Appendix 8 - 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

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

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 8 - 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 8 - 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

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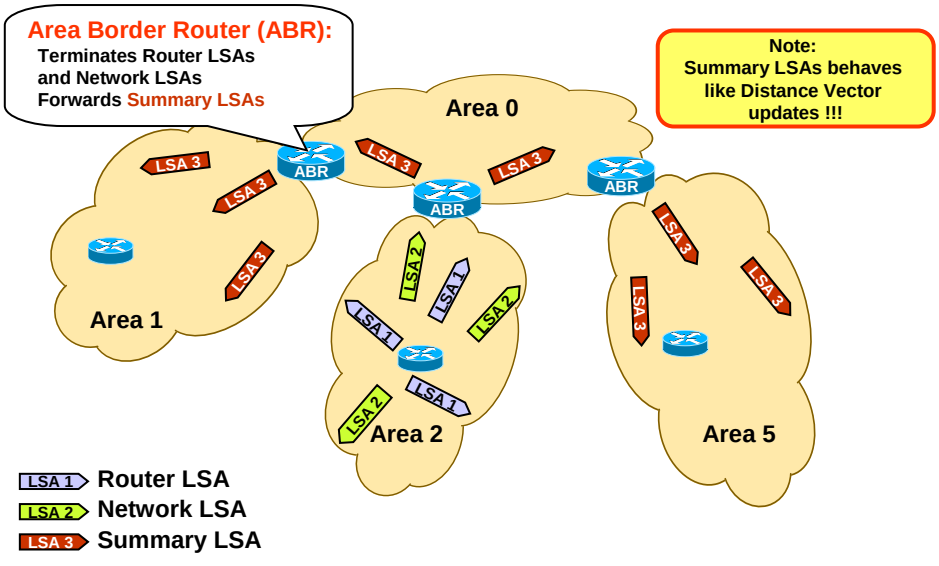
ABR



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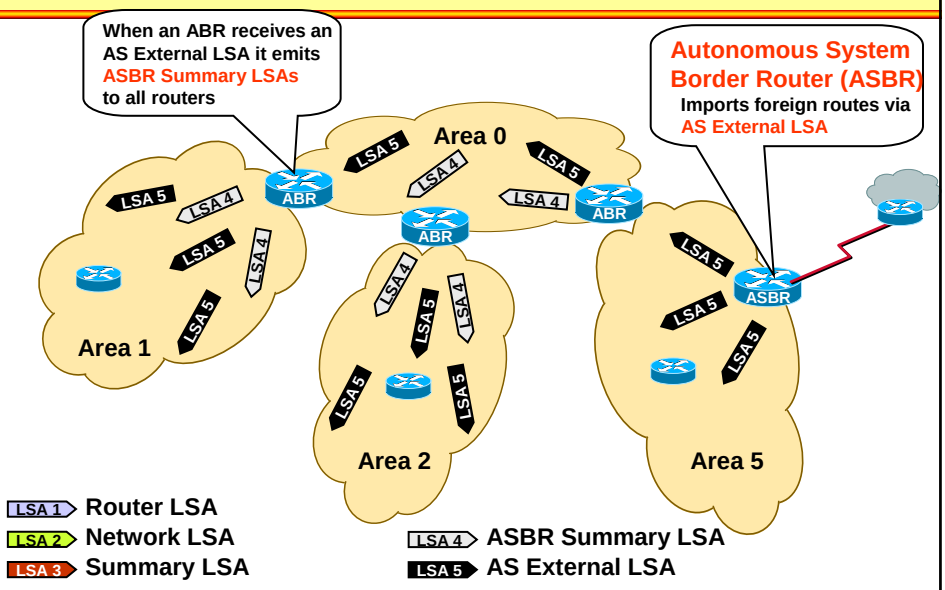
ASBR



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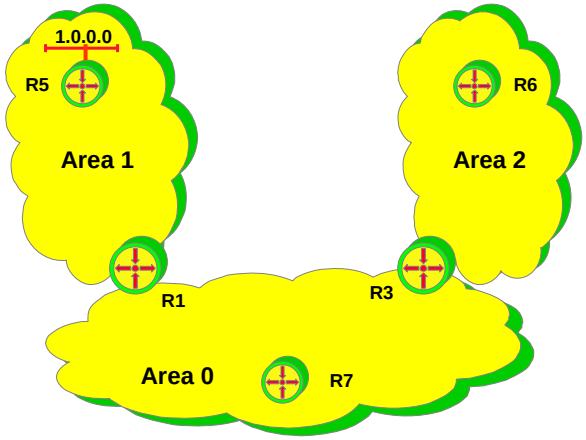
Appendix 8 - OSPF Advanced Topics

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

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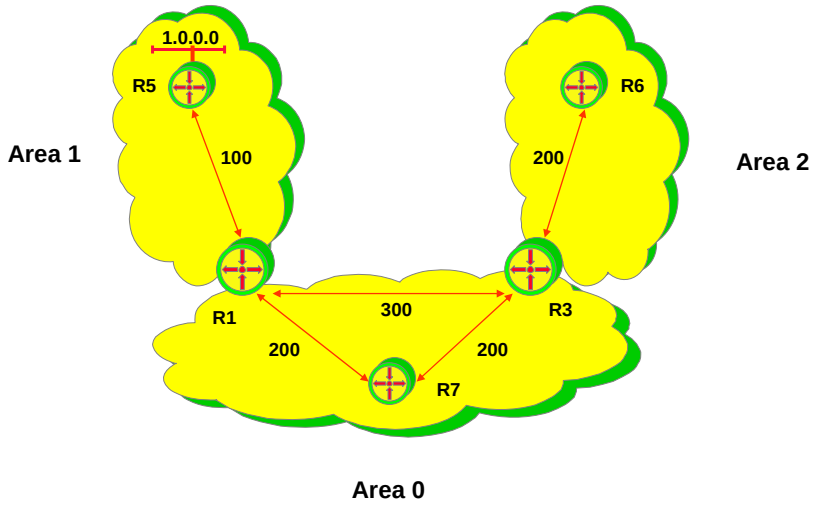
OSPF Costs of Best Paths



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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

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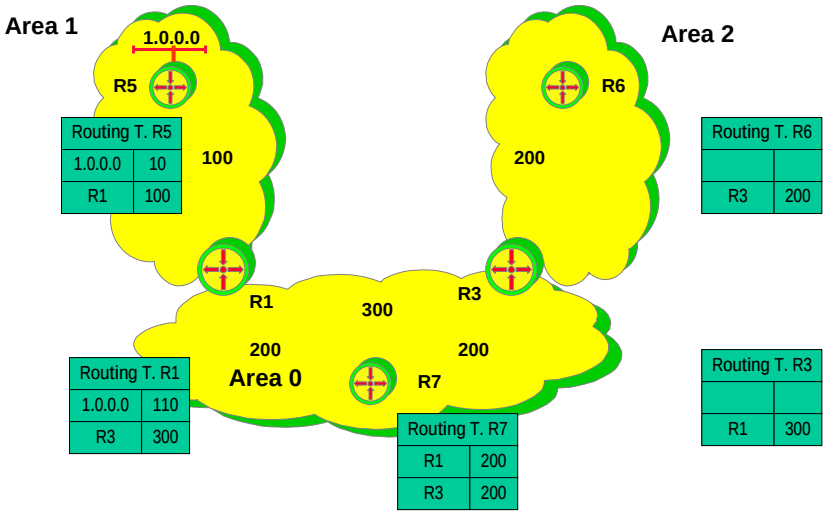
Activation of 1.0.0.0



