Network interconnection and routing protocols

Ing. Yelena Trofimova

Department of Computer Systems
Faculty of Information Technology
Czech Technical University in Prague

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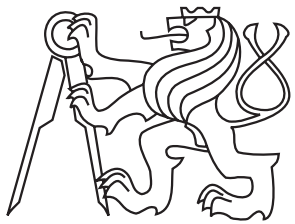
`https://courses.fit.cvut.cz/BIE-PSI/`

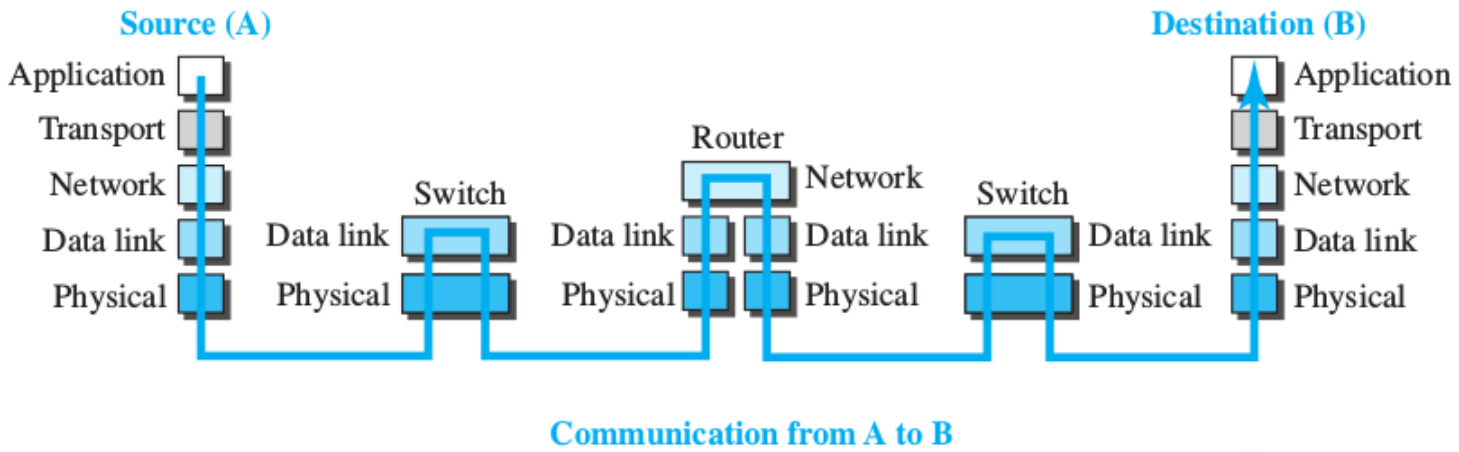


Content

- interconnection of networks
  - hub, repeater
  - bridge
  - switch
  - router
- routing
- routing protocols
  - RIP
  - OSPF
  - EIGRP
- autonomous systems
  - BGP

Network Interconnection

- refers to a some ISO/OSI layer – network device implements stack up to this layer
- features:
  - received block of data (packet, frame) is passed to this layer
  - final action is determined according to the content of the header
  - data packet travels through the network stack down and is then sent



Repeater, hub

Repeater

- operates at the physical layer
- has no memory or complex logic
- amplifies the signal
  - increasing the distance between communicating nodes
  - improving the signal to noise ratio

Hub

- hub is repeater with 3 or more ports
- in the collision network (eg. CSMA/CD) collisions are distributed
- star topology with hub in the center

Bridge

- works on the data link layer (L2)
  - separates collision segments
  - overcomes restriction to the physical size of the network segment
  - compared with hub/repeater, bridge has better reliability and performance
- joins two network segments
- contains buffer for data

Switch

- switch is a bridge with more than two ports
- interconnects on the link layer (L2)
- modern, the most used active network element

Switch operation I

- remembers MAC addresses:
  - table of pairs [port, address]
  - learns MAC of the sender (source MAC)
  - entries expire after some time
- behavior
  - frame with known destination MAC address is sent to the port specified in the table
  - frame with unknown destination MAC address is sent to all ports
  - broadcast is sent to all ports
- reduction of trafic on network links
- network security is increased – we cannot eavesdrop all packets in the network

Switch operation II

- Store-and-forward – waits until the frame has been completely received to internal memory, slower (has bigger delay), has error checking
- Cut-through – waits only for destination MAC (first 6 bytes), faster, no error checking

Problems

- tree topology is required
- loops are a problem (broadcast storm) $\Rightarrow$ Spanning Tree Protocol (STP) – finds the span of the network topology
- when using STP, loops can serve as backup links

Spanning tree algorithm

- finds the span topology
- breaks loops by blocking some ports on the switch
- in case of failure, some blocked ports are activated
- supported by all modern switches (IEEE 802.1d)
- HELLO messages, 2 phases:
  - root switch election (lower MAC)
  - designated switch election (the best way to the root switch)

Switches at higher layers

- work with frames, but scan the headers on higher layers than L2
- support QoS, VLAN and other features
- frame processing at different levels:
  - Link layer
  - Network layer ⇒ Layer 3 Switch (IP filtering)
  - Transport layer ⇒ Layer 4 Switch (filtering by TCP and UDP ports, load balancer)
  - Application layer ⇒ Layer 7 Switch (load balancing across multiple servers)

Router

- works at the network layer
- connects network segments
- works with network addresses
- does not forward broadcast
- transferring data among networks that could use completely different link technology – they are absolutely necessary for Internet
- some additional features (firewall, NAT, VPN)
- routing is static or dynamic (eg. RIP, OSPF, ...)

Routing

- flood
- random
- static
- dynamic

Flood routing

- router sends the packet to each output link
- delivering in the shortest possible time
- limited lifetime of packets: counter in the header
- packet duplicates exponentially
- improvement: router remembers the packet and processes it only once
- very inefficient network utilization

Random routing

- received packet is sent to a randomly selected link
- the delivery time is not known
- can be used as an improvement to other algorithms, for example when output link is blocked or down
- good probability that packet will be delivered

Static routing

- routing table is given by configuration
- does not change when the state of the network is changed
- unable to respond to network failures
- example: computer on the local network – two records in the routing table:
  - local network address range
  - default gateway - all other addresses

Dynamic routing

- routing table is changed according to the state of the network
- update methods:
  - isolated – router performs changes separately, regardless of other routers
  - centralized – calculation of new tables is performed by central router, routing tables are distributed to other routers
  - decentralized – each router performs the calculation using data from other routers

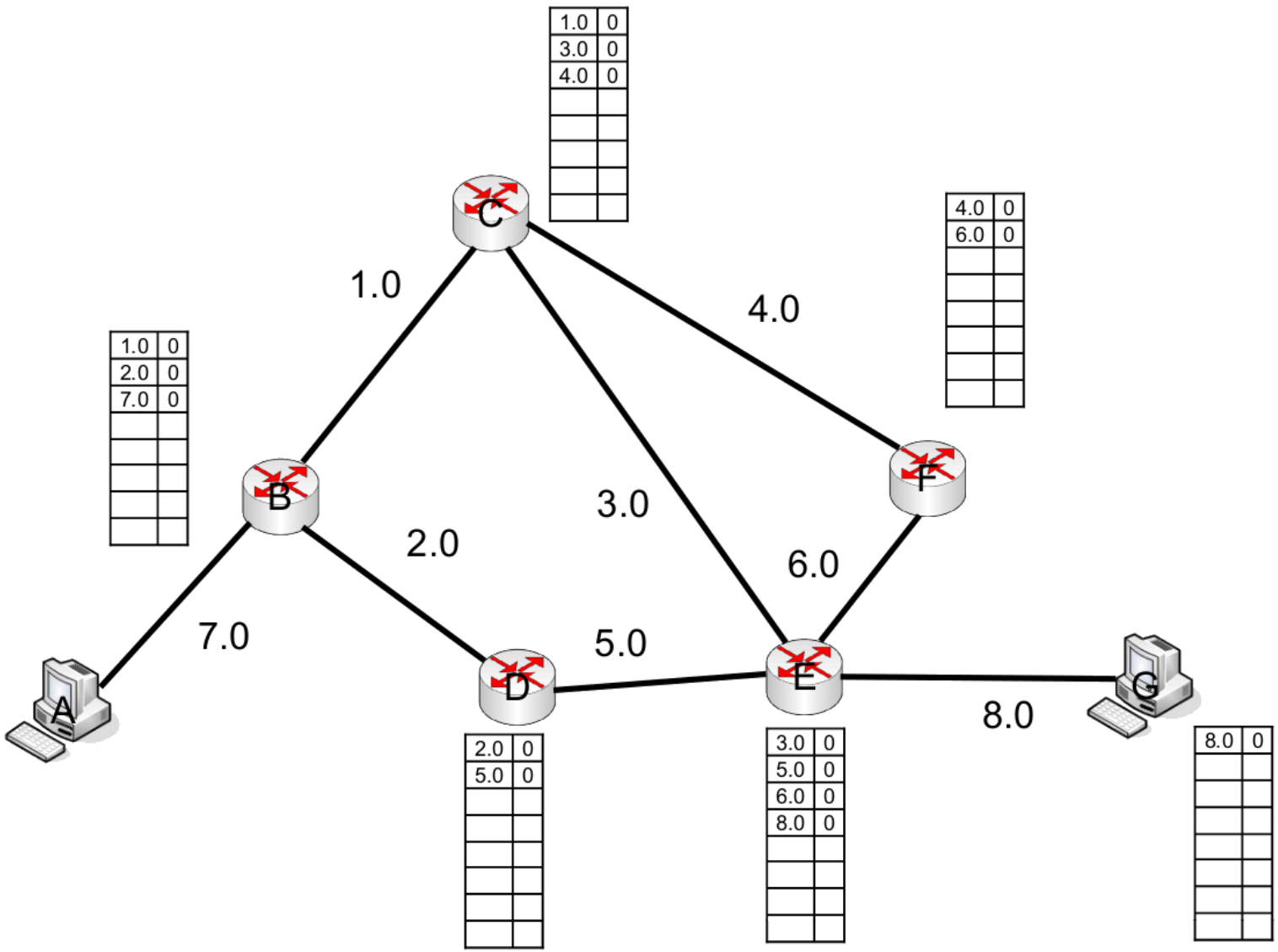
Decentralized routing methods

- DVA – Distance Vector Algorithm
  - routers periodically broadcast the contents of their routing tables to neighbors
  - update their own tables, if "shorter" path is found
  - metric is the number of nodes on the way
  - problem: limited diameter of the network – everything greater is interpreted as "infinity"
- LSA – Link State Algorithm
  - routers inform each other about the state of links
  - each router has an information about complete network topology
  - router then use Dijkstra's algorithm to calculate the map of the shortest paths
- Path Vector Routing
  - routers update each other about the paths
  - looped updates are detected and discarded
  - entry in the routing table contains the destination network, the next router and the path to reach the destination

