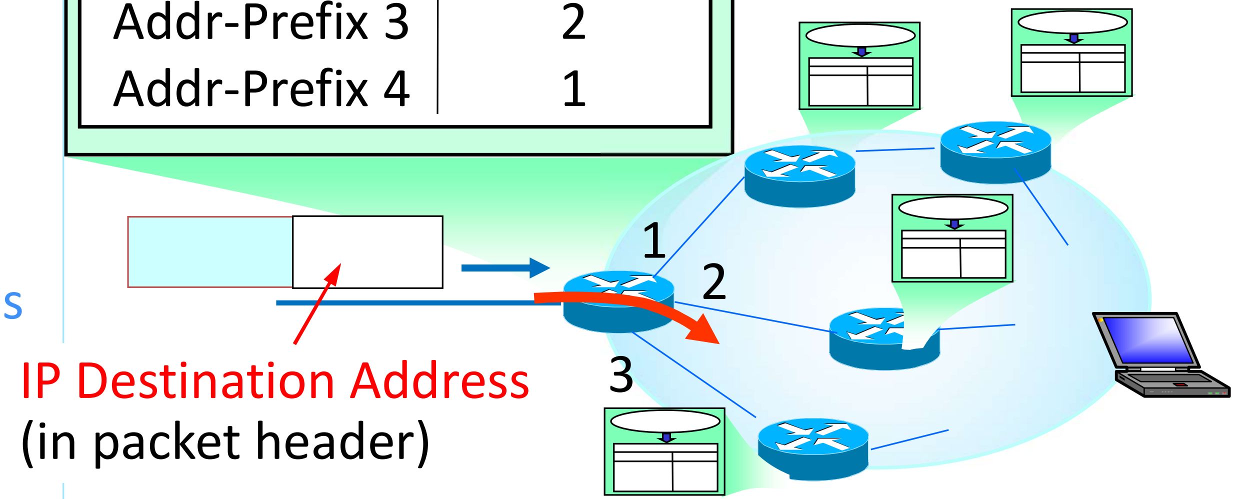
2) Forwarding: **data plane**
   moves packets from router input to appropriate router output
   - Based on IP Destination Addresses
   - **Fast** time-scales (**per-packet**)

Routing Protocol — Determines end-end-route

Forwarding Table — Determines one-hop forwarding

IP Destination	Out link
Addr-Prefix 1	3
Addr-Prefix 2	2
Addr-Prefix 3	2
Addr-Prefix 4	1

