Network Layer

Routing Algorithm

Distance Vector Routing

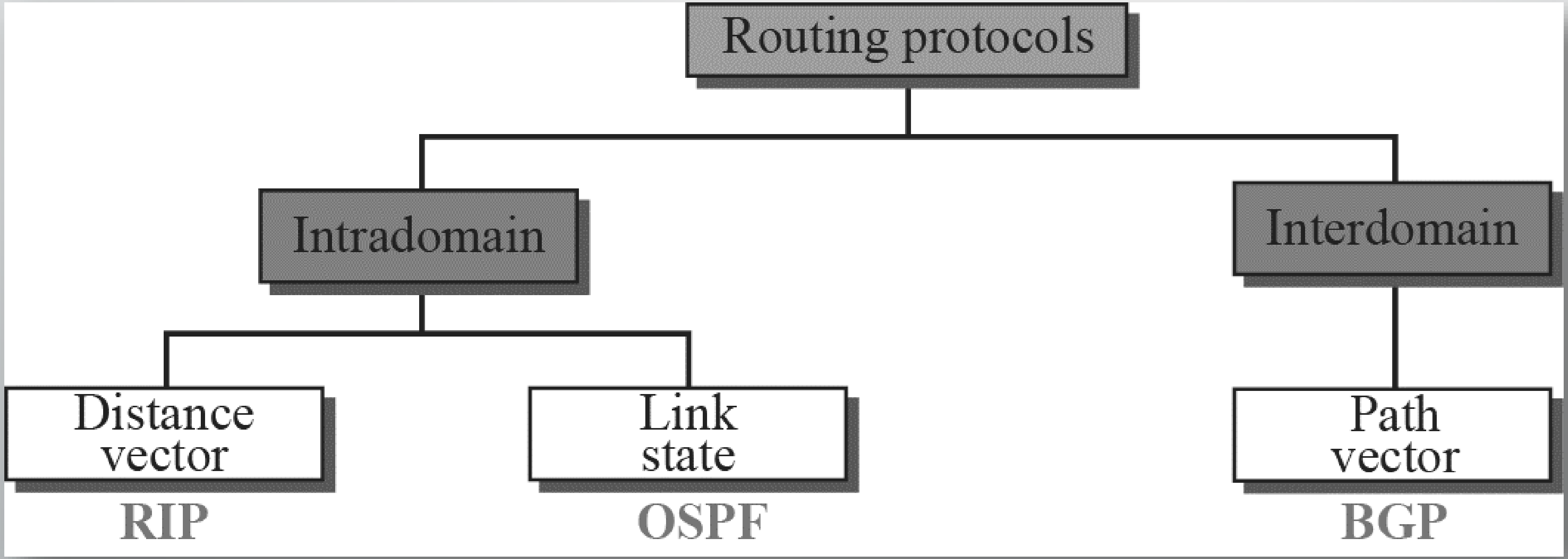
Lecture 13 | Part 1| CSE421 – Computer Networks

Department of Computer Science and Engineering
School of Data & Science

Objectives

- understand principles behind network layer services:
  - network layer service models
  - forwarding versus routing
  - how a router works
  - routing algorithms
    - **distance vector**
    - **link state**
    - hierarchical routing
  - broadcast, multicast

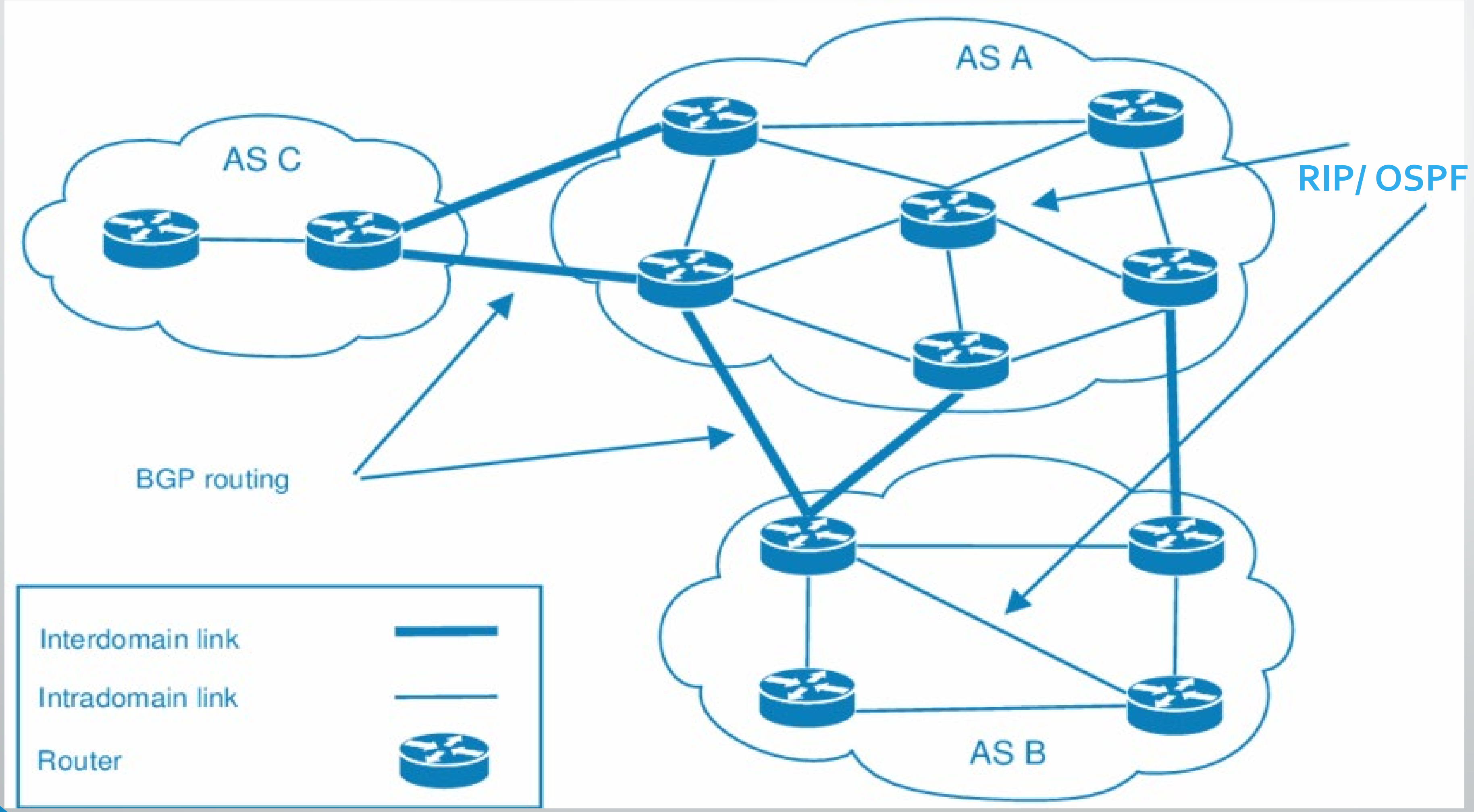
Popular Routing Protocols



Autonomous Systems

- Internet is divided into autonomous systems.
- An autonomous system (AS) is a group of networks and routers under the authority of a single administration.
- Routing *inside* an autonomous system is called **intra -domain routing** . Routing ***between*** autonomous systems is called **inter -domain routing** .

