

L10 - OSPF Fundamentals

OSPF Fundamentals

Open Shortest Path First Routing Protocol
Internet's Second IGP

Agenda

- **OSPF Principles**
 - Introduction
 - The Dijkstra Algorithm
 - Communication Procedures
 - LSA Broadcast Handling
 - Broadcast Networks
 - Summary of Benefits

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OSPF - Open Shortest Path First

- **distance vector protocols like RIP have several dramatic disadvantages:**
 - slow adaptation of network modifications !!
 - size of routing update is proportional to network size !!
- this led to**
- link-state protocols**
- **OSPF is an important implementation for IP**
 - **basic idea: every router knows topology of the whole network, including subnets and other routers**
 - **see RFC 2328 (2178, 1583 are obsolete)**

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OSPF Topology Database

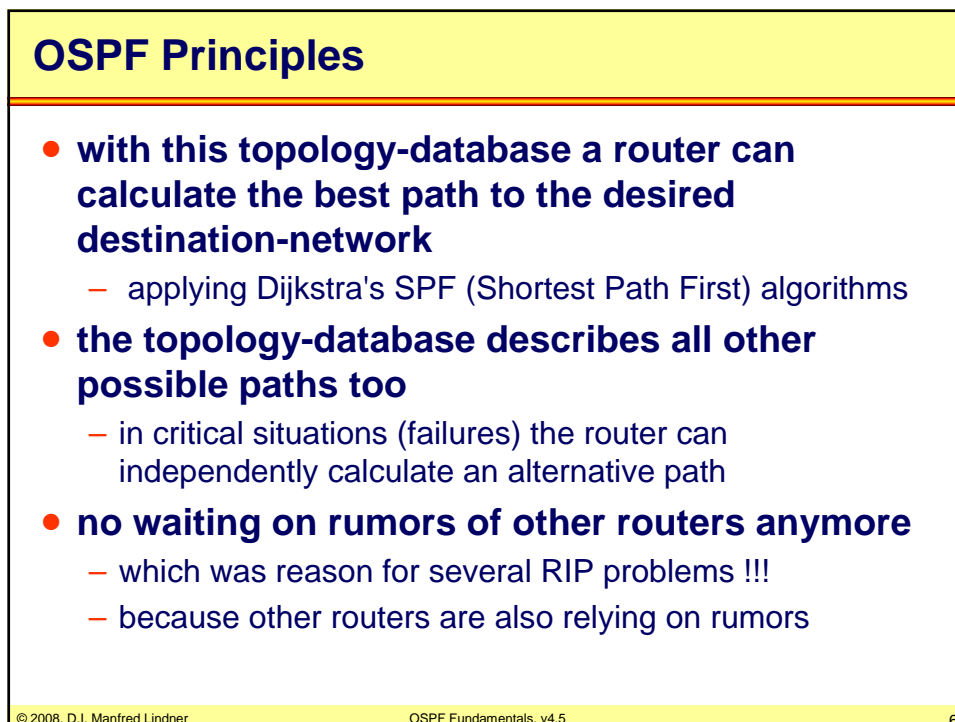
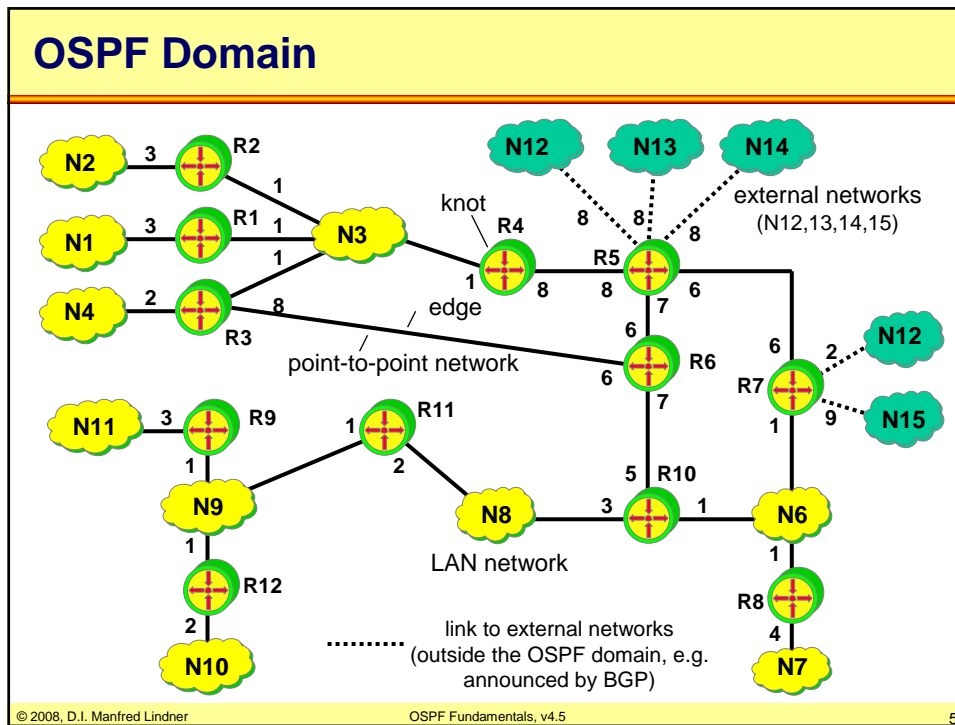
- **every router maintains a topology database**
 - is like a "network roadmap"
 - describes the whole network !!
 - note: RIP provides only "signposts"
- **database is based on a graph**
 - where each knot stands for a router
 - where each edge stands for a subnet
 - connecting the routers
 - path-costs are assigned to the edges
 - where the actual router uses the graph as root
 - to calculate shortest paths to all subnets

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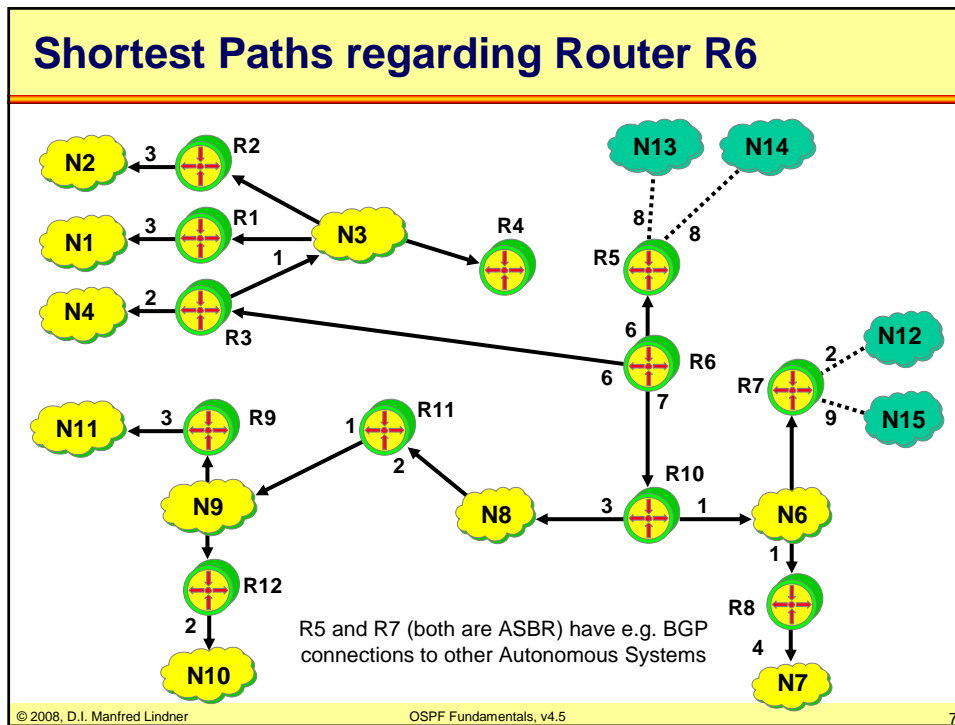
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Routing Table

- **after calculating the shortest path, this path is entered in the routing table**
- **OSPF is able to differentiate between internal and external net-IDs**
 - Autonomous System Boundary Router ASBR imports external net-IDs
 - paths to ASBR's are considered as special internal destinations
 - path-costs to external networks can be calculated (E1 metric) by adding:
 - internal costs to ASBR
 - and external costs (from ASBR to the external networks)

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NET-ID	NEXT HOP	DISTANCE
N1	R3	10
N2	R3	10
N3	R3	7
N4	R3	8
N6	R10	8
N7	R10	12
N8	R10	10
N9	R10	11
N10	R10	13
N11	R10	14
R5	R5	6
R7	R10	8

internal destinations of router 6;
R5 and R7 are ASBR's

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Routing Table Router 6

NET-ID	NEXT HOP	DISTANCE
N12	R10	10
N13	R5	14
N14	R5	14
N15	R10	17

external destinations of router 6

assumption: ASBR R5 and R7 announce external
networks (which have been noticed using e.g. BGP-4) via
type 1 external link advertisements (E1 metric)

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- **OSPF Principles**

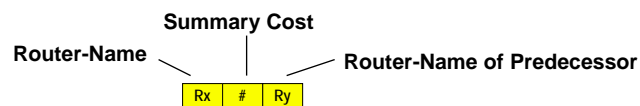
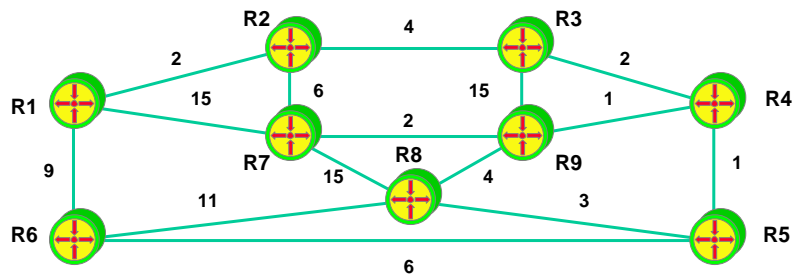
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Example Topology for Dijkstra Algorithm



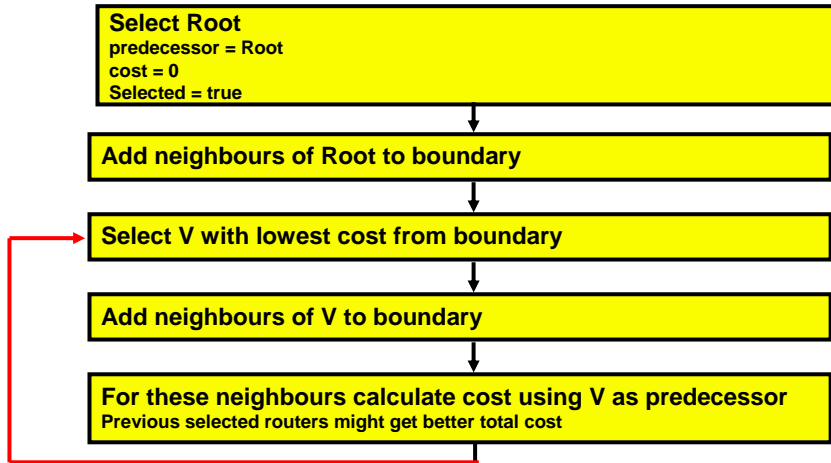
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The Principle

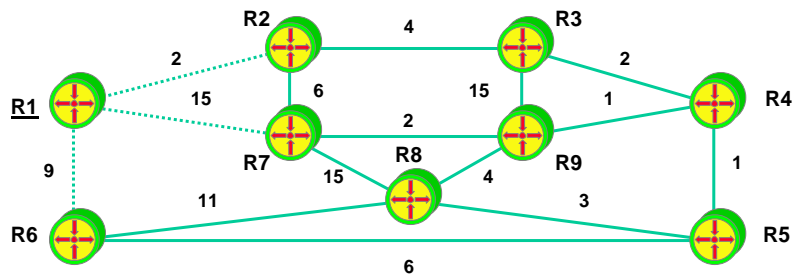


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Select root (R1)



