Lab 6

OSPF routing protocol

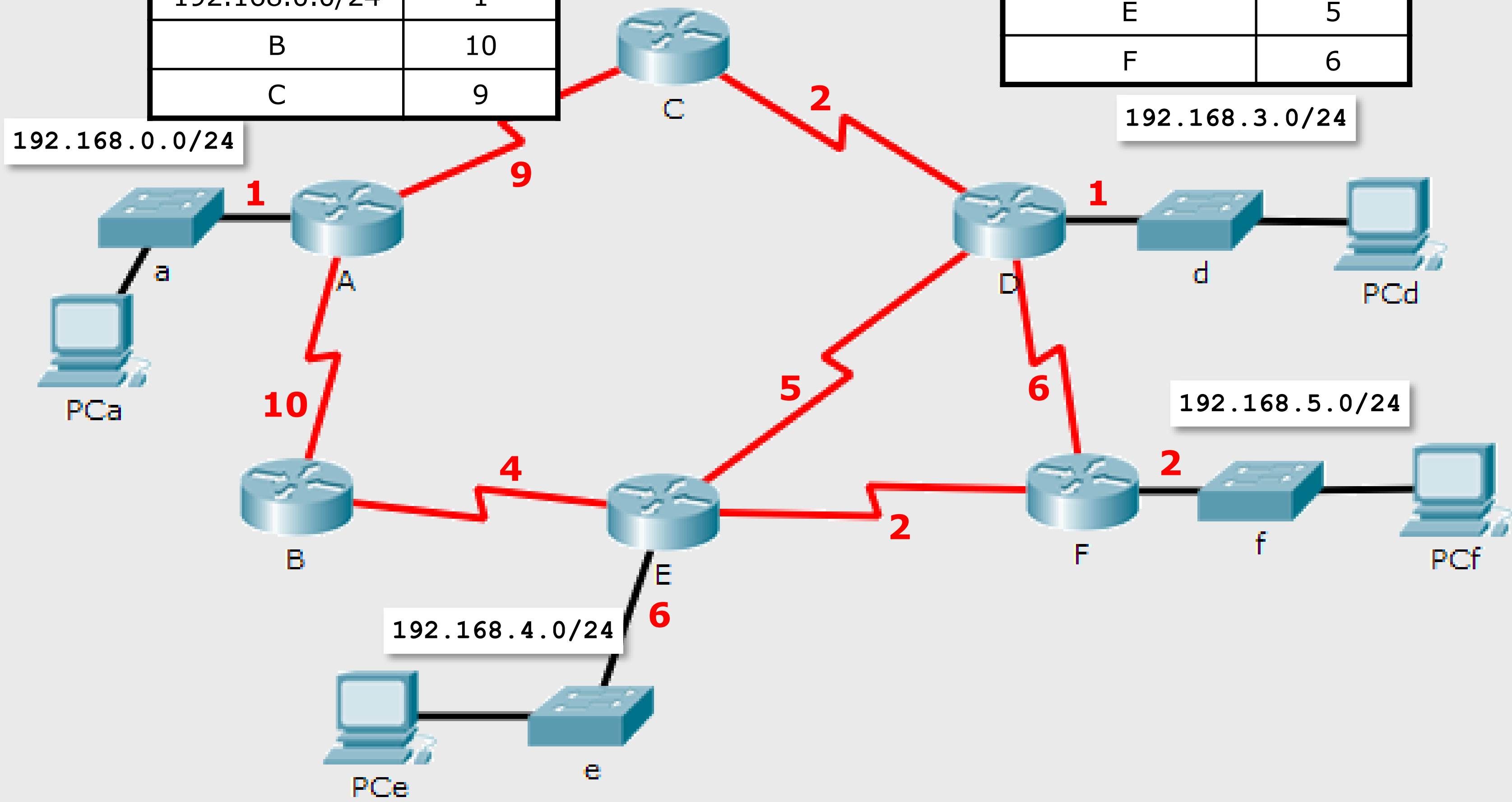
Recap – link state routing algorithm

- Each router advertises its neighbor topology, i.e., link states, through Link State Packets (LSP)
- For each link it is specified
  - The address of the neighboring node
  - The metric associated to traversing the link
- The router sends its own LSP to its neighbors, and cooperates to the propagation of LSPs generated by the other routers
- Each router receives all LSPs generated in the network
  - Stores LSPs in an LSP database
  - Determines the route topology from the LSP database
  - Computes the minimum cost path to each destination by means of the Shortest Path First algorithm
  - Builds the routing table based on the previous result

Recap – LSP propagation

Link	Metric
192.168.0.0/24	1
B	10
C	9

Link	Metric
192.168.3.0/24	1
C	2
E	5
F	6

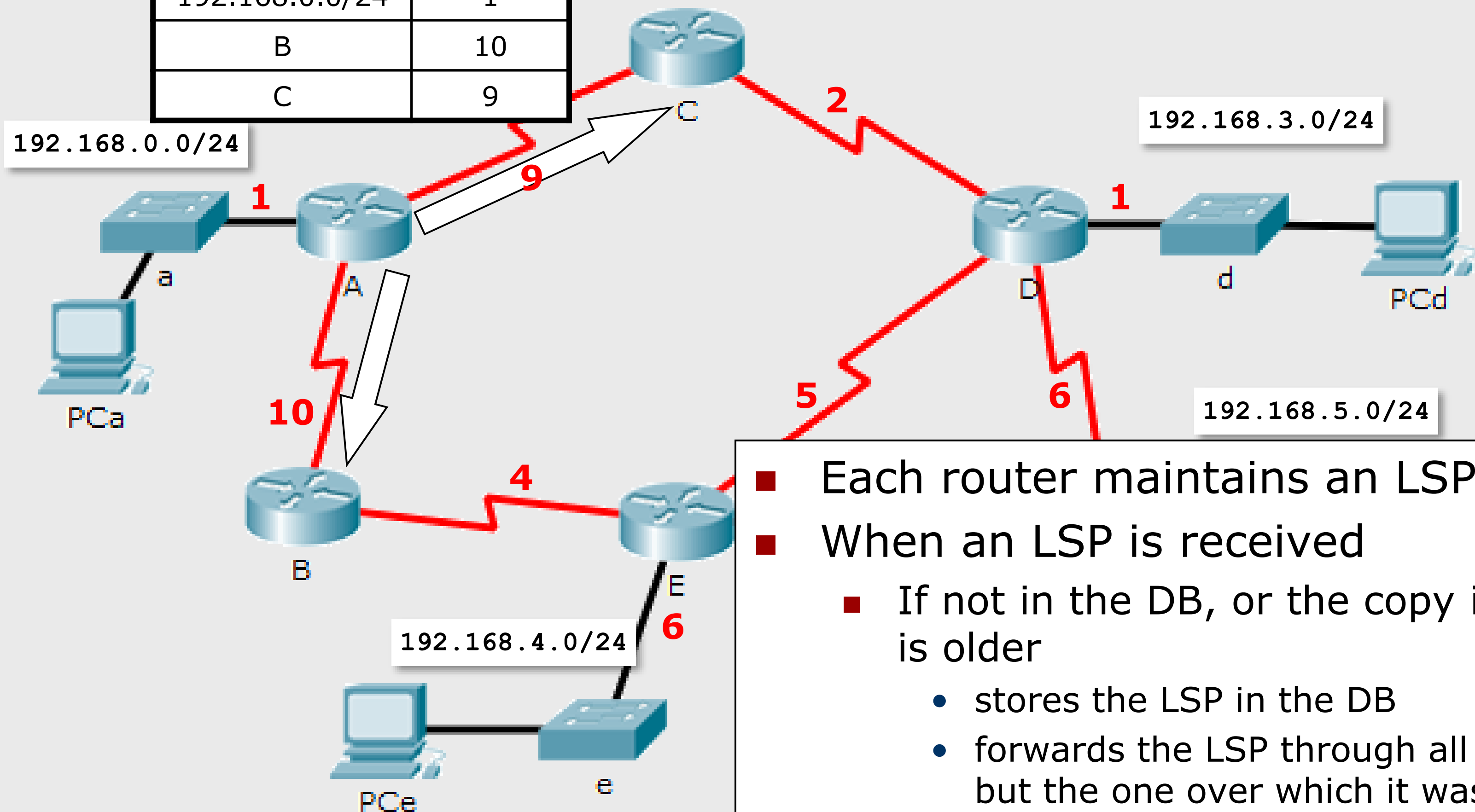


Selective flooding

Each LSP is propagated only the first time it is received

Recap – LSP propagation

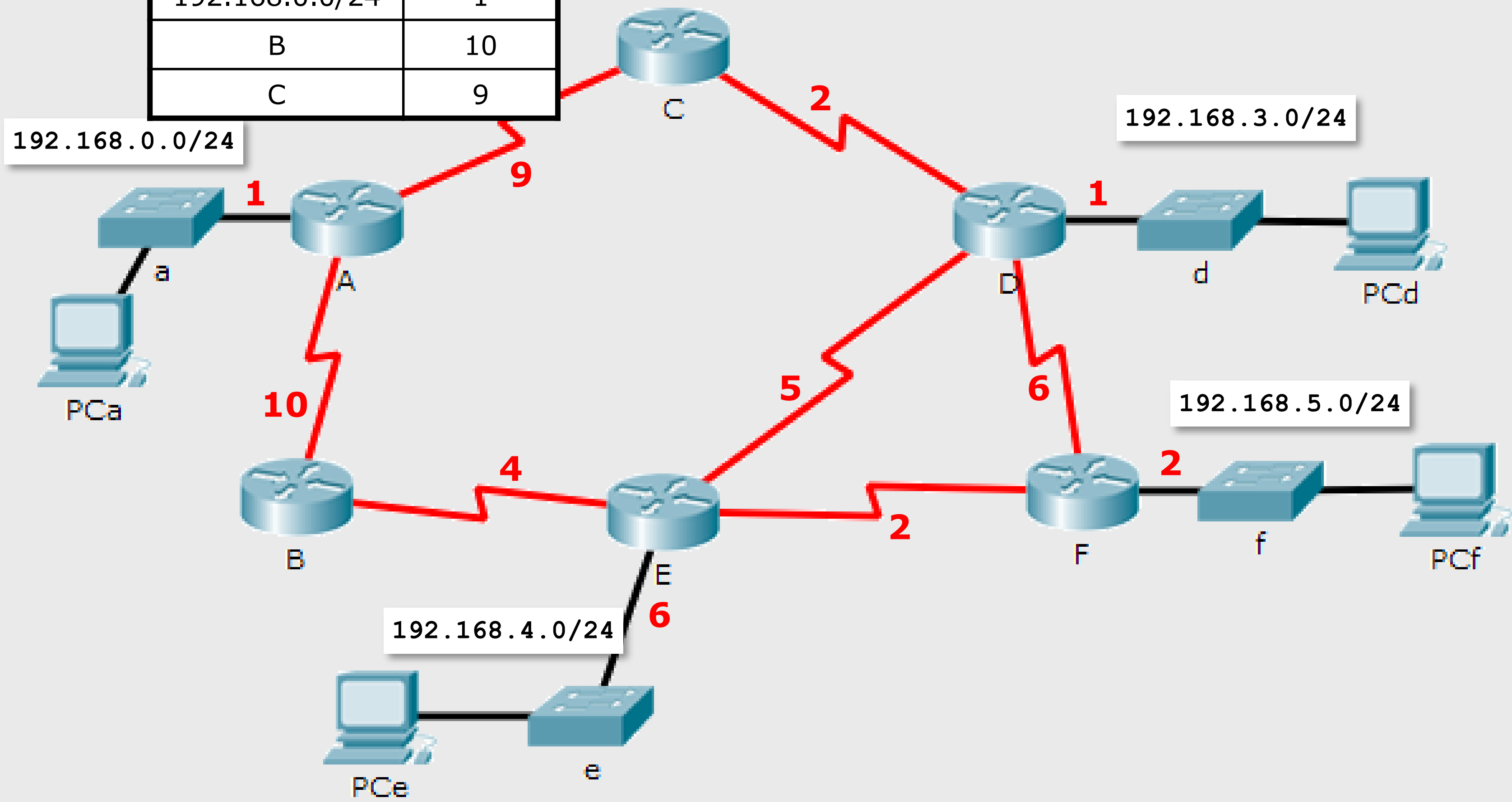
Link	Metric
192.168.0.0/24	1
B	10
C	9



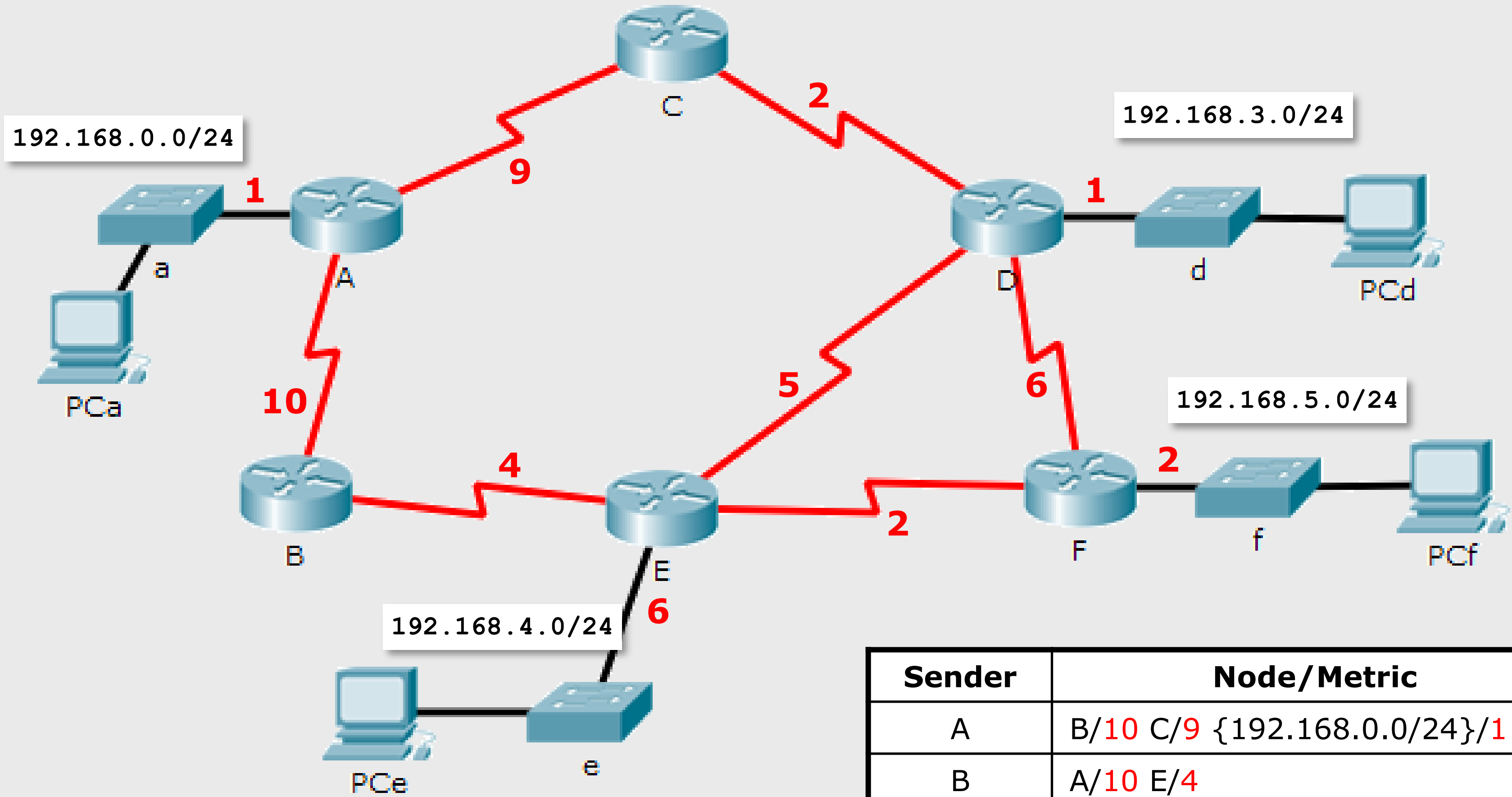
- Each router maintains an LSP DB
- When an LSP is received
  - If not in the DB, or the copy in the DB is older
    - stores the LSP in the DB
    - forwards the LSP through all interfaces but the one over which it was received
  - Otherwise, if the copy in the DB
    - is the same, ignores it
    - is more recent, sends back to the sender its own copy to update it

Recap – LSP propagation

Link	Metric
192.168.0.0/24	1
B	10
C	9



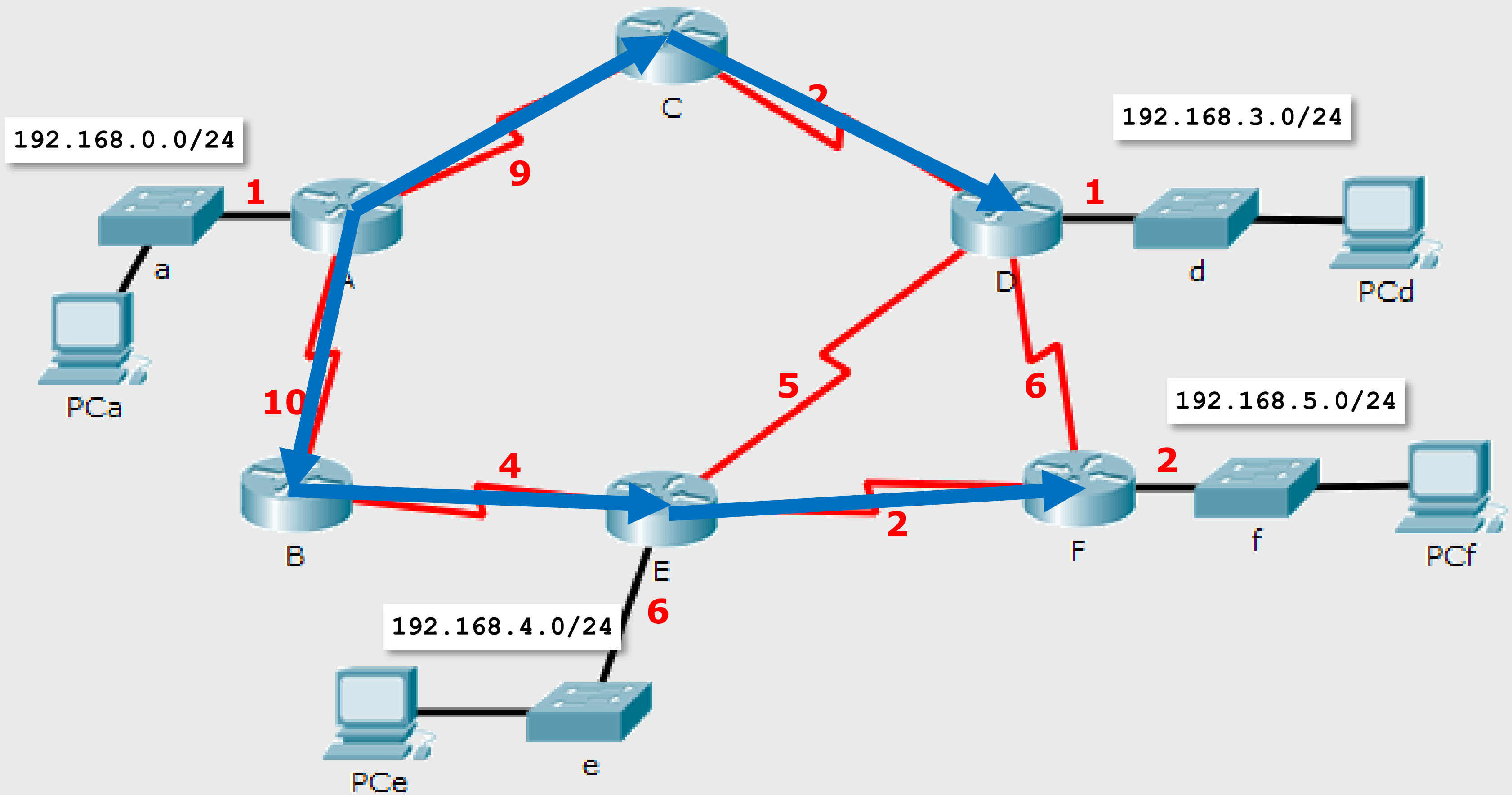
LSP Database



Sender	Node/Metric
A	B/10 C/9 {192.168.0.0/24}/1
B	A/10 E/4
C	A/9 D/2
D	C/2 E/5 F/6 {192.168.3.0/24}/1
E	B/4 D/5 F/2 {192.168.4.0/24}/6
F	D/6 E/2 {192.168.5.0/24}/2

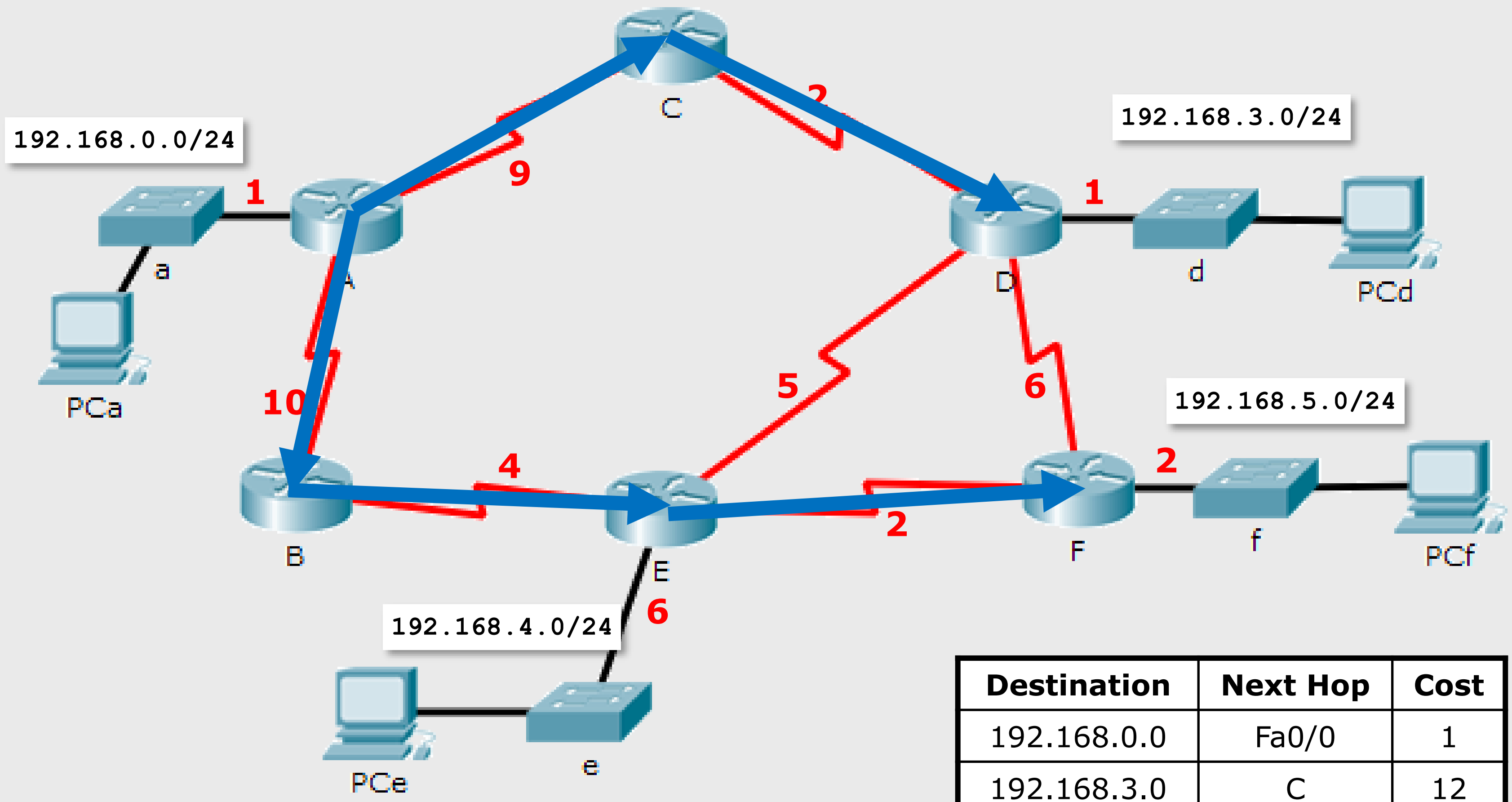
Dijkstra algorithm

- Shortest path tree rooted at A



Dijkstra algorithm

- Shortest path tree rooted at A



Destination	Next Hop	Cost
192.168.0.0	Fa0/0	1
192.168.3.0	C	12
192.168.4.0	B	20
192.168.5.0	B	18

Proprietà dell’algoritmo link state

- Strong stability
  - Short convergence time
    - In the order of ***C* log(*N*)**, where *C* is the number of links and *N* the number of nodes
    - Routers compute the topology independently of each other (no bottleneck)
    - Quick reaction to topology changes
  - Little inclination to create loops
    - Depends on the coherence property of shortest path trees
    - Temporary loops only during LSP exchange, which is very fast

- Easy troubleshooting, based on the availability of the LSP database at each router

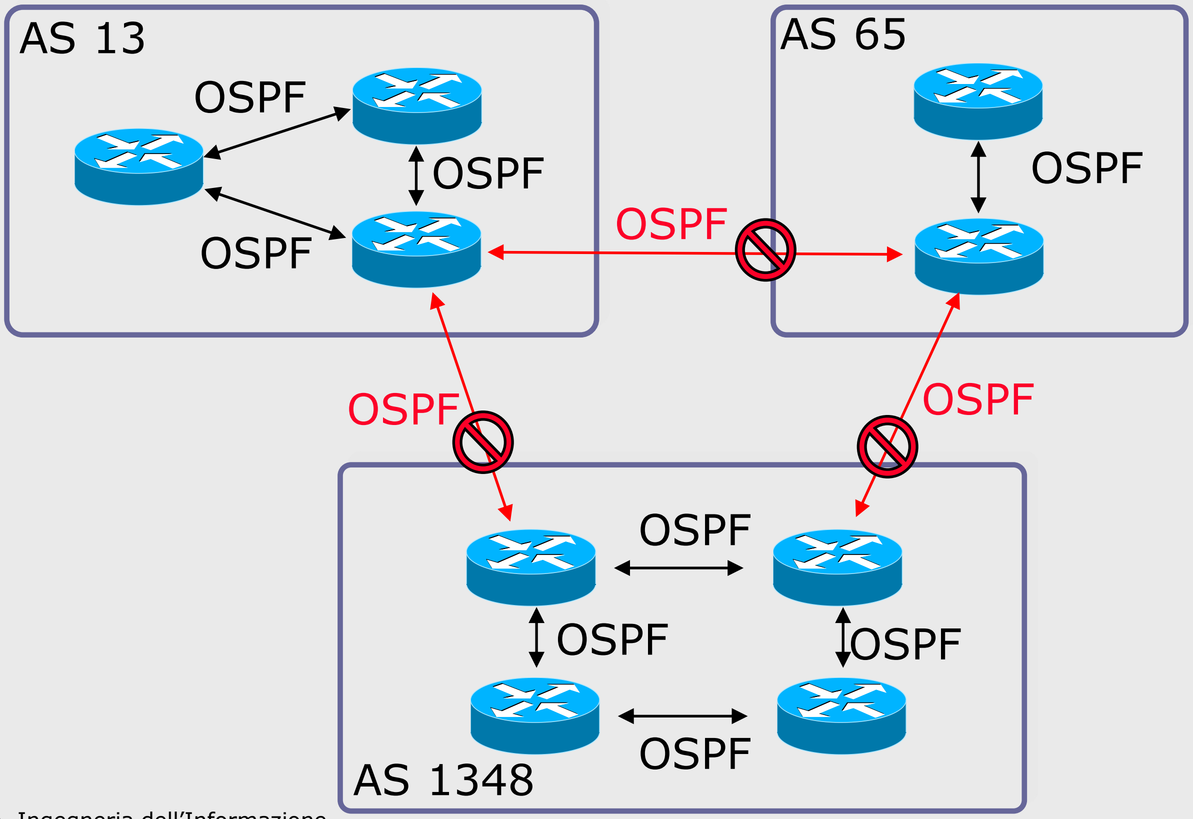
OSPF – Open Shortest Path First

- Routing protocol implementing the *link state algorithm*
- Version
  - **OSPF version 2** [RFC 2328]
  - OSPF version 3 [RFC 5340] – for IPv6