Autonomous Systems



Routing Algorithms

- Given a set of routers and links connecting the routers.
- Routing algorithm finds a "good" path from the source to destination router.
- Good path = Least cost path

Routing Algorithm classification

Static or dynamic?

Static:

- routes change slowly over time
- Manually configured

Dynamic:

- routes change more quickly
  - in response to link cost changes

Routing Algorithm classification

Global or Decentralized

Global:

- all routers have complete topology and link cost info
- "link state" algorithms

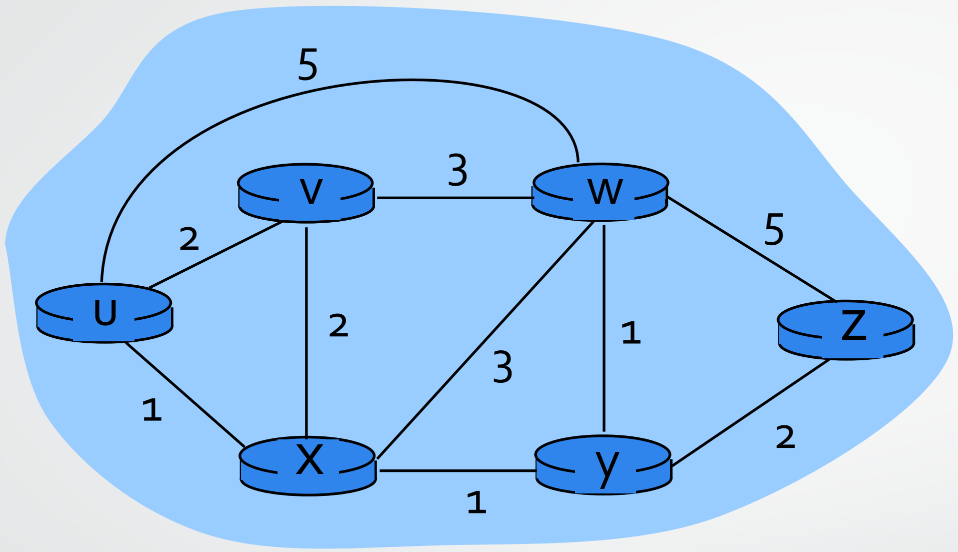
Decentralized:

- router knows physically-connected neighbors, link costs to neighbors
- iterative process of computation, exchange of info with neighbors
- "distance vector" algorithms

Routing on a Graph

- Essentially a graph theory problem
  - Network is a directed graph; routers are vertices
- Find “best” path between every pair of vertices
  - In the simplest case, best path is the shortest path

Graph abstraction

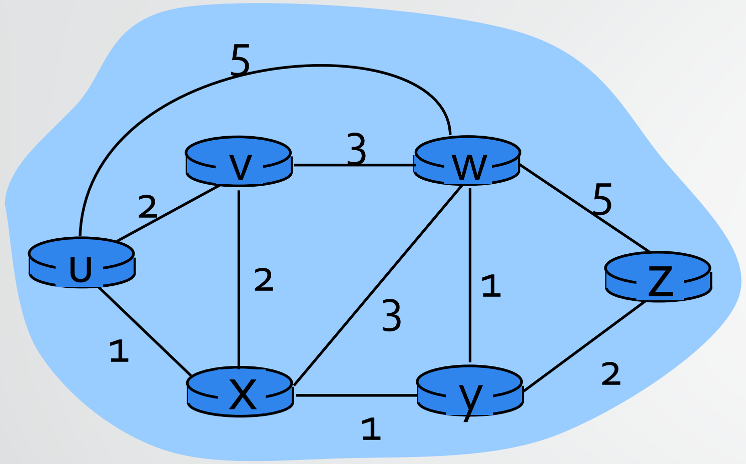


Graph: G = (N,E)

N = set of routers = { u, v, w, x, y, z }

E = set of links ={ (u,v), (u,x), (u,w), (v,x), (v,w), (x,w), (x,y), (w,y), (w,z), (y,z) }

Graph abstraction: costs



c(x,x') = cost of link (x,x')

- e.g., c(w,z) = 5

Question: What's the least-cost path between u and z ?

Routing algorithm: algorithm that finds least-cost path

Distance Vector Algorithm

Distance Vector Algorithm

Distributed:

- each node receives info from one or more of its directly connected neighbors
- Performs a calculations
- Distributes the results back to its neighbors

Iterative

- Process continues until no more info to exchange

Asynchronous:

- All nodes operate independently

Distance Vector Algorithm

Iterative, asynchronous: each local iteration caused by:

- Local link cost change
- Distance vector update message from neighbor

Distributed:

- Each node notifies neighbors *only* when its DV changes
- Neighbors then notify their neighbors if necessary

Each node:

wait for (change in local link cost or message from neighbor)

recompute estimates

if distance to any destination has changed, *notify* neighbors

Distance Vector Algorithm

Bellman-Ford Equation Algorithm

- computes shortest paths from a single source vertex to all of the other vertices in a weighted digraph.

- Distributed route computation using only neighbor's info

Distance Vector Algorithm

Objective:

$d_x(y)$:= cost of least-cost path from x to y

Then

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

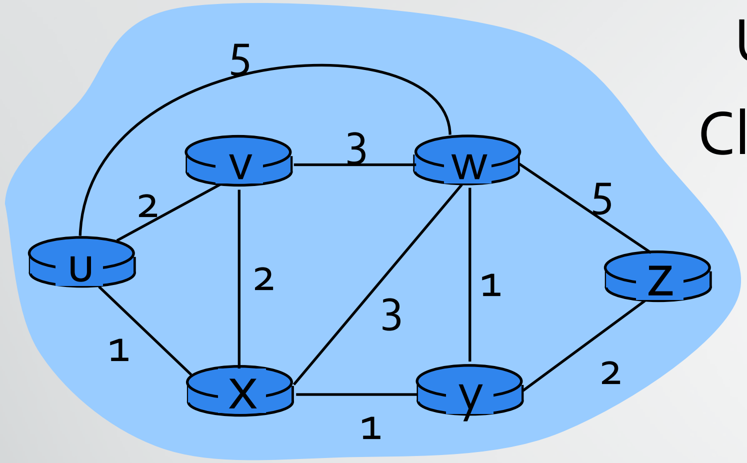
where min is taken over all neighbors v of x

Distance Vector Algorithm

With the Distance Vector Routing algorithm, the node x contains the following routing information:

- For each neighbor v, the cost $c(x,v)$ is the path cost from x to directly attached neighbor, v.
- The distance vector x, i.e., $D_x = [\ D_x(y) : y \text{ in } N\ ]$, containing its cost to all destinations, y, in N.
- The distance vector of each of its neighbors, i.e., $D_v = [\ D_v(y) : y \text{ in } N\ ]$ for each neighbor v of x.