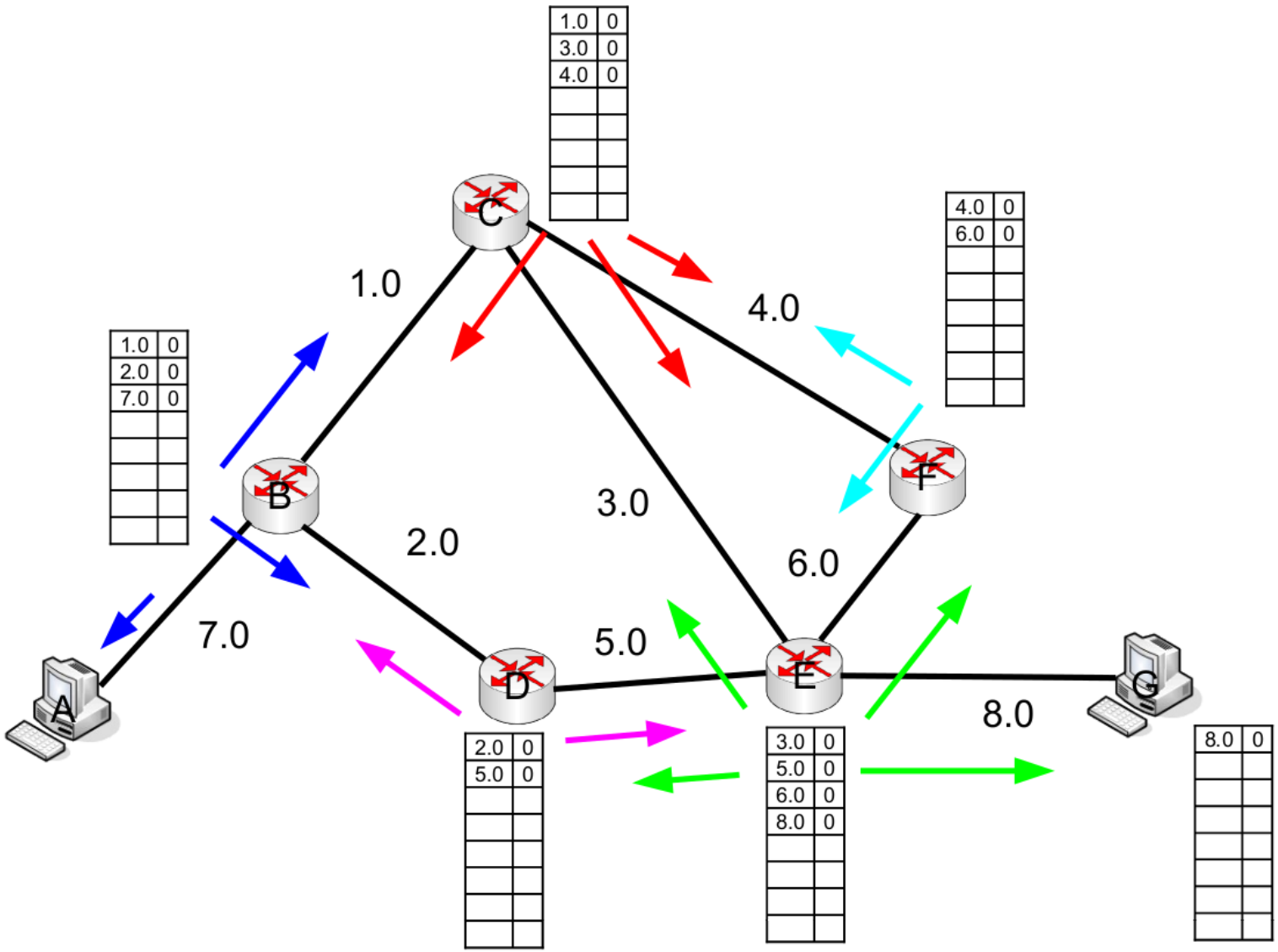
RIP (Routing Information Protocol)

- RIP: rfc1058 - classfull (class A, B, C)
  RIPv2: rfc1388 - classless (CIDR)
  RIPng: rfc2086 - added IPv6 support
- Distance Vector Algorithm
  - Bellman-Ford algorithm to search the shortest path
  - metric is the number of "hops" to the destination network (hop count)
  - max. number of hops (network diameter) is 15 (16 is interpreted as "infinity")
- router periodically (30s) sends his table to all neighbors
- problems of RIP: limited size of the network, network load when forwarding tables, slow convergence after a link failure

