

kathara lab(s)

ospf

Version	1.0
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Description	A set of labs showing the operation of the ospf routing protocol in different scenarios – kathara version of an existing netkit lab

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about ospf

- open shortest path first
- an interior gateway protocol

	specification	authentication confidentiality
version 2	rfc 2328	rfc 5709
version 3 (with ipv6 support)	rfc 5340	rfc 4552

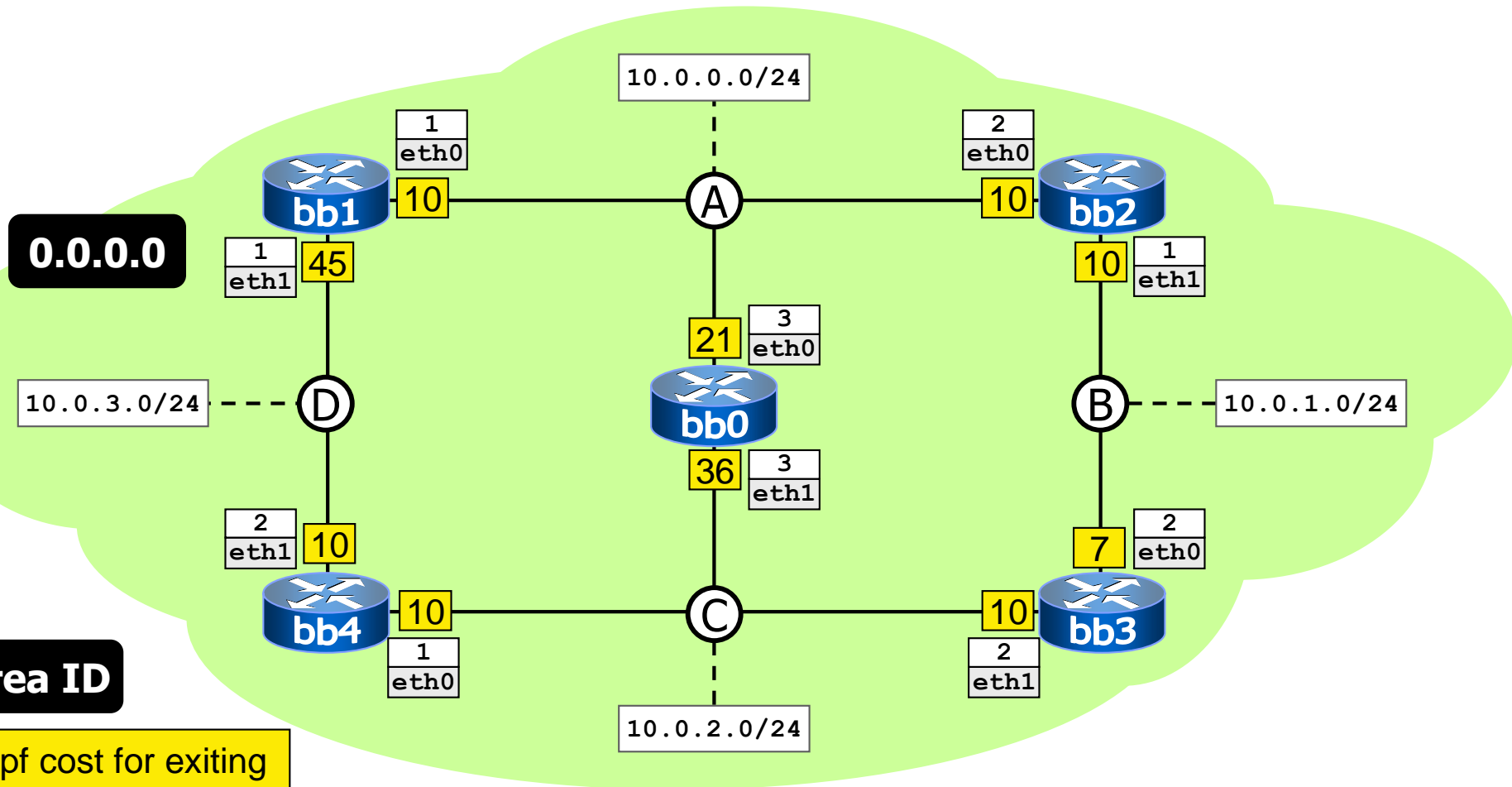
ospf: overview

- each router floods its local state (usable interfaces, reachable neighbors) through the network, using **link state advertisements (lsa)**
- based on this information, each router builds and maintains a **link state database (lsdb)** describing the whole network topology
 - identical for (almost) all routers
 - each entry is a router's local state
- each router uses the lsdb to compute a shortest path tree rooted at itself
 - interfaces may be assigned costs
- note: designed to operate on broadcast networks, but has modes to operate on non-broadcast ones

a simple ospf lab

single-area

lab topology

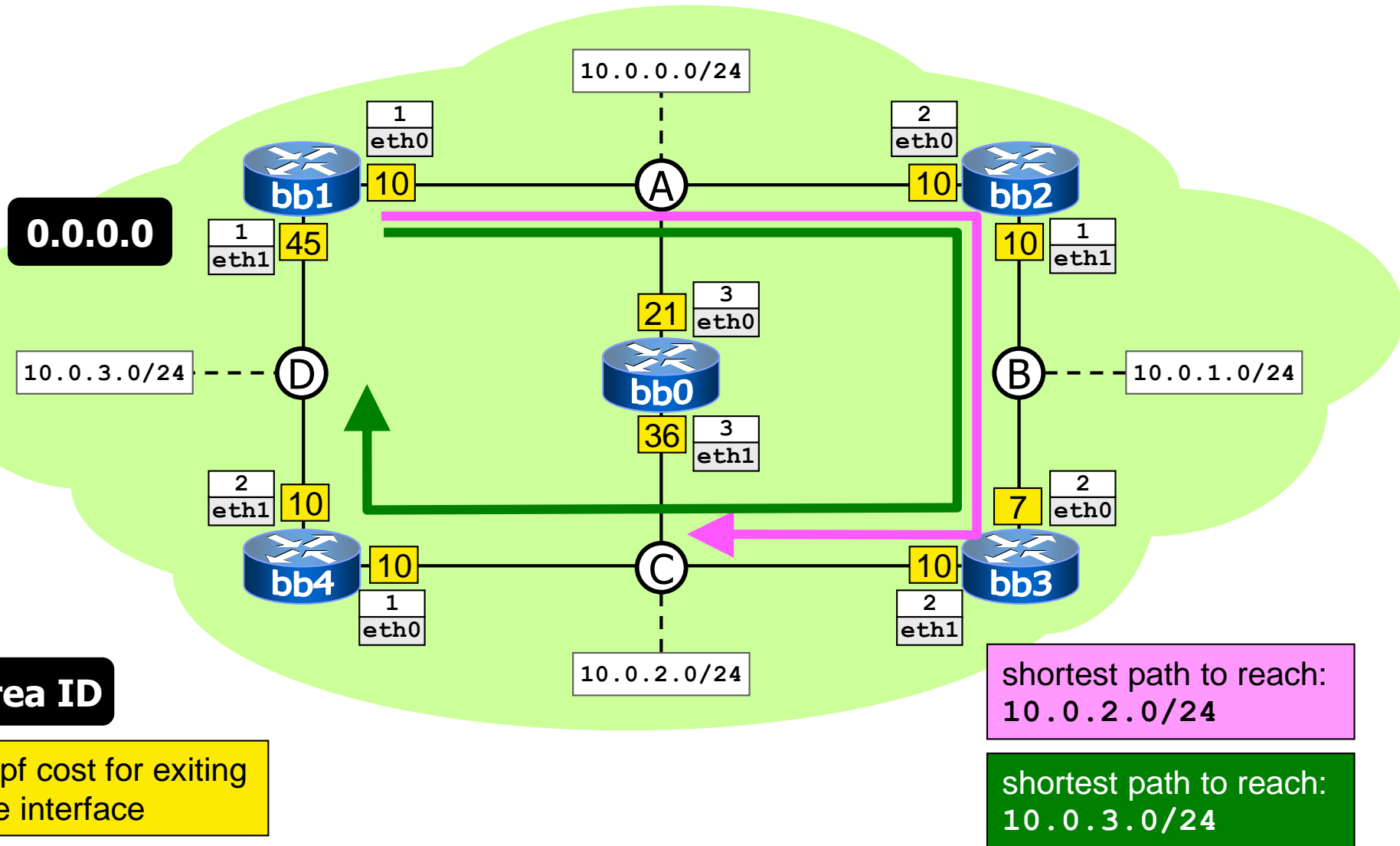


lab description

- single (backbone) area (0.0.0.0)
- each interface is assigned an ospf cost
 - default: 10
 - we have tweaked the costs to force paths taken by traffic
- to set interface costs:

```
interface eth1  
ospf cost 45
```

(some) shortest paths



experiments

- perform traceroutes from/to different interfaces
- perform a **traceroute -I** from **bb1** to **10.0.2.1**
 - what path is the traceroute expected to take?
 - what path are ICMP replies expected to take?
- perform a **traceroute -I** from **bb1** to **10.0.3.2**
 - what path is the traceroute expected to take?
 - observe the interplay between ospf routes and directly connected networks (i.e., perform a **show ip route** in zebra)
- try to alter the costs and observe the effect of the changes

experiments

- access the ospfd cli on the various routers and issue the following commands:
 - `show ip ospf database`
 - `show ip ospf neighbor`
 - `show ip ospf route`
- check that the lsdb is exactly the same for all routers

designated routers

(router interfaces designated for each network)

- for each network, one of the interfaces attached to that network is elected as designated (dr)
- priority-based election, using hello packets
 - the router (interface) sending hello packets with highest priority wins the election
 - break ties on highest router id
 - by default, a router id is the address of one of its interfaces
 - $\text{priority} \in [0, 255]$
default priority: 1
 $\text{priority} = 0 \Rightarrow$ never become a dr
- a backup dr (i.e., the one with second highest priority) is also elected, to quickly recover from dr failures

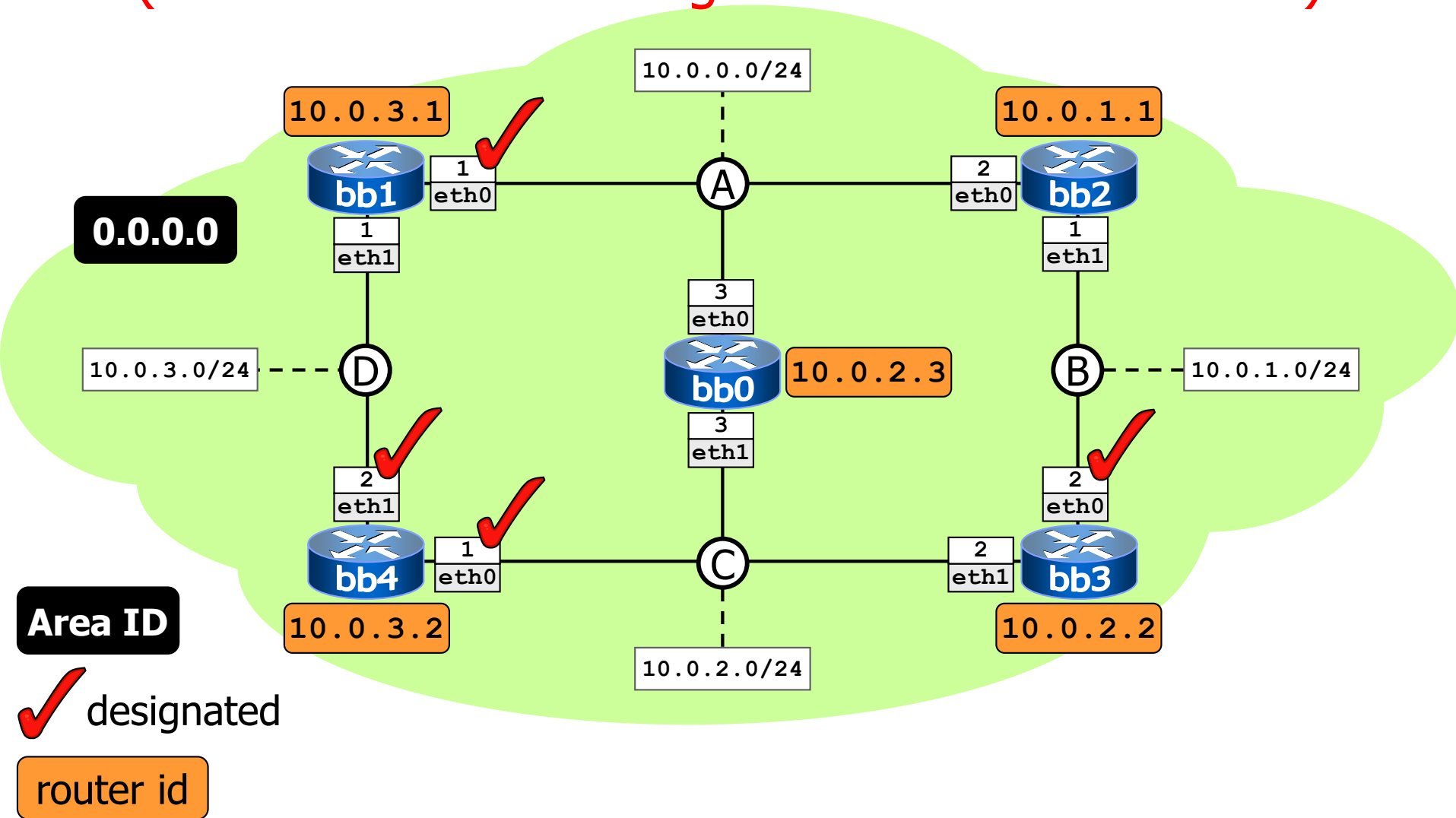
designated routers

(router interfaces designated for each network)

- a change of the dr is a change in ospf's topology model (new lsas are sent)
- for this reason, the dr is changed infrequently
 - if a router with high priority wakes up and finds that a dr already exists, it accepts that dr

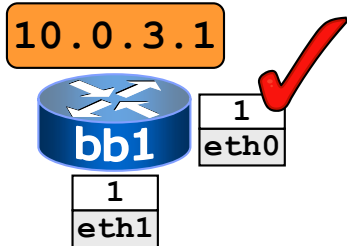
designated routers

(router interfaces designated for each network)



designated routers

(router interfaces designated for each network)



bb1

```
bb1# show ip ospf interface
```

```
eth0 is up
```

```
  ifindex 3, MTU 1500 bytes, BW 0 Kbit <UP,BROADCAST,RUNNING,MULTICAST>
```

```
  Internet Address 10.0.0.1/24, Broadcast 10.0.0.255, Area 0.0.0.0
```

```
  MTU mismatch detection:enabled
```

```
  Router ID 10.0.3.1, Network Type BROADCAST, Cost: 10
```

```
  Transmit Delay is 1 sec, State DR, Priority 1
```

```
  Designated Router (ID) 10.0.3.1, Interface Address 10.0.0.1
```

```
  Backup Designated Router (ID) 10.0.3.1, Interface Address 10.0.0.3
```

```
  Multicast group memberships: OSPFAllRouters OSPFDesignatedRouters
```

```
  Timer intervals configured, Hello 10s, Dead 40s, Wait 40s, Retransmit 5
```

```
    Hello due in 8.784s
```

```
  Neighbor Count is 2, Adjacent neighbor count is 2
```

```
eth1 is up
```

```
  ifindex 4, MTU 1500 bytes, BW 0 Kbit <UP,BROADCAST,RUNNING,MULTICAST>
```

```
  Internet Address 10.0.3.1/24, Broadcast 10.0.3.255, Area 0.0.0.0
```

```
  MTU mismatch detection:enabled
```

```
  Router ID 10.0.3.1, Network Type BROADCAST, Cost: 45
```

```
  Transmit Delay is 1 sec, State Backup, Priority 1
```

```
  Designated Router (ID) 10.0.3.2, Interface Address 10.0.3.2
```

```
  Backup Designated Router (ID) 10.0.3.1, Interface Address 10.0.3.1
```

```
  Multicast group memberships: OSPFAllRouters OSPFDesignatedRouters
```

```
  Timer intervals configured, Hello 10s, Dead 40s, Wait 40s, Retransmit 5
```

```
    Hello due in 3.504s
```

```
  Neighbor Count is 1, Adjacent neighbor count is 1
```

```
lo is up
```

```
  ifindex 1, MTU 16436 bytes, BW 0 Kbit <UP,LOOPBACK,RUNNING>
```

```
  OSPF not enabled on this interface
```

```
teql0 is down
```

```
  ifindex 2, MTU 1500 bytes, BW 0 Kbit <NOARP>
```

```
  OSPF not enabled on this interface
```

```
bb1#
```