Bellman-Ford example from u to z



U has 3 neighbors v, x and w

Clearly, $d_v(z) = 5$, $d_x(z) = 3$, $d_w(z) = 3$

B-F equation says:

$$d_u(z) = \min \{ c(u,v) + d_v(z),\ c(u,x) + d_x(z),\ c(u,w) + d_w(z) \}$$

$$= \min \{2 + 5,\ 1 + 3,\ 5 + 3\} = 4$$

- Node that achieves minimum is the next hop in shortest path to a destination,
- To go to z from u, x in the next hop in the forwarding table

Distance vector algorithm

Basic idea:

- Each node periodically sends its own distance vector estimate to neighbors
- When a node x receives new DV estimate from neighbor;
- It updates its own DV using B-F equation:

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

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

node x table

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

node y table

cost to

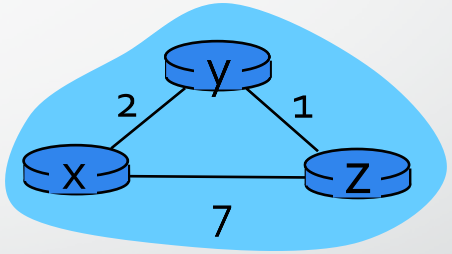
from	x	y	z
x	∞	∞	∞
y	2	0	1
z	∞	∞	∞

node z table

cost to

from	x	y	z
x	∞	∞	∞
y	∞	∞	∞
z	7	1	0

time



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

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

node x table

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

node y table

cost to

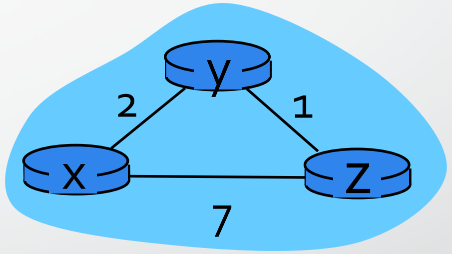
from	x	y	z
x	∞	∞	∞
y	2	0	1
z	∞	∞	∞

from	x	y	z
x	0	2	7
y	2	0	1
z	7	1	0

node z table

cost to

from	x	y	z
x	∞	∞	∞
y	∞	∞	∞
z	7	1	0



time

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

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

node x table

from \ cost to	x	y	z
x	0	2	7
y	∞	∞	∞
z	∞	∞	∞

from \ cost to	x	y	z
x	0	2	3
y	2	0	1
z	7	1	0

node y table

from \ cost to	x	y	z
x	∞	∞	∞
y	2	0	1
z	∞	∞	∞

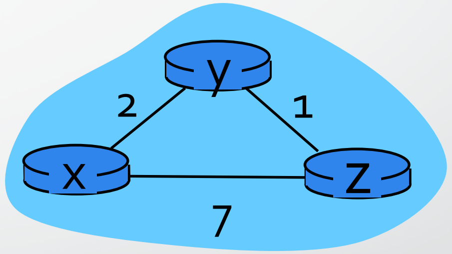
from \ cost to	x	y	z
x	0	2	7
y	2	0	1
z	7	1	0

node z table

from \ cost to	x	y	z
x	∞	∞	∞
y	∞	∞	∞
z	7	1	0

from \ cost to	x	y	z
x	0	2	7
y	2	0	1
z	3	1	0

time



node x table

from \ cost to	x	y	z
x	0	2	7
y	∞	∞	∞
z	∞	∞	∞

from \ cost to	x	y	z
x	0	2	3
y	2	0	1
z	7	1	0

from \ cost to	x	y	z
x	0	2	3
y	2	0	1
z	3	1	0

node y table

from \ cost to	x	y	z
x	∞	∞	∞
y	2	0	1
z	∞	∞	∞

from \ cost to	x	y	z
x	0	2	7
y	2	0	1
z	7	1	0

from \ cost to	x	y	z
x	0	2	3
y	2	0	1
z	3	1	0

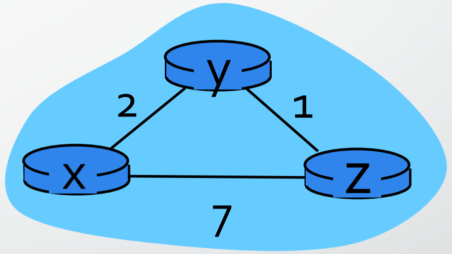
node z table

from \ cost to	x	y	z
x	∞	∞	∞
y	∞	∞	∞
z	7	1	0

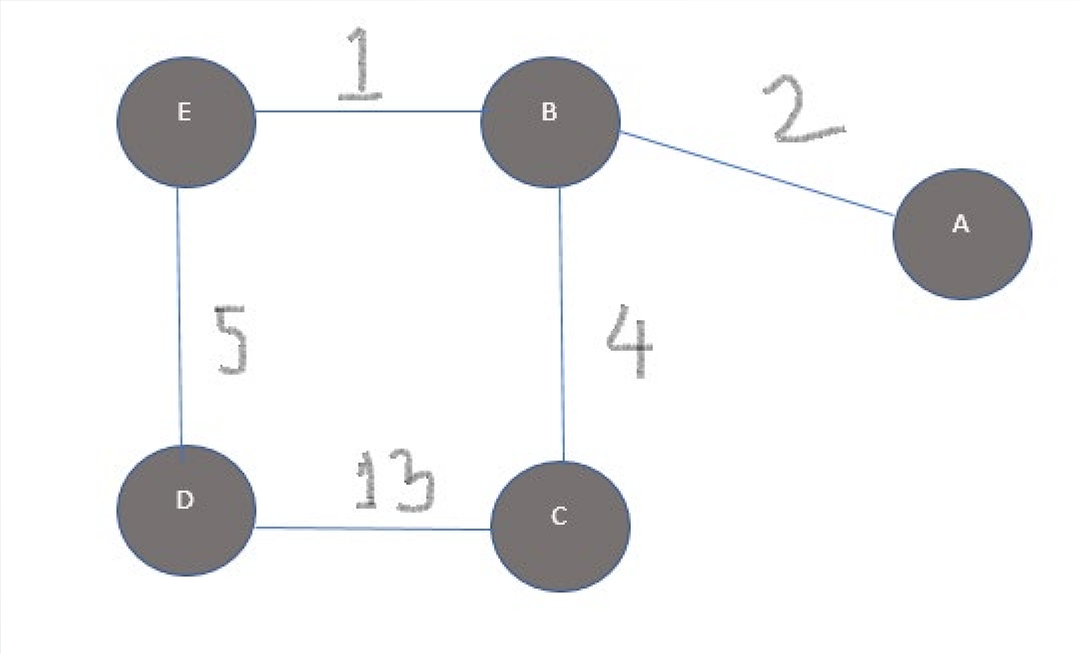
from \ cost to	x	y	z
x	0	2	7
y	2	0	1
z	3	1	0

from \ cost to	x	y	z
x	0	2	3
y	2	0	1
z	3	1	0

time



Example



- How many iterations are needed to make the final routing tables of each router?
- What will be the routing table of B and D after the 2^{nd} iteration?