Selected			Boundary								
R1	0	R1	R2	2	R1	R6	9	R1	R7	15	R1

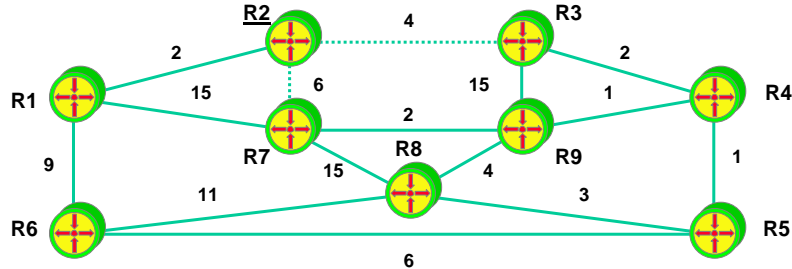
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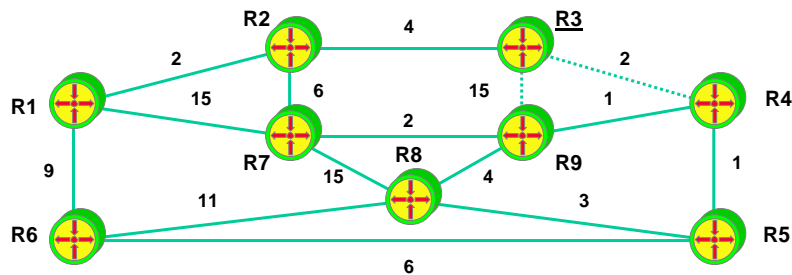
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Select router with lowest cost in boundary (R2), calculate cost for neighbours R3, R7



Selected			Boundary								
R1	0	R1	R2	2	R1	R6	9	R1	R7	15	R1
R2	2	R1	R6	9	R1	R7	8	R2	R3	6	R2

Select router with lowest cost in boundary (R3), calculate cost for neighbours R9, R4



Selected			Boundary								
R1	0	R1	R2	2	R1	R6	9	R1	R7	15	R1
R2	2	R1	R6	9	R1	R7	8	R2	R3	6	R2
R3	6	R2	R6	9	R1	R7	8	R2	R9	21	R3
									R4	8	R3

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Select one router with lowest cost in boundary (R7), calculate cost for neighbours R8, R9

Selected		
R1	0	R1
R2	2	R1
R3	6	R2
R7	8	R2

Boundary								
R2	2	R1	R6	9	R1	R7	15	R1
R6	9	R1	R7	8	R2	R3	6	R2
R6	9	R1	R7	8	R2	R9	21	R3
R6	9	R1	R4	8	R3	R9	10	R7
			R8	23	R7			

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Select router with lowest cost in boundary (R4), calculate cost for neighbours R9, R5

Selected		
R1	0	R1
R2	2	R1
R3	6	R2
R7	8	R2
R4	8	R3

Boundary								
R2	2	R1	R6	9	R1	R7	15	R1
R6	9	R1	R7	8	R2	R3	6	R2
R6	9	R1	R7	8	R2	R9	21	R3
R6	9	R1	R4	8	R3	R9	10	R7
R6	9	R1	R8	23	R7	R9	9	R4
			R5	9	R4			

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Select one router with lowest cost in boundary (R6), calculate cost for neighbours R5 and R8

Selected		
R1	0	R1
R2	2	R1
R3	6	R2
R7	8	R2
R4	8	R3
R6	9	R1

Boundary					
R2	2	R1	R6	9	R1
R6	9	R1	R7	8	R2
R6	9	R1	R7	8	R2
R6	9	R1	R9	21	R3
R6	9	R1	R4	8	R3
R6	9	R1	R4	8	R3
R6	9	R1	R9	10	R7
R6	9	R1	R8	23	R7
R6	9	R1	R9	9	R4
R6	9	R1	R5	9	R4
R9	9	R4	R8	20	R6
R9	9	R4	R5	9	R4

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Select one neighbour with lowest cost in boundary (R5), calculate cost for neighbour R8

Selected		
R1	0	R1
R2	2	R1
R3	6	R2
R7	8	R2
R4	8	R3
R6	9	R1
R5	9	R4

Boundary					
R2	2	R1	R6	9	R1
R6	9	R1	R7	8	R2
R6	9	R1	R7	8	R2
R6	9	R1	R9	21	R3
R6	9	R1	R4	8	R3
R6	9	R1	R4	8	R3
R6	9	R1	R9	10	R7
R6	9	R1	R8	23	R7
R6	9	R1	R9	9	R4
R6	9	R1	R5	9	R4
R9	9	R4	R8	20	R6
R9	9	R4	R8	12	R5

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Select router with lowest cost in boundary (R9), calculate cost for neighbours R8

Selected		
R1	0	R1
R2	2	R1
R3	6	R2
R7	8	R2
R4	8	R3
R6	9	R1
R5	9	R4
R9	9	R4

Boundary		
R2	2	R1
R6	9	R1
R7	8	R2
R3	6	R2
R6	9	R1
R7	8	R2
R9	21	R3
R4	8	R3
R6	9	R1
R4	8	R3
R9	10	R7
R8	23	R7
R6	9	R1
R8	23	R7
R9	9	R4
R5	9	R4
R9	9	R4
R8	20	R6
R5	9	R4
R9	9	R4
R8	12	R5
R8	12	R5

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Select last router in boundary (R8), algorithm terminated, all shortest paths found

Selected		
R1	0	R1
R2	2	R1
R3	6	R2
R7	8	R2
R4	8	R3
R6	9	R1
R5	9	R4
R9	9	R4
R8	12	R5

Boundary		
R2	2	R1
R6	9	R1
R7	8	R2
R3	6	R2
R6	9	R1
R7	8	R2
R9	21	R3
R4	8	R3
R6	9	R1
R4	8	R3
R9	10	R7
R8	23	R7
R6	9	R1
R8	23	R7
R9	9	R4
R5	9	R4
R9	9	R4
R8	20	R6
R5	9	R4
R9	9	R4
R8	12	R5
R8	12	R5

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Creating the Database

- **until now an “a priori” existing consistent database in every router has been assumed**
- **in fact, the basic means for creating and maintaining the database are the so-called link states**
- **a link state stands for a local neighbourhood between two routers**
 - the link state is created by these two routers
 - other routers are notified about this link state via a broadcast-mechanism (“traffic-news”)
 - link states are verified continuously

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How are Link States used?

- **adjacent routers declare themselves as neighbours by setting the link state up (or down otherwise)**
 - the link-state can be checked with hello messages
- **every link state change is published to all routers of the OSPF domain using Link State Advertisements (LSAs)**
 - is a broadcast mechanism
 - LSAs are much shorter than routing tables
 - because LSAs contain only the actual changes
 - that's why distance vector protocols are much slower
 - whole topology map relies on LSAs

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OSPF Communication Principle 1

- **OSPF messages are transported by IP**
 - ip protocol number 89
- **during initialization a router sends hello-messages to all directly reachable routers**
 - to determine its neighbourhood
 - can be done automatically in broadcast networks and point-to-point connections by using the IP multicast-address 224.0.0.5 (all OSPF routers)
 - non-broadcast networks: configuration of the neighbourhood-routers is required (e.g. X25)
- **this router also receives hello-messages from other routers**

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OSPF Communication Principle 2

- **each two acquainted routers send database description messages to each other, in order to publish their topology database**
- **unknown or old entries are updated via link state request and link state update messages**
 - which synchronizes the topology databases
- **after successful synchronization both routers declare their neighbourhood (adjacency) via router LSAs (using link state update messages)**
 - distributed across the whole network

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OSPF Communication Principle 3

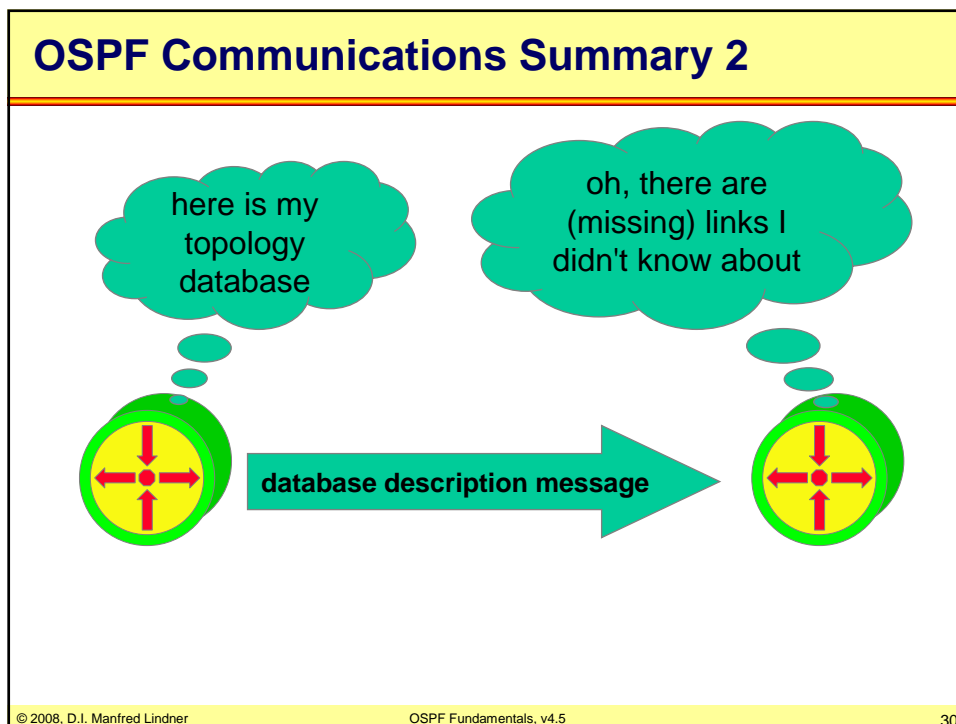
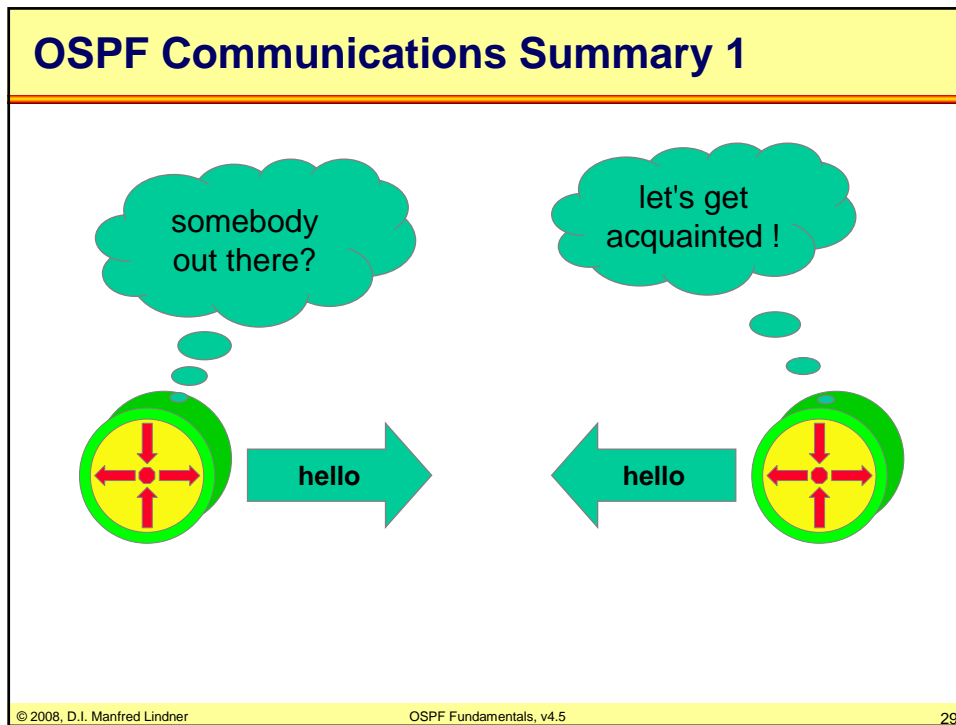
- **periodically, every router verifies its link state to its adjacent neighbours using hello messages**
- **from now only changes of link states are distributed**
 - using link state update messages (LSA broadcast-mechanism)
- **if neighbourhood situation remains unchanged, the periodic hello messages represents the only routing overhead**
 - note: additionally all Link States are refreshed every 30 minutes with LSA broadcast mechanism