- Speed of convergence
- Support for CIDR and VLSM
- Network reachability
  - Virtually no limitations on network size
- Low protocol overhead
- Generic link cost metric
- Careful planning and configuration is needed

OSPF – general principles

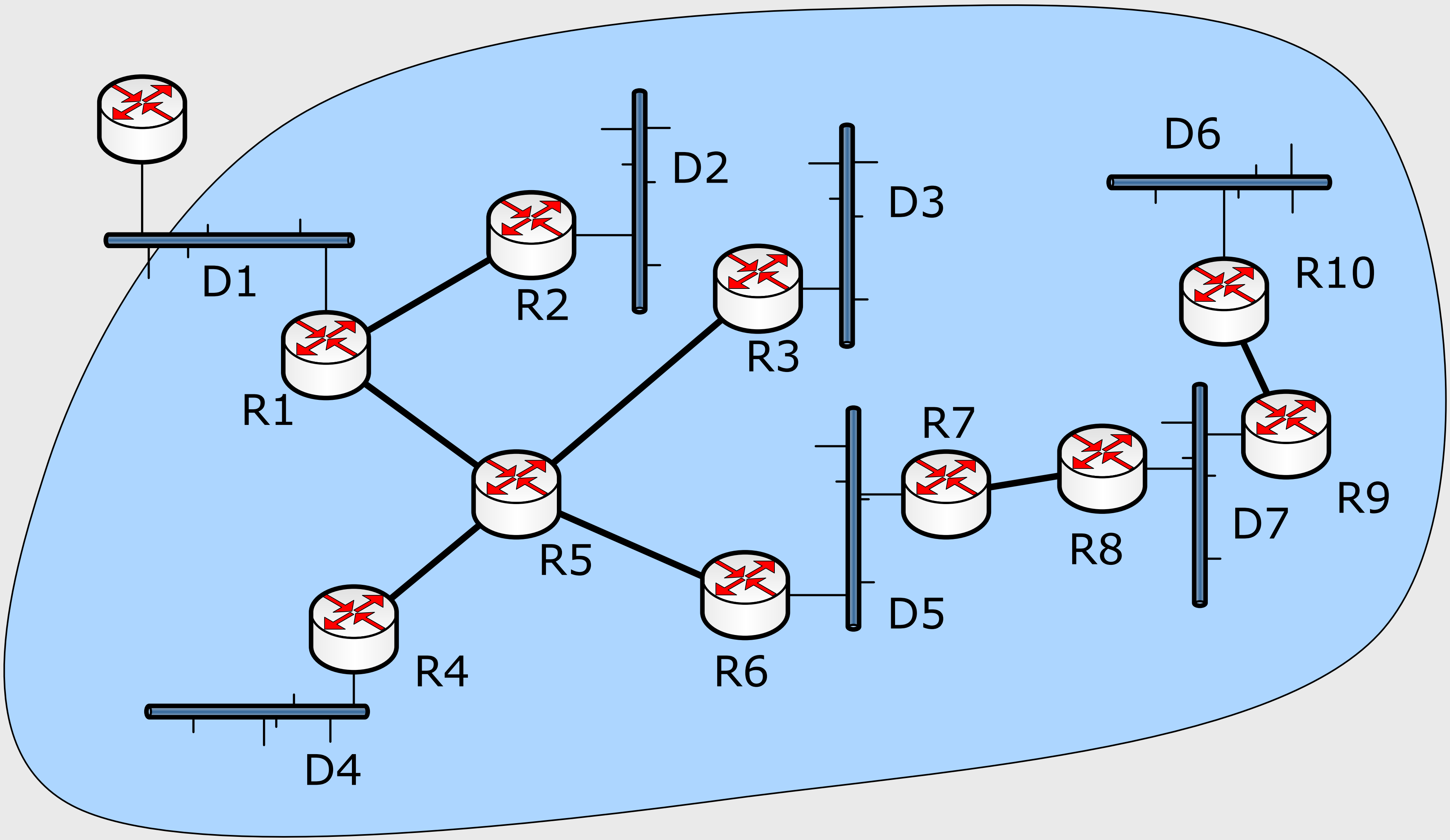
- A single OSPF routing domain is referred to as an *Autonomous System*
  - In the Internet, each AS is uniquely identified by a centrally-assigned number
- Within the AS, each router is uniquely identified by a 32-bit ***router id***



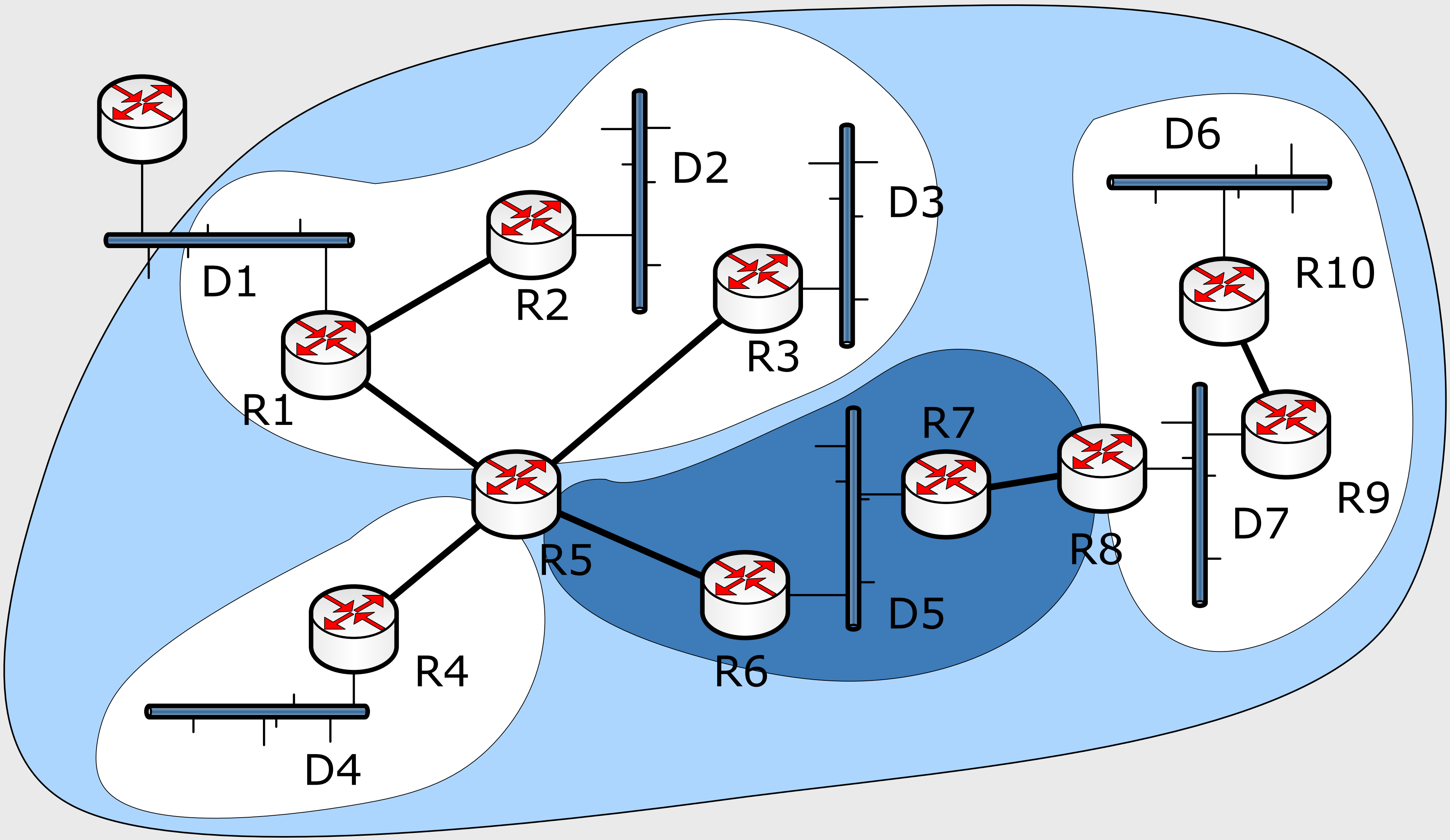
OSPF – general principles

- To support scalability of operation, the AS can be further partitioned into *areas*
  - An area includes a connected subset of links and attached router interfaces
  - A router belongs to an area if it has an interface attached to it
- Each area is identified by a unique 32-bit ***area id***
  - 4-octect dotted notation is used
- OSPF operates in a hierarchical manner
  - Routing is managed **independently** in each area
  - Mechanisms are defined for the exchange of information between areas

OSPF – areas within an AS

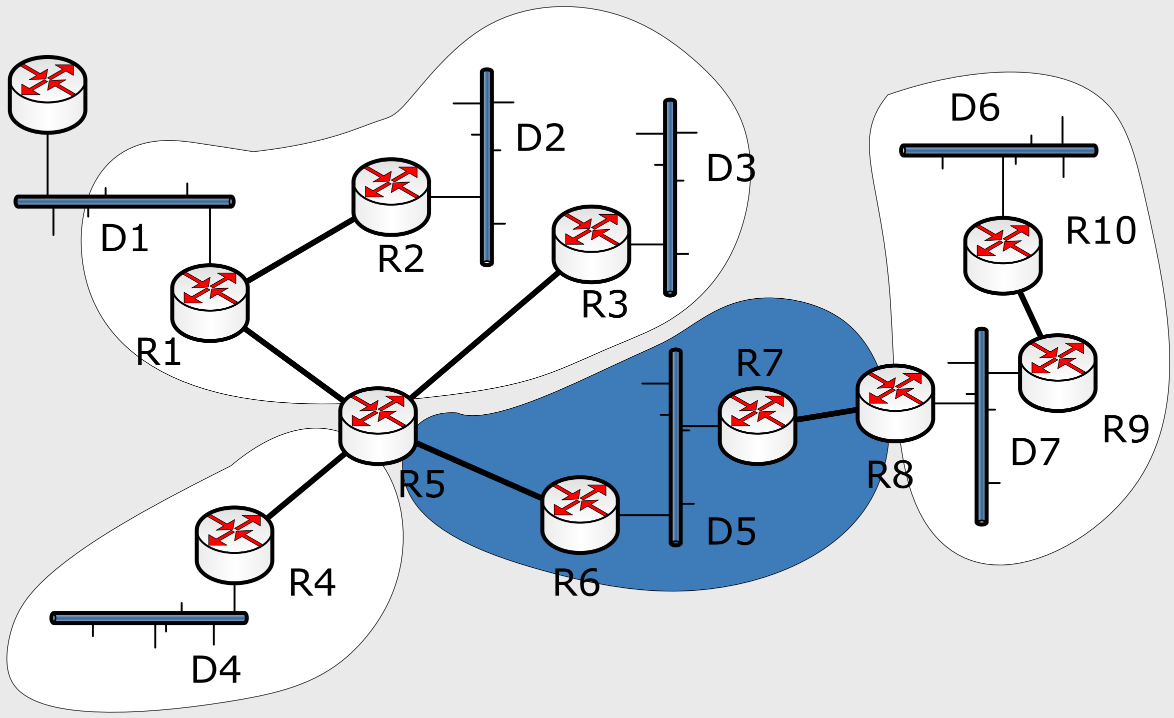


OSPF – areas within an AS

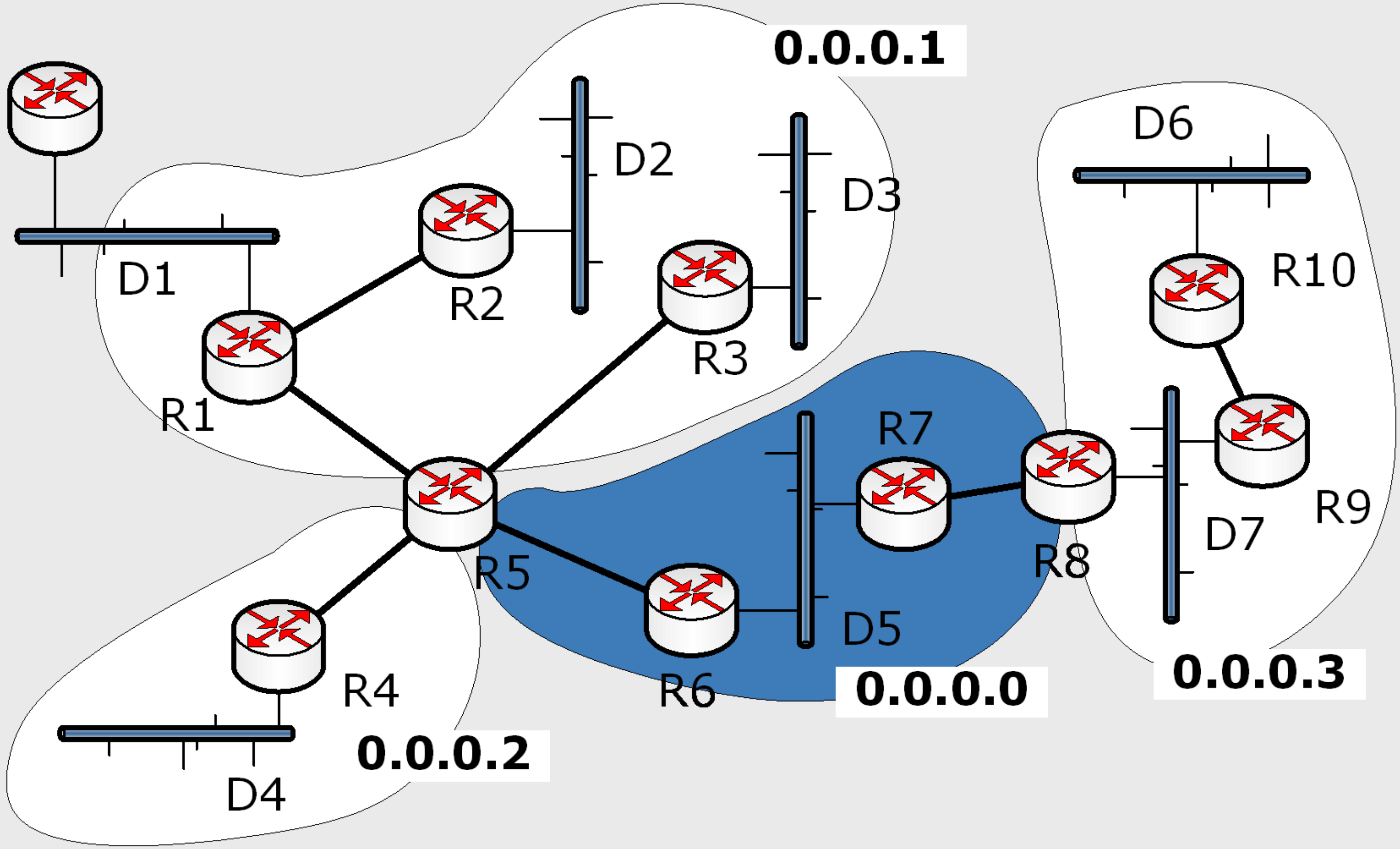


OSPF – router types

- *Internal router* (e.g. R2): all interfaces in the same area
- *Area Border router* (e.g. R5): have interfaces attached to multiple areas
  - All ABRs must have at least one interface attached to a ***backbone area***, with pre-defined id **0.0.0.0**
- *AS boundary router* (e.g. R1): at least one interface attached to another AS

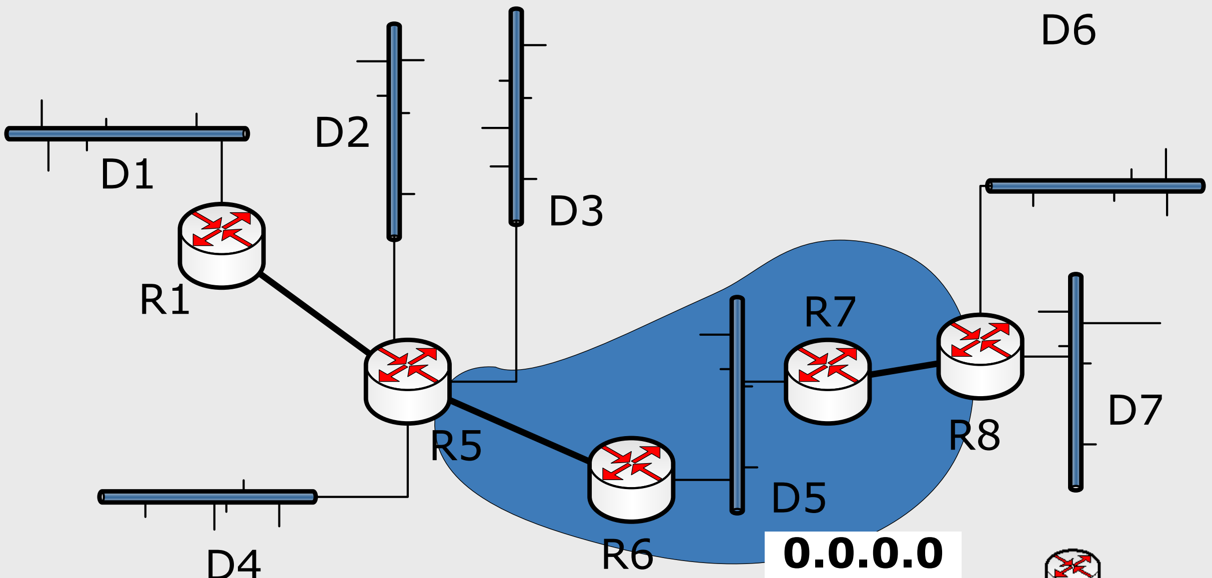


OSPF – multiple area operation

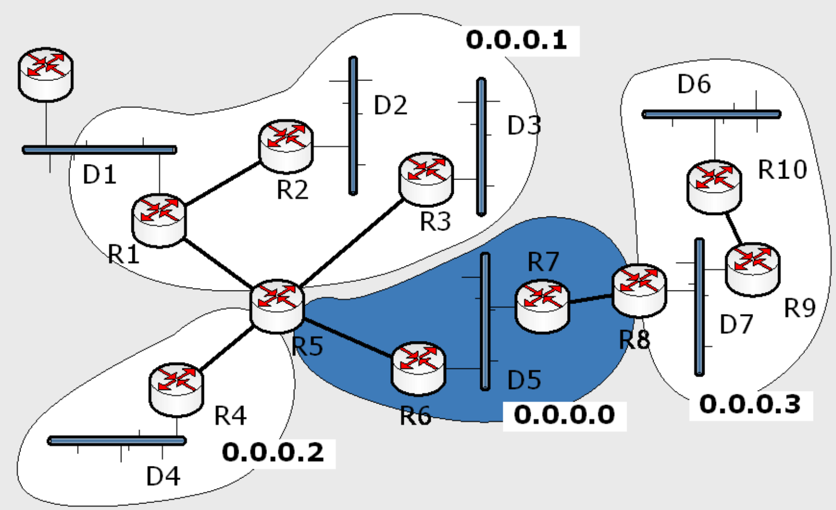


OSPF – multiple area operation

- Each area border router summarizes within one area the topology of all other areas it is attached to

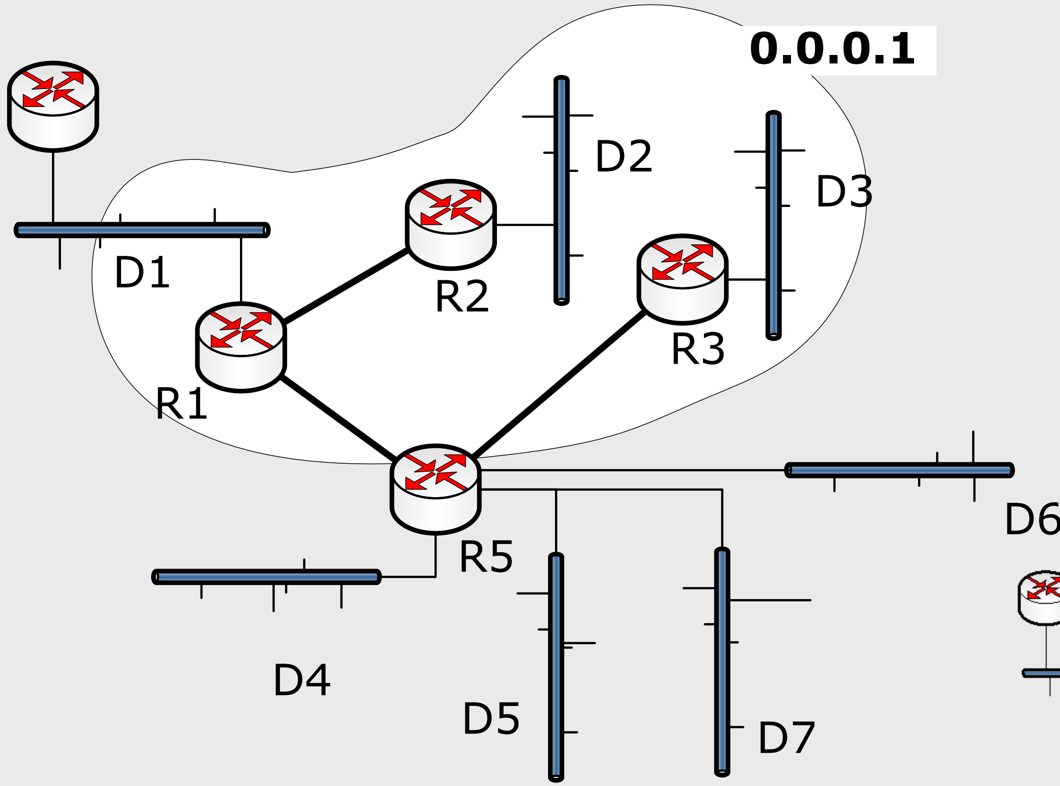


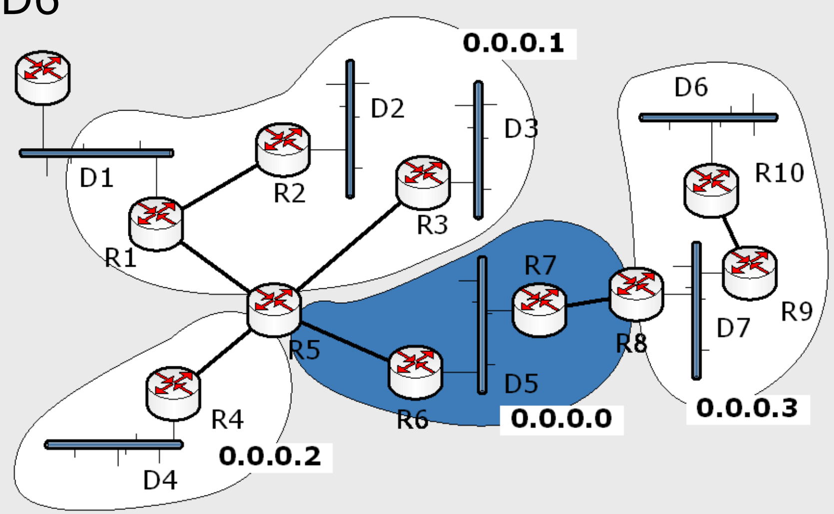
OSPF distributes inter-area topology information essentially by means of a distance-vector technique



OSPF – multiple area operation

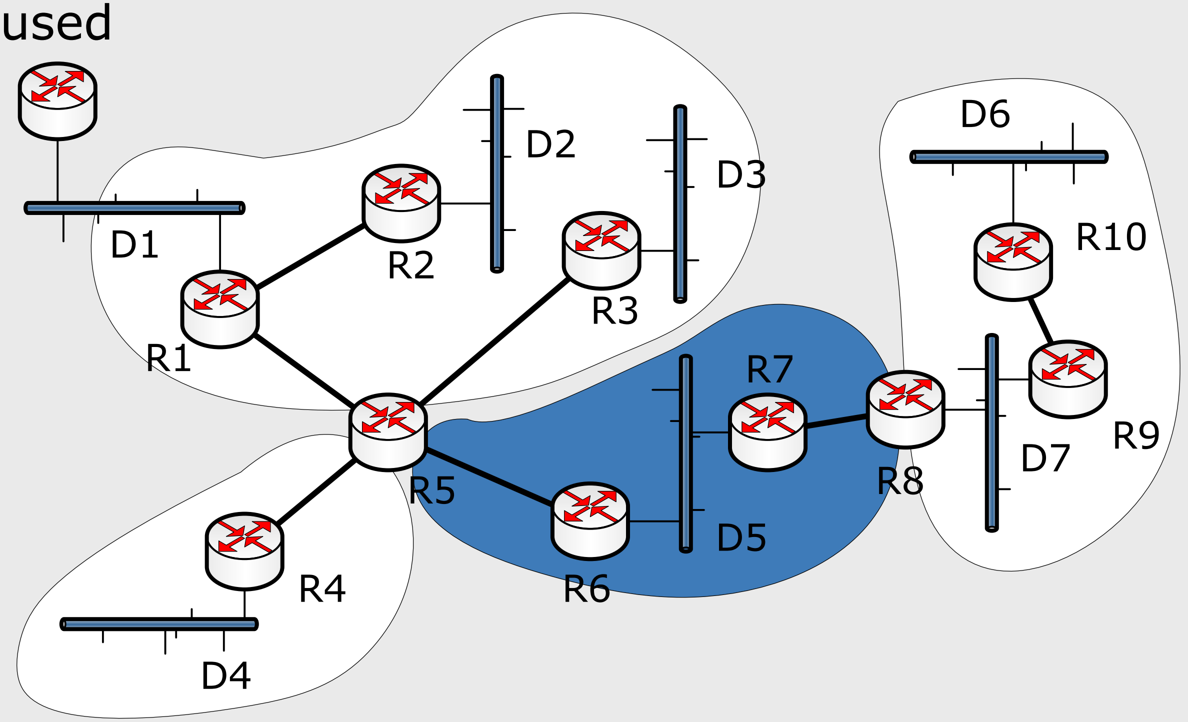
- ABRs are allowed to announce inter-area routes <u>but only those learned from the Backbone Area</u>





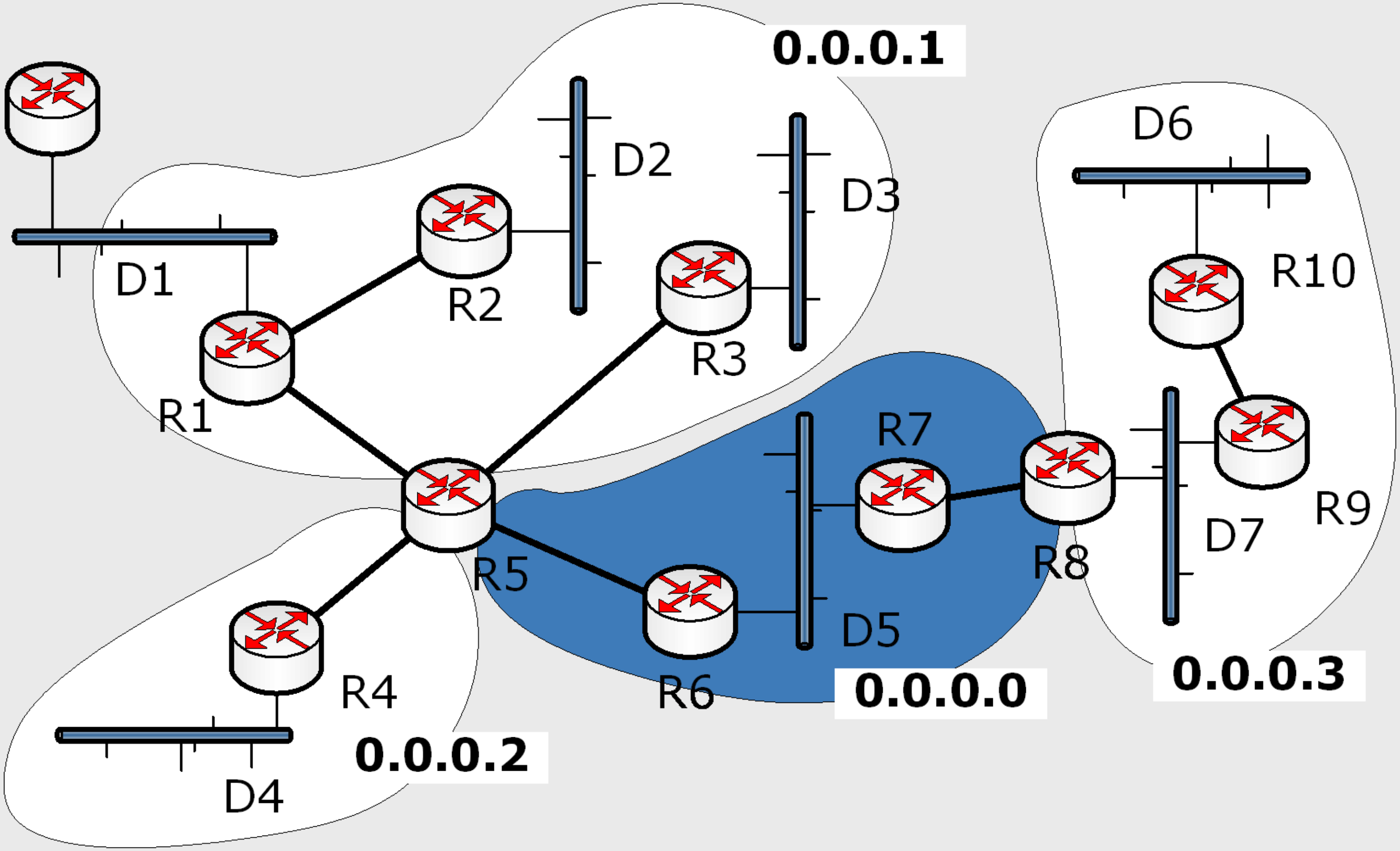
OSPF – multiple area forwarding

- The routing of information within an AS takes place in one of three ways
  - if the source and destination addresses of a packet reside within the same area, *intra-area routing* is used
  - if the source and destination addresses of a packet reside within different areas but are still within the AS, *inter-area routing* is used
  - if the destination address of a packet resides outside the AS, *external routing* is used