Network Layer

Routing Algorithm

Distance Vector Routing

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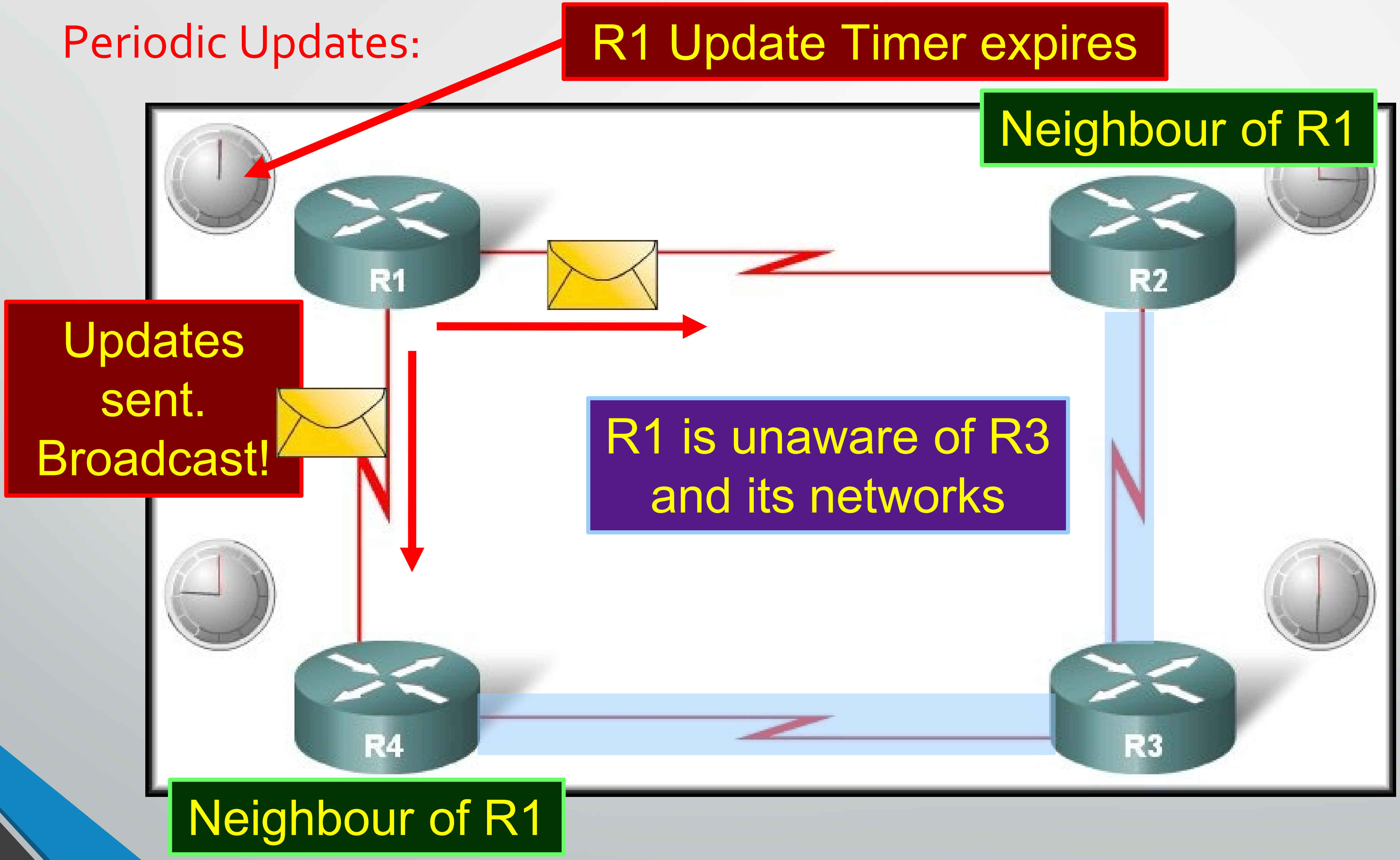
Operation of Distance Vector

- Periodic Updates:
  - Periodically broadcast the entire routing table to each of its neighbors (RIP – every 30 seconds).
    - Inefficient
  - Router is only aware of the:
    - Network addresses of its own interfaces.
    - Network addresses the neighbors running the same routing protocol.

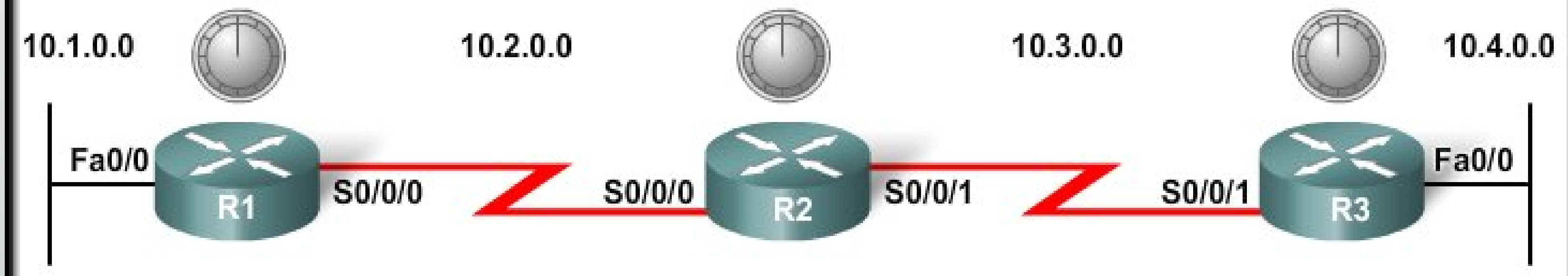
Operation of Distance Vector

Periodic Updates:



Distance Vector Routing Protocols

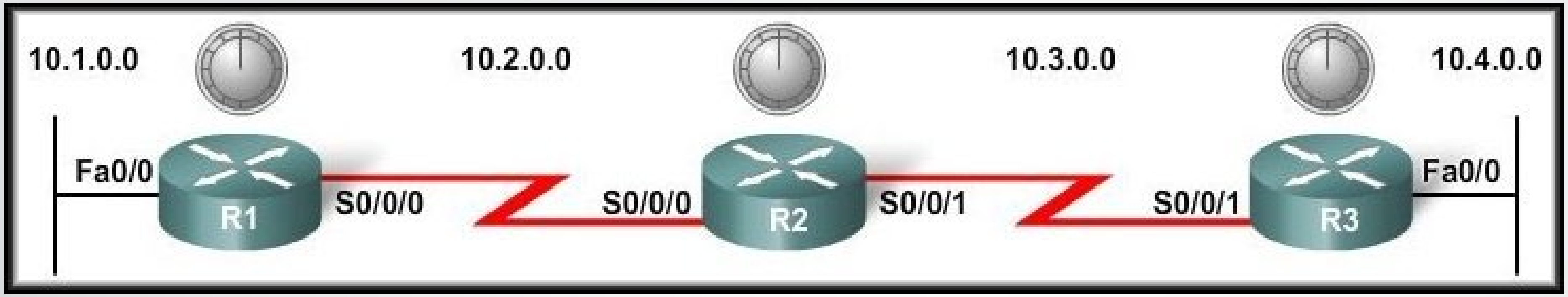
Network Discovery



Network	Interface	Hop
10.1.0.0	Fa0/0	0
10.2.0.0	S0/0/0	0
10.3.0.0	S0/0/0	1
10.4.0.0	S0/0/0	2

