Appendix 1 - OSPF Advanced Topics

OSPF Advanced Topics

Areas, ABR, Backbone, Summary-LSA, ASBR, Stub Area, Route Summarization, Virtual Links, Header Details

Agenda

- **OSPF Advanced Topics**
  - Area Principles
  - Summary LSA Operation Example 1
  - Summary LSA Operation Example 2
  - Computation Example
  - Stub Areas
  - Route Summarization
  - Virtual Link
- **OSPF Header Details**
  - Message Formats
  - LSA Formats

Appendix 1 - OSPF Advanced Topics

OSPF Domain / OSPF Area

- **OSPF domain can be divided in multiple OSPF areas**
  - to improve performance
  - to decouple network parts from each other
- **performance improvement**
  - by restricting Router-LSA and Network-LSA to the originating area
    - note: receiving a Router-LSA will cause the SPF algorithm to be performed
- **decoupling is actually done**
  - by route summarization enabled through the usage of classless routing and careful IP address plan

OSPF Domain / OSPF Area

- **every area got its own topology database**
  - which is unknown to other areas
  - area specific routing information stays inside this area
- **on topology changes**
  - routing traffic causing Dikstra algorithm to be performed stays inside the area where the change appears
  - route summarization reduces routing traffic drastically
- **OSPF areas are labelled with area-IDs**
  - unique within the OSPF domain
  - written in IP address like format or just as number
- **an OSPF domain contains**
  - at least one single area or several areas

Appendix 1 - OSPF Advanced Topics

OSPF Area Border Router

- **OSPF areas are connected by special routers**
  - Area Border Router (ABR)
- **ABR**
  - maintains a topology database for each area he is connected to
- **all OSPF areas must be connected over a special area**
  - Backbone Area
    - area-ID = 0.0.0.0
    - or area-ID = 0
  - if there is only one area in the OSPF domain this OSPF area will be the backbone area

OSPF Backbone Area

- **non-backbone areas must not be connected directly**
  - connection allowed only via Backbone Area
- **this OSPF rule forces**
  - a star-like topology of areas with the backbone area in the centre
- **ABRs**
  - are connected to the backbone area by direct physical links in normal cases
  - exception with virtual link technique if direct physical link can not be provided
    - a virtual link can be used to "tunnel" the routing traffic between an isolated area and the backbone area through another area

Appendix 1 - OSPF Advanced Topics

OSPF Routing Types 1

- **OSPF provides three types of routing:**
  - intra-area routing:
    - inside of an area (using Level 1 Router; Internal Router IR)
    - Router Link LSA (LSA type1)
    - Network Link LSA (LSA type2)
    - note: Backbone Router is a Backbone Area Internal Router
  - inter-area routing:
    - between areas over a Backbone Area (using Area Border)
    - Summary Link LSA (LSA type3 and type4)
    - type 3 to announce networks
    - type 4 to announce IP address of ASBRs

OSPF Routing Types 2

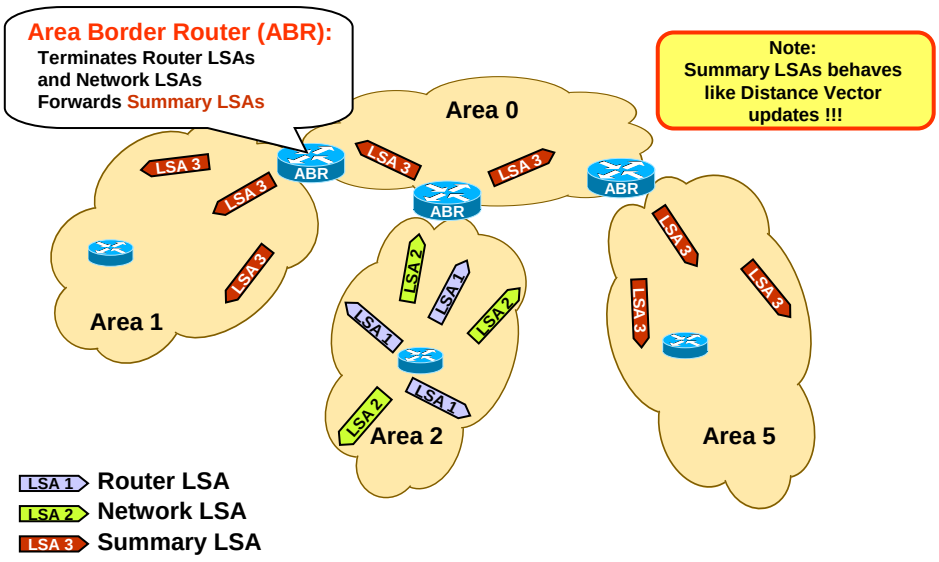
- **OSPF provides three types of routing (cont.):**
  - exterior routing:
    - paths to external destinations (other AS) are configured statically or imported with EGP or BGP using Autonomous Systems Boundary Routers (ASBRs)
    - AS External Summary LSA (LSA type5) to announce external networks

Appendix 1 - OSPF Advanced Topics

Area Border Router

- **Area Border Router maintains two topology maps**
  - one for its area
  - one for the Backbone Area
- **Area Border Router exports the routes of its area to the Backbone Area**
  - collects all topology information of its area and sends Summary LSAs to the Backbone Area
- **Area Border Router imports all routes of other areas in its own area**
  - this is done again using Summary LSAs

ABR



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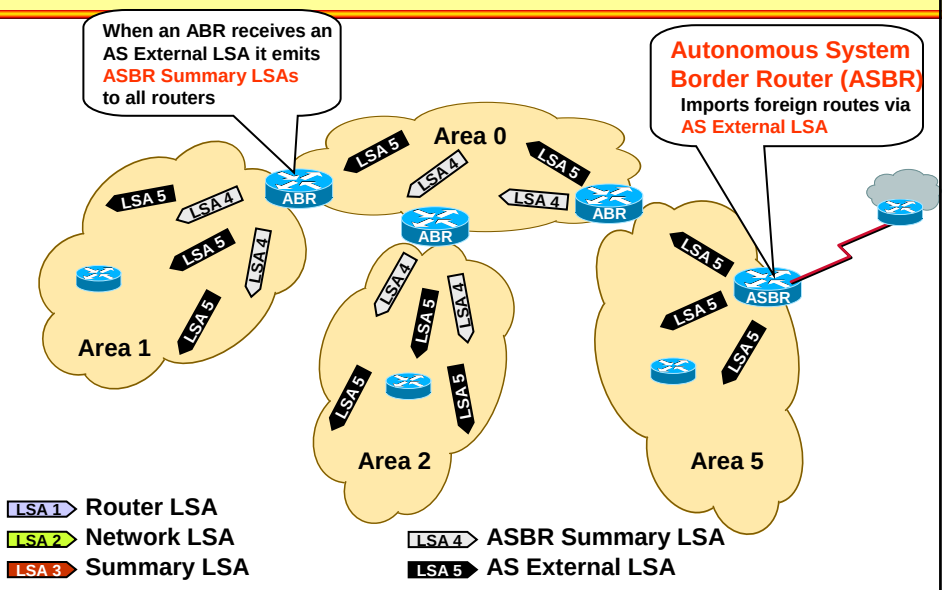
ASBR



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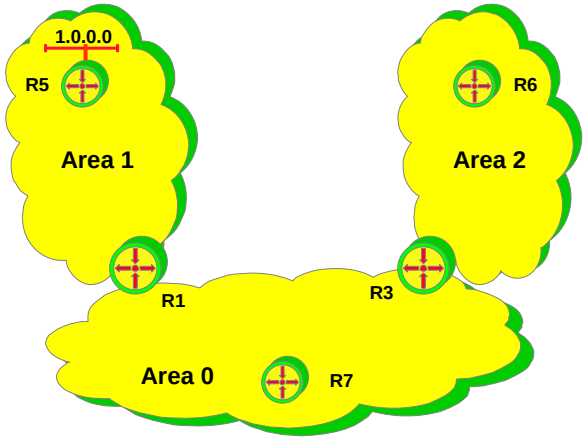
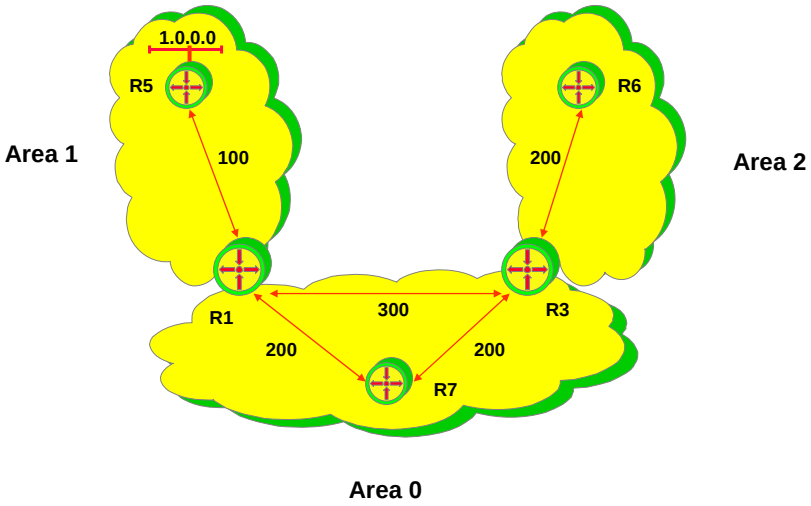
Areas and Topology (Single ABRs)