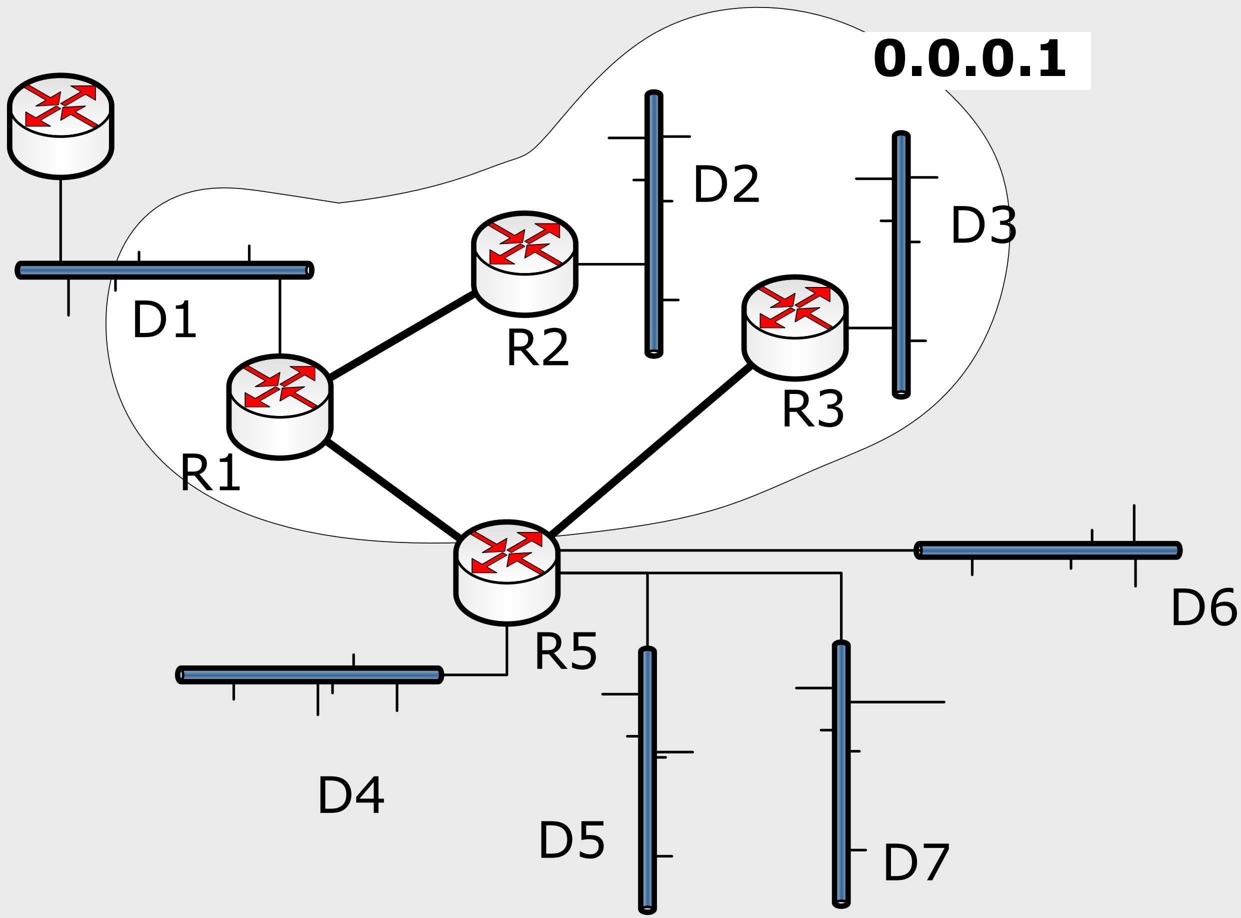
OSPF – multiple area forwarding

- D1 → D6



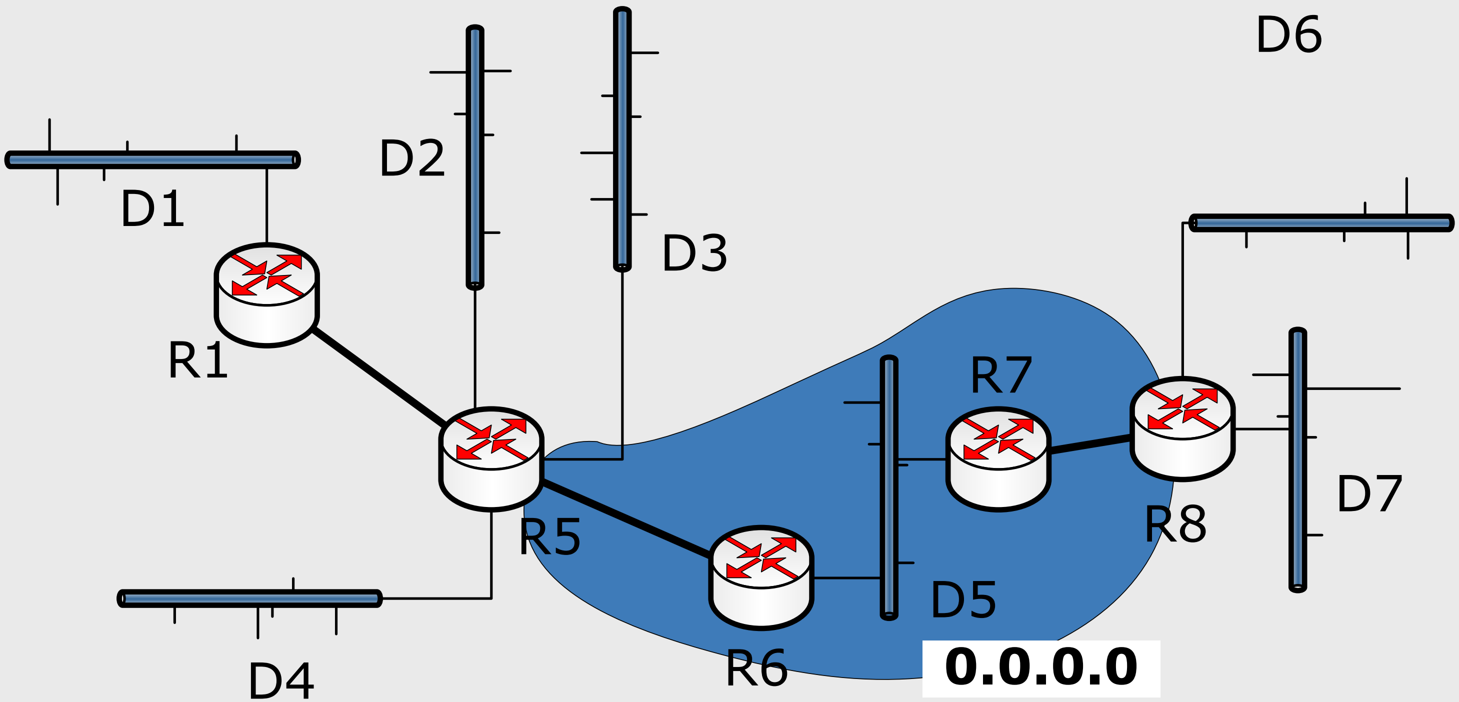
OSPF – multiple area forwarding

- D1 → D6



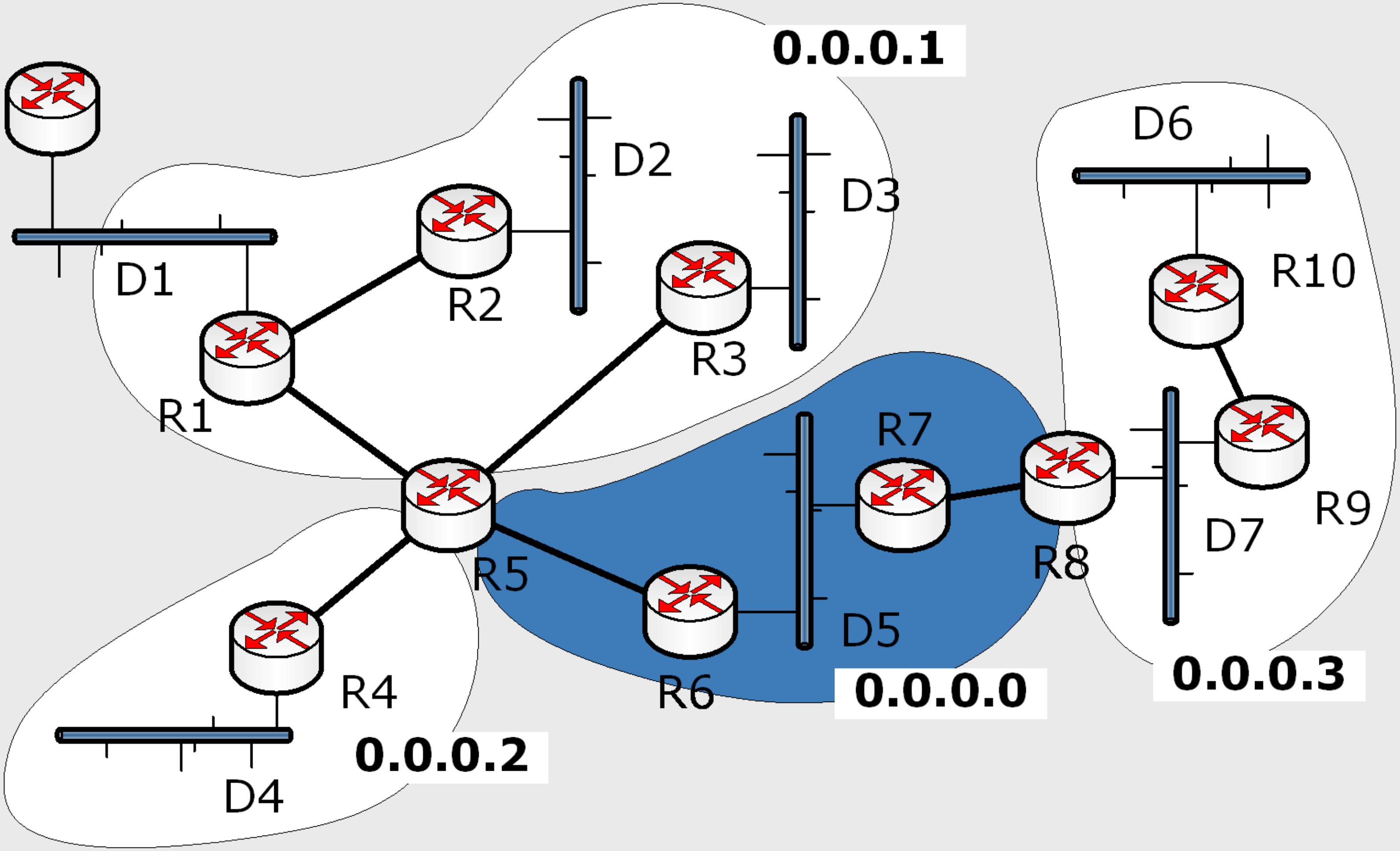
OSPF – multiple area forwarding

- D1 → D6



OSPF – multiple area forwarding

- D1 → D6



OSPF – hierarchical topology advantages

- *Reduced frequency of path calculations*
  Because detailed route information is kept within each area, it is not necessary to flood all link-state changes to every area
  - Thus not all AS routers need to run the path calculation when a topological change happens

- *Smaller routing tables*
  When using multiple areas, detailed route entries are kept within the area
  - Instead of advertising these explicit routes outside the area, these routes can be summarized into one or more summary addresses
  - Advertising these summaries reduces the number of LSAs propagated between areas, while keeping all networks reachable

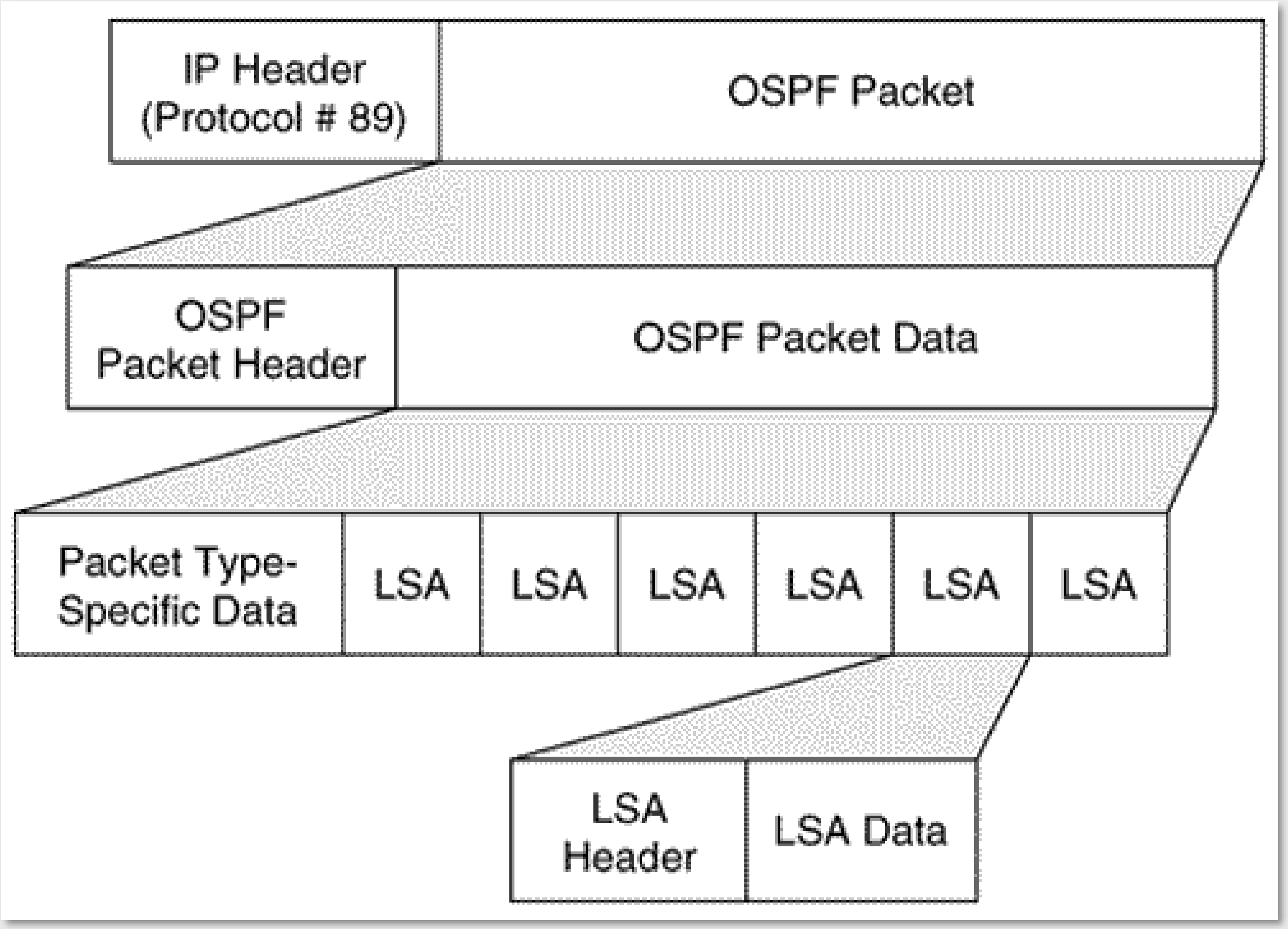
OSPF – design notes

- When designing your OSPF network, the following factors should be taken into consideration:

  1. Never use more than six router hops from source to destination
  2. Use 30 to 100 routers per area
  3. Do not allow more than two areas per Area Border Router (ABR) in addition to the ABR's connection to the Backbone area, otherwise, the ABR must keep track of too many link-state databases

OSPF Link State Packets

- Five packet **types** with a common header



OSPF common header

- Version
  - 2
- Router ID
  - ID of the packet's source
- Area ID
  - Area the packet belongs to
- Authentication

- Type
  - 1 – Hello
  - 2 – Database Description
  - 3 – Link State Request
  - 4 – Link State Update
  - 5 – Link State Acknowledgement

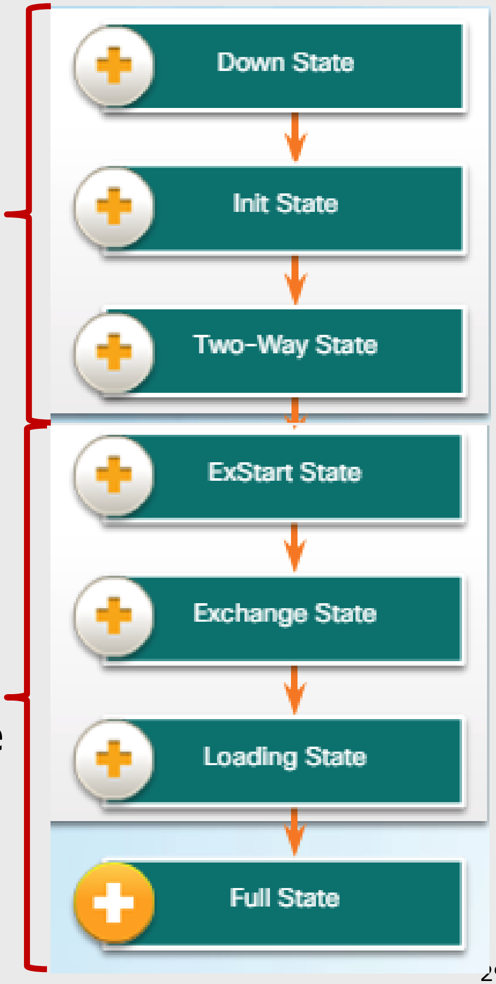
Version	Type	Length	
Router ID			
Area ID			
Checksum		AuthType	
AuthData			
AuthData			

OSPF Link State Packets

- **Hello** Packet (type 1)
  - provides a means for dynamic neighbor discovery
  - supports the election of Designated and Backup Designated Routers on a LAN segment
- **Database Description** Packet (type 2)
  - All routers within the same area share the same link state database
  - This packet is used to allow quick synchronization between adjacent routers without waiting for LSA flooding
- **Link State Request** Packet (type 3)
  - is sent to ask for a specific set of LSAs to an adjacent router
- **Link State Update** Packet (type 4)
  - is sent either in response to a request or to implement LSA flooding
- **Link State Acknowledgement** Packet (type 5)
  - used to make the flooding of LSAs reliable
  - each LSA received by a router from a neighbor must be explicitly acknowledged

OSPF – protocol operation

- At startup an OSPF router forms ***adjacencies*** with its neighbor routers
- Adjacencies are established in four general phases
  - **Neighbor discovery**
    - Established and maintained through the exchange of *hello packets*
    - *Hellos* are multicast to the *AllSPFRouters* address (224.0.0.5)
  - **Bidirectional communication**
    - This communication is accomplished when two neighbors list each other's Router IDs in their Hello packets
  - **Database synchronization**
    - Packets are exchanged to ensure that both neighbors have identical information in their link-state databases
    - For the purposes of this process, one neighbor will become the master and the other will become the slave
  - **Full adjacency**



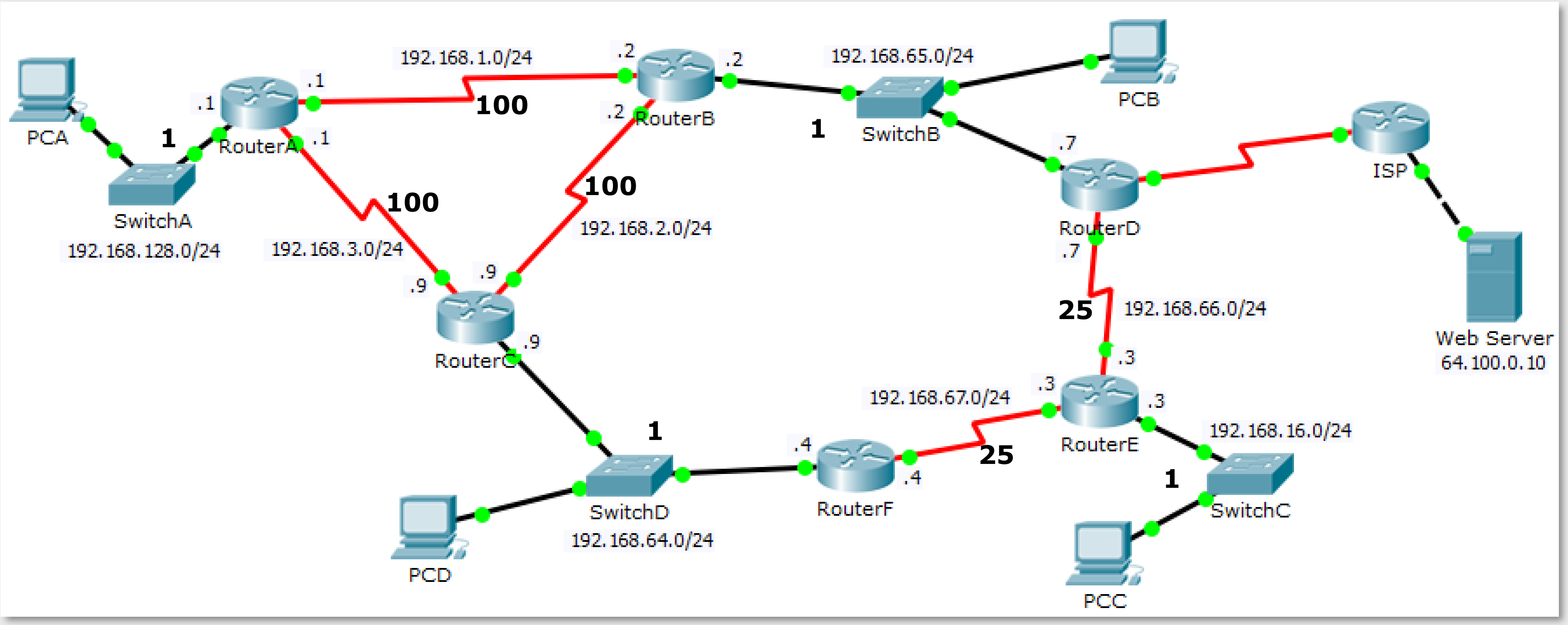
OSPF – protocol operation

- A cost is associated to each interface (referred to as *interface output cost*)
  - Costs are assigned administratively, or
  - Computed by a default (non standard) algorithm

- Topological information is exchanged by means of **LSAs** (***Link State Advertisements***)
  - *A router has a separate link-state database for each area it is connected to*

Example network (1)

- Single area – One AS boundary router (RouterD)
- Router IDs: *n.n.n.n*



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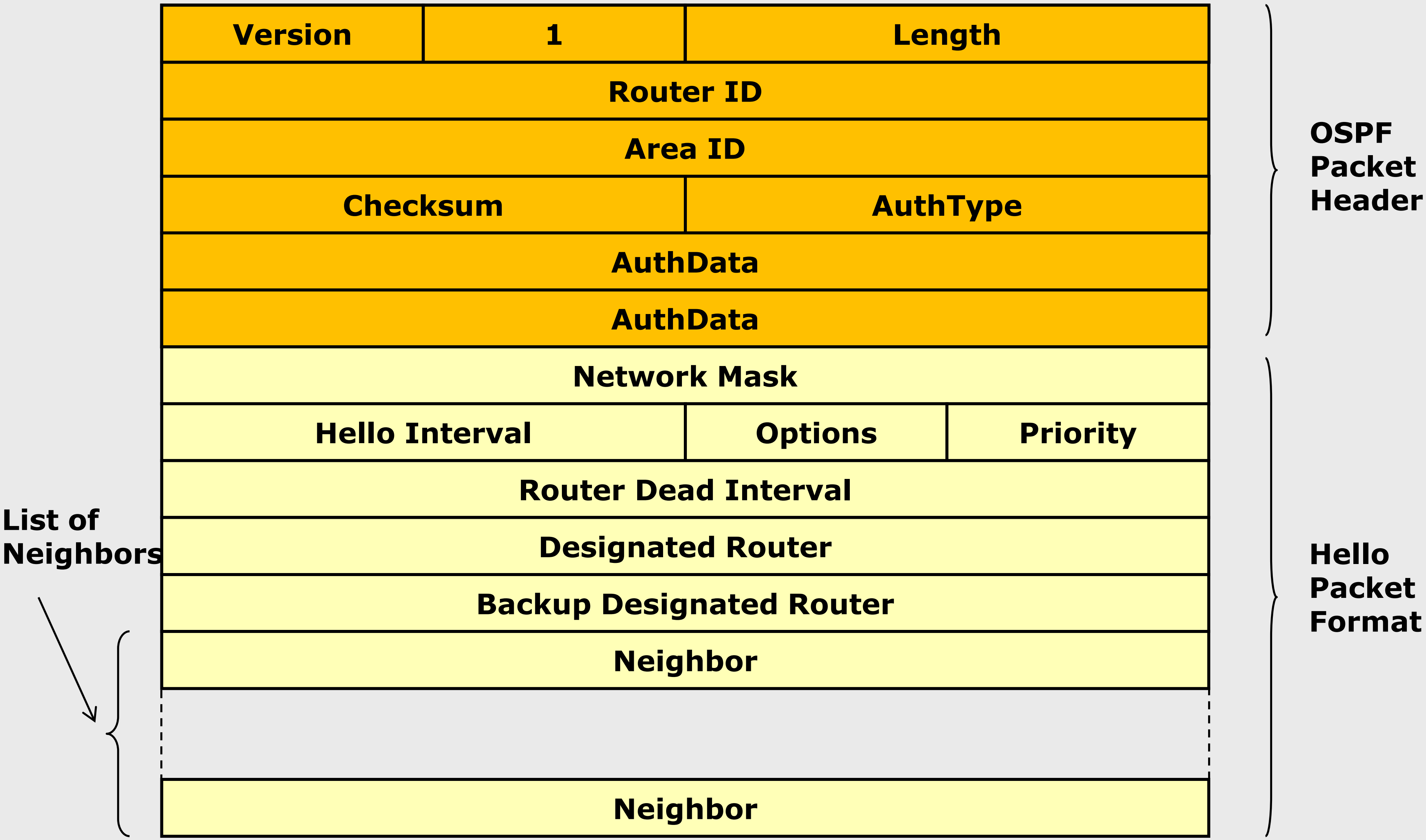
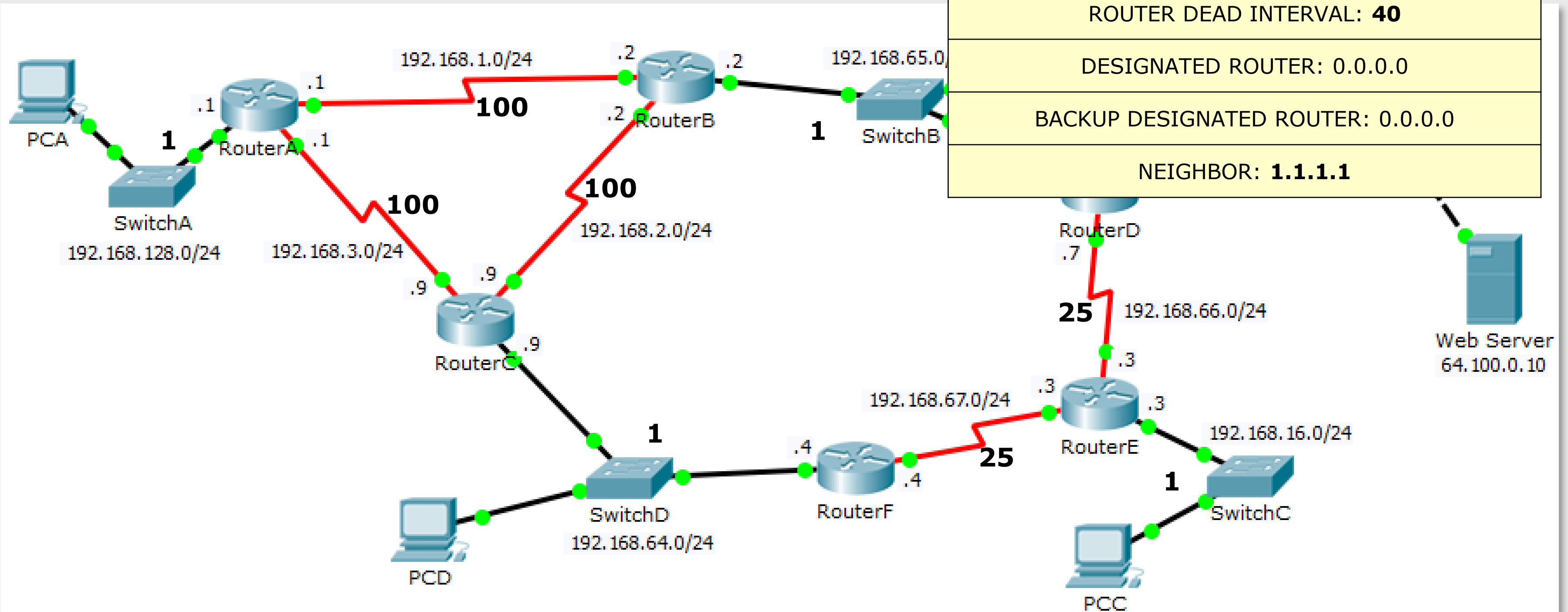
Hello Packet