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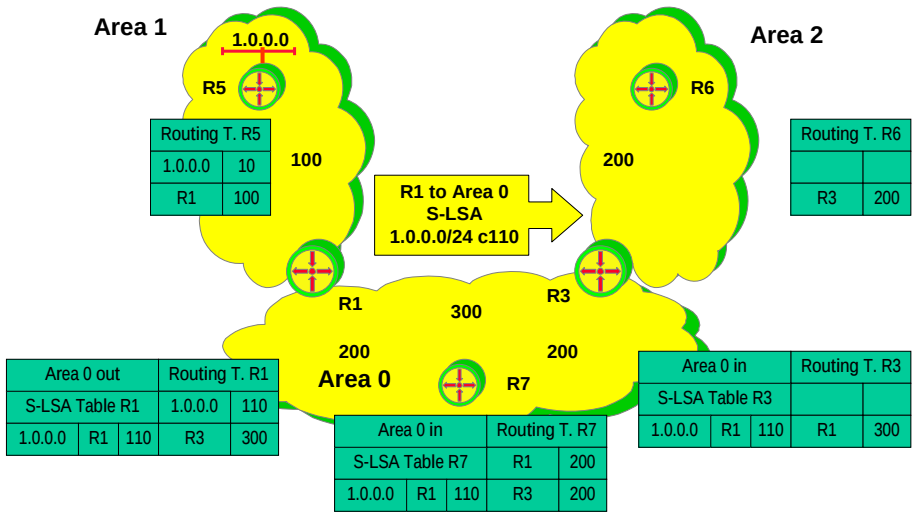
ABR R1 -> Summary LSA 1.0.0.0



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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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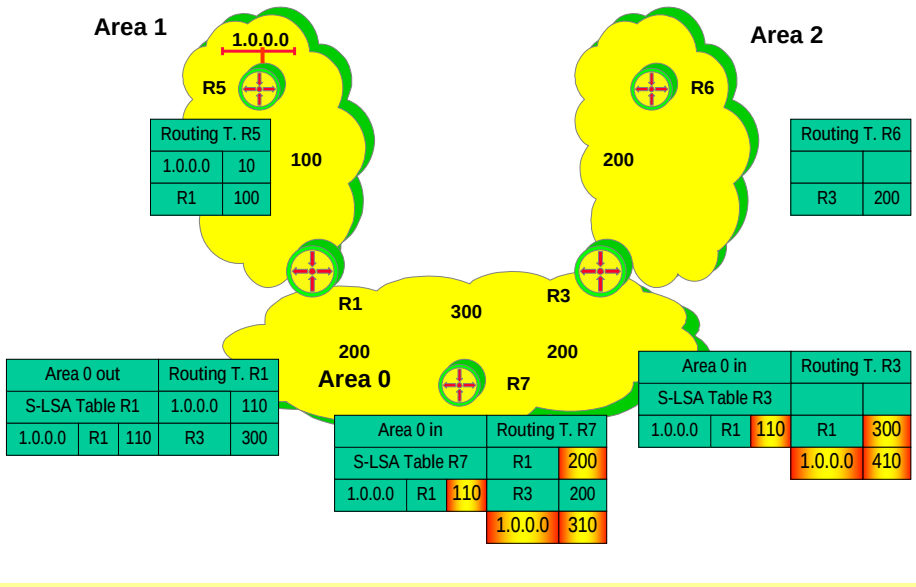
Calculation R7, ABR R3



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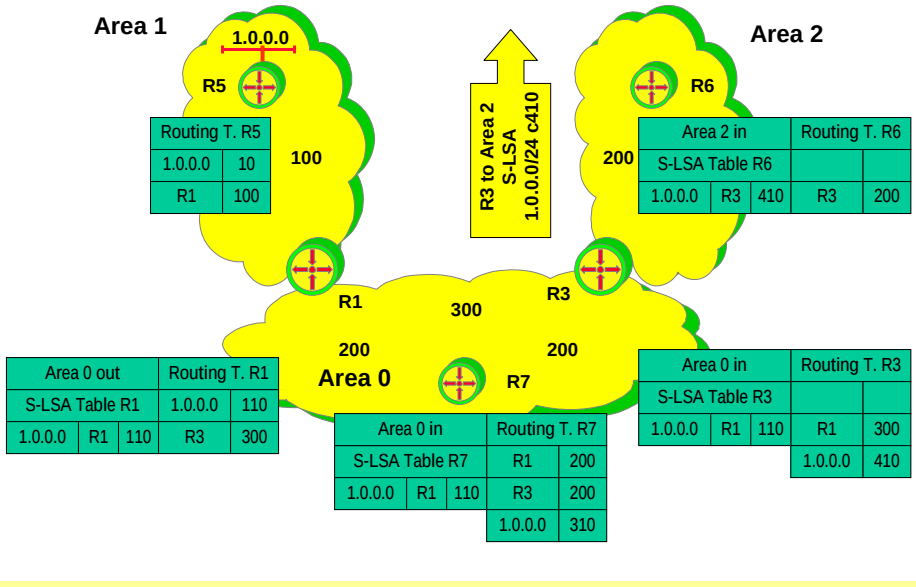
ABR R3 -> Summary LSA 1.0.0.0



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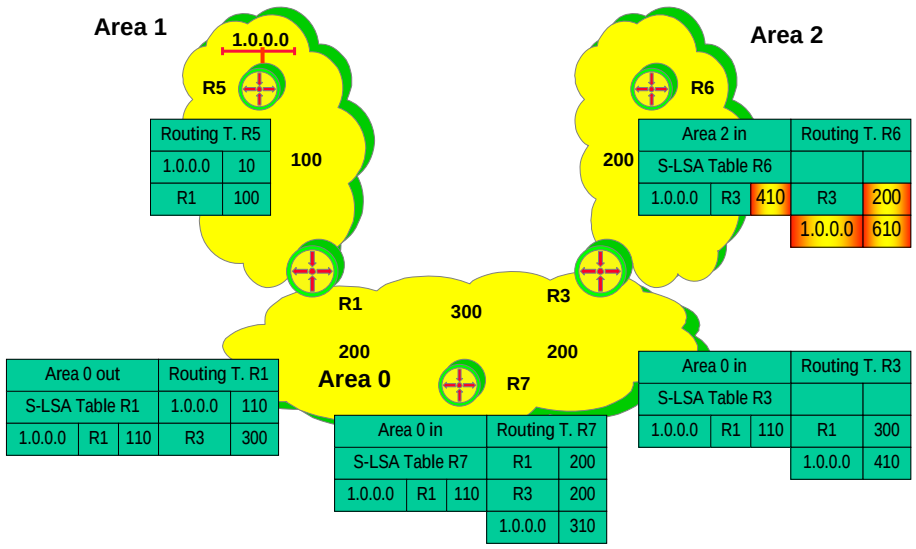
Calculation R6