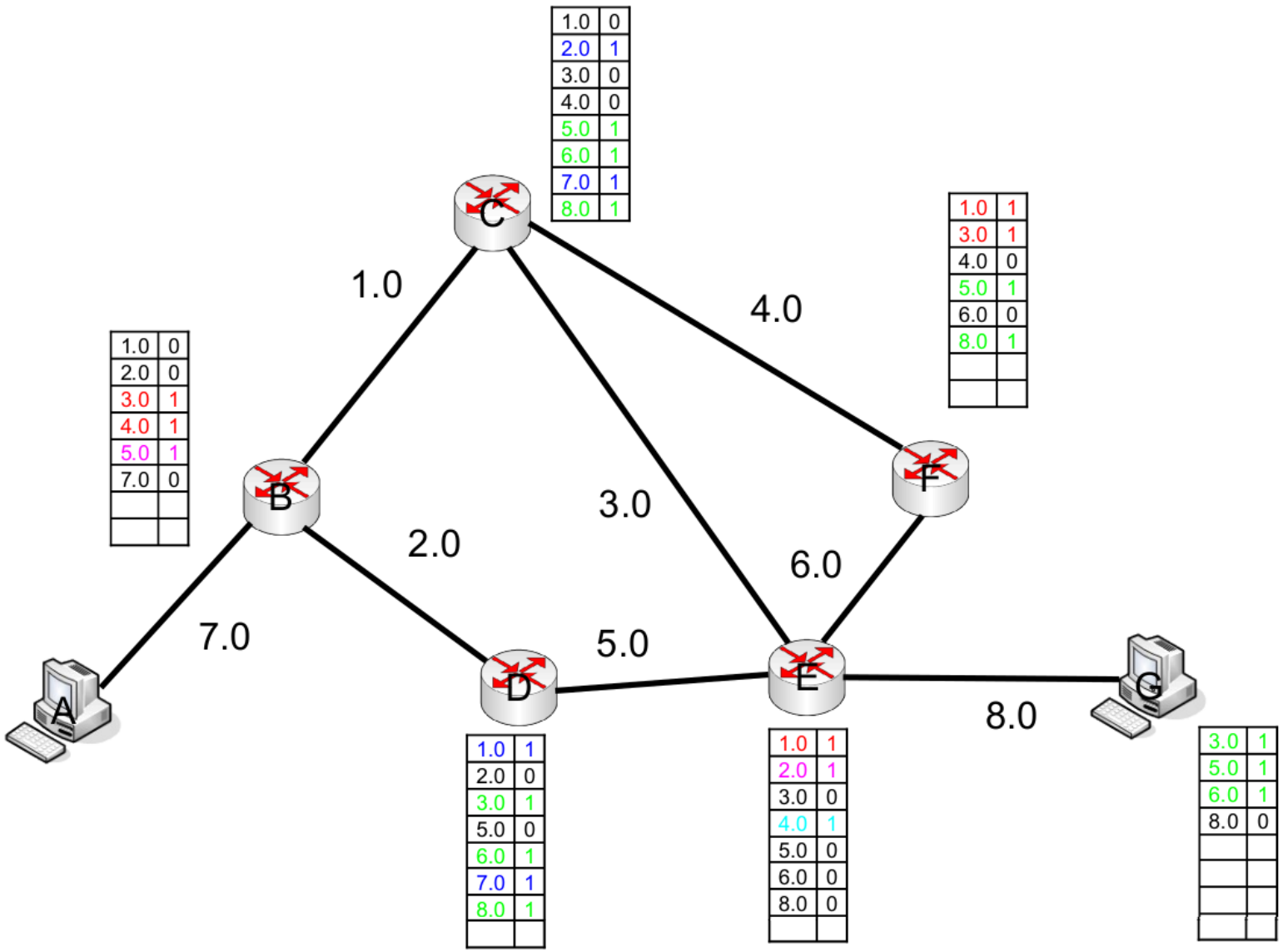
RIP calculation of routing table I



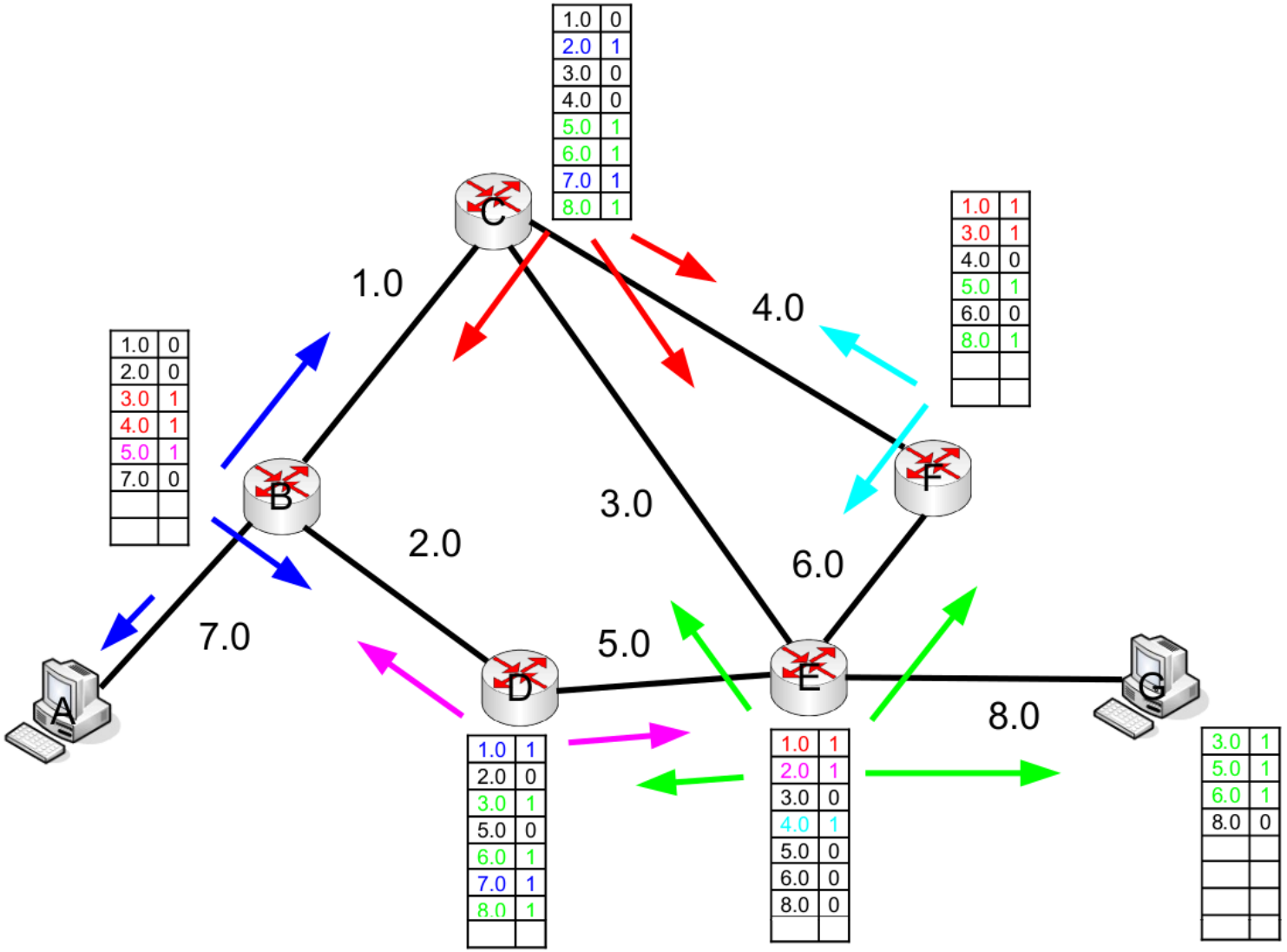
RIP calculation of routing table II



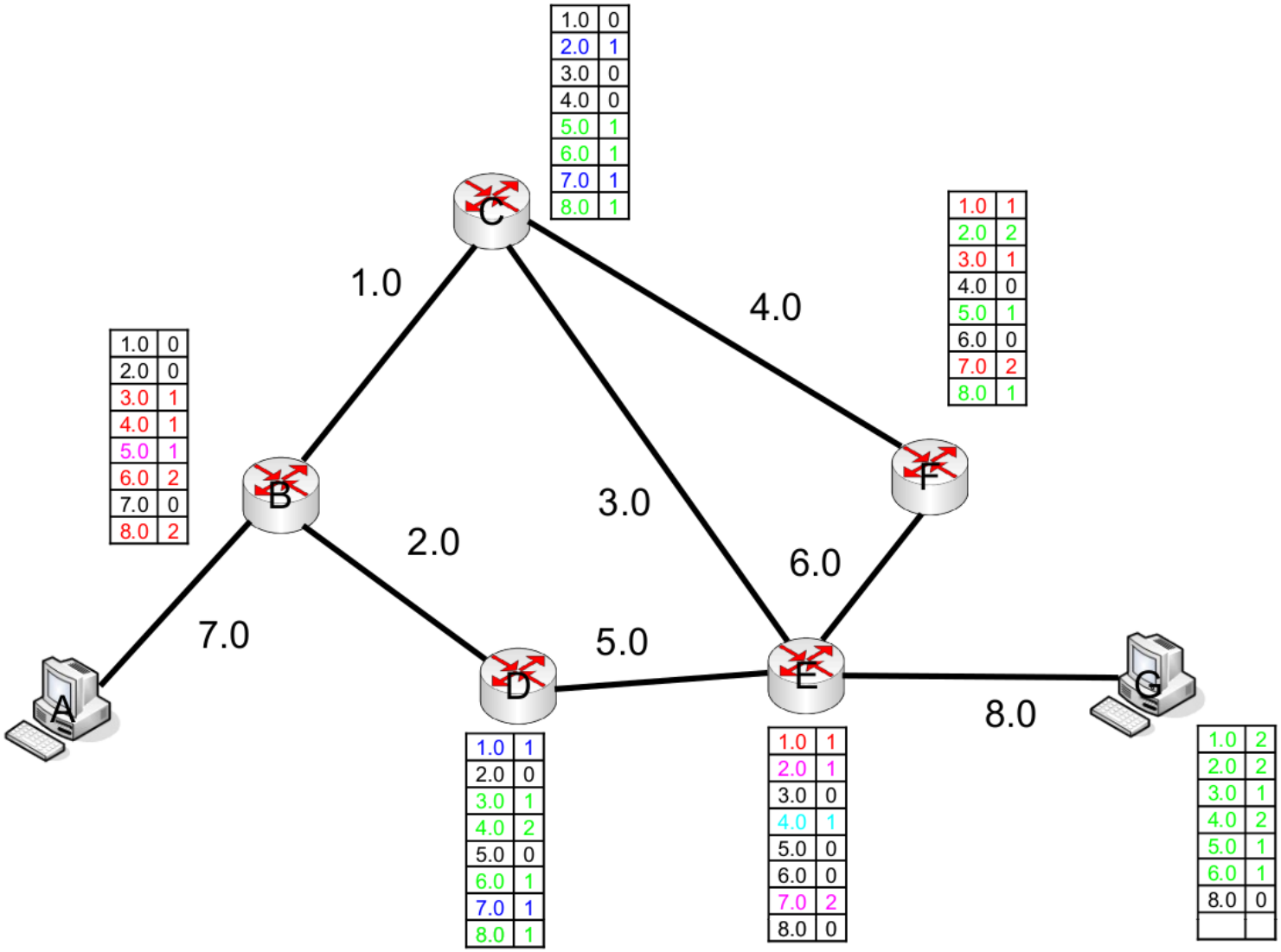
RIP calculation of routing table III



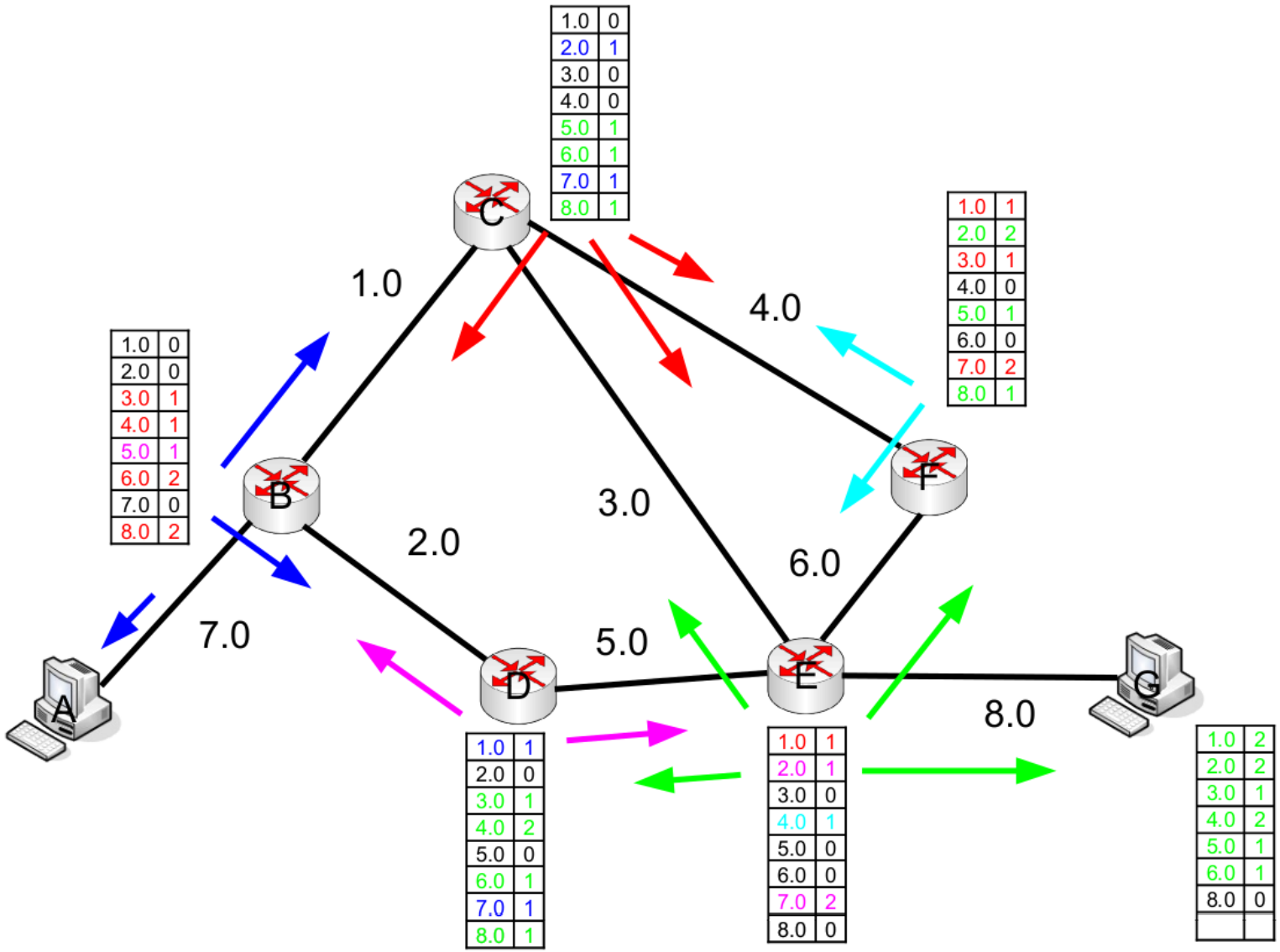
RIP calculation of routing table IV



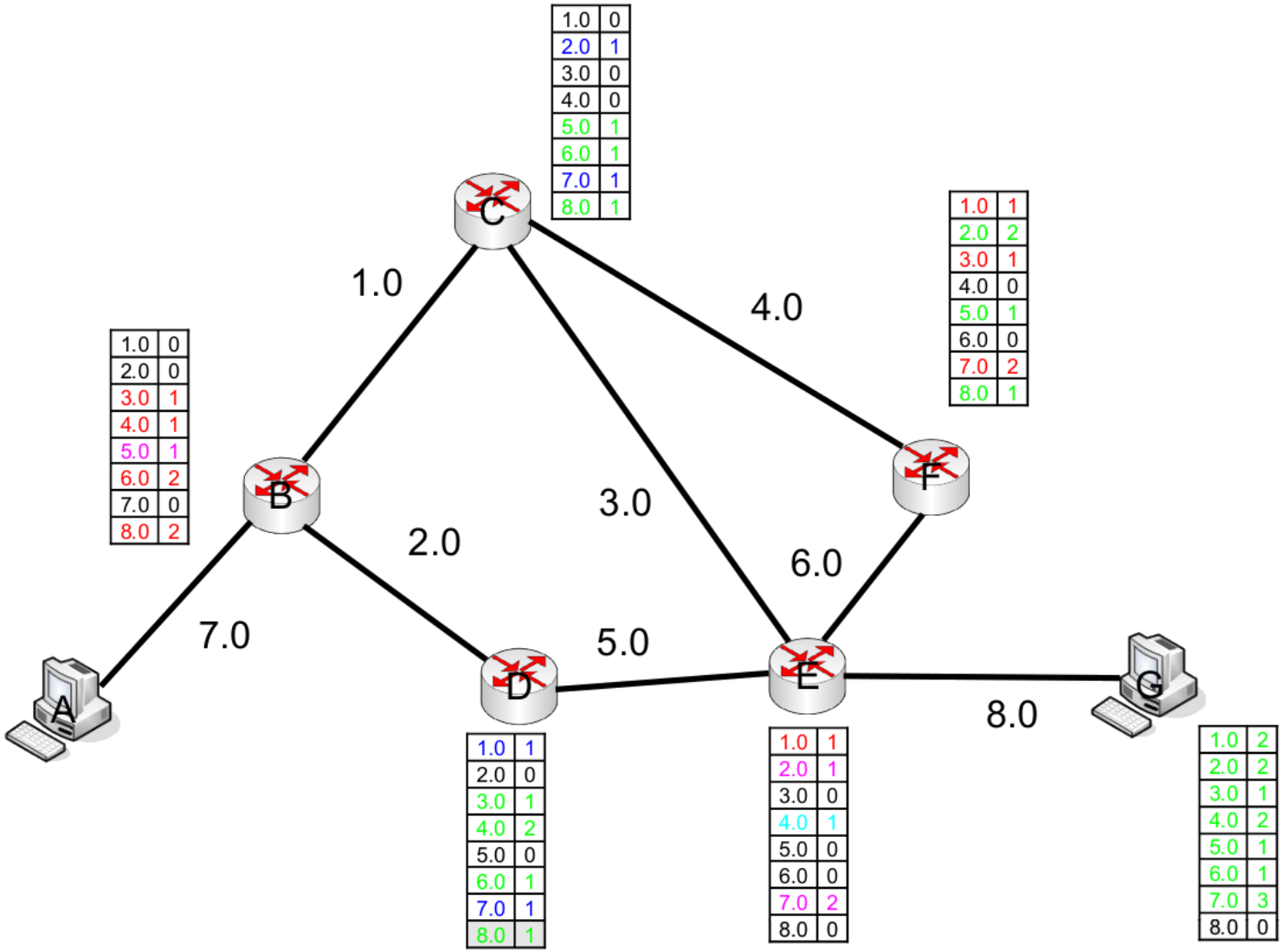
RIP calculation of routing table V



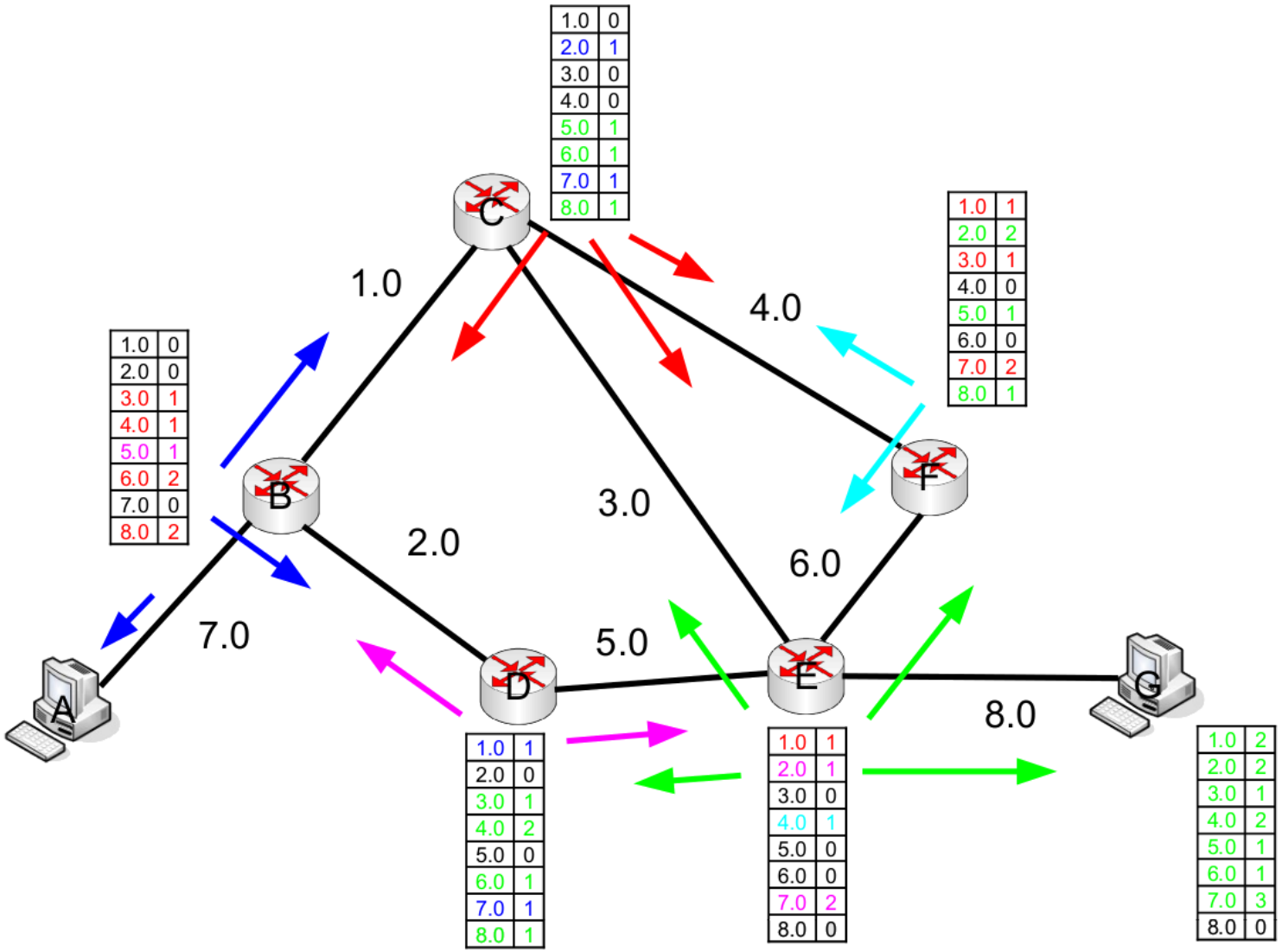
RIP calculation of routing table VI



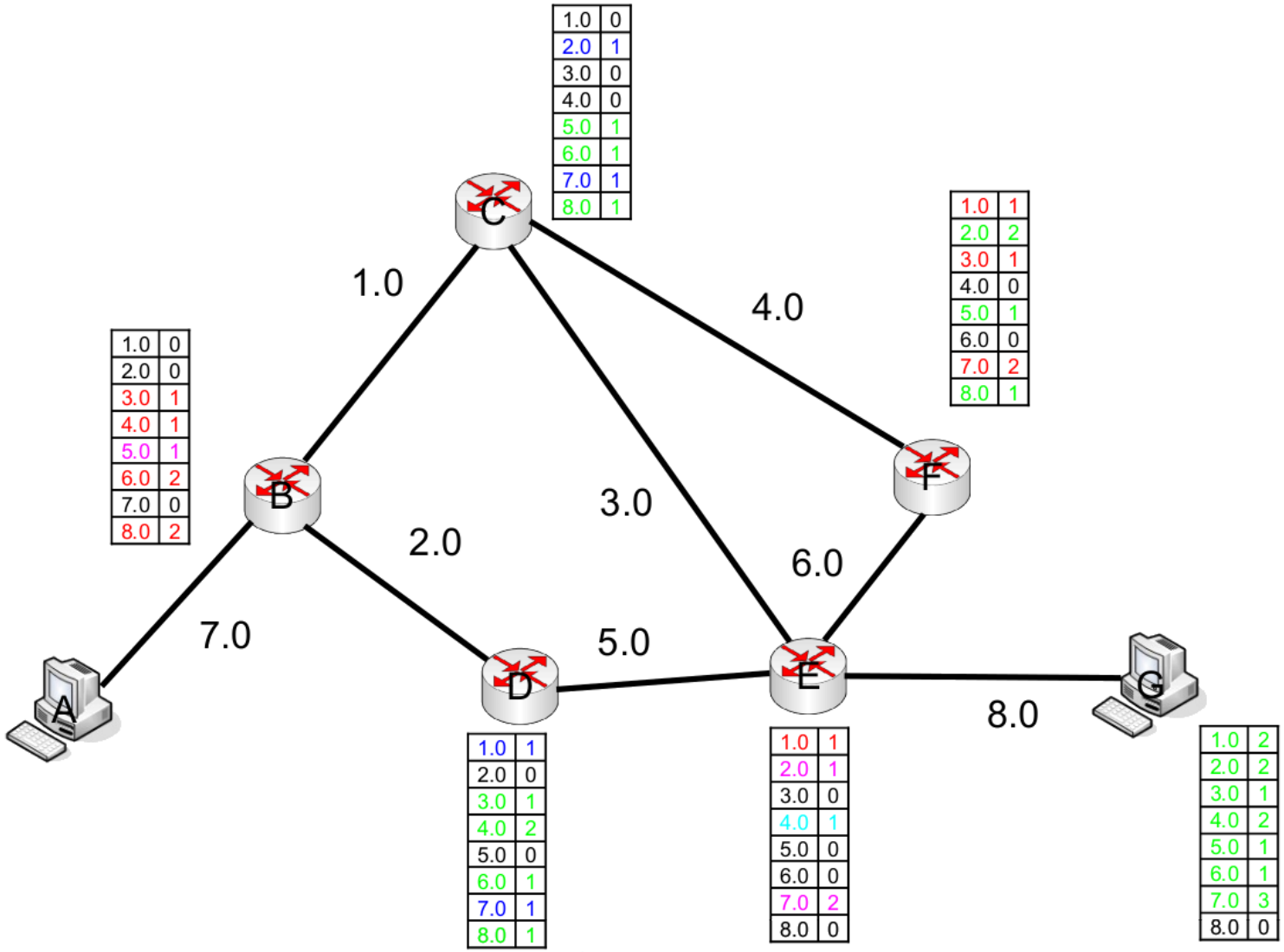
RIP calculation of routing table VII