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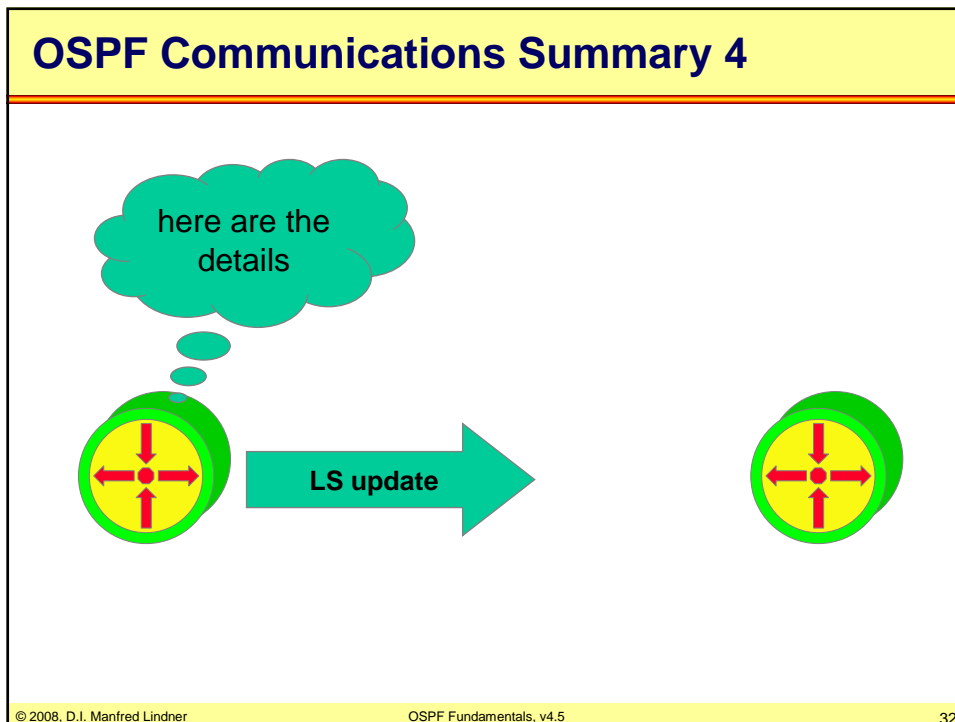
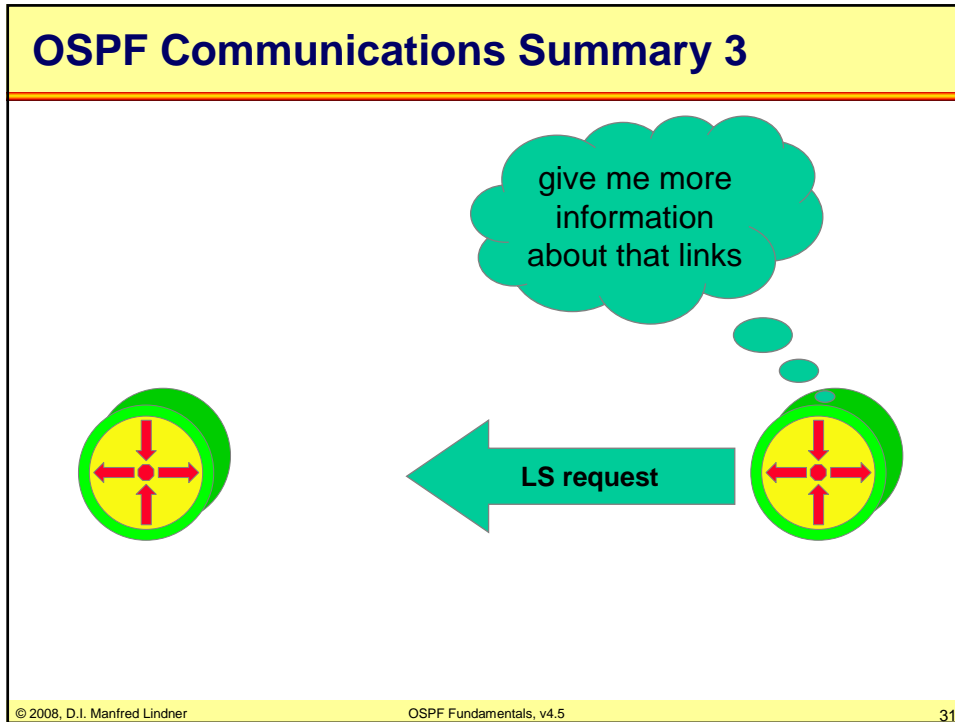
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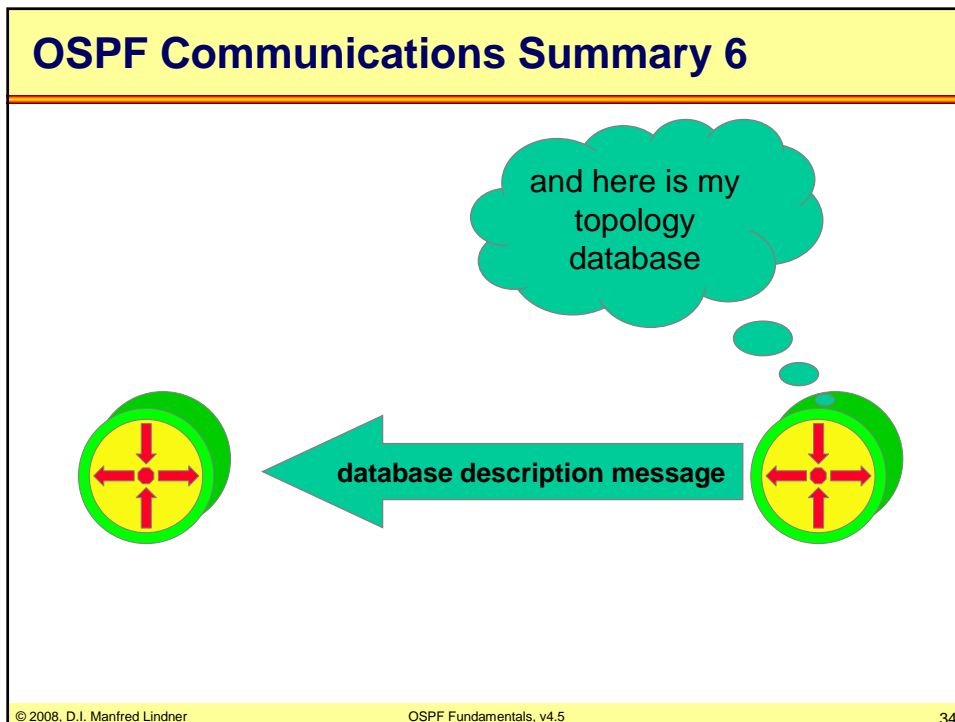
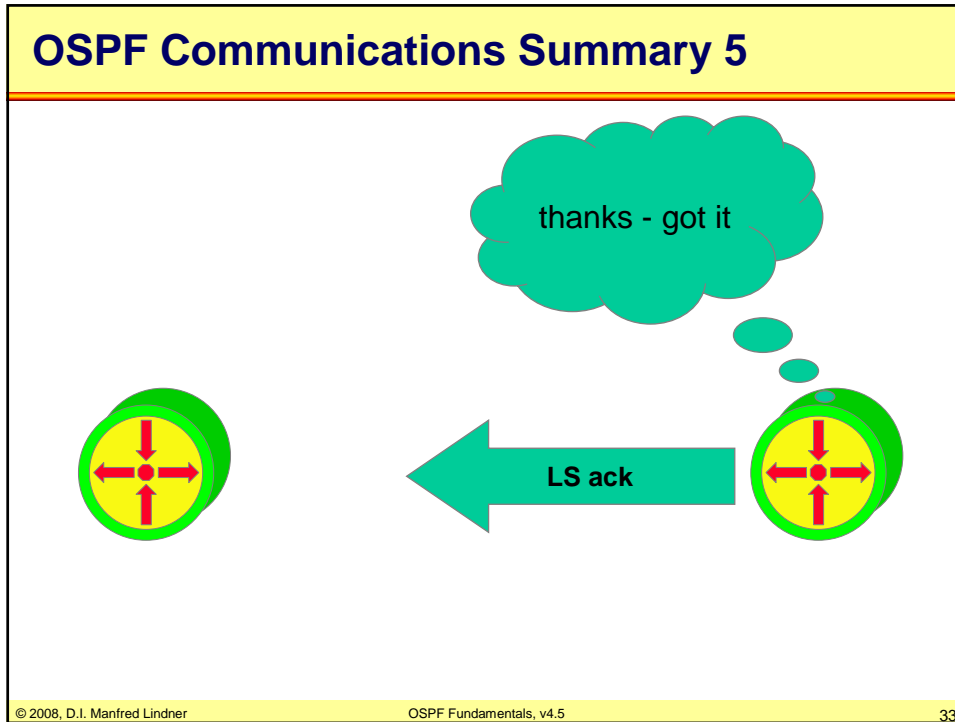
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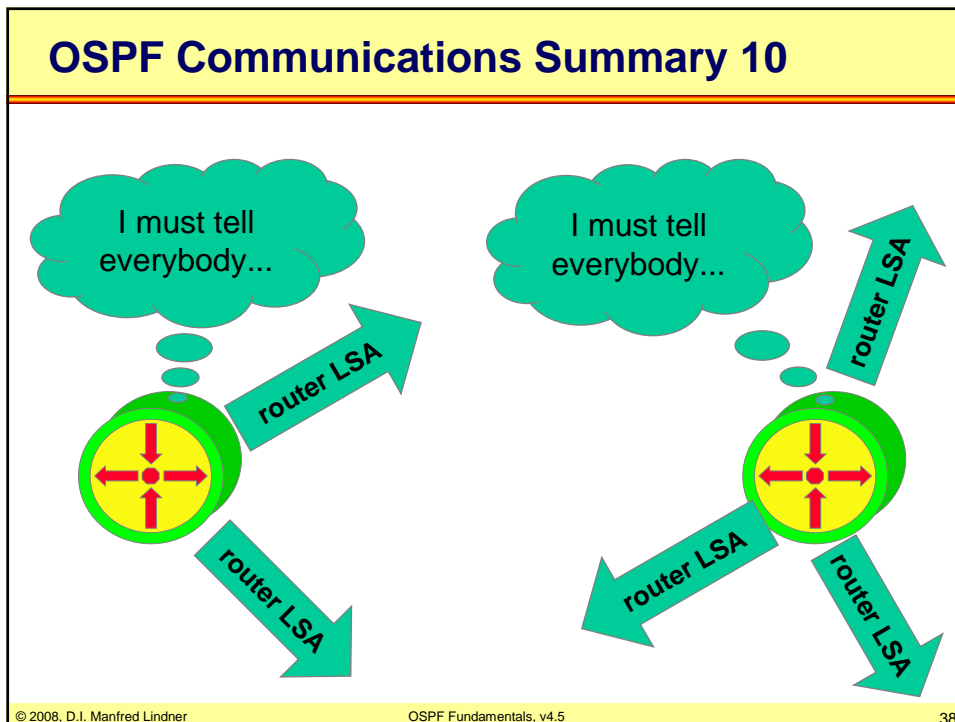
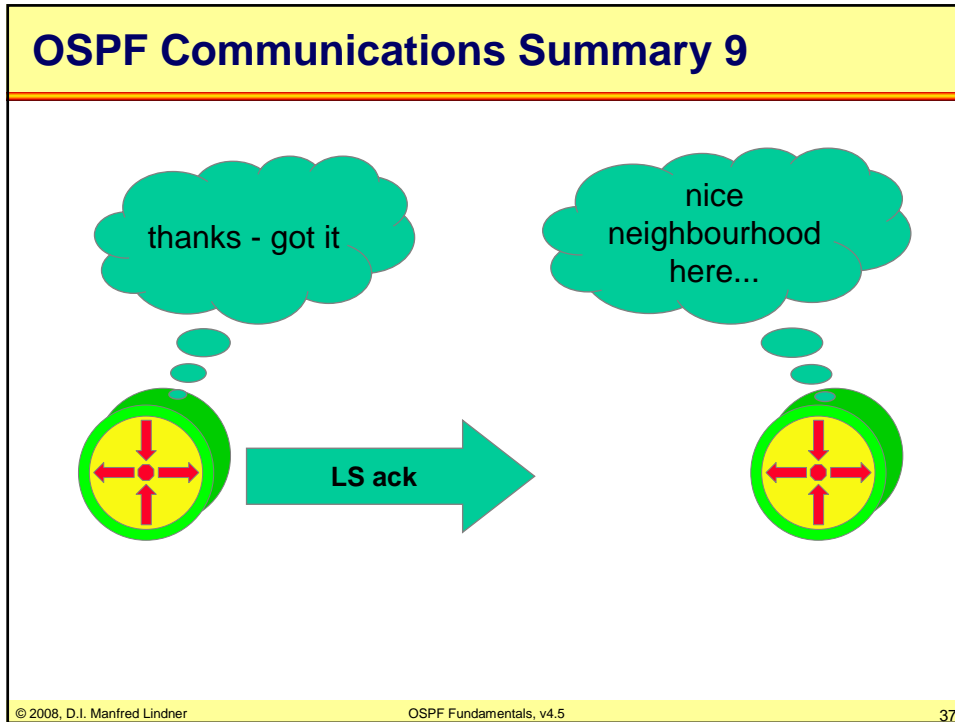