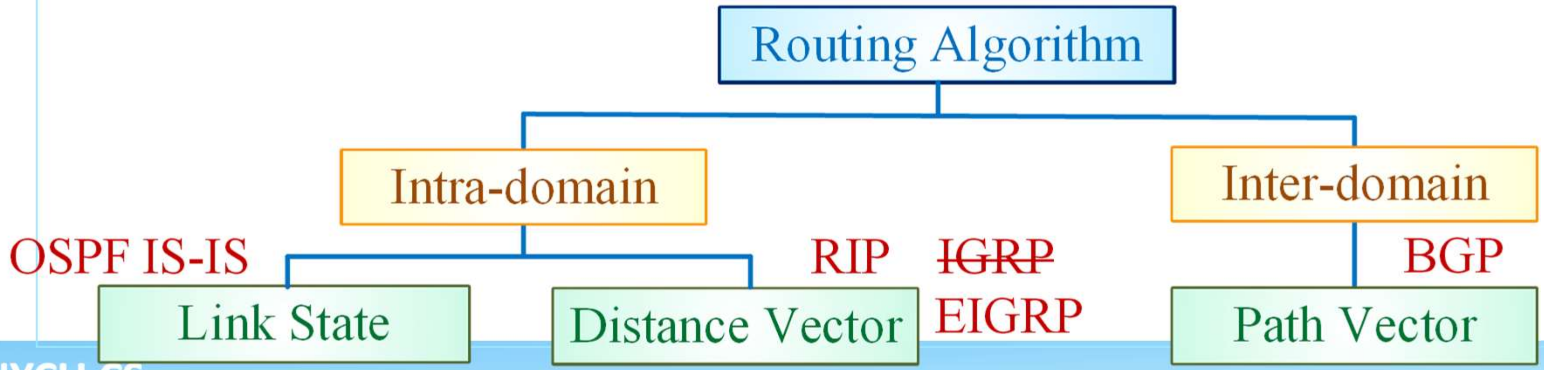
Longest Prefix Matching

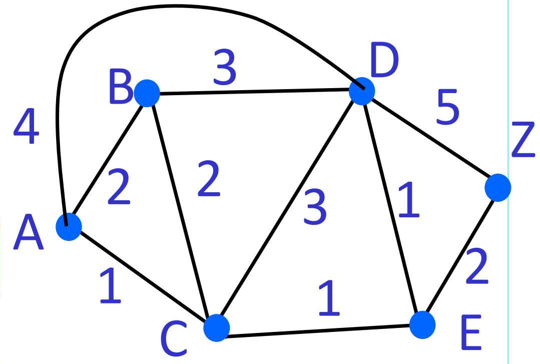


Inter- and Intra-Domain Routing

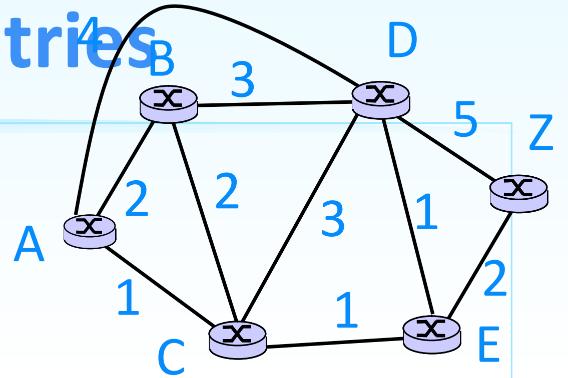
- Internet is divided into **Autonomous Systems (AS).**
- **Autonomous System (AS):**
  a group of networks and routers under the authority of a single administration.
- **Two Types of Routing Algorithms**
  - **Intra-domain (AS) Routing**: Routing inside an AS
    - Interior Gateway Protocol (IGP)
  - **Inter-domain (AS) Routing**: Routing between ASs
    - Exterior Gateway Protocol (EGP)

- OSPF: Open Shortest Path First
- IS-IS: Intermediate system to intermediate system
- RIP: Route Information Protocol
- IGRP: Interior Gateway Routing Protocol (Cisco)
- EIGRP: Enhanced IGRP (Cisco)
- BGP: Border Gateway Protocol





Techniques for Routing Table Entries



- Every host or router has **Routing Tables (RTs)**
- Techniques that make the size of RT **manageable**,

1) **Next-hop Routing**:
   RT entry holds only **Address of Next Hop**,
   – instead of **complete route**

E.g., Packet: A-to-Z

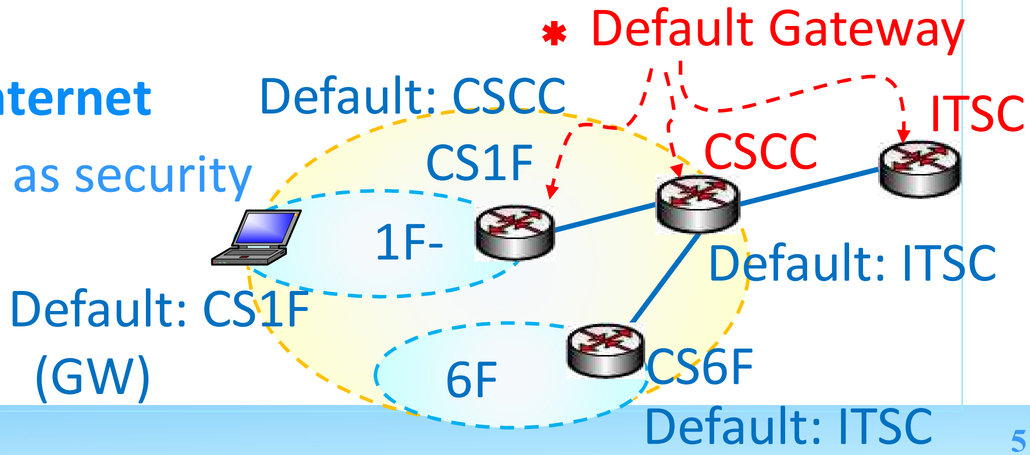
Node A: **C→ Z**, Node C: E → Z, Node E: E → Z