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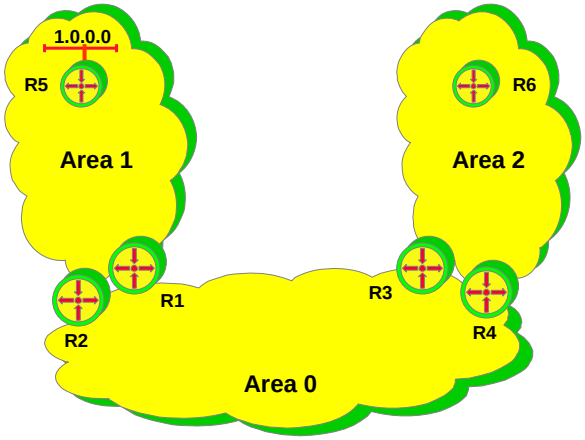
Areas and Topology (Redundant ABRs)



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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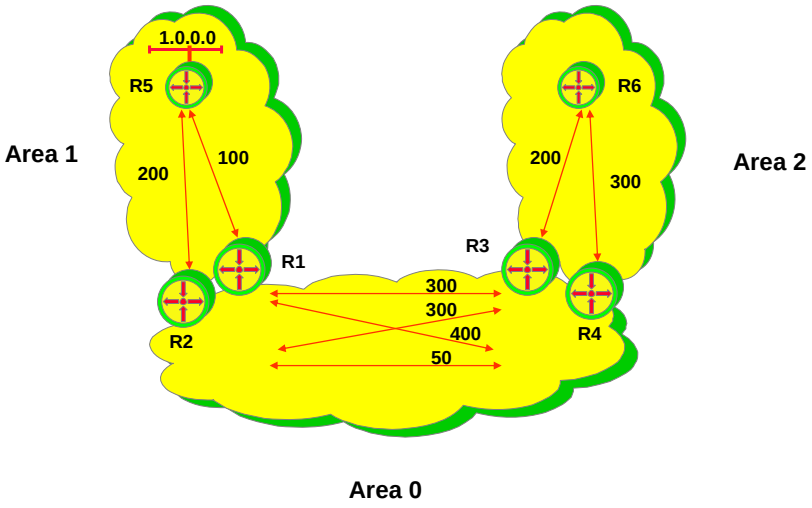
OSPF Costs



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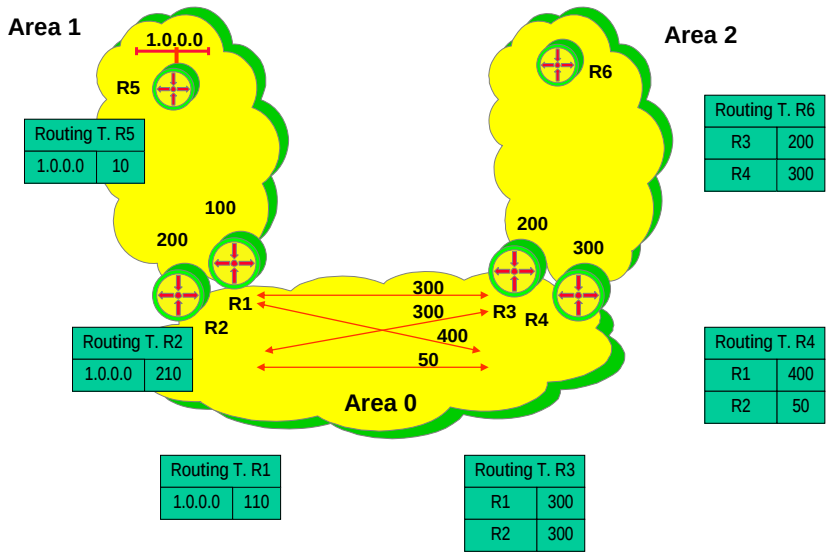
Activation of 1.0.0.0



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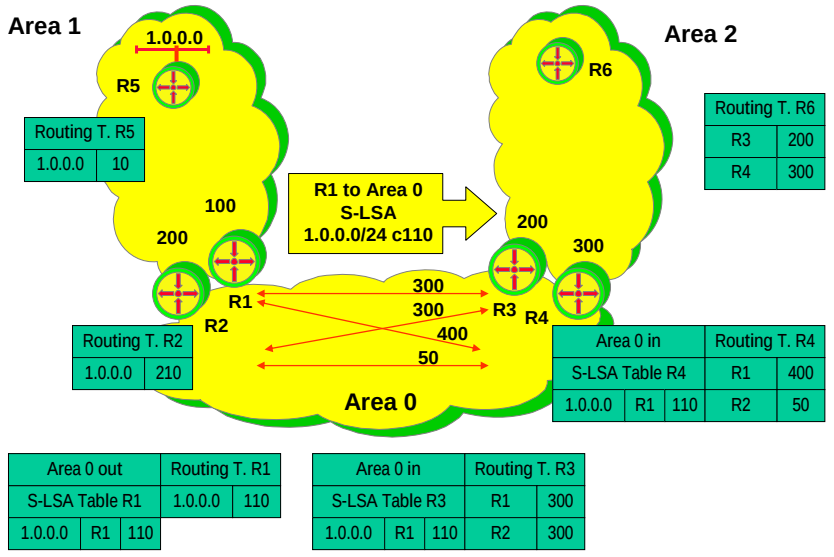
ABR R1 -> Summary LSA 1.0.0.0



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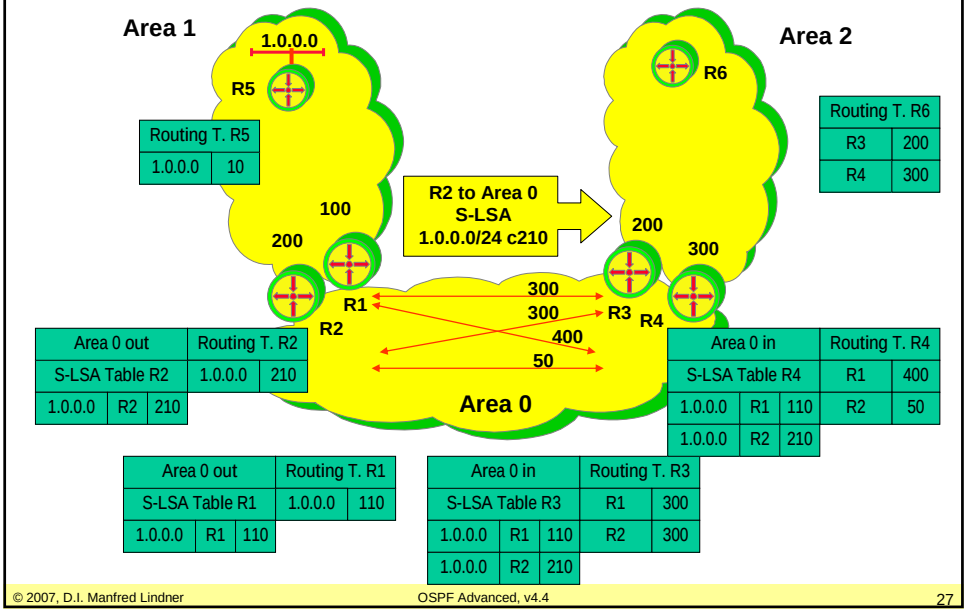
ABR R2 -> Summary LSA 1.0.0.0