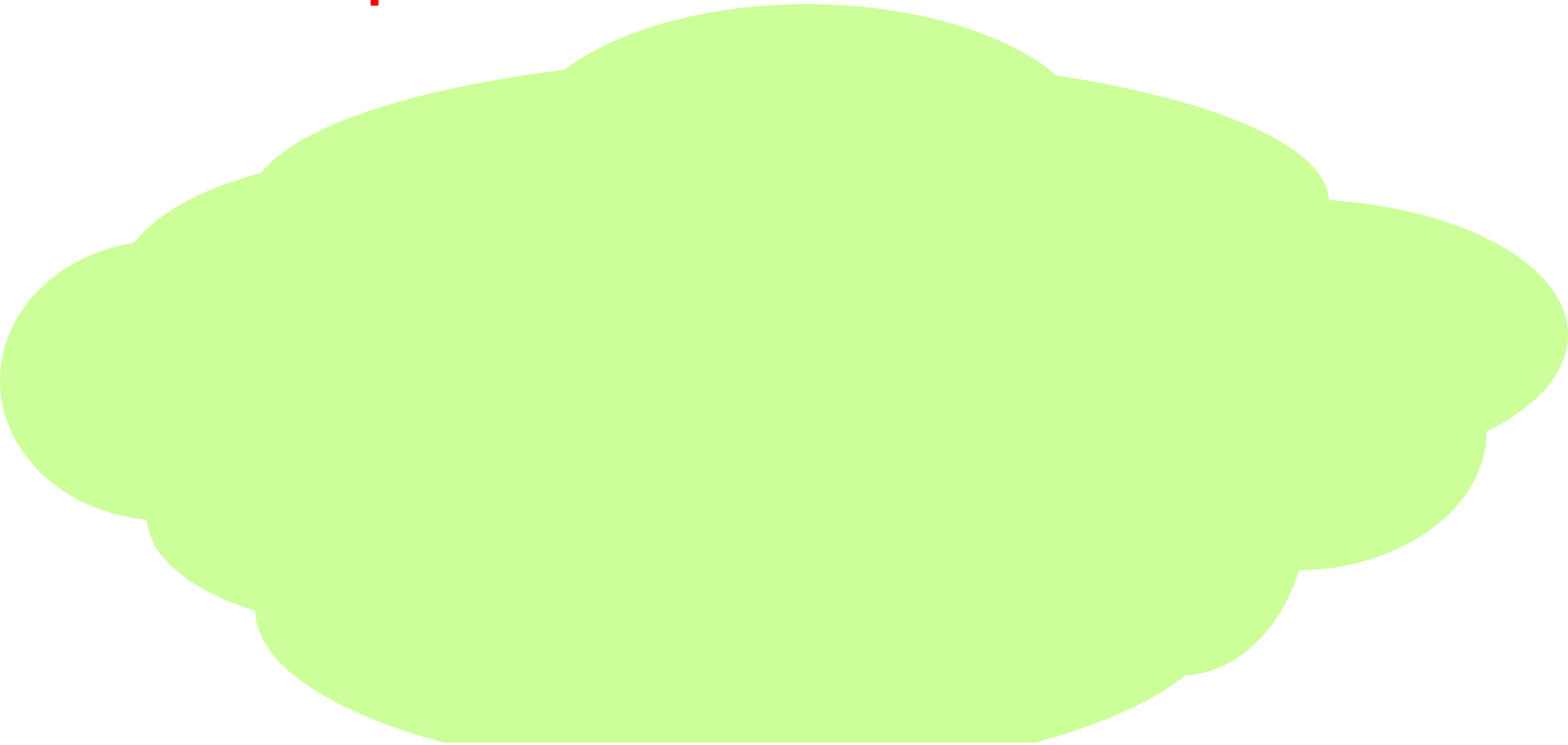
✓ designated

router id

ospf's view of the network

- by exchanging link state update packets, every router learns about the complete network topology, that is:
 - routers
 - subnets
 - adjacencies between routers and networks

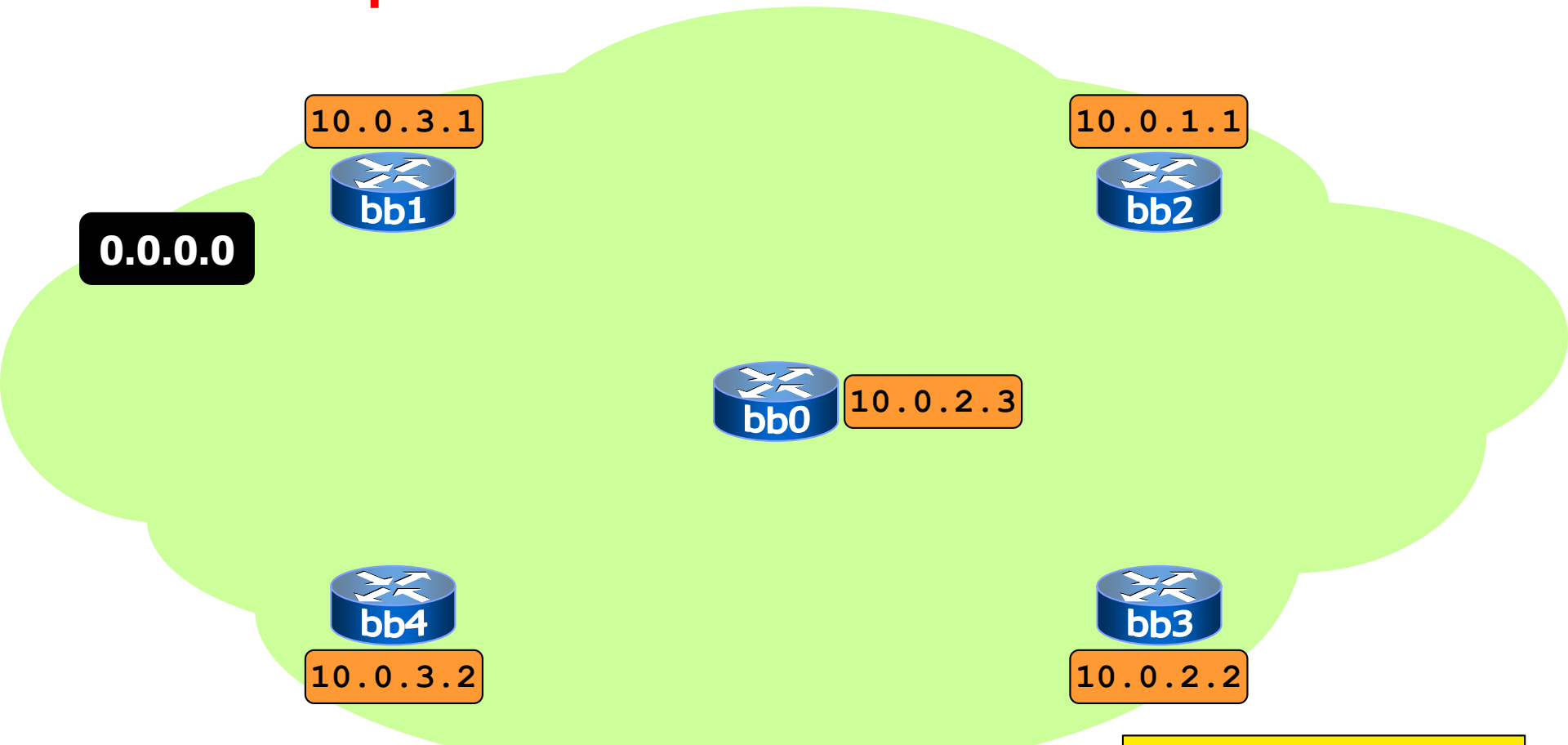
ospf's view of the network



bb0

```
bb0# show ip ospf database
```


ospf's view of the network



bb0

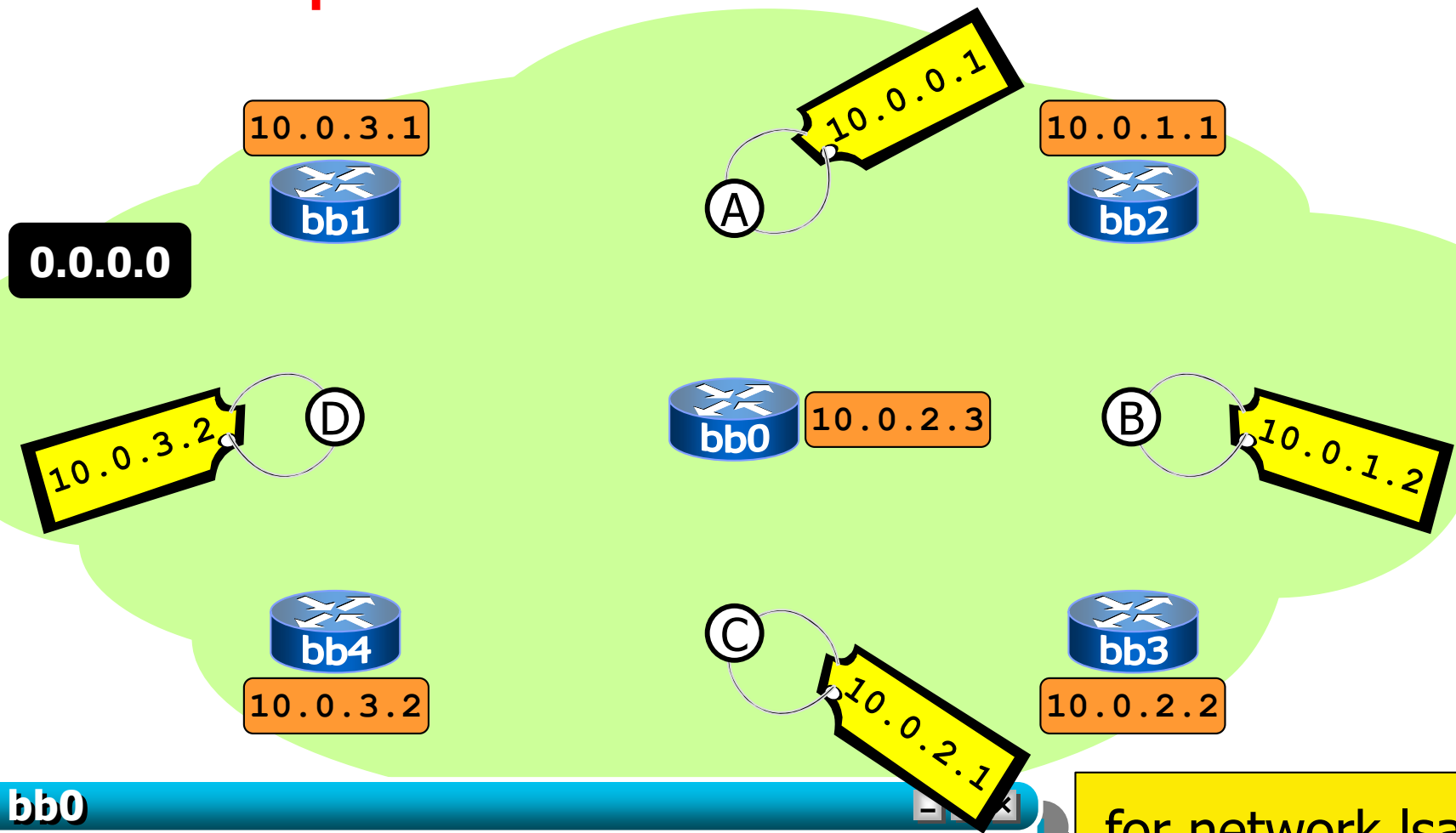
OSPF Router with ID (10.0.2.3)

Router Link States (Area 0.0.0.0)

Link ID	ADV Router	Age	Seq#	CkSum	Link count
10.0.1.1	10.0.1.1	553	0x80000003	0xe9fa	2
10.0.2.2	10.0.2.2	552	0x80000003	0xe3fa	2
10.0.2.3	10.0.2.3	552	0x80000003	0xe7cd	2
10.0.3.1	10.0.3.1	552	0x80000003	0x3288	2
10.0.3.2	10.0.3.2	548	0x80000004	0x488d	2

for router lsas,
the Link ID is
the router's id

ospf's view of the network

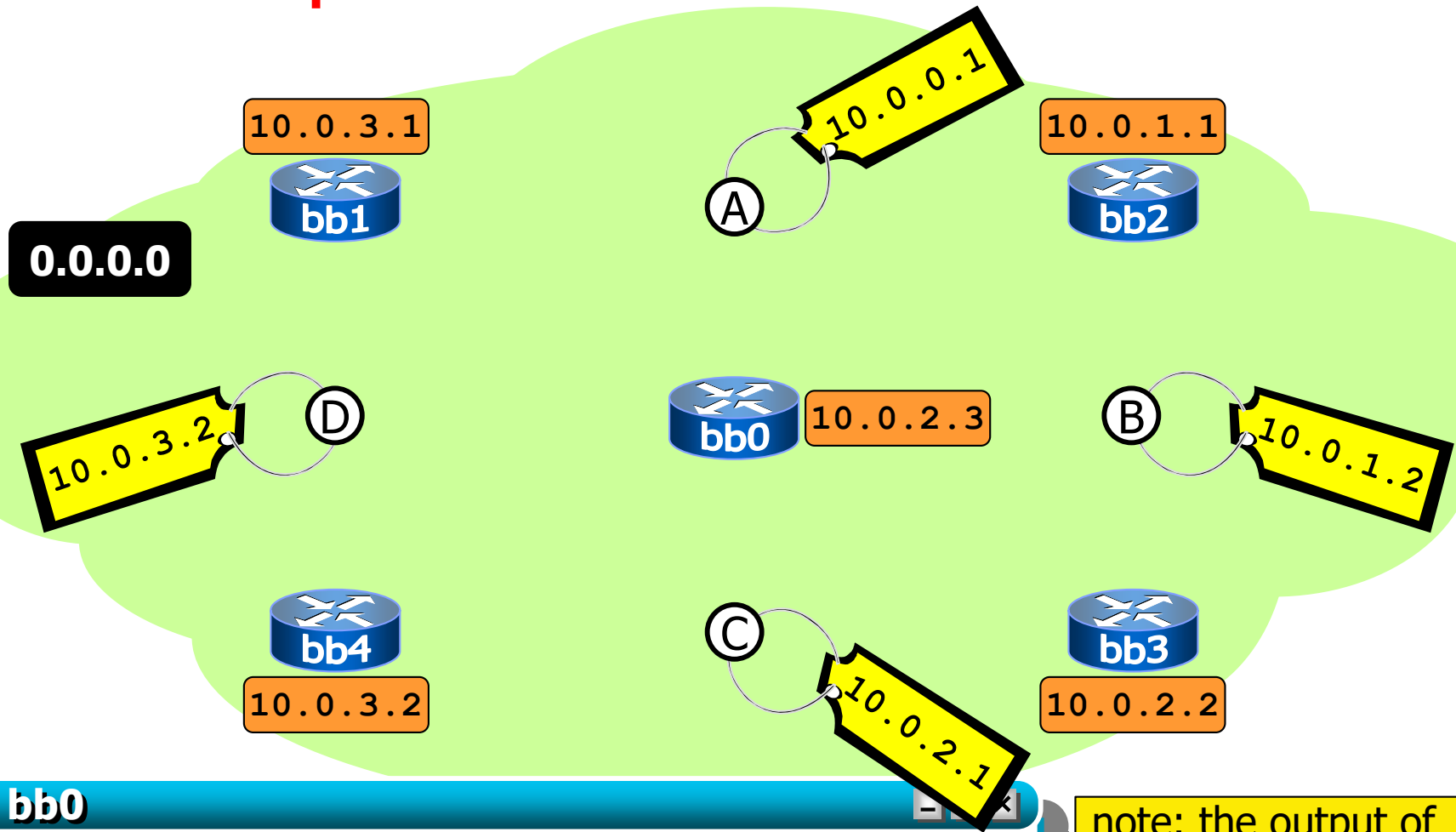


Net Link States (Area 0.0.0.0)				
Link ID	ADV Router	Age	Seq#	CkSum
10.0.0.1	10.0.3.1	557	0x80000001	0x6ba8
10.0.1.2	10.0.2.2	559	0x80000001	0x69bb
10.0.2.1	10.0.3.2	553	0x80000002	0x729a
10.0.3.2	10.0.3.2	553	0x80000001	0x6bb3