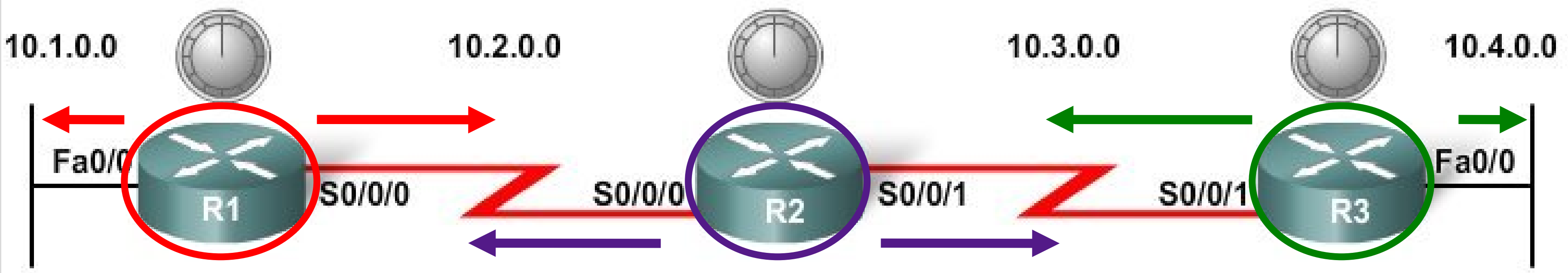
Network	Interface	Hop
10.2.0.0	S0/0/0	0
10.3.0.0	S0/0/1	0
10.1.0.0	S0/0/0	1
10.4.0.0	S0/0/1	1

Network	Interface	Hop
10.3.0.0	S0/0/1	0
10.4.0.0	Fa0/0	0
10.2.0.0	S0/0/1	1
10.1.0.0	S0/0/1	2



- Network Discovery:
  - Is part of the process of the routing protocol algorithm that enables routers to learn about remote networks for the first time.

Cold Start



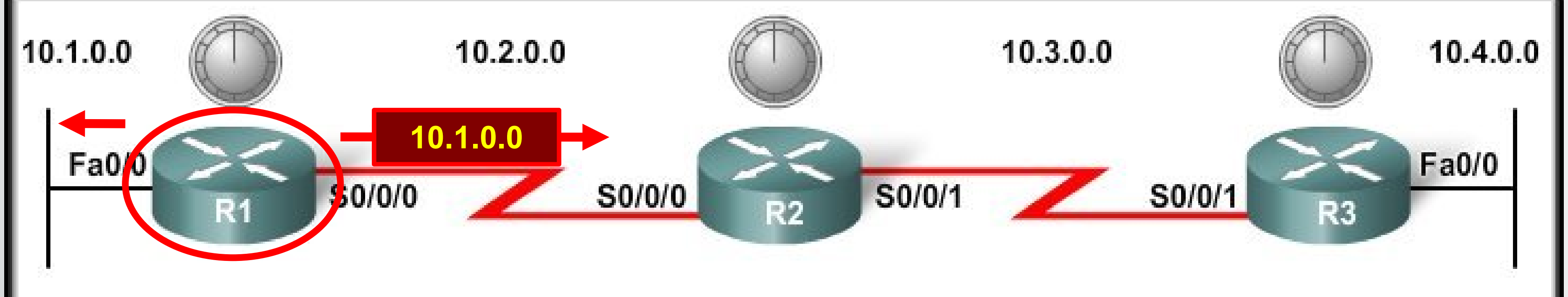
Network	Interface	Hop

Network	Interface	Hop

Network	Interface	Hop

- When a router powers up:
  - Knows nothing about the network topology.
  - Knows only the information saved in NVRAM.
  - Sends updates about its known networks out all ports.

Initial Exchange of Routing Information



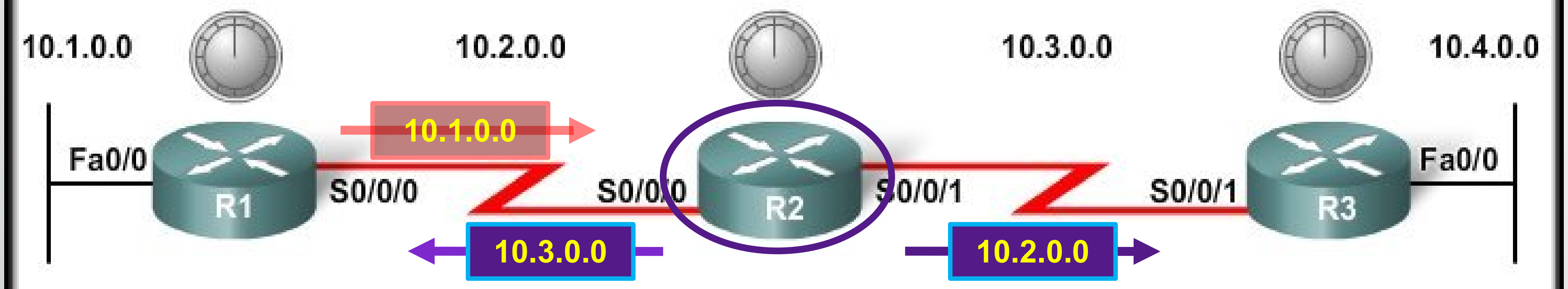
Network	Interface	Hop
10.1.0.0	Fa0/0	0
10.2.0.0	S0/0/0	0

Network	Interface	Hop
10.2.0.0	S0/0/0	0
10.3.0.0	S0/0/1	0

Network	Interface	Hop
10.3.0.0	S0/0/1	0
10.4.0.0	Fa0/0	0

- Sends an update about network 10.1.0.0 out the Serial 0/0/0 interface with a metric of 1.
- Sends an update about network 10.2.0.0 out the Fa0/0 interface with a metric of 1.