Node A: **A→C → E → Z**, Node C: C → E → Z

2) **Network-Specific Routing**:
   RT entry holds **Destination Network Address**, instead of **Destination Host Address**
   – Holds Destination NW ID (or Prefix,) Instead of Host ID
3) **Default Routing**:
   One RT entry (Default Route) for **Rest of Internet**

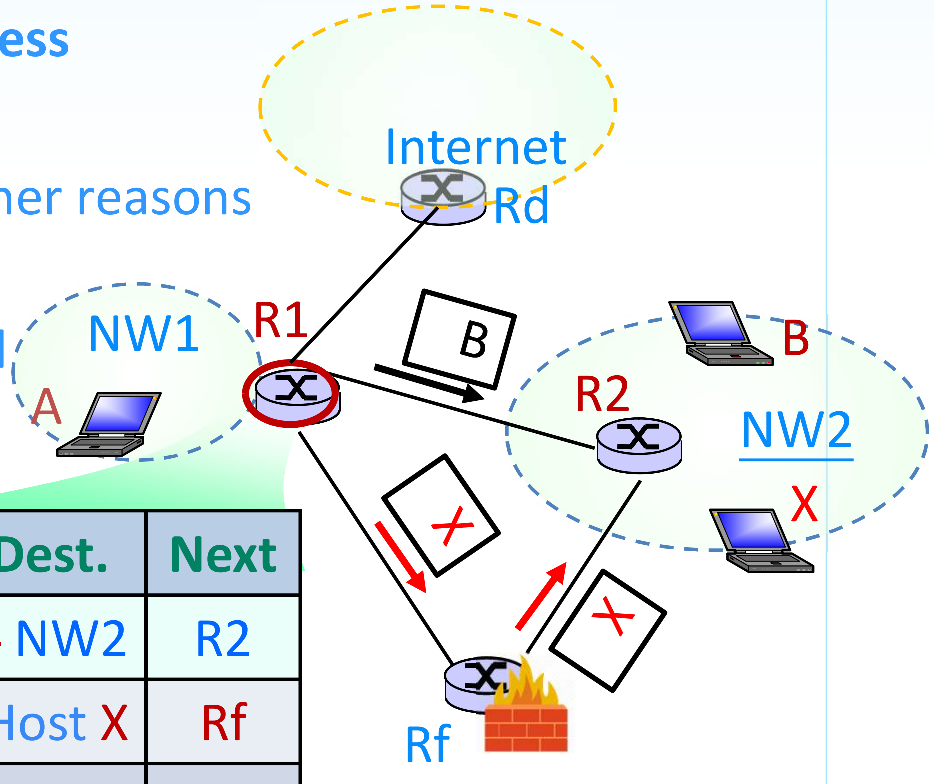
- Techniques that handles **other issues** such as security

4) **Host-Specific Routing**:
   RT entry holds Destination Host address



More Specific Routing

- Host-Specific Routing:
  Routing Table entry holds **Destination Host Address**
- **Sacrifice efficiency** for other advantages
- e.g., **More control** over routing for security or other reasons
  - Packets destined for B, normal
  - Packets destined for X must go thru the firewall
- An extreme case of the **more specific route**