RIP calculation of routing table VIII



RIP calculation of routing table IX

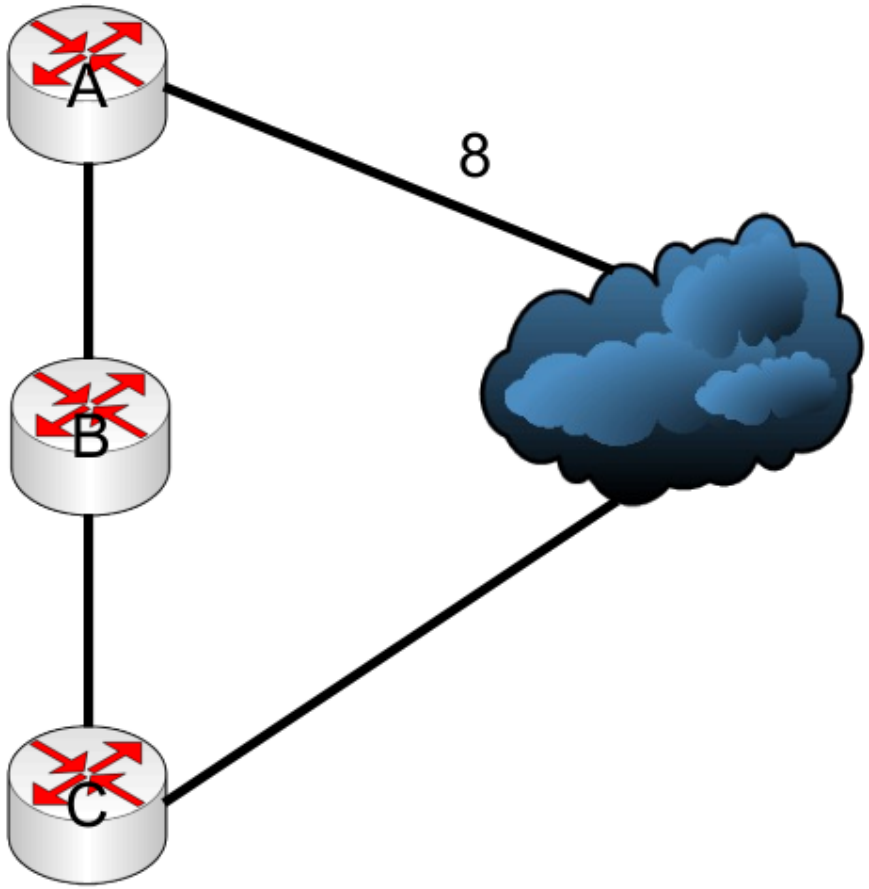


RIP convergence I

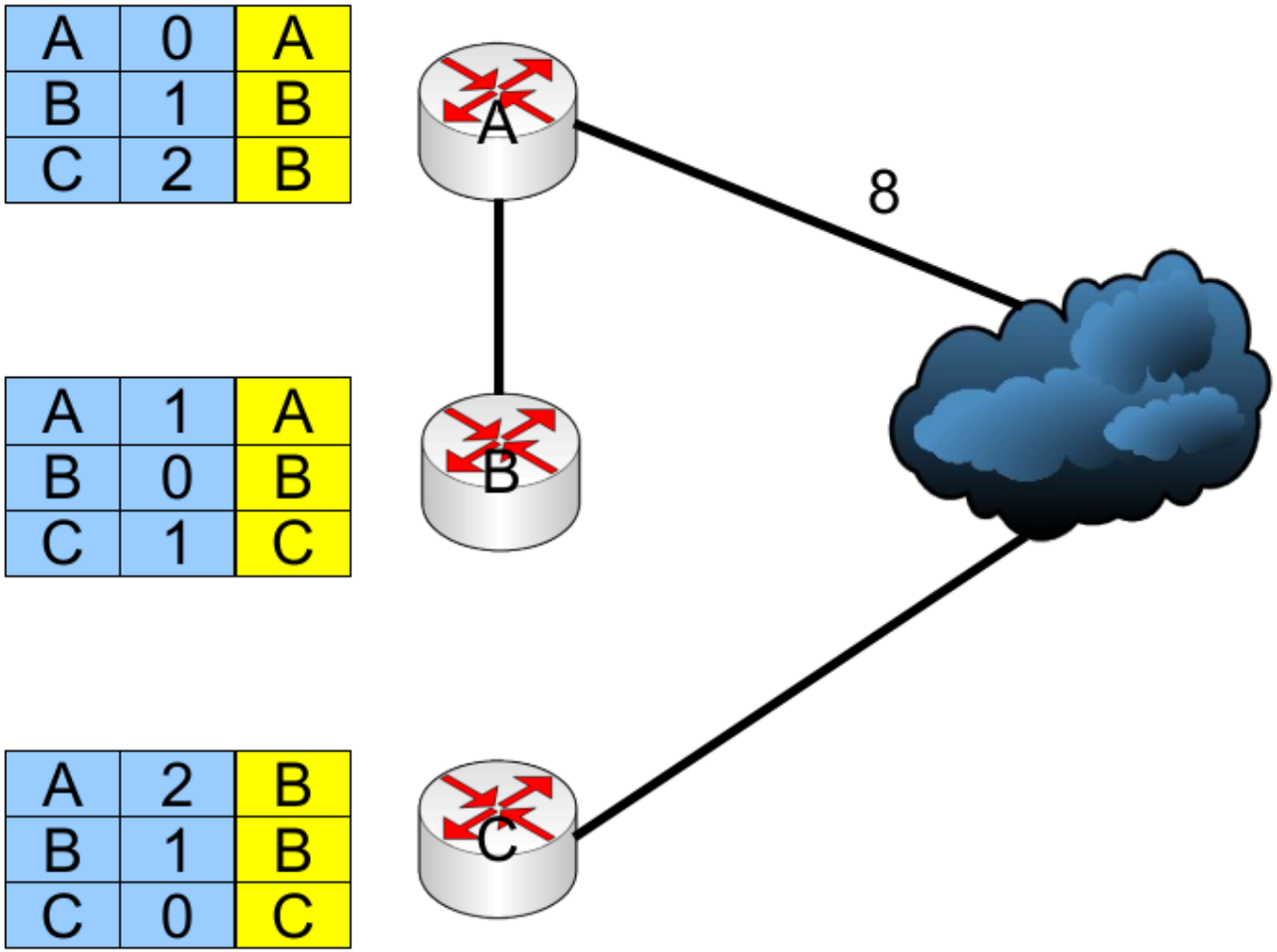
A	0	A
B	1	B
C	2	B

A	1	A
B	0	B
C	1	C

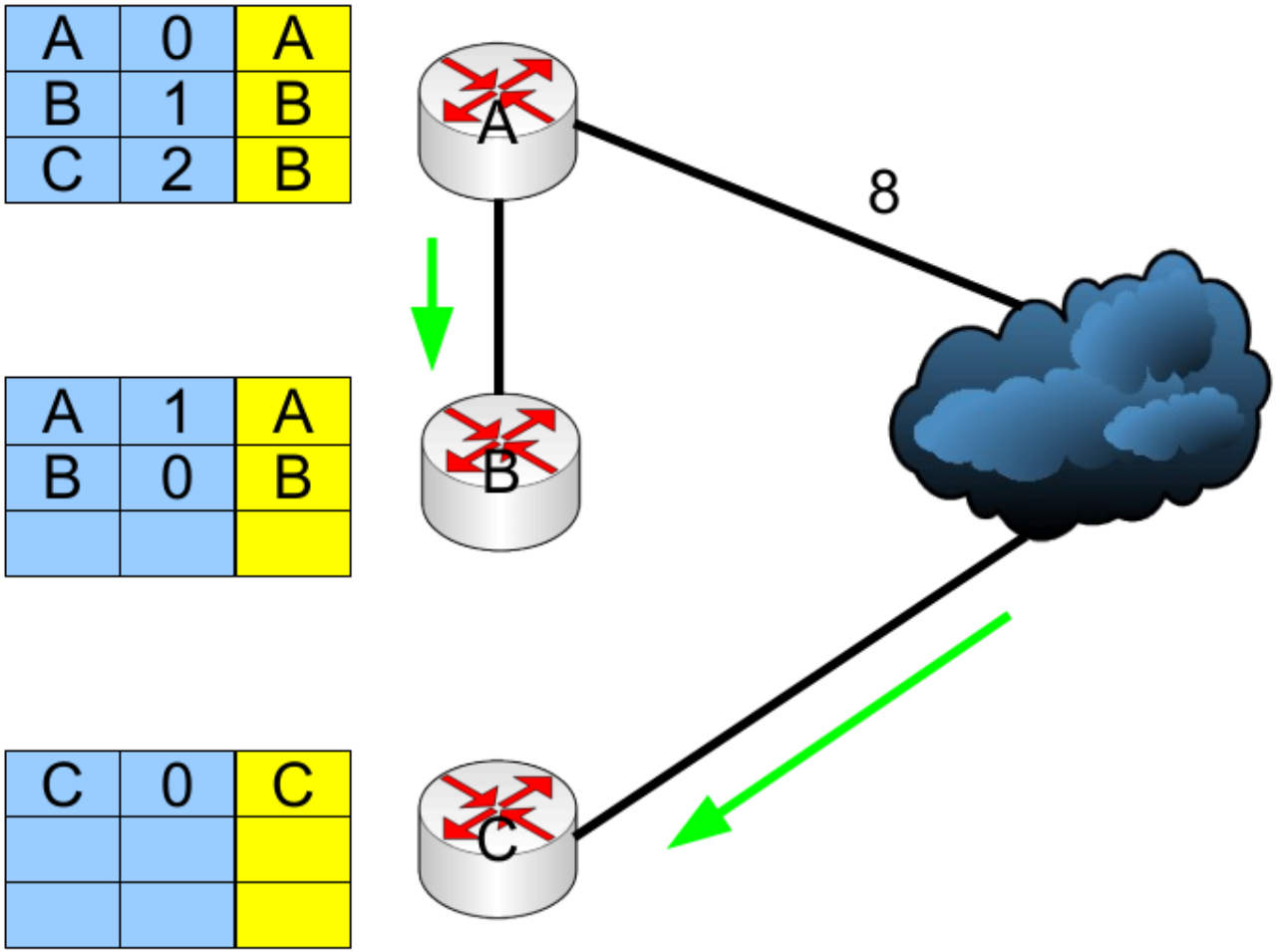
A	2	B
B	1	B
C	0	C



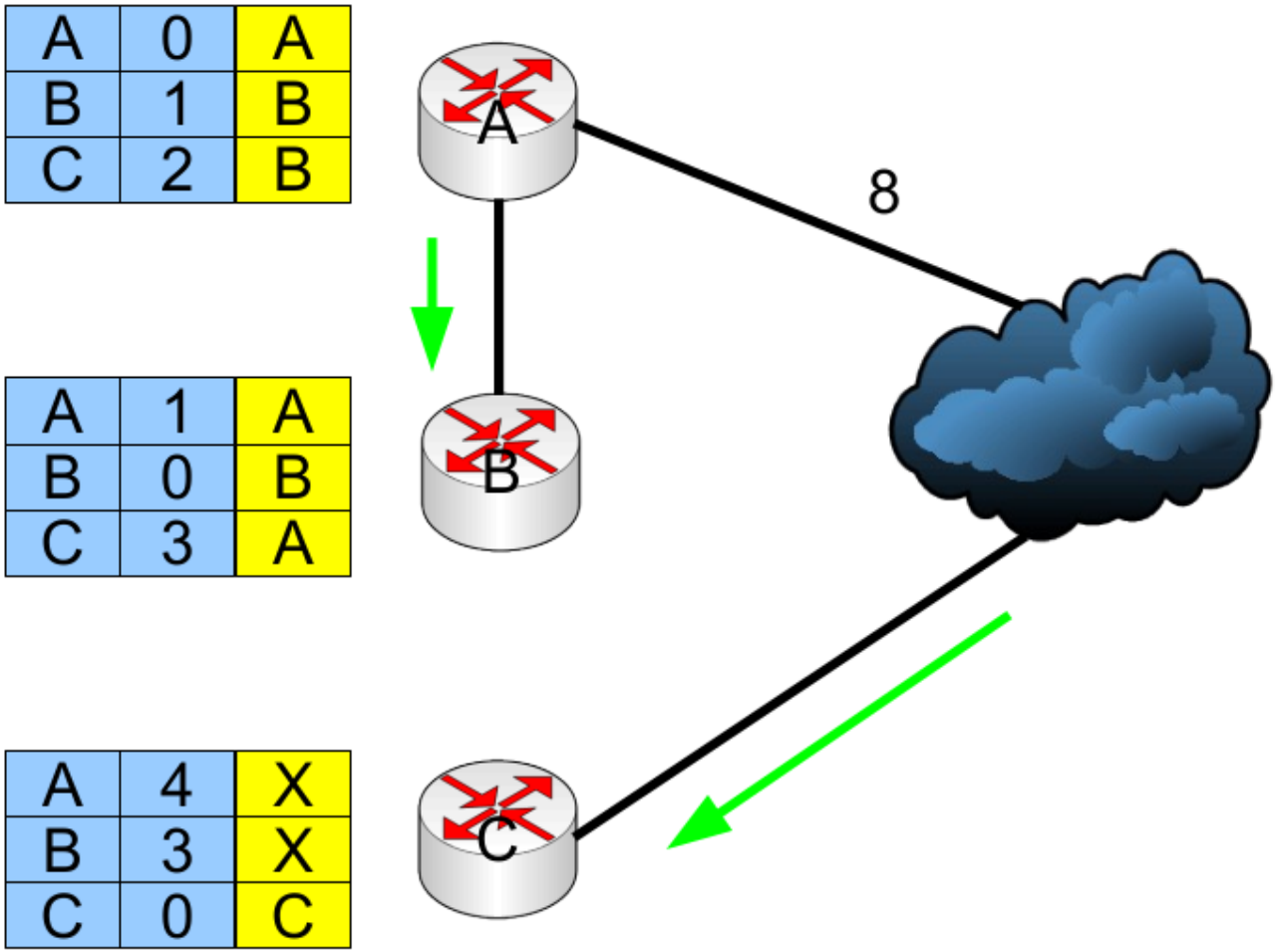
RIP convergence II



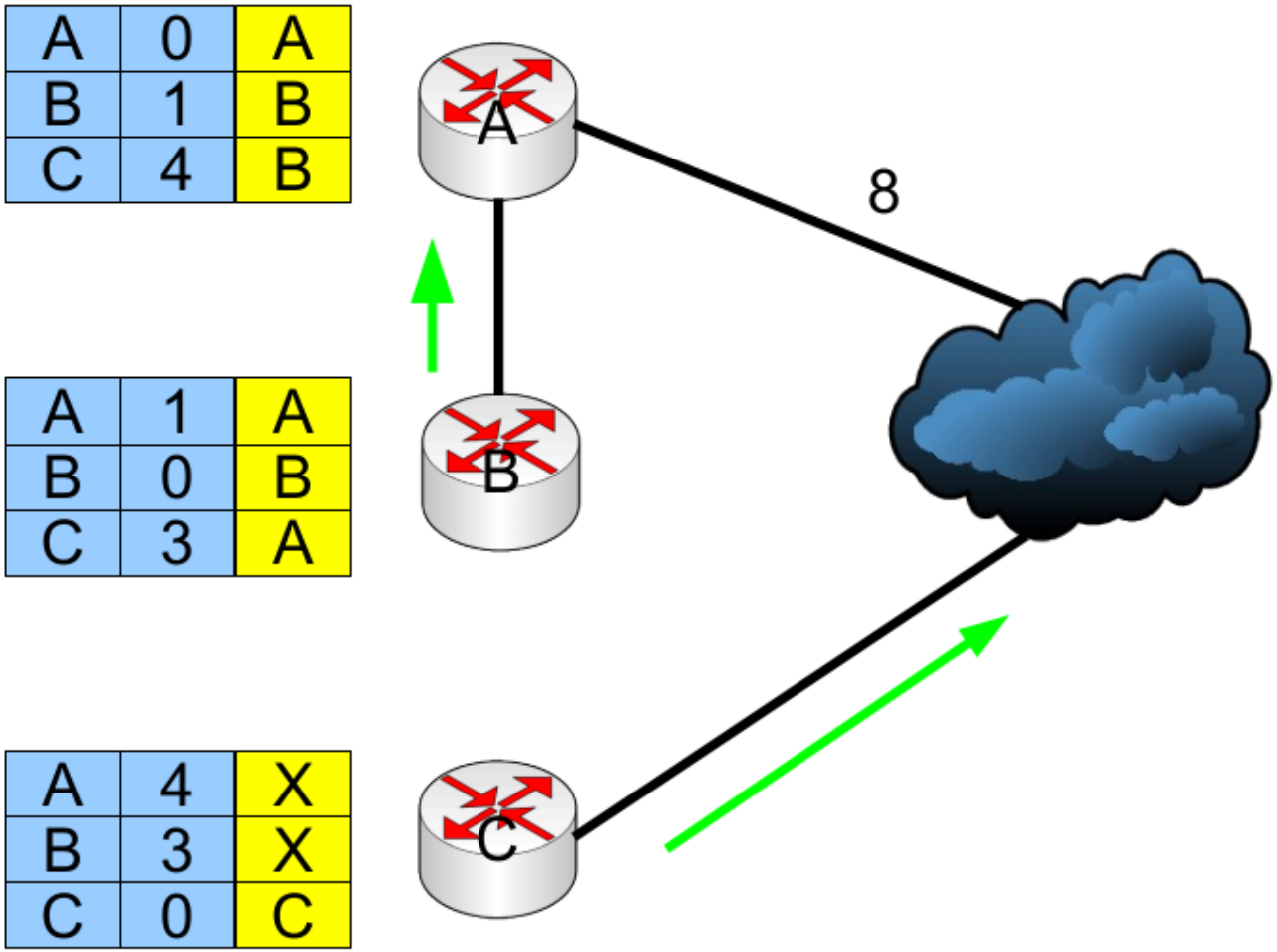
RIP convergence III



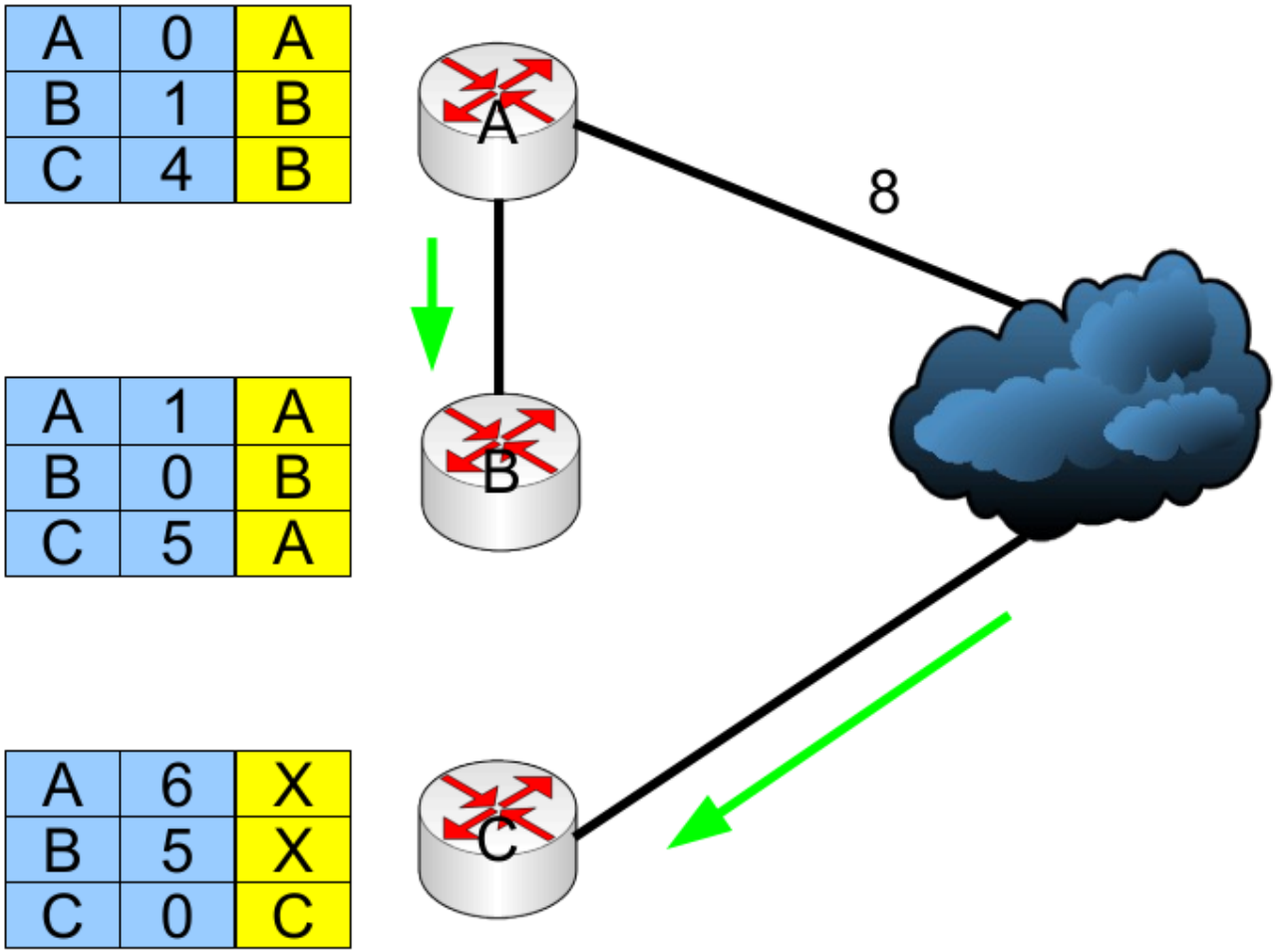
RIP convergence IV



RIP convergence V



RIP convergence VI

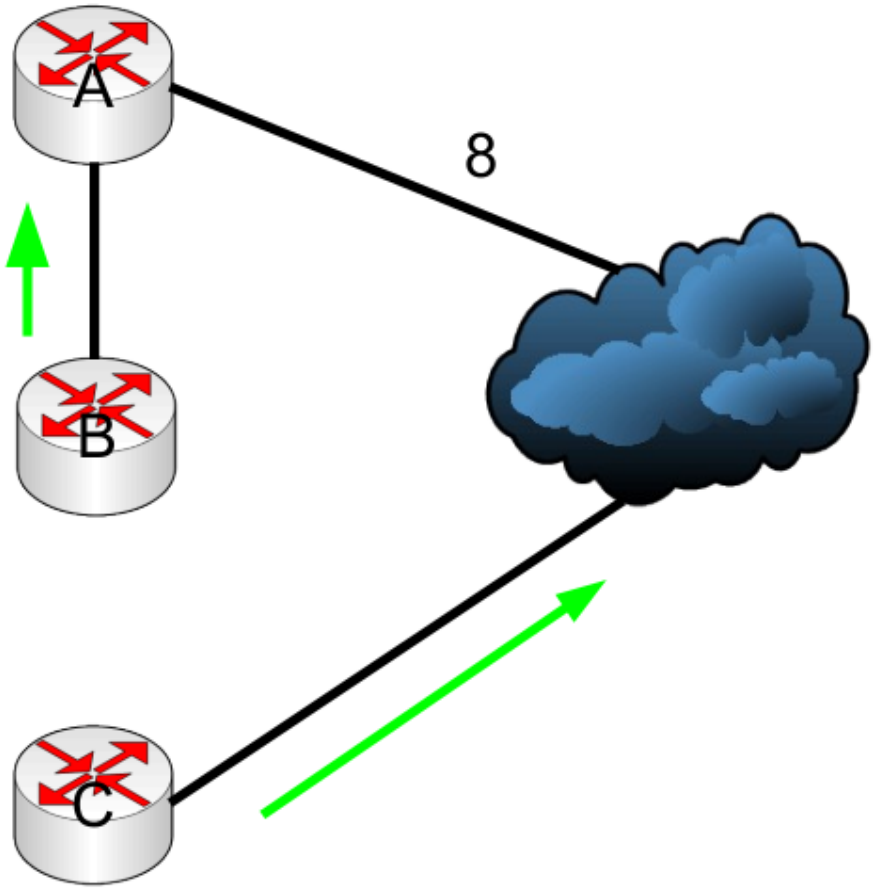


RIP convergence VII