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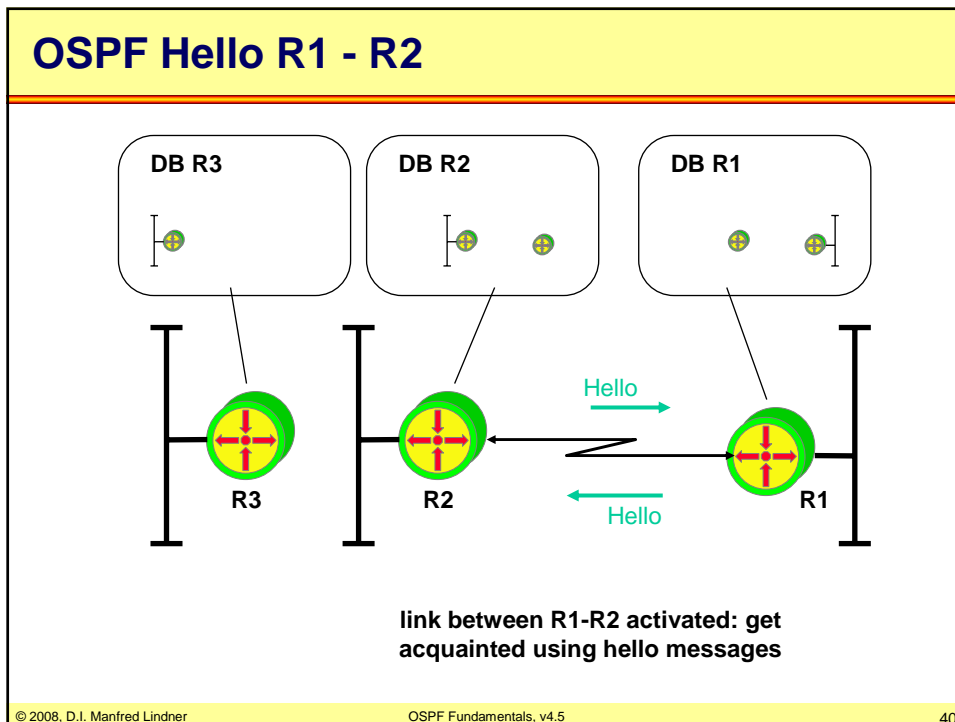
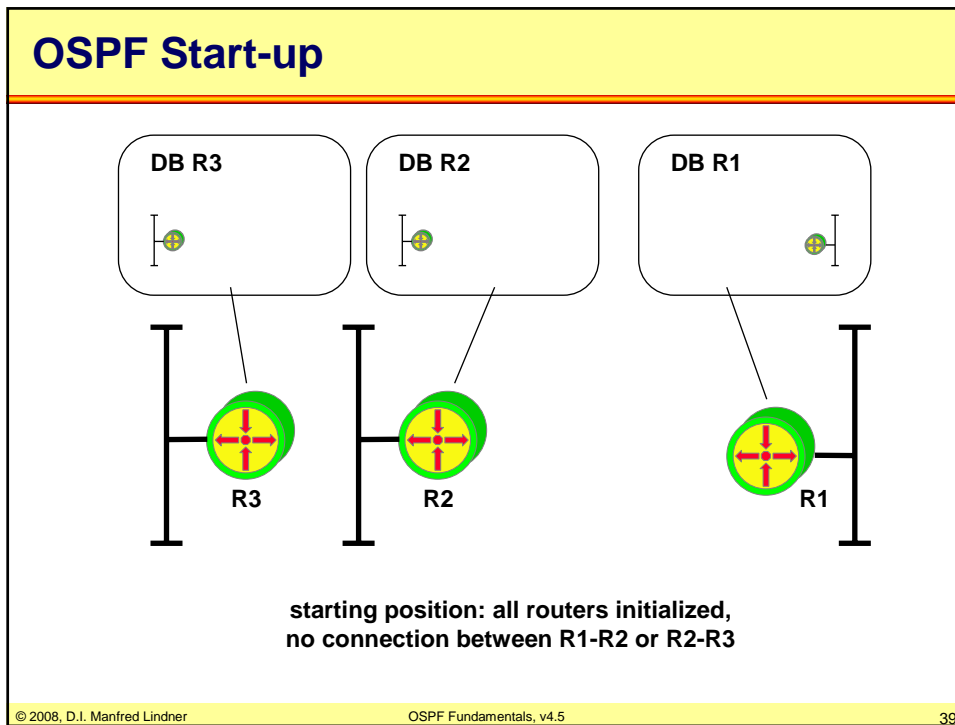
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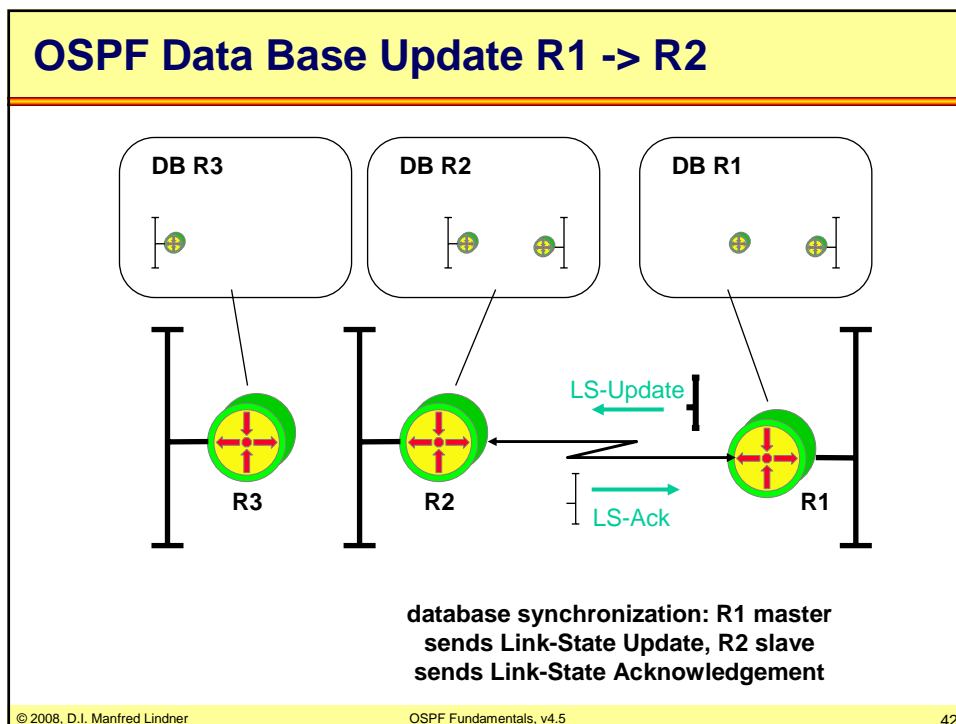
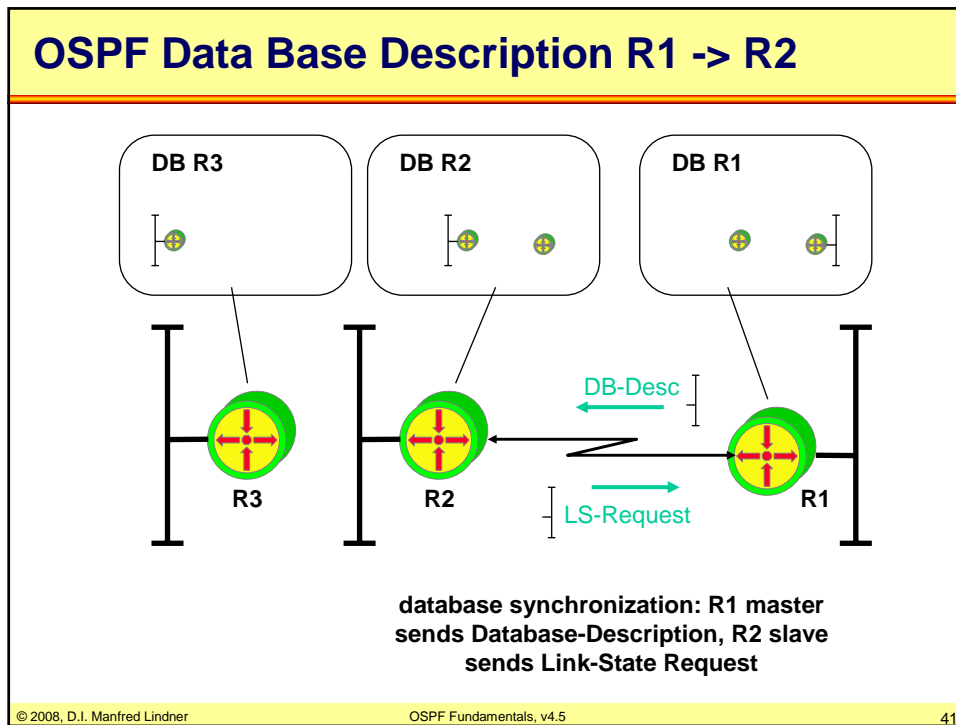
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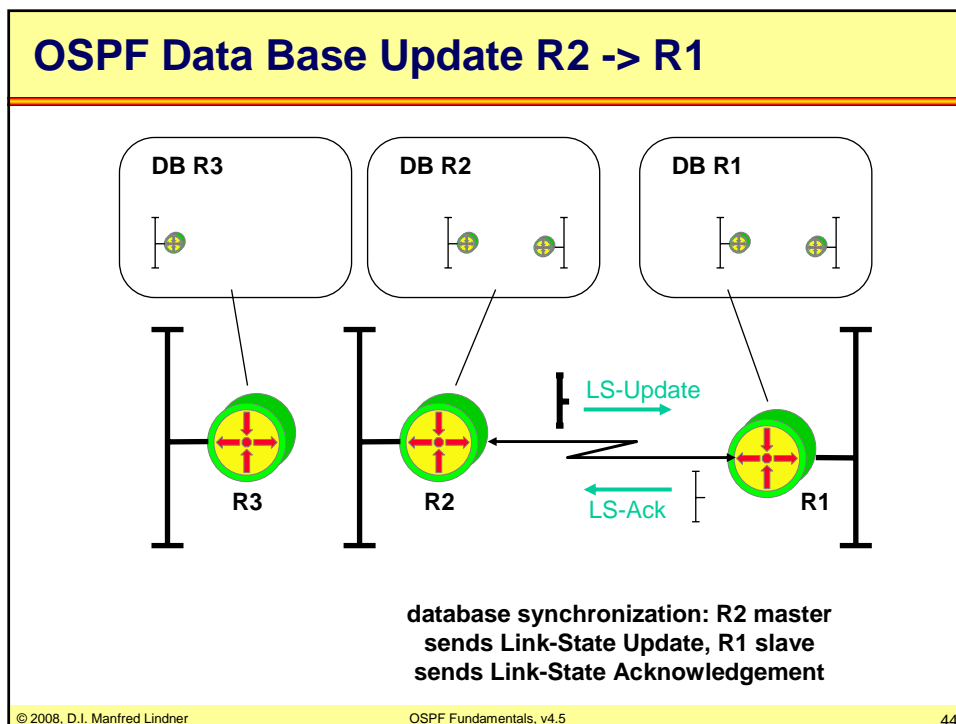
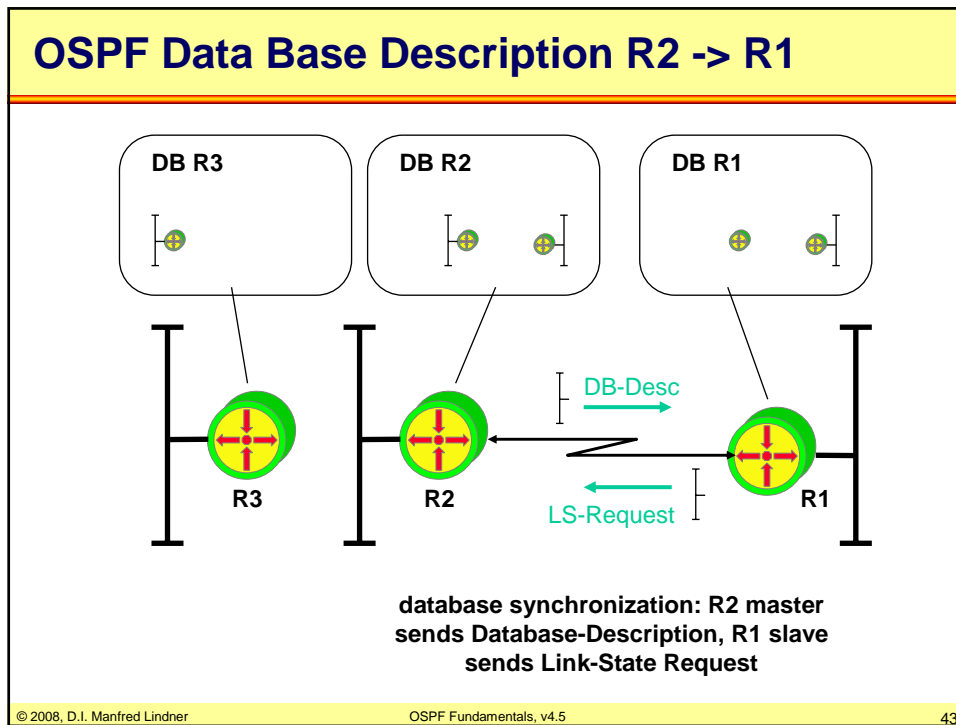
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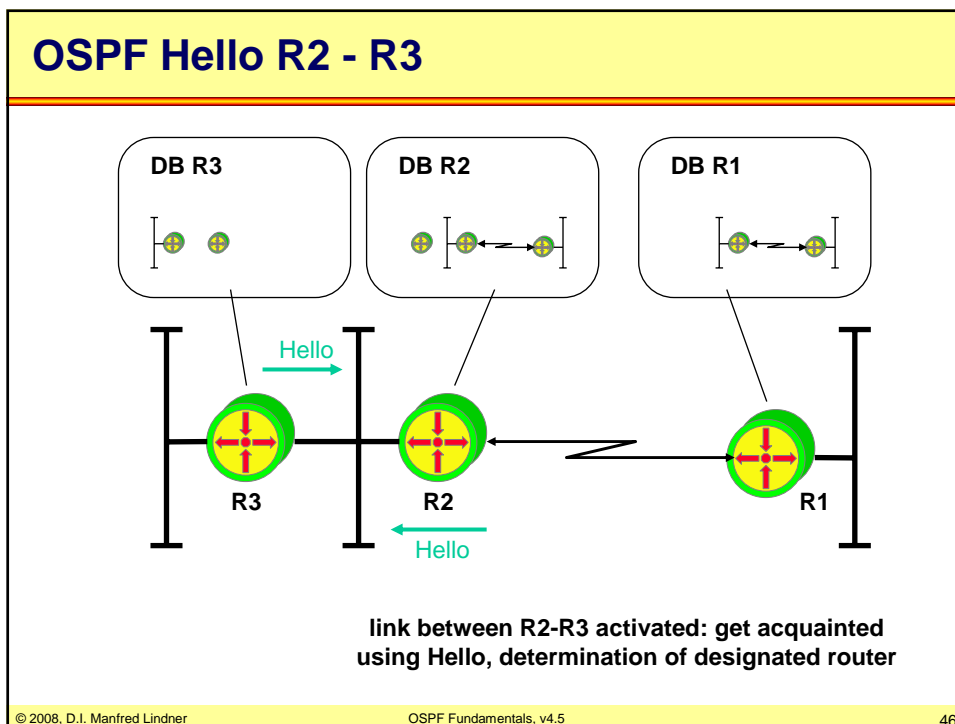
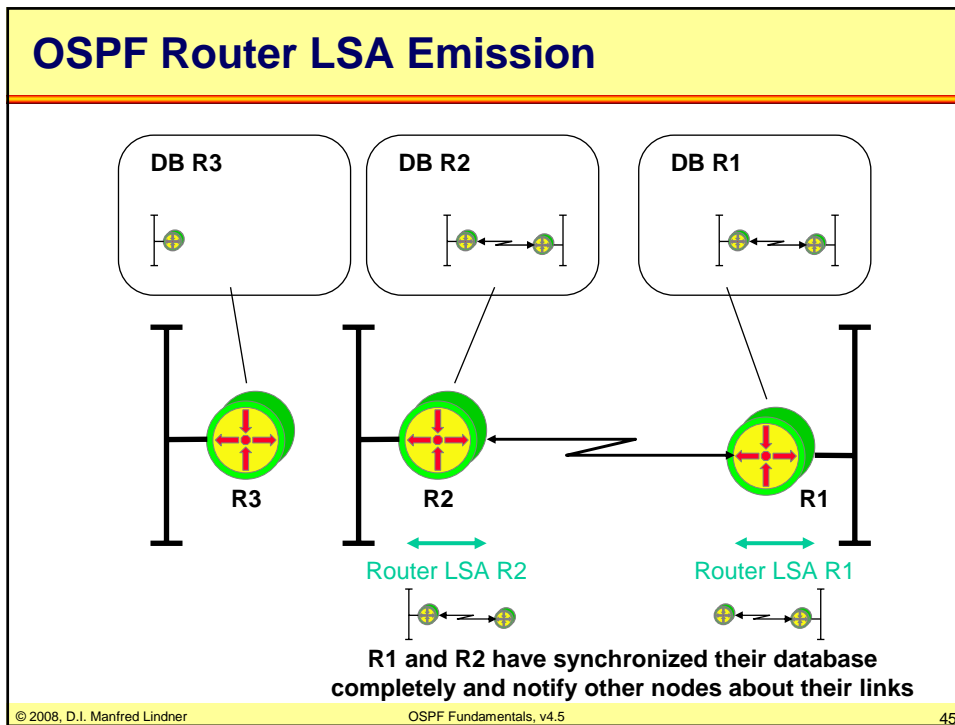