for network lsas,
the Link ID is
the dr's address

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ospf's view of the network

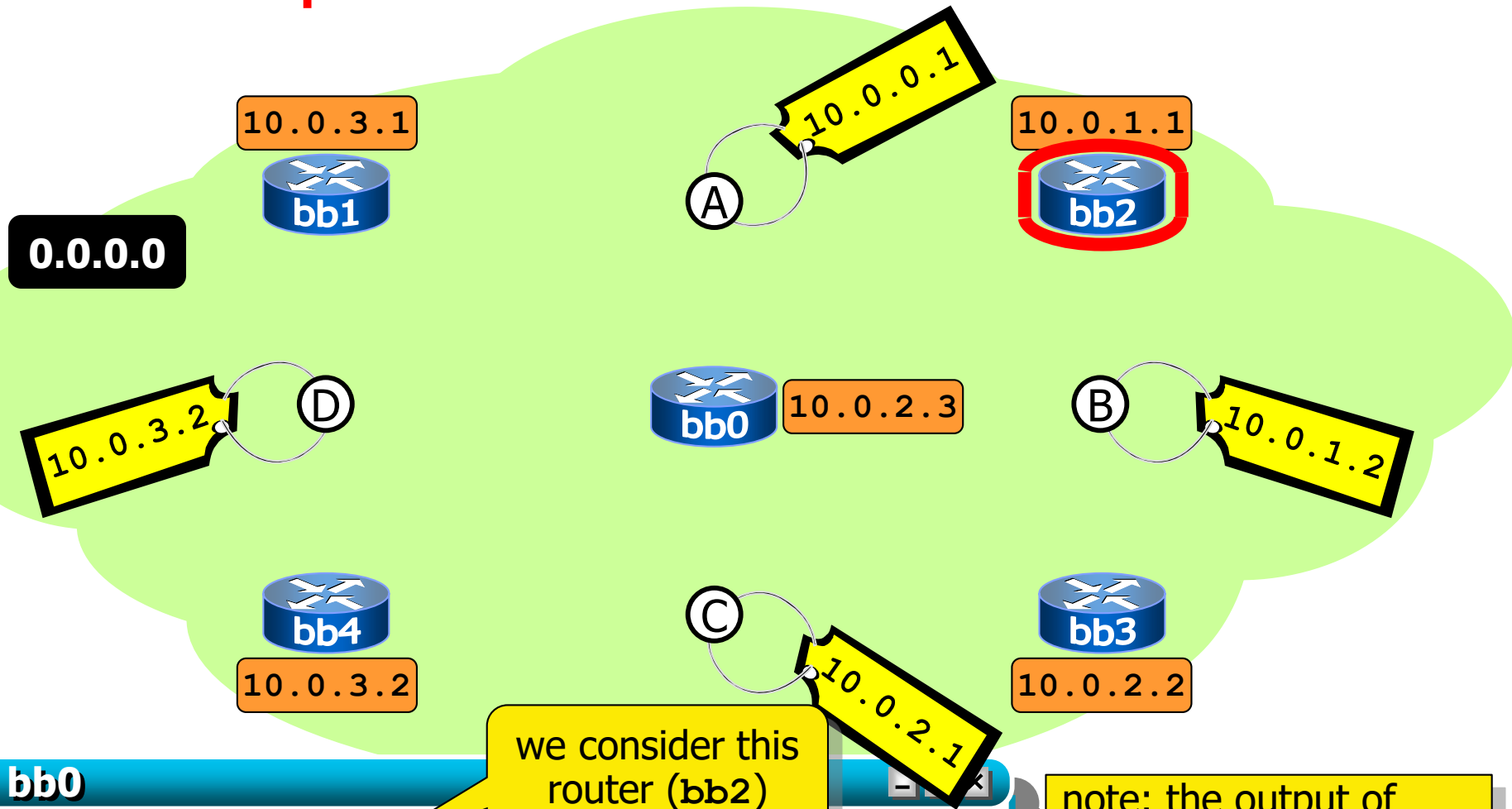


bb0

```
bb0# show ip ospf database router
Link State ID: 10.0.1.1
Number of Links: 2
Link connected to: a Transit Network
(Link ID) Designated Router address: 10.0.0.1
(Link Data) Router Interface address: 10.0.0.2
Link connected to: a Transit Network
(Link ID) Designated Router address: 10.0.1.2
(Link Data) Router Interface address: 10.0.1.1
```

note: the output of
**show ip ospf
database router**
has been summarized

ospf's view of the network

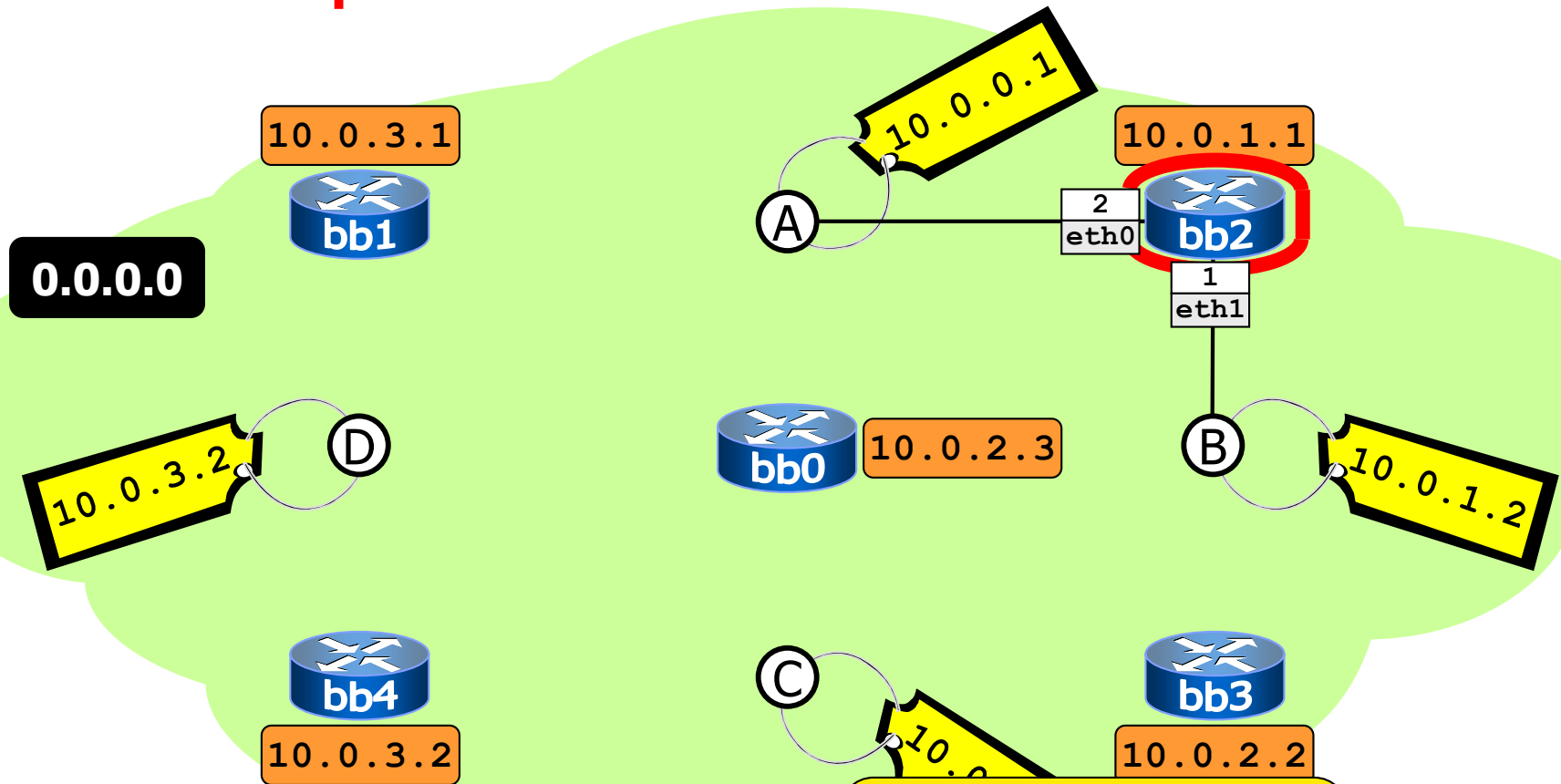


bb0

```
bb0# show ip ospf database router
Link State ID: 10.0.1.1
Number of Links: 2
Link connected to: a Transit Network
(Link ID) Designated Router address: 10.0.0.1
(Link Data) Router Interface address: 10.0.0.2
Link connected to: a Transit Network
(Link ID) Designated Router address: 10.0.1.2
(Link Data) Router Interface address: 10.0.1.1
```

note: the output of
**show ip ospf
database router**
has been summarized

ospf's view of the network



bb0

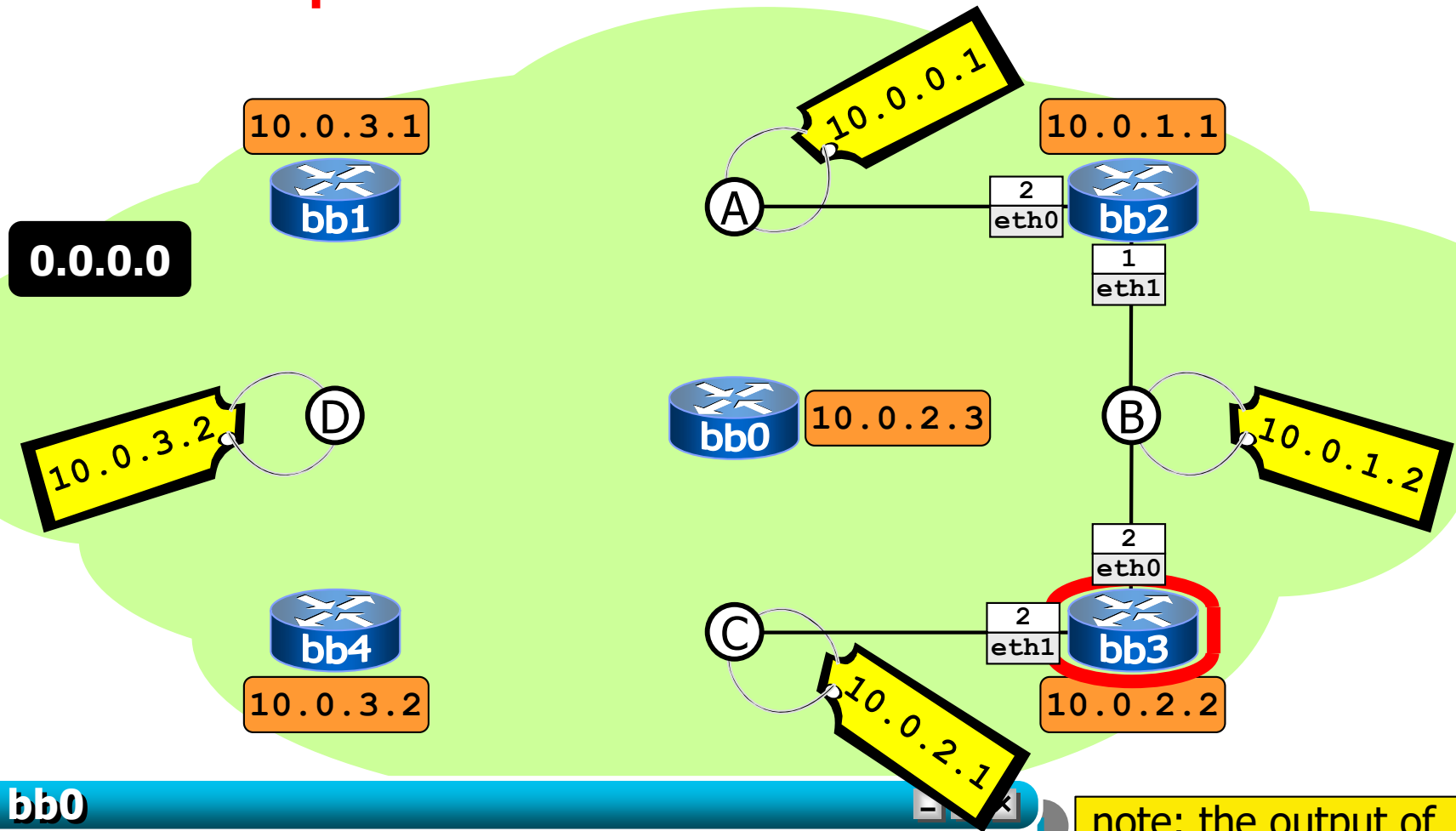
```
bb0# show ip ospf database
Link State ID: 0.0.0.0
Number of Links: 2
Link connected to: a Transit Network
(Link ID) Designated Router address: 10.0.0.1
(Link Data) Router Interface address: 10.0.0.2
Link connected to: a Transit Network
(Link ID) Designated Router address: 10.0.1.2
(Link Data) Router Interface address: 10.0.1.1
```

this router interface...

...is connected to the subnet represented by this dr

output of ospf database router has been summarized

ospf's view of the network

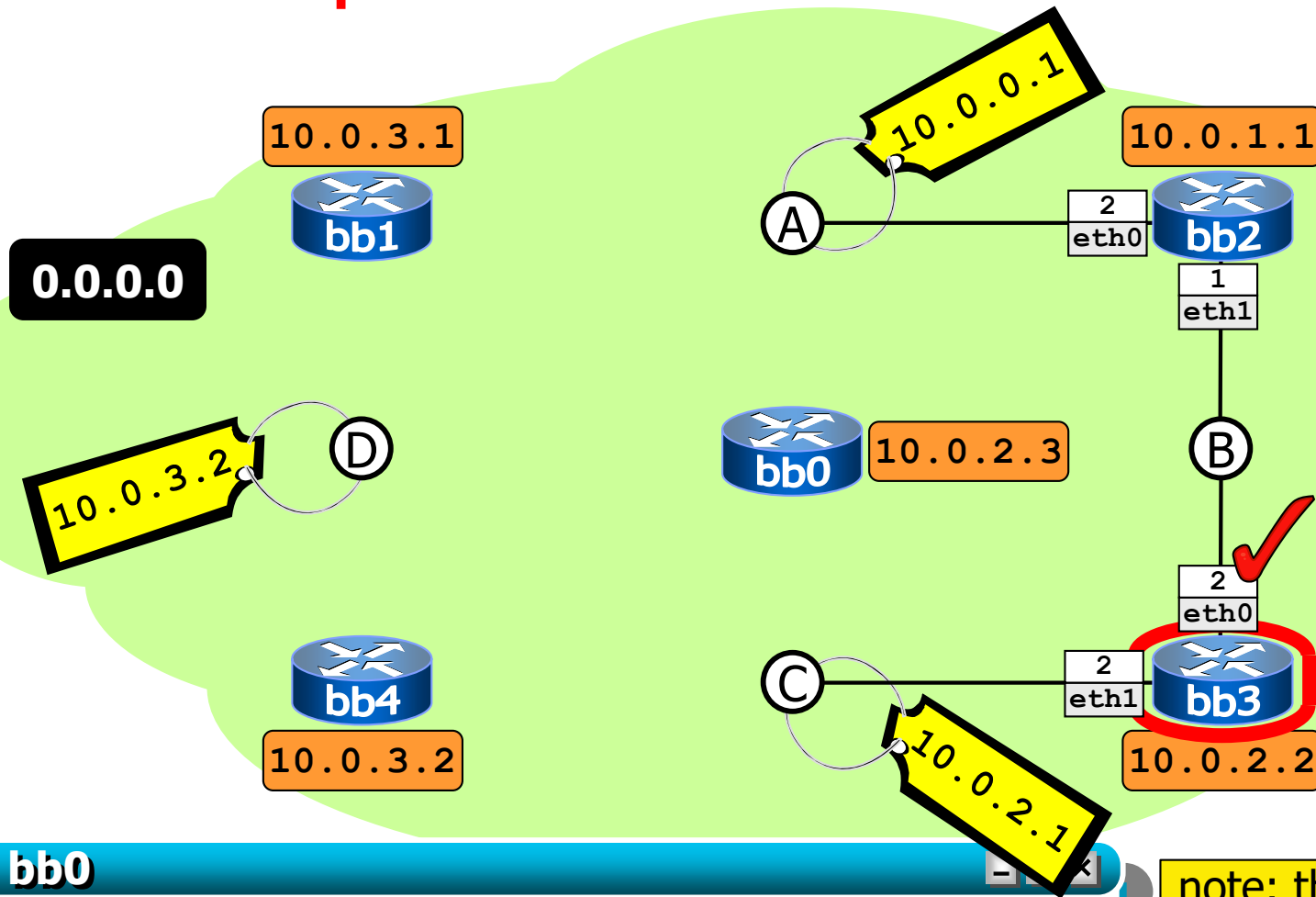


```
Link State ID: 10.0.2.2
Number of Links: 2
  Link connected to: a Transit Network
    (Link ID) Designated Router address: 10.0.1.2
    (Link Data) Router Interface address: 10.0.1.2
  Link connected to: a Transit Network
    (Link ID) Designated Router address: 10.0.2.1
    (Link Data) Router Interface address: 10.0.2.2
```