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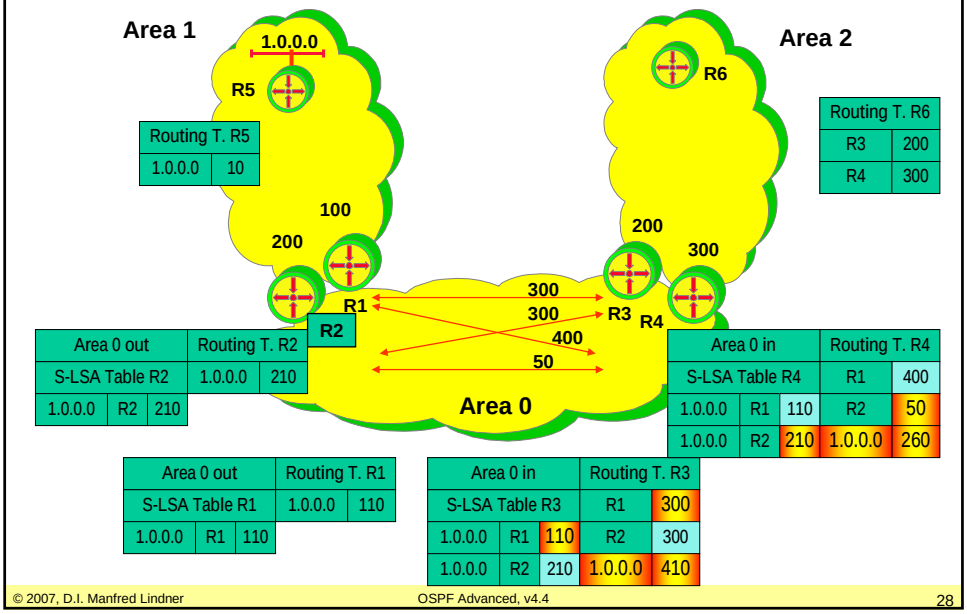
Calculation R3, R4



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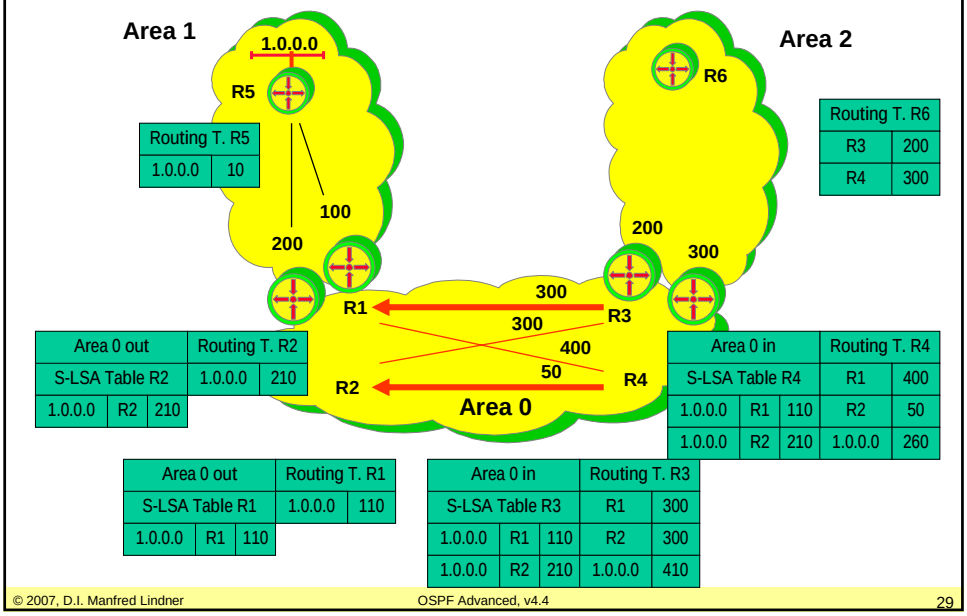
Best Path to 1.0.0.0 for R3, R4



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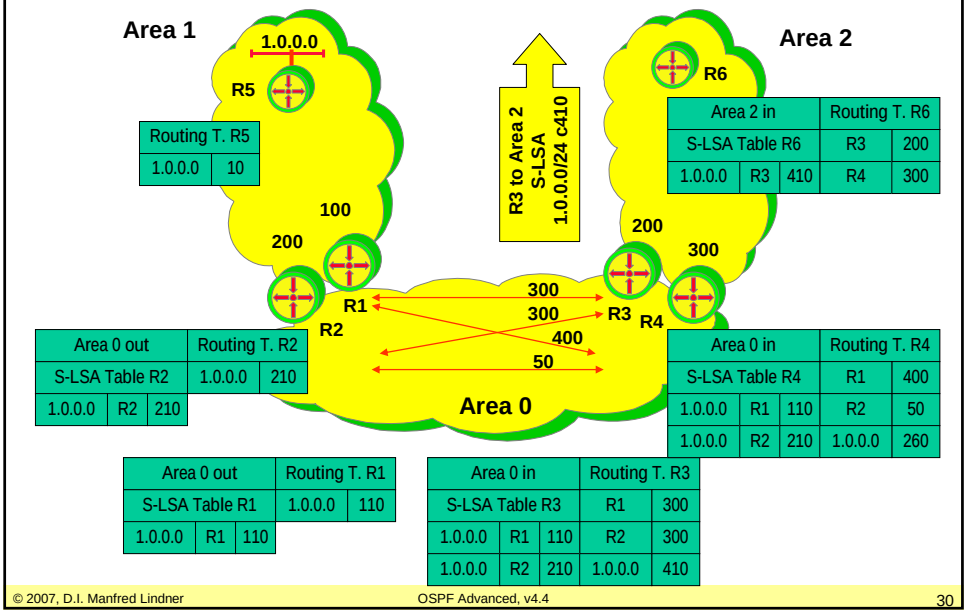
ABR R3 -> Summary LSA 1.0.0.0



