Lecture 7: Routing

Reading 5.2

Computer Networks, Tanenbaum

Bài giảng có sử dụng nguồn tài liệu cung cấp bởi trường Đại học Keio, Nhật Bản

Contents

- What is routing?
- Static routing and dynamic routing
- Routing algorithms and protocols

What is routing?

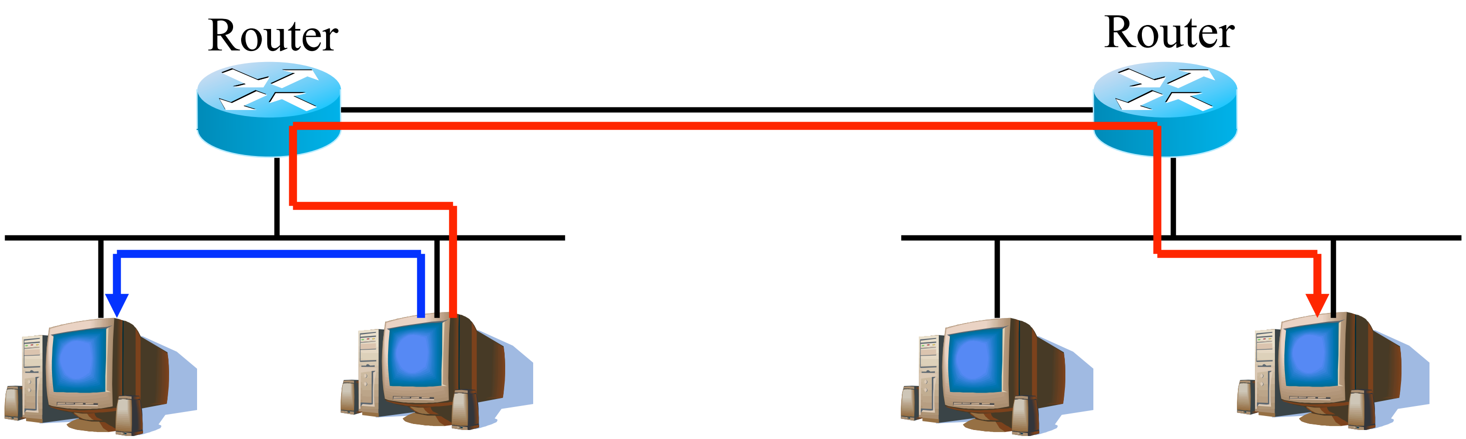
Routing principals

Forwarding mechanism

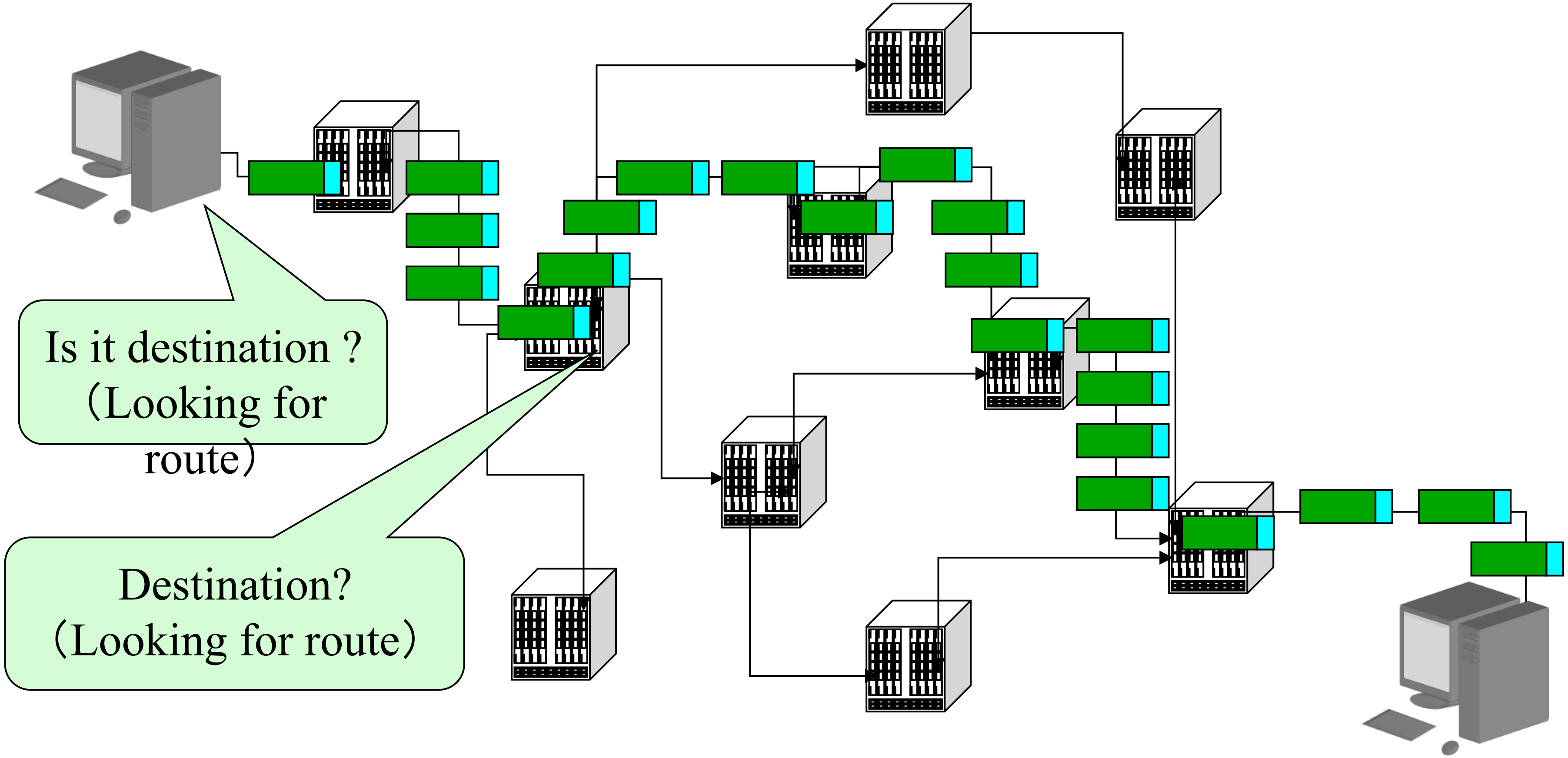
"Longest matching" rule

Routing principles (1)

- When a host send an IP packet to another host
  - If the destination and the source are in the same physical medium: Transfer directly
  - If the destination is in a different network with the source: Send through some other routers (need to choose route)



Routing principles (2)



What is routing?