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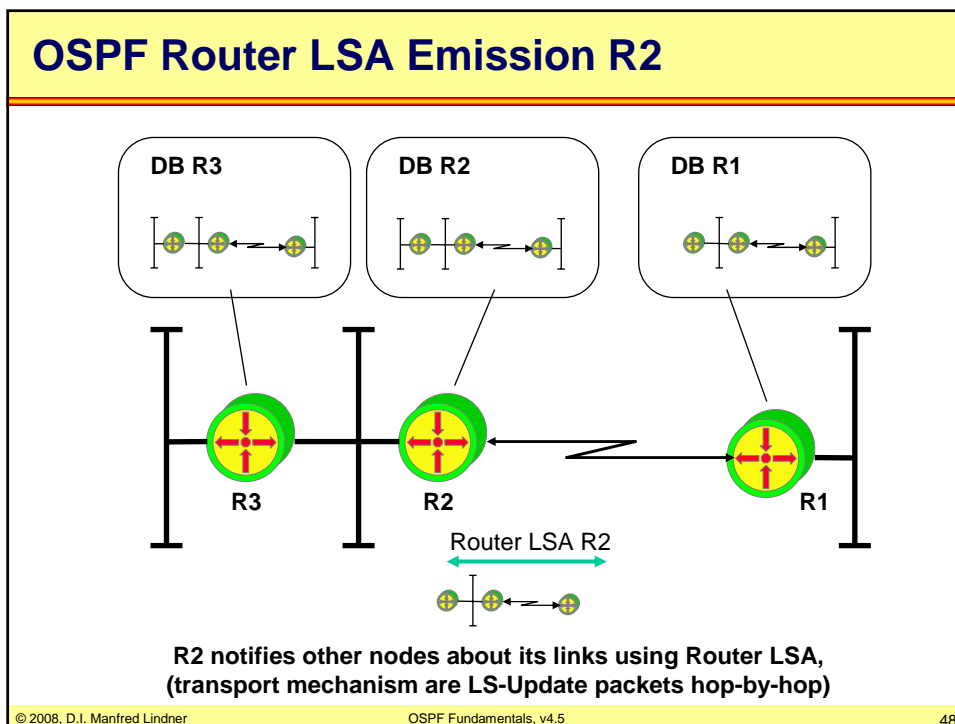
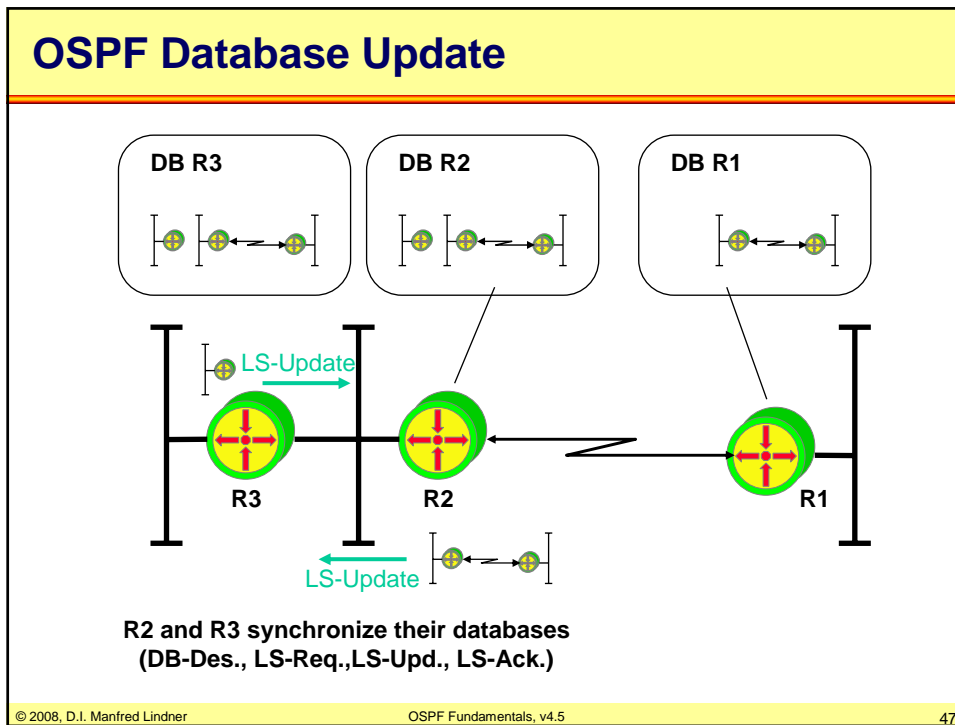
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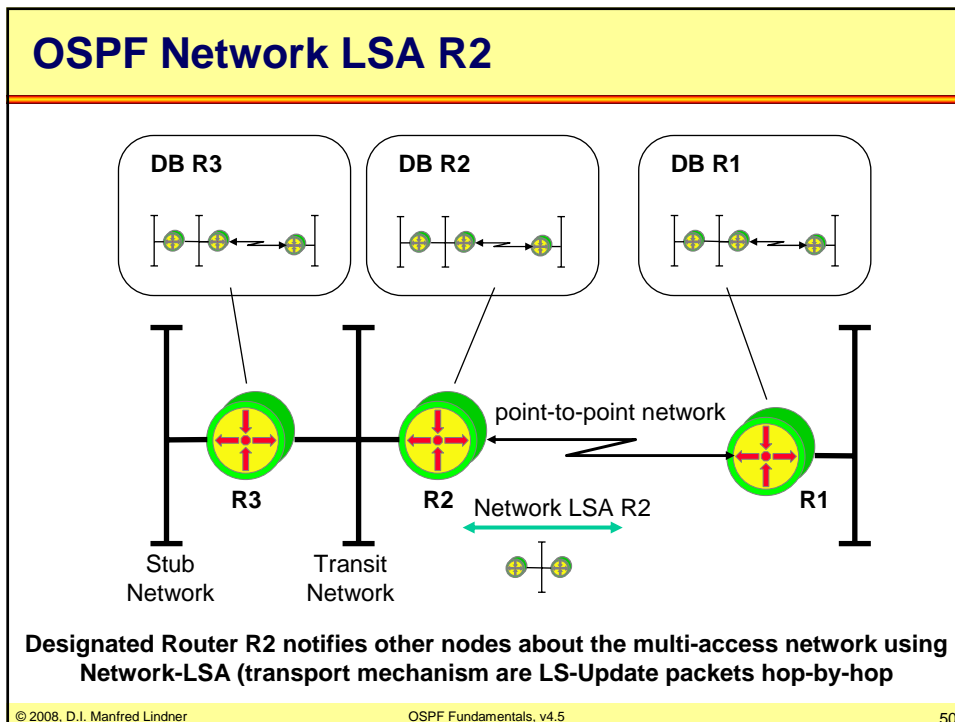
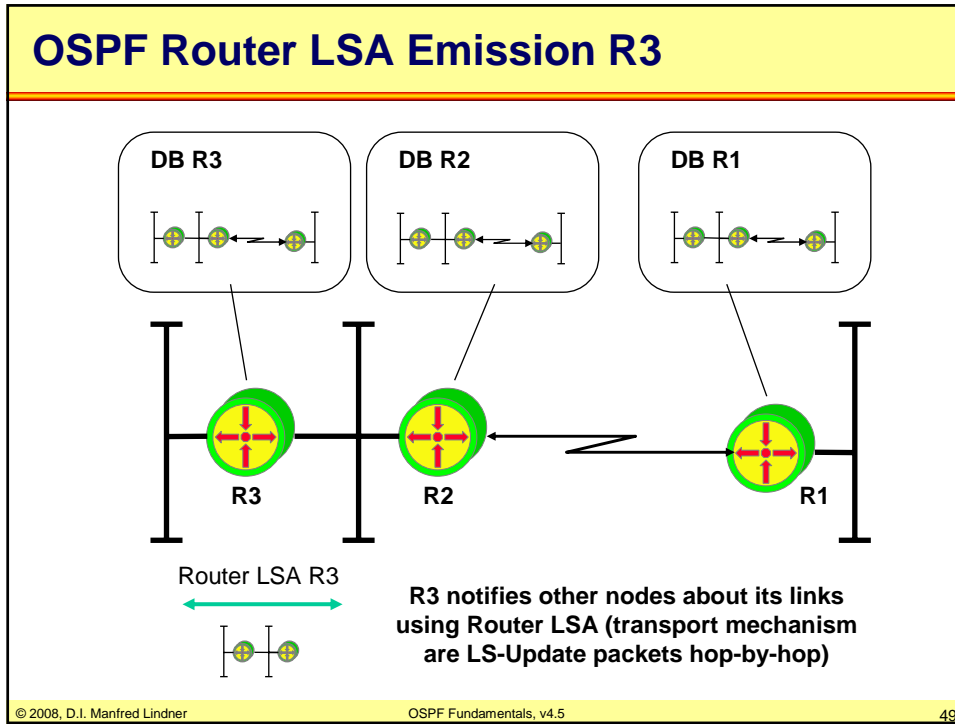
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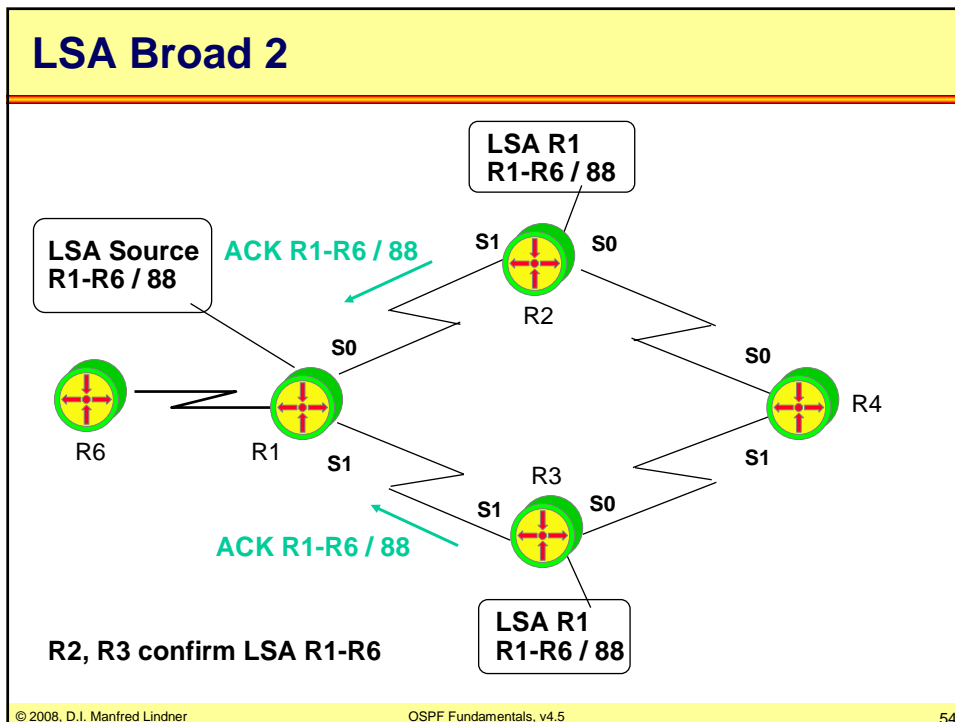
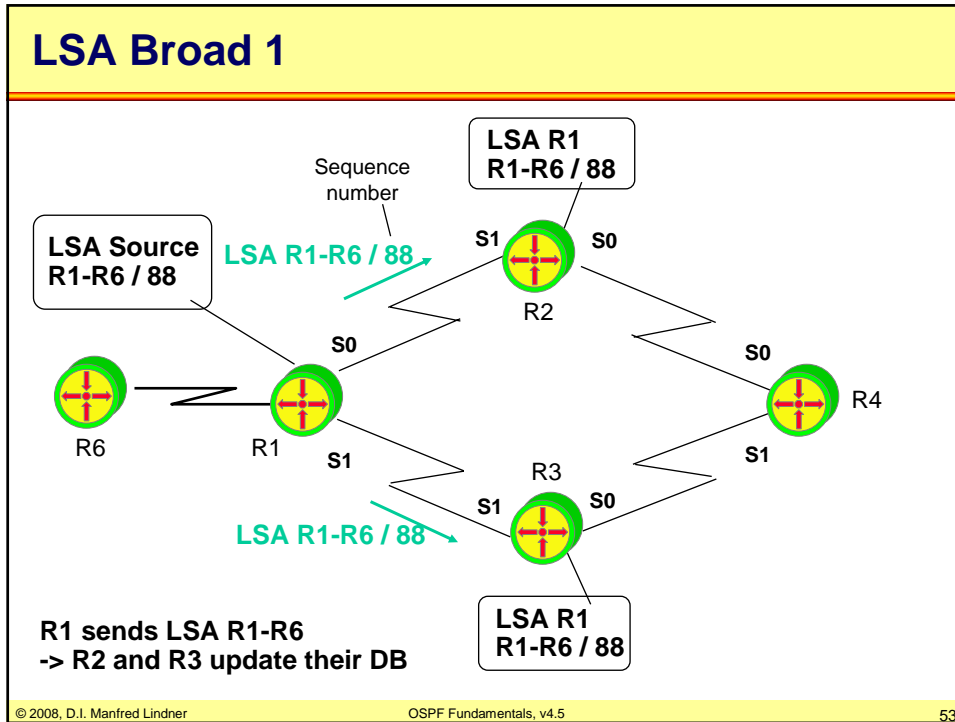
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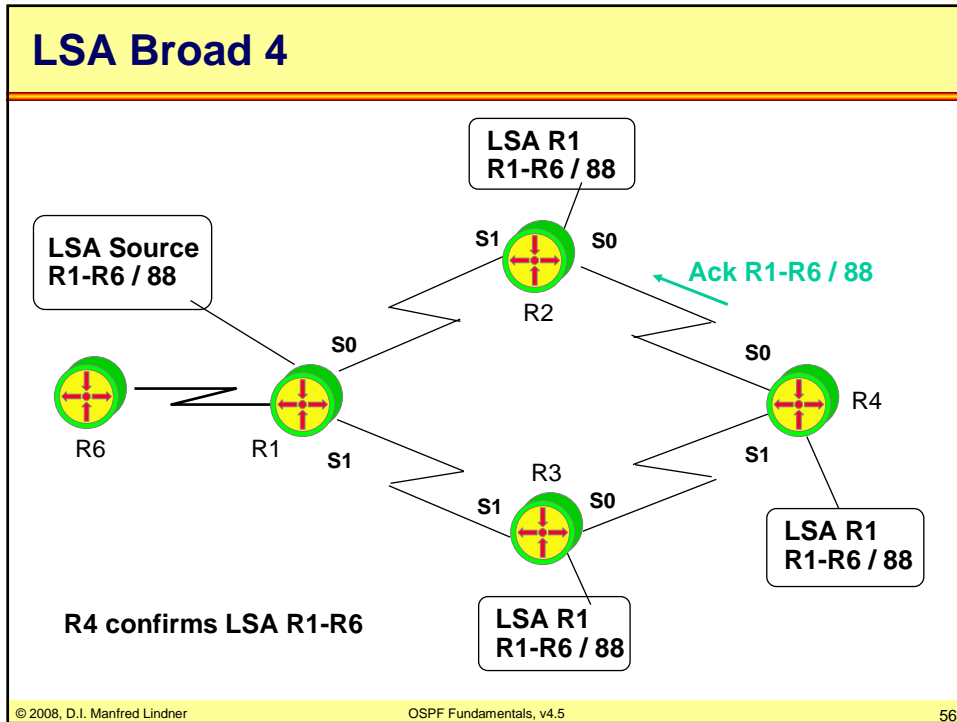
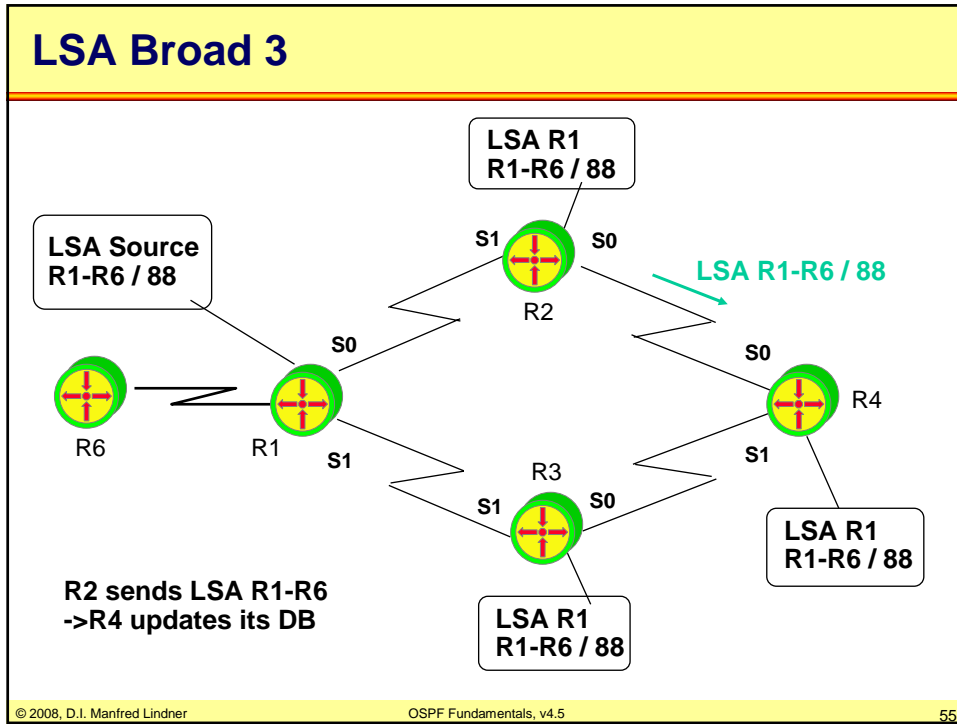
LSA Broadcast Mechanism