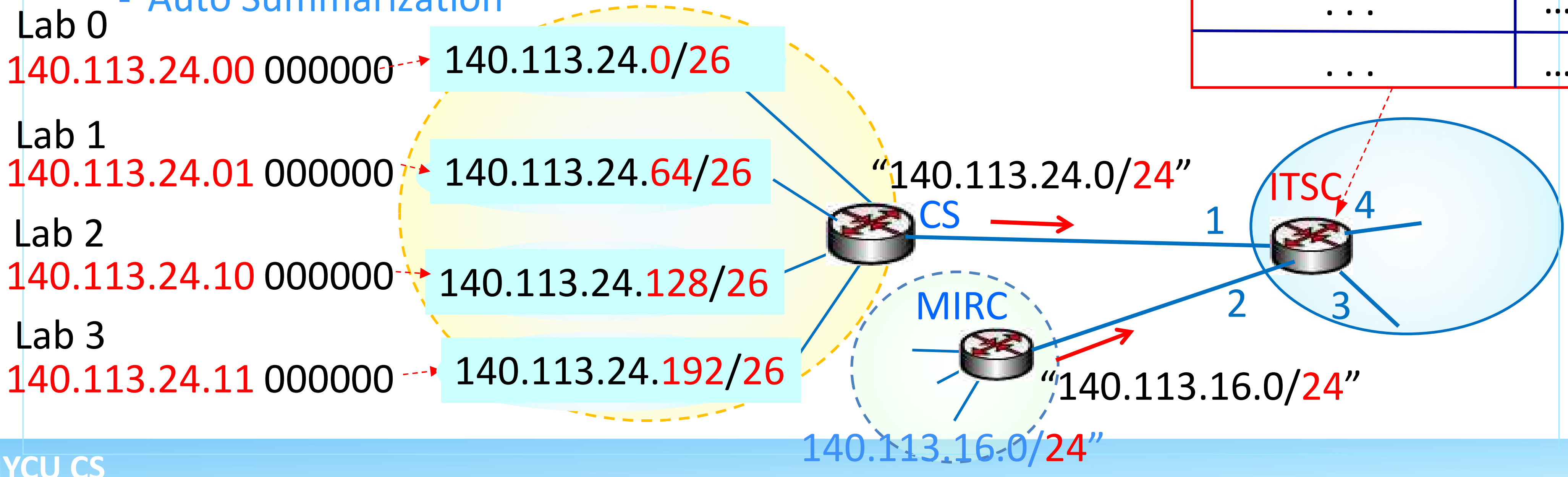


Dest.	Next
~~B~~ NW2	R2
Host X	Rf
…	…
Rest	Rd

Why Longest Prefix Matching – Route Aggregation

- Hierarchical Addressing allows efficient advertisement of routing information:
  - ➢ **Route Aggregation**
- E.g., Given a network of 140.113.24.0/24
  - We can divide it into four subnets of /26
  - But router CS advises 140.113.24.0/24, instead
    - Auto Summarization

Prefix	IF
140.113.24.0/24	1
140.113.16.0/24	2
. . .	…
. . .	…

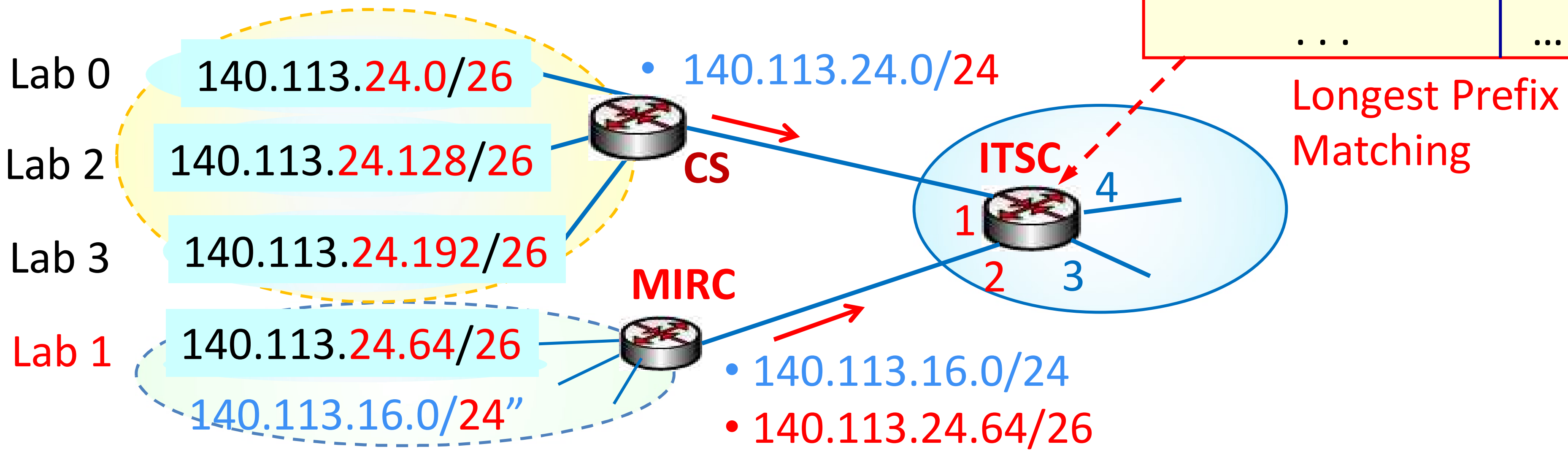


Route Aggregation and Longest Prefix Matching

- ★ Ex., Lab 1 moves to MIRC, but retains original addresses
  - ◦ MIRC advises **more specific route** to 140.113.24.64/26
  - ➢ ITSC RT entries: 140.113.24.0/24, 140.113.24.64/26
- ● Longest Prefix Matching: 140.113.24.100 matches both
  - ➢ ITSC forwards packet to MIRC (via interface 2)