Initial Exchange of Routing Information

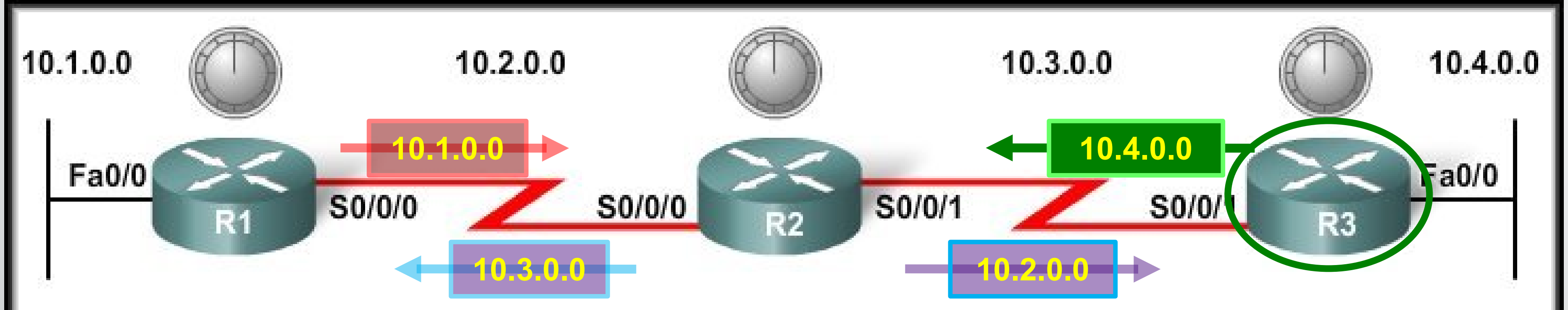


Network	Interface	Hop
10.1.0.0	Fa0/0	0
10.2.0.0	S0/0/0	0

Network	Interface	Hop
10.2.0.0	S0/0/0	0
10.3.0.0	S0/0/1	0

Network	Interface	Hop
10.3.0.0	S0/0/1	0
10.4.0.0	Fa0/0	0

Initial Exchange of Routing Information

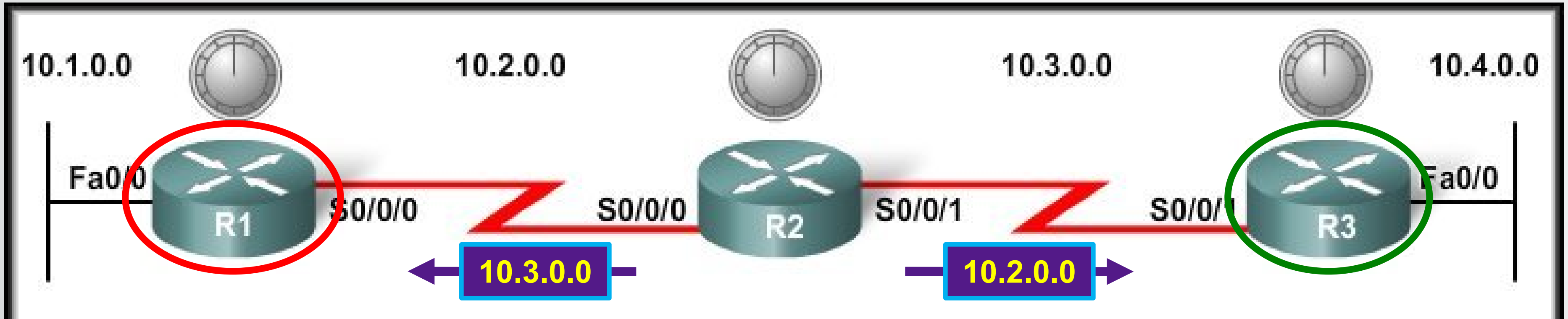


Network	Interface	Hop
10.1.0.0	Fa0/0	0
10.2.0.0	S0/0/0	0

Network	Interface	Hop
10.2.0.0	S0/0/0	0
10.3.0.0	S0/0/1	0

Network	Interface	Hop
10.3.0.0	S0/0/1	0
10.4.0.0	Fa0/0	0

Initial Exchange of Routing Information



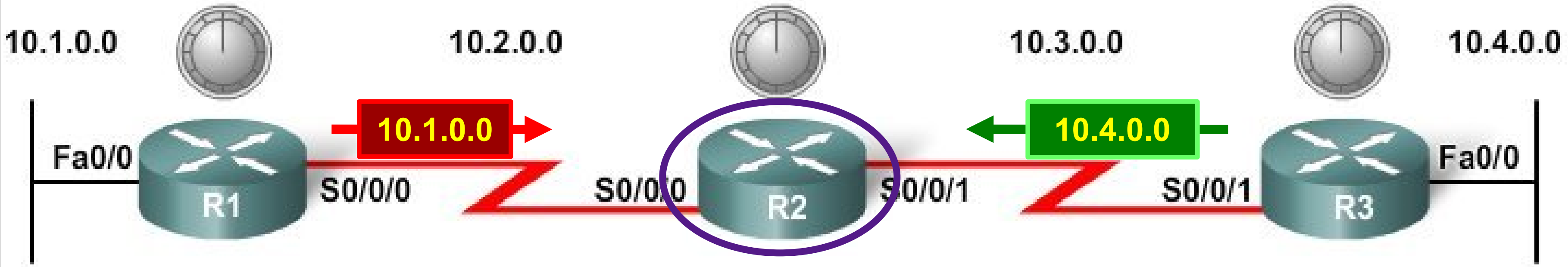
Network	Interface	Hop
10.1.0.0	Fa0/0	0
10.2.0.0	S0/0/0	0

Network	Interface	Hop
10.2.0.0	S0/0/0	0
10.3.0.0	S0/0/1	0

Network	Interface	Hop
10.3.0.0	S0/0/1	0
10.4.0.0	Fa0/0	0

- R1 Receives the update from R2 about network 10.3.0.0 and adds it to its routing table.
- R3 Receives the update from R2 about network 10.2.0.0 and adds it to its routing table.

Initial Exchange of Routing Information



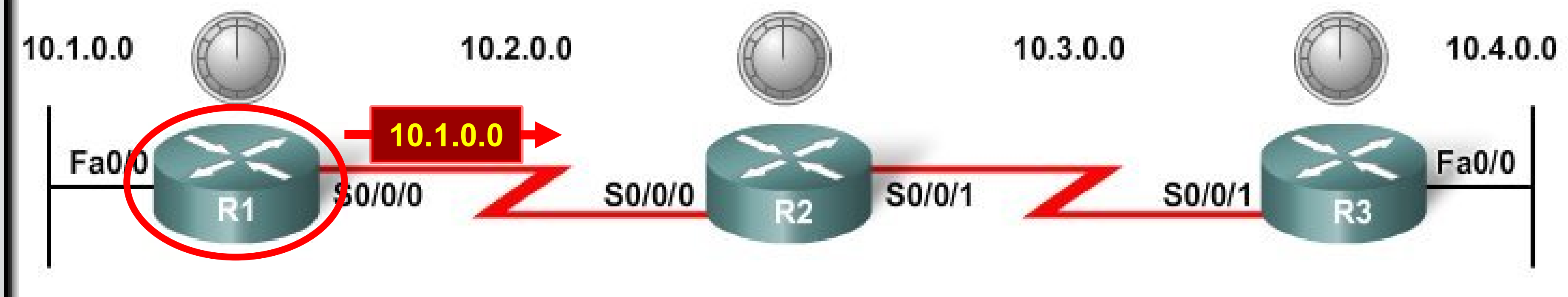
Network	Interface	Hop
10.1.0.0	Fa0/0	0
10.2.0.0	S0/0/0	0
10.3.0.0	S0/0/0	1

Network	Interface	Hop
10.2.0.0	S0/0/0	0
10.3.0.0	S0/0/1	0

Network	Interface	Hop
10.3.0.0	S0/0/1	0
10.4.0.0	Fa0/0	0
10.2.0.0	S0/0/1	1

- R2 Receives the update from R1 about network 10.1.0.0 and adds it to its routing table.
- R2 Receives the update from R3 about network 10.4.0.0 and adds it to its routing table.