- A mechanism so that a host or a router decides how to forward a packet from source to destination.
- Result of the routing is a routing table
- What to consider in routing
  - Building routing table
  - Information need to calculating route
  - Routing algorithm and protocol.

What is a router?

- Router is the device that forwards data between networks
  - Is a computer with particular hardware
  - Connects multiple networks together, has multiple network interfaces
  - Forward packets according to routing table

Some examples of routers…

BUFFALO
BHR-4RV

PLANEX
GW-AP54SAG

YAMAHA
RTX-1500

Cisco 2600

Router ngoại vi

Cisco CRS-1

Router mạng trục

Hitachi
GR2000-1B

Juniper M10

Foundry Networks
NetIron 800

Cisco 3700

Router cỡ trung

http://www.cisco.com.vn

http://www.juniper.net/

http://www.buffalotech.com

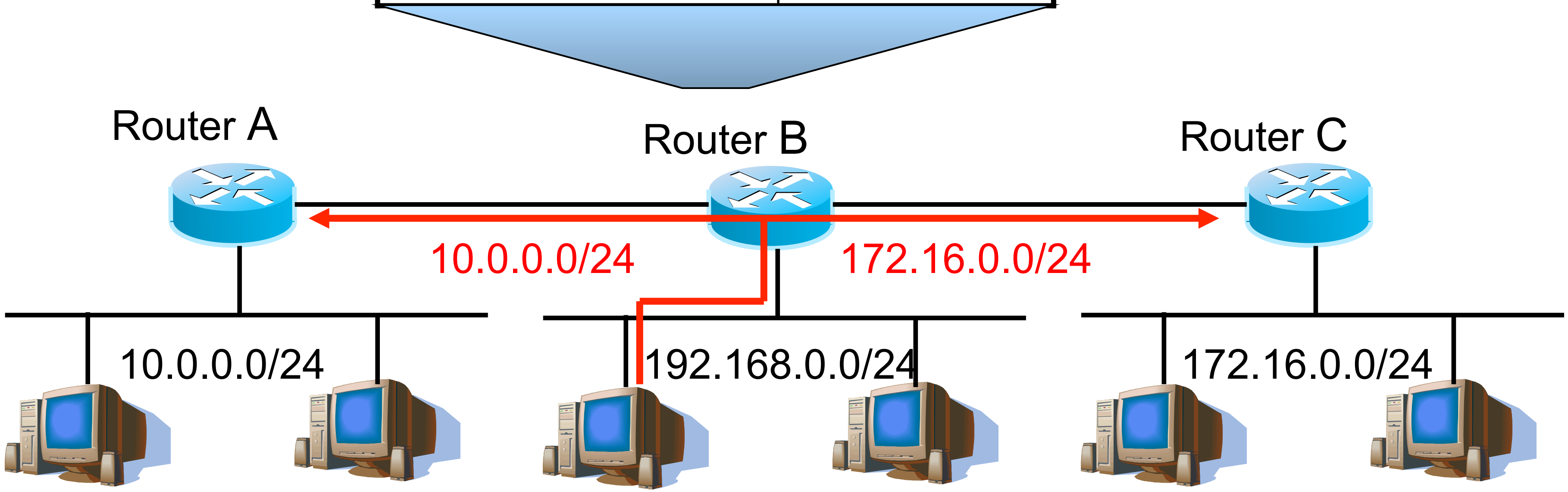
Routing table

- Lists of possible routes, saved in the memory of router
- Main components of routing table
  - Destination network address/network mask
  - Next router

```
#show ip route
Prefix                      Next Hop
203.238.37.0/24 via 203.178.136.14
203.238.37.96/27 via 203.178.136.26
203.238.37.128/27 via 203.178.136.26
203.170.97.0/24 via 203.178.136.14
192.68.132.0/24 via 203.178.136.29
203.254.52.0/24 via 203.178.136.14
202.171.96.0/24 via 203.178.136.14
```

Routing table and forwarding mechanism (1)

Network	Next-hop
10.0.0.0/24	A
172.16.0.0/24	C



Rule: ***No routes, no reachability*!**

"Longest matching" rule (1)

- Assume that there are more than one entry matching with a destination network in routing table.
- Destination address: 11.1.2.5
- What should be chosen as the next hop?

Network	Next hop
11.0.0.0/8	A
11.1.0.0/16	B
11.1.2.0/24	C

“Longest matching” rule (2)

Destination address:

11.1.2.5 = 00001011.00000001.00000010.00000101

Route 1:

11.1.2.0/24 = 00001011.00000001.00000010.00000000

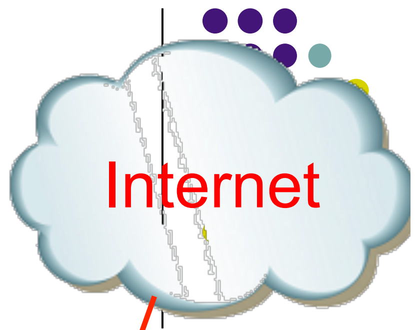
Route 2:

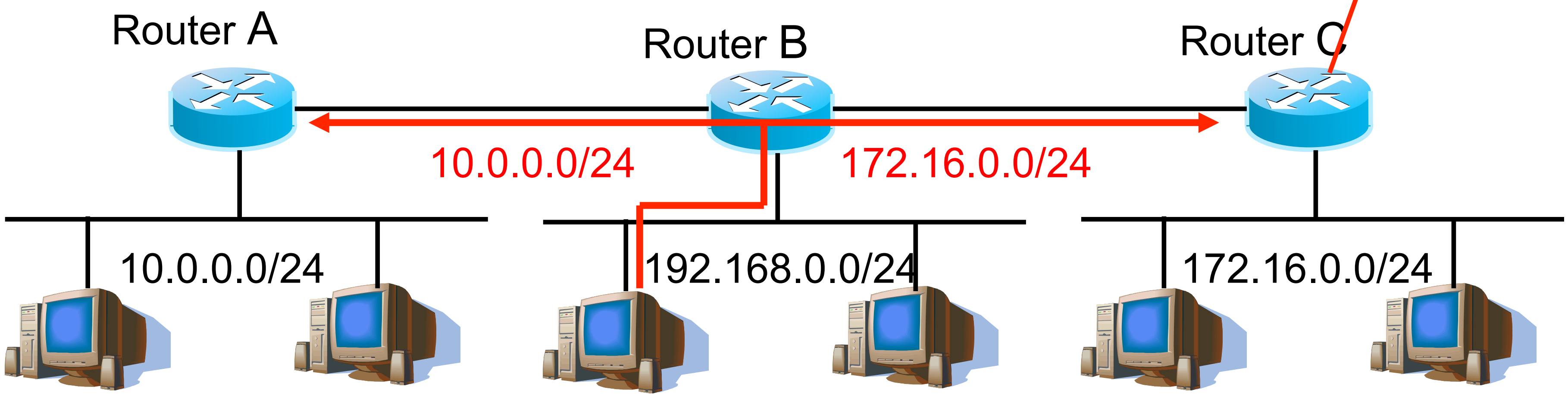
11.1.0.0/16 = 00001011.00000001.00000000.00000000

