

## L10 - OSPF Fundamentals

### OSPF Fundamentals

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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

## L10 - OSPF Fundamentals

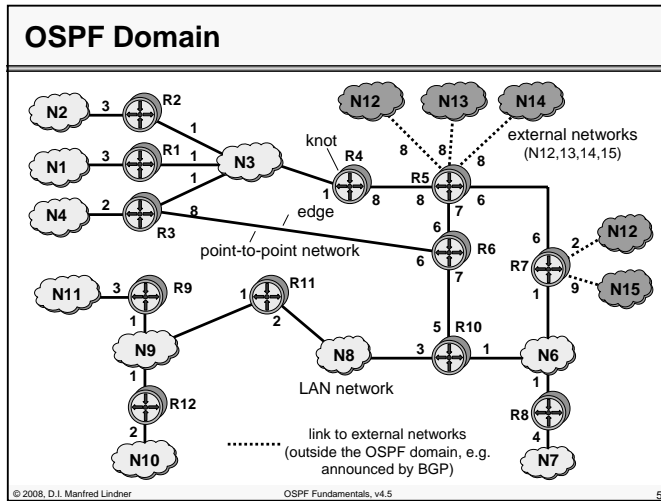
### OSPF - Open Shortest Path First

- **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)**

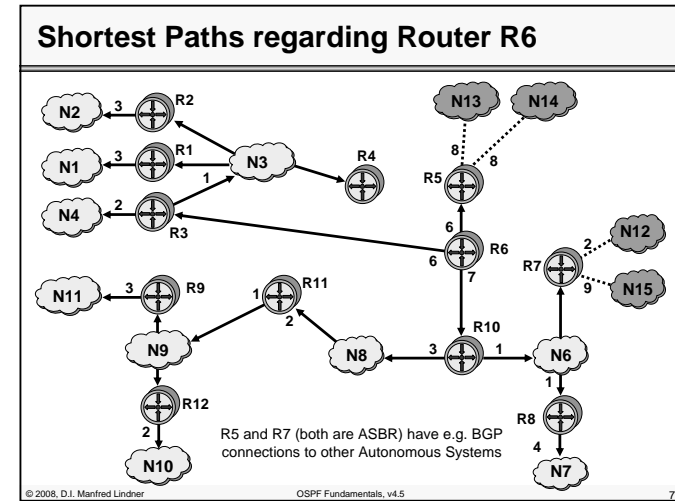
### OSPF Topology Database

- **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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### OSPF Principles

- **with this topology-database a router can calculate the best path to the desired destination-network**
  - applying Dijkstra's SPF (Shortest Path First) algorithms
- **the topology-database describes all other possible paths too**
  - in critical situations (failures) the router can independently calculate an alternative path
- **no waiting on rumors of other routers anymore**
  - which was reason for several RIP problems !!!
  - because other routers are also relying on rumors

### 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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**Routing Table Router 6**

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

**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

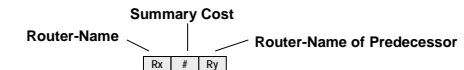
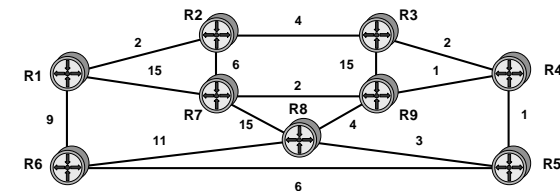
assumption: ASBR R5 and R7 announce external networks (which have been noticed using e.g. BGP-4) via type 1 external link advertisements (E1 metric)

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**Agenda**

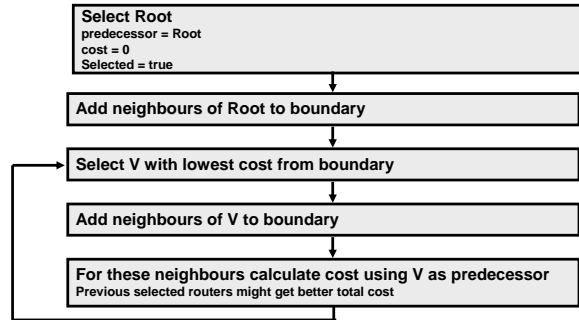
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**Example Topology for Dijkstra Algorithm**



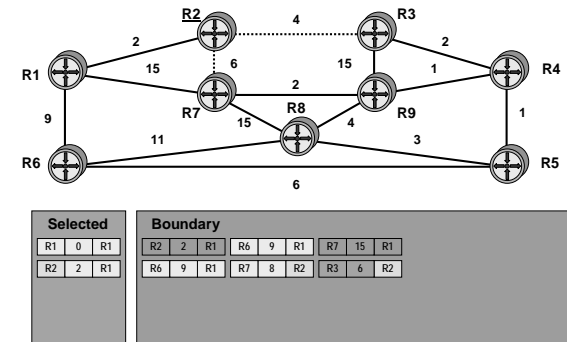
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The Principle