Area 0 ...Backbone Area
R1, R3 ... Area Border Router ABR
R5, R6, R7 ... Internal Router
R1, R3, R7 ... Backbone Router

OSPF Costs of Best Paths

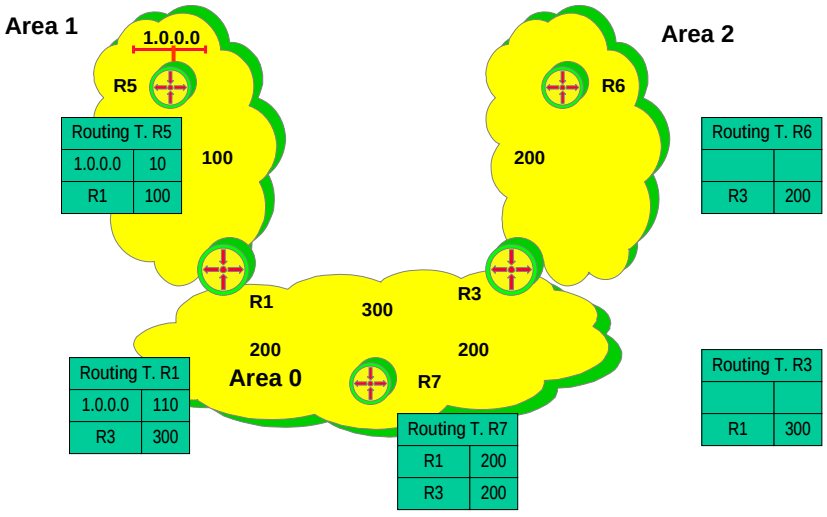


Appendix 1 - OSPF Advanced Topics

Topology Information Maintained

- **every router knows about**
  - exact topology of its own area and hence best paths to all networks of its own network
    - best paths stored in routing table
      - e.g. for R5 -> 1.0.0.0 reachable with cost 10
      - e.g. for R1 -> 1.0.0.0 reachable with cost 110
  - ABR of its own area and costs to reach ABRs
    - ABRs stored in separate list
      - e.g. for R5 -> ABR R1 reachable with cost 100
      - e.g. for R1 -> ABR R3 reachable with cost 300
  - on activation of a network
    - a corresponding Summary LSA is sent out by the ABR
      - with actual cost in order to reach the network from the given ABR

Activation of 1.0.0.0



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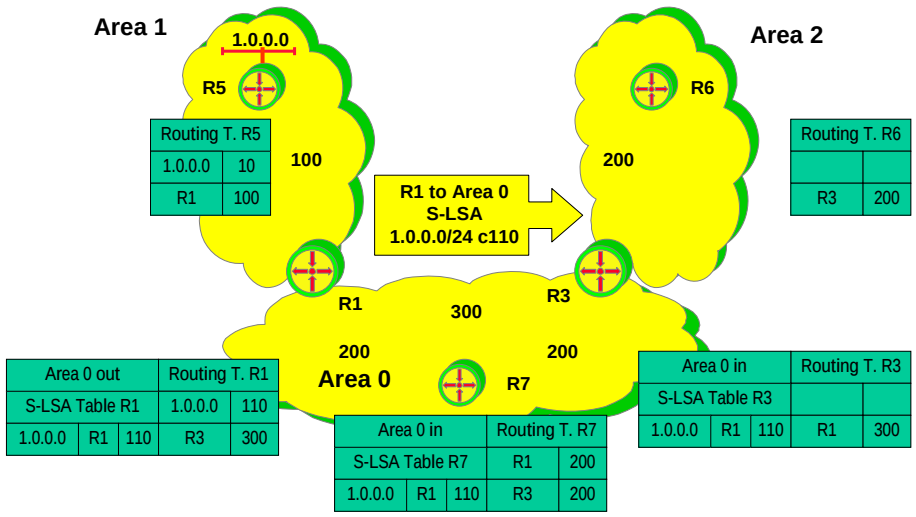
ABR R1 -> Summary LSA 1.0.0.0



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Topology Information Actualized

- **If a router receives a Summary LSA**
  - the costs announced in this Summary LSA are added to the costs in order to reach the announcing ABR
  - result is stored in routing table
- **If an ABR router receives a Summary LSA from the Backbone**
  - the costs announced in this Summary LSA are added to the costs in order to reach the announcing ABR
  - result is stored in routing table
  - a Summary LSA is send out in the other Area with the culminated costs and ABR-ID set to the actual value

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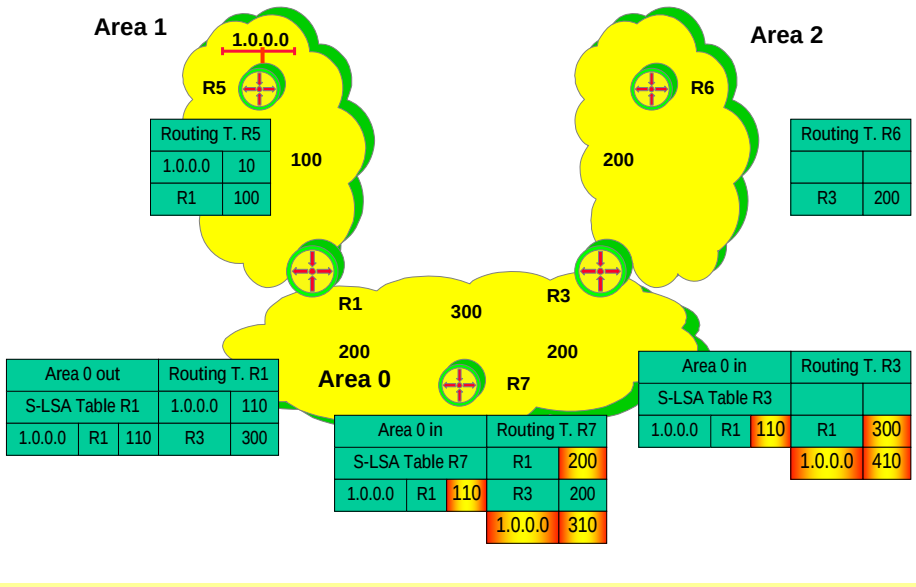
Calculation R7, ABR R3



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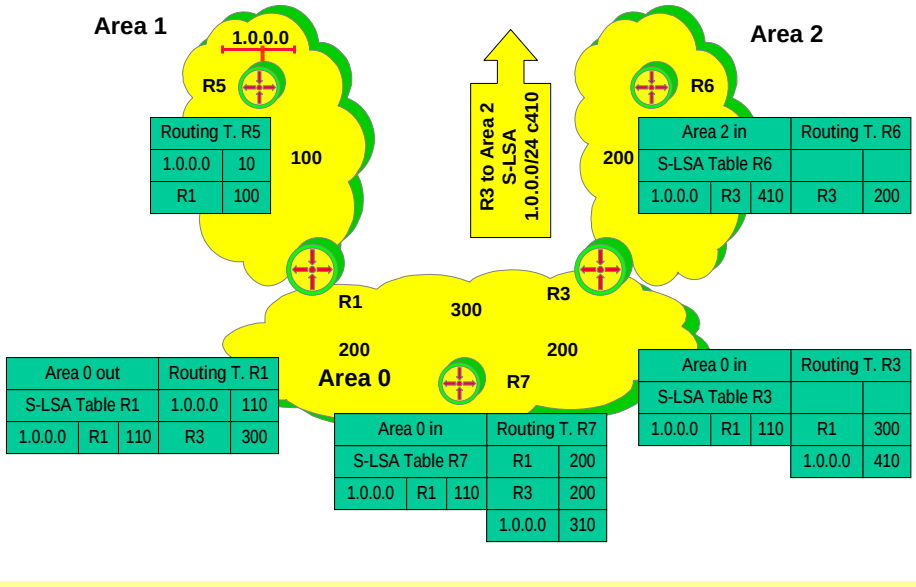
ABR R3 -> Summary LSA 1.0.0.0



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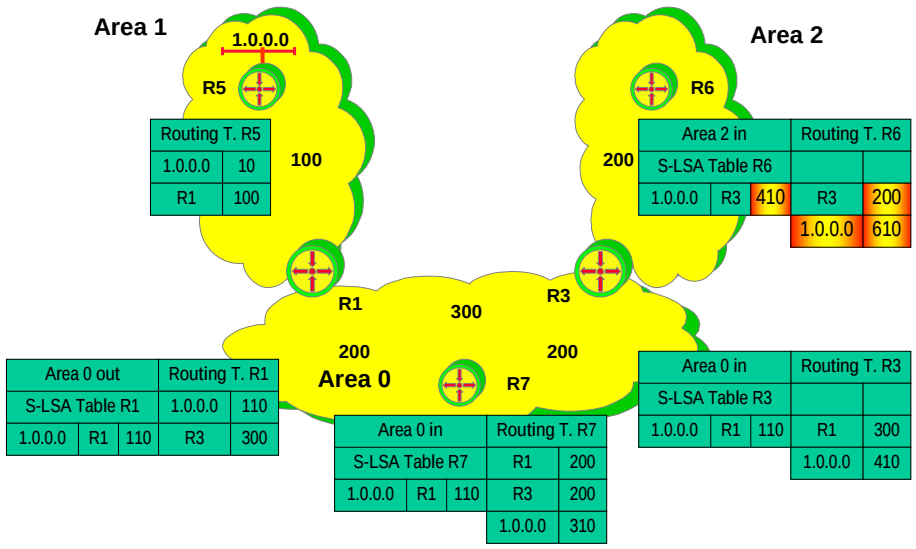
Calculation R6