Route 3:

11.0.0.0/8 = 00001011.00000000.00000000.00000000

Routing table and forwarding mechanism (2)





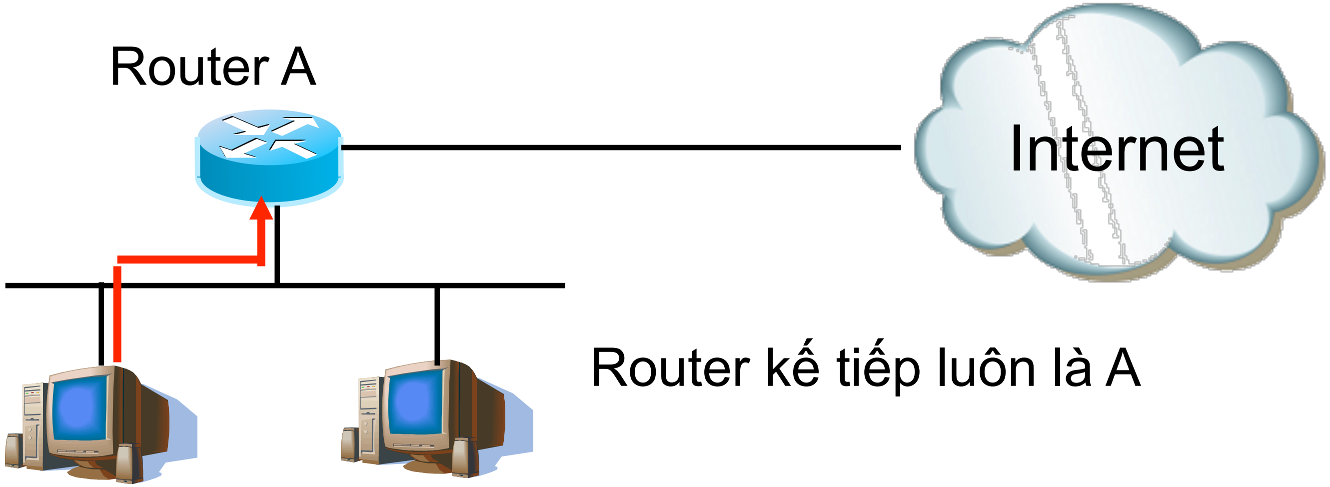
Network	Next-hop
10.0.0.0/24	A
172.16.0.0/24	C
192.168.0.0/24 0.0.0.0/0	Direct C

Q. What is the routing table in C?

Q: What if C is connected to the Internet?

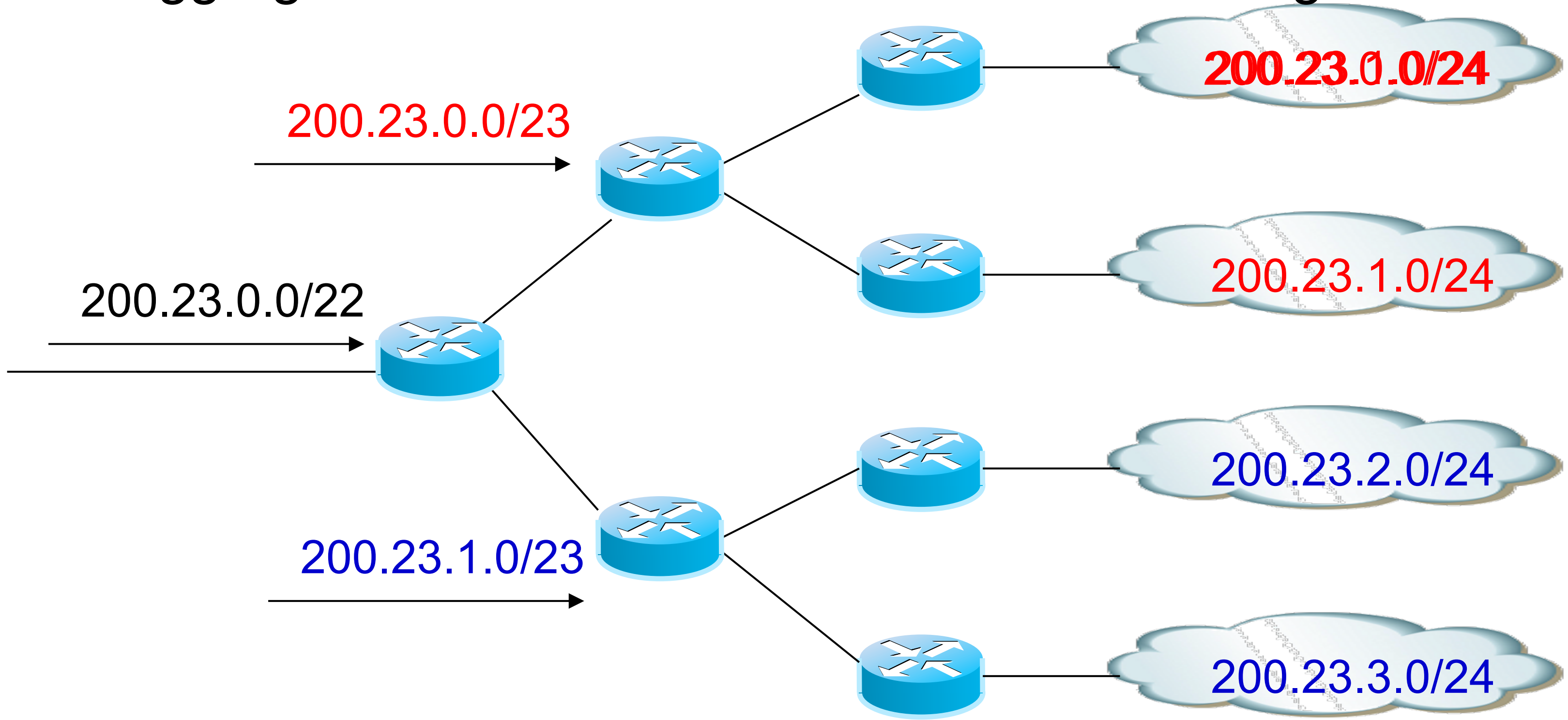
Default route

- If router does not find a route to a destination in its routing table, default route is necessary
  - Default route is defined for all destination networks that are not figured in the routing table.
- 0.0.0.0/0
  - Is a special notation for all destination networks



Route aggregation

- How many networks in the Internet?
- There will be a lot of entries in the routing table?
- The entries to sub-networks of the same "big" network can be aggregated inorder to reduce the size of routing table.