note: the output of
show ip ospf
database router
has been summarized

last update: Nov 2018

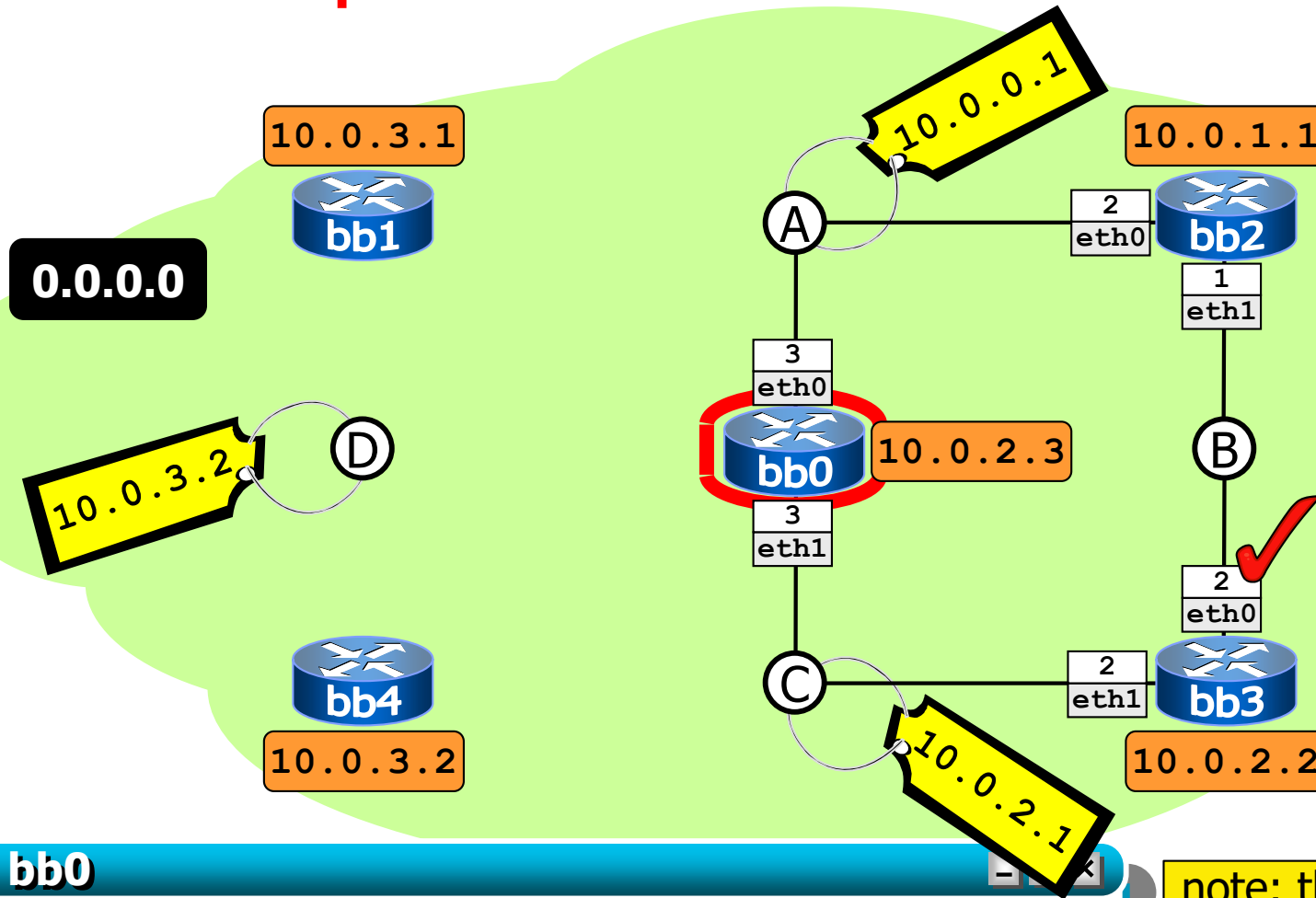
ospf's view of the network



note: the output of
show ip ospf
database router
has been summarized

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ospf's view of the network

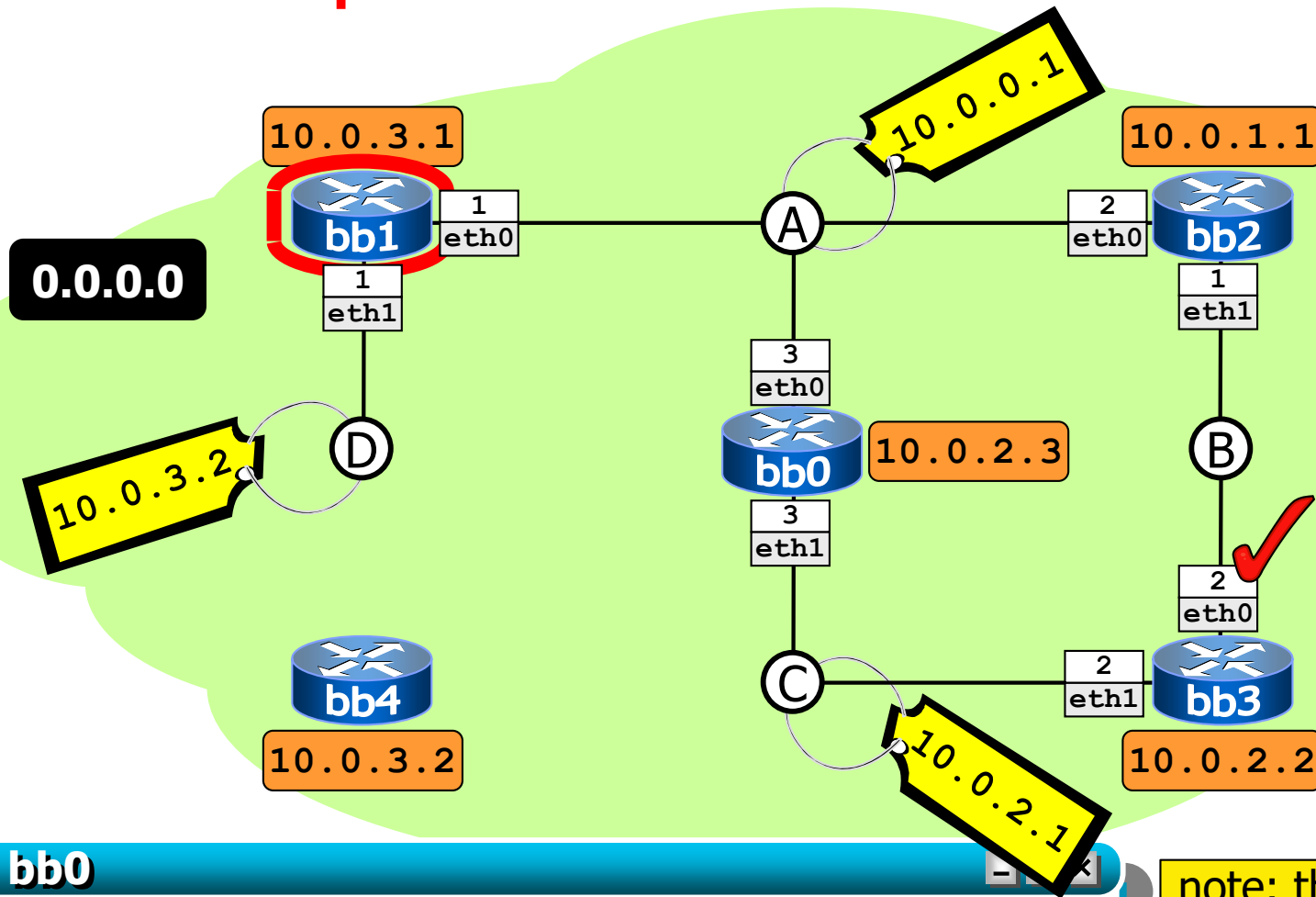


bb0

Link State ID: 10.0.2.3
Number of Links: 2
Link connected to: a Transit Network
(Link ID) Designated Router address: 10.0.0.1
(Link Data) Router Interface address: 10.0.0.3
Link connected to: a Transit Network
(Link ID) Designated Router address: 10.0.2.1
(Link Data) Router Interface address: 10.0.2.3 ■

note: the output of
**show ip ospf
database router**
has been summarized

ospf's view of the network

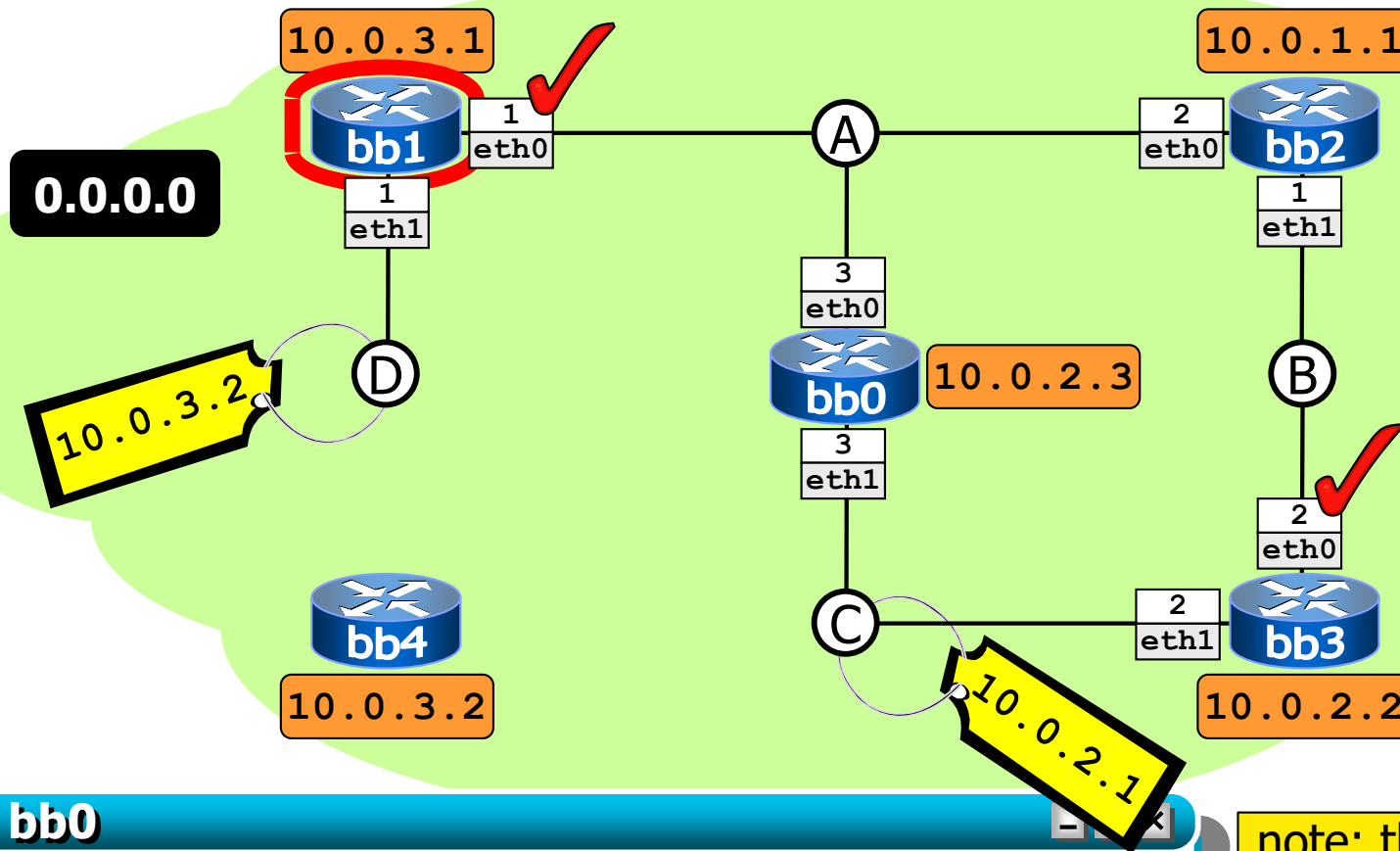


▼ **bb0**

Link State ID: 10.0.3.1
Number of Links: 2
Link connected to: a Transit Network
(Link ID) Designated Router address: 10.0.0.1
(Link Data) Router Interface address: 10.0.0.1
Link connected to: a Transit Network
(Link ID) Designated Router address: 10.0.3.2
(Link Data) Router Interface address: 10.0.3.1 ■

note: the output of
**show ip ospf
database router**
has been summarized

ospf's view of the network

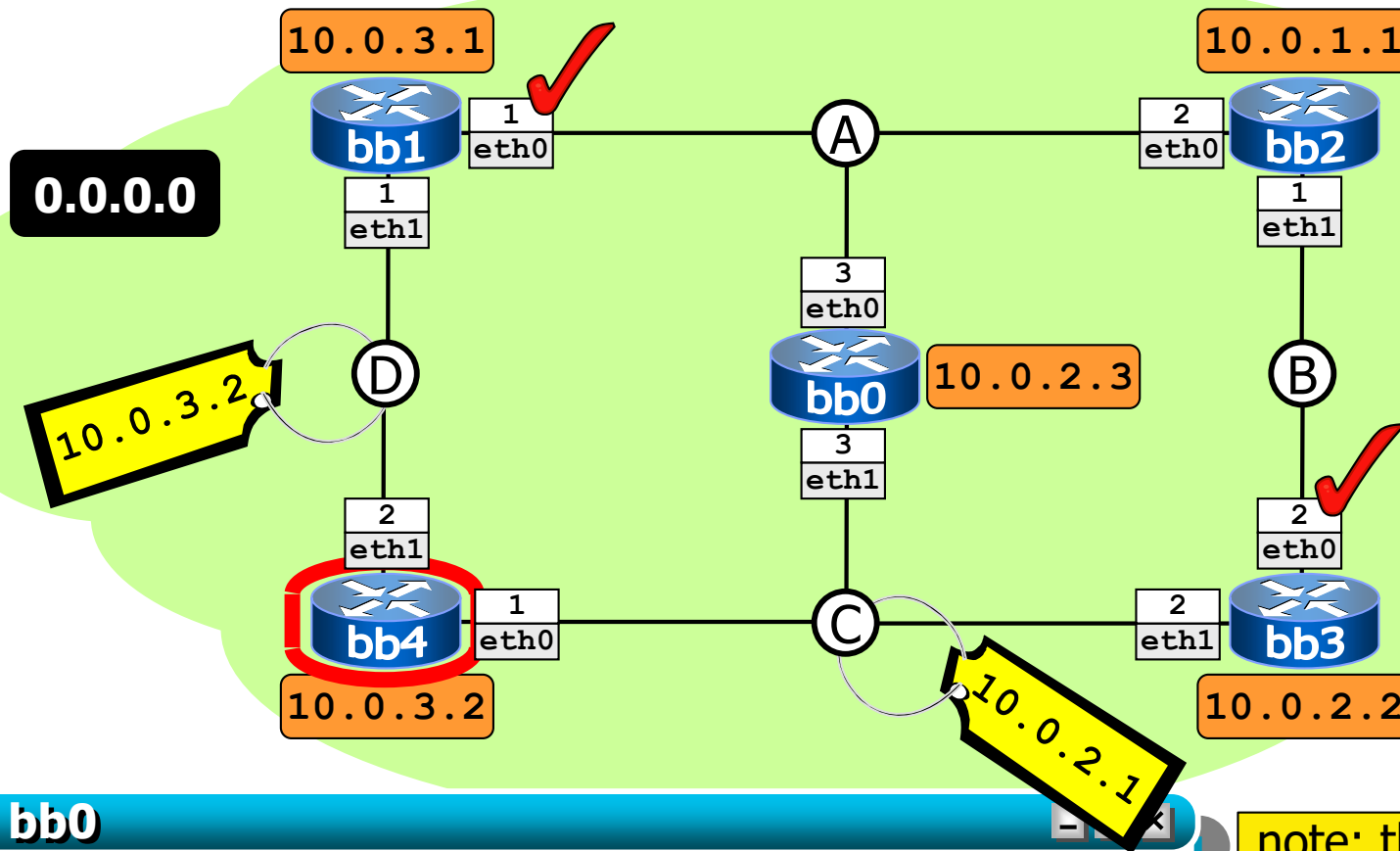


bb0

Link State ID: 10.0.3.1
Number of Links: 2
Link connected to: a Transit Network
(Link ID) Designated Router address: 10.0.0.1
(Link Data) Router Interface address: 10.0.0.1
Link connected to: a Transit Network
(Link ID) Designated Router address: 10.0.3.2
(Link Data) Router Interface address: 10.0.3.1 ■

note: the output of
**show ip ospf
database router**
has been summarized

ospf's view of the network

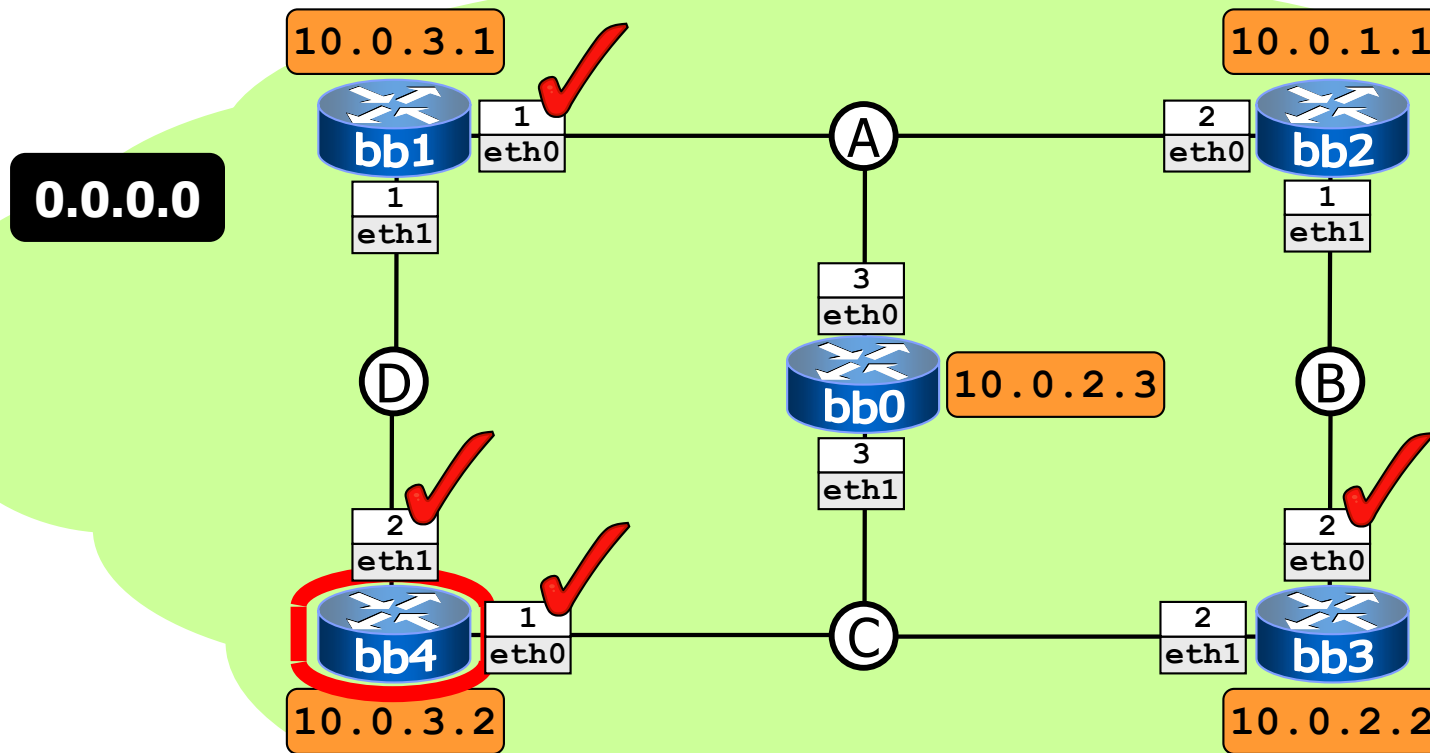


bb0

Link State ID: 10.0.3.2
Number of Links: 2
Link connected to: a Transit Network
(Link ID) Designated Router address: 10.0.2.1
(Link Data) Router Interface address: 10.0.2.1
Link connected to: a Transit Network
(Link ID) Designated Router address: 10.0.3.2
(Link Data) Router Interface address: 10.0.3.2 ■