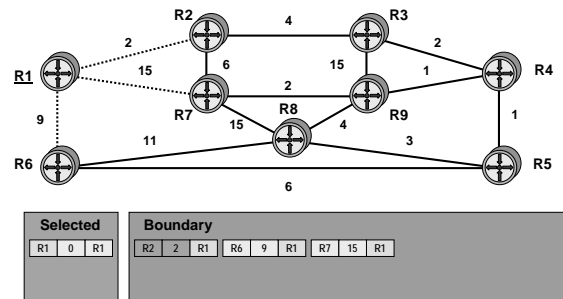


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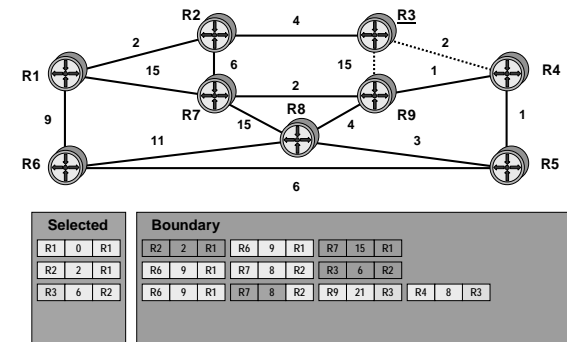
Select router with lowest cost in boundary (R2), calculate cost for neighbours R3, R7



Select root (R1)

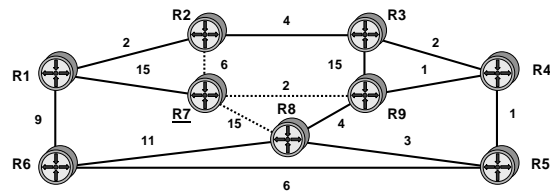


Select router with lowest cost in boundary (R3), calculate cost for neighbours R9, R4



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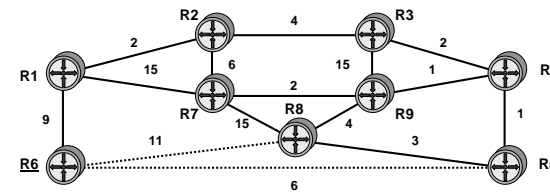
Select one router with lowest cost in boundary (R7), calculate cost for neighbours R8, R9



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			
R7	8	R2	R6	9	R1	R4	8	R3	R9	10	R7	R8	23	R7			

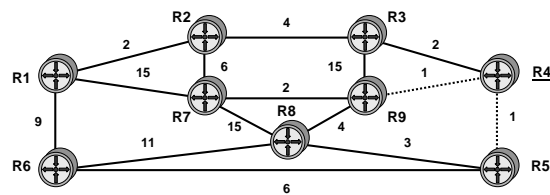
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Select one router with lowest cost in boundary (R6), calculate cost for neighbours R5 and R8



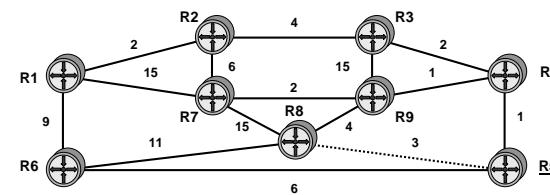
Selected			Boundary														
R1	0	R1	R2	2	R1	R6	9	R1	R7	15	R1						
R2	2	R1	R6	9	R1	R7	8	R2	R3	6	R2						
R3	6	R2	R6	9	R1	R7	8	R2	R9	21	R3	R4	8	R3			
R7	8	R2	R6	9	R1	R4	8	R3	R9	10	R7	R8	23	R7			
R4	8	R3	R6	9	R1	R8	23	R7	R9	9	R4	R5	9	R4			
R6	9	R1	R9	9	R4	R8	20	R6	R5	9	R4						

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



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			
R7	8	R2	R6	9	R1	R4	8	R3	R9	10	R7	R8	23	R7			
R4	8	R3	R6	9	R1	R8	23	R7	R9	9	R4	R5	9	R4			

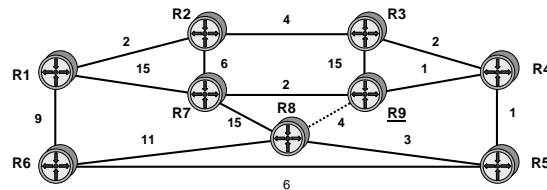
Select one neighbour with lowest cost in boundary (R5), calculate cost for neighbour R8



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

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



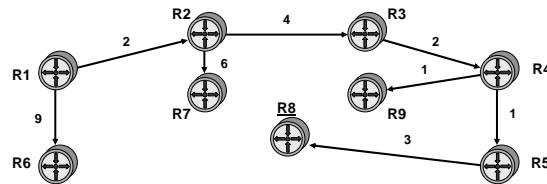
Selected			Boundary											
R1	0	R1	R2	2	R1	R6	9	R1	R7	15	R1			
R2	2	R1	R6	9	R1	R7	8	R2	R3	6	R2			
R3	6	R2	R6	9	R1	R7	8	R2	R9	21	R3	R4	8	R3
R7	8	R2	R6	9	R1	R4	8	R3	R9	10	R7	R8	23	R7
R4	8	R3	R6	9	R1	R8	23	R7	R9	9	R4	R5	9	R4
R6	9	R1	R9	9	R4	R8	20	R6	R5	9	R4			
R5	9	R4	R9	9	R4	R8	12	R5						
R9	9	R4	R8	12	R5									