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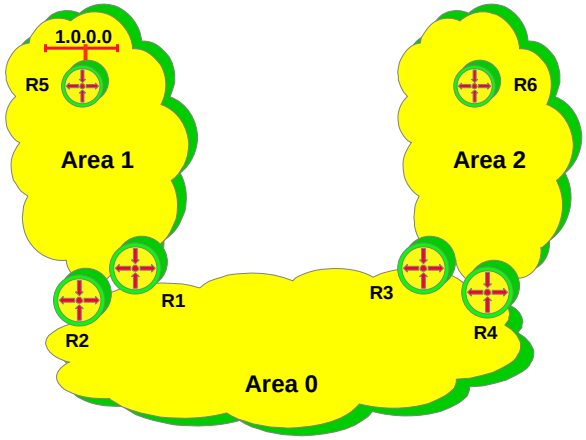
Areas and Topology (Redundant ABRs)



Area 0 …Backbone Area
R1, R2, R3, R4 … Area Border Router ABR
R5, R6 … Internal Router
R1, R2, R3, R4 … Backbone Router

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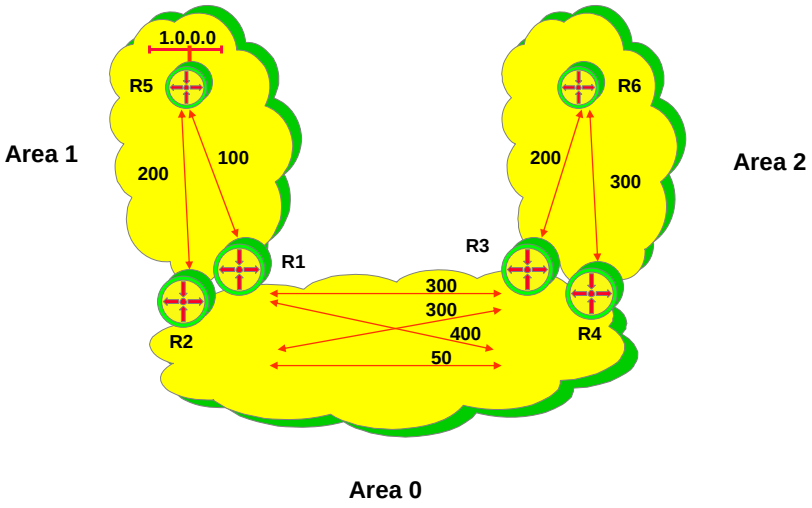
OSPF Costs



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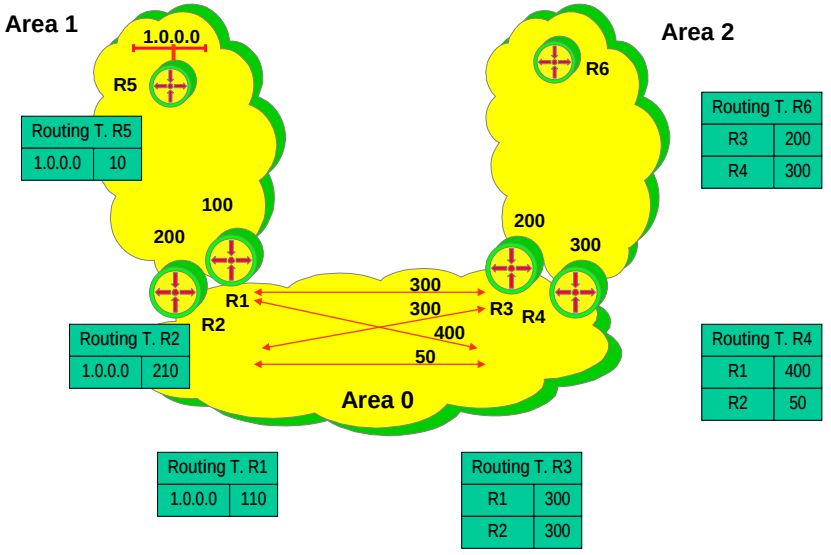
Activation of 1.0.0.0



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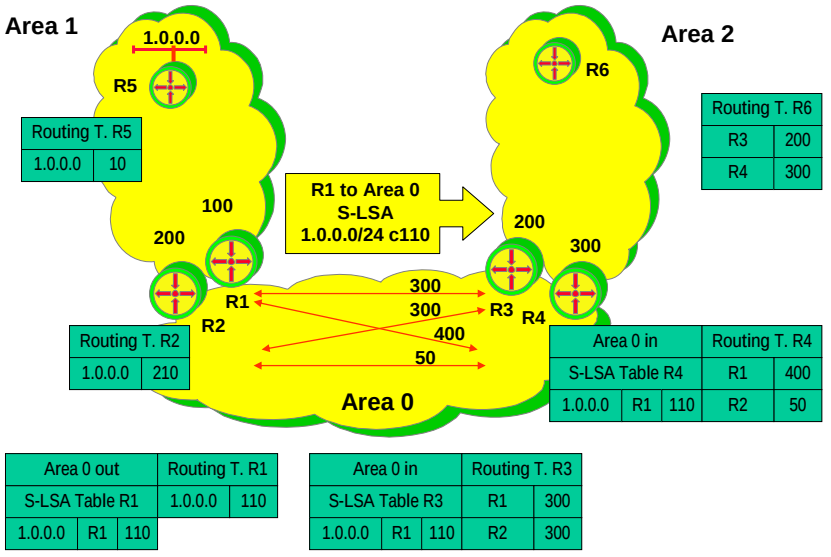
ABR R1 -> Summary LSA 1.0.0.0



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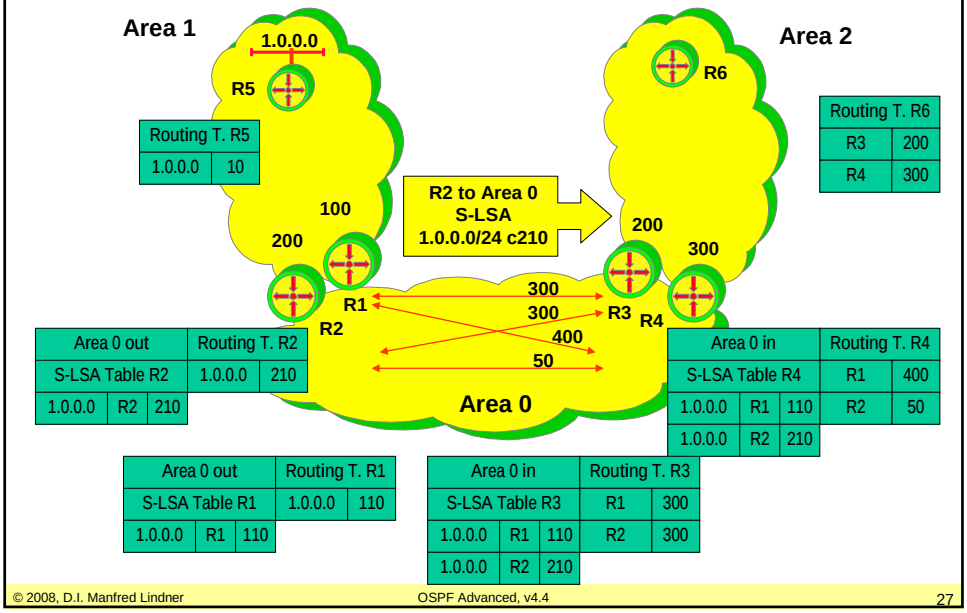
ABR R2 -> Summary LSA 1.0.0.0



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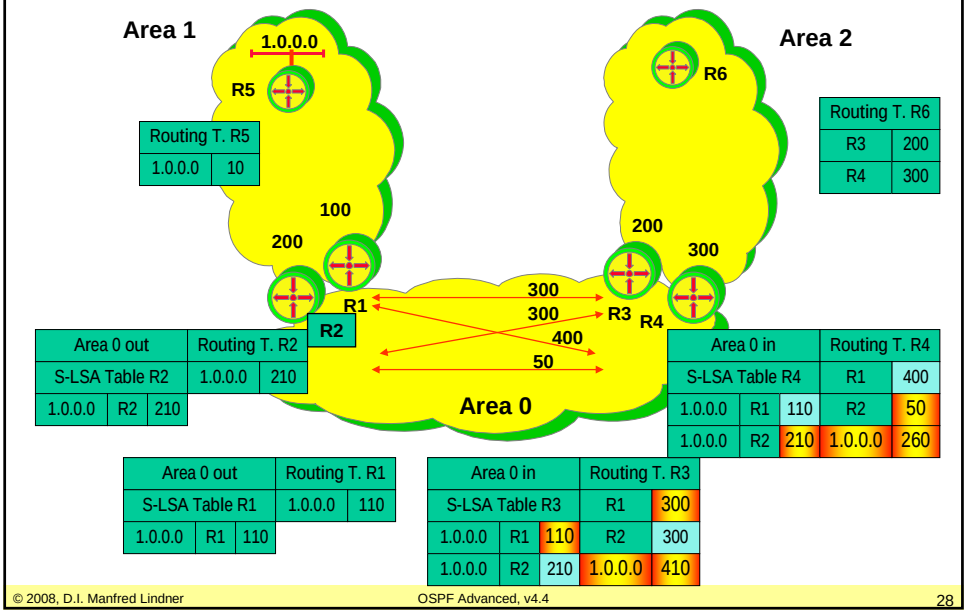
Calculation R3, R4