note: the output of
**show ip ospf
database router**
has been summarized

ospf's view of the network

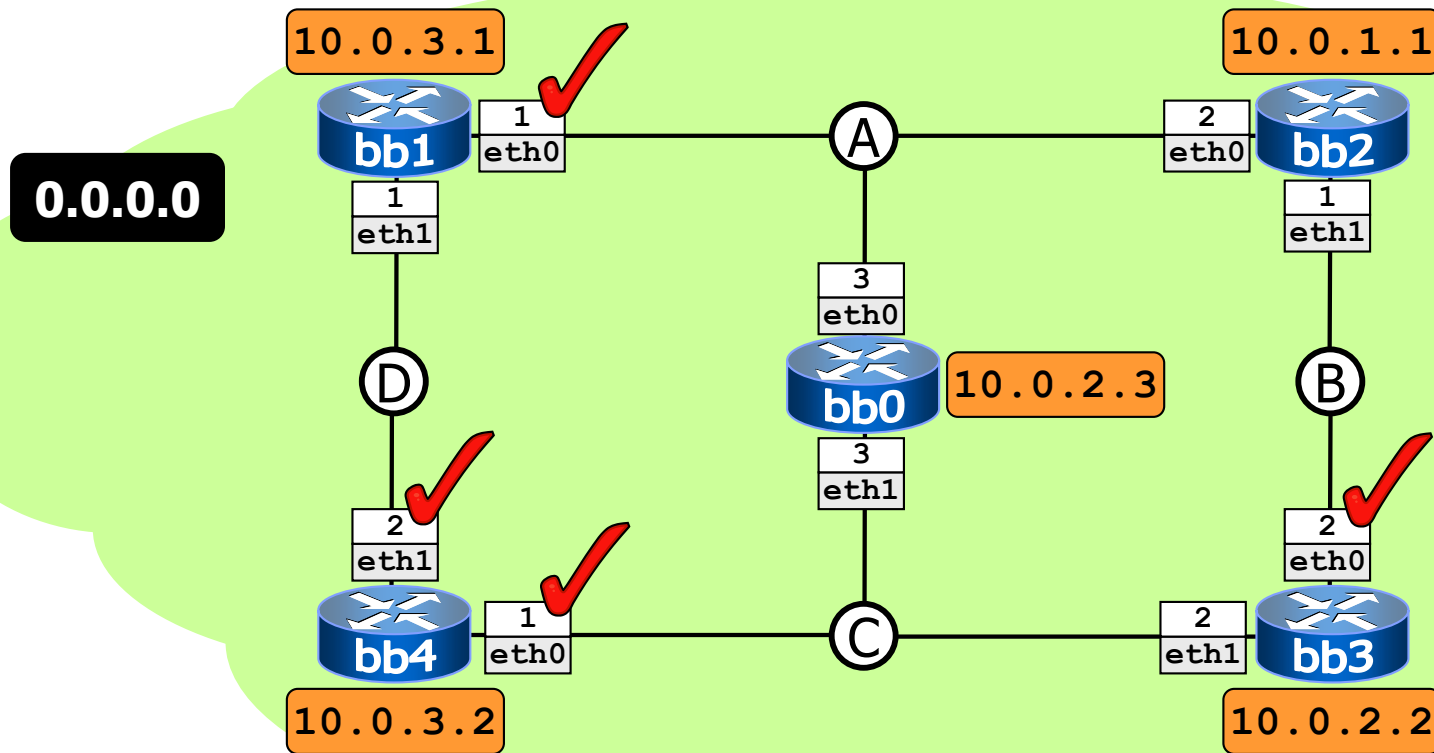


bb0

```
Link State ID: 10.0.3.2
Number of Links: 2
Link connected to: a Transit Network
(Link ID) Designated Router address: 10.0.2.1
(Link Data) Router Interface address: 10.0.2.1
Link connected to: a Transit Network
(Link ID) Designated Router address: 10.0.3.2
(Link Data) Router Interface address: 10.0.3.2 ■
```

note: the output of
**show ip ospf
database router**
has been summarized

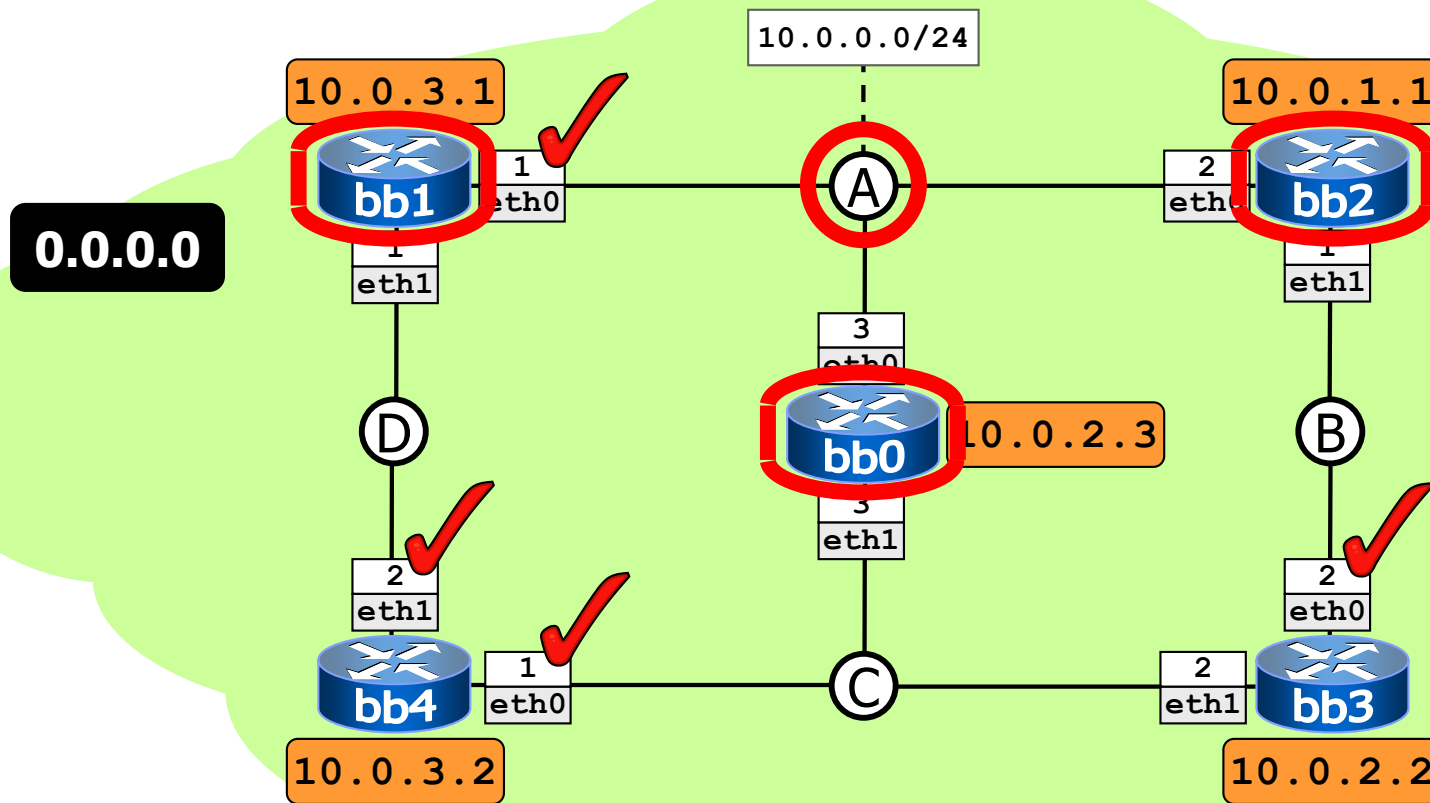
ospf's view of the network



bb0

```
bb0# show ip ospf database network
```

ospf's view of the network

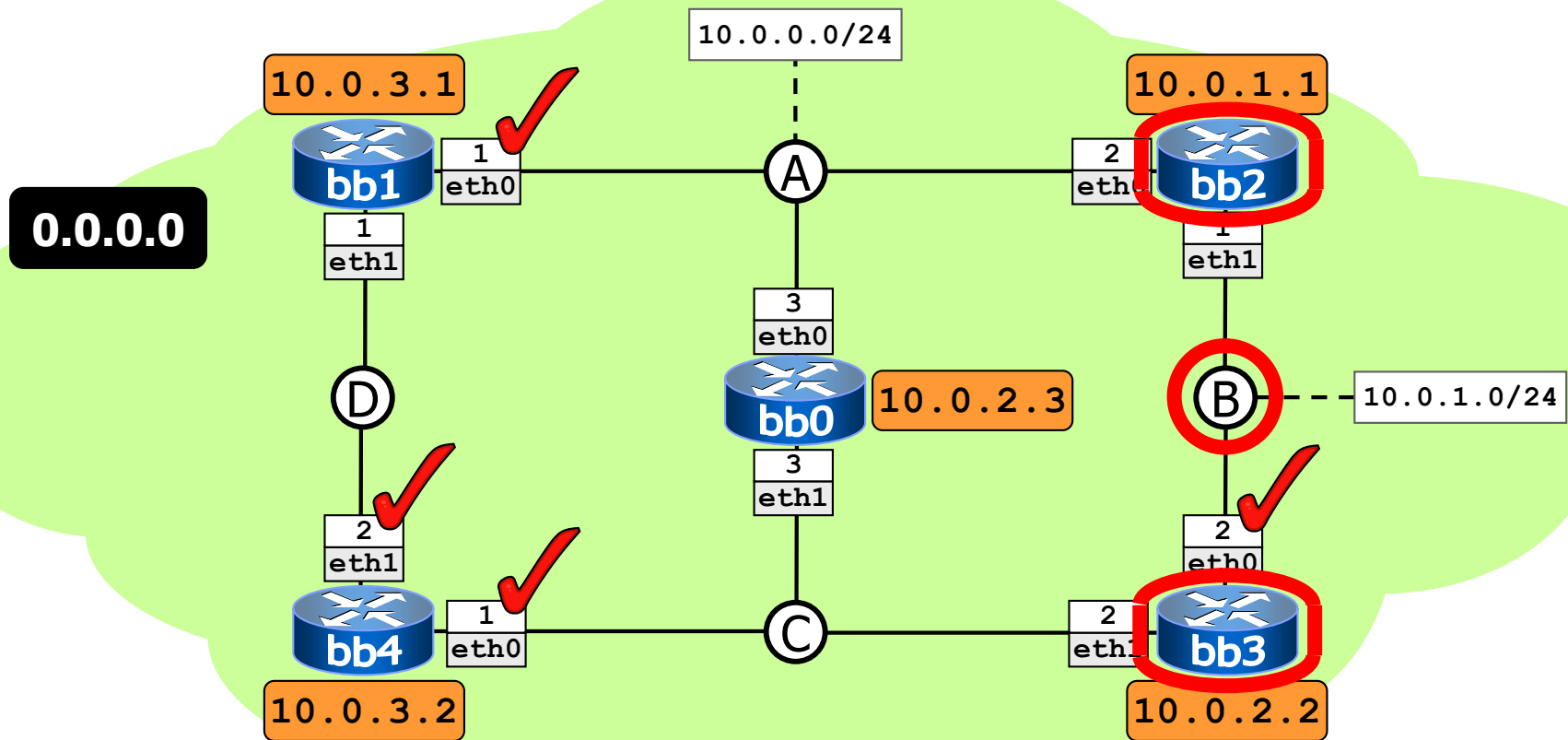


bb0

Link State ID: 10.0.0.1 (address of Designated Router)
Advertising Router: 10.0.3.1
Network Mask: /24
Attached Router: 10.0.3.1
Attached Router: 10.0.1.1
Attached Router: 10.0.2.3

note: the output of
`show ip ospf
database network`
has been summarized

ospf's view of the network

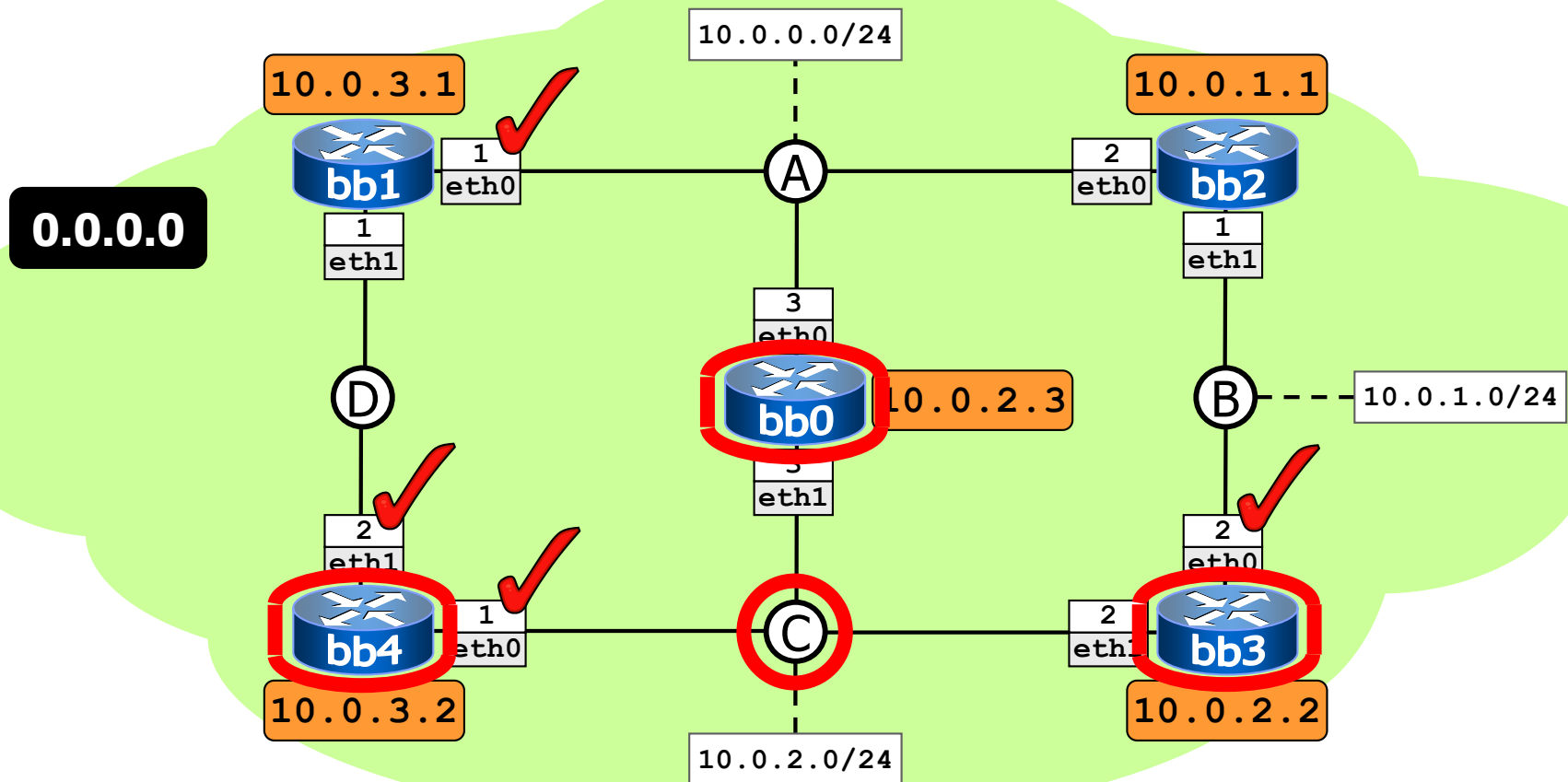


bb0

Link State ID: 10.0.1.2 (address of Designated Router)
Advertising Router: 10.0.2.2
Network Mask: /24
Attached Router: 10.0.1.1
Attached Router: 10.0.2.2 ■