ITSC RT Entries

Prefix	IF
140.113.24.64/26	2
140.113.24.0/24	1
140.113.16.0/24	2
. . .	…

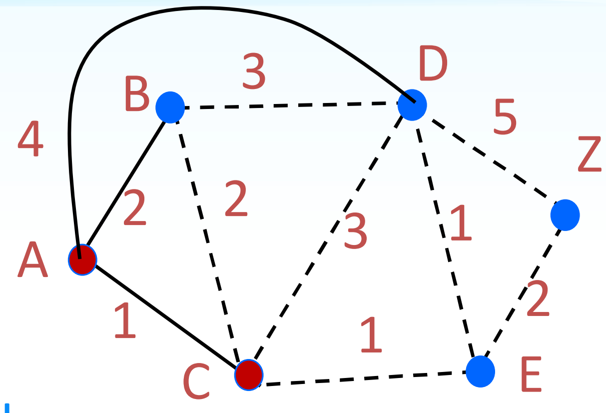


✓ Another example of Longest Prefix Matching: Host-specific route

Back

Link State Algorithm

- Tell **everyone** what you know about **your neighbors**
  - Advertise
    "The state of the links from yourself to all neighbors"



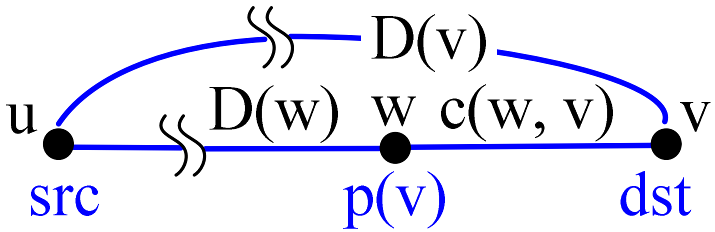
- Two Phases
  1. **Link State Broadcasting**
     - Each node transmits **link-state packets** (**LSPs**) on all links
     - A neighboring router floods (forwards out all links except the incoming one)
     - ➢ All nodes know network topology and link costs
  2. **Path Calculation**: Based on **Dijkstra's algorithm**
     - Each node computes the least cost paths from itself ('source") to all other nodes
     - ➢ Construct the routing table with the least cost paths

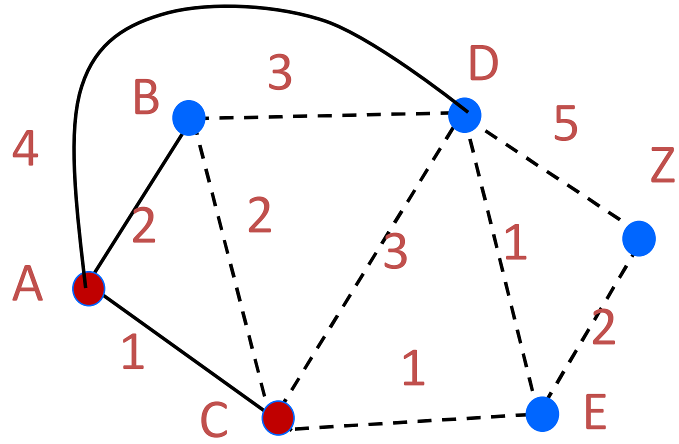
Link State Dijkstra's algorithm

- Dijkstra's algorithm for Best path calculation (to every other node)
  1. Pick unprocessed node w with smallest weight,
  2. Mark w as processed and

     Update cost of all unprocessed node v that adjacent to w

     D(v) = min(D(v), D(w) + c(w,v))





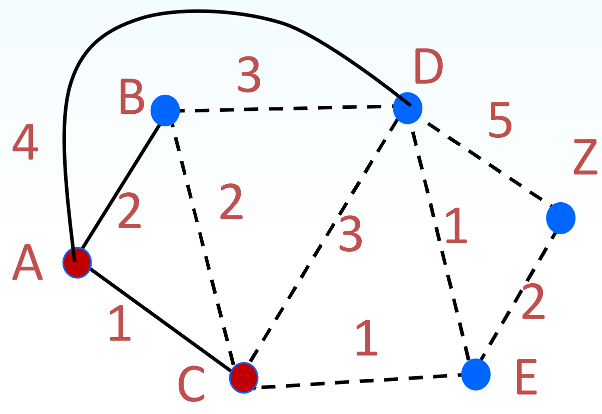
p(v): precedence of v

w is p(v)