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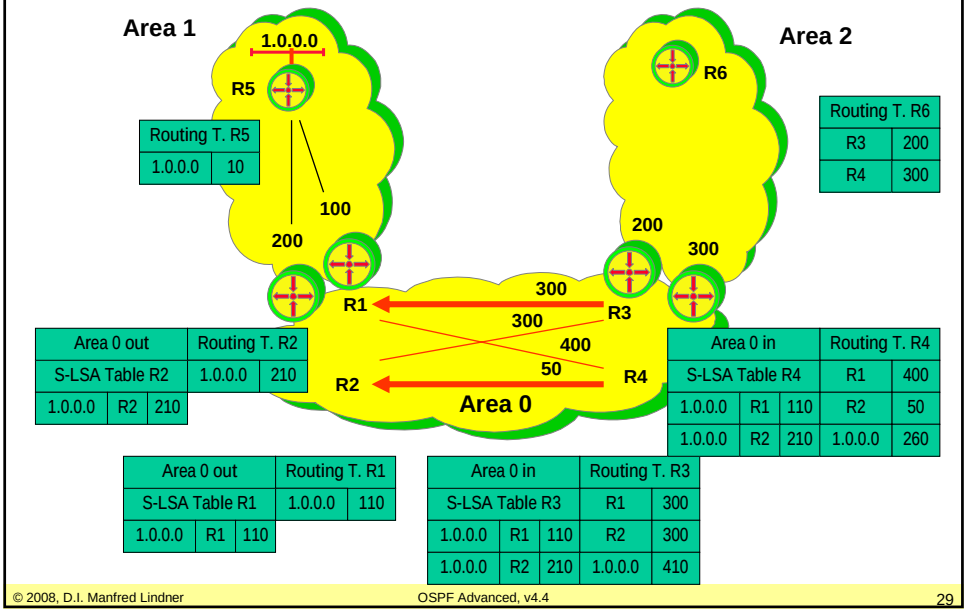
Best Path to 1.0.0.0 for R3, R4



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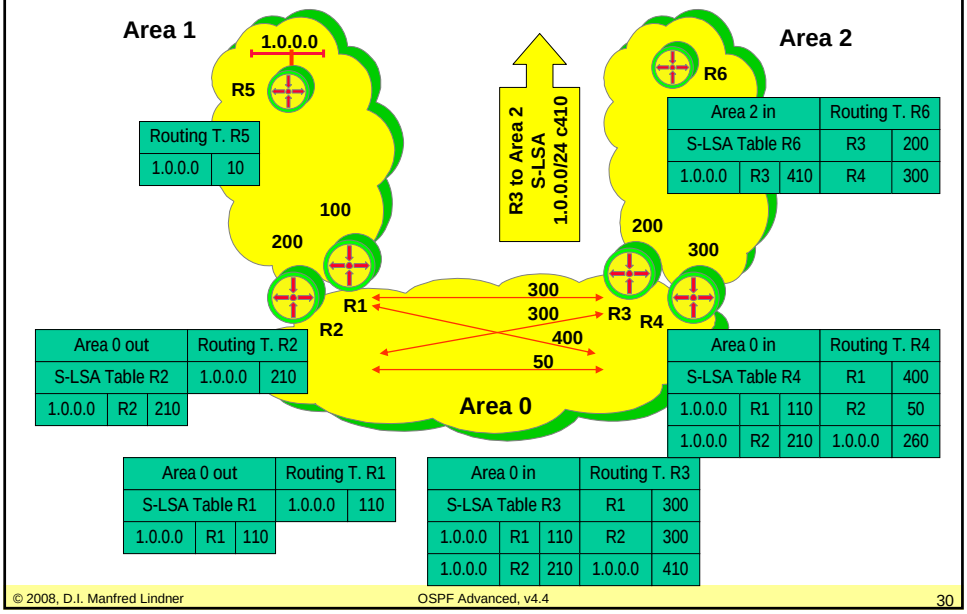
ABR R3 -> Summary LSA 1.0.0.0



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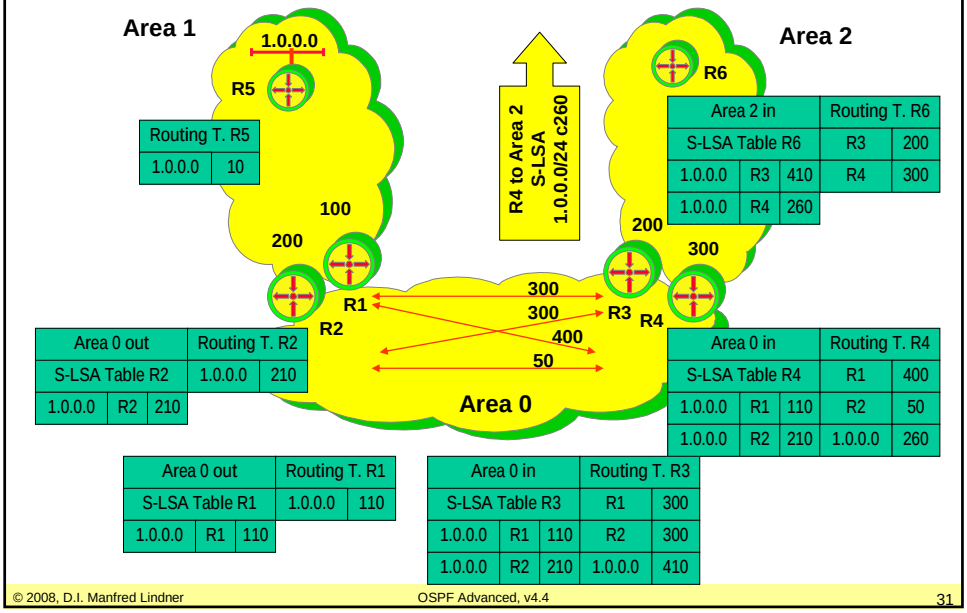
ABR R4 -> Summary LSA 1.0.0.0



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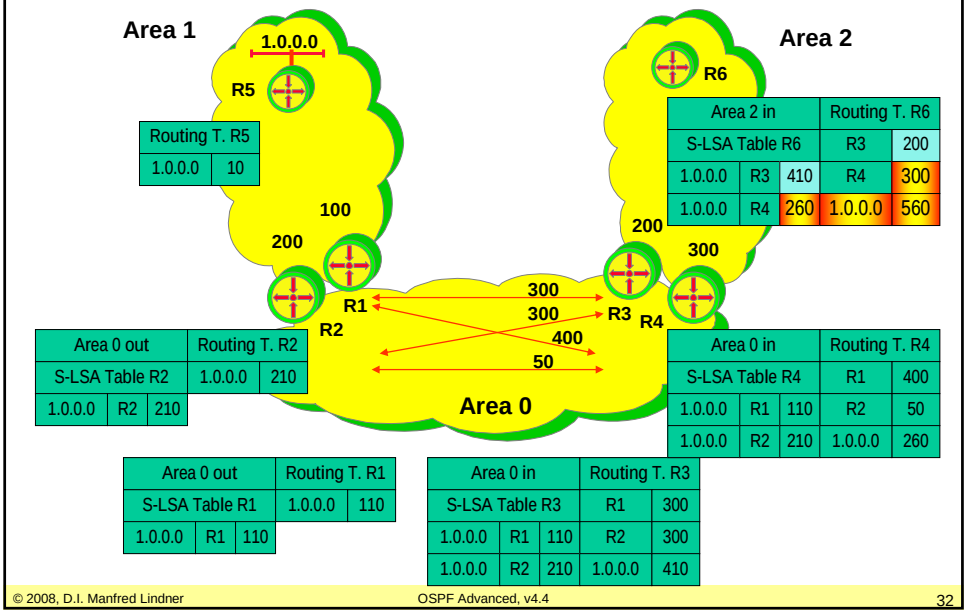
Calculation R6



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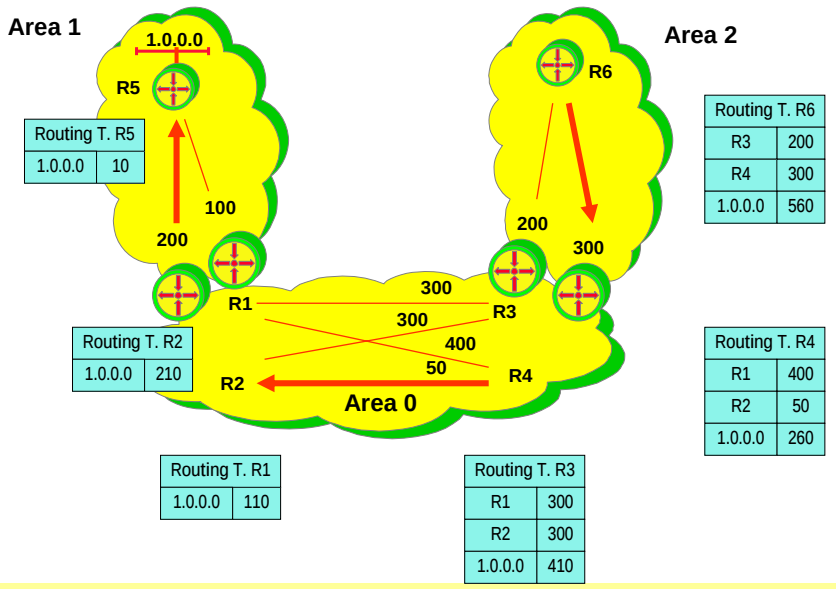
Best Path to 1.0.0.0 for R6