note: the output of
`show ip ospf
database network`
has been summarized

ospf's view of the network

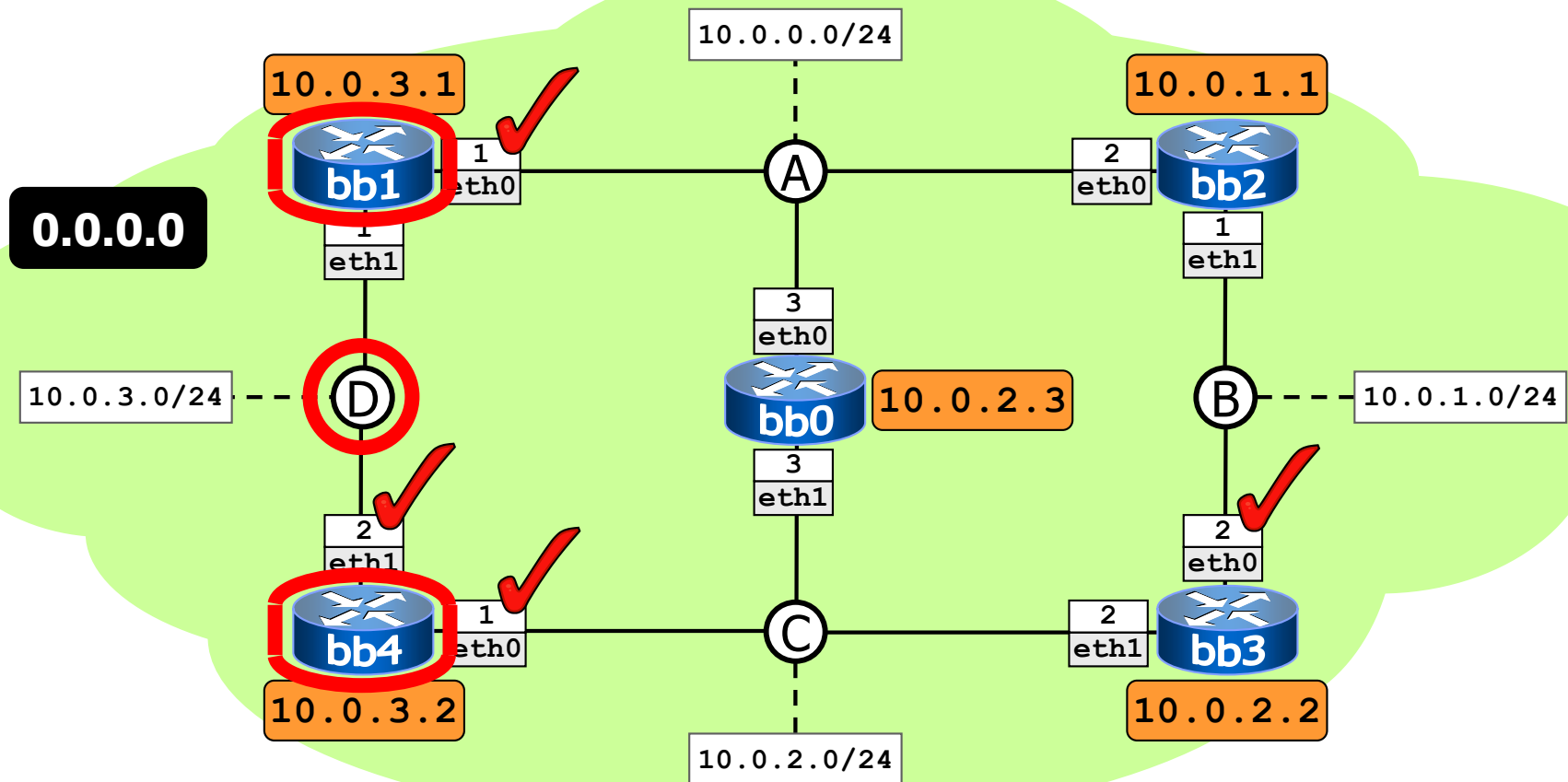


bb0

Link State ID: 10.0.2.1 (address of Designated Router)
Advertising Router: 10.0.3.2
Network Mask: /24
Attached Router: 10.0.3.2
Attached Router: 10.0.2.2
Attached Router: 10.0.2.3

note: the output of
`show ip ospf
database network`
has been summarized

ospf's view of the network

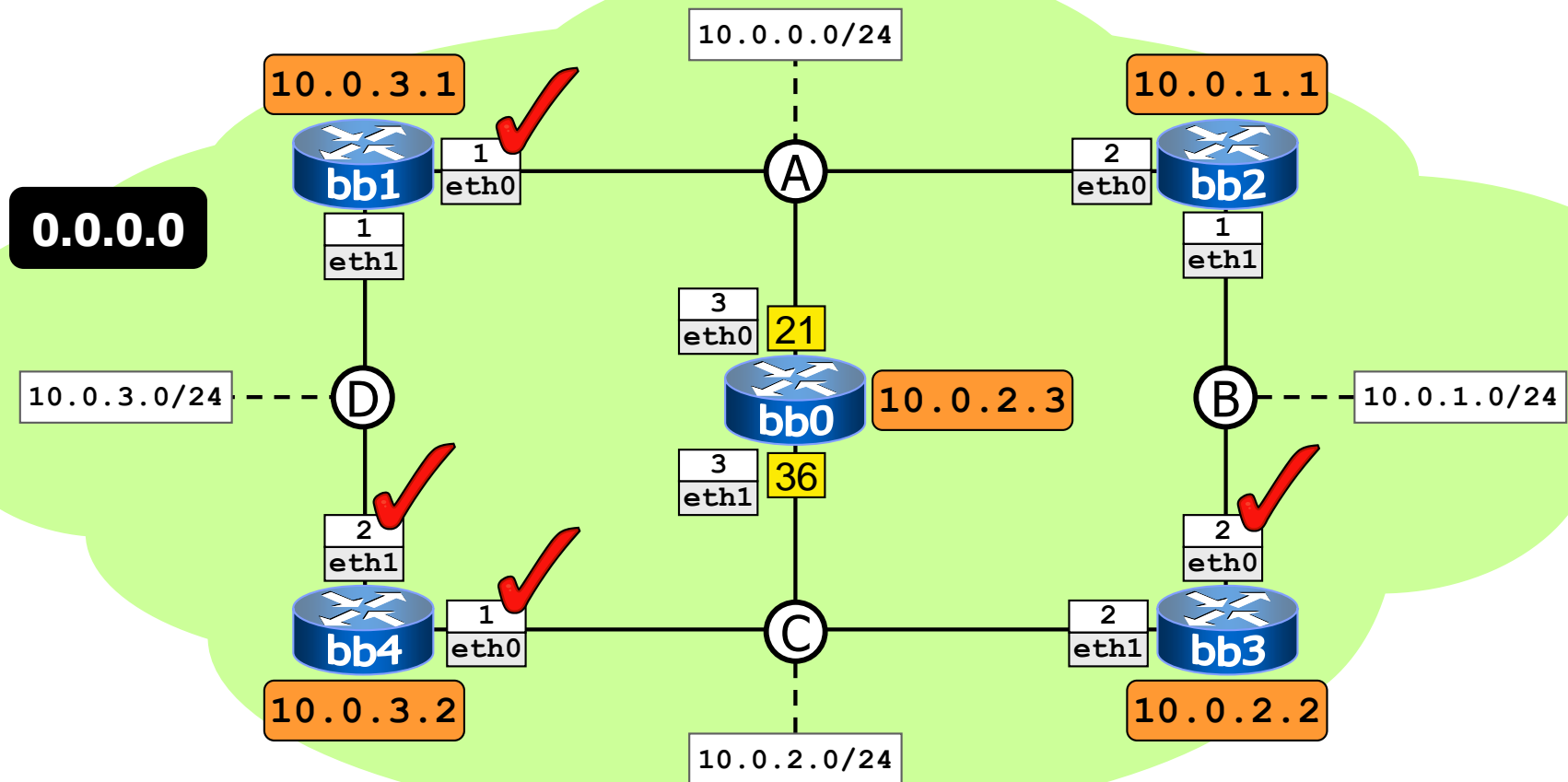


```
Link State ID: 10.0.3.2 (address of Designated Router)
Advertising Router: 10.0.3.2
Network Mask: /24
    Attached Router: 10.0.3.1
    Attached Router: 10.0.3.2
```

note: the output of
**show ip ospf
database network**
has been summarized

last update: Nov 2018

ospf's view of the network



bb0

```
bb0:~# vtysh -e "show ip ospf interface" | egrep "eth|Cost"
eth0 is up
  Router ID 10.0.2.3, Network Type BROADCAST, Cost: 21
eth1 is up
  Router ID 10.0.2.3, Network Type BROADCAST, Cost: 36
```

a shortcut to quickly
get the cost

ospf interface costs can
be queried on all
routers

last update: Nov 2018

neighborhood

- router neighbors can be shown by using the `show ip ospf neighbor` command
- note: lsas are only sent between neighbors in **Fu11** state (i.e., capable of a bidirectional exchange of information); reaching the **Fu11** state requires that:
 - neighbors have been discovered (using hello packets)
 - bidirectional communication is possible
 - a designated router has been elected
- once reached, routers immediately synchronize their lsdb's

```
bb0# show ip ospf neighbor
```

Neighbor ID	Pri	State	Dead Time	Address	Interface	RXmtL	RqstL	DBsmL
10.0.3.1	1	Fu11/DR	30.462s	10.0.0.1	eth0:10.0.0.3	0	0	0
10.0.1.1	1	Fu11/DROther	30.462s	10.0.0.2	eth0:10.0.0.3	0	0	0
10.0.3.2	1	Fu11/DR	31.587s	10.0.2.1	eth1:10.0.2.3	0	0	0
10.0.2.2	1	Fu11/DROther	31.586s	10.0.2.2	eth1:10.0.2.3	0	0	0

```
bb0#
```

ospf routing table

- the ospf routing table can be dumped by using **show ip ospf route**

```
bb0# show ip ospf route
===== OSPF network routing table =====
N    10.0.0.0/24          [21] area: 0.0.0.0
                        directly attached to eth0
N    10.0.1.0/24          [31] area: 0.0.0.0
                        via 10.0.0.2, eth0
N    10.0.2.0/24          [36] area: 0.0.0.0
                        directly attached to eth1
N    10.0.3.0/24          [46] area: 0.0.0.0
                        via 10.0.2.1, eth1

===== OSPF router routing table =====
R    10.0.1.1             [21] area: 0.0.0.0, ASBR
                        via 10.0.0.2, eth0
R    10.0.2.2             [31] area: 0.0.0.0, ASBR
                        via 10.0.0.2, eth0
R    10.0.3.1             [21] area: 0.0.0.0, ASBR
                        via 10.0.0.1, eth0
R    10.0.3.2             [36] area: 0.0.0.0, ASBR
                        via 10.0.2.1, eth1

===== OSPF external routing table =====
bb0#
```

route
cost

experiments

- issue the `show ip ospf database` and `show ip ospf neighbor` commands on different routers
- capture and look at exchanged ospf packets using `tcpdump`

ospf is fast at detecting topology changes



■ case #1: link fault

■ bring down a single network interface using **ifconfig**

- the change is **immediately** propagated by the router inside lsa packets
- routing tables are **immediately** updated (**show ip ospf route**)



ospf is fast at detecting topology changes



- case #1: link fault
 - bring down a single network interface using **ifconfig**
 - the change is **immediately** propagated by the router inside lsa packets
 - routing tables are **immediately** updated (**show ip ospf route**)
 - the lsdb is handled a little differently...

ospf is fast at detecting topology changes



■ case #1: link fault

■ bring down a single network interface using **ifconfig**

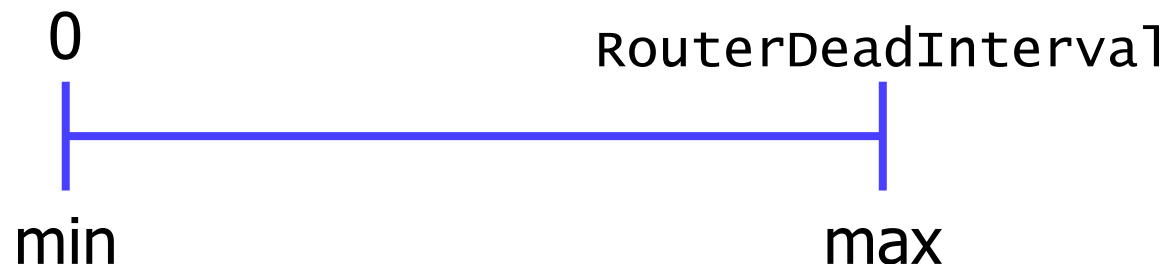
- if this brings down a dr, the information is immediately flushed from the lsdb(s)...
 - ...and eventually reannounced when a dr is re-elected
- otherwise, ospf waits expiry of the RouterDeadInterval timer (default: 40s) before removing the adjacency from the lsdb (**show ip ospf database network**)
 - note: networks that are connected to one router only, called **stub networks**, are only visible using **show ip ospf database router**

ospf is fast at detecting topology changes



- case #1: link fault
 - bring down a single network interface using `ifconfig`

overall reaction time (estimated)



ospf is (often) fast at detecting topology changes



- case #2: router fault
 - bring down a router (by crashing it or by shutting down all its interfaces simultaneously)
 - the router has no chance to propagate lsas
 - the change *cannot* be immediately propagated
 - neighboring routers can only realize it (and update routing tables) after expiry of the RouterDeadInterval timer

ospf is (often) fast at detecting topology changes



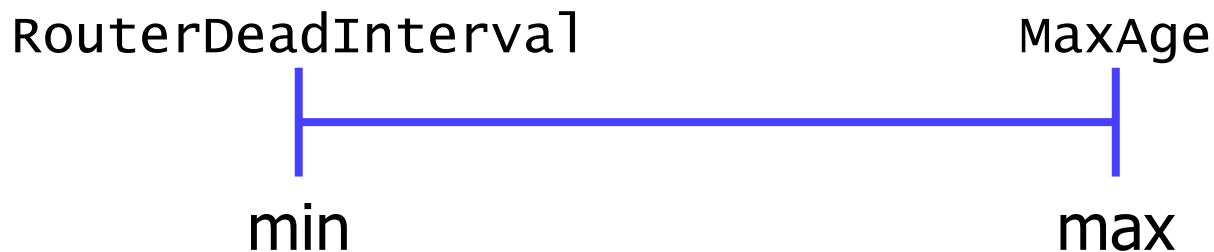
- case #2: router fault
 - bring down a router (by crashing it or by shutting down all its interfaces simultaneously)
 - after the change has been propagated...
 - ...lsdb information about networks for which the failed router was not dr is immediately flushed from other routers' lsdb
 - the dr takes care of sending appropriate lsas
 - ...lsdb information about networks for which the failed router was dr (including those where a dr will be re-elected) and about routers is more "tough"
 - ospf waits for the lsa to expire (expiration happens when the age of the lsa reaches the MaxAge value of **1 hour**) before taking any actions

ospf is (often) fast at detecting topology changes



- case #2: router fault
 - bring down a router (by crashing it or by shutting down all its interfaces simultaneously)

overall reaction time (estimated)



lab: ospf-multiarea

ospf areas

- an abstraction that simplifies administration and improves scalability
 - the topology of an area is invisible from the outside
 - routers internal to a given area don't see the detailed external topology
- each area runs a separate instance of the link state routing algorithm
 - all routers in an area construct the same lsdb
 - each router keeps a distinct lsdb for each area it belongs to

ospf areas

- identified by a 32-bit number,
often in dotted decimal notation (1.2.3.4)
 - different interfaces of the same router can be assigned to different areas
 - each
 - router interface...
 - network...
 - router adjacency...
- ...is associated with a single area

area types



- **backbone (0.0.0.0)**
 - must be (virtually) connected
 - all other areas are connected to it
 - contains all the area border routers
- **stub**
 - does not receive advertisements of external routes
 - internal nodes are offered a default route
 - cannot contain autonomous system boundary routers
 - the backbone can't be a stub area
- **transit**
 - used to pass traffic from one adjacent area to another, via virtual links