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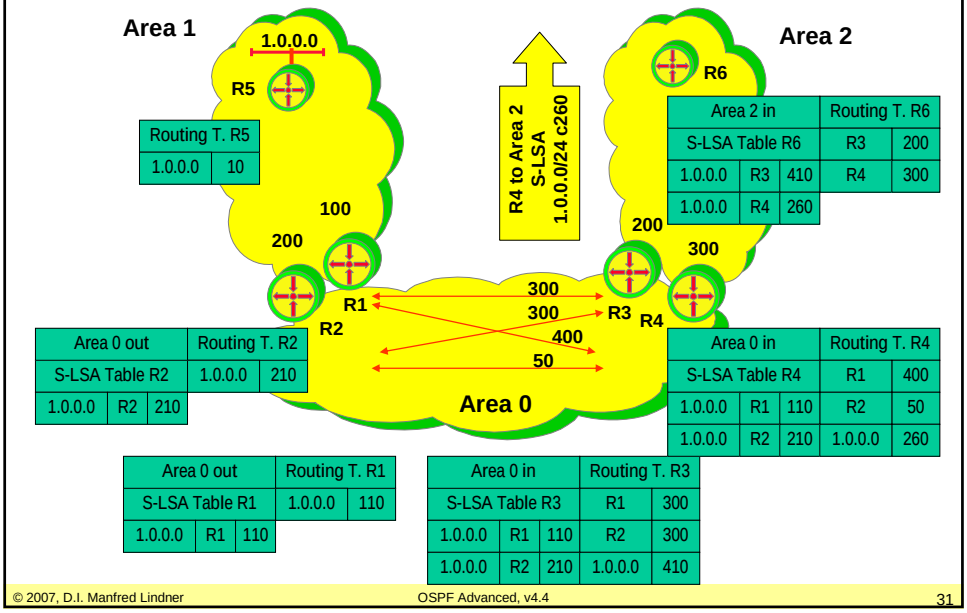
ABR R4 -> Summary LSA 1.0.0.0



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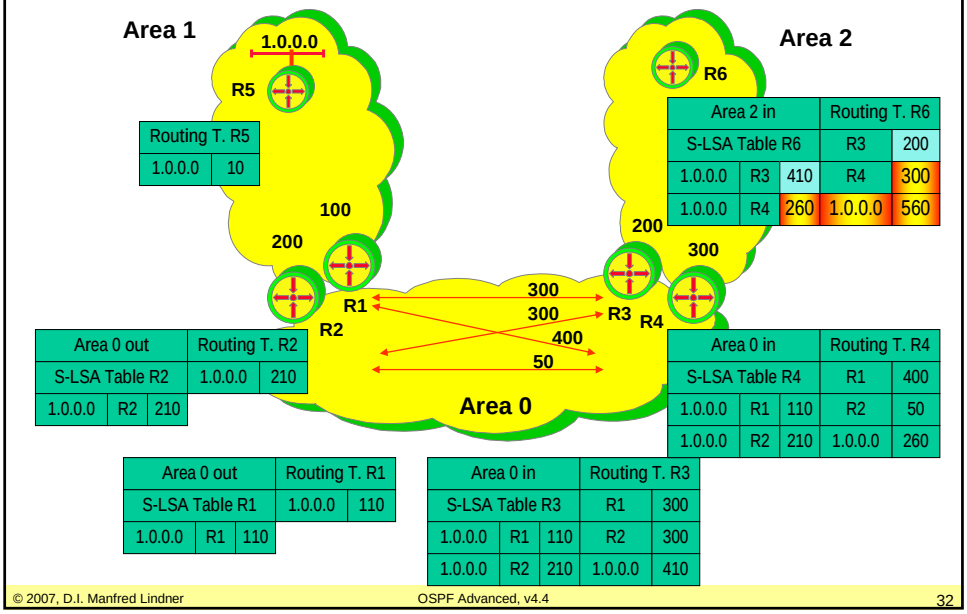
Calculation R6



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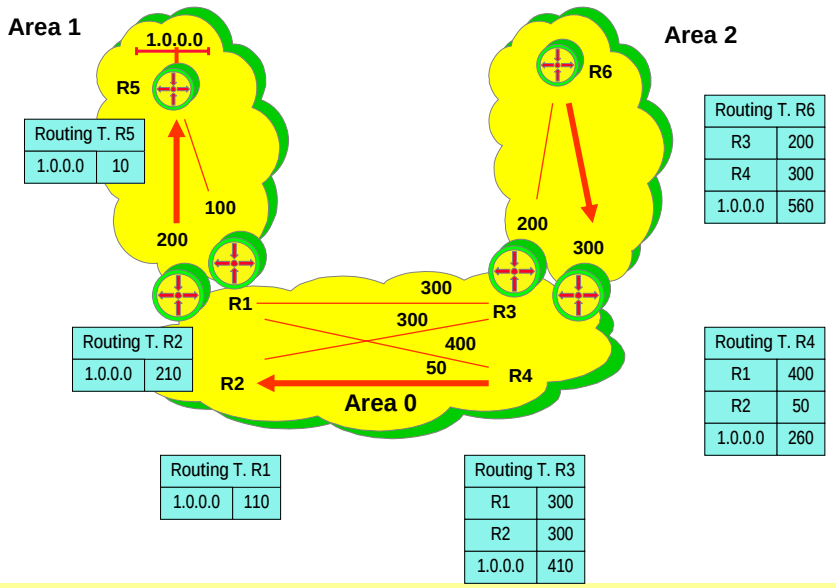
Best Path to 1.0.0.0 for R6



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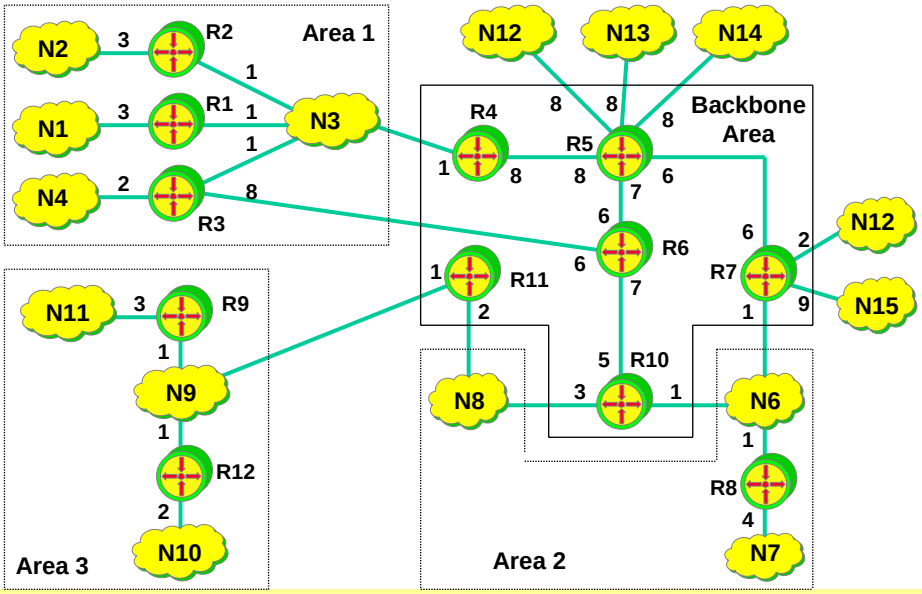
OSPF Domain with 4 Areas