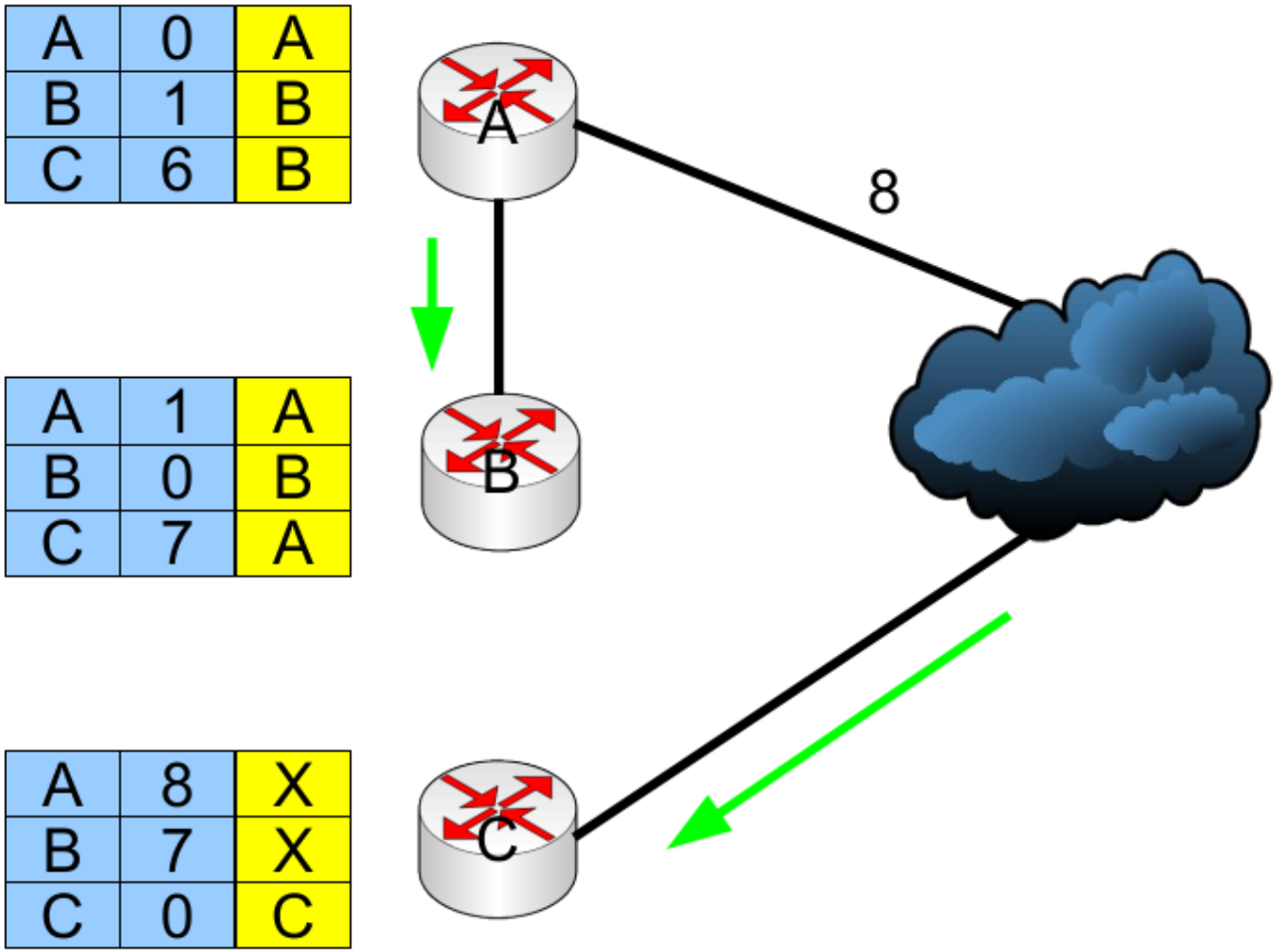
A	0	A
B	1	B
C	6	B

A	1	A
B	0	B
C	5	A

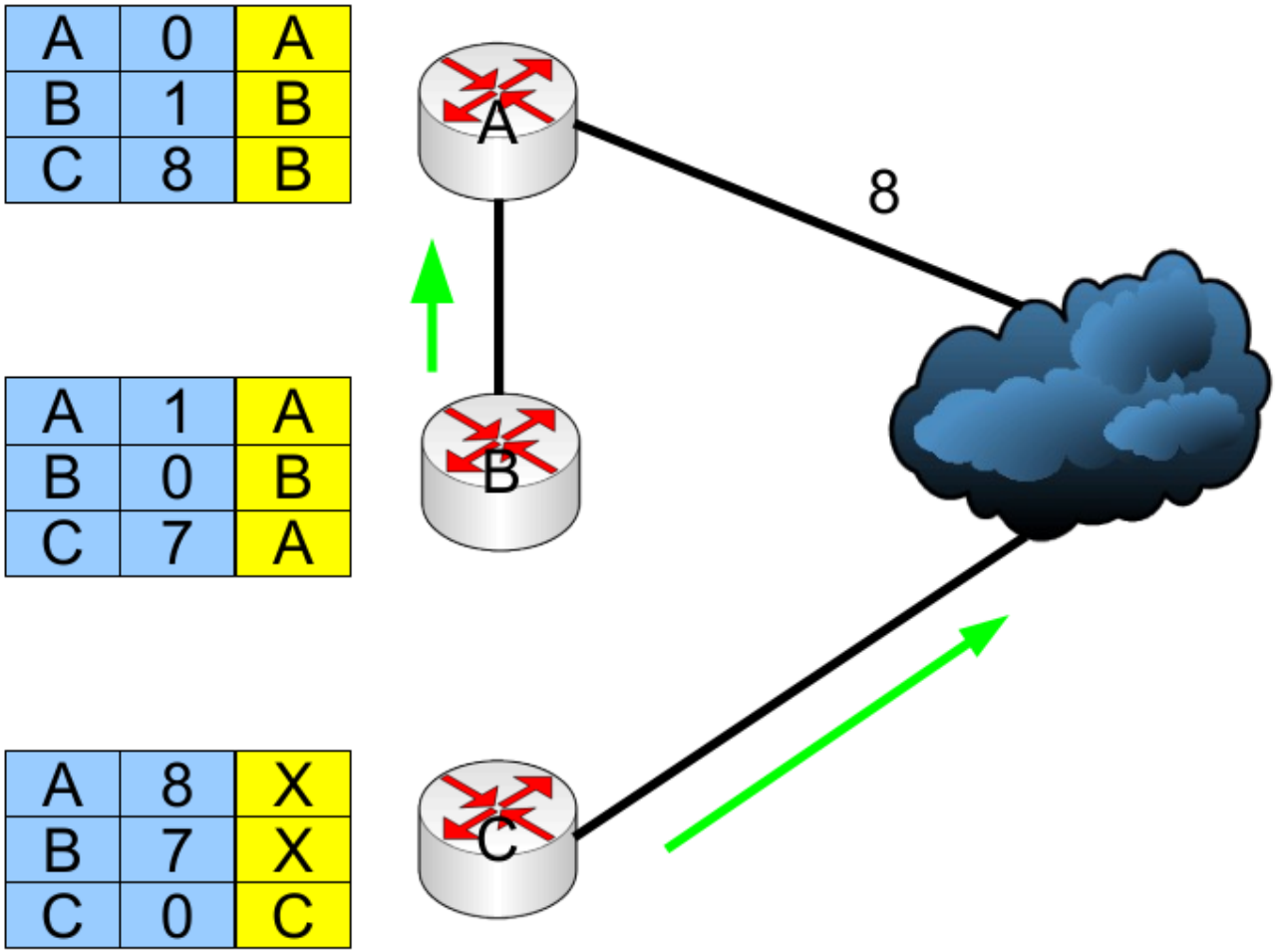
A	6	X
B	5	X
C	0	C



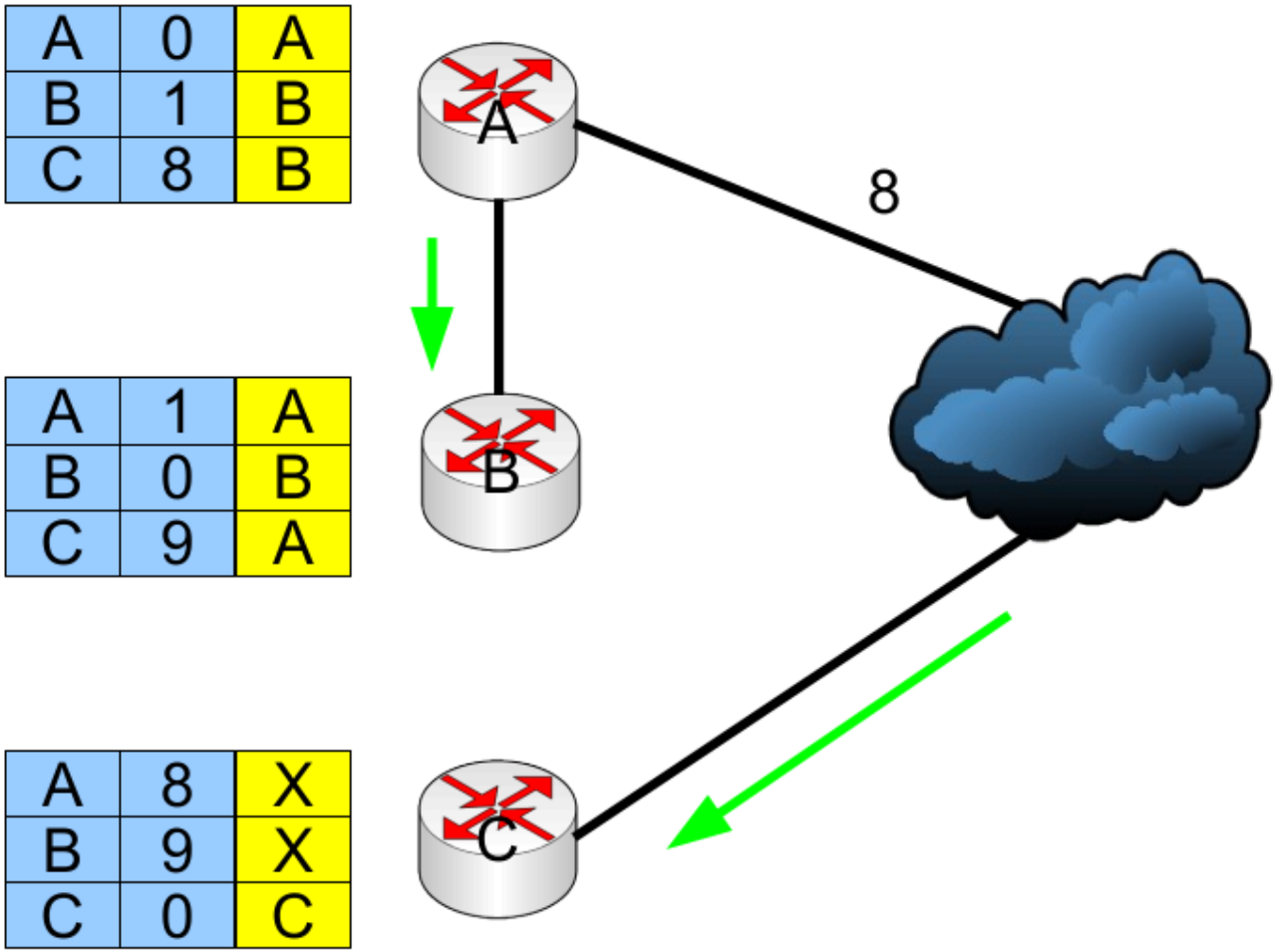
RIP convergence VIII



RIP convergence IX



RIP convergence X

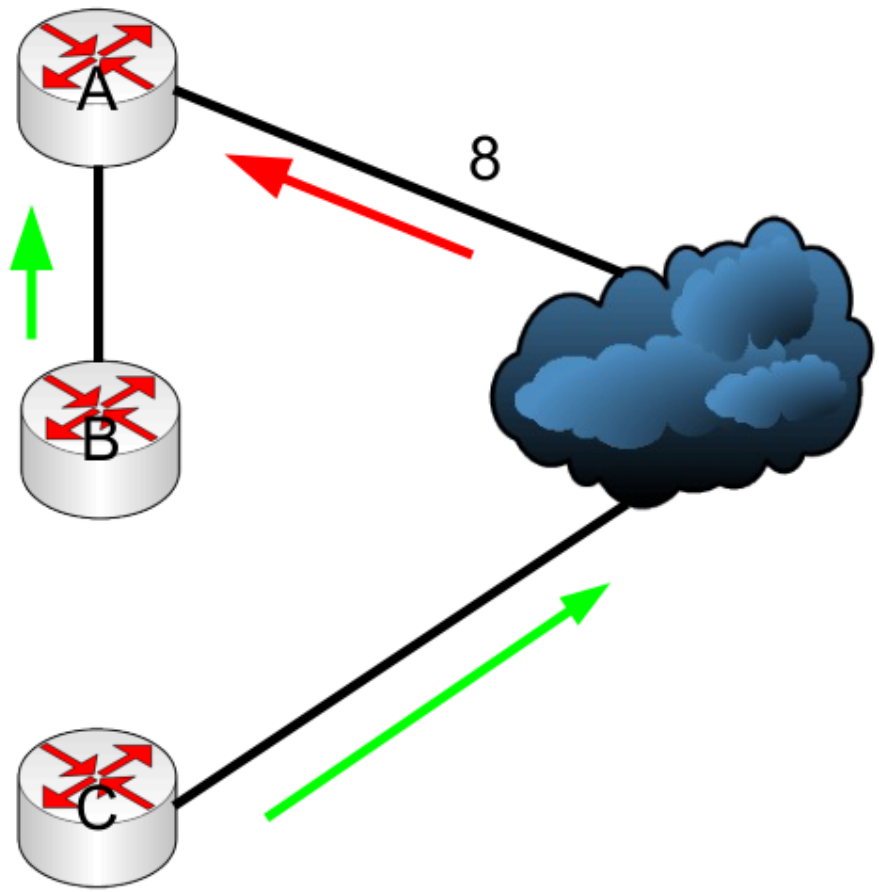


RIP convergence XI

A	0	A
B	1	B
C	8	Y

A	1	A
B	0	B
C	9	A

A	8	X
B	9	X
C	0	C



OSPF (Open Shortest Path First)

- OSPF v2: rfc2328 – IPv4
  OSPF v3: rfc5340 – IPv6
- implementation of Link State Algorithm
- Dijkstra's algorithm for searching the shortest path in a graph