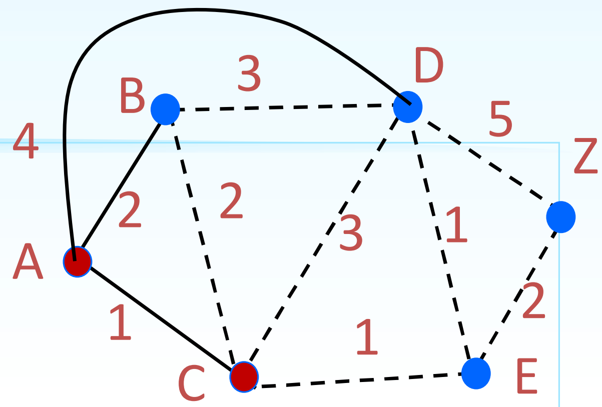
  3. Repeat step 1 until done

Distance Vector Algorithm

- Tell **your neighbors** what you know about **everyone**
  - Advertise
    "The shortest distance to everyone"
- Iterative, Asynchronous and Distributed:
  - Each local iteration caused by
    - Local link cost change
    - Distance Vector (DV) update-messages from neighbors
  - Algorithm: Each node
    1. Wait for local link cost change or update messages from neighbors
    2. Estimates its own DV, based on the **Bellman-Ford Algorithm**
    3. Notifies neighbors *only* when its DV changes,
       - Neighbors then notify their neighbors if necessary
    4. Repeat step 1



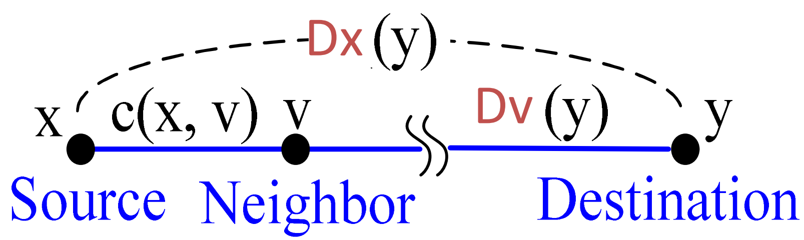
Bellman-Ford Algorithm



- *c(x,v)*: cost for direct link from *x* to *v*
- *Dx(y)*: estimate of least cost from *x* to *y*
- Node *x* maintains
  - Costs of direct links *c(x,v)*
  - Distance vector: from *x* to every node *y*

    ***D**x = [Dx(y): y ϵ N]*
  - Distance vectors of x's neighbors

    ***D**v = [Dv(y): y ϵ N] for* each neighbor *v*



- When **node x** receives a new update message from a neighbor v,
  - Update its own distance vectors using **Bellman–Ford Equation**

    Dx(y) ← minv{c(x,v) + Dv(y)} for each node *y* ε *N*

Best Path

- Metric (度量):
  Quantitative value routing protocols use to measure the **distance to** a given network
- Best path: selected by a routing protocol
  - The path with the **lowest metric**
- **Dynamic routing protocols**
  Use **rules** and **metrics** to **build** and **update routing tables**
  - **Routing Table** (Routing Information Base)
    - Data structure used by Routing Protocols
  - Forwarding Table (Forwarding Information Base)
- **Routing algorithm**
  generates a metric for each path through the network,
  - Based on path characteristic