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



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

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

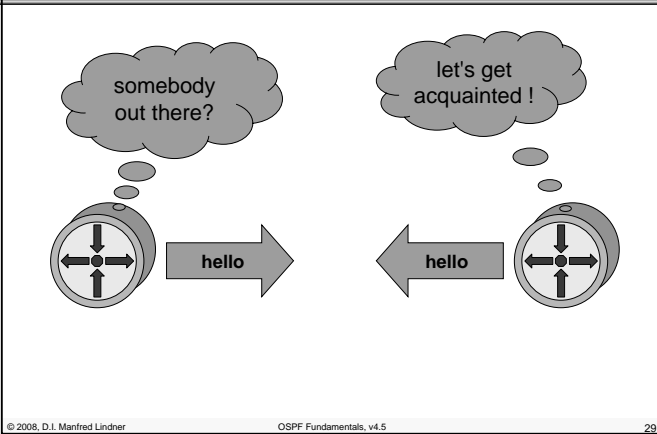
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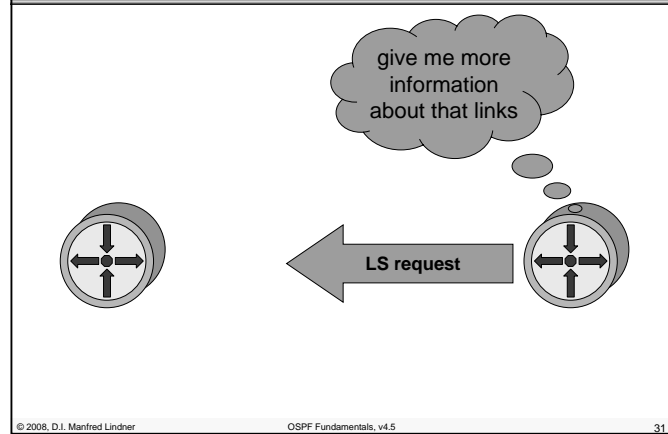
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#### OSPF Communications Summary 1

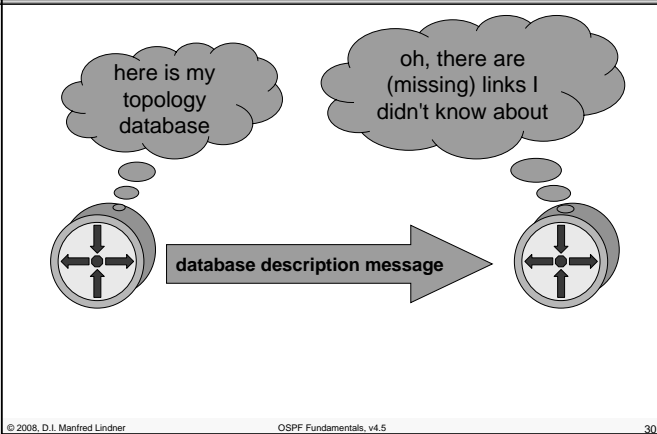


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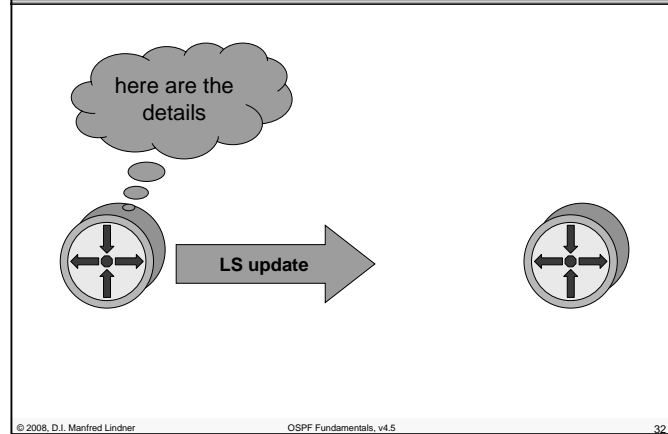
#### OSPF Communications Summary 3