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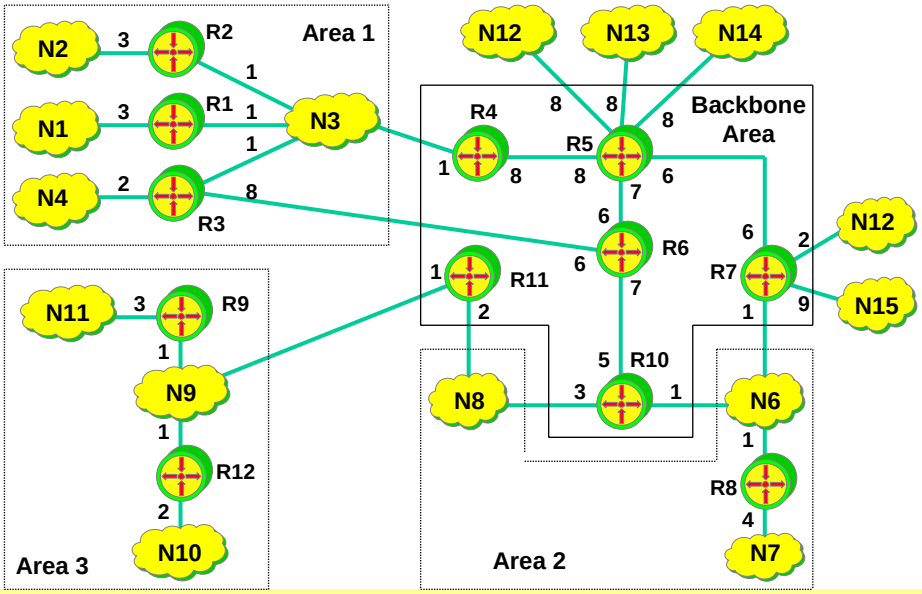
OSPF Domain with 4 Areas



OSPF Domain with 4 Areas

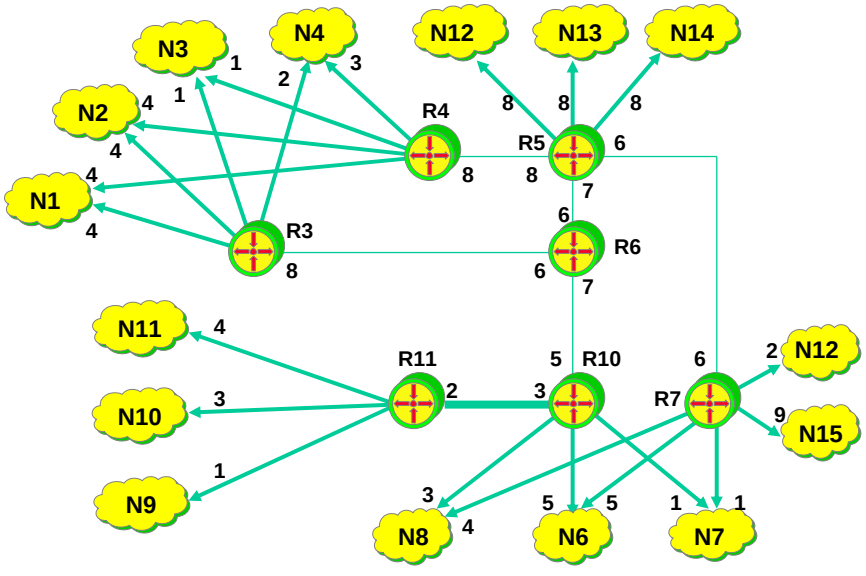
- **internal routers: 1, 2, 5, 6, 8, 9, 12**
  - router 1,2 ..... area 1
  - router 8 ..... area 2
  - router 9, 12 ... area 3
  - router 5,6 ..... backbone
- **Area Border Routers: 3, 4, 7, 10, 11**
  - router 3, 4 ..... topology of area 1 and backbone
  - router 7, 10 .... topology of area 2 and backbone
  - router 11 ..... topology of area 3 and backbone
- **Backbone Routers: 4, 5, 6, 7, 10, 11**
  - router 11 is connected to the backbone (router 10) over a virtual link

Appendix 1 - OSPF Advanced Topics

OSPF Domain with 4 Areas

- **Autonomous Systems Boundary Routers: 5, 7**
  - additionally, router 5 and 7 provide connections to external Autonomous Systems

Backbone Topology Database



Router 3/4 Summary LSAs -> Backbone

- router 3 and 4 have topology map of area 1
- Area Border Router 3 and 4 forward network information (costs for reaching internal destinations) as Summary LSAs to the Backbone Area

network	costs, notified by router 3	costs, notified by router 4
N1	4	4
N2	4	4
N3	1	1
N4	2	3

Router 7 Summary LSAs -> Backbone

- router 7 has topology map of area 2
- Area Border Router 7 forwards network information of area 2 as Summary LSA to the Backbone Area
- thus, notifying also R3 and R4

network	costs, notified by router 7
N6	1
N7	5
N8	4

Router 10 Summary LSAs -> Backbone

- router 10 has topology map of area 2
- Area Border Router 10 forwards network information of area 2 as Summary LSA to the Backbone Area
- thus, notifying also R3 and R4

network	costs, notified by router 10
N6	1
N7	5
N8	3

Router 11 Summary LSAs -> Backbone

- router 11 has topology map of area 3
- Area Border Router 11 forwards network information of area 3 as Summary LSA to the Backbone Area
- thus, notifying also R3 and R4

network	costs, notified by router 11
N9	1
N10	3
N11	4

Appendix 1 - OSPF Advanced Topics

Router 3/4 SPF Calculation for Backbone

- **router 3 and 4 have topology map of Backbone Area -> router 3 and 4 can calculate SPF to any Area Border Router**

Area Border Router	costs of R3	costs of R4
to R3	*	21
to R4	22	*
to R7	20	14
to R10	15	22
to R11	18	25
to R5	14	8
to R7	20	14

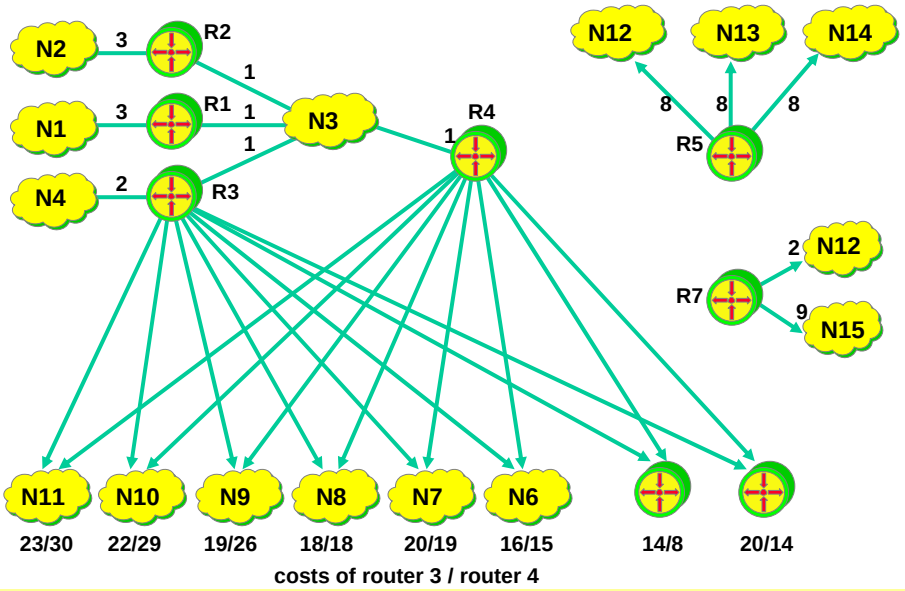
Router 3/4 S-LSAs -> Area 1

- **router 3 and 4 can calculate best costs to any destinations outside of area 1**
  - by analyzing Summary LSAs of other Area Border Routers
  - and SPF calculations to the backbone routers
- **and notify their own area with Summary-LSA**

destination	costs, notified by router 3	costs, notified by router 4
N6	16 (R10)	15 (R7)
N7	20 (R10)	19 (R7)
N8	18 (R10)	18 (R7)
N9	19 (R11)	26 (R11)
N10	21 (R11)	28 (R11)
N11	22 (R11)	29 (R11)
R5	14	8
R7	20	14

Appendix 1 - OSPF Advanced Topics

Topology Database of Area 1



Routing Tables R1, R2

- **these cost-information to any network (provided by Summary LSA of router 3 and 4) outside of area 1**
  - are added to the internal shortest paths to the Area Border Routers R3 and R4 by the internal routers R1 and R2
  - determination of best paths to any subnet finally
  - best path is noted in routing table
  - best path from R1, R2 to
    - N6 over R4 with costs of 16
    - N7 over R4 with costs of 20
    - N8 over R3/R4 with costs of 19 (load balancing)
    - N9 over R3 with costs of 20 etc.