1.1.1.1

stub

2.2.2.2

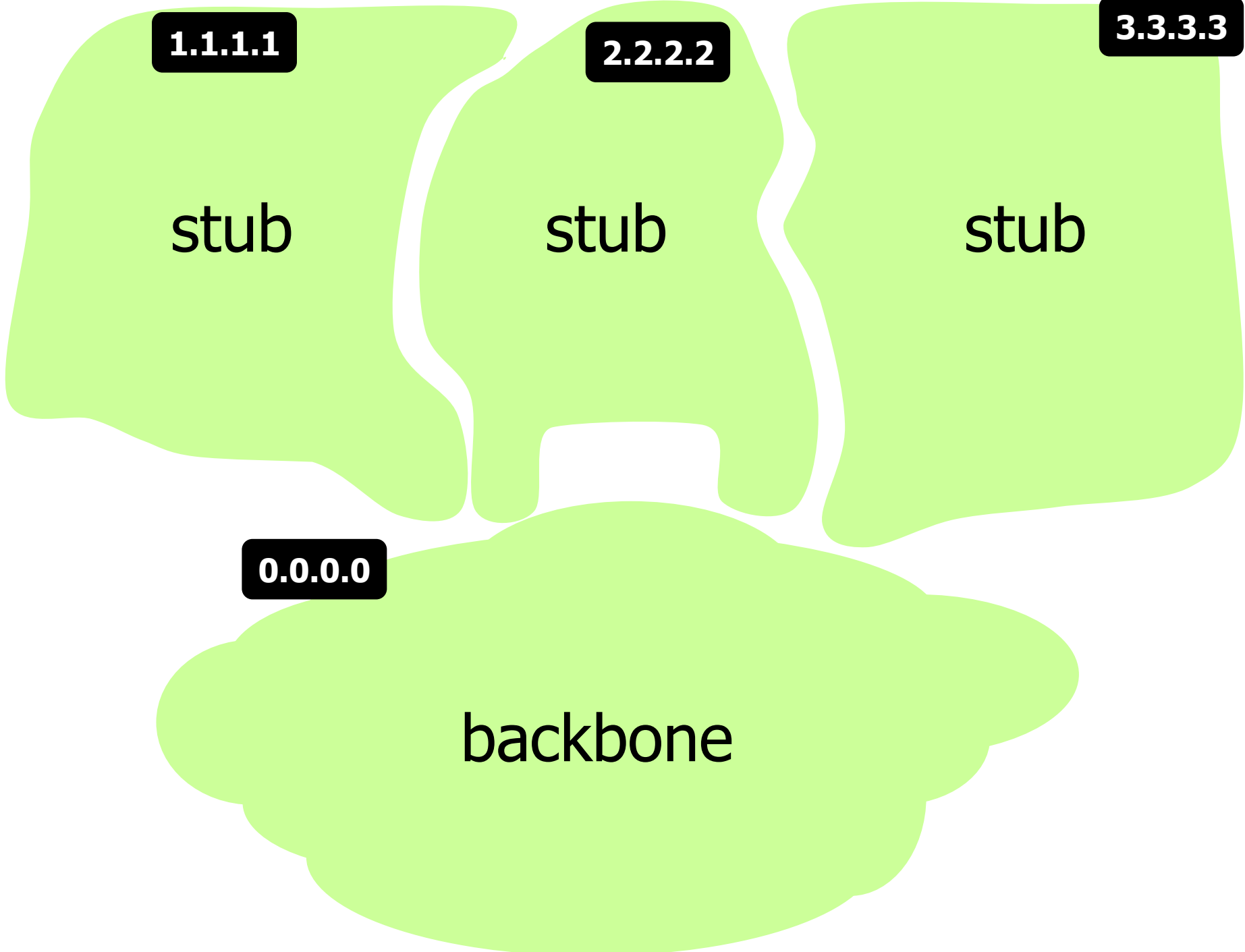
stub

3.3.3.3

stub

0.0.0.0

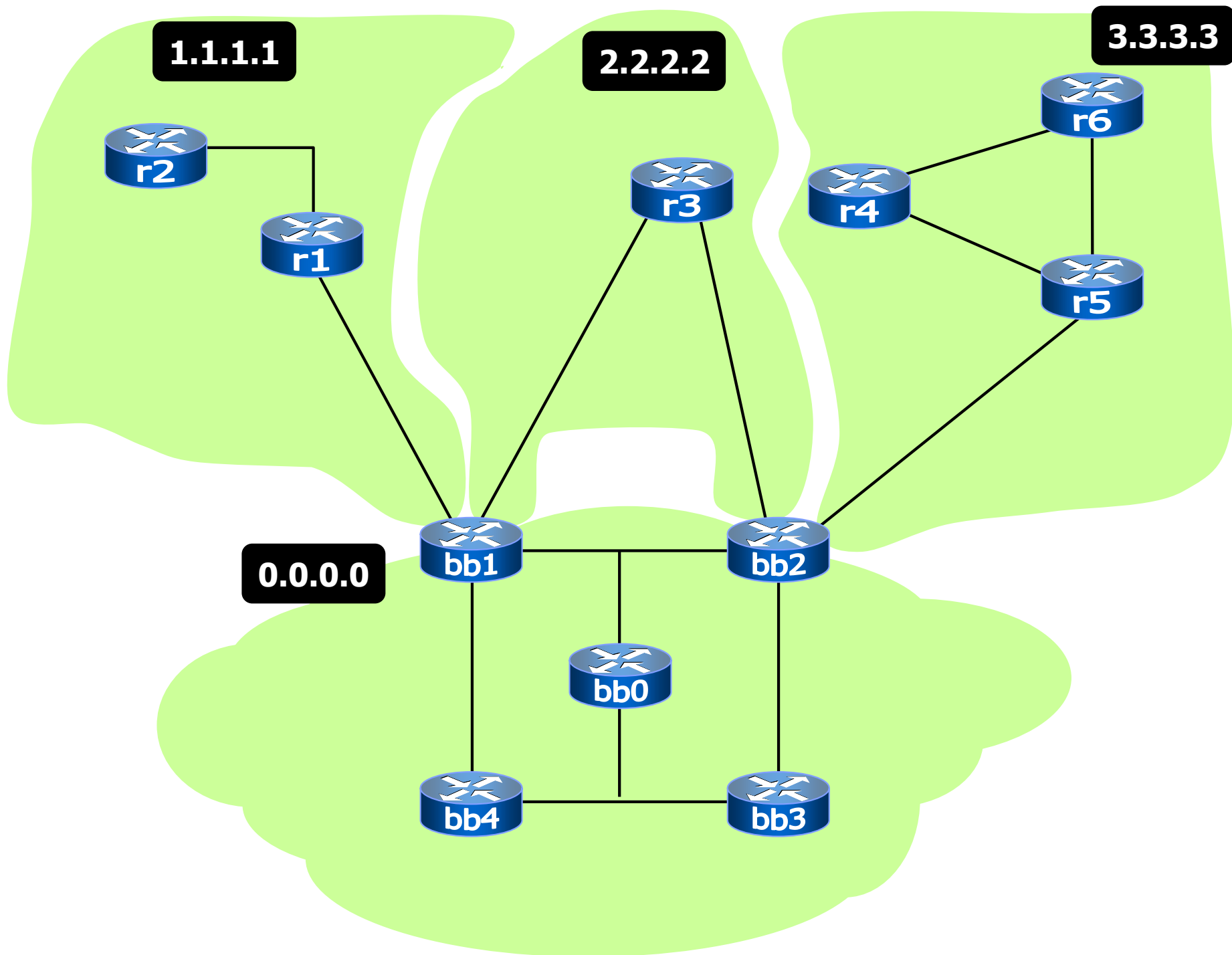
backbone



router types



- internal router
 - all interfaces belong to the same area
- area border router (abr)
 - connects one or more areas to the backbone
 - keeps multiple lsdb's, one for each area
- backbone router
 - has at least one interface connected to the backbone
 - an abr is always a backbone router
- autonomous system boundary router (asbr)
 - imports and floods routing information from other routing protocols (typically, bgp)
- note: a router can be of more than one type



1.1.1.1



2.2.2.2



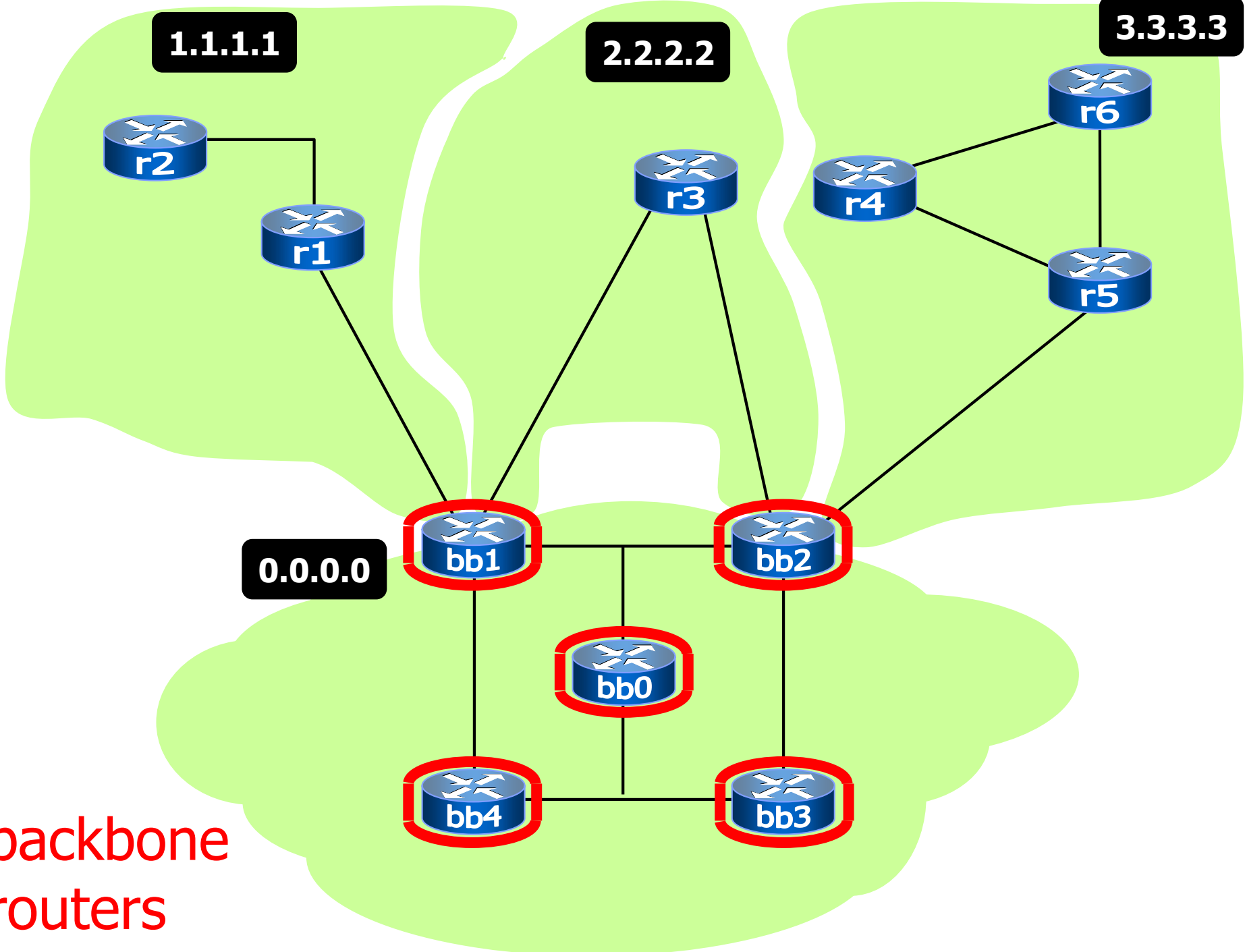
3.3.3.3



0.0.0.0



backbone
routers



1.1.1.1

2.2.2.2

3.3.3.3



0.0.0.0



area border
routers

1.1.1.1

2.2.2.2

3.3.3.3

r2

r1

r3

r4

r6

r5

bb1

bb2

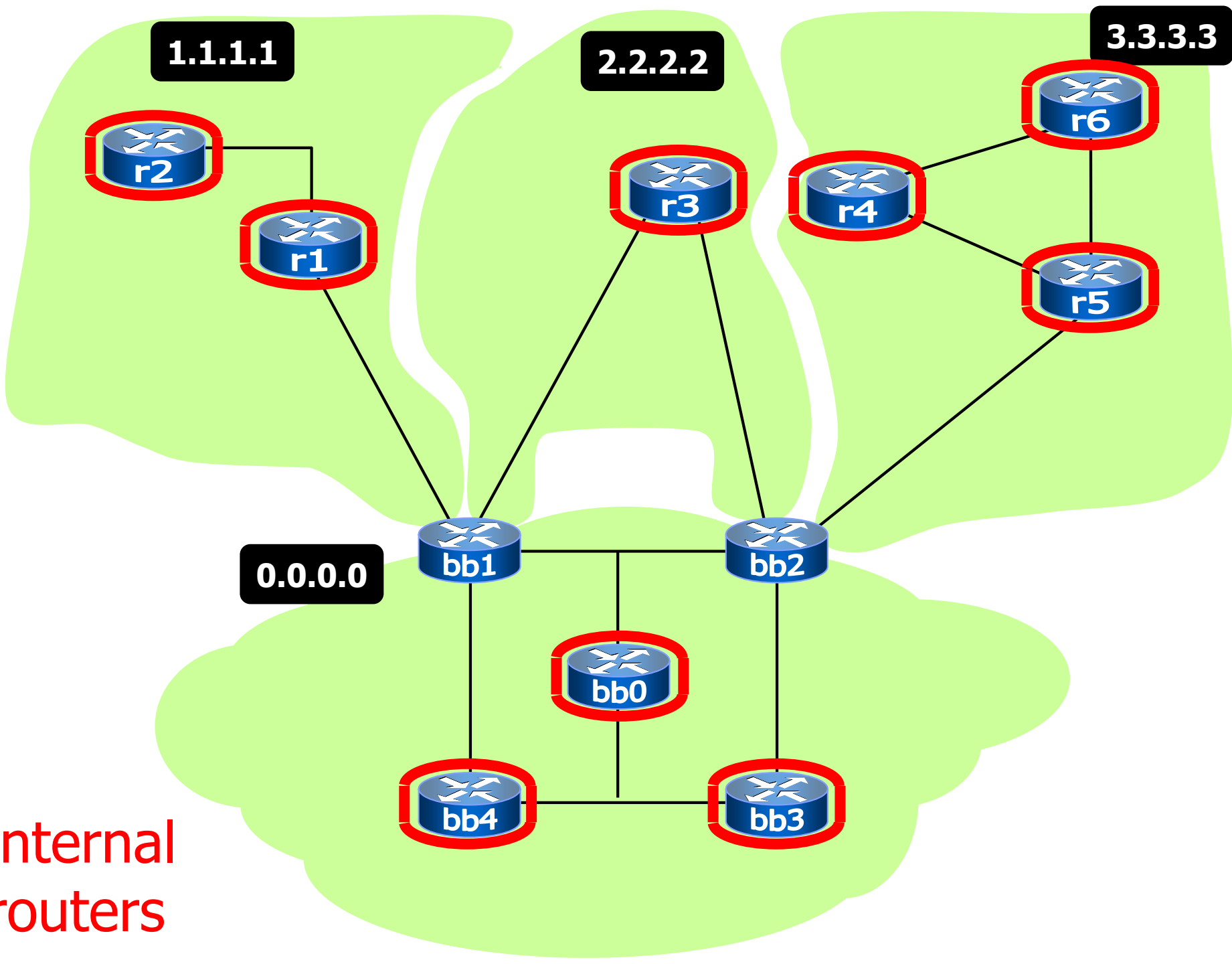
0.0.0.0

bb0

bb4

bb3

internal
routers



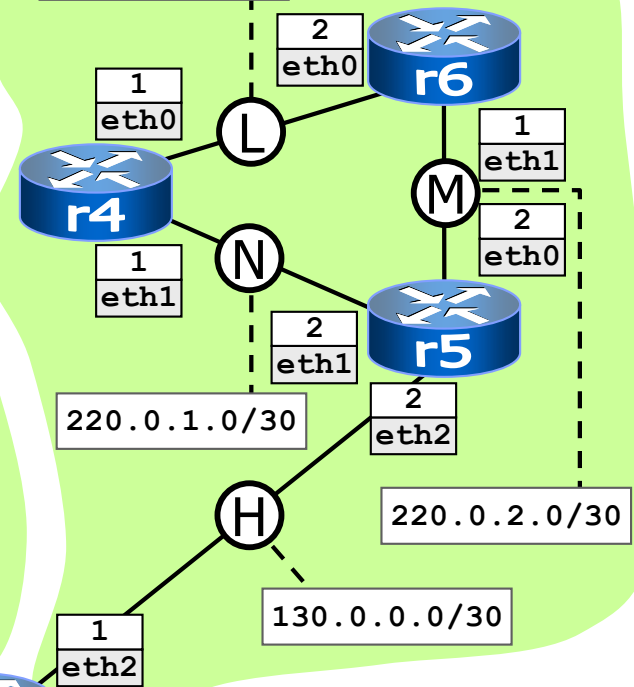
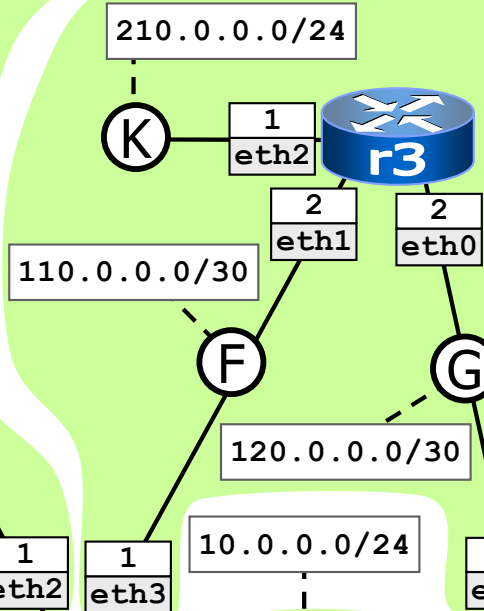
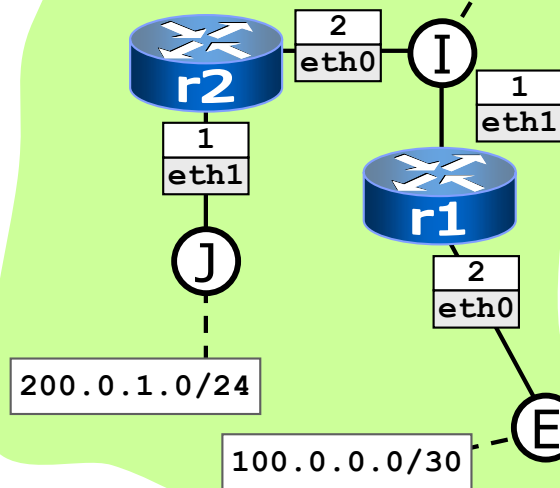
1.1.1.1