Route aggregation (2)

- Example of Viettel network
  - Viettel own a big IP address space
    - 203.113.128.0-203.113.191.255
  - For connecting to a subnet (client) of Viettel, routing table needs only to have a route to Viettel network.
- Default route is a type of route aggregation
  - 0.0.0.0/0

Exercises

- A router has the following (CIDR) entries in its routing table:

Address/mask Next hop

135.46.56.0/22 Interface 0

135.46.60.0/22 Interface 1

192.53.40.0/23 Router 1

default Router 2

- For each of the following IP addresses, what does the router do if a packet with that address arrives?

(a) 135.46.63.10

(b) 135.46.57.14

(c) 135.46.52.2

(d) 192.53.40.7

(e) 192.53.56.7

Solution:

Apply longest matching rule.

Solution

Apply longest matching rule.

(students should explain why by matching binary form of the addresses)

(a) 135.46.63.10 → Interface 1

(b) 135.46.57.14 → Interface 0

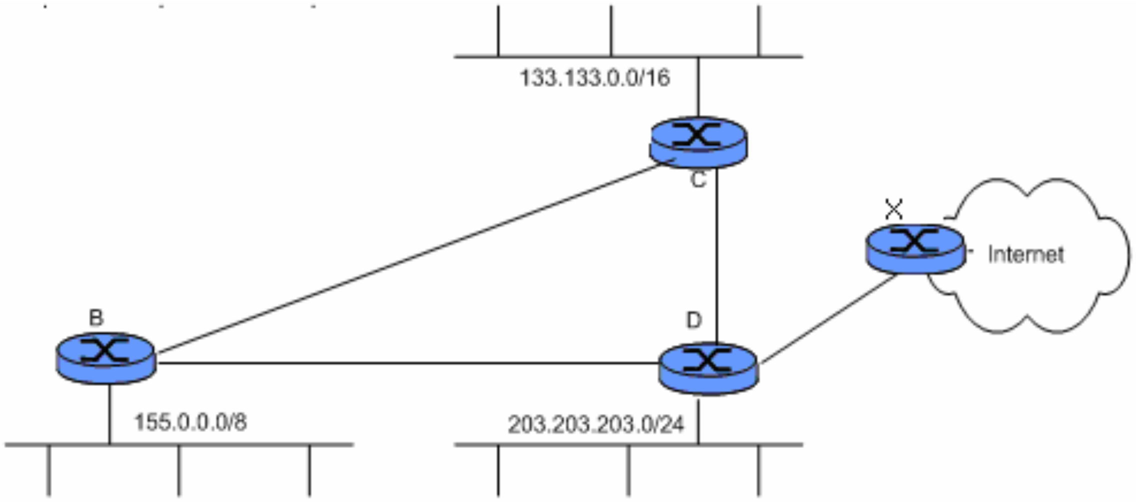
(c) 135.46.52.2 → Router 2 (default route)

(d) 192.53.40.7 → Router 1

(e) 192.53.56.7 → Router 2 (default route)

Exercise

- Assume that we have a network with following topology. What should be routing table of routers B, C, D in order to assure that all hosts can send data to each other and to the Internet.



Solution

- Routing table on B

Network	Next hop
133.133.0.0/16	C
155.0.0.0/8	Direct
203.203.203.0/24	D
0.0.0.0/0	D

- Routing table on C

Network	Next hop
133.133.0.0/16	Direct
155.0.0.0/8	B
203.203.203.0/24	D
0.0.0.0/0	D

- Routing table on D

Network	Next hop
133.133.0.0/16	C
155.0.0.0/8	B
203.203.203.0/24	Direct
0.0.0.0/0	X

Example of routing table on a host

C:\Documents and Settings\hongson>netstat -rn
Route Table
===
Interface List
0x1 .... ………MS TCP Loopback interface
0x2 ...08 00 1f b2 a1 a3 ...... Realtek RTL8139 Family PCI Fast Ethernet NIC -
===

Active Routes:

Network	Netmask	Gateway	Interface	Metric
0.0.0.0	0.0.0.0	192.168.1.1	192.168.1.34	20
127.0.0.0	255.0.0.0	127.0.0.1	127.0.0.1	1
192.168.1.0	255.255.255.0	192.168.1.34	192.168.1.34	20
192.168.1.34	255.255.255.255	127.0.0.1	127.0.0.1	20
192.168.1.255	255.255.255.255	192.168.1.34	192.168.1.34	20
224.0.0.0	240.0.0.0	192.168.1.34	192.168.1.34	20
255.255.255.255	255.255.255.255	192.168.1.34	192.168.1.34	1

Default Gateway: 192.168.1.1
===

Example of routing table in a Router

```
#show ip route
Prefix                  Next Hop
203.238.37.0/24 via 203.178.136.14
203.238.37.96/27 via 203.178.136.26
203.238.37.128/27 via 203.178.136.26
203.170.97.0/24 via 203.178.136.14
192.68.132.0/24 via 203.178.136.29
203.254.52.0/24 via 203.178.136.14
202.171.96.0/24 via 203.178.136.14
```

Static and dynamic routing

Static routing

Dynamic routing

Advantage – Weakness

Problem of update routing table

- When topology change: new networks, a router is out of power
- It is necessary that routing tables are updated
  - In theory, all routers need to be updated
  - In reality, only few routers need to be updated