#### OSPF Communications Summary 2



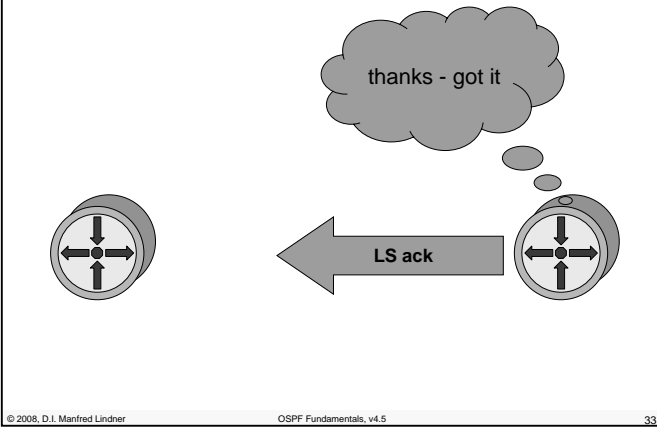
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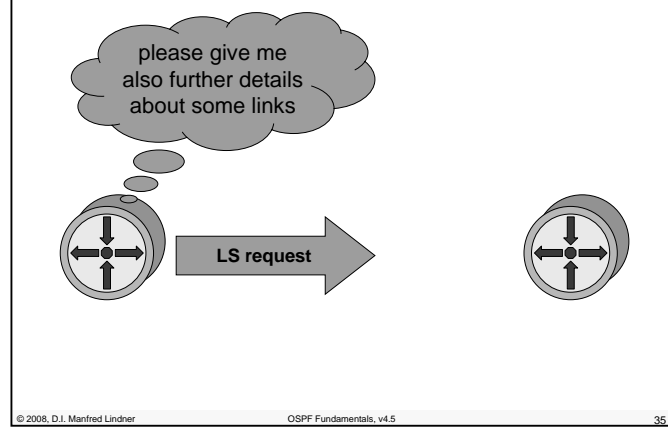
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#### OSPF Communications Summary 5

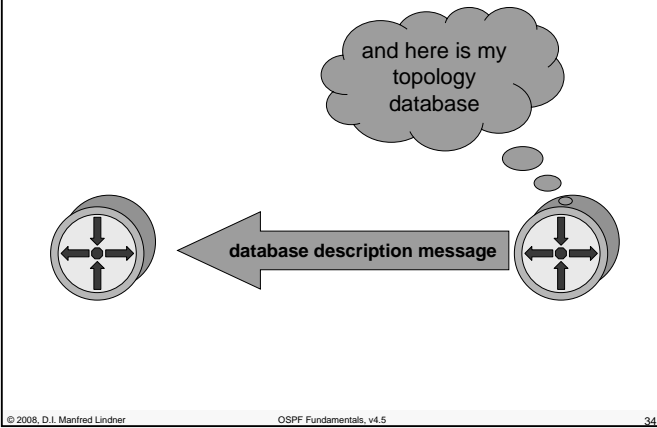


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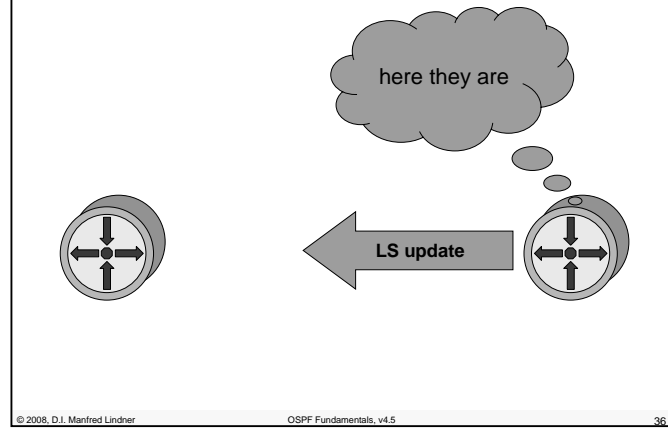
#### OSPF Communications Summary 7



#### OSPF Communications Summary 6

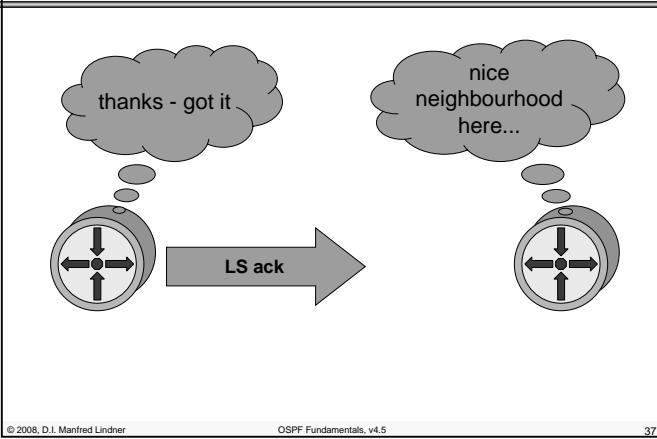


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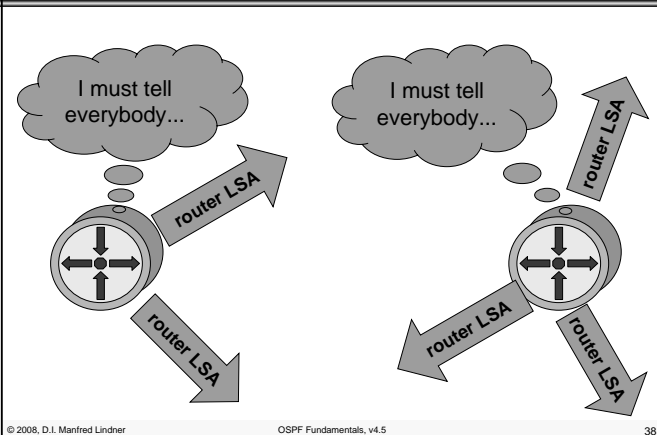