- **LSA must be distributed safely to all routers within an area (domain)**
 - consistency of the topology-database depends on it
 - every LS-update is acknowledged explicitly (using LS-ack) by the neighbour-router
 - if a LS-ack stays out, the LS-update is repeated (timeout)
 - if the LS-ack fails after several trials, the adjacency-relation is cleared
 - this method assures a reliable distribution of LSAs

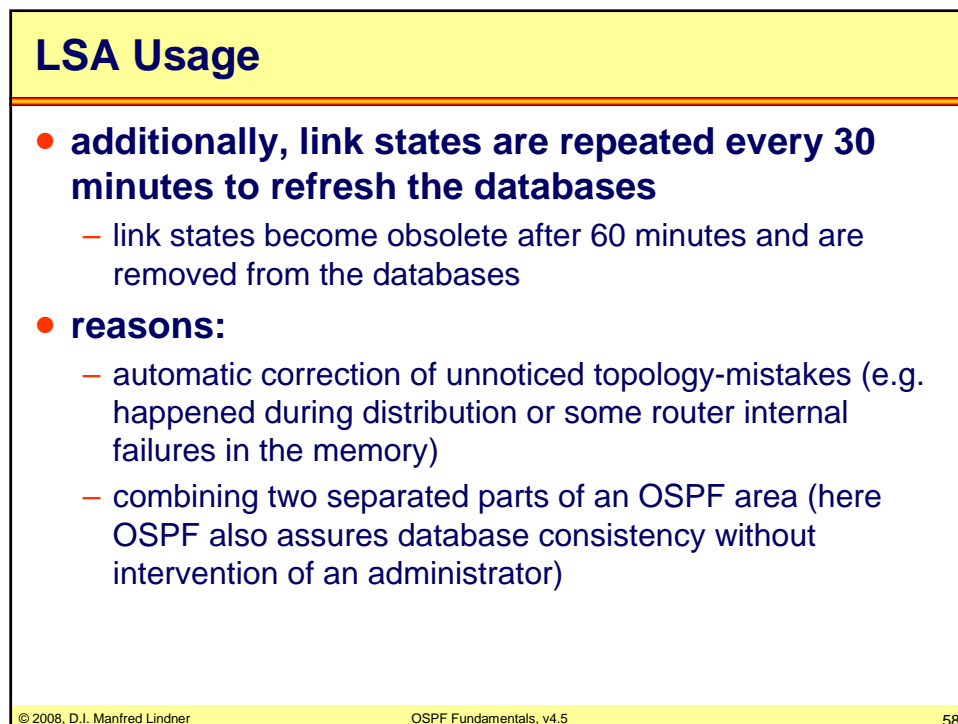
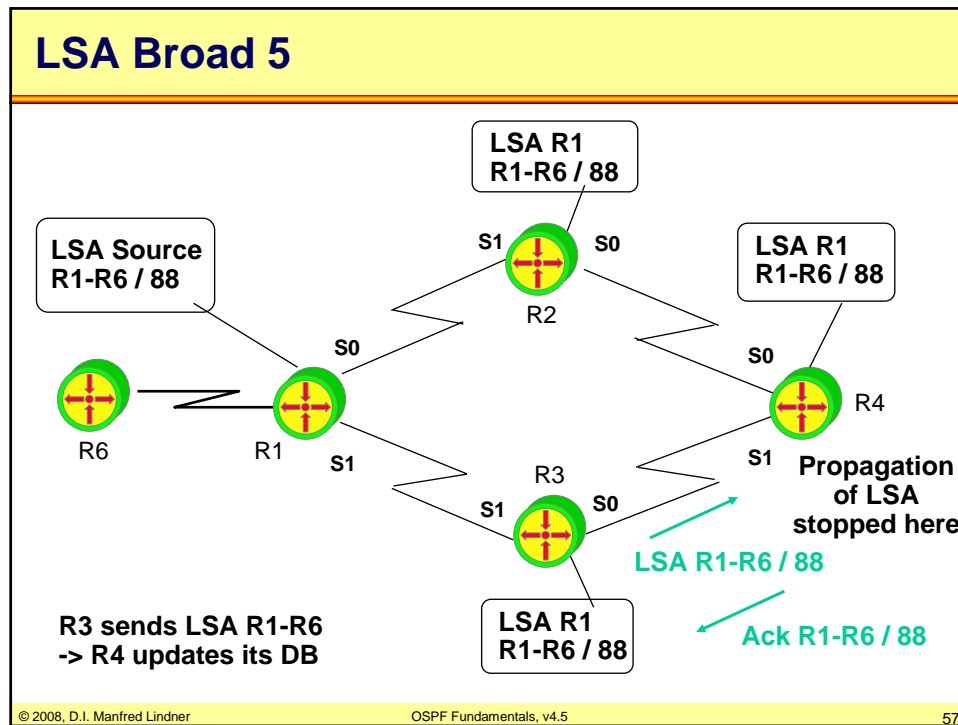
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How are LSA unique?