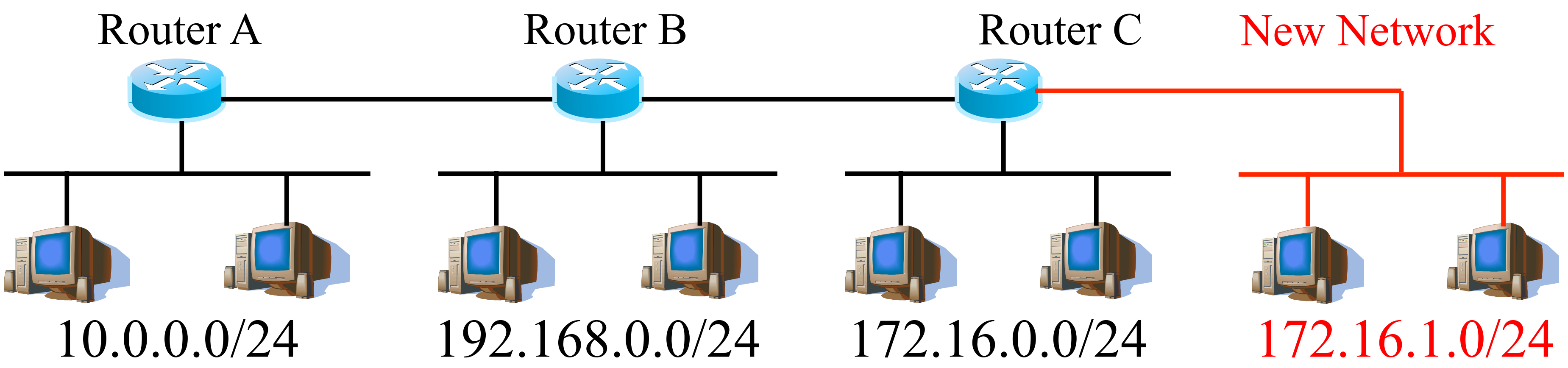
Network	Next-hop
192.168.0.0/24	B
172.16.0.0/24	B

172.16.1.0/24 B

Network	Next-hop
10.0.0.0/24	A
172.16.0.0/24	C

172.16.1.0/24 C

Network	Next-hop
10.0.0.0/24	B
192.168.0.0/24	B



How to update routing table?

- Static routing
  - Entries in the routing tables are updated manually by network administrator.
- Dynamic routing
  - The routing table is updated automatically by some routing protocols

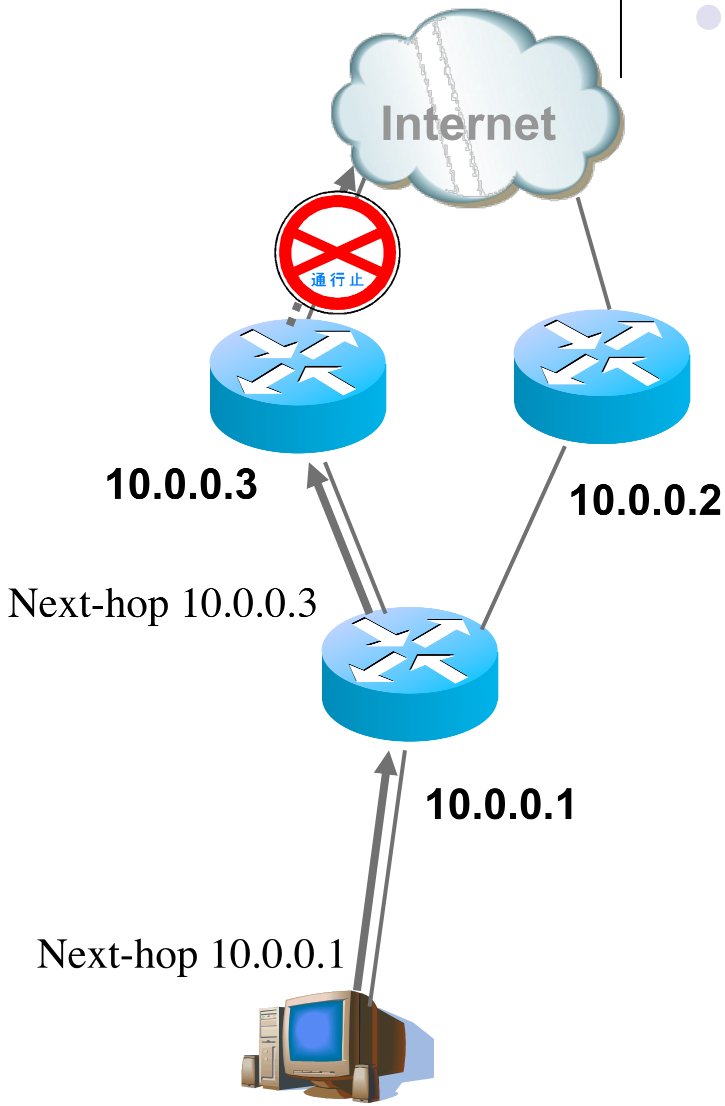
Static routing

- When there is some failures on a route:
  - Impossible to access to Internet even though there is an alternative route
  - Admin needs to update routing table at 10.0.0.1

Extract of routing table at 10.0.0.1

Prefix	Next-hop
0.0.0.0/0	**10.0.0.3**

Entry causing error



Dynamic routing

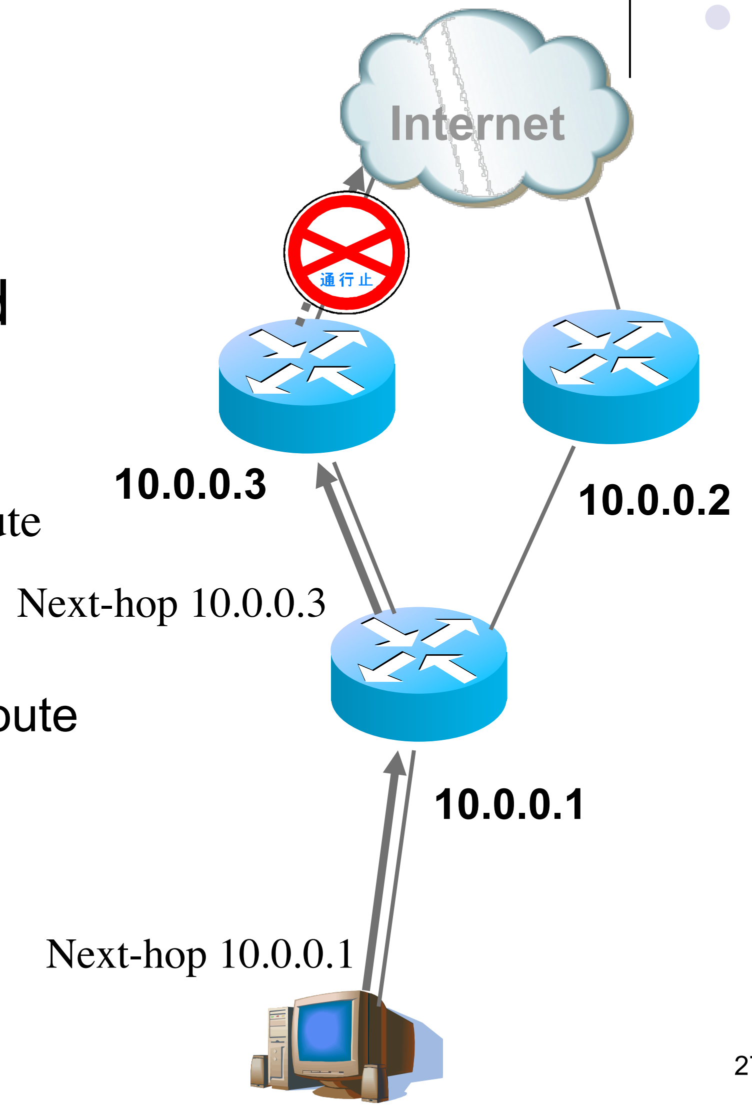
- When there is failure :
  - The entries related on the affected routes are updated automatically