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#### OSPF Communications Summary 9

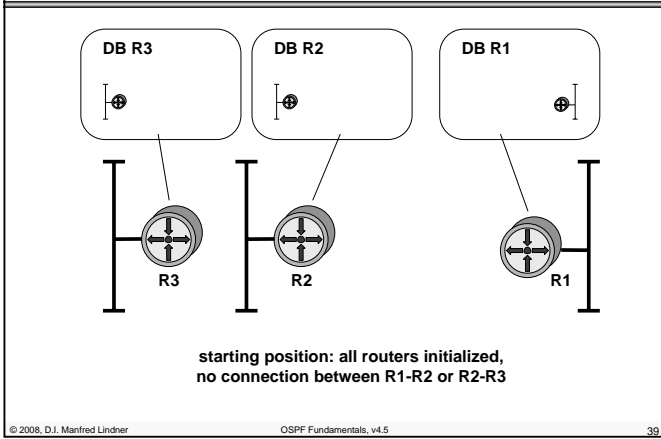


#### OSPF Communications Summary 10

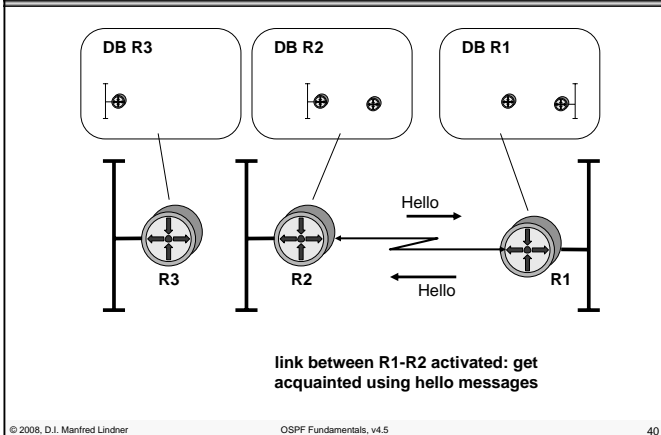


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#### OSPF Start-up

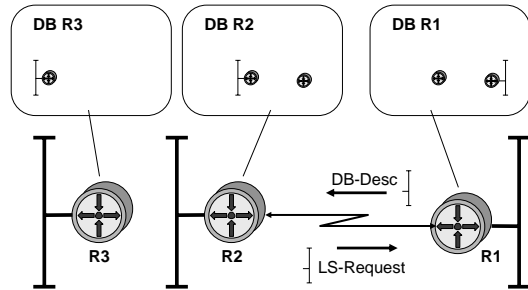


#### OSPF Hello R1 - R2



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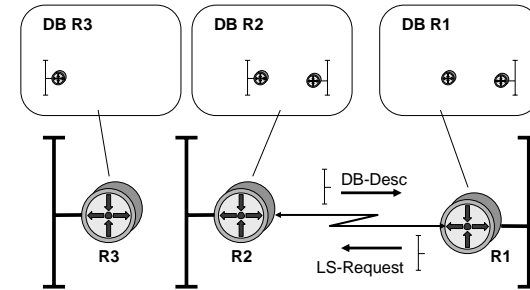
OSPF Data Base Description R1 -> R2



database synchronization: R1 master sends Database-Description, R2 slave sends Link-State Request

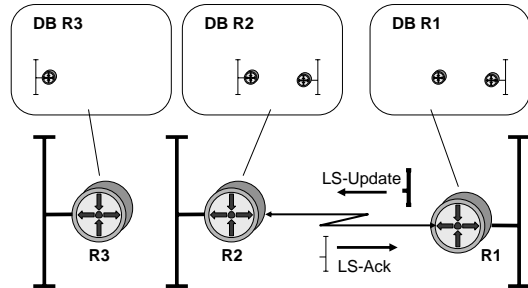
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OSPF Data Base Description R2 -> R1



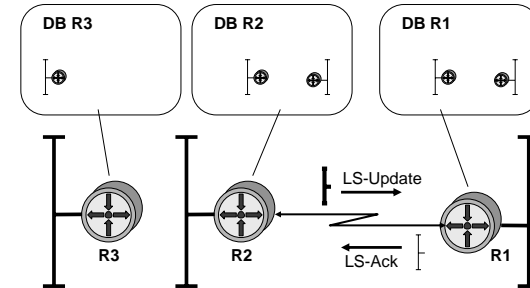
database synchronization: R2 master sends Database-Description, R1 slave sends Link-State Request