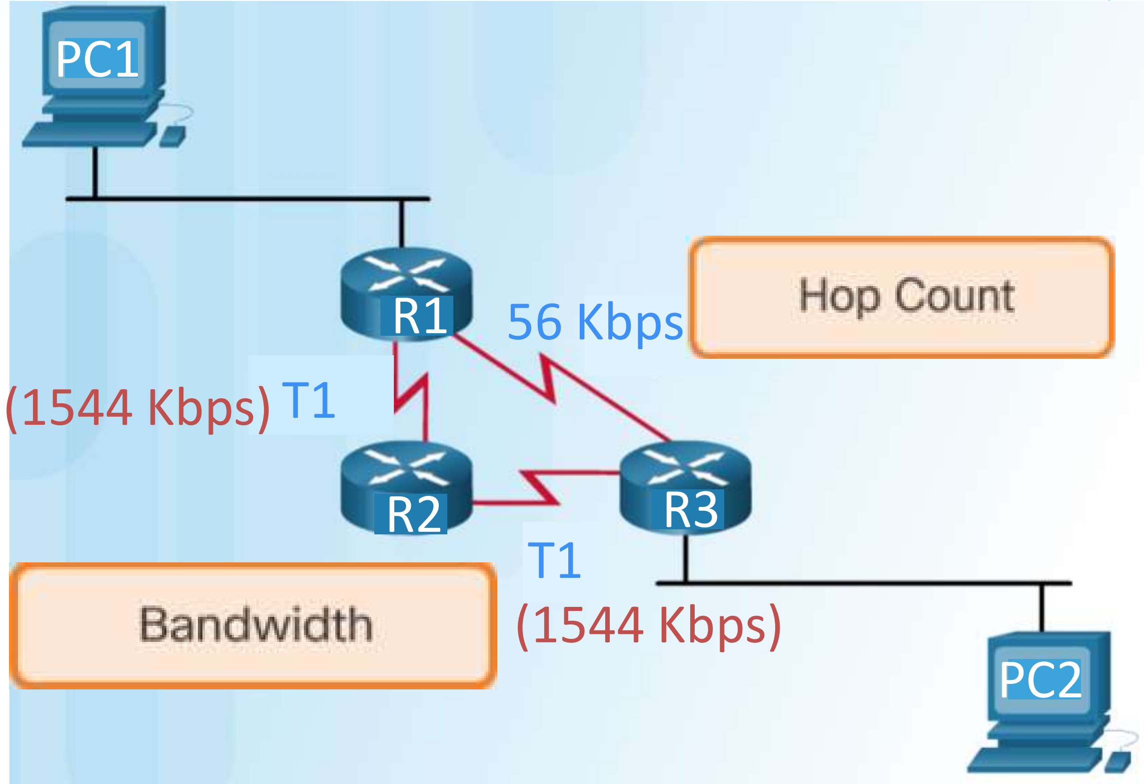
Routing Protocol

Forwarding Table

IP Destination	Out link
Addr-Prefix 1	3
Addr-Prefix 2	2
Addr-Prefix 3	2
Addr-Prefix 4	1

Example Metrics

- Some dynamic protocols and metrics in use:
  - **Routing Information Protocol (RIP):**
    - Hop count
  - **Open Shortest Path First (OSPF):**
    - Cisco's cost based on **cumulative bandwidth** from source to destination
  - **Enhanced Interior Gateway Routing Protocol (EIGRP):**
    - Bandwidth,
    - delay,
    - load,
    - reliability



Administrative Distance

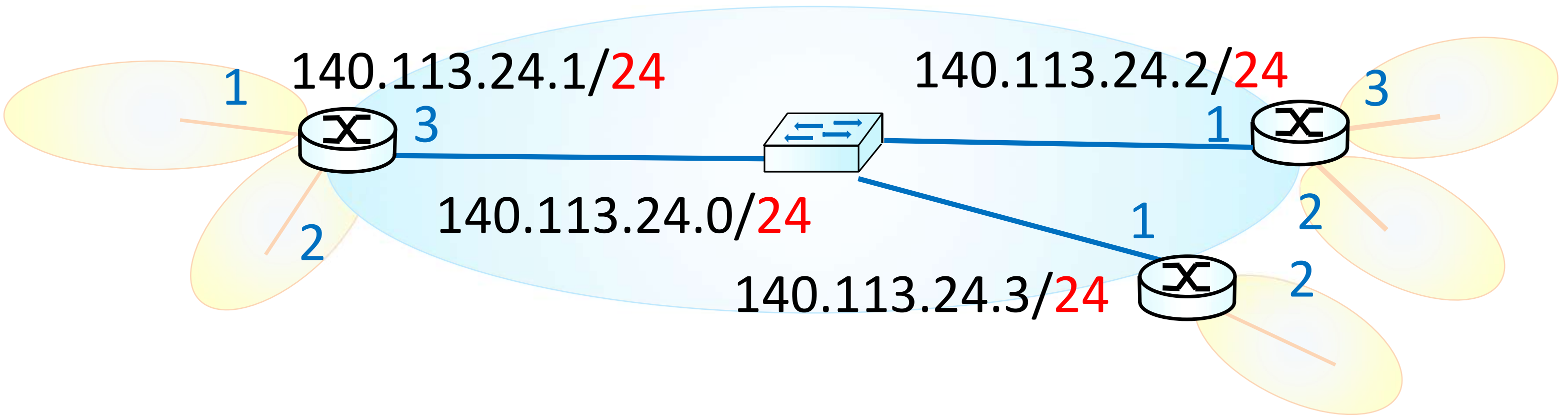
- A router may have **more than one route source** for the same destination network
  - Due to
    - **Multiple routing protocols** (OSPF, RIP, or …) and
    - **Static routes**
- Different routing protocols may decide **different paths** to reach a destination network
  - Due to different metrics in use.
- ➢ How does the **router** determine **which route to use**?
- Cisco IOS uses Administrative Distance (AD) to determine the route
  - AD represents the "trustworthiness" of the **route**;
    - The **first criterion** routers use to determine which route source to use
    - The lower the AD, the more trustworthy the **route source**
  - ➢ Given **two different routes** to **the same destination**, a router chooses the route with the lowest AD,