Extract of routing table of 10.0.0.1

Prefix	Next-hop
0.0.0.0/0	**10.0.0.2**
~~0.0.0.0/0~~	~~10.0.0.3~~

Alternative route

Affected route



Pros/cons of static routing

- Pros
  - Stable
  - Secure
  - Not influence by external factor
  - Không bị ảnh hưởng bởi các yếu tố tác động
- Cons
  - Not flexible
  - It is impossible for using automatically backup routes
  - Difficult to manage

Dynamic routing

- Pros
  - Easy to manage
  - Backup routes are used automatically when there are failures
- Cons
  - Not secure
  - Routing protocols are complex

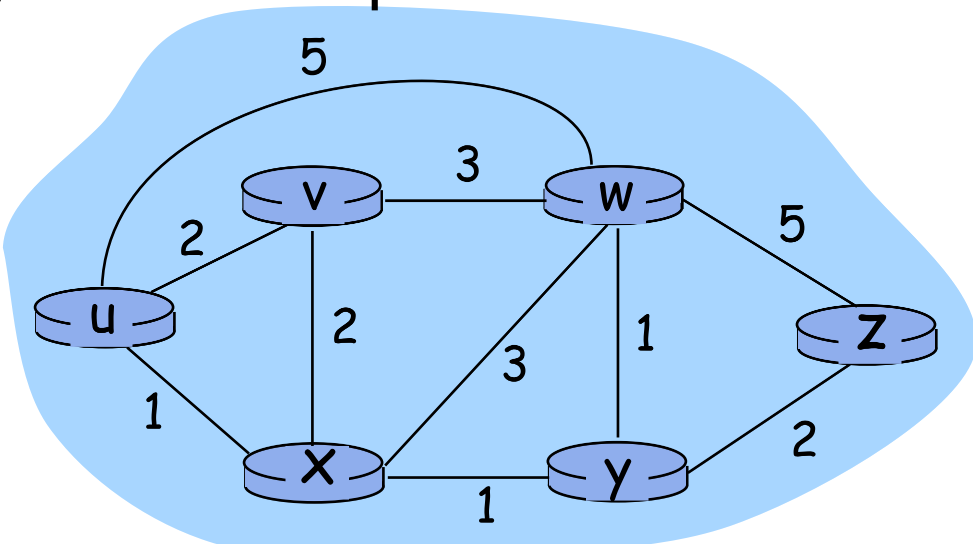
Routing algorithm and protocols

Dijkstra and Bellman-Ford Algo

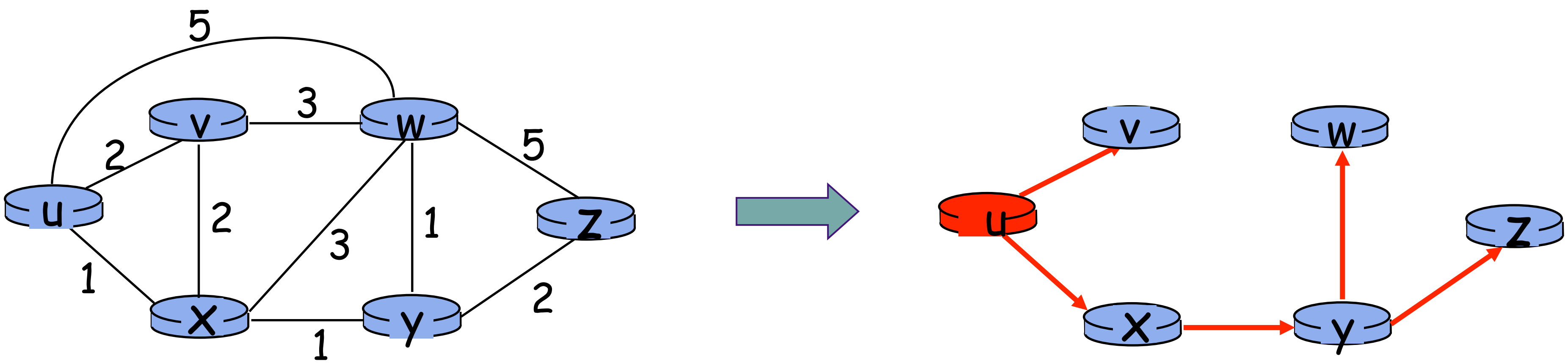
link-state and distance-vector protocols

Graph representing the networks

- Graph with nodes (routers) and edges (links)
- Weight on each link c(x,y)
  - Weigh can be bandwidth, delay, congestion level, cost… expressing the contribution of the link in the total cost of a route
- Routing algorithm: Determine the shortest path (in term of weight) between a pair of two nodes.



Shortest path tree-SPT



- SPT – Shortest Path Tree
- Compose of shortest paths from a single source node to all other nodes.
- Each source node has it own SPT

Two classes of routing algorithm

- Link-state
  - Gathering the topology information at a node → build graph
  - Run a path calculation algorithm on the node
  - Build routing table on the node
  - OSPF routing protocol
- Distance vector
  - Each node build temporary a routing table
  - Exchange routing tables for finding better routes through the neighbors
  - RIP routing protocol

Link-state algorithms- Dijikstra

- Notations:
  - *G = (V,E) : Graph representing the network: V*: set of nodes, *E: set of links*
  - *c(x,y):* cost of using link *x* to *y*;
    - = ∞ f the two nodes are not linked together
  - *d(v):* current cost for going from the source node to node *v*
  - *p(v):* node right before v on the route from the source to destination
  - *T:* Set of nodes whose shortest paths have been identified.