Hello Packet

- RouterC on Serial Se0/0/0

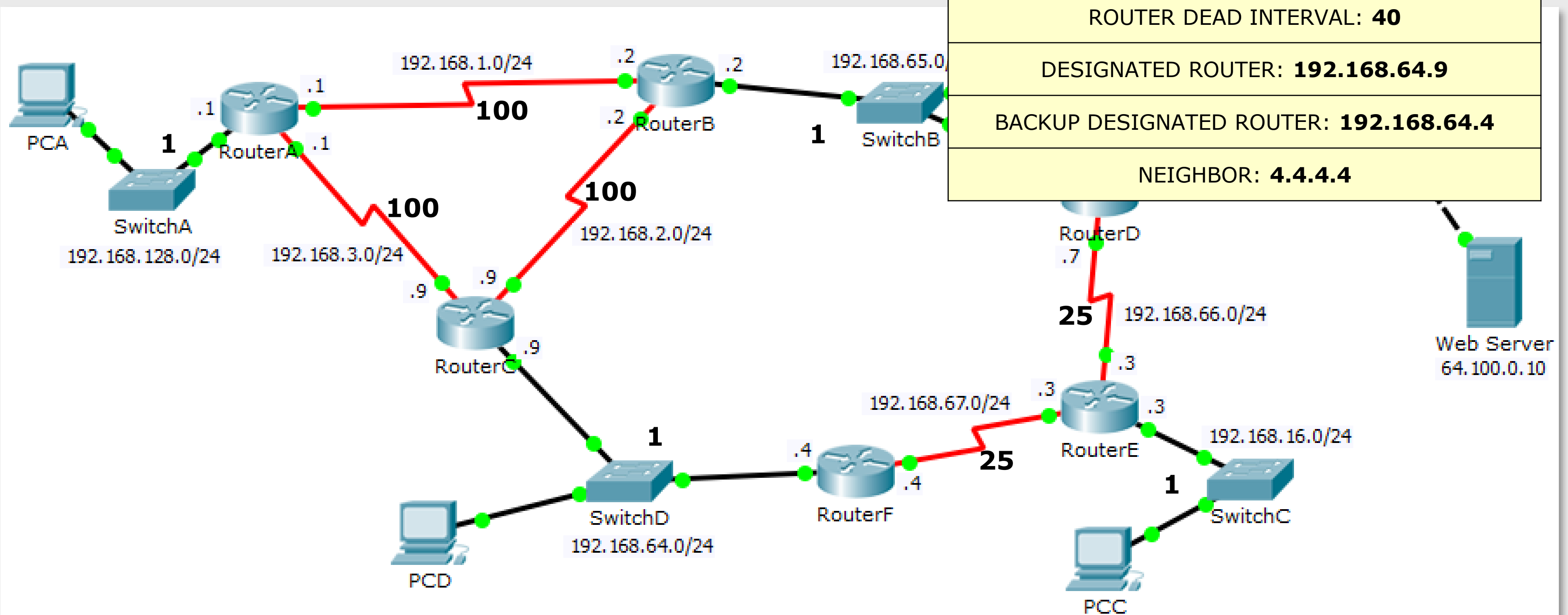
VERSION: 2	TYPE: **1**	PKT LENGTH: **48**
ROUTER ID: **9.9.9.9**		
AREA ID: **0.0.0.0**		
CHECKSUM		AUTH TYPE
AUTHENTICATION DATA		
NETWORK MASK: **255.255.255.0**		
HELLO INTERVAL: **10**	OPTIONS: 0	RP: 0
ROUTER DEAD INTERVAL: **40**		
DESIGNATED ROUTER: 0.0.0.0		
BACKUP DESIGNATED ROUTER: 0.0.0.0		
NEIGHBOR: **1.1.1.1**		



Hello Packet

- RouterC on Fa0/0

VERSION: 2	TYPE: **1**	PKT LENGTH: **48**
ROUTER ID: **9.9.9.9**		
AREA ID: **0.0.0.0**		
CHECKSUM	AUTH TYPE	
AUTHENTICATION DATA		
NETWORK MASK: **255.255.255.0**		
HELLO INTERVAL: **10**	OPTIONS: 0	RP: **1**
ROUTER DEAD INTERVAL: **40**		
DESIGNATED ROUTER: **192.168.64.9**		
BACKUP DESIGNATED ROUTER: **192.168.64.4**		
NEIGHBOR: **4.4.4.4**		

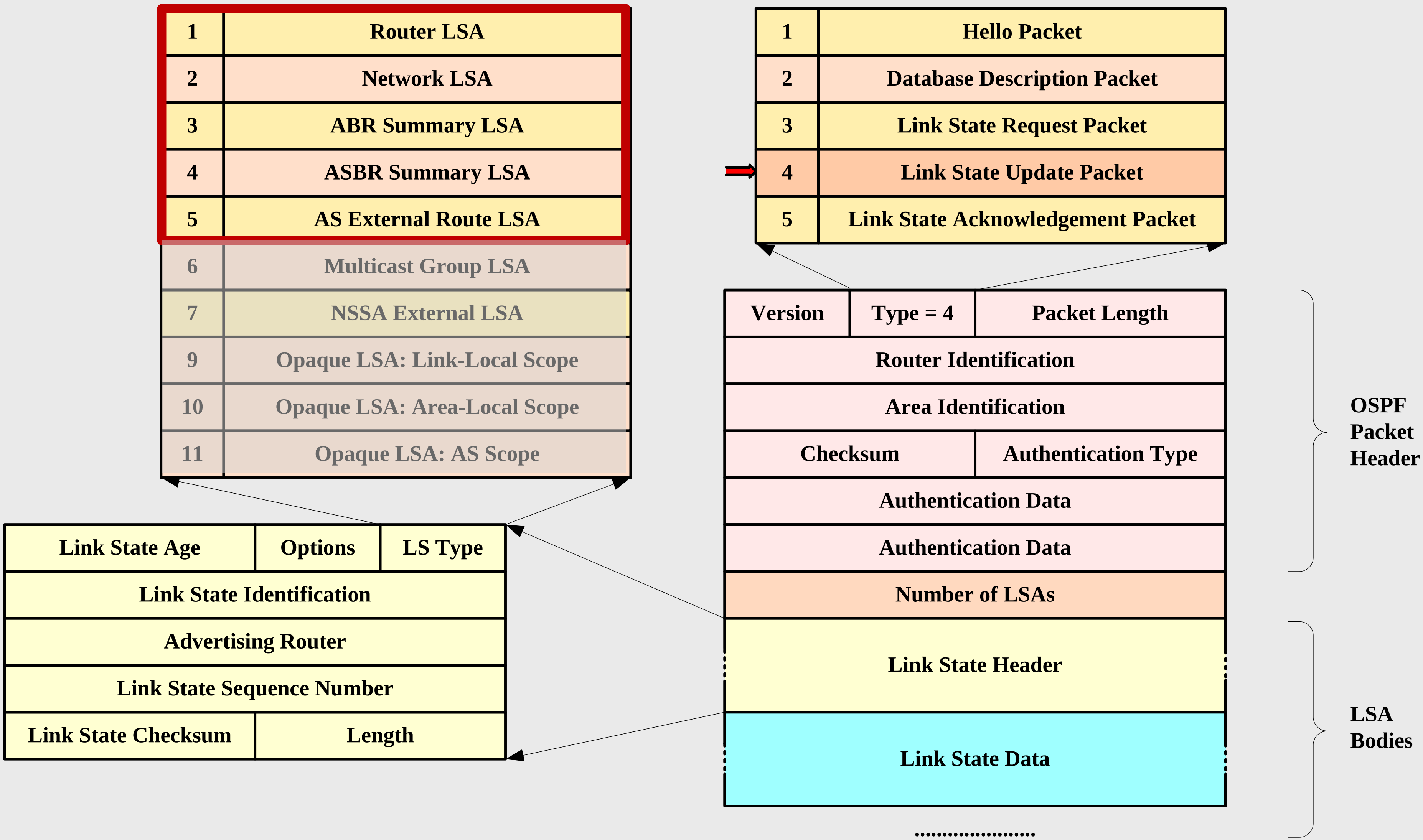


Link State Update Packet

- It includes one or more **Link State Advertisements**
- The LSA might have been generated by a router other than the one sending the packet (LSA flooding)

Version	**4**	**Length**
Router ID		
Area ID		
Checksum		**AuthType**
AuthData		
AuthData		
Number of LSAs		
LSA Bodies		

Link State Advertisements



Link State Header

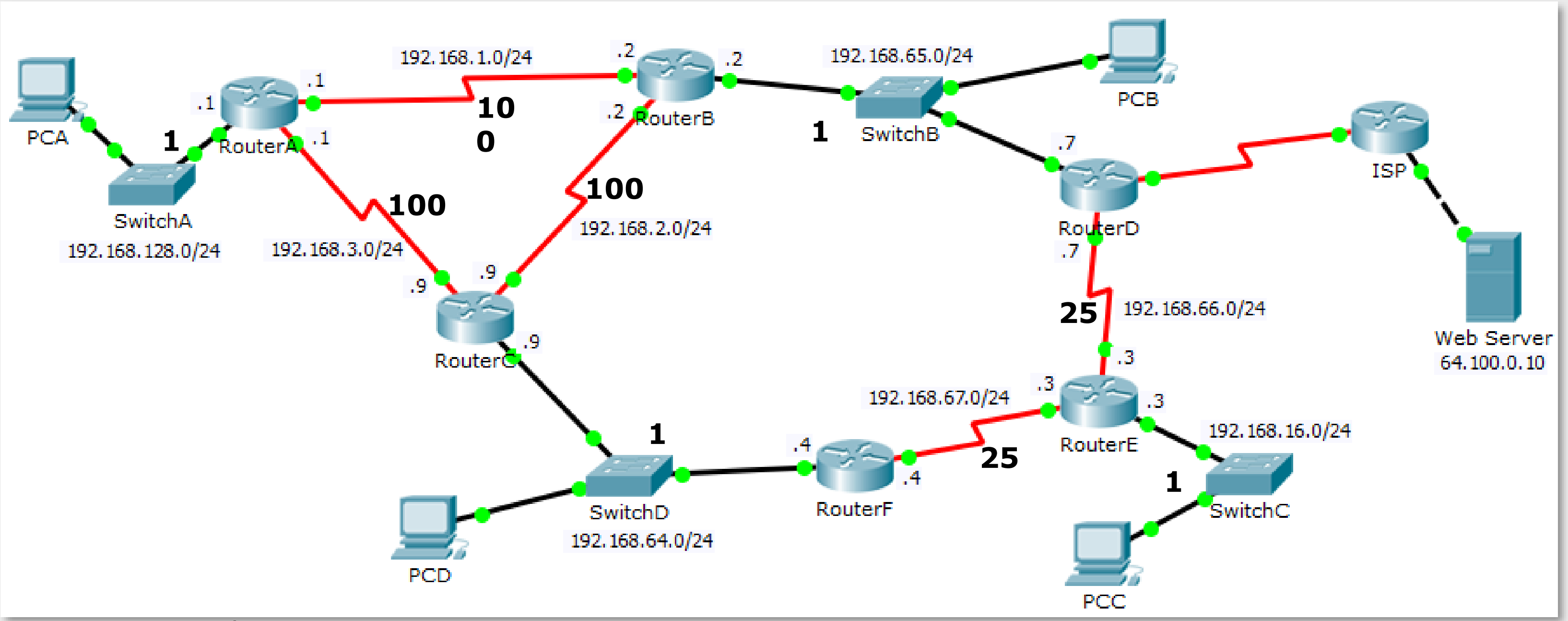
Link State Age	Options	LS Type
Link State Identification		
Advertising Router		
Link State Sequence Number		
Link State Checksum	Length	

- Aging mechanism to enforce quick topology updates
- LS IDentification interpretation depends on the LS type
- Advertising Router: the router that generated the LSA
- LS Sequence Number: to enable selective flooding

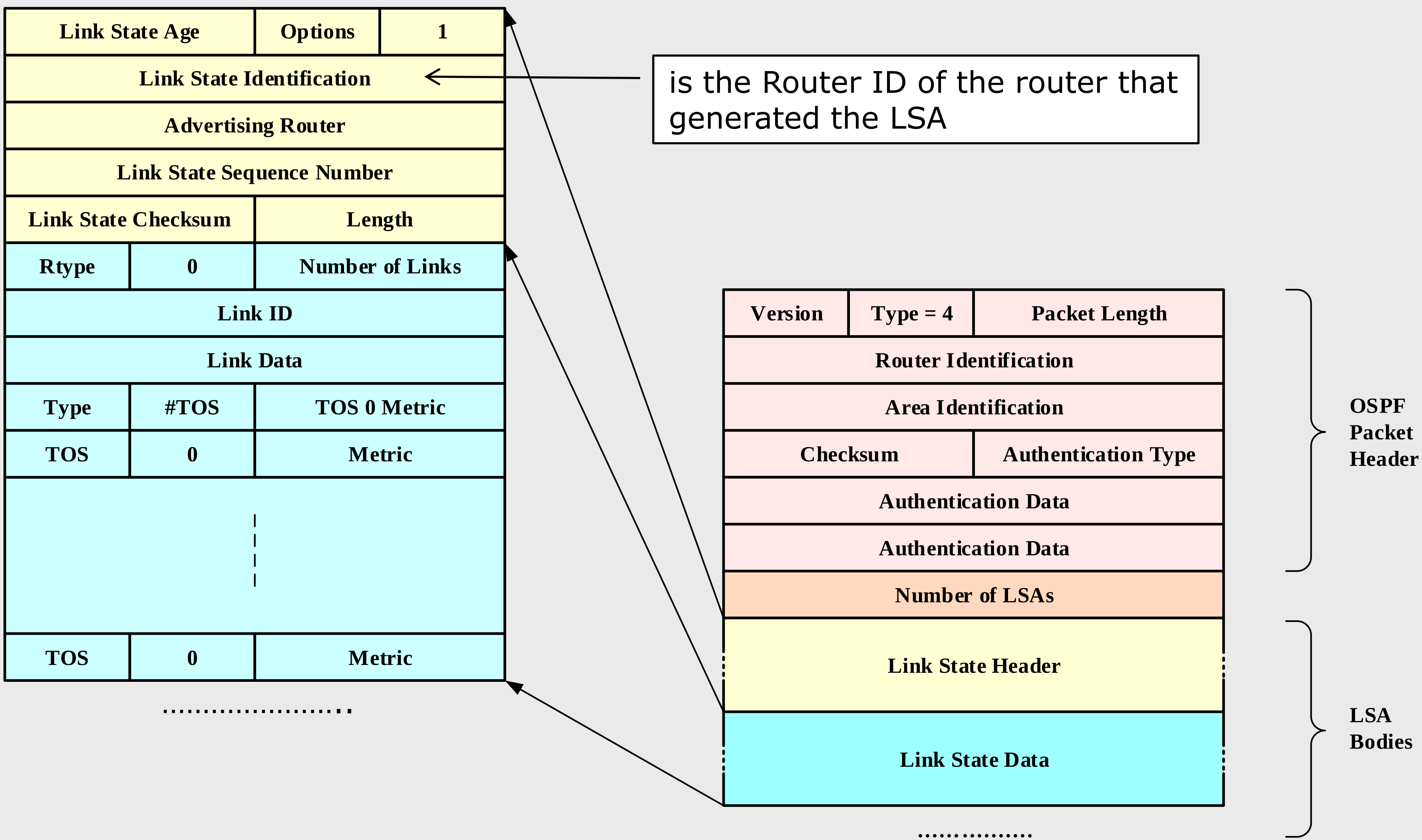
- An LSA is uniquely identified by its LS Type, LS ID and Advertising Router
- The most recent instance is determined by examining the LS age and the LS Sequence Number

Router links LSA (LS type 1)

- It includes adjacency information of a router, and related costs
- Is propagated by selective flooding only within the area where it has been generated
  - Internal routers specifies the full adjacency information
  - ABRs specify the subset of adjacencies within the area
    - One Router LSA per area is thus generated
  - ABRs flood a Router LSA only through the interfaces belonging to the same area from which it has been received



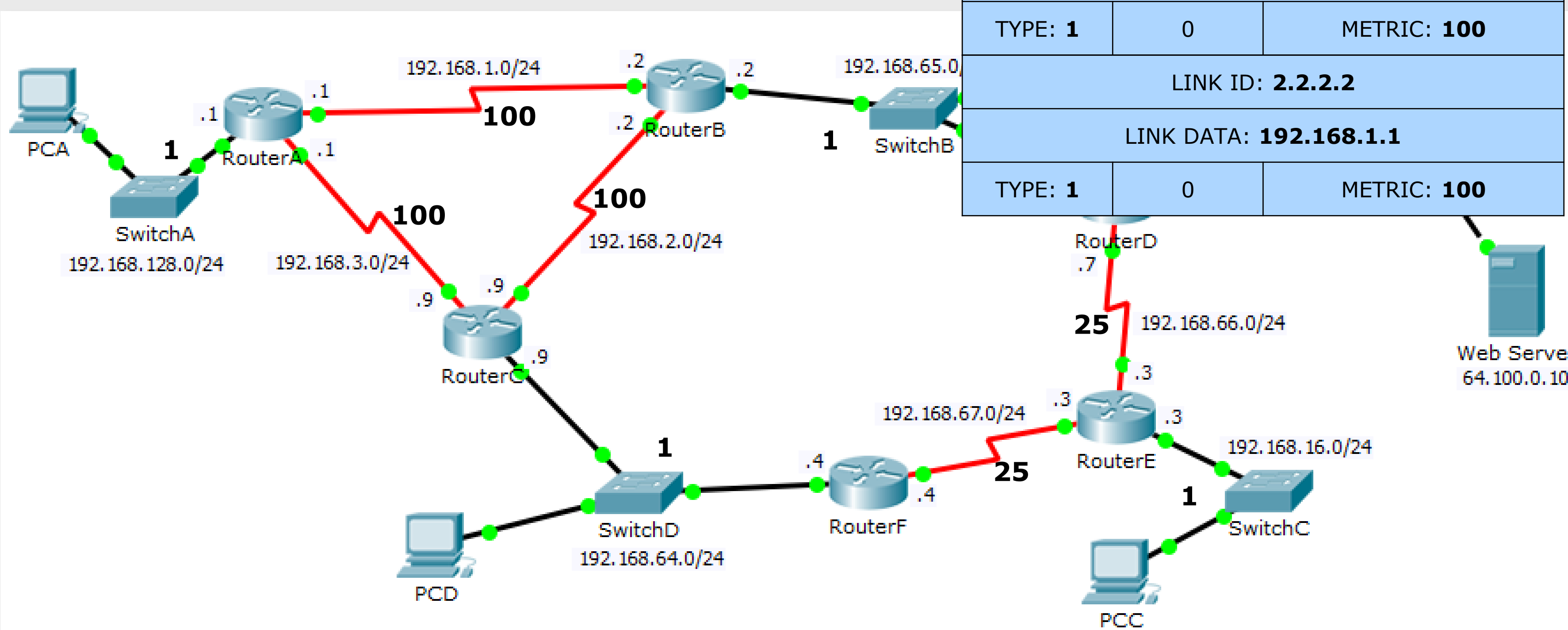
Router links LSA (LS type 1)



Router links LSA (LS type 1)

- **RouterA**
  - Link type 1 – point-to-point connection to another router

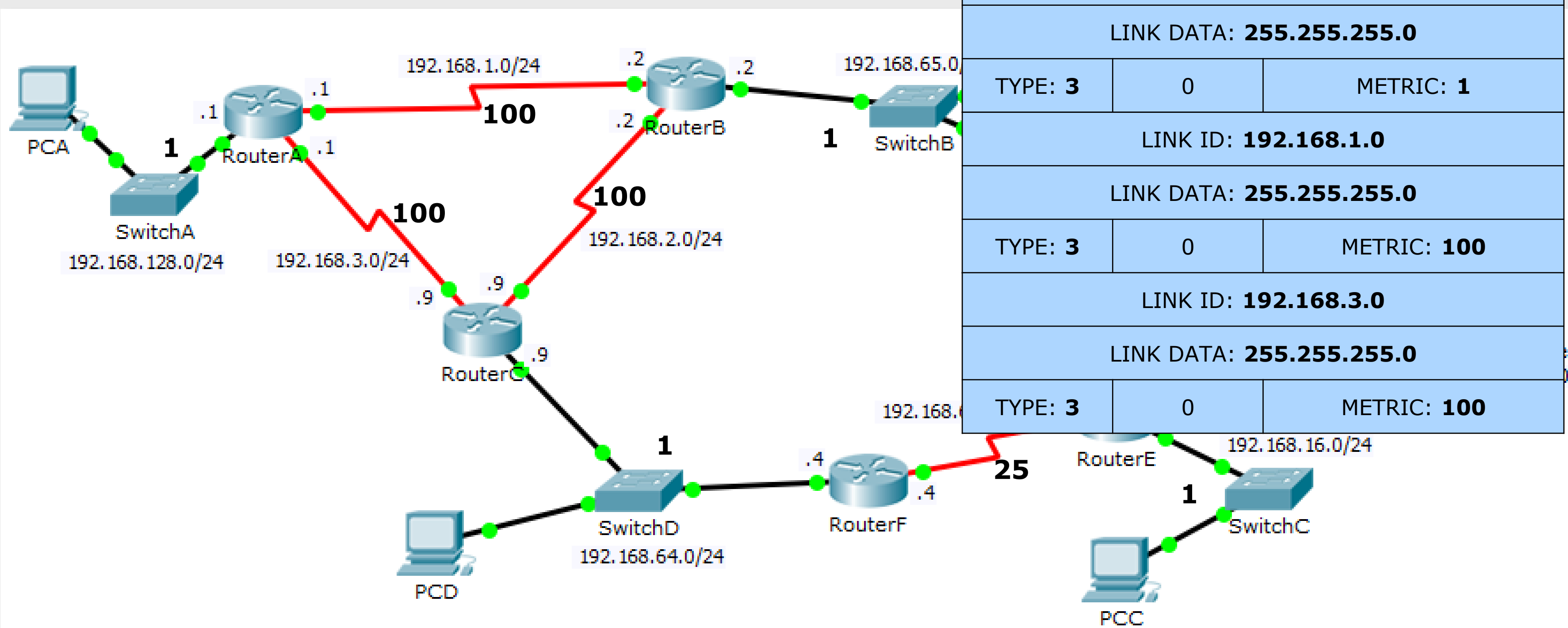
LSA AGE: 0		OPTIONS: 0	LS TYPE: **1**	
LINK STATE ID: **1.1.1.1**				
ADVERTSING ROUTER: **1.1.1.1**				
LS SEQUENCE NUM: 0X80000006				
CHECKSUM: 27683		LENGTH: 84		
V+E+B	0	LINK COUNT: **5**		
LINK ID: **9.9.9.9**				1
LINK DATA: **192.168.3.1**				
TYPE: **1**	0	METRIC: **100**		
LINK ID: **2.2.2.2**				2
LINK DATA: **192.168.1.1**				
TYPE: **1**	0	METRIC: **100**		



Router links LSA (LS type 1)

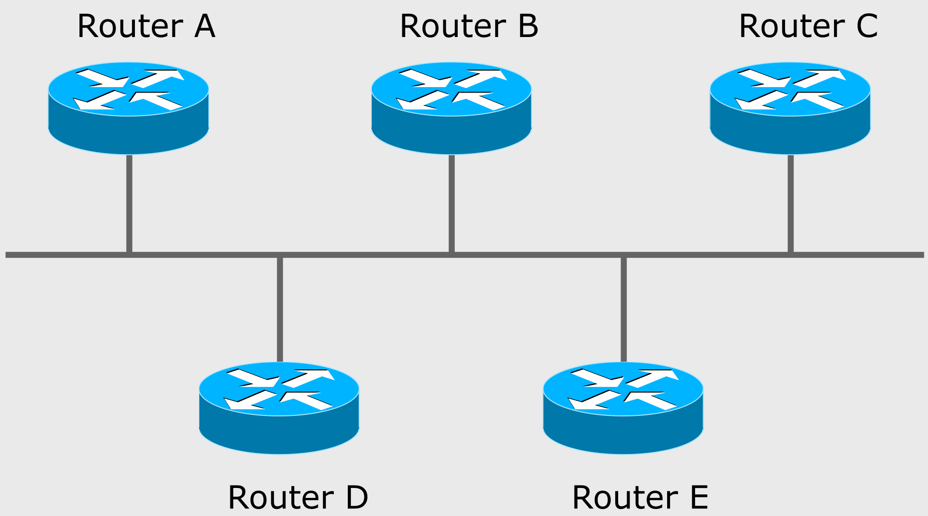
- **RouterA**
  - Link type 3 – stub network

LSA AGE: 0		OPTIONS: 0	LS TYPE: **1**	
LINK STATE ID: **1.1.1.1**				
ADVERTSING ROUTER: **1.1.1.1**				
LS SEQUENCE NUM: 0X80000006				
CHECKSUM: 27683		LENGTH: 84		
V+E+B	0	LINK COUNT: **5**		
LINK ID: **192.168.128.0**				3
LINK DATA: **255.255.255.0**				
TYPE: **3**	0	METRIC: **1**		
LINK ID: **192.168.1.0**				4
LINK DATA: **255.255.255.0**				
TYPE: **3**	0	METRIC: **100**		
LINK ID: **192.168.3.0**				5
LINK DATA: **255.255.255.0**				
TYPE: **3**	0	METRIC: **100**		