OSPF Domain with 4 Areas

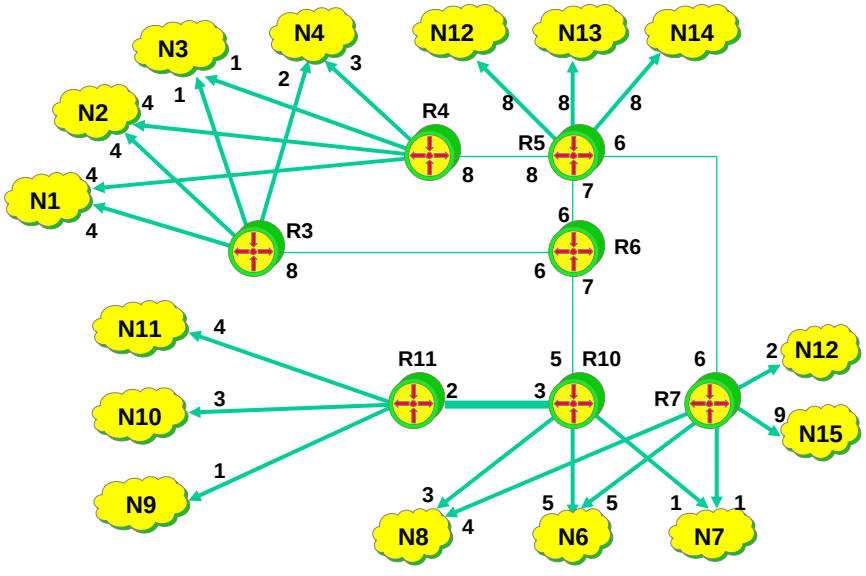
- **internal routers: 1, 2, 5, 6, 8, 9, 12**
  - router 1,2 ..... area 1
  - router 8 ..... area 2
  - router 9, 12 ... area 3
  - router 5,6 ..... backbone
- **Area Border Routers: 3, 4, 7, 10, 11**
  - router 3, 4 ..... topology of area 1 and backbone
  - router 7, 10 .... topology of area 2 and backbone
  - 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 8 - 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

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

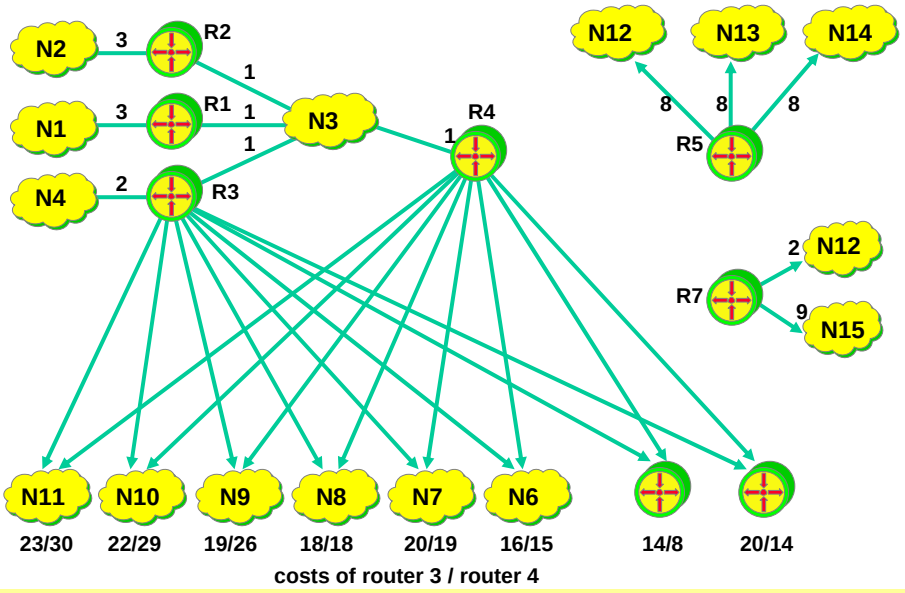
Router 3/4 S-LSAs -> Area 1

- **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 8 - 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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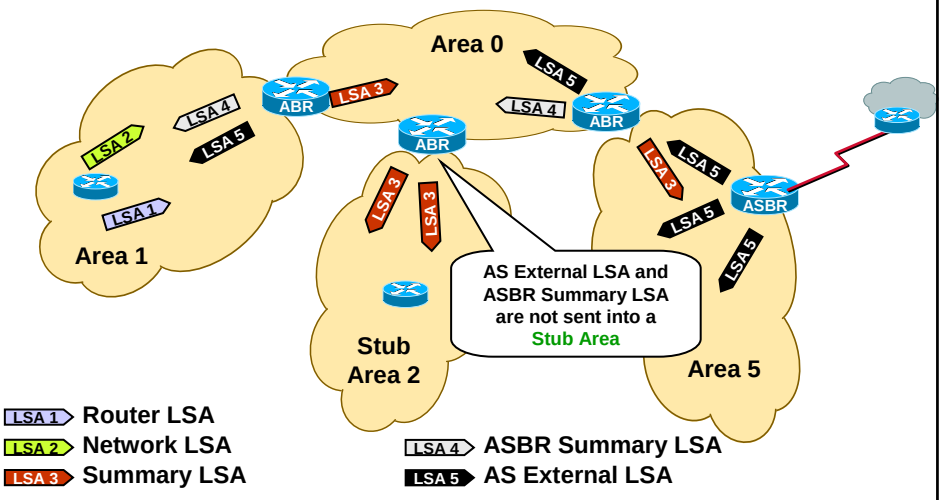
Stub Area



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

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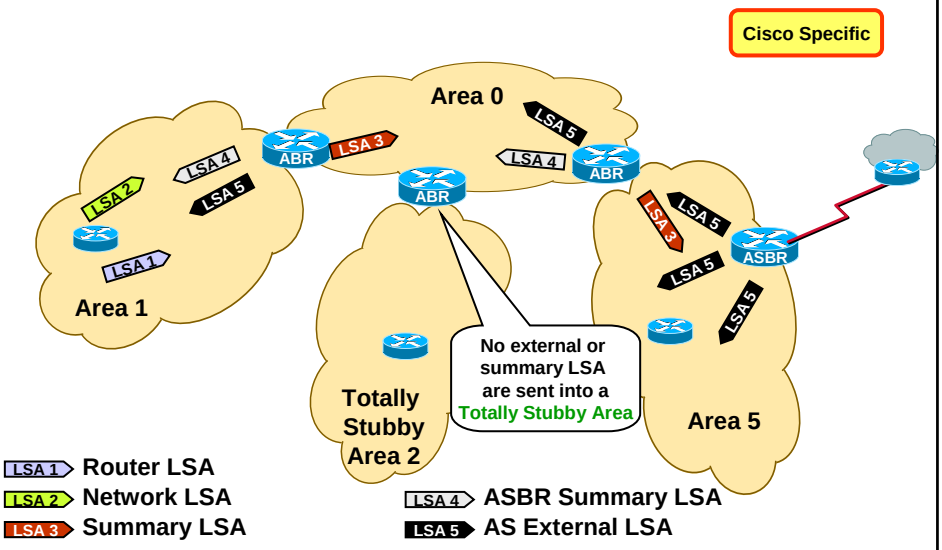
Totally Stubby Area



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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)