Administrative Distances (Ads) of Route Sources

Route Source	Administrative Distance
Connected	0
Static	1
EIGRP summary route	5
External BGP	20
Internal EIGRP	90
IGRP	100
OSPF	110
RIP	120
External EIGRP	170
Internal BGP	200

Local Route and Directly Connected Route

- When we configure an IP address on a router's interface, the router will automatically add **two routes** from this IP configuration.
  - Local Route: route to the interface that belongs to the router itself.
  - Directly Connected Route: route to the network directly attached to the interface
    - We use the router's interface as the default gateway to the network connected to the interface



Routing Table Sources

- Entries in the routing table can be added as:
  - **Local Route** Interfaces - Added when an interface is configured and active,
    - L: Identifies a router's interface
    - Displayed in IOS 15 or newer for IPv4 routes and all IOS releases for IPv6 routes
  - **Directly Connected** Interfaces - Added when an interface is configured and active
    - C: Identifies a directly connected network.
  - **Static Routes** - Added when **manually configured** and the **exit** interface is active
  - **Dynamic Routing Protocol** - Dynamically learned by a routing protocol
    - EIGRP, OSPF, RIP, …
- On a Cisco router, **`show ip route`** command displays IPv4 routing table
  - Additional route information, including
    - How the route was learned,
    - How long the route has been in the table, and
    - Which specific interface to use to reach the destination

Directly Connected Routing Table Entries

- Contains the following information:
  - A. **Route Source:** How the route was learned.
    - Two codes for Directed Connected Routing Table entries.
      - ’`L`’: IPv4 address assigned to **router’s interface**
      - ‘`C`’: a directly connected network
  - B. **Destination Network** - Address of the remote network
  - C. **Outgoing Interface** - Exit interface to use when forwarding packets to the destination network

A		B	C
C		192.168.10.0/24 is directly connected,	GigabitEthernet0/0
L		192.168.10.1/32 is directly connected,	GigabitEthernet0/0

- **Note**: Local route (`L`) entry:
  - was not displayed prior to IOS 15 in IPv4 routing table.
  - has always been a part of IPv6 routing table

Remote Network Routing Table Entries

Manually configured or learned from Routing Protocols

- Contains the following information:
  - **A. Route source** - how the route was learned. *(C – connected, S – static, R – RIP, …)*
  - **B. Destination Network** - address of the remote network.
  - **C. Administrative Distance** - trustworthiness of the route source.
    - Lower values indicate the preferred route sources.
  - **D. Metric - value (cost) assigned to reach the remote network.**
    - Lower values indicate the preferred routes.
  - **E. Next-hop** - **IPv4 address of the next router** to forward the packet to a network.
  - **F. Route Timestamp** - how much time has passed since the route was learned.
  - **G. Outgoing Interface** - exit interface to use when forwarding a packet toward the destination network

A	B	C	D		E	F	G
D	10.1.1.0/24	[90/	2170112]	via	209.165.200.226,	00:00:05,	Serial0/0/0

(EIGRP)