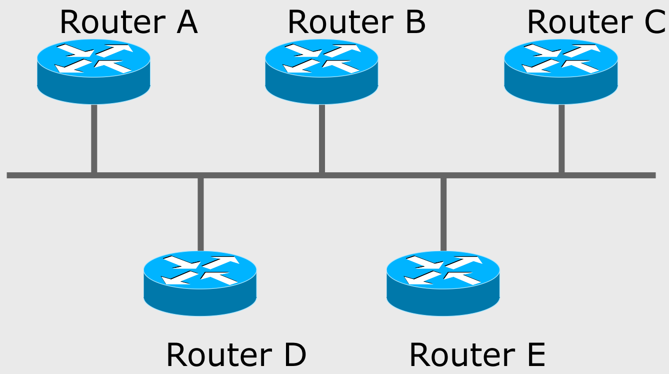
OSPF – broadcast networks

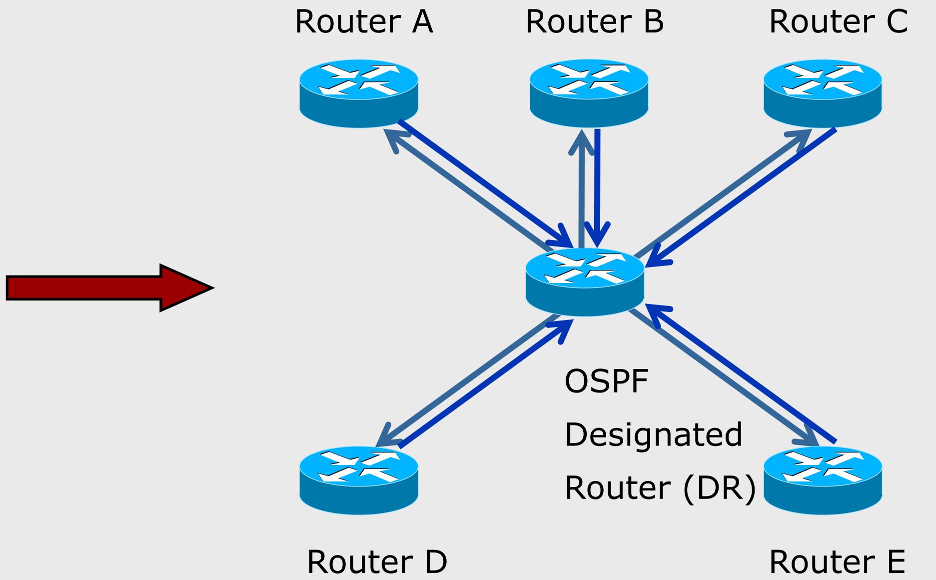
- Broadcast networks (LAN, MAN) deserve special treatment because of their *any-to-any* flexibility
- Multiple routers may be adjacent pairwise on the same link
- Example: five routers on the same LAN
  - Since each router can communicate with the other four, each would consider that it had four neighbors
  - Five routers, each with four neighbors, creates a total of 20 entries in the link state database
  - Moreover, LSAs are flooded and “reflooded” on the same LAN



OSPF – broadcast networks

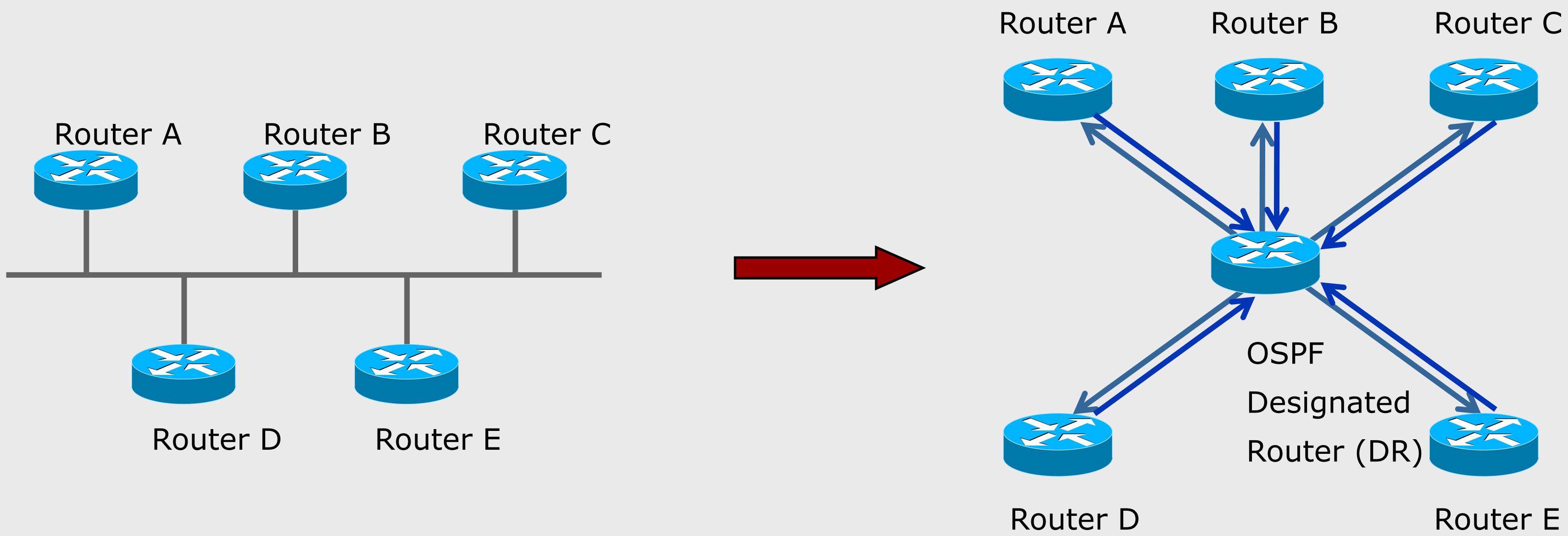
- To help keep the size of link state databases manageable, OSPF treats broadcast networks a special way
- It elects a special router from among those present on the network (based on a configured *router priority*)
- This router, known as the **Designated Router** (DR), treats all routers on the network as adjacent neighbors, whereas the other routers consider the designated router as their only adjacent neighbor





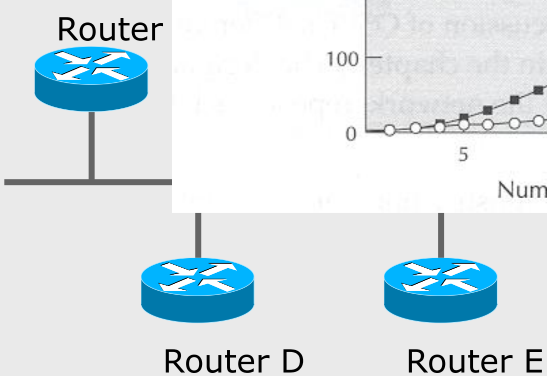
OSPF – broadcast networks

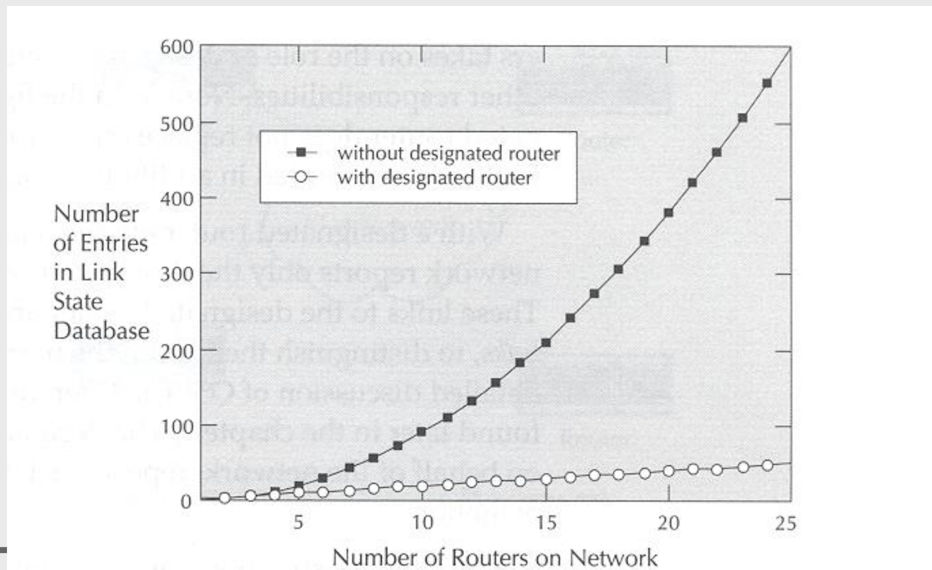
- The designated router <u>does not replace</u> one of the normal routers
  - Rather, it is included in addition to those routers
- Each <u>true</u> router reports only the designated router as a neighbor, with the actual cost of the link
- The designated router reports each true router as a neighbor with cost 0

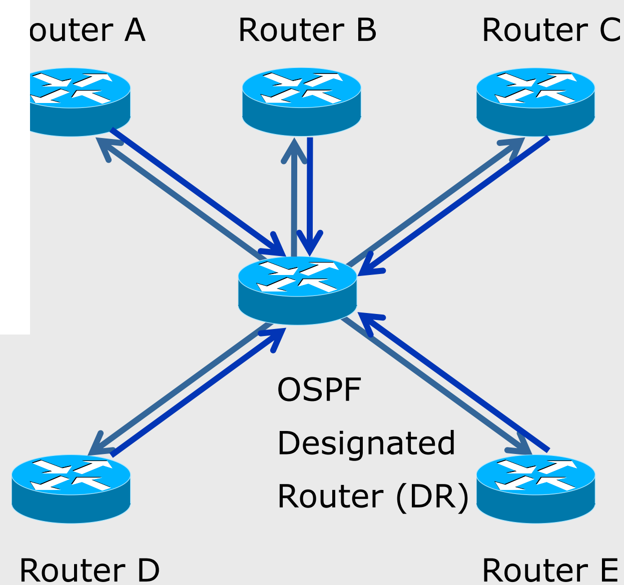


OSPF – broadcast networks

- With this construction, there are only 10 entries in the link state database: each of the five true routers lists one neighbor, and the designated router lists five
- The DR plays a role also in LSA flooding

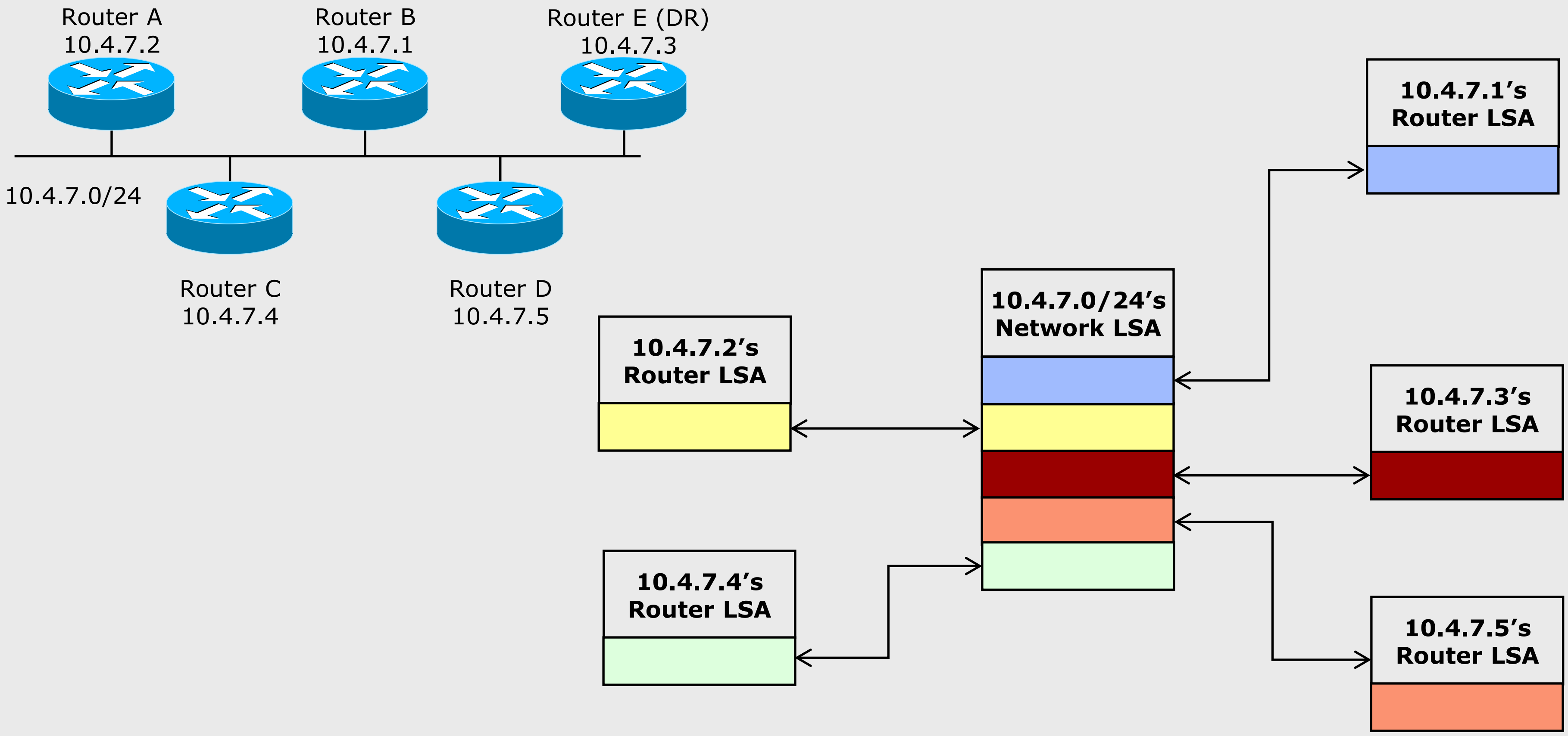






Network links LSA

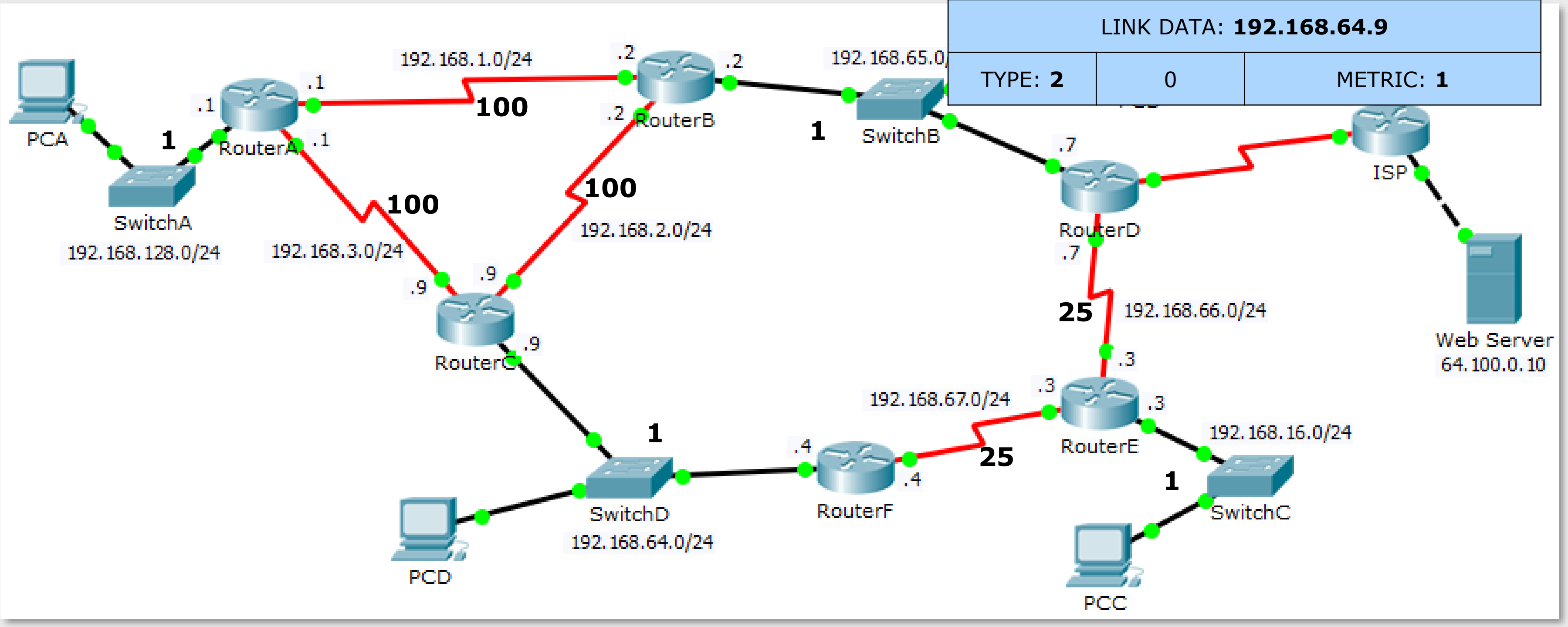
- Generated only by Designated Routers
  - describe the set of routers attached to a particular broadcast network
  - a form of internal summarization



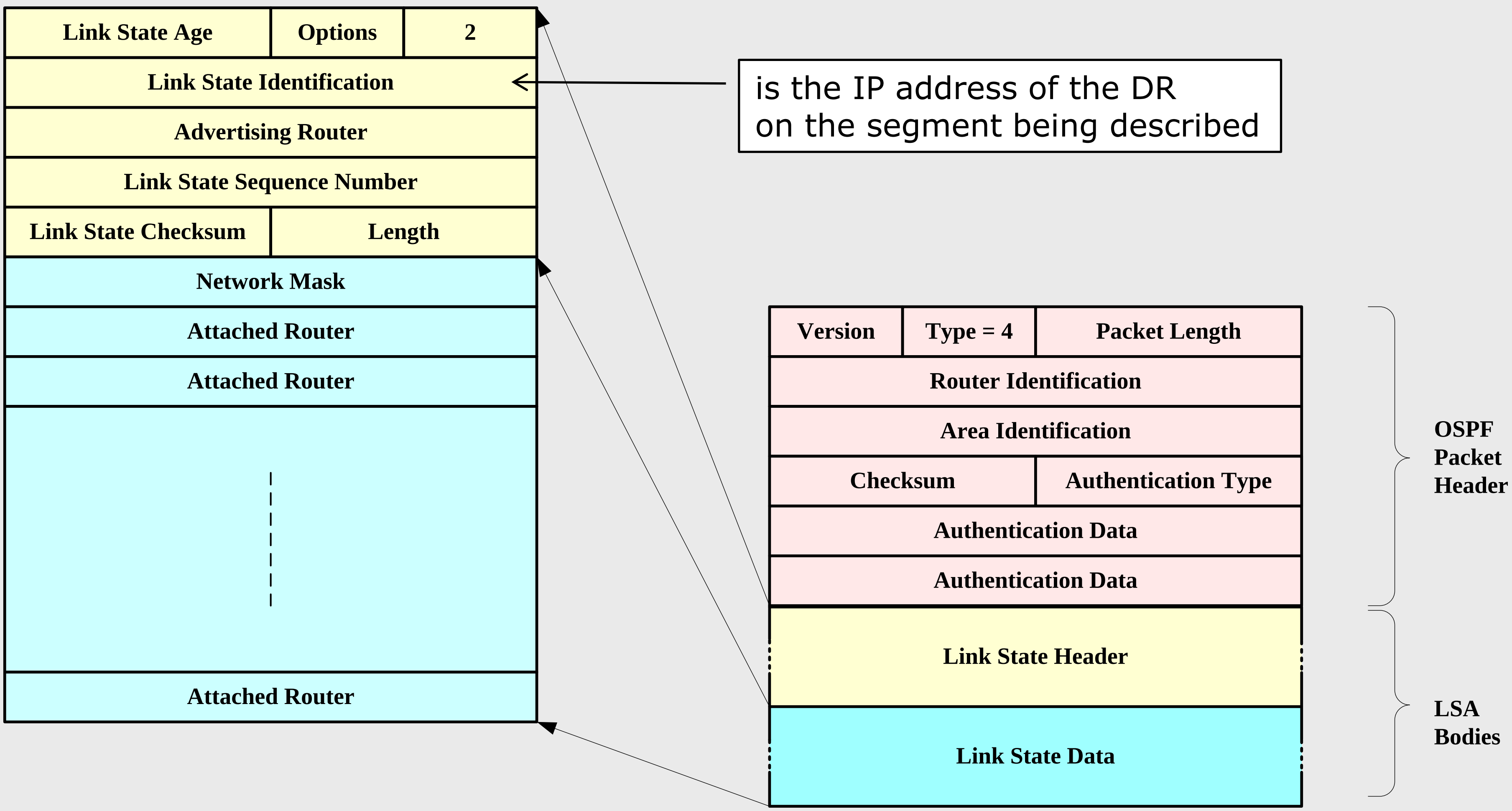
Router links LSA (LS type 1)

- **RouterC**
  - Link type 2 – transit network

LSA AGE: 0		OPTIONS: 0	LS TYPE: **1**
LINK STATE ID: **9.9.9.9**			
ADVERTSING ROUTER: **9.9.9.9**			
LS SEQUENCE NUM: 0X80000007			
CHECKSUM: 15705		LENGTH: 84	
V+E+B	0	LINK COUNT: **5**	
LINK ID: **192.168.64.9**			
LINK DATA: **192.168.64.9**			
TYPE: **2**	0	METRIC: **1**	



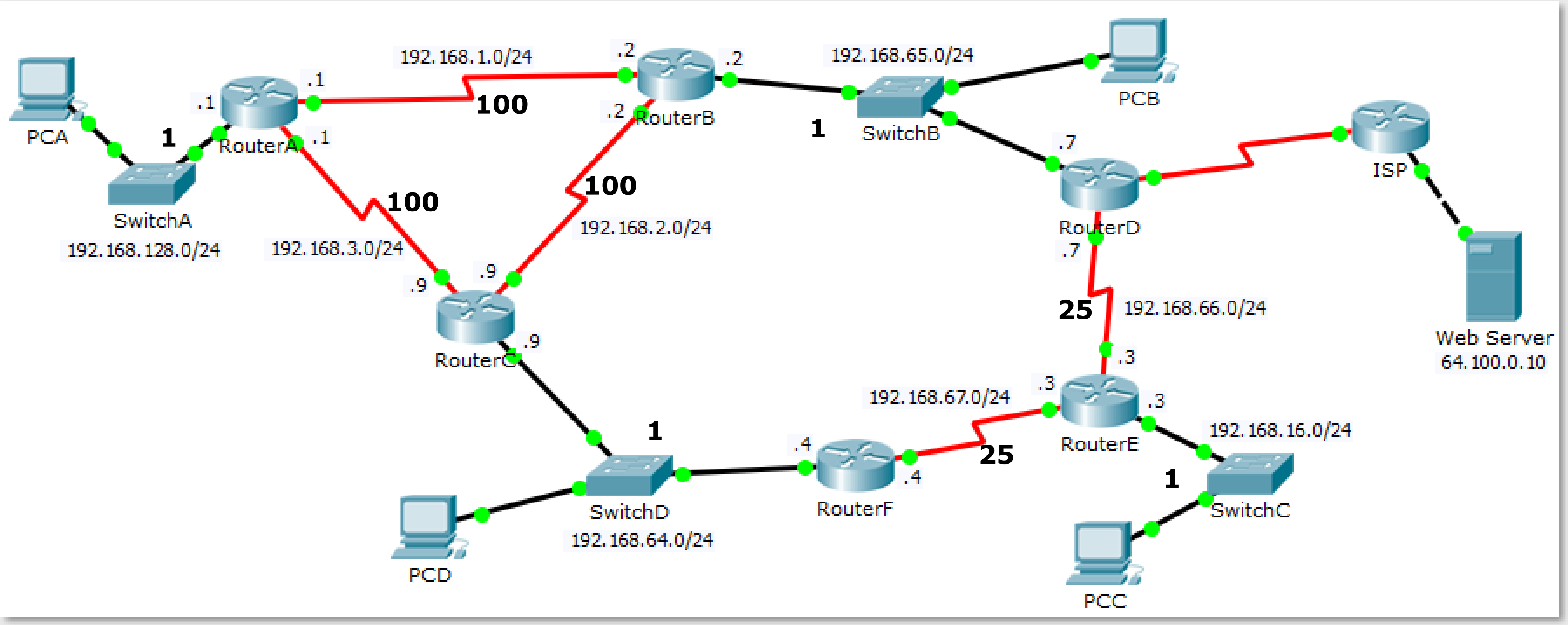
Network links LSA (type 2)



Network links LSA (LS type 2)

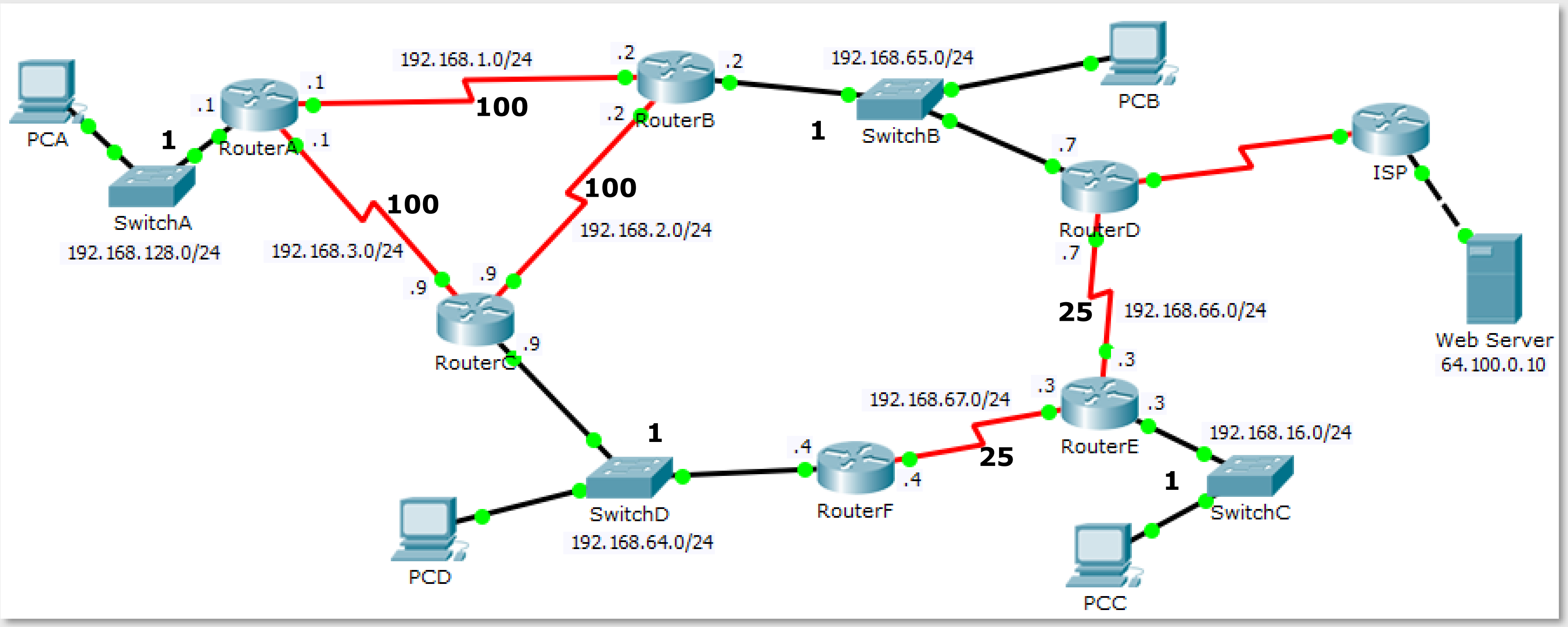
- **RouterC**
  - Designated router on LAN D

LSA AGE: 0	OPTIONS: 0	LS TYPE: **2**
LINK STATE ID: **192.168.64.9**		
ADVERTSING ROUTER: **9.9.9.9**		
LS SEQUENCE NUM: 0X80000001		
CHECKSUM: 45610	LENGTH: 32	
NETWORK MASK: **255.255.255.0**		
ATTACHED ROUTER: **4.4.4.4**		
ATTACHED ROUTER: **9.9.9.9**		