Link-state algorithms-Dijikstra

- **Procedures:**
- Init():

  For each node v, $d[v] = \infty$, $p[v]$ = NIL

  $d[s] = 0$
- Improve(u,v), where (u,v) is an edge of G

  if $d[v] > d[u] + c(u,v)$ then

  $d[v] = d[u] + c(u,v)$

  $p[v] = u$

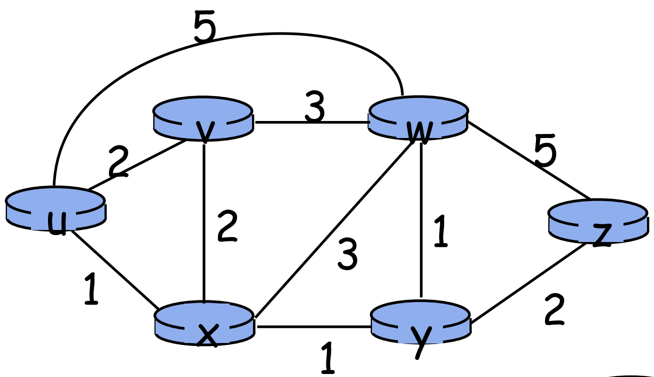
Link-state algorithms- Dijikstra

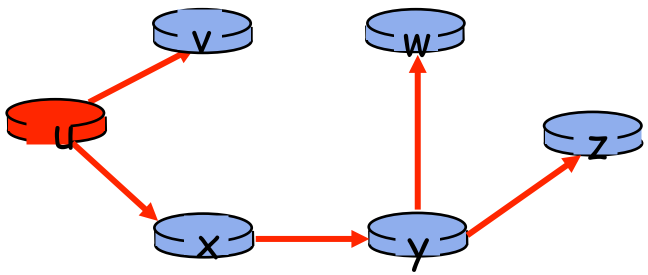
1. **Init()** ;
2. $T = \Phi;$
3. **Repeat**
4. u: u $\notin T$ | $d(u)$ is the smallest;
5. $T = T \cup \{u\};$
6. **for all** $v \in$ neighbor(u) and $v \notin T$
7. *improve(u,v)* ;
8. **Until** $T = V$

Browse all *u* from those are nearest to the source, and try to improve the route from source to all neighbor of *u* by going through *u*

Dijkstra's algorithm: Example

Step	T	d(v),p(v)	d(w),p(w)	d(x),p(x)	d(y),p(y)	d(z),p(z)
0	u	2,u	5,u	1,u	∞	∞
1	ux	2,u	4,x		2,x	∞
2	uxy	2,u	3,y			4,y
3	uxyv		3,y			4,y
4	uxyvw					4,y
5	uxyvwz					





SPT of u:

Routing table of u:

destination	link
v	(u,v)
x	(u,x)
y	(u,x)
w	(u,x)
z	(u,x)

Distance-vector algorithm Bellman-Ford (1)

Definitions:

$d_x(y)$:= cost of the shortest path from x to y

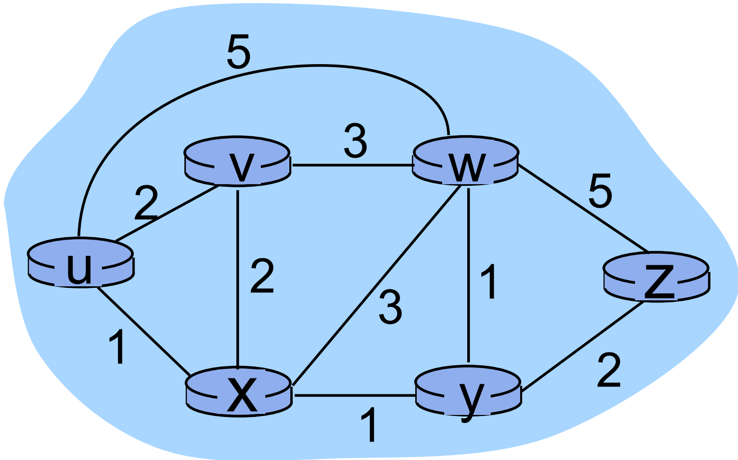
We have: Bellman-Ford equation:

$$\boxed{d_x(y) = \min_v \{c(x,v) + d_v(y)\}}$$

For all v are adjacent to x

Distance-vector algorithm Bellman-Ford (2)

Easy to see that, $d_v(z) = 5$, $d_x(z) = 3$, $d_w(z) = 3$



According to B-F eq. :

$$
\begin{aligned}
d_u(z) &= \min \{\, c(u,v) + d_v(z),\\
&\qquad\quad c(u,x) + d_x(z),\\
&\qquad\quad c(u,w) + d_w(z) \,\}\\
&= \min \{2 + 5,\\
&\qquad\quad 1 + 3,\\
&\qquad\quad 5 + 3\} \;=\; 4
\end{aligned}
$$

Amongst all paths from u→ z, choose to go through the neighbo of u that make the path shortest

Distance-vector algorithm (2)

Main ideas:

- Distance vector: vector of all distance from the current node to all other nodes
- Each node send periodically the its distance vector to its adjacent nodes
- When a node x receives a distance vector, it updates its distance vector by using equation Bellman-ford
- With some condition, the distance $D_x(y)$ *in each vector will converge to the smallest value of* $d_x(y)$

At each node:

Wait for a DV from neighbor

↓

Re-calculate its DV

↓

If DV changes, *Inform its neighbor*

$$D_x(y) = \min\{c(x,y) + D_y(y), c(x,z) + D_z(y)\}$$
$$= \min\{2+0 , 7+1\} = 2$$

Node x

Cost to

from	x	y	z
x	0	2	7
y	∞	∞	∞
z	∞	∞	∞

Cost to

From	x	y	z
x	0	2	3
y	2	0	1
z	7	1	0

$$D_x(z) = \min\{c(x,y) + D_y(z), c(x,z) + D_z(z)\}$$
$$= \min\{2+1 , 7+0\} = 3$$