OSPF Data Base Update R1 -> R2



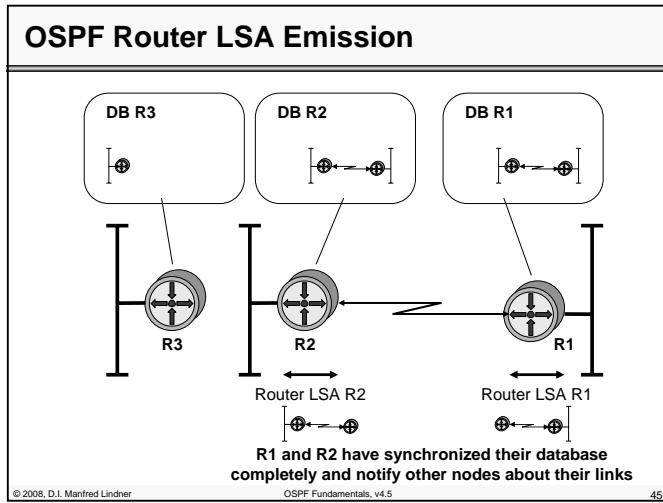
database synchronization: R1 master sends Link-State Update, R2 slave sends Link-State Acknowledgement

OSPF Data Base Update R2 -> R1

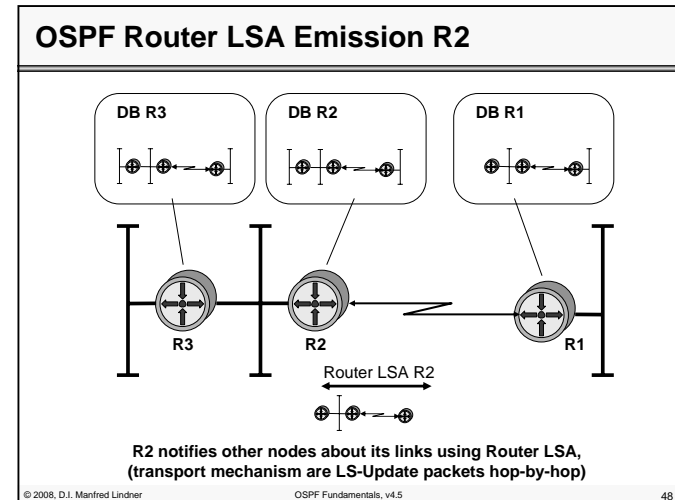
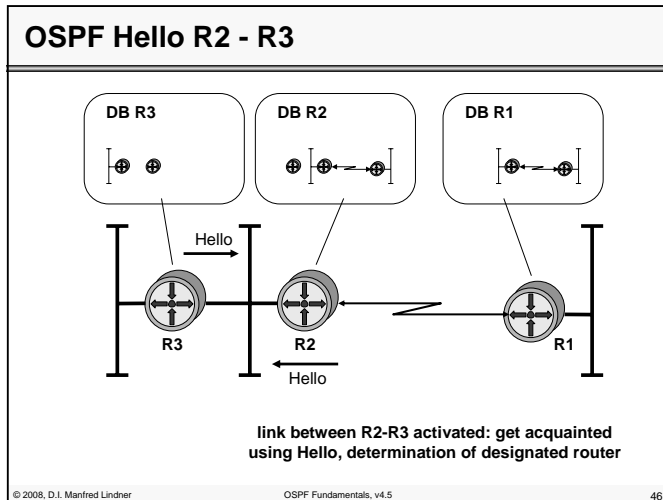
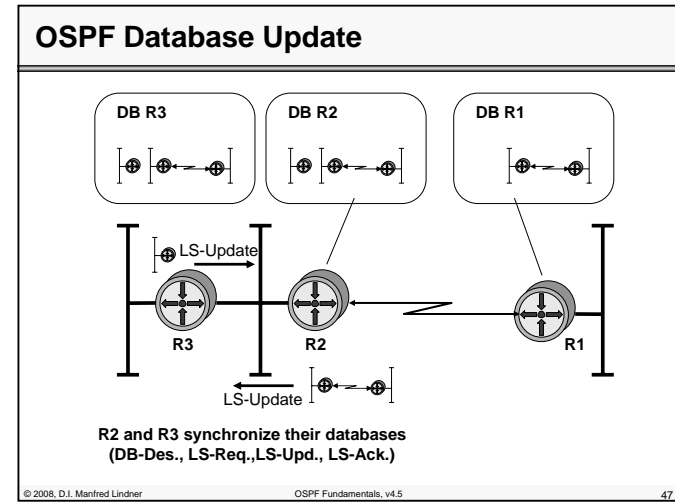


database synchronization: R2 master sends Link-State Update, R1 slave sends Link-State Acknowledgement

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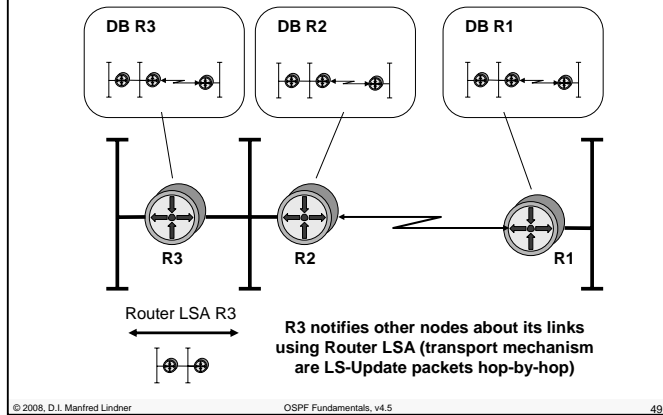