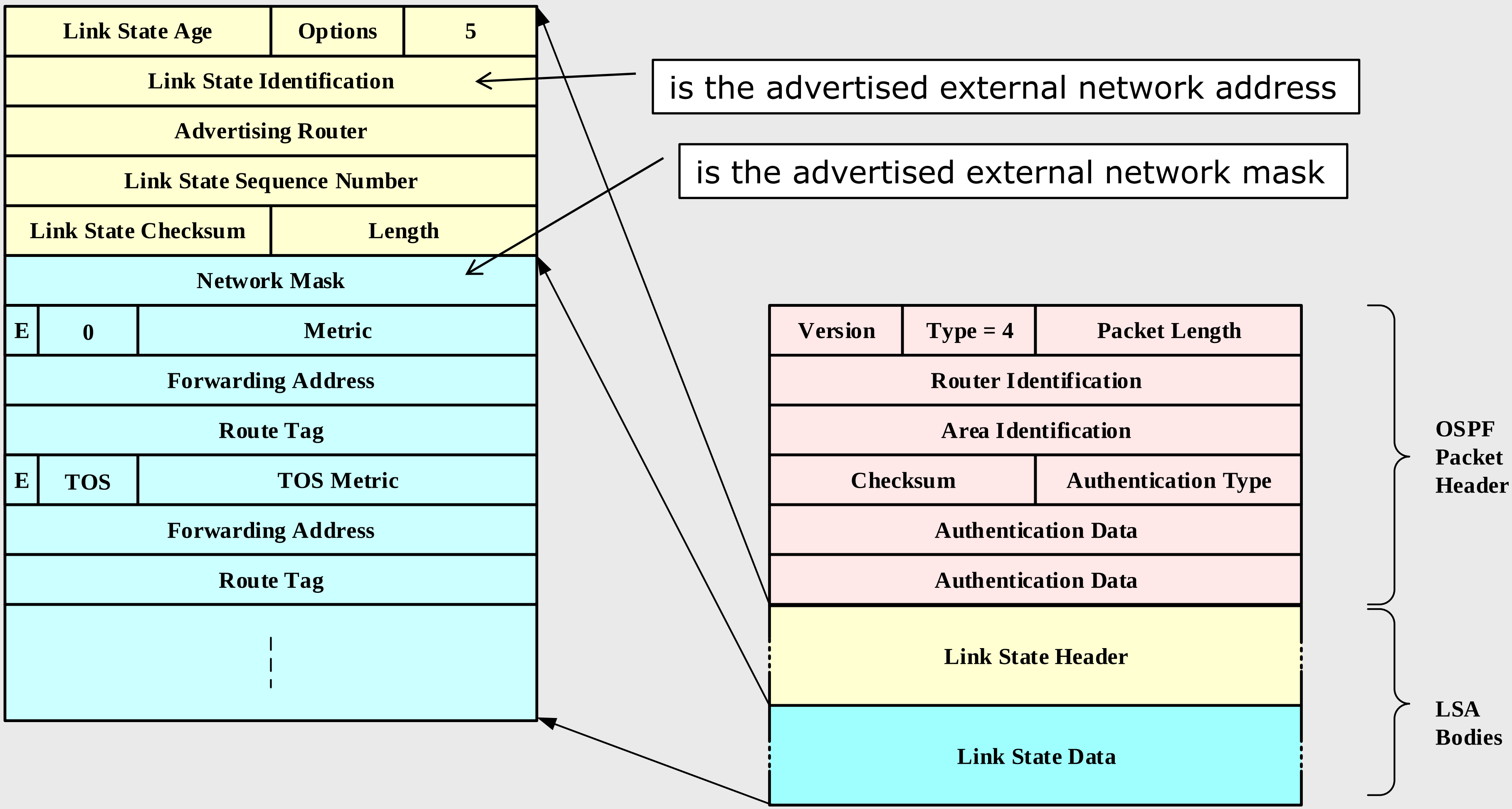


AS external link LSA (LS type 5)

- Generated by ASBRs to advertise networks outside the AS
- Propagated by selective flooding throughout the AS irrespectively of area boundaries



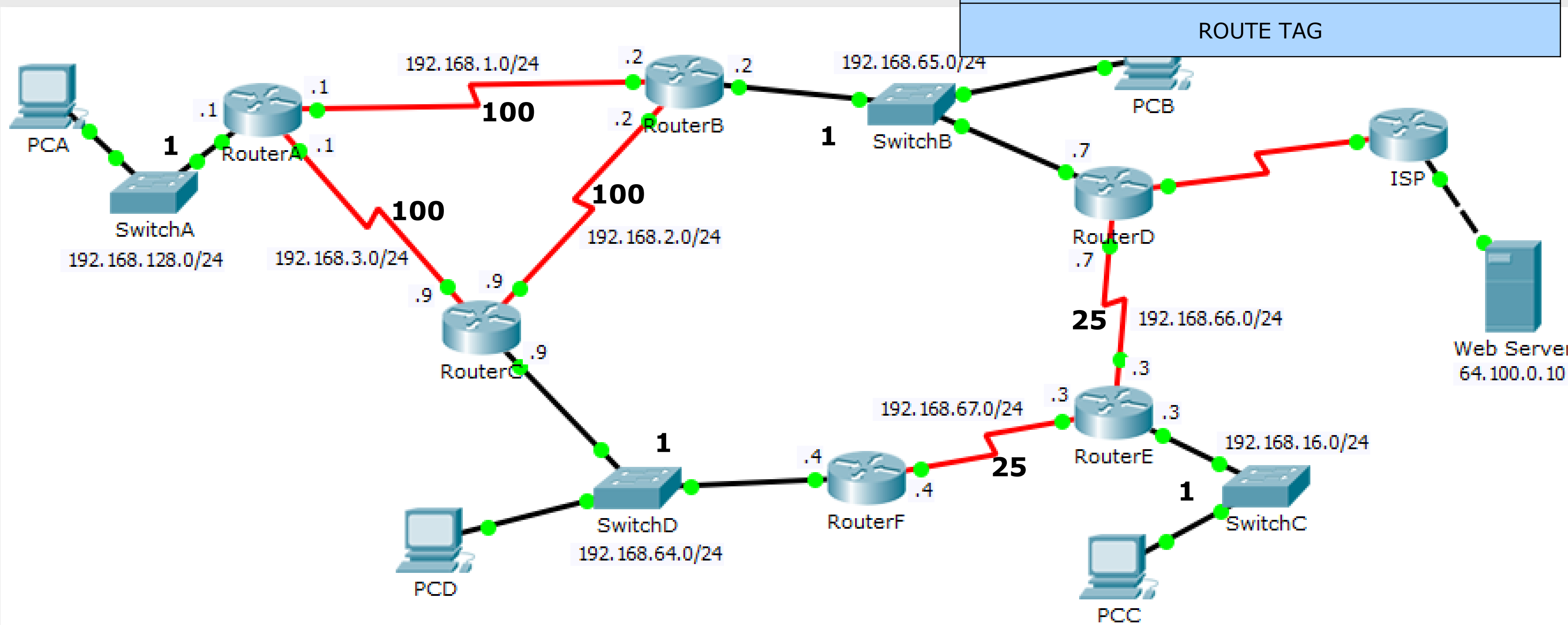
AS external link LSA (LS type 5)



AS external link LSA (LS type 5)

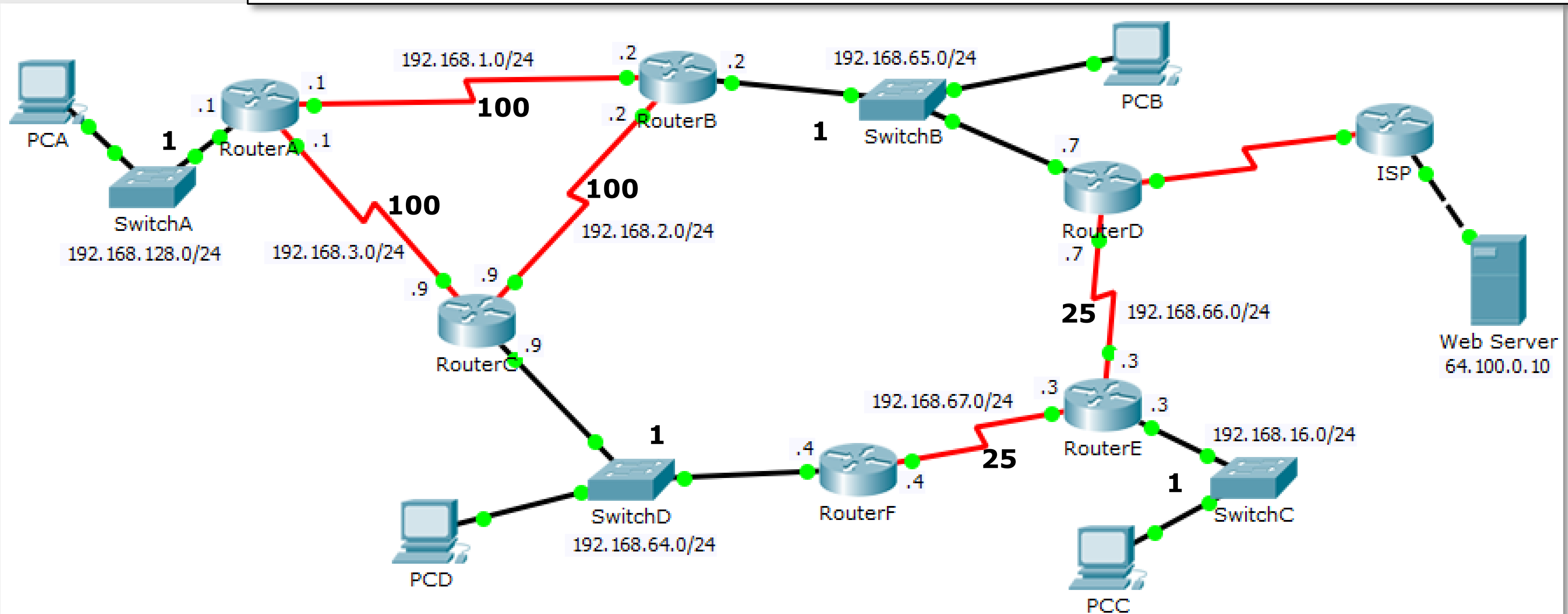
- **RouterD**
  - Default route for the AS

LSA AGE: 44	OPTIONS: 0	LS TYPE: **5**
LINK STATE ID: **0.0.0.0**		
ADVERTSING ROUTER: **7.7.7.7**		
LS SEQUENCE NUM: 0X80000001		
CHECKSUM: 19052	LENGTH: 36	
NETWORK MASK: **0.0.0.0**		
E: **1**	0	METRIC: **1**
FORWARDING ADDRESS: **0.0.0.0**		
ROUTE TAG		



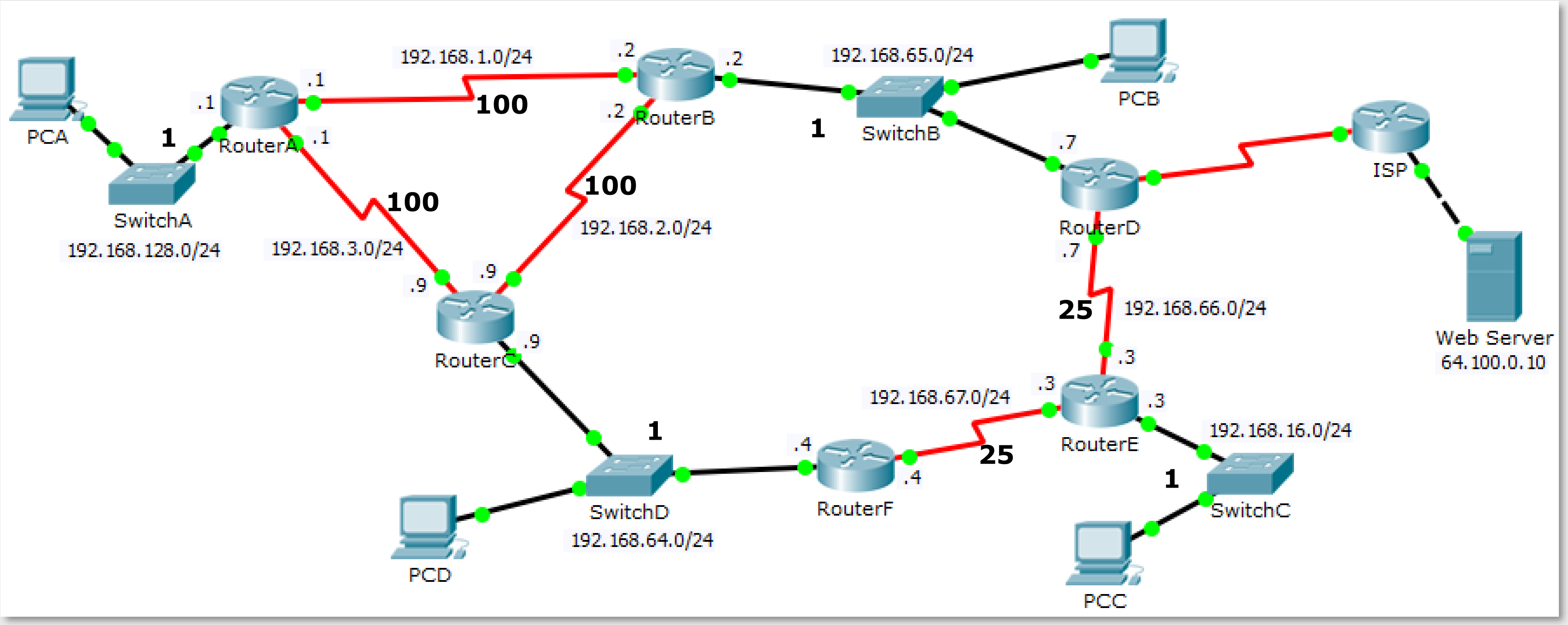
IP rout

```
RouterA#show ip route
...
Gateway of last resort is 192.168.1.2 to network 0.0.0.0

C    192.168.1.0/24 is directly connected, Serial0/0/0
O    192.168.2.0/24 [110/200] via 192.168.1.2, 00:04:53, Serial0/0/0
                    [110/200] via 192.168.3.9, 00:04:53, Serial0/0/1
C    192.168.3.0/24 is directly connected, Serial0/0/1
O    192.168.16.0/24 [110/127] via 192.168.1.2, 00:04:18, Serial0/0/0
                     [110/127] via 192.168.3.9, 00:04:18, Serial0/0/1
O    192.168.64.0/24 [110/101] via 192.168.3.9, 00:04:18, Serial0/0/1
O    192.168.65.0/24 [110/101] via 192.168.1.2, 00:04:18, Serial0/0/0
O    192.168.66.0/24 [110/126] via 192.168.1.2, 00:04:18, Serial0/0/0
O    192.168.67.0/24 [110/126] via 192.168.3.9, 00:04:18, Serial0/0/1
C    192.168.128.0/24 is directly connected, FastEthernet0/0
O*E2 0.0.0.0/0 [110/1] via 192.168.1.2, 00:04:18, Serial0/0/0
```



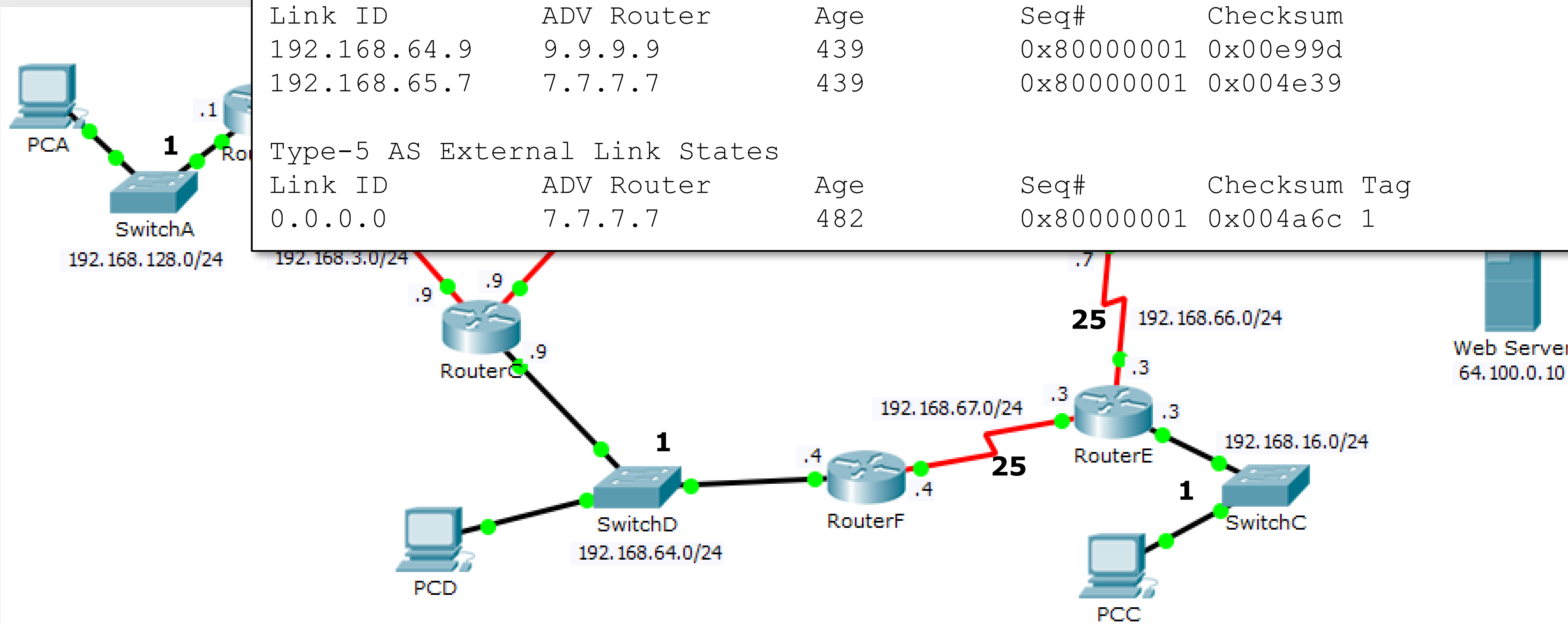
IP rout

```
RouterF#show ip route
...
Gateway of last resort is 192.168.67.3 to network 0.0.0.0

O    192.168.1.0/24 [110/151] via 192.168.67.3, 00:05:52, Serial0/0/0
O    192.168.2.0/24 [110/101] via 192.168.64.9, 00:05:52, FastEthernet0/0
O    192.168.3.0/24 [110/101] via 192.168.64.9, 00:05:52, FastEthernet0/0
O    192.168.16.0/24 [110/26] via 192.168.67.3, 00:06:32, Serial0/0/0
C    192.168.64.0/24 is directly connected, FastEthernet0/0
O    192.168.65.0/24 [110/51] via 192.168.67.3, 00:05:52, Serial0/0/0
O    192.168.66.0/24 [110/50] via 192.168.67.3, 00:06:32, Serial0/0/0
C    192.168.67.0/24 is directly connected, Serial0/0/0
O    192.168.128.0/24 [110/102] via 192.168.64.9, 00:05:52, FastEthernet0/0
O*E2 0.0.0.0/0 [110/1] via 192.168.67.3, 00:06:32, Serial0/0/0
```



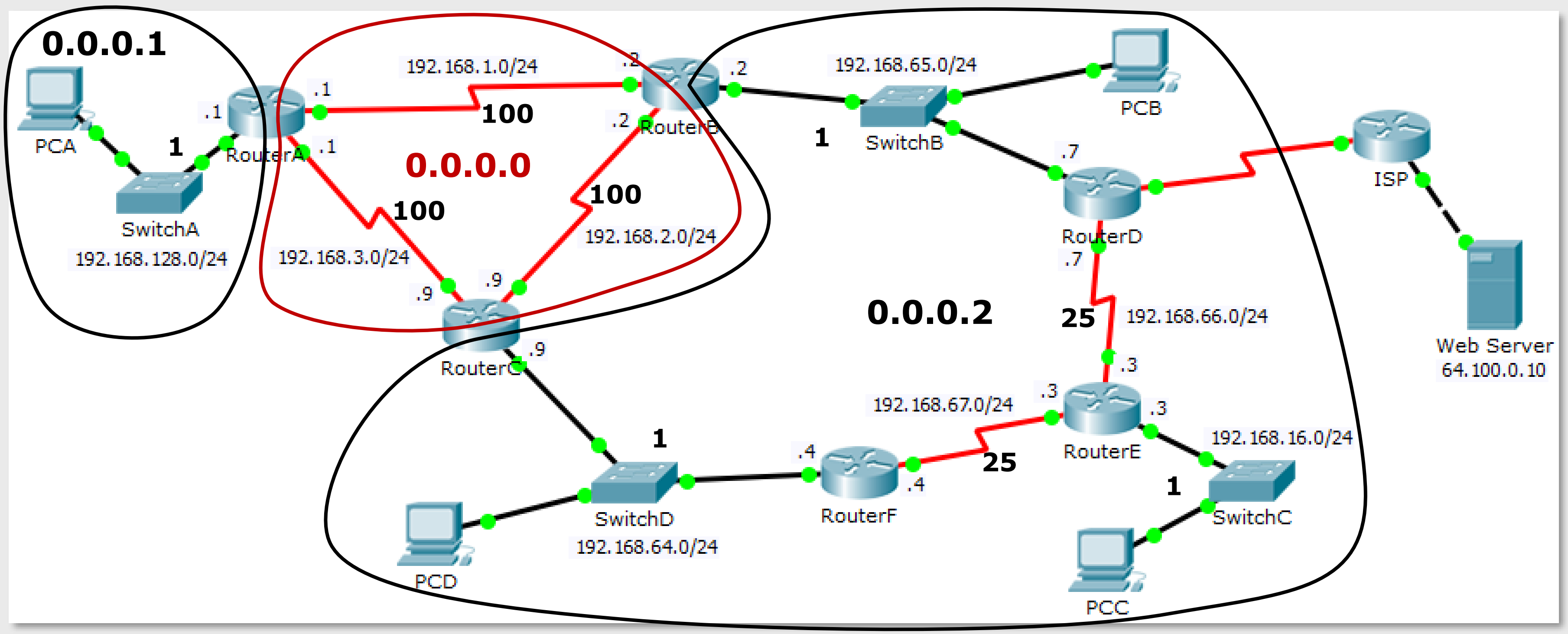
OSPF database

```
            OSPF Router with ID (4.4.4.4) (Process ID 1)

                Router Link States (Area 0)

Link ID         ADV Router      Age         Seq#       Checksum Link count
3.3.3.3         3.3.3.3         474         0x80000006 0x006637 5
1.1.1.1         1.1.1.1         473         0x80000006 0x006fd4 5
4.4.4.4         4.4.4.4         439         0x80000005 0x005c71 3
7.7.7.7         7.7.7.7         439         0x80000006 0x00edbb 3
2.2.2.2         2.2.2.2         438         0x80000007 0x004b80 5
9.9.9.9         9.9.9.9         434         0x80000007 0x000b90 5

Net Link States (Area 0)
Link ID         ADV Router      Age         Seq#       Checksum
192.168.64.9    9.9.9.9         439         0x80000001 0x00e99d
192.168.65.7    7.7.7.7         439         0x80000001 0x004e39

Type-5 AS External Link States
Link ID         ADV Router      Age         Seq#       Checksum Tag
0.0.0.0         7.7.7.7         482         0x80000001 0x004a6c 1
```



Example network (2)

- Multi-area – One AS boundary router (RouterD)
- Router IDs: *n.n.n.n*

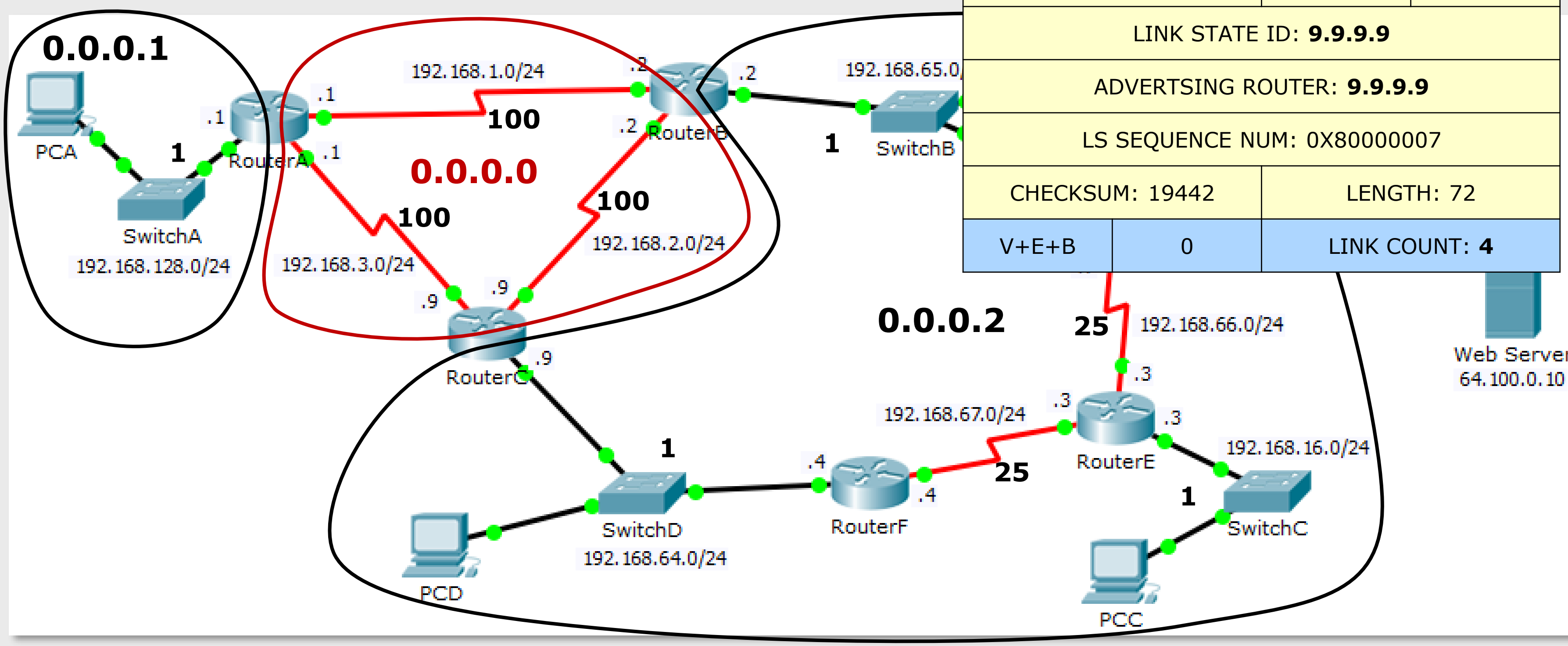


L

Router links LSA (LS type 1)

- **RouterC**
  - Area 0.0.0.0
  - 2 Links type 1 + 2 Links type 3

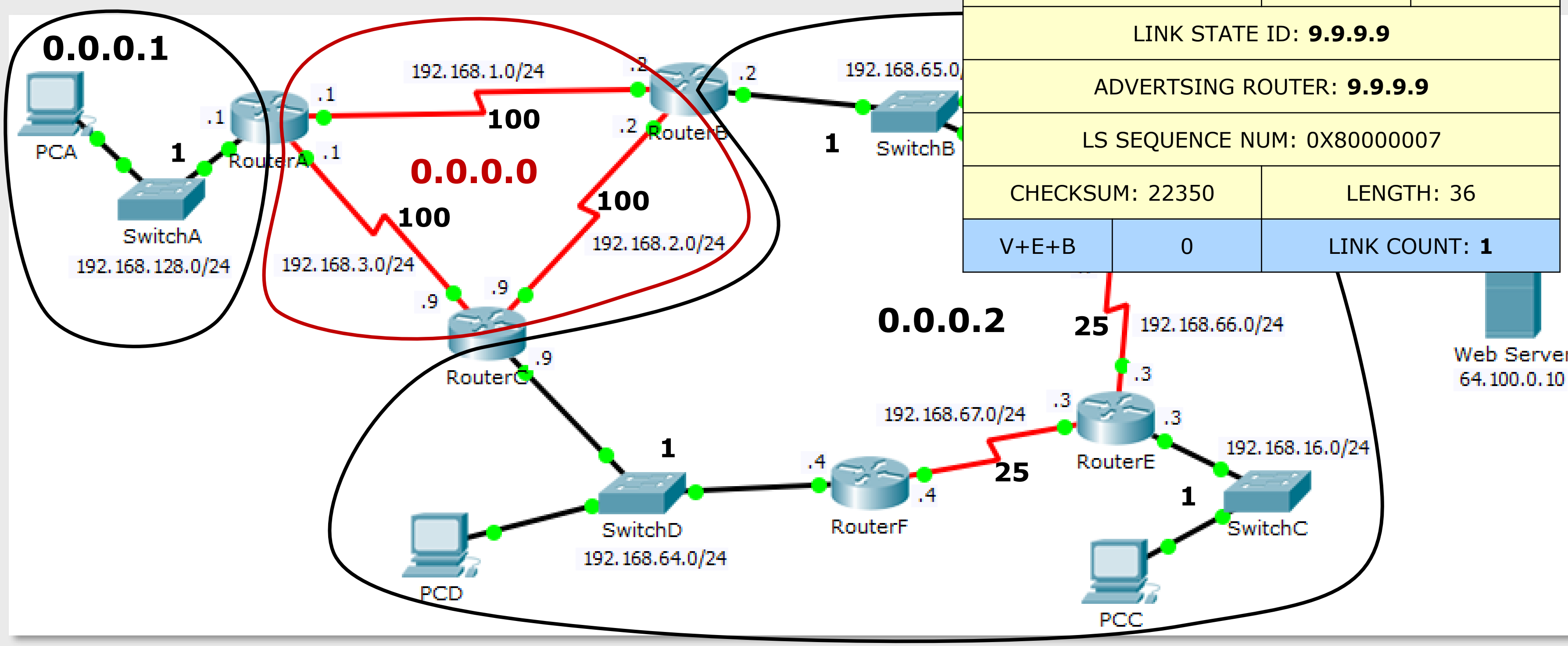
VERSION: 2	TYPE: **4**	PKT LENGTH: **96**	
ROUTER ID: **9.9.9.9**			
AREA ID: **0.0.0.0**			
CHECKSUM		AUTH TYPE	
AUTHENTICATION DATA			
# LSAs: **1**			
LSA AGE: 0		OPTIONS: 0	LS TYPE: **1**
LINK STATE ID: **9.9.9.9**			
ADVERTSING ROUTER: **9.9.9.9**			
LS SEQUENCE NUM: 0X80000007			
CHECKSUM: 19442		LENGTH: 72	
V+E+B	0	LINK COUNT: **4**	