- **each router as a node in the graph (link state topology database)**
 - is identified by a unique Router-ID
 - note: automatically selected on Cisco routers
 - either numerically highest IP address of all loopback interfaces
 - or if no loopback interfaces then highest IP address of physical interfaces
- **every link and hence LS between two routers**
 - can be identified by the combination of the corresponding Router-IDs
 - note:
 - if there are several parallel physical links between two routers the Port-ID will act as tie-breaker

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OSPF Broadcast Networks

- **basic concept of link state**
 - point-to-point relationships
- **that fits best for**
 - point-to-point networks like serial lines
- **that causes a problem with shared media multi-access networks**
 - e.g. with LANs or with networks running in NBMA-mode (Non Broadcast Multi Access) like X.25, Frame Relay, ATM
 - hello, database description and LSA updates between each of these routers can cause huge network traffic and CPU load

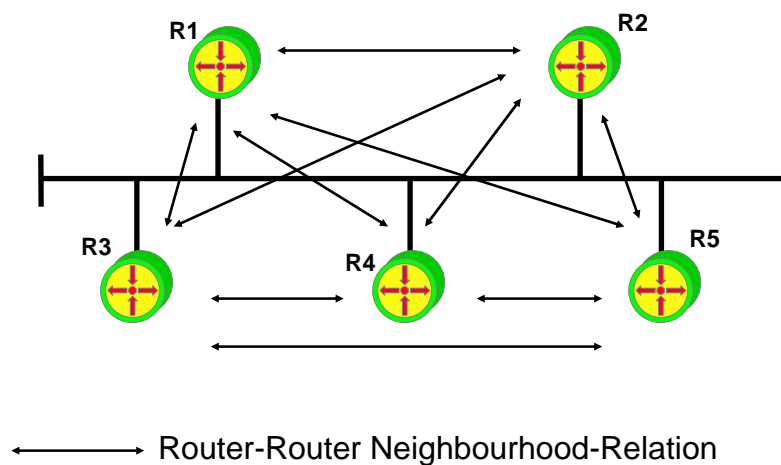
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Broadcast Network

Any-to-Any Relation



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OSPF Broadcast Networks

- **if several routers share a multi-access network**
 - any-to-any doesn't scale well -> $N*(N-1)/2$ problem
 - information about all possible neighbourhood-relations seems to be redundant
 - concept of virtual (network) node (or virtual router) is introduced to solve the problem
- **only the virtual node needs**
 - to maintain N-1 point-to-point relationship to the other nodes
 - any-to-any is not necessary
- **in OSPF the virtual node is called**
 - Designated Router (DR)