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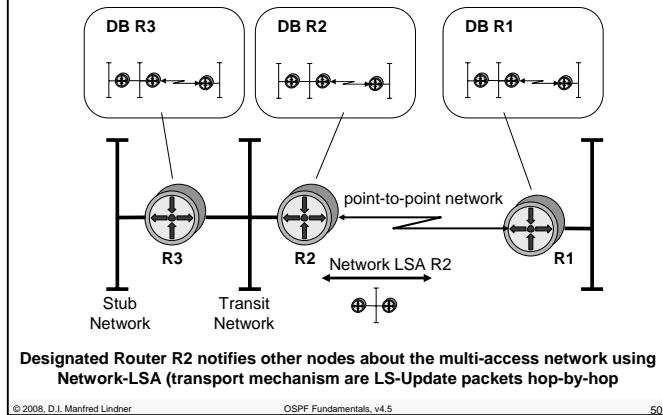


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#### OSPF Router LSA Emission R3



#### OSPF Network LSA R2



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#### Agenda

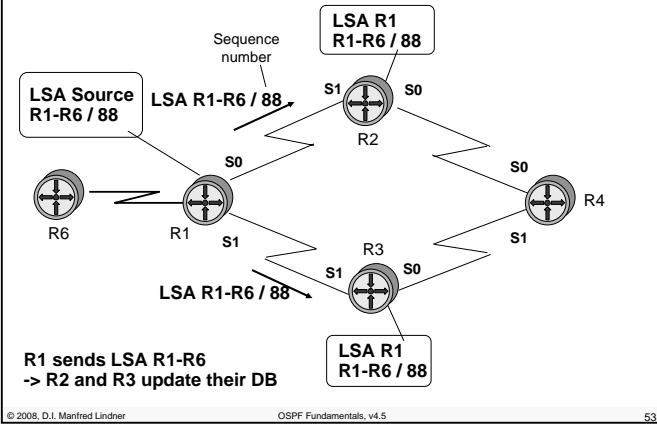
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#### LSA Broadcast Mechanism

- **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

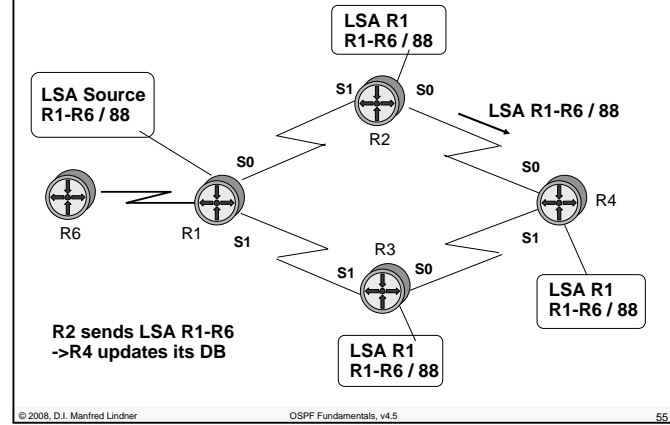
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LSA Broad 1

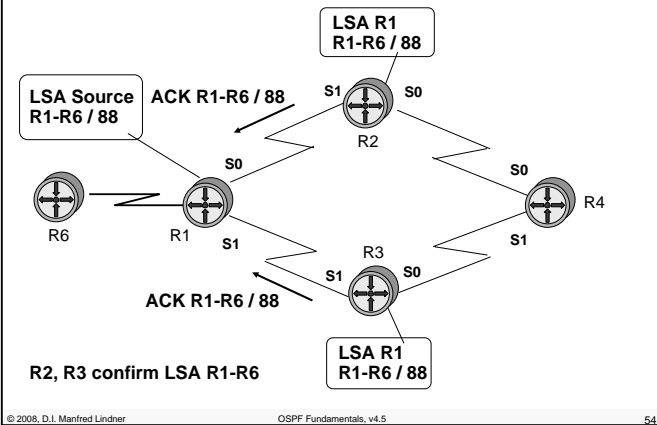


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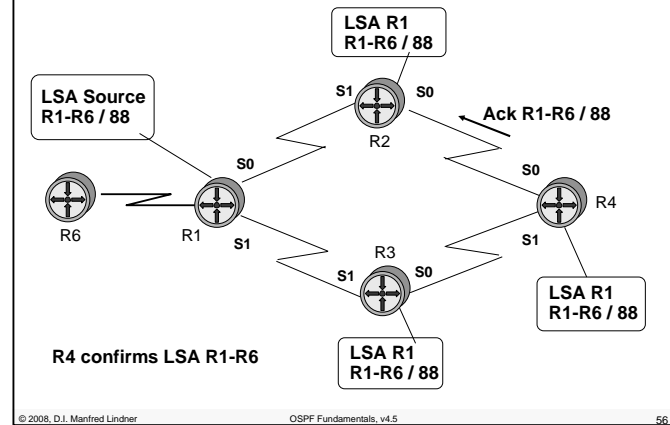
LSA Broad 3