- routers periodically send the state of links (every 30 minutes or on change of the state)
- metric is the actual speed of the link (bandwidth)

OSPF II

- each router knows the network topology (nodes and edges)
- each router independently calculates the table of shortest distances to all nodes
- rapid convergence (in seconds)
- there is no strict limit for the diameter of the network
- lower overhead – less traffic, greater interval between data exchange

EIGRP (Enhanced Interior Gateway Routing Protocol)

- advanced distance-vector routing protocol
- was designed by Cisco Systems as a proprietary protocol, available only on Cisco routers
- was converted to an open standard in 2013 and was published as RFC 7868 in 2016
- unlike RIP, EIGRP only sends incremental updates, reducing the workload on the router and the amount of data that needs to be transmitted
- synchronizes routing tables between neighbors at startup, and then sends specific updates only when topology changes occur to multicast address 224.0.0.10
- Hello messages are sent to neighbors every 5 seconds in a LAN and every 60 seconds in a WAN environment

Routing in the Internet

- autonomous system (AS) is a collection of connected IP networks under the control of one network operator or company (eg. ISP)
- AS is identified by ASN – Autonomous System Number
- Interior Gateway Protocol (IGP)
  - routing inside autonomous systems
  - RIP, OSPF (dominant), EIGRP
- Exterior Gateway Protocols (EGP)
  - routing between autonomous systems
  - BGP

BGP (Border Gateway Protocol)

- rfc1771, rfc4271
- dominant Exterior Gateway Protocol
- path-vector routing protocol
- routing between autonomous systems