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OSPF Stub Areas

- **normally, every internal router gets information about all networks**
  - internal and external NET-IDs
- **OSPF allows definition of Stub Areas**
  - to minimize memory requirements of internal routers of non-backbone areas for external networks
  - only the Area Border Router of a particular area knows all external destinations
  - internal routers only get a default route entry (to this Area Border Router)
  - any traffic that do not stay inside the OSPF domain (external networks) is forwarded to the Area Border Router

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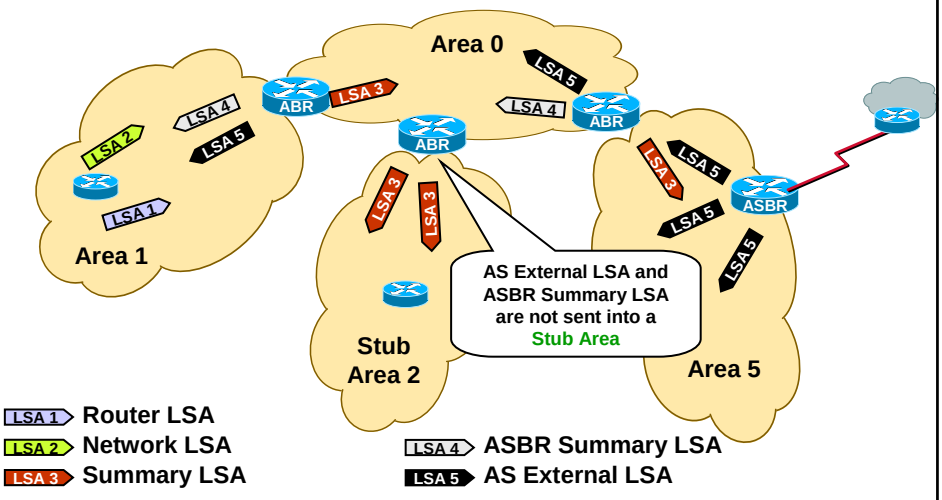
Stub Area

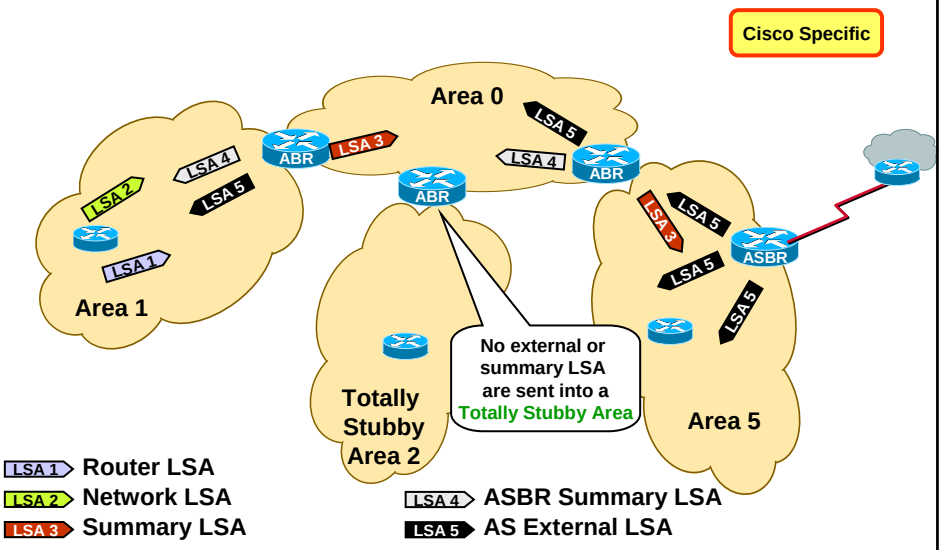


OSPF Totally Stubby Areas

- **Cisco allows definition of Totally Stubby Areas**
  - internal routers follow default route also for networks of other areas (no Summary-LSA)
  - that means for internal networks of other areas
- **In such an area**
  - ASBRs are forbidden

Appendix 1 - OSPF Advanced Topics

Totally Stubby Area



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Summary LSA and Route Summarization

- **Summary LSA is generated by Area Border Router to inform**
  - routers inside its area about costs of networks from outside (message direction: Backbone Area -> Area)
    --> import of net-IDs
  - routers outside its area about costs of its internal networks (message direction: Area -> Backbone Area)
    --> export of net-IDs
- **additionally Summary Link LSA can be used for Route Summarization**
  - several net-IDs can be summarized to a single net-ID using an appropriate subnet-mask

Route Summarization 1

- **Route Summarization can be configured manually for Area Border Routers**
  - to minimize number of routing table entries
  - to provide decoupling of OSPF areas
- **basically, an OSPF domain allows combining any IP-address with any arbitrary subnet masks**
  - Classless Routing
- **no automatic Route Summarization at the IP address class boundary (A,B or C) like RIPv1**
  - note: RIPv1 implements Classful Routing

Route Summarization 2

- **summarization can occur at any place of the IP-address**
- **for instance, many class C addresses can be summarized to one single address (with a prefix)**
  - e.g. class C addresses 201.1.0.0 to 201.1.255.0 (subnet-mask 255.255.255.0) can be summarized by a single entry 201.1.0.0 with subnet-mask 255.255.0.0
  - note1: when summarizing several networks, only the lowest costs of all these networks are reported (RFC 1583)
  - note2: when summarizing several networks, only the highest costs of all these networks are reported (RFC 2328)

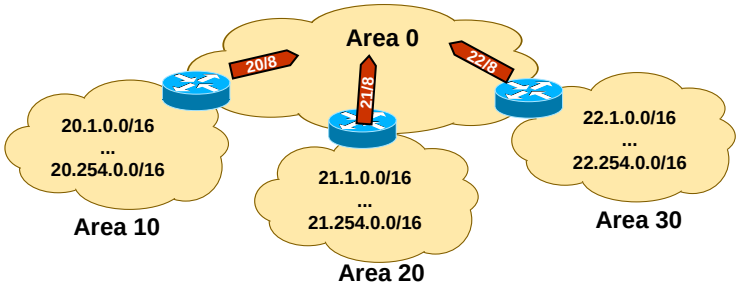
Route Summarization 3

- **OSPF Route Summarization demands**
  - a clever assignment of IP-addresses and areas to enable Route Summarization
- **hence OSPF not only forces a star shaped area topology but also demands for a sound IP-address design**
- **note:**
  - it is still possible to use arbitrary subnet masks and arbitrary addresses anywhere in the network because of classless routing
  - in conflict cases ”Longest Match Routing Rule" is applied
  - but this means a bad network design

Appendix 1 - OSPF Advanced Topics

Example Summarization

- **Efficient OSPF address design requires hierarchical addressing**
- **Address plan should support summarization at ABRs**



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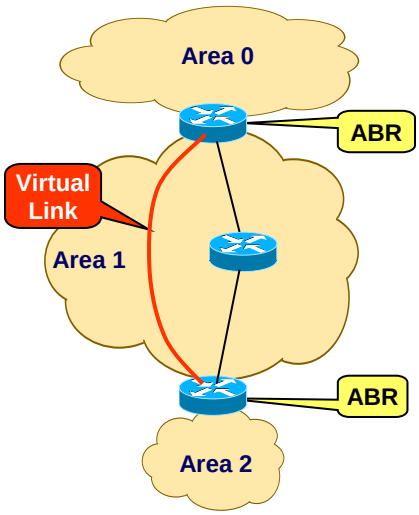
Virtual Links

- **Another way to connect to area 0 using a point-to-point tunnel**
- **Transit area must have full routing information**
  - Must *not* be stub area
- **Bad Design!**



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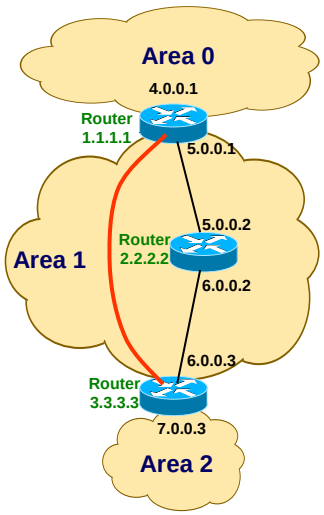
Virtual Link Example

- **Now router 3.3.3.3 has an interface in area 0**
- **Thus router 3.3.3.3 becomes an ABR**
  - Generates summary LSA for network 7.0.0.0/8 into area 1 and area 0
  - Also summary LSAs in area 2 for all the information it learned from areas 0 and 1



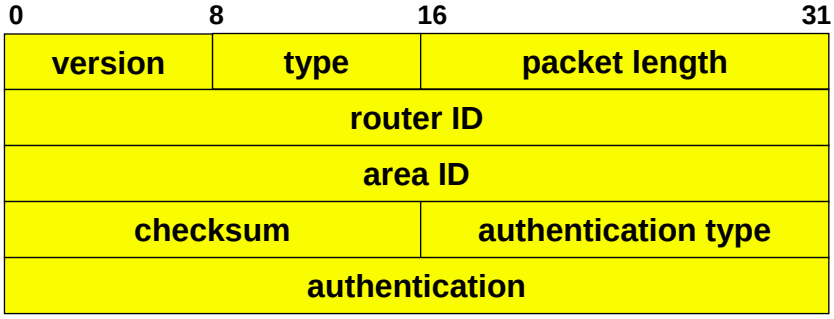
 OSPF Advanced, v4.4 60

Appendix 1 - OSPF Advanced Topics

Agenda

- **OSPF Advanced Topics**
  - Area Principles
  - Summary LSA Operation Example 1
  - Summary LSA Operation Example 2
  - Computation Example
  - Stub Areas
  - Route Summarization
  - Virtual Link
- **OSPF Header Details**
  - Message Formats
  - LSA Formats