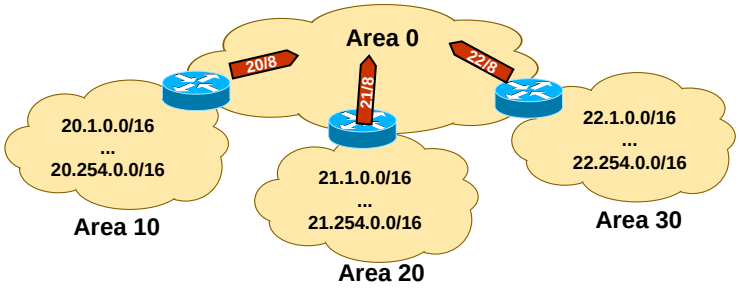
Route Summarization 3

- **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 8 - OSPF Advanced Topics

Example Summarization

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



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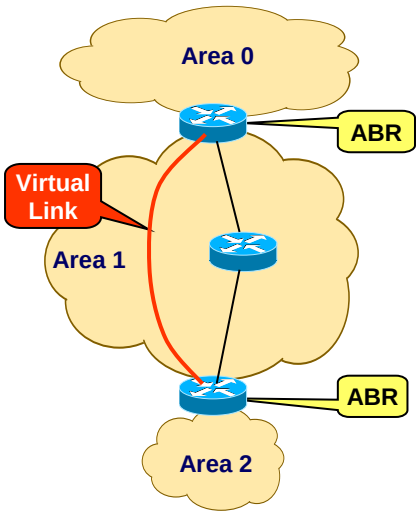
Appendix 8 - OSPF Advanced Topics

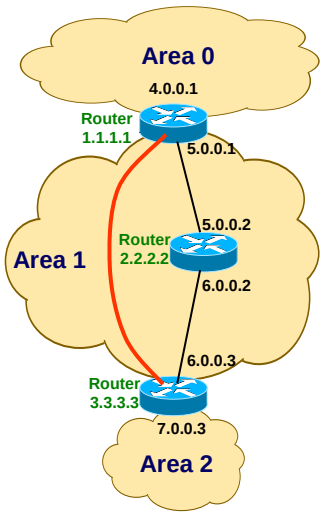
Virtual Links

- **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!**



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

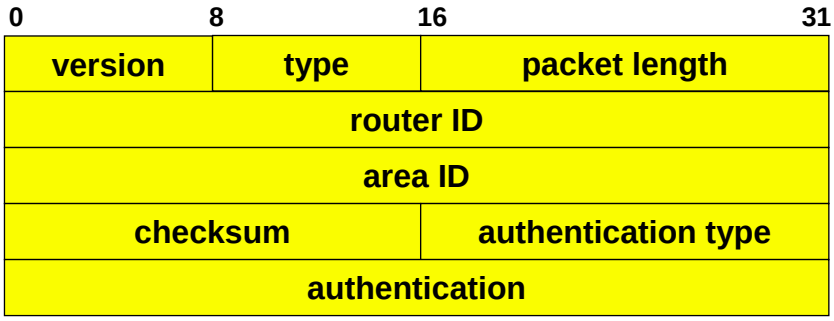


Appendix 8 - OSPF Advanced Topics

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



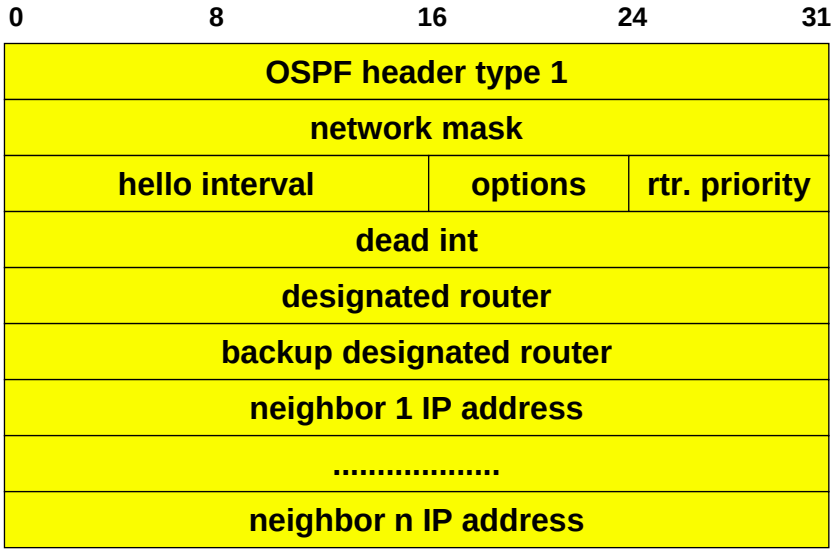
OSPF Header

Appendix 8 - 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

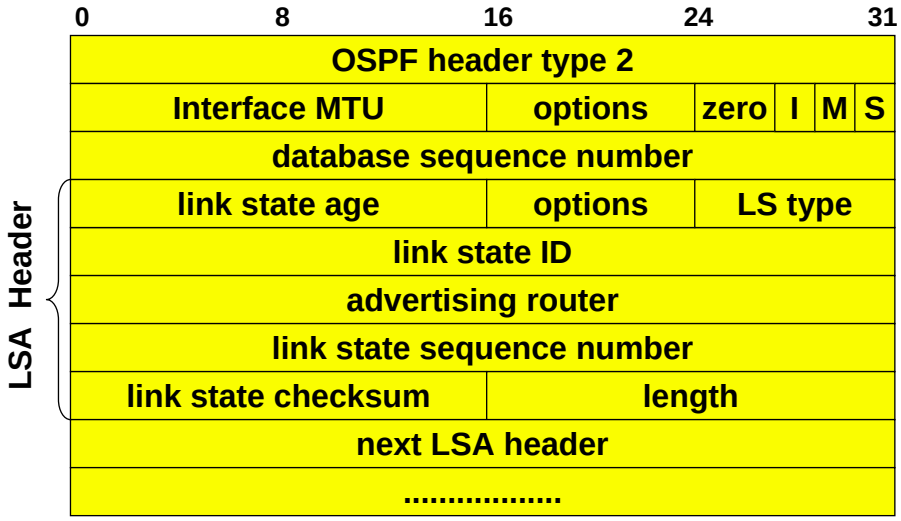
    ToS of IP contains 4 bit (delay, throughput, reliability, cost) -> provides 16 different metrics
  - E - Bit ... router sends or receives external information (External Link Advertisements)

    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)

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

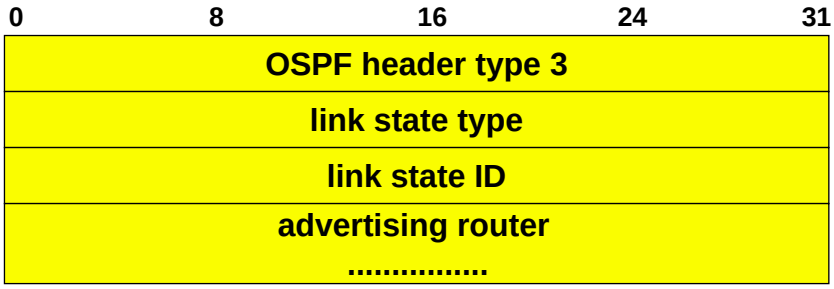
OSPF Database Description Message

- **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)

