# netkit lab(s)

## ospf

<table>
<thead>
<tr>
<th>Version</th>
<th>1.4</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Author(s)</strong></td>
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<tr>
<td><strong>Web</strong></td>
<td><a href="http://www.netkit.org/">http://www.netkit.org/</a></td>
</tr>
<tr>
<td><strong>Description</strong></td>
<td>A set of labs showing the operation of the ospf routing protocol in different scenarios</td>
</tr>
</tbody>
</table>
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about ospf

- open shortest path first
- an interior gateway protocol (like rip, is-is)

<table>
<thead>
<tr>
<th>version 2</th>
<th>specification</th>
<th>authentication confidentiality</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>rfc 2328</td>
<td>rfc 5709</td>
</tr>
<tr>
<td>version 3 (with ipv6 support)</td>
<td>rfc 5340</td>
<td>rfc 4552</td>
</tr>
</tbody>
</table>

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netkit – [ labs: ospf ]
last update: Nov 2014}
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

Area ID

ospf cost for exiting the interface

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netkit – [ labs: ospf ]

last update: Nov 2014
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

Area ID

ospf cost for exiting the interface

netkit – [ labs: ospf ]

shortest path to reach: 10.0.2.0/24
短経路で到達する: 10.0.2.0/24

shortest path to reach: 10.0.3.0/24
短経路で到達する: 10.0.3.0/24
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
  - priority ∈ [0, 255]
    - default priority: 1
    - priority=0 ⇒ 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)
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
ospf’s view of the network

- **0.0.0.0**
- **10.0.1.1**
- **10.0.2.2**
- **10.0.2.3**
- **10.0.3.1**
- **10.0.3.2**
- **bb0**
- **bb1**
- **bb2**
- **bb3**
- **bb4**

For router LSAs, the Link ID is the router’s id

**OSPF Router with ID (10.0.2.3)**

<table>
<thead>
<tr>
<th>Link ID</th>
<th>ADV Router</th>
<th>Age</th>
<th>Seq#</th>
<th>CkSum</th>
<th>Link count</th>
</tr>
</thead>
<tbody>
<tr>
<td>10.0.1.1</td>
<td>10.0.1.1</td>
<td>553</td>
<td>0x80000003</td>
<td>0xe9fa</td>
<td>2</td>
</tr>
<tr>
<td>10.0.2.2</td>
<td>10.0.2.2</td>
<td>552</td>
<td>0x80000003</td>
<td>0xe3fa</td>
<td>2</td>
</tr>
<tr>
<td>10.0.2.3</td>
<td>10.0.2.3</td>
<td>552</td>
<td>0x80000003</td>
<td>0xe7cd</td>
<td>2</td>
</tr>
<tr>
<td>10.0.3.1</td>
<td>10.0.3.1</td>
<td>552</td>
<td>0x80000003</td>
<td>0x3288</td>
<td>2</td>
</tr>
<tr>
<td>10.0.3.2</td>
<td>10.0.3.2</td>
<td>548</td>
<td>0x80000004</td>
<td>0x488d</td>
<td>2</td>
</tr>
</tbody>
</table>

last update: Nov 2014
ospf’s view of the network

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

last update: Nov 2014
ospf’s view of the network

**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

last update: Nov 2014
ospf’s view of the network

We consider this router (bb2).

Note: The output of show ip ospf database router has been summarized.

Last update: Nov 2014
ospf’s view of the network

This router interface... is connected to the subnet represented by this dr

Output of show ip ospf database router has been summarized

Last update: Nov 2014
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 2014
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
```
ospf’s view of the network

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

last update: Nov 2014
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

**bb1**

- 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

**bb2**

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

**bb3**

- Link State ID: 10.0.2.3
  - Number of Links: 2
  - Link connected to: a Transit Network
    - (Link ID) Designated Router address: 10.0.3.2
    - (Link Data) Router Interface address: 10.0.3.1

**bb4**

- Link State ID: 10.0.3.2
  - 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

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

last update: Nov 2014
ospf’s view of the network

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

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

last update: Nov 2014
ospf’s view of the network

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

Last update: Nov 2014
ospf’s view of the network

bb0# show ip ospf database network

last update: Nov 2014
ospf’s view of the network

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

last update: Nov 2014
ospf’s view of the network

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

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

last update: Nov 2014
ospf’s view of the network

Note: The output of `show ip ospf database network` has been summarized.
ospf’s view of the network

ospf interface costs can be queried on all routers

a shortcut to quickly get the cost

last update: Nov 2014
router neighbors can be shown by using the `show ip ospf neighbor` command.

Note: Lsas are only sent between neighbors in Full state (i.e., capable of a bidirectional exchange of information); reaching the Full 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.
**ospf routing table**

- The ospf routing table can be dumped by using `show ip ospf route`.

```
bb0# show ip ospf route

<p>| | | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>N</td>
<td>10.0.0.0/24</td>
<td>[21] area: 0.0.0.0</td>
<td>directly attached to eth0</td>
</tr>
<tr>
<td>N</td>
<td>10.0.1.0/24</td>
<td>[31] area: 0.0.0.0</td>
<td>via 10.0.0.2, eth0</td>
</tr>
<tr>
<td>N</td>
<td>10.0.2.0/24</td>
<td>[36] area: 0.0.0.0</td>
<td>directly attached to eth1</td>
</tr>
<tr>
<td>N</td>
<td>10.0.3.0/24</td>
<td>[46] area: 0.0.0.0</td>
<td>via 10.0.2.1, eth1</td>
</tr>
</tbody>
</table>

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<p>| | | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>R</td>
<td>10.0.1.1</td>
<td>[21] area: 0.0.0.0, ASBR</td>
<td>via 10.0.0.2, eth0</td>
</tr>
<tr>
<td>R</td>
<td>10.0.2.2</td>
<td>[31] area: 0.0.0.0, ASBR</td>
<td>via 10.0.0.2, eth0</td>
</tr>
<tr>
<td>R</td>
<td>10.0.3.1</td>
<td>[21] area: 0.0.0.0, ASBR</td>
<td>via 10.0.0.1, eth0</td>
</tr>
<tr>
<td>R</td>
<td>10.0.3.2</td>
<td>[36] area: 0.0.0.0, ASBR</td>
<td>via 10.0.2.1, eth1</td>
</tr>
</tbody>
</table>

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<p>| | | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

```
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)

```
0 - RouterDeadInterval
```

**min** | **max**
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)

\[
\begin{align*}
\text{RouterDeadInterval} & \quad \text{MaxAge} \\
\text{min} & \quad \text{max}
\end{align*}
\]
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
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
area border routers
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 50.0.0.0.0/16       [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:

<table>
<thead>
<tr>
<th>N</th>
<th>E2</th>
<th>50.0.0.0/16</th>
<th>[10/495] tag: 0</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>via 10.0.1.2, eth1</td>
</tr>
</tbody>
</table>
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

```
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: 200.0.0.2
    (Link Data) Router Interface address: 200.0.0.2
  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

```
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
```
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

```
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
default cost (10) is assumed where unspecified
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:

1. **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

2. **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)

3. **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