OSPF Message Formats



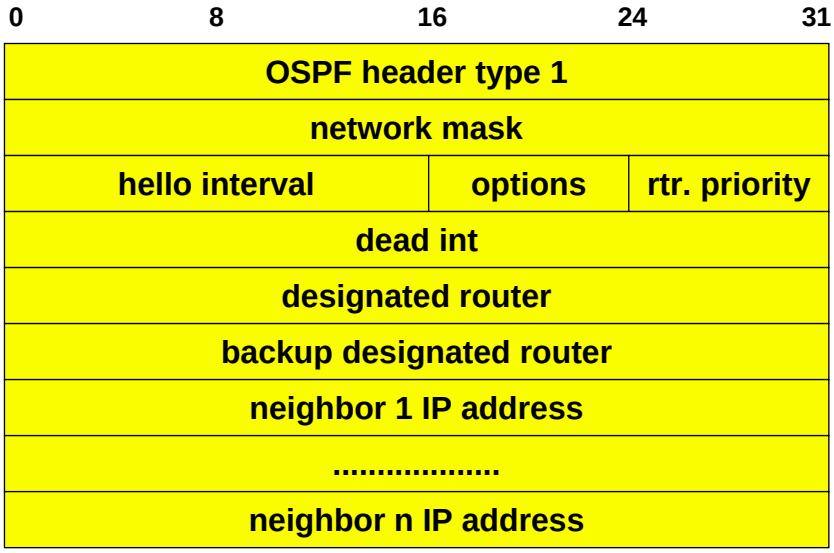
OSPF Header

Appendix 1 - OSPF Advanced Topics

OSPF Header

- **VERSION**
- **TYPE of the OPSF message**
  - 1 ..... Hello Message
    2 ..... Database Description
    3 ..... Link Status Request
    4 ..... Link Status Update
    5 ..... Link Status Ackowledgement
- **ROUTER ID, AREA ID**
  - IP - address (largest IP-address or dummy-IP-address) of the router sending this message, and area number
- **AUTHENTICATION TYPE**
  - 0 ... no authentication; 1 .... simple password authentication; 2 … cryptographic authentication

OSPF Hello Message



OSPF Hello Message

- **NETWORK MASK**
  - network-mask of the network over which this message has been send
- **HELLO INTERVAL**
  - amount of time between two Hello messages
- **RTR PRIORITY**
  - priority of the sending router; important for determination Designated Router and Backup Router
- **DEAD INT**
  - timeout-value to consider a not-replying neighbor-router as being out of order

OSPF Hello Message

- **OPTIONS**
  - T - Bit ... router supports Type of Service Routing

    ToS of IP contains 4 bit (delay, throughput, reliability, cost) -> provides 16 different metrics
  - E - Bit ... router sends or receives external information (External Link Advertisements)

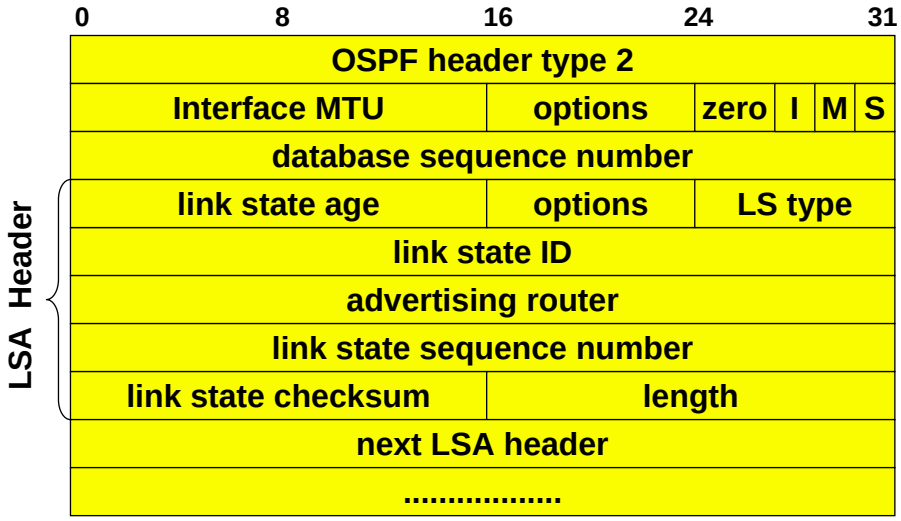
    E - Bit is mechanism for "Tagged External" (marking external routes in the whole area)
  - M - Bit ... indicates multicast OSPF (MOSPF)
- **DESIGNATED + BACKUP ROUTER**
  - IP-addresses of designated and backup routers (assumed by the sending router for this network segment)

Appendix 1 - OSPF Advanced Topics

Usage of OSPF Hello Message

- **NEIGHBOUR x IP ADDRESS**
  - IP- addresses of neighbour routers that sending Hello messages recently
- **set-up and test reachability of neighbours**
- **determination of Designated Routers**
- **failure detection (router or link)**
  - values for DEAD INT and HELLO INTERVAL directly influences the duration time a router needs to detect failures and furthermore to select a new path (rerouting)

OSPF Database Description Message



OSPF Database Description Message

- **is used to initialize the topology-database after establishing communication**
  - master / slave principle
- **OPTIONS is similar as in OSPF header**
- **FLAGS**
  - I ... first packet of the database description
  - M ... further database description packets will follow
  - S .... specifies master or slave
- **DATABASE SEQUENCENUMBER**
  - indicates successive database description packets

OSPF Database Description Message

- **LINK STATE AGE**
  - describes age of information
  - initially set to zero; increased by one by every forwarding router
  - also increased as database entry until aging-timeout (60 min) expires -> LS is removed
- **LINK STATE (LS) TYPE and LINK STATE ID**
  - type identifies LS type (one out of 5 different LS types)
  - type also identifies type of Link State ID and data range of the LSA
  - Description Message contains LSA-header only !!!

OSPF Database Description Message

- **LS types and associated Link State ID:**

Link State Type:	*Link State ID:*
1 ..... Router LSA	-> ID of source router
2 ..... Network LSA	-> IP address of DR
3 ..... Summary LSA (IP Network)	-> IP address of destination network
4 ..... Summary LSA (ASBR)	-> Router ID of AS Boundary Router
5 ..... AS External LSA	-> IP address of destination network

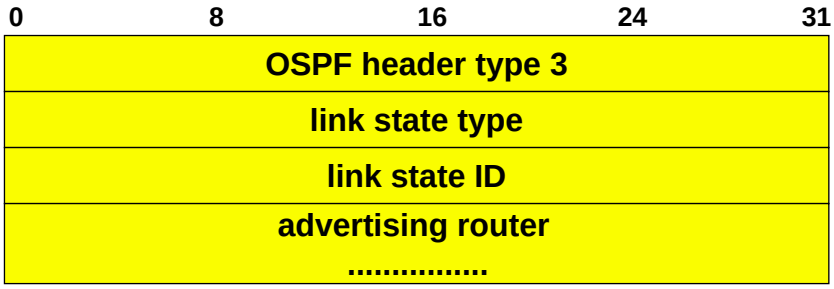
OSPF Database Description Message

- **usage of LSA types:**
  - type 1 is used by any router inside an area; describes Router Link State of a router inside this area (Router-LSA)
  - type 2 is used by Designated Routers inside an area; describes which routers are connected to the same network segment (Network LSA)
  - type 3 are used by Area Border Routers to announce networks outside of the area (Summary LSA), type 4 notifies Autonomous System Boundary Routers (ASBR)
  - type 5 is used by ASBR to announce external networks (outside OSPF domain, Net-IDs of other AS)

OSPF Database Description Message

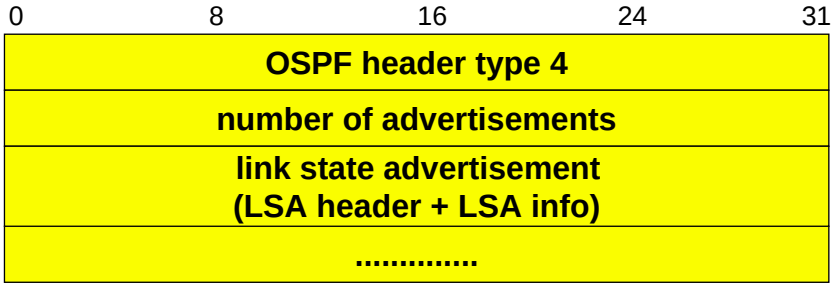
- **ADVERTISING ROUTER**
  - ID of router which generates this state information
- **LINK STATE SEQUENCENUMBER**
  - to differentiate successive link state information of a LSA
- **LENGTH**
  - length of LSA including LSA-header (depends on type field)
  - further entries only in case of Update Messages (not database description messages)
- **LINK STATE CHECKSUM**