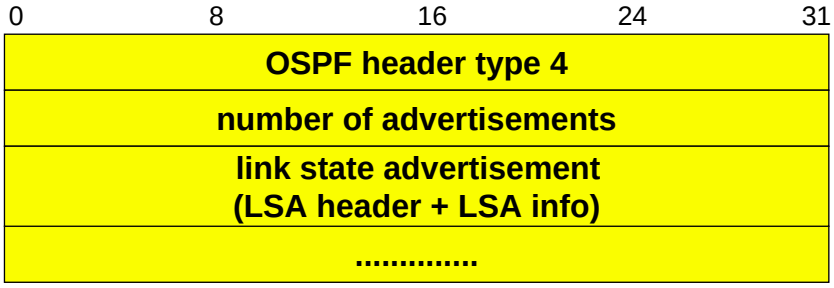
OSPF Database Description Message

- **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



OPSF Link State Update Message

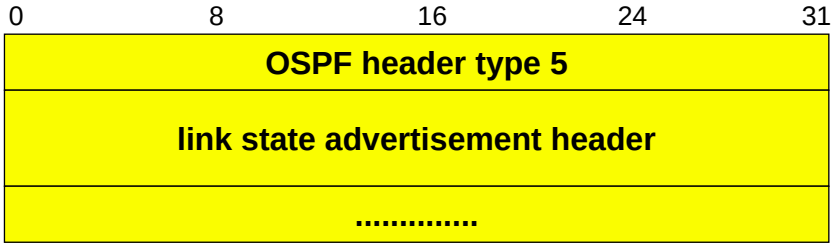


OSPF LS Request/Update Message

- **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 8 - 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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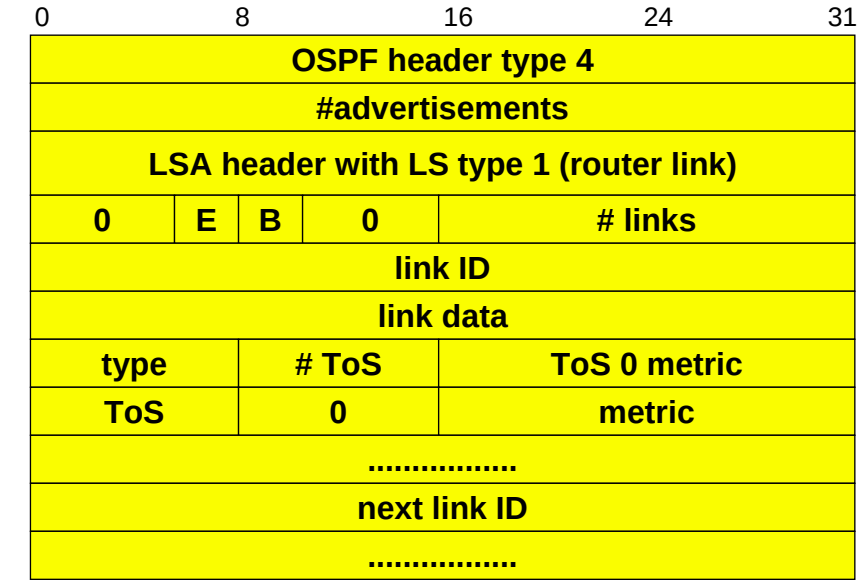
  - LSA Formats

Appendix 8 - 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

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

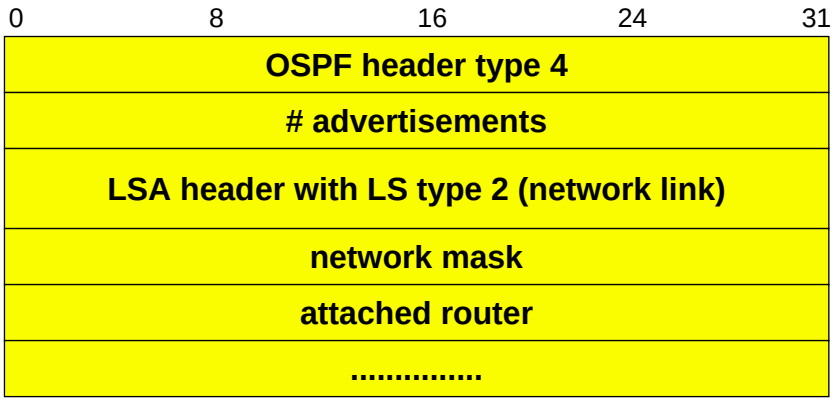
- **type 1**
  - describes a neighborhood relation
  - only description of a physical point-to-point line in case of IP-unnumbered lines
- **type 2**
  - to announce network address of a Designated Router of a transit network
- **type 3**
  - to announce network address and subnet mask of a stub network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

Appendix 8 - 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

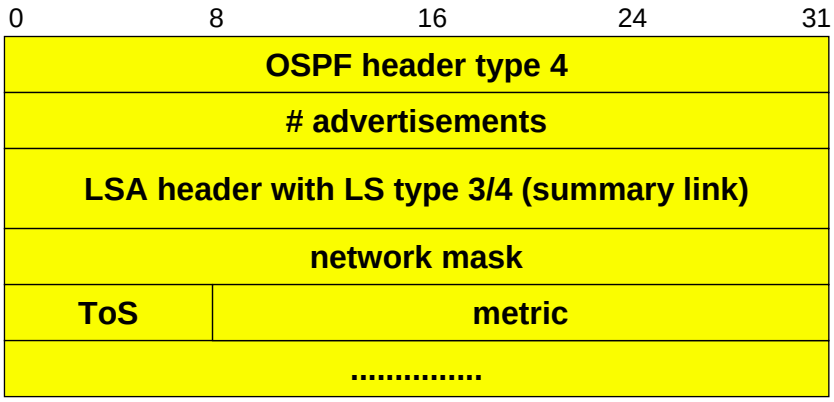
Network Link LSA



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

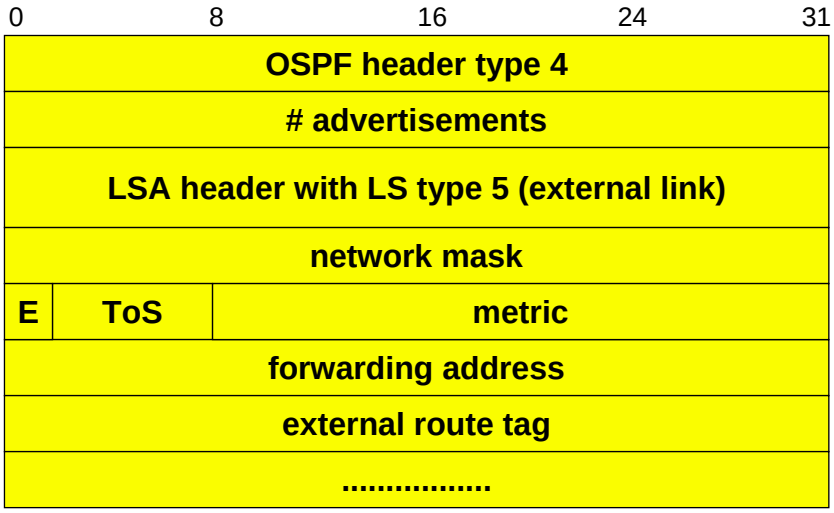
Summary Link LSA



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)