Router links LSA (LS type 1)

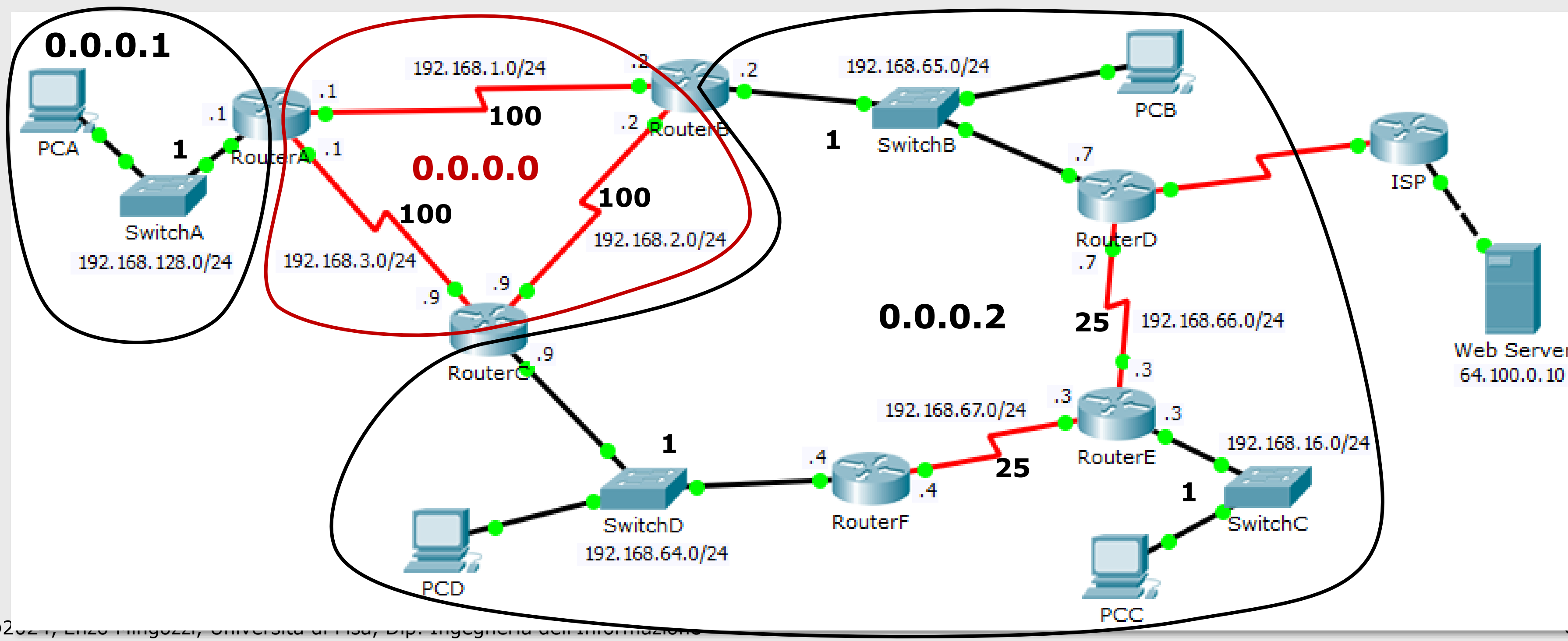
- **RouterC**
  - Area 0.0.0.2
  - 1 Link type 2

VERSION: 2	TYPE: **4**	PKT LENGTH: **60**	
ROUTER ID: **9.9.9.9**			
AREA ID: **0.0.0.2**			
CHECKSUM		AUTH TYPE	
AUTHENTICATION DATA			
# LSAs: **1**			
LSA AGE: 0		OPTIONS: 0	LS TYPE: **1**
LINK STATE ID: **9.9.9.9**			
ADVERTSING ROUTER: **9.9.9.9**			
LS SEQUENCE NUM: 0X80000007			
CHECKSUM: 22350		LENGTH: 36	
V+E+B	0	LINK COUNT: **1**	

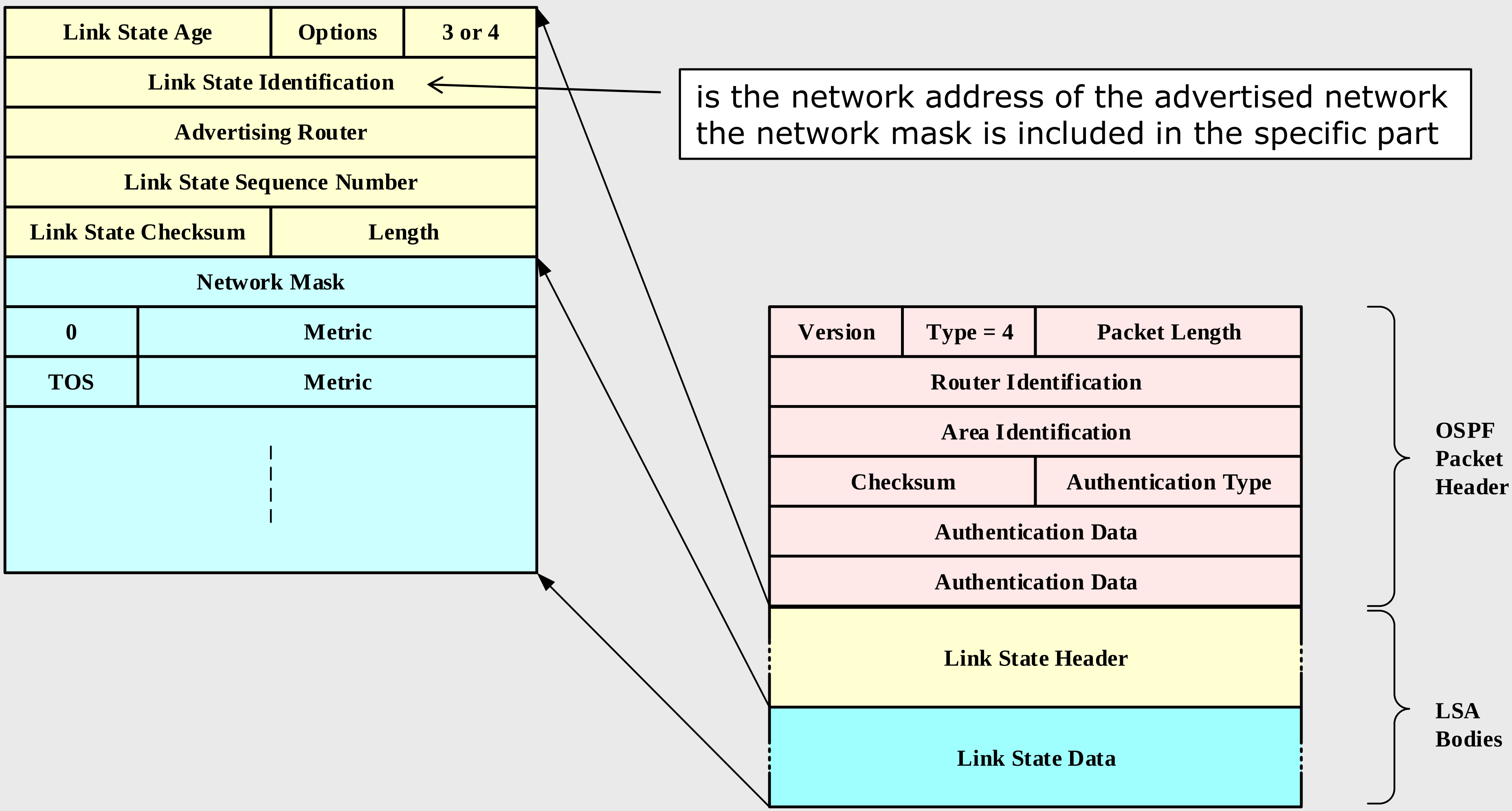


ABR summary link LSA (LS type 3)

- generated only by Area Border Routers (ABRs), describe inter-area routes
  - networks that are within the OSPF autonomous system but outside of the particular OSPF area that is receiving the LSA
- one summary LSA per destination network
- flooding is limited to the area where the summary LSA has been generated



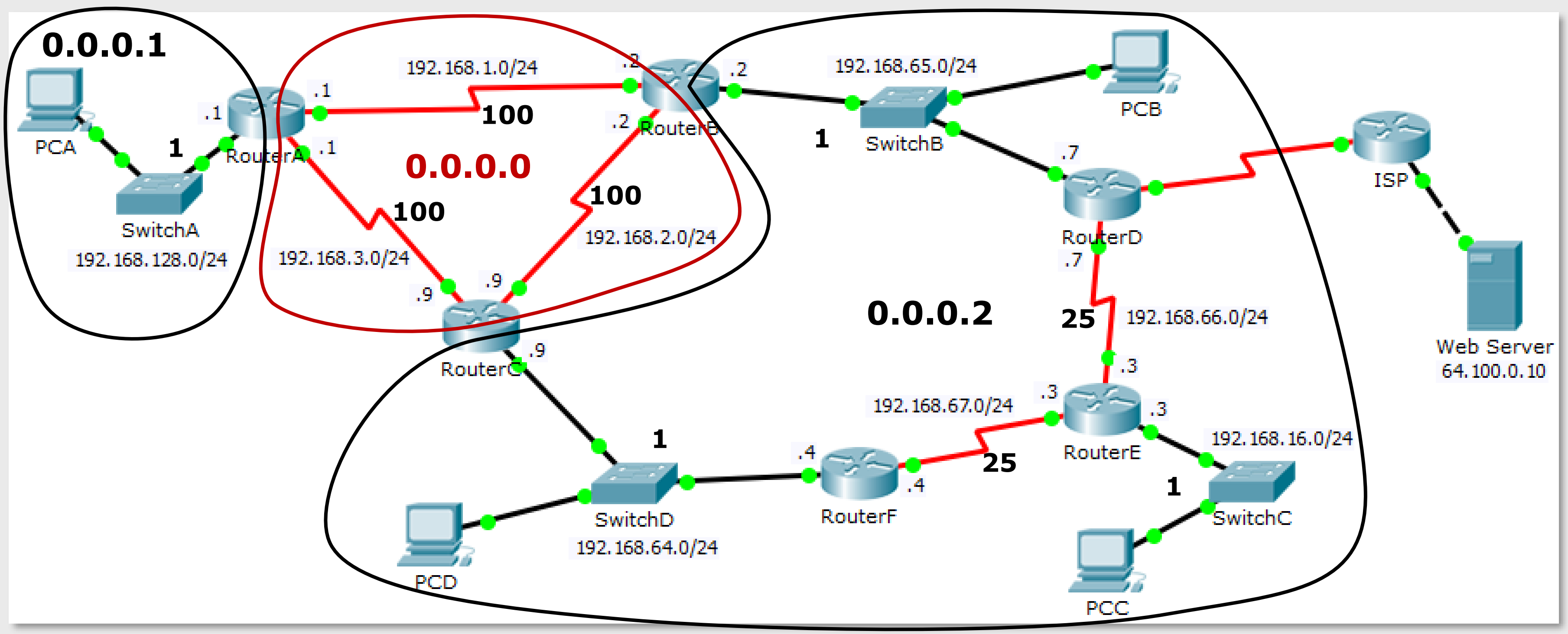
ABR summary link LSA (LS type 3)



ABR summary link LSA (LS type 3)

- **RouterC**
  - Area 0.0.0.0

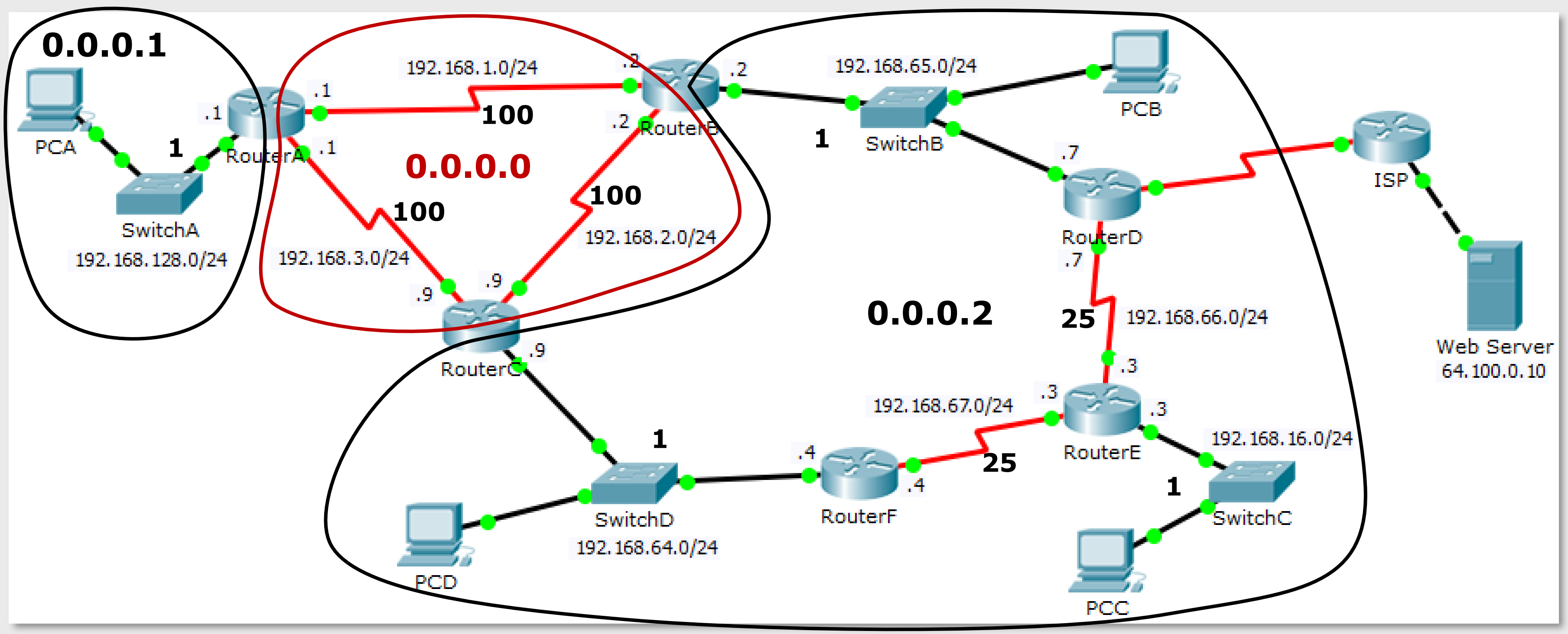
LSA AGE: 0	OPTIONS: 0	LS TYPE: **3**
LINK STATE ID: **192.168.16.0**		
ADVERTSING ROUTER: **9.9.9.9**		
LS SEQUENCE NUM: 0X80000007		
CHECKSUM: 47720	LENGTH: 28	
NETWORK MASK: **255.255.255.0**		
0	METRIC: **27**	



ABR summary link LSA (LS type 3)

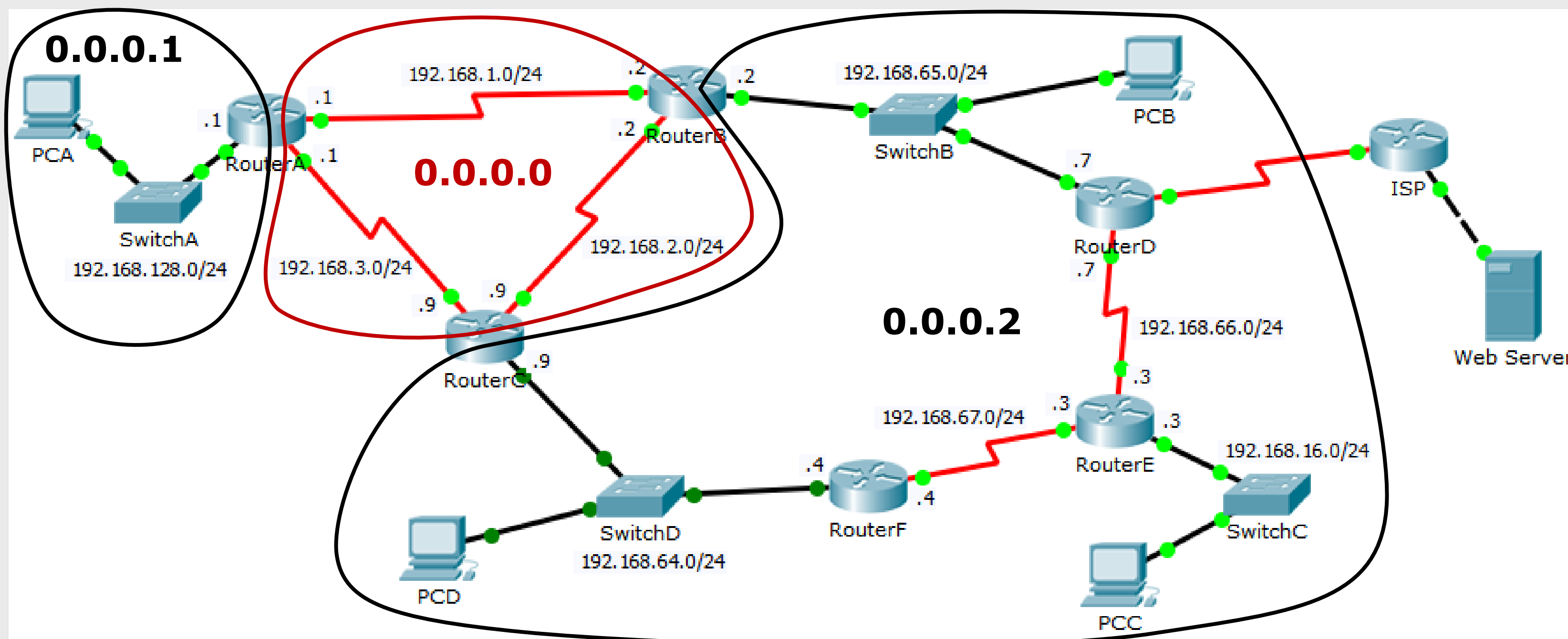
- **RouterC**
  - Area 0.0.0.2

LSA AGE: 0		OPTIONS: 0	LS TYPE: **3**
LINK STATE ID: **192.168.1.0**			
ADVERTSING ROUTER: **9.9.9.9**			
LS SEQUENCE NUM: 0X80000007			
CHECKSUM: 47720		LENGTH: 28	
NETWORK MASK: **255.255.255.0**			
0	METRIC: **200**		

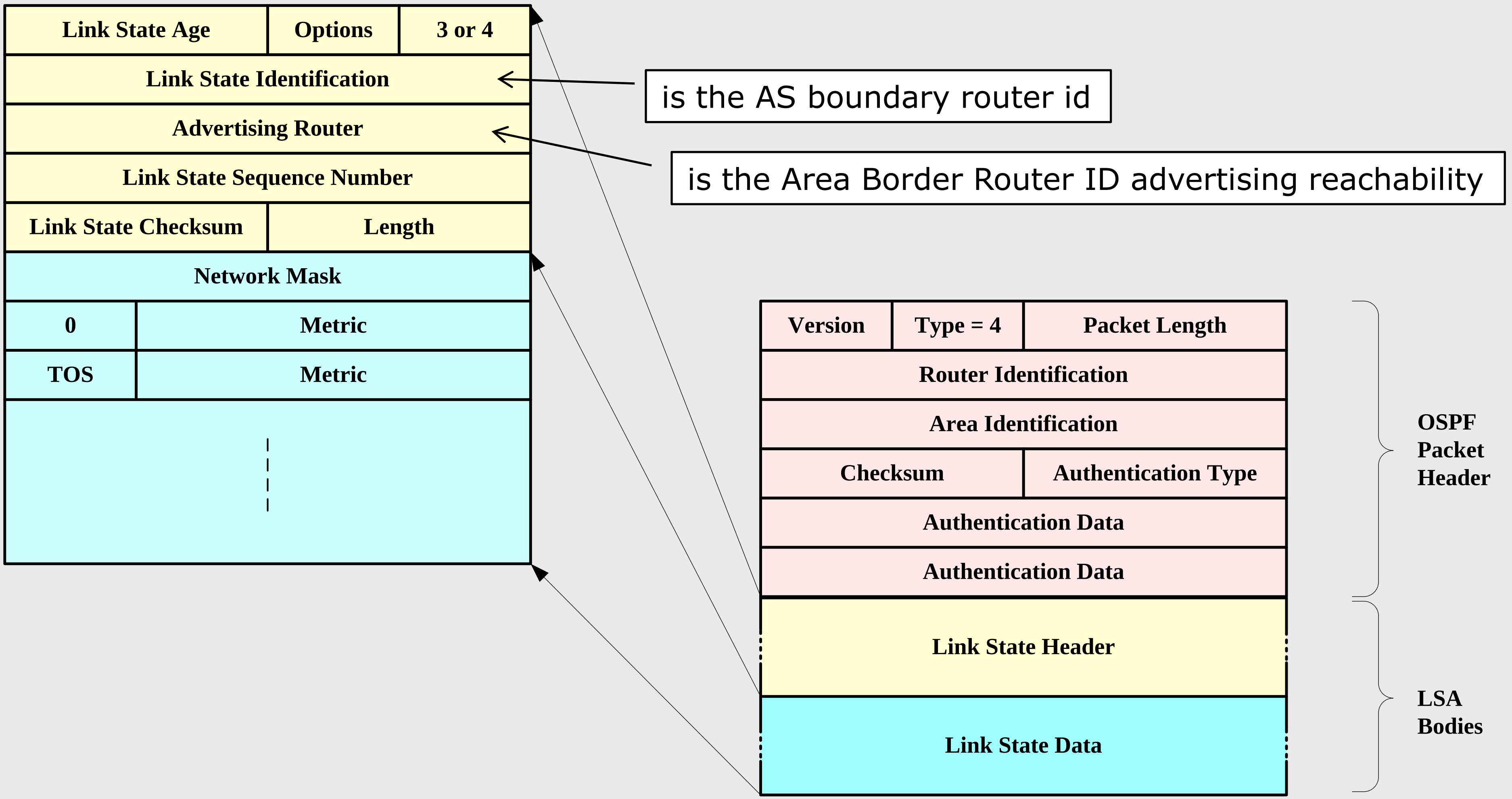


ASBR summary link LSA (type 4)

- Generated by ABRs to advertise the reachability of an ASBR
- ABRs in the same area compute the shortest path (and cost) to the ASBR and advertise a type 4 LSA in all other areas
  - ASBRs identify themselves as such by setting the Router Type field in the generated Router LSA
- ABRs in remote areas compute the path (and cost) based on received type 4 LSAs



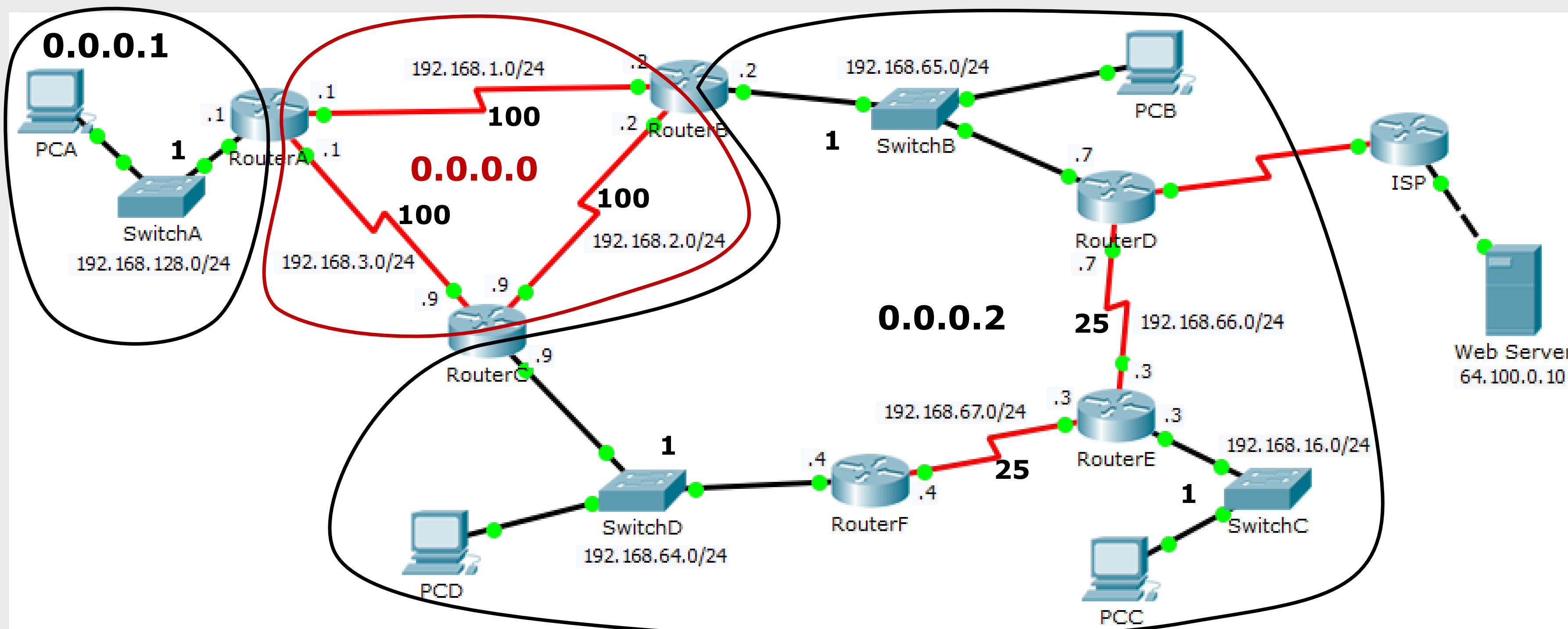
ASBR summary LSA (type 4)