OPSF Link State Request Message



Appendix 1 - OSPF Advanced Topics

OPSF Link State Update Message

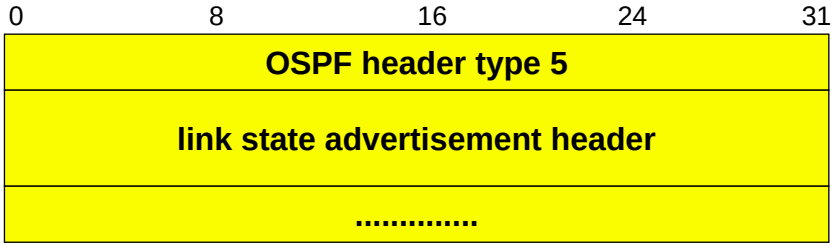


OSPF LS Request/Update Message

- **a request message triggers one or more Link State Updates from the neighbour's database**
- **neighbour router replies with Link State Update**
  - contains LSA-header and associated information
    -> Link State Advertisement, LSA
- **Link State Update Message is also used to refresh the state information every 30 minutes**
- **every Update Message is confirmed with an Acknowledgement Message**

Appendix 1 - OSPF Advanced Topics

OSPF LS Acknowledgement Message



to enable proper confirmation the Link State Acknowledgement Message contains LSA header of the previous Update

Agenda

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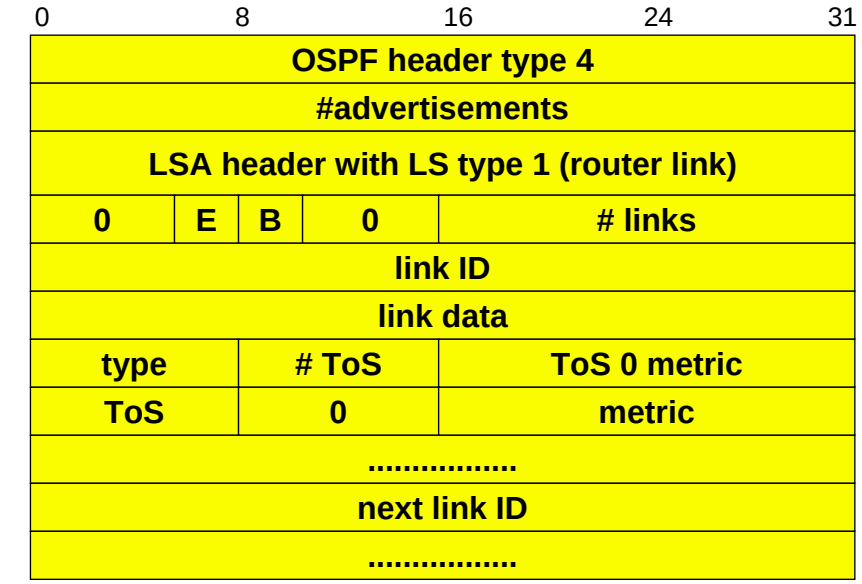
Appendix 1 - OSPF Advanced Topics

Router Link LSA



Router Link LSA

- **E-bit**
  - state message of AS Boundary Router
- **B-bit**
  - state message of Area Border Router
- **# links**
  - number of described connections
- **type, link ID, link data**
  - see table on next page
- **ToS 0 metric**
  - costs of connection if using service class ToS 0
- **ToS and metric**
  - further service class plus cost values

Appendix 1 - OSPF Advanced Topics

Router Link LSA

type	connection type	link ID	link data
1	point-to- point connection to other routers	ID of neighbor router	IP address of router
2	connection to transit network	IP address of DR	IP address of router
3	connection to stub network	IP address of network	subnet mask
4	virtual link	ID of neighbor router	IP address of router

Meaning of Router Link LSA

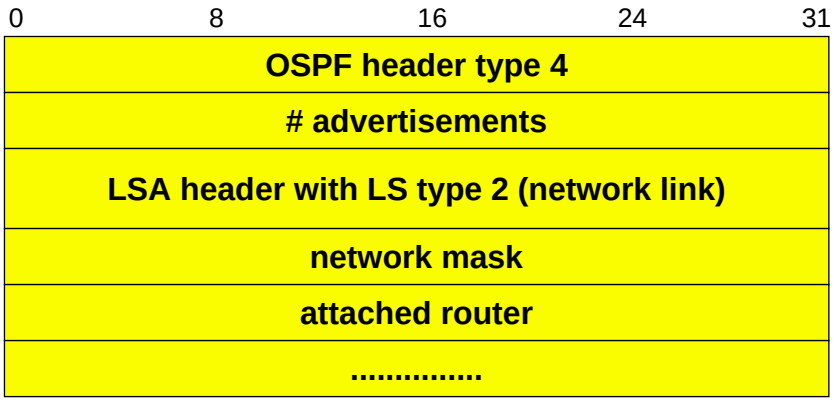
- **type 1**
  - describes a neighborhood relation
  - only description of a physical point-to-point line in case of IP-unnumbered lines
- **type 2**
  - to announce network address of a Designated Router of a transit network
- **type 3**
  - to announce network address and subnet mask of a stub network
  - using a point-to-point line with IP numbering, these IP-addresses are also announced as stub network

Appendix 1 - OSPF Advanced Topics

Mapping IP ToS Bits to OSPF ToS Service Classes

OSPF ToS	IP ToS bits D(elay)	T(hroughput)	R(eliability)
0	0	0	0
4	0	0	1
8	0	1	0
12	0	1	1
16	1	0	0
20	1	0	1
24	1	1	0
28	1	1	1

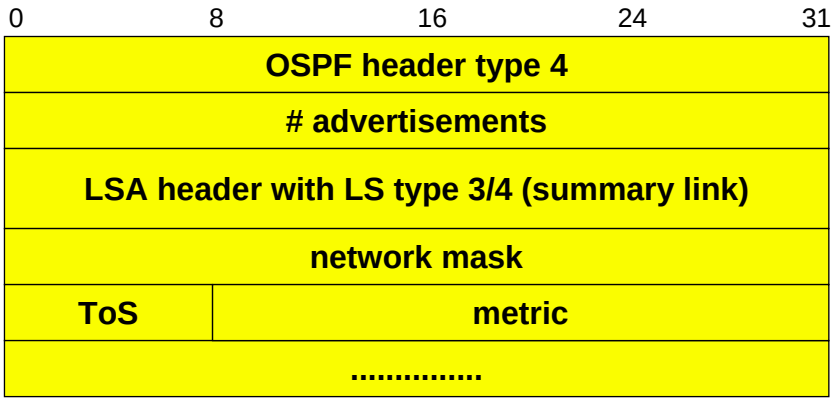
Network Link LSA



Network Link LSA

- **generated by Designated Router of a network segment with multiple access (transit network)**
  - network mask and connected routers are reported
  - net-ID of the transit network can be calculated from the address of the Designated Router (which can be found in the OSPF header) and the subnet mask

Summary Link LSA

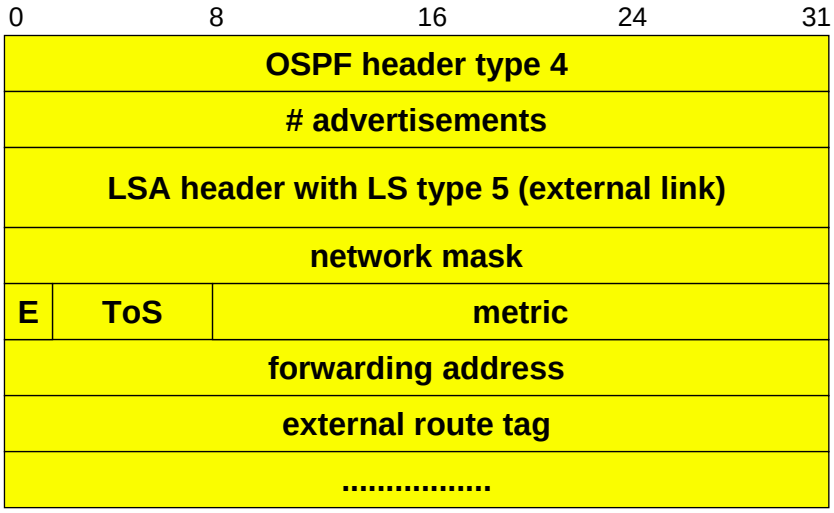


Appendix 1 - OSPF Advanced Topics

Summary Link LSA

- **generated by Area Border Router to notify costs**
  - to networks outside of its area (message direction: Backbone Area -> Area) (type 3)
  - to networks inside of its area (message direction: Area -> Backbone Area) (type 3)
  - to ASBR or to notify the router-ID of the ASBR (type 4, network -ID in header)
- **Summary Link LSA can be additionally used for Route Summarization**

AS External Link LSA



AS External Link LSA 1

- **to announce external networks outside of the Autonomous System (OSPF Domain)**
  - generated by ASBR and distributed across the whole OSPF domain
  - note: net-ID of external network is found in the OSPF header

AS External Link LSA 2

- **E - bit:**
  - to differentiate type 1 (E1) and type 2 (E2) metrics
- **how are these metrics interpreted?**
  - E1 type means: costs can be compared with internal metric; if there exist two ASBR with different costs to the external network, this external costs can be added to the internal to determine the best of both paths
  - E2 type means: costs can not be compared with internal metric; only external costs specify the best path

AS External Link LSA 3

- **FORWARDING ADDRESS**
  - to specify a router (not ASBR) who should receive packets for external targets (0.0.0.0 means ASBR)
- **using Forwarding Address a redirect-hint to another router (than the ASBR) can be specified**
  - then this router is used as datagram forwarder for the given network

AS External Link LSA 4

- **EXTERNAL ROUTE TAG**
  - supports communication between ASBRs by route tagging external networks (net-ID of other ASs)
- **external net-IDs can be labelled (route tagging) via External Route Tag**
  - External Route Tag plays an important role for routing policy (BGP and Internet Service Provider concerns)