Next Exchange of Routing Information



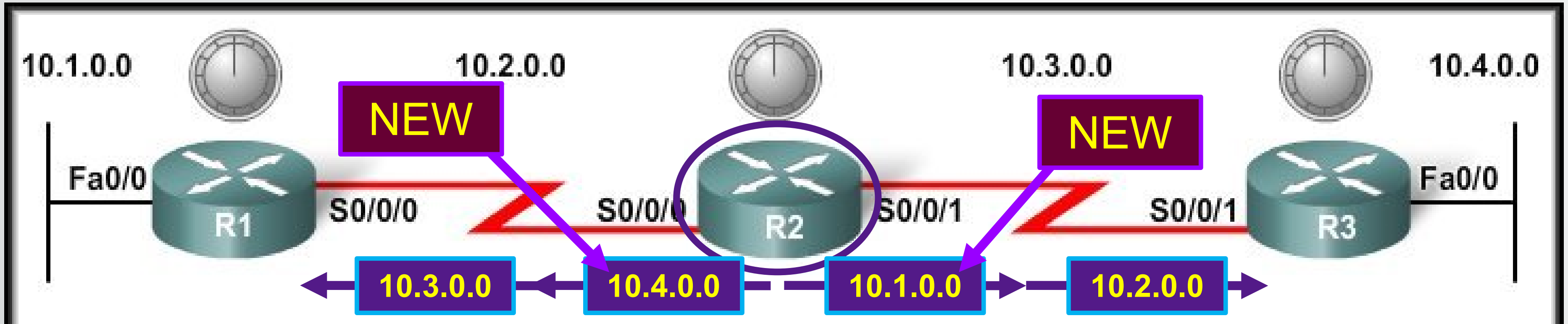
Network	Interface	Hop
10.1.0.0	Fa0/0	0
10.2.0.0	S0/0/0	0
10.3.0.0	S0/0/0	1

Network	Interface	Hop
10.2.0.0	S0/0/0	0
10.3.0.0	S0/0/1	0
10.1.0.0	S0/0/0	1
10.4.0.0	S0/0/1	1

Network	Interface	Hop
10.3.0.0	S0/0/1	0
10.4.0.0	Fa0/0	0
10.2.0.0	S0/0/1	1

- Sends an update about network 10.1.0.0 out the So/o/o interface with a metric of 1 - AGAIN!
- When R2 receives the update, there is no change in information so the update is ignored.

Next Exchange of Routing Information



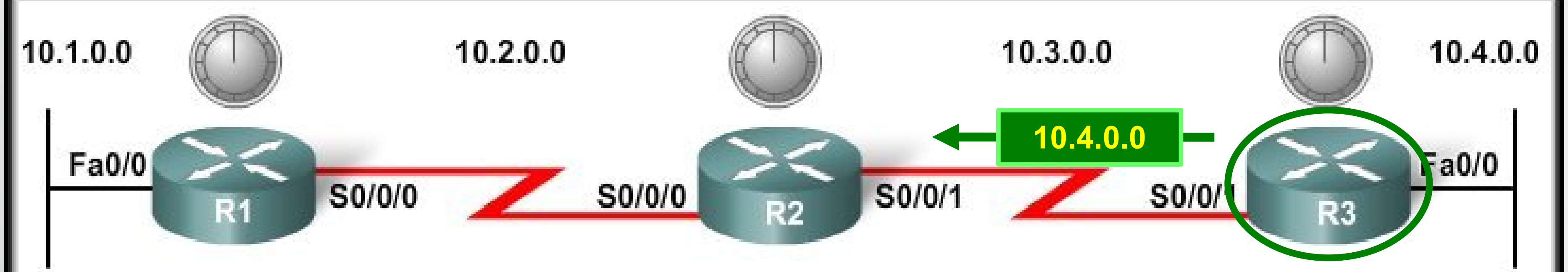
Network	Interface	Hop
10.1.0.0	Fa0/0	0
10.2.0.0	S0/0/0	0
10.3.0.0	S0/0/0	1

Network	Interface	Hop
10.2.0.0	S0/0/0	0
10.3.0.0	S0/0/1	0
10.1.0.0	S0/0/0	1
10.4.0.0	S0/0/1	1

Network	Interface	Hop
10.3.0.0	S0/0/1	0
10.4.0.0	Fa0/0	0
10.2.0.0	S0/0/1	1

- Sends an update about networks 10.3.0.0 with a metric of 1 and 10.4.0.0 with a metric of 2 out the Serial 0/0/0 interface.
- Similarly sends updates about networks 10.1.0.0 with a metric of 2 and 10.2.0.0 with a metric of 1 out the Serial 0/0/1 interface.

Next Exchange of Routing Information



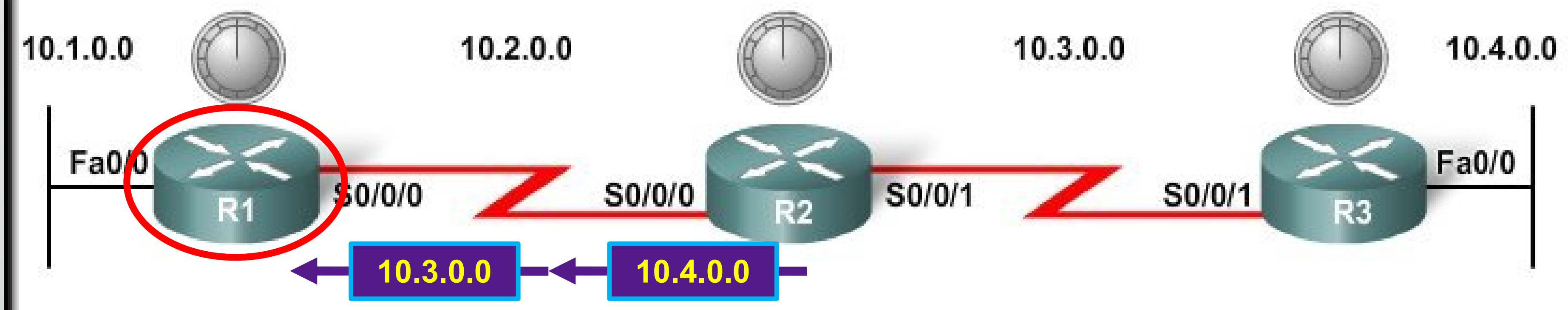
Network	Interface	Hop
10.1.0.0	Fa0/0	0
10.2.0.0	S0/0/0	0
10.3.0.0	S0/0/0	1

Network	Interface	Hop
10.2.0.0	S0/0/0	0
10.3.0.0	S0/0/1	0
10.1.0.0	S0/0/0	1
10.4.0.0	S0/0/1	1

Network	Interface	Hop
10.3.0.0	S0/0/1	0
10.4.0.0	Fa0/0	0
10.2.0.0	S0/0/1	1

- Sends an update about network 10.4.0.0 out the So/o/o interface with a metric of 1 - AGAIN!
- When R2 receives the update, there is no change in information so the update is ignored.