Node y

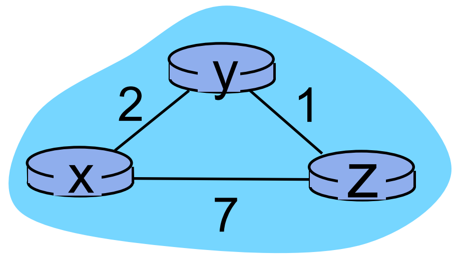
Cost to

from	x	y	z
x	∞	∞	∞
y	2	0	1
z	∞	∞	∞

Node z

Cost to

from	x	y	z
x	∞	∞	∞
y	∞	∞	∞
z	7	1	0



Time

$D_x(y) = \min\{c(x,y) + D_y(y), c(x,z) + D_z(y)\}$
$= \min\{2+0 , 7+1\} = 2$

$D_x(z) = \min\{c(x,y) + D_y(z), c(x,z) + D_z(z)\}$
$= \min\{2+1 , 7+0\} = 3$

Node x

từ \ Cost to	x	y	z
x	0	2	7
y	∞	∞	∞
z	∞	∞	∞

từ \ Cost to	x	y	z
x	0	2	3
y	2	0	1
z	7	1	0

từ \ Cost to	x	y	z
x	0	2	3
y	2	0	1
z	3	1	0

Node y

từ \ Cost to	x	y	z
x	∞	∞	∞
y	2	0	1
z	∞	∞	∞

từ \ Cost to	x	y	z
x	0	2	7
y	2	0	1
z	7	1	0

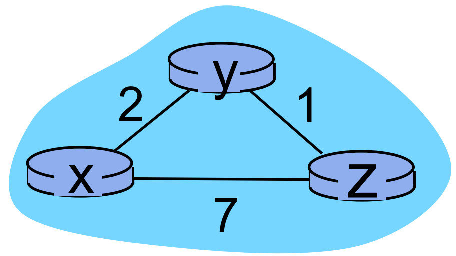
từ \ Cost to	x	y	z
x	0	2	3
y	2	0	1
z	3	1	0

Node z

từ \ Cost to	x	y	z
x	∞	∞	∞
y	∞	∞	∞
z	7	1	0

từ \ Cost to	x	y	z
x	0	2	7
y	2	0	1
z	3	1	0

từ \ Cost to	x	y	z
x	0	2	3
y	2	0	1
z	3	1	0



Time

Comparison of Link-state and Distance vector

Number of exchange messages

- LS: n nodes, E links, O(nE) messages
- DV: Exchange only with neighbor

Convergent time

- LS: Complexity $O(n^2)$
- DV: Varies

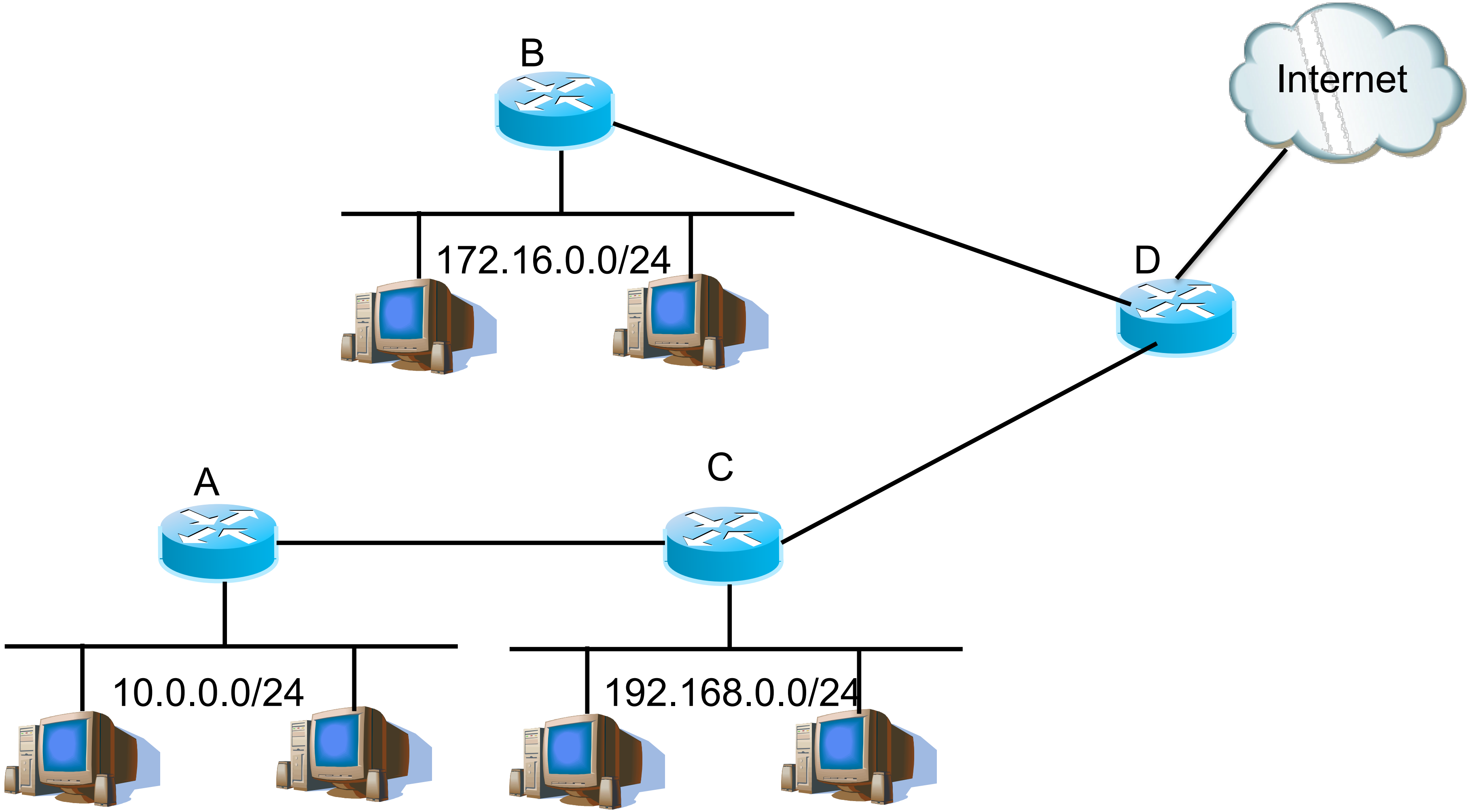
Reliability: If one routers provide incorrect information

LS:

- The router may send out incorrect cost
- Each node calculate its own routing table

DV:

- Incorrect distance vector may be sent out
- Each node calculate its DV based to what receives from the neighbor
  - Error propagates in the network.


B
Internet
172.16.0.0/24
D
A
C
10.0.0.0/24
192.168.0.0/24