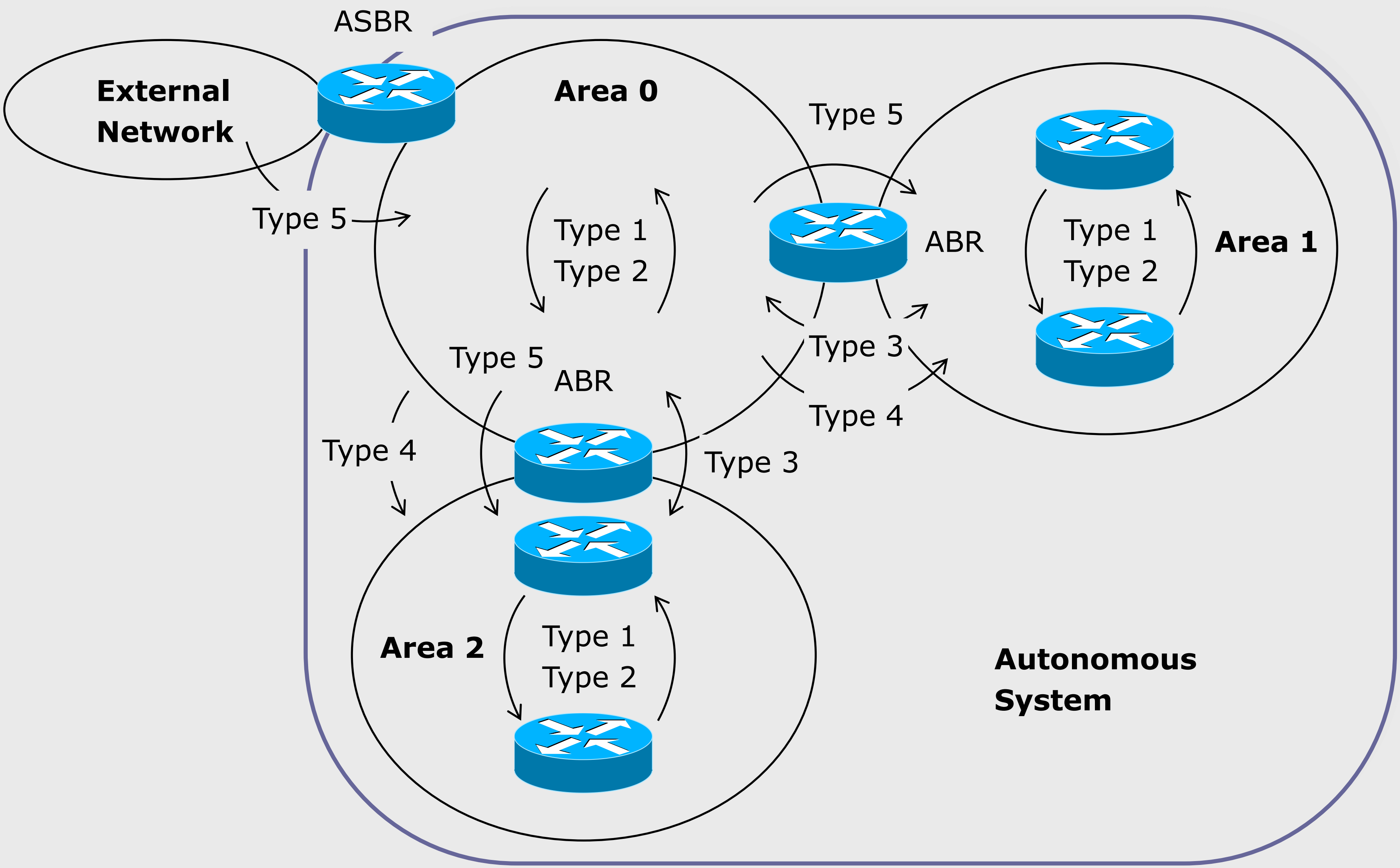
ABR summary link LSA (LS type 4)

- **RouterC**
  - Area 0.0.0.0

LSA AGE: 0		OPTIONS: 0	LS TYPE: **4**
LINK STATE ID: **7.7.7.7**			
ADVERTSING ROUTER: **9.9.9.9**			
LS SEQUENCE NUM: 0X80000007			
CHECKSUM: 47720		LENGTH: 28	
NETWORK MASK: 0.0.0.0			
0	METRIC: **51**		

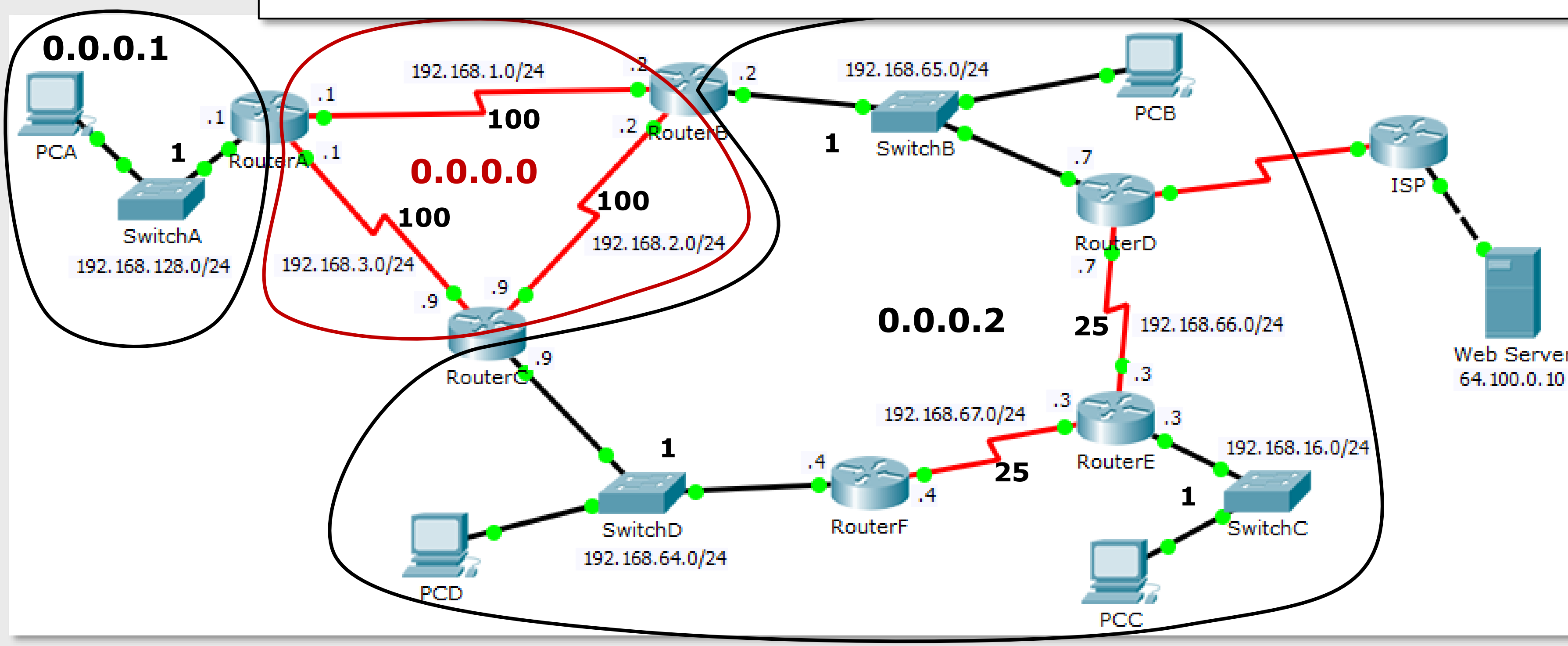


LSA propagation scope by type



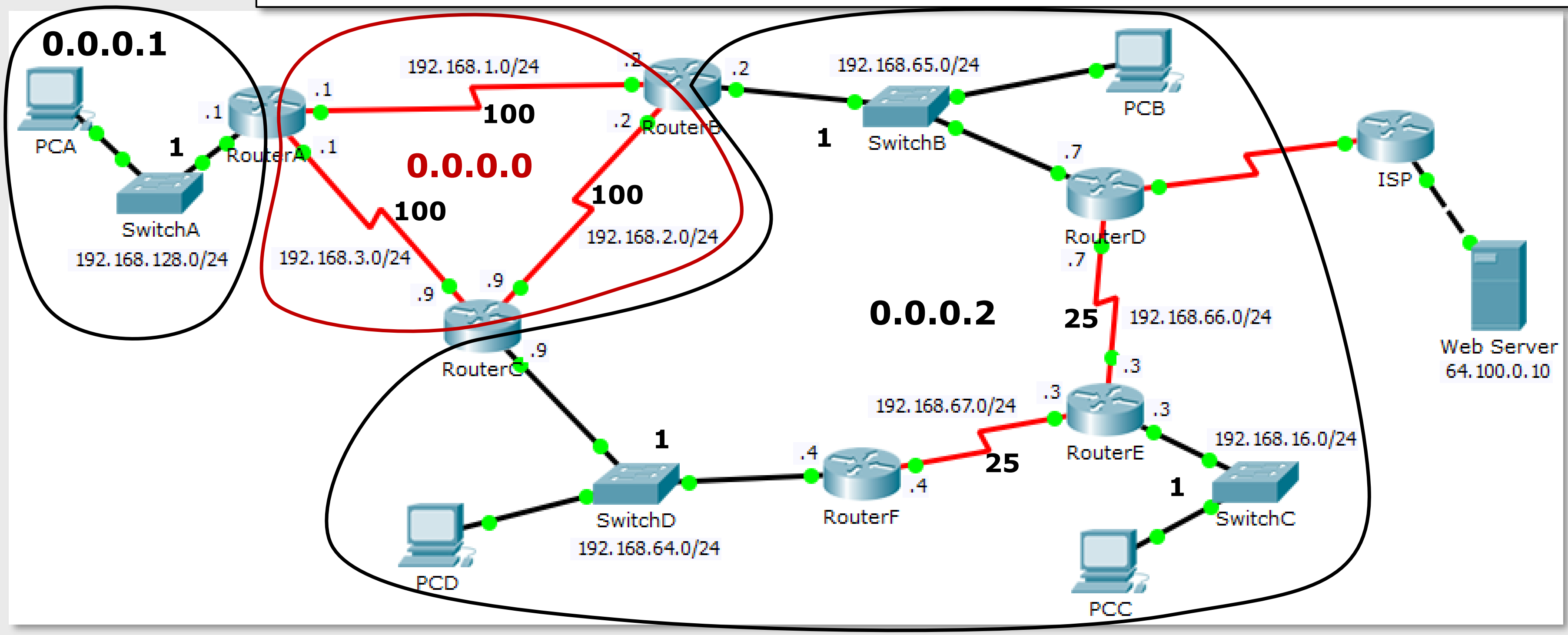
IP rout

```
RouterA#show ip route
...
Gateway of last resort is 192.168.1.2 to network 0.0.0.0

C    192.168.1.0/24 is directly connected, Serial0/0/0
O    192.168.2.0/24 [110/200] via 192.168.1.2, 00:01:12, Serial0/0/0
                    [110/200] via 192.168.3.9, 00:01:12, Serial0/0/1
C    192.168.3.0/24 is directly connected, Serial0/0/1
O IA 192.168.16.0/24 [110/127] via 192.168.1.2, 00:00:32, Serial0/0/0
                     [110/127] via 192.168.3.9, 00:00:32, Serial0/0/1
O IA 192.168.64.0/24 [110/101] via 192.168.3.9, 00:01:12, Serial0/0/1
O IA 192.168.65.0/24 [110/101] via 192.168.1.2, 00:01:02, Serial0/0/0
O IA 192.168.66.0/24 [110/126] via 192.168.1.2, 00:00:32, Serial0/0/0
O IA 192.168.67.0/24 [110/126] via 192.168.3.9, 00:00:32, Serial0/0/1
C    192.168.128.0/24 is directly connected, FastEthernet0/0
O*E2 0.0.0.0/0 [110/1] via 192.168.1.2, 00:00:32, Serial0/0/0
```



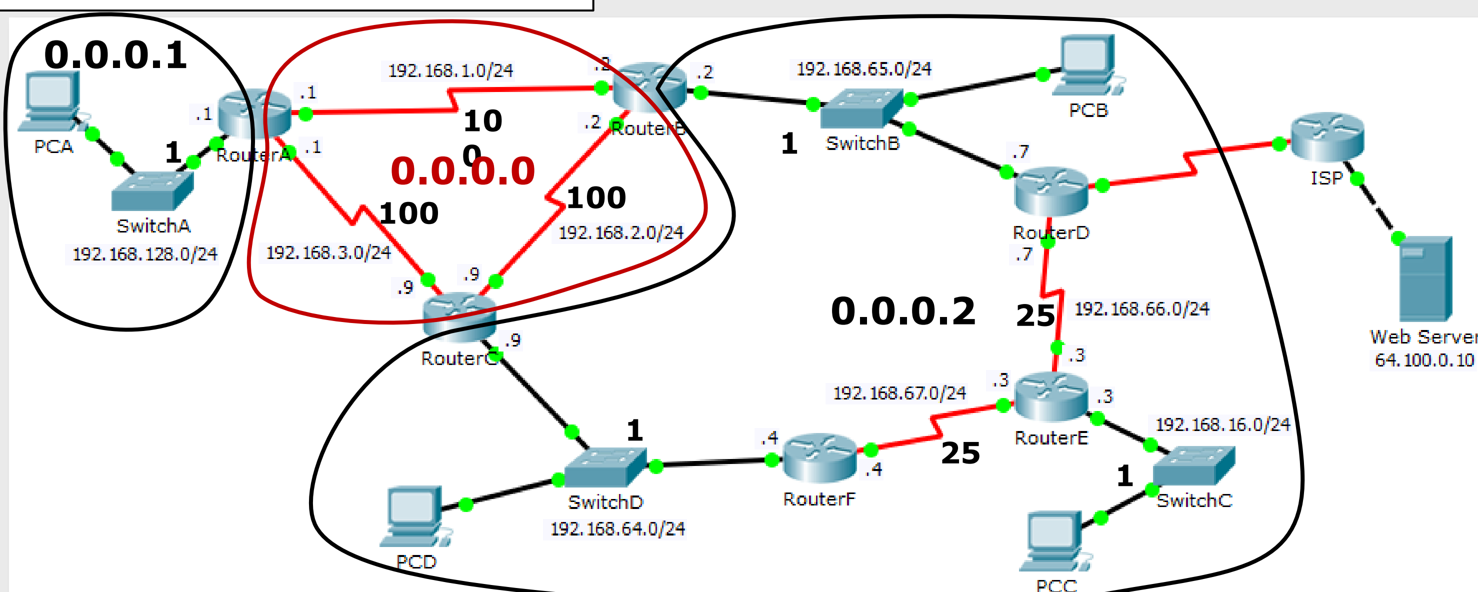
IP routing table

```
RouterF#show ip route
...
Gateway of last resort is 192.168.67.3 to network 0.0.0.0

O IA 192.168.1.0/24 [110/151] via 192.168.67.3, 00:03:11, Serial0/0/0
O IA 192.168.2.0/24 [110/101] via 192.168.64.9, 00:03:21, FastEthernet0/0
O IA 192.168.3.0/24 [110/101] via 192.168.64.9, 00:03:21, FastEthernet0/0
O    192.168.16.0/24 [110/26] via 192.168.67.3, 00:03:56, Serial0/0/0
C    192.168.64.0/24 is directly connected, FastEthernet0/0
O    192.168.65.0/24 [110/51] via 192.168.67.3, 00:03:21, Serial0/0/0
O    192.168.66.0/24 [110/50] via 192.168.67.3, 00:03:56, Serial0/0/0
C    192.168.67.0/24 is directly connected, Serial0/0/0
O IA 192.168.128.0/24 [110/102] via 192.168.64.9, 00:03:21, FastEthernet0/0
O*E2 0.0.0.0/0 [110/1] via 192.168.67.3, 00:03:56, Serial0/0/0
```



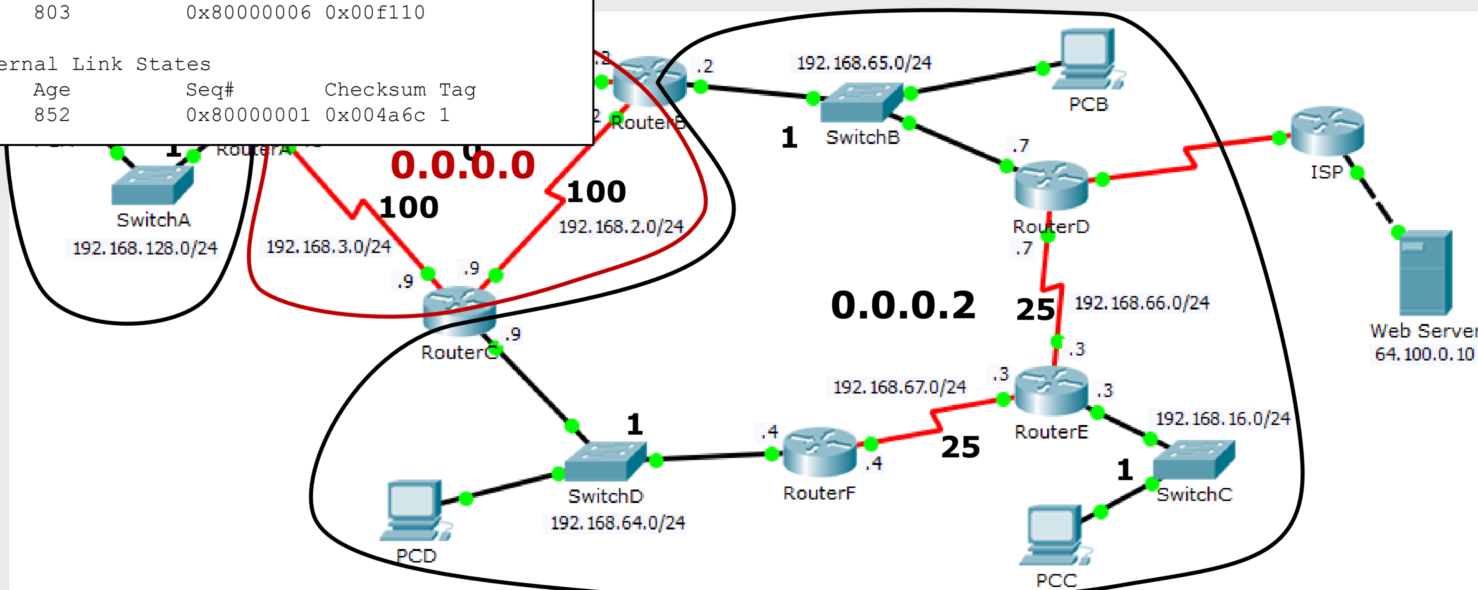
Example – Link state database

```
            OSPF Router with ID (9.9.9.9) (Process ID 1)

                Router Link States (Area 0)

Link ID         ADV Router      Age         Seq#       Checksum Link count
9.9.9.9         9.9.9.9         1253        0x80000006 0x001d5e 4
1.1.1.1         1.1.1.1         1254        0x80000006 0x009f0e 4
2.2.2.2         2.2.2.2         1249        0x80000006 0x001396 4

                Summary Net Link States (Area 0)
Link ID         ADV Router      Age         Seq#       Checksum
192.168.16.0    2.2.2.2         1214        0x80000005 0x00f1cc
192.168.16.0    9.9.9.9         1214        0x80000005 0x001f83
192.168.64.0    9.9.9.9         1249        0x80000001 0x001080
192.168.64.0    2.2.2.2         1214        0x80000003 0x00de98
192.168.65.0    2.2.2.2         1239        0x80000001 0x00d7d3
192.168.65.0    9.9.9.9         1214        0x80000003 0x000159
192.168.66.0    2.2.2.2         1214        0x80000004 0x00c1cc
192.168.66.0    9.9.9.9         1214        0x80000006 0x00e571
192.168.67.0    2.2.2.2         1214        0x80000006 0x00adc4
192.168.67.0    9.9.9.9         1214        0x80000004 0x00e38d
192.168.128.0   1.1.1.1         1244        0x80000001 0x003e32

                Summary ASB Link States (Area 0)
Link ID         ADV Router      Age         Seq#       Checksum
7.7.7.7         2.2.2.2         1214        0x80000002 0x000434
7.7.7.7         9.9.9.9         1214        0x80000002 0x0027c2
```



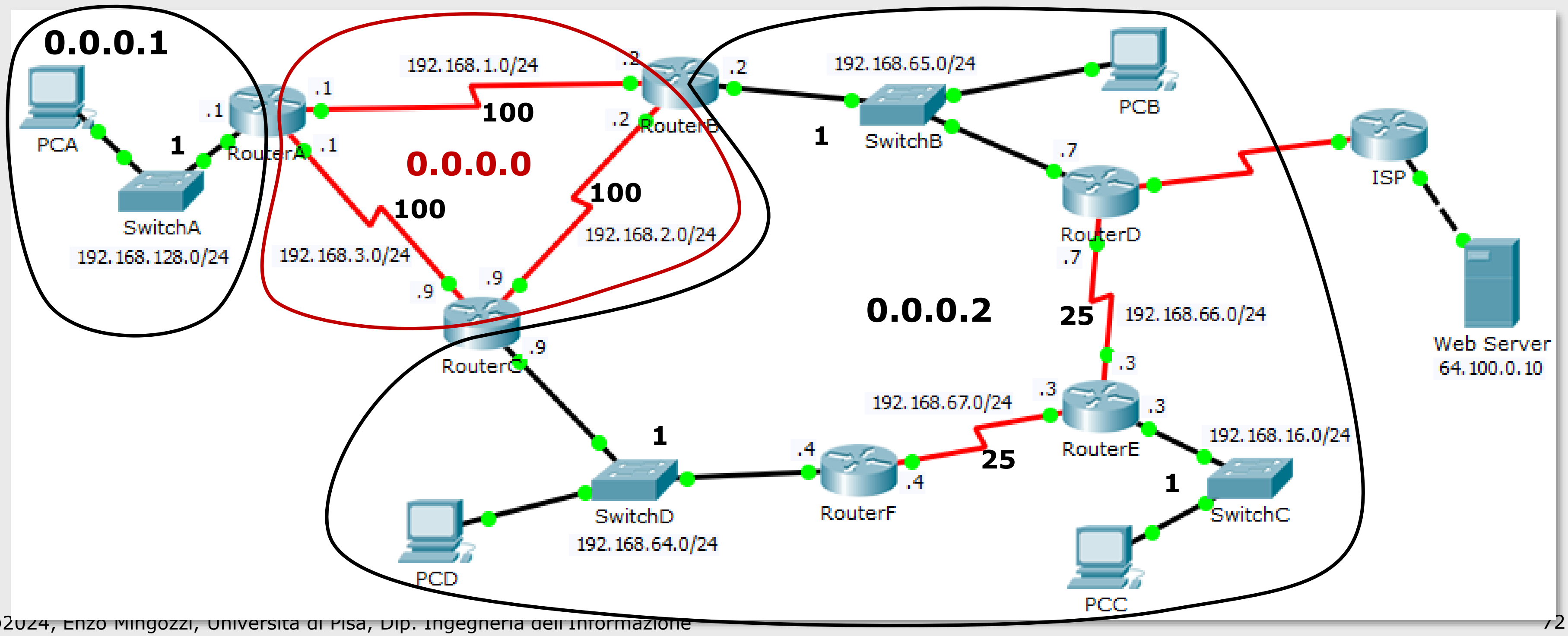
database

```
            OSPF Router with ID (9.9.9.9) (Process ID 1)

                Router Link States (Area 2)

Link ID         ADV Router      Age         Seq#       Checksum Link count
3.3.3.3         3.3.3.3         843         0x80000006 0x009f9a 5
9.9.9.9         9.9.9.9         808         0x80000002 0x00574e 1
4.4.4.4         4.4.4.4         808         0x80000004 0x008d8a 3
7.7.7.7         7.7.7.7         808         0x80000006 0x00fcfa 3
2.2.2.2         2.2.2.2         803         0x80000002 0x000dd7 1

                Net Link States (Area 2)
Link ID         ADV Router      Age         Seq#       Checksum
192.168.64.9    9.9.9.9         808         0x80000001 0x0071fc
192.168.65.7    7.7.7.7         808         0x80000001 0x004e39

                Summary Net Link States (Area 2)
Link ID         ADV Router      Age         Seq#       Checksum
192.168.1.0     9.9.9.9         838         0x80000003 0x009174
192.168.1.0     2.2.2.2         847         0x80000001 0x007c0c
192.168.2.0     9.9.9.9         838         0x80000002 0x009ccd
192.168.2.0     2.2.2.2         847         0x80000002 0x006f17
192.168.3.0     9.9.9.9         848         0x80000001 0x0093d6
192.168.3.0     2.2.2.2         828         0x80000003 0x004ed1
192.168.128.0   2.2.2.2         828         0x80000005 0x0004ff
192.168.128.0   9.9.9.9         803         0x80000005 0x0031b6

                Summary ASB Link States (Area 2)
Link ID         ADV Router      Age         Seq#       Checksum
7.7.7.7         9.9.9.9         803         0x80000004 0x002dec
7.7.7.7         2.2.2.2         803         0x80000006 0x00f110

                Type-5 AS External Link States
Link ID         ADV Router      Age         Seq#       Checksum Tag
0.0.0.0         7.7.7.7         852         0x80000001 0x004a6c 1
```



Stub areas

- Stub areas can be configured
  - No ASBR inside
  - One ABR to the backbone area (multiple are also allowed, but with constraints)
- No type 4 and 5 LSAa are propagated, type 3 LSAs can be filtered
- Network 0.0.0.0/0.0.0.0 is advertised by the ABR in a Summary LSA



Stub areas

- Stub areas can be configured
  - No ASBR inside
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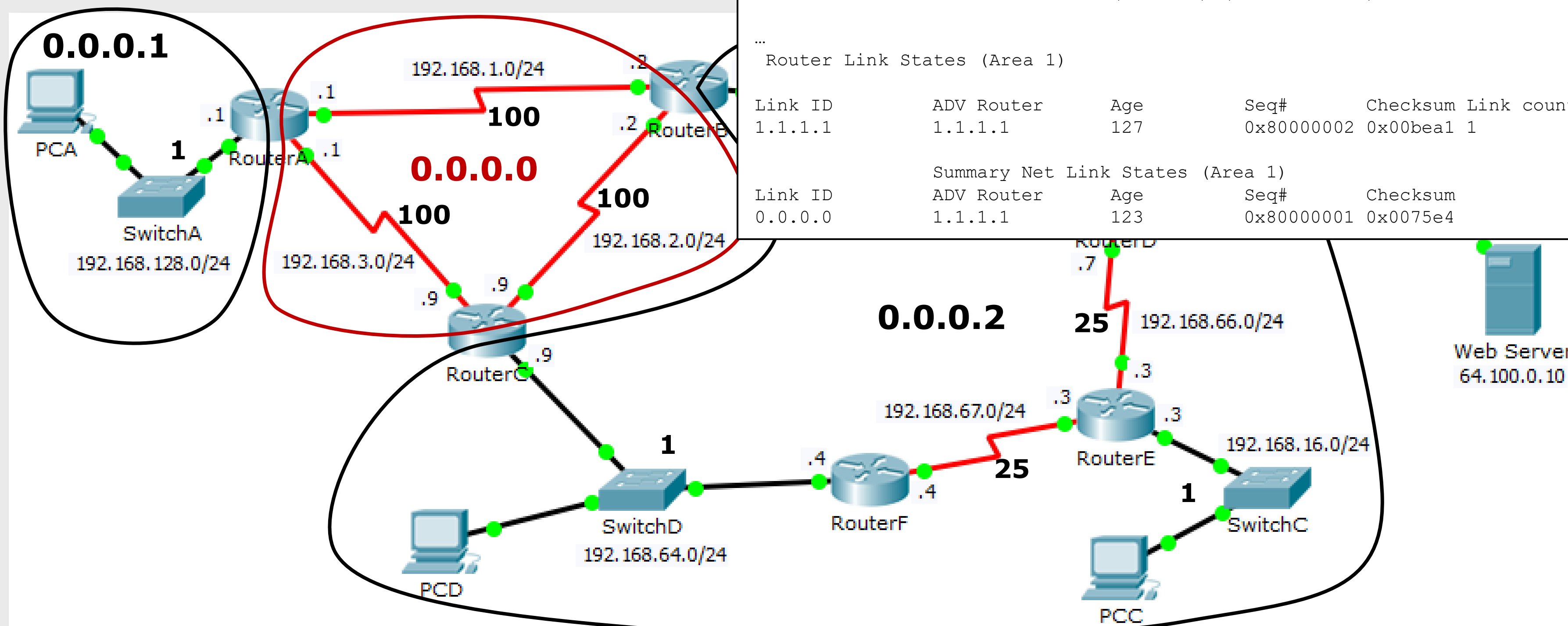
- No type 4 and 5 LSAa are propagated, type 3 LSAs can be filtered
- Network 0.0.0.0/0.0.0.0 is advertised by the ABR in a Summary LSA




```
                OSPF Router with ID (1.1.1.1) (Process ID 1)

…
 Router Link States (Area 1)

Link ID         ADV Router      Age         Seq#       Checksum Link count
1.1.1.1         1.1.1.1         127         0x80000002 0x00bea1 1

                Summary Net Link States (Area 1)
Link ID         ADV Router      Age         Seq#       Checksum
0.0.0.0         1.1.1.1         123         0x80000001 0x0075e4
```