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OSPF Broadcast Networks

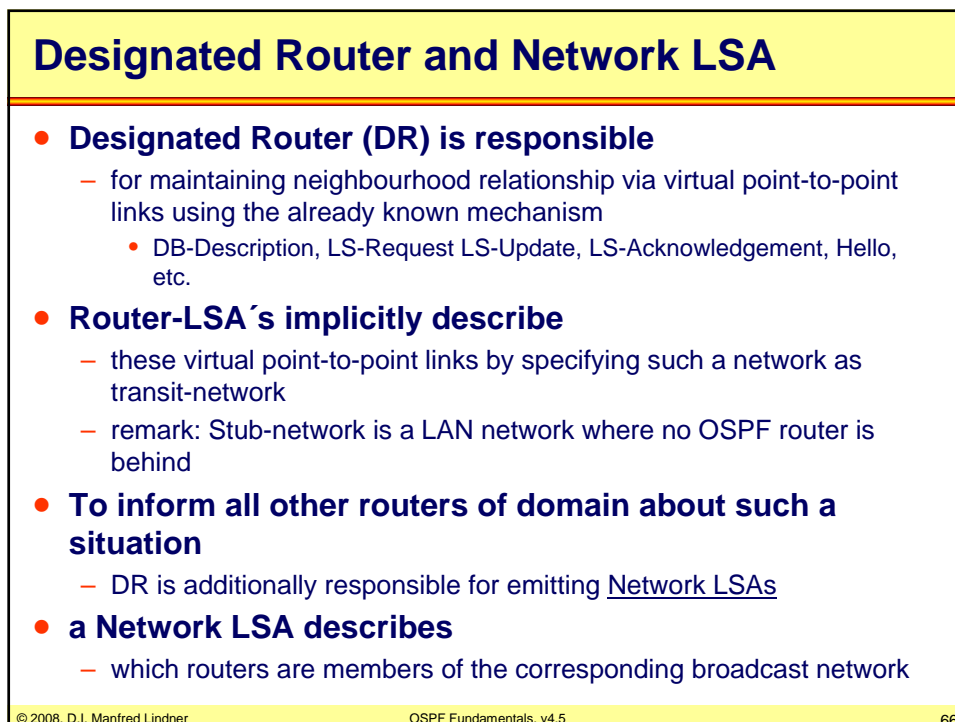
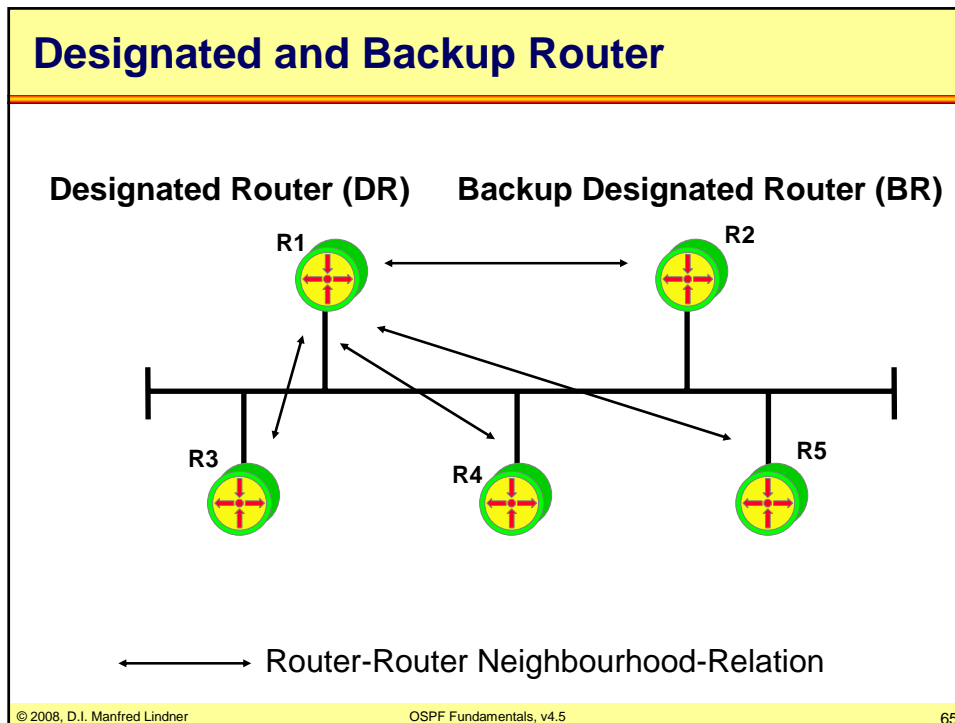
- **in case of a failure the Designated Router**
 - would be single point of failure
- **therefore**
 - a Backup Designated Router (BR) is used
- **DR and BR**
 - are elected by exchanging hello-messages at start-up
- **Attention !!!**
 - this concept influences only how routing information is exchanged among those routers
 - no influence on actual IP forwarding which is based on routing tables

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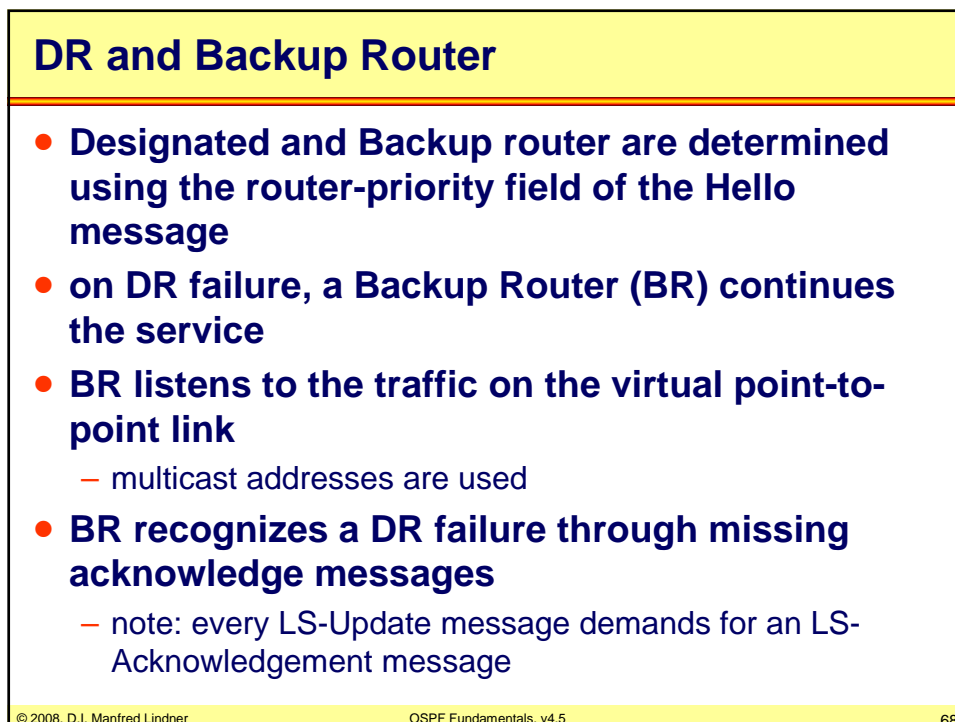
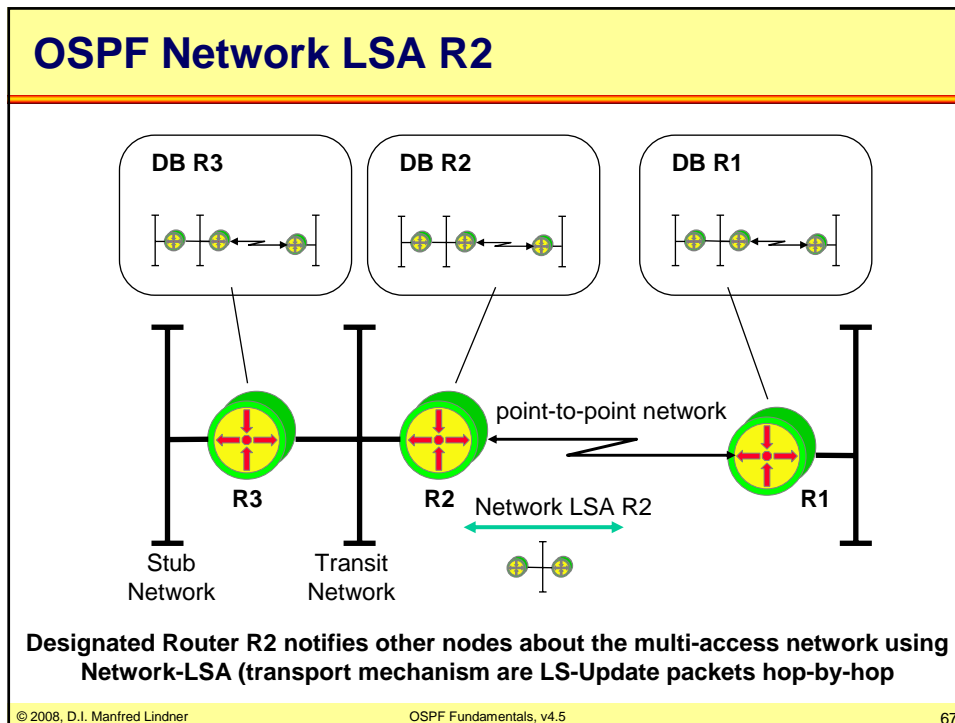
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OSPF Multicast Addresses

- **OSPF uses dedicated IP multicast addresses for exchanging routing messages**
 - 224.0.0.5 (“All OSPF Routers”)
 - 224.0.0.6 (“All Designated Routers”)
- **224.0.0.5 is used as destination address**
 - by all routers for Hello-messages
 - DR and BR determination at start-up
 - link state supervision
 - by DR router for messages towards all non-DR routers
 - LS-Update, LS-Acknowledgement
- **224.0.0.6 is used as destination address**
 - by all non-DR routers for messages towards the DR
 - LS-Update, LS-Request, LS-Acknowledgement and database description messages

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Agenda

- **OSPF Principles**
 - Introduction
 - The Dijkstra Algorithm
 - Communication Procedures
 - LSA Broadcast Handling
 - Broadcast Networks
 - Summary of Benefits

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Distance-Vector **versus** Link-State

- Distance-Vector:
 - every router notifies directly connected routers about all reachable routes
 - using broadcast messages
 - maintains its routing table according to information from neighbor routers

- Link-State:
 - every router notifies all routers about the state of his directly connected links
 - using flooding mechanism (LSA)
 - calculates optimal paths whenever a new LSA is received

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OSPF Benefits 1

- **network load is significantly smaller than that of distance vector protocols**
 - short hello messages between adjacent routers versus periodical emission of the whole routing table
- **even update messages after topology modifications are smaller than the routing table of distance vector protocols**
 - LSAs only describe the local links for which a router is responsible -> incremental updates !!!
- **massive network load**
 - occurs only on combining large splitted network parts of an OSPF domain (many database synchronizations)

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OSPF Benefits 2

- **SPF-techniques take advantages from several features:**
 - every router maintains a complete topology-map of the entire network and calculates independently its desired paths (actually based on the original LSA message)
 - this local ability for route calculation grants a fast convergence
 - LSA is not modified by intermediate routers across the network
 - the size of LSAs depends on the number of direct links of a router to other routers and not on the number of subnets!

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OSPF Benefits 3

- **during router configuration, every physical port is assigned a cost value**
 - depends on ToS (Type of Service)
 - each ToS can be assigned a separate topology map (8 possible combinations)
 - IP's ToS field is examined for packet forwarding
 - note: OSPF ToS support disappeared in RFC 2328
- **determination of the best path with a specific TOS is based on the costs of the particular segments (RIP uses hop count only)**
- **equal costs automatically enables load balancing between these paths**

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OSPF Benefits 4

- **subnet masks of variable length can be attached to routes (in contrast to RIPv1)**
- **external routes are marked (tagged) explicitly to be differentiated from internal routes**
- **OSPF messages can be authenticated to grant secure update information**
- **OSPF routing messages use IP-multicast addresses: lower processing effort**
- **point-to-point connections do not need own IP-address: economic use of address space**

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OSPF in Large Networks

- **OSPF area concept can be used**
 - a two level hierarchy is used to decrease
 - CPU time for SPF calculations
 - memory requirement for storing topology database
 - one backbone area
 - several non-backbone areas
 - non-backbone area can be connected by area border router to backbone area only
 - summarization possible at area border routers
 - route aggregation to reduce size of routing tables
 - summarization means that some net-IDs can be summarized as one net-ID only
- **For a detailed description of OSPF areas see the corresponding appendix chapter**

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