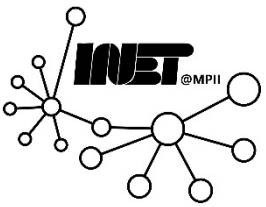