Next Exchange of Routing Information



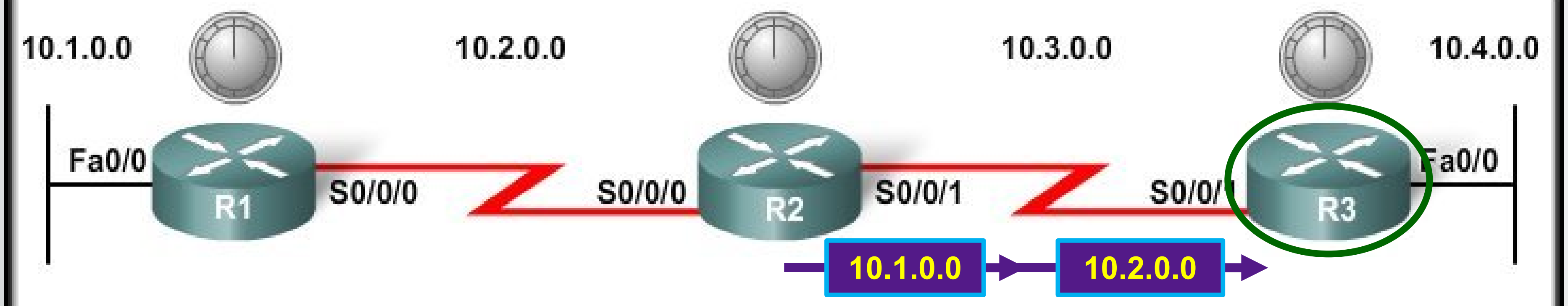
Network	Interface	Hop
10.1.0.0	Fa0/0	0
10.2.0.0	S0/0/0	0
10.3.0.0	S0/0/0	1

Network	Interface	Hop
10.2.0.0	S0/0/0	0
10.3.0.0	S0/0/1	0
10.1.0.0	S0/0/0	1
10.4.0.0	S0/0/1	1

Network	Interface	Hop
10.3.0.0	S0/0/1	0
10.4.0.0	Fa0/0	0
10.2.0.0	S0/0/1	1

- R1 receives an update from R2 about network 10.3.0.0 and there is no change – update ignored.
- R1 receives an update from R2 about network 10.4.0.0 (new) and adds it to its routing table.

Next Exchange of Routing Information



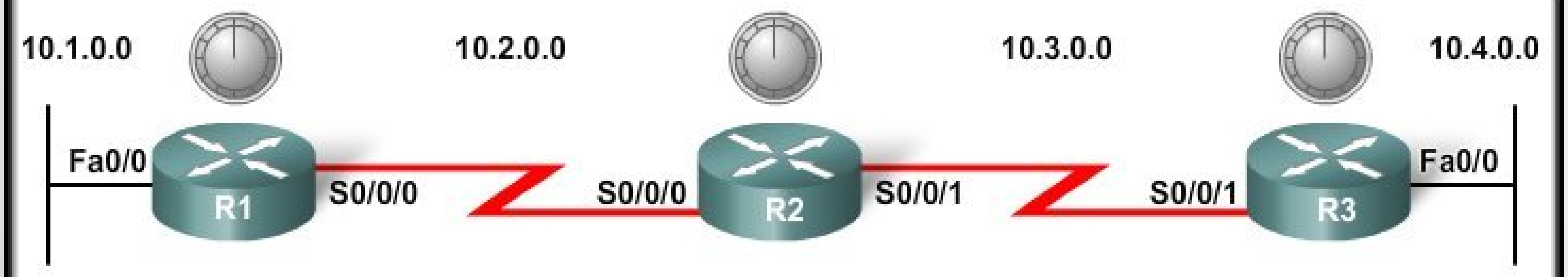
Network	Interface	Hop
10.1.0.0	Fa0/0	0
10.2.0.0	S0/0/0	0
10.3.0.0	S0/0/0	1
10.4.0.0	S0/0/0	2

Network	Interface	Hop
10.2.0.0	S0/0/0	0
10.3.0.0	S0/0/1	0
10.1.0.0	S0/0/0	1
10.4.0.0	S0/0/1	1

Network	Interface	Hop
10.3.0.0	S0/0/1	0
10.4.0.0	Fa0/0	0
10.2.0.0	S0/0/1	1

- R3 receives an update from R2 about network 10.2.0.0 and there is no change – update ignored.
- R3 receives an update from R2 about network 10.1.0.0 (new) and adds it to its routing table.

Next Exchange of Routing Information



Network	Interface	Hop
10.1.0.0	Fa0/0	0
10.2.0.0	S0/0/0	0
10.3.0.0	S0/0/0	1
10.4.0.0	S0/0/0	2

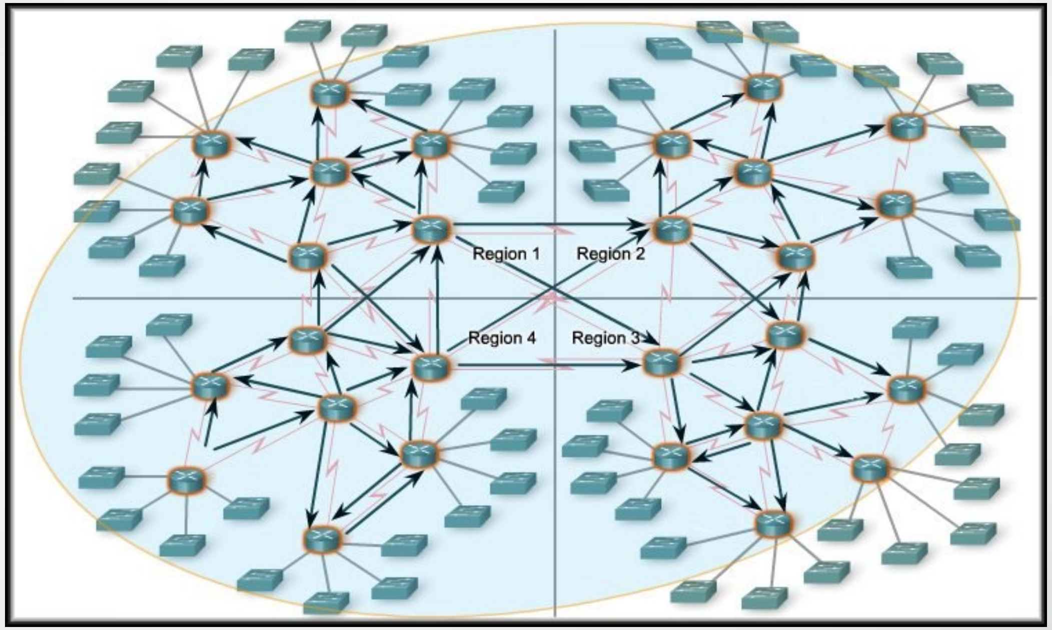
Network	Interface	Hop
10.2.0.0	S0/0/0	0
10.3.0.0	S0/0/1	0
10.1.0.0	S0/0/0	1
10.4.0.0	S0/0/1	1

Network	Interface	Hop
10.3.0.0	S0/0/1	0
10.4.0.0	Fa0/0	0
10.2.0.0	S0/0/1	1
10.1.0.0	S0/0/1	2

- The network has CONVERGED!
  - All routers now know about all of the networks attached to all of their neighbouring routers.

Convergence

- The amount of time it takes for a network to converge is directly proportional to the size of that network.



- Routing protocols are compared based on how fast they can propagate this information - their speed to convergence.

- A network is not completely operable until it has converged.
    - Network administrators prefer routing protocols with shorter convergence times.

THE END