200.0.0.0/30

2.2.2.2

210.0.0.0/24

220.0.0.0/30

3.3.3.3**0.0.0.0**

10.0.3.0/24

90

100

10.0.1.0/24

10.0.2.0/24

default cost (10) is
assumed where
unspecified

area configuration

- area information is found in two places
 - when enabling ospf on router interfaces
network 200.0.0.0/16 area 1.1.1.1
 - when specifying the area type (not required for the backbone)
area 1.1.1.1 stub

ospf path types



- there are 4 path types
 - 1.intra-area
 - 2.inter-area
 - 3.external type 1
 - 4.external type 2
- types can coexist in the same network
- each type is preferred over the following ones

ospf path types

- intra-area paths
 - calculated using the shortest-path tree



ospf path types



- inter-area paths
 - abrs inject summary information inside each area, to make it aware of available destinations in other areas
 - such information includes the cost of the shortest path from the abr to the destination
 - if multiple subnets are summarized into a single network, the route cost will be the maximum cost to any of the component subnets
 - an inter-area path is always composed of:
 - an intra-area path from the source to the abr
 - a backbone path between the source and destination areas
 - an intra-area path to the destination

ospf path types



- external paths are learned from other routing protocols (e.g., bgp)
- type 1: the cost is expressed in terms of
 - the external (bgp) route cost* +
 - the ospf cost to the asbr

example with bgp cost=495, ospf cost=10:

```
N  E1  50.0.0.0/16          [505] tag: 0  
                               via 10.0.1.2, eth1
```

* cost used when redistributing the protocol (bgp) into ospf; default for bgp=20; configurable by using redistribute bgp metric *value*

ospf path types



- external paths are learned from other routing protocols (e.g., bgp)
 - type 1: the cost is expressed in terms of
 - the external (bgp) route cost* +
 - the ospf cost to the asbr
 - type 2: the cost is expressed in terms of
 - the external (bgp) route cost* only
(distance to the asbr is only used to break ties)
- example with bgp cost=495, ospf cost=10:

```
N  E2  50.0.0.0/16          [10/495] tag: 0  
                                via 10.0.1.2, eth1
```


ospf path types



- external paths are learned from other routing protocols (e.g., bgp)
- type 1: the cost is expressed in terms of
 - the external (bgp) route cost* +
 - the ospf cost to the asbr
- type 2: the cost is expressed in terms of
 - the external (bgp) route cost* only
(distance to the asbr is only used to break ties)
- metric type is user-configurable
`redistribute bgp metric-type 2 metric 495`

experiments

- check that routers know detailed topology information only about their own area

```
r2# show ip ospf neighbor
```

Neighbor ID	Pri	State	Dead Time	Address	Interface	RXmtL	RqstL	DBsmL
200.0.0.1	1	Full/Backup	34.184s	200.0.0.1	eth0:200.0.0.2	0	0	0

```
r2# show ip ospf database router
```

OSPF Router with ID (200.0.1.1)

Router Link States (Area 1.1.1.1 [Stub])

Link State ID: 110.0.0.1

Number of Links: 1

Link connected to: a Transit Network

(Link ID) Designated Router address: 100.0.0.2

(Link Data) Router Interface address: 100.0.0.1

Link State ID: 200.0.0.1

Number of Links: 2

Link connected to: a Transit Network

(Link ID) Designated Router address: 100.0.0.2

(Link Data) Router Interface address: 100.0.0.2

Link connected to: a Transit Network

(Link ID) Designated Router address: 200.0.0.2

(Link Data) Router Interface address: 200.0.0.1

Link State ID: 200.0.1.1

Number of Links: 2

Link connected to: a Transit Network

(Link ID) Designated Router address: 200.0.0.2

(Link Data) Router Interface address: 200.0.0.2

Link connected to: Stub Network

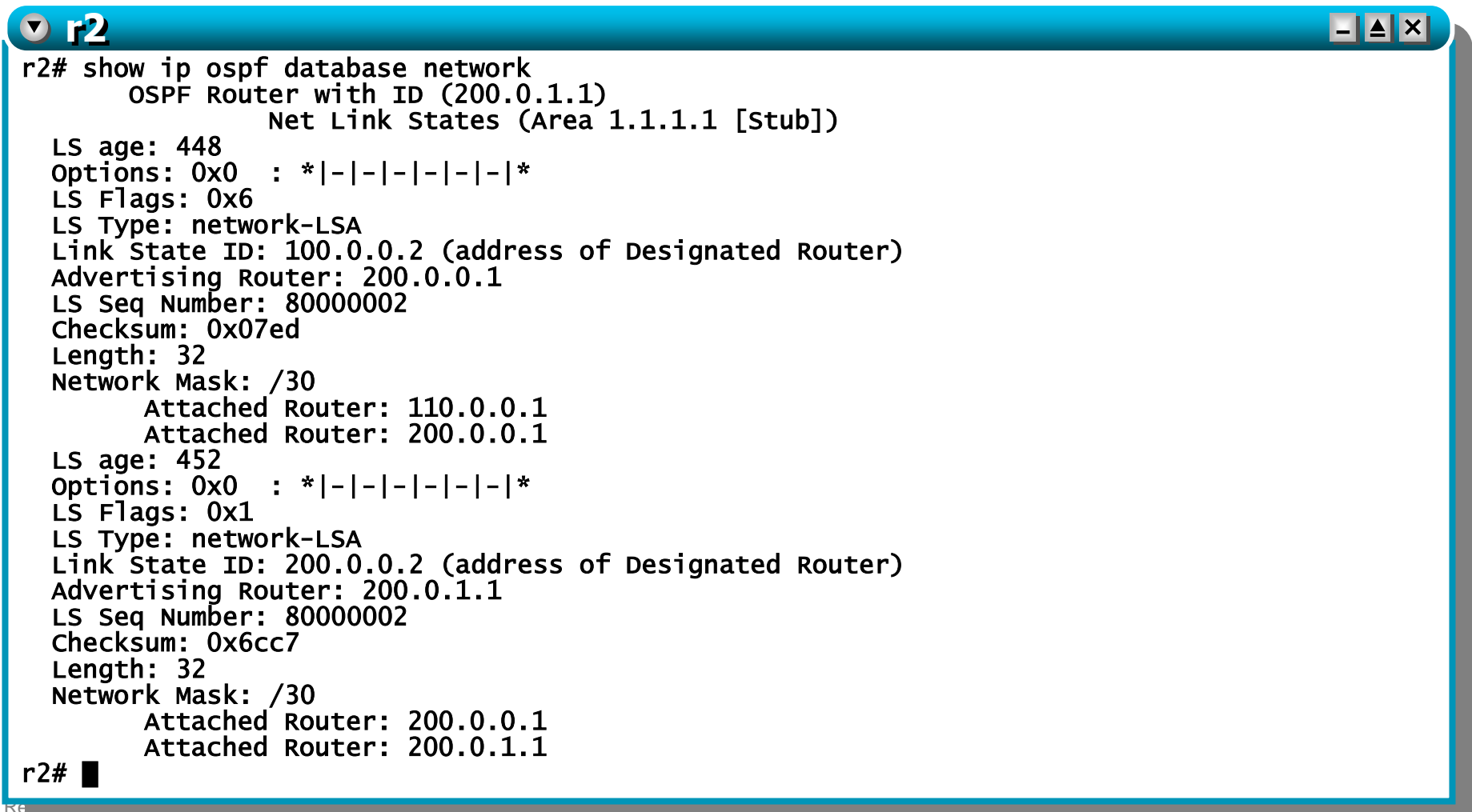
(Link ID) Net: 200.0.1.0

(Link Data) Network Mask: 255.255.255.0 ■

note: the output has been summarized

experiments

- check that routers know detailed topology information only about their own area



```
r2# show ip ospf database network
      OSPF Router with ID (200.0.1.1)
        Net Link States (Area 1.1.1.1 [Stub])
  LS age: 448
  Options: 0x0   : *|---|---|---|*
  LS Flags: 0x6
  LS Type: network-LSA
  Link State ID: 100.0.0.2 (address of Designated Router)
  Advertising Router: 200.0.0.1
  LS Seq Number: 80000002
  Checksum: 0x07ed
  Length: 32
  Network Mask: /30
    Attached Router: 110.0.0.1
    Attached Router: 200.0.0.1
  LS age: 452
  Options: 0x0   : *|---|---|---|*
  LS Flags: 0x1
  LS Type: network-LSA
  Link State ID: 200.0.0.2 (address of Designated Router)
  Advertising Router: 200.0.1.1
  LS Seq Number: 80000002
  Checksum: 0x6cc7
  Length: 32
  Network Mask: /30
    Attached Router: 200.0.0.1
    Attached Router: 200.0.1.1

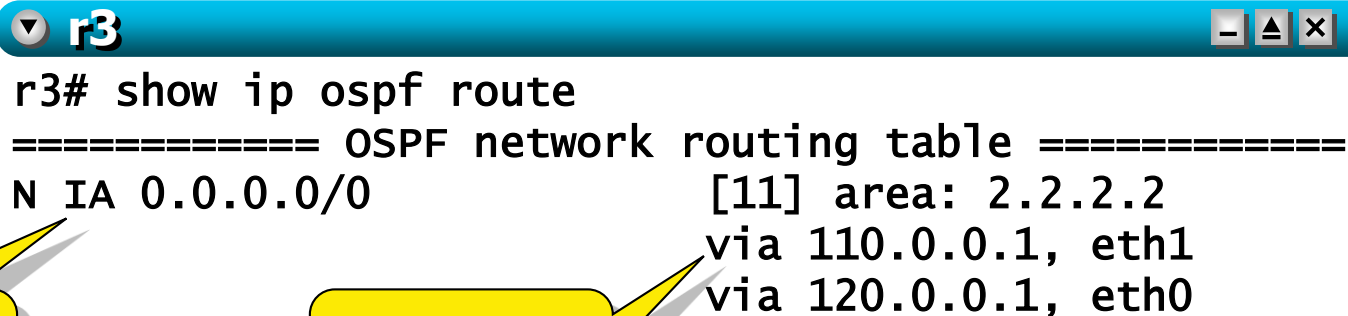
r2#
```


experiments

- check what routers know about the outside of the area, using the **show ip ospf database summary** command
 - in particular, check the **Metric** values, that show how far away the destination is from the advertising abr
- check that routers in stub areas are offered a default route, whereas routers in the backbone are not
 - also check what **Metric** is assigned to the default route

experiments

- experiment ospf's recovery capabilities
 - when multiple equal cost routes are available, ospf keeps all of them
 - check it by verifying what r3 knows about the default route



A terminal window titled 'r3' with standard window controls. It displays the output of the command 'show ip ospf route'. The output shows the OSPF network routing table for area 2.2.2.2, specifically for the default route (0.0.0.0/0). It lists two equal-cost paths: one via 110.0.0.1 on eth1, and another via 120.0.0.1 on eth0.

```
r3# show ip ospf route
===== OSPF network routing table =====
N IA 0.0.0.0/0                               [11] area: 2.2.2.2
                                           via 110.0.0.1, eth1
                                           via 120.0.0.1, eth0
```

inter-area
path

equal cost
routes

experiments

- experiment ospf's recovery capabilities
 - when multiple equal cost routes are available, ospf keeps all of them
 - check it by verifying what r3 knows about the default route
 - zebra performs the actual selection

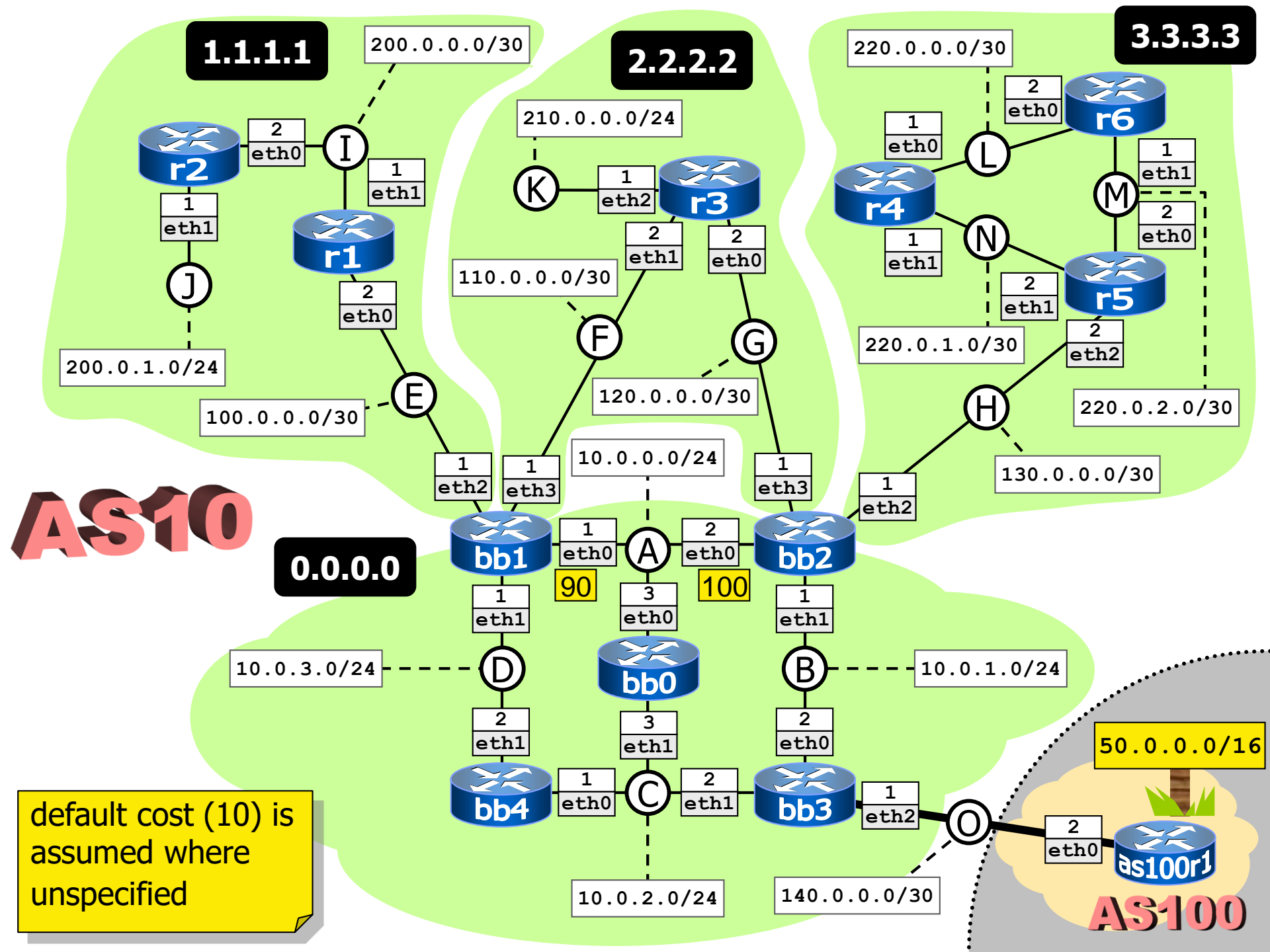
```
r3# show ip route
Codes: K - kernel route, C - connected, S - static, R - RIP, O - OSPF,
       I - ISIS, B - BGP, > - selected route, * - FIB route

O>* 0.0.0.0/0 [110/11] via 110.0.0.1, eth1, 00:04:56
    *                  via 120.0.0.1, eth0, 00:04:56
```

experiments

- experiment ospf's recovery capabilities
 - when multiple equal cost routes are available, ospf keeps all of them
 - check it by verifying what `r3` knows about the default route
 - zebra performs the actual selection
 - now bring `bb1's eth3` down using `ifconfig`, wait a few seconds and check how the routing is changed
 - bring `bb1's eth3` back up and check again how the routing is changed

lab: ospf-complex

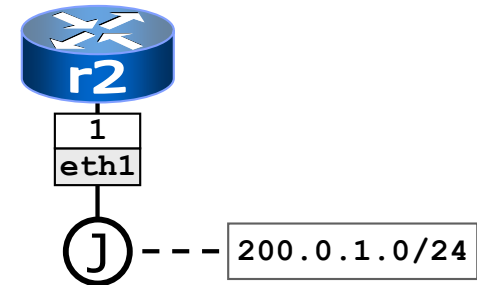


lab description

- same as multiarea + some information is injected via bgp from an external as
 - also, abrs are configured to just inject the default route
area 1.1.1.1 stub no-summary
- perform the same experiments as for the multiarea lab
 - in addition, check asbr information using **show ip ospf database asbr-summary**
 - also check that such information is not propagated inside stub areas

a quick note about stub networks

- “stub” = not used for transit
- three possible situations:



ospf is enabled also on the stub network's interface

then

the stub network is advertised in the entire ospf domain

but

interface uselessly sends hello packets

ospf is not enabled on the stub network's interface

then

the stub network is advertised

but

the stub network is advertised as an AS-external route (hence, only through the backbone)

ospf is enabled on the stub network's interface, which is configured as **passive-interface**

then

the stub network is advertised in the entire ospf domain

but

N/A