LSA Broad 2

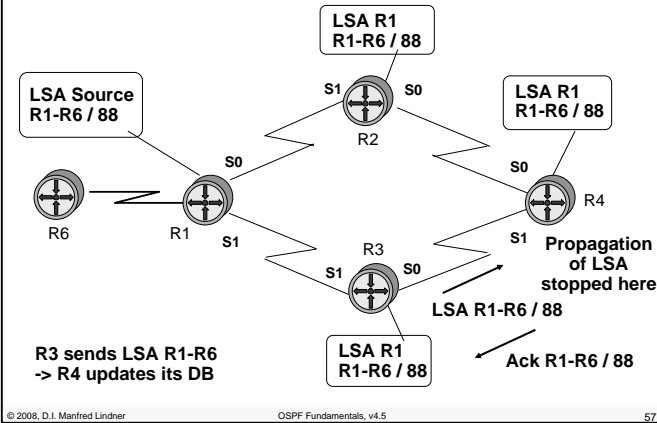


LSA Broad 4



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### LSA Broad 5



### LSA Usage

- **additionally, link states are repeated every 30 minutes to refresh the databases**
  - link states become obsolete after 60 minutes and are removed from the databases
- **reasons:**
  - automatic correction of unnoticed topology-mistakes (e.g. happened during distribution or some router internal failures in the memory)
  - combining two separated parts of an OSPF area (here OSPF also assures database consistency without intervention of an administrator)

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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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## OSPF Broadcast Networks

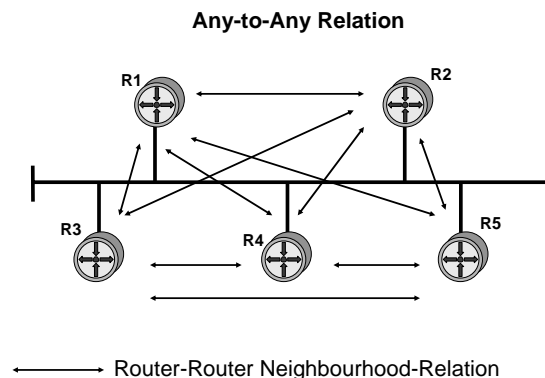
- **if several routers share a multi-access network**
  - any-to-any doesn't scale well ->  $N*(N-1)/2$  problem
  - information about all possible neighbourhood-relations seems to be redundant
  - concept of virtual (network) node (or virtual router) is introduced to solve the problem
- **only the virtual 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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## Broadcast Network



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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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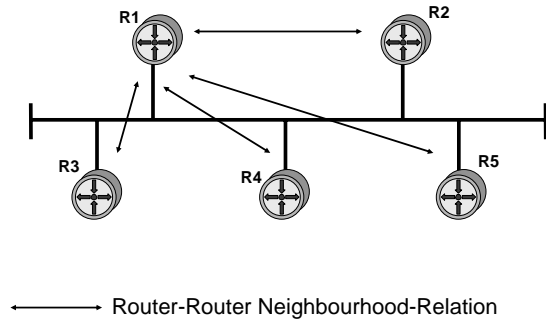
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**Designated and Backup Router**

**Designated Router (DR) Backup Designated Router (BR)**

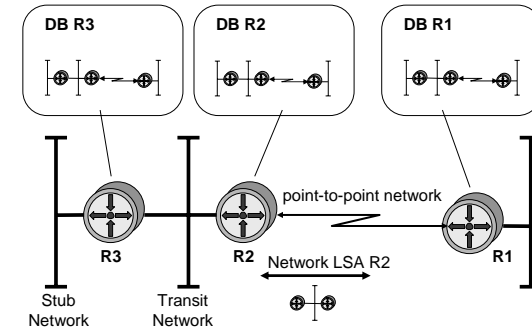


**Designated Router and Network LSA**

- **Designated Router (DR) is responsible**
  - for maintaining neighbourhood relationship via virtual point-to-point links using the already known mechanism
    - DB-Description, LS-Request LS-Update, LS-Acknowledgement, Hello, etc.
- **Router-LSA´s implicitly describe**
  - these virtual point-to-point links by specifying such a network as transit-network
  - remark: Stub-network is a LAN network where no OSPF router is behind
- **To inform all other routers of domain about such a situation**
  - DR is additionally responsible for emitting Network LSAs
- **a Network LSA describes**
  - which routers are members of the corresponding broadcast network

**L10 - OSPF Fundamentals**

**OSPF Network LSA R2**



**Designated Router R2 notifies other nodes about the multi-access network using Network-LSA (transport mechanism are LS-Update packets hop-by-hop)**

**DR and Backup Router**

- **Designated and Backup router are determined using the router-priority field of the Hello message**
- **on DR failure, a Backup Router (BR) continues the service**
- **BR listens to the traffic on the virtual point-to-point link**
  - multicast addresses are used
- **BR recognizes a DR failure through missing acknowledge messages**
  - note: every LS-Update message demands for an LS-Acknowledgement message

**L10 - OSPF Fundamentals****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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**L10 - OSPF Fundamentals****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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**L10 - OSPF Fundamentals****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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**L10 - OSPF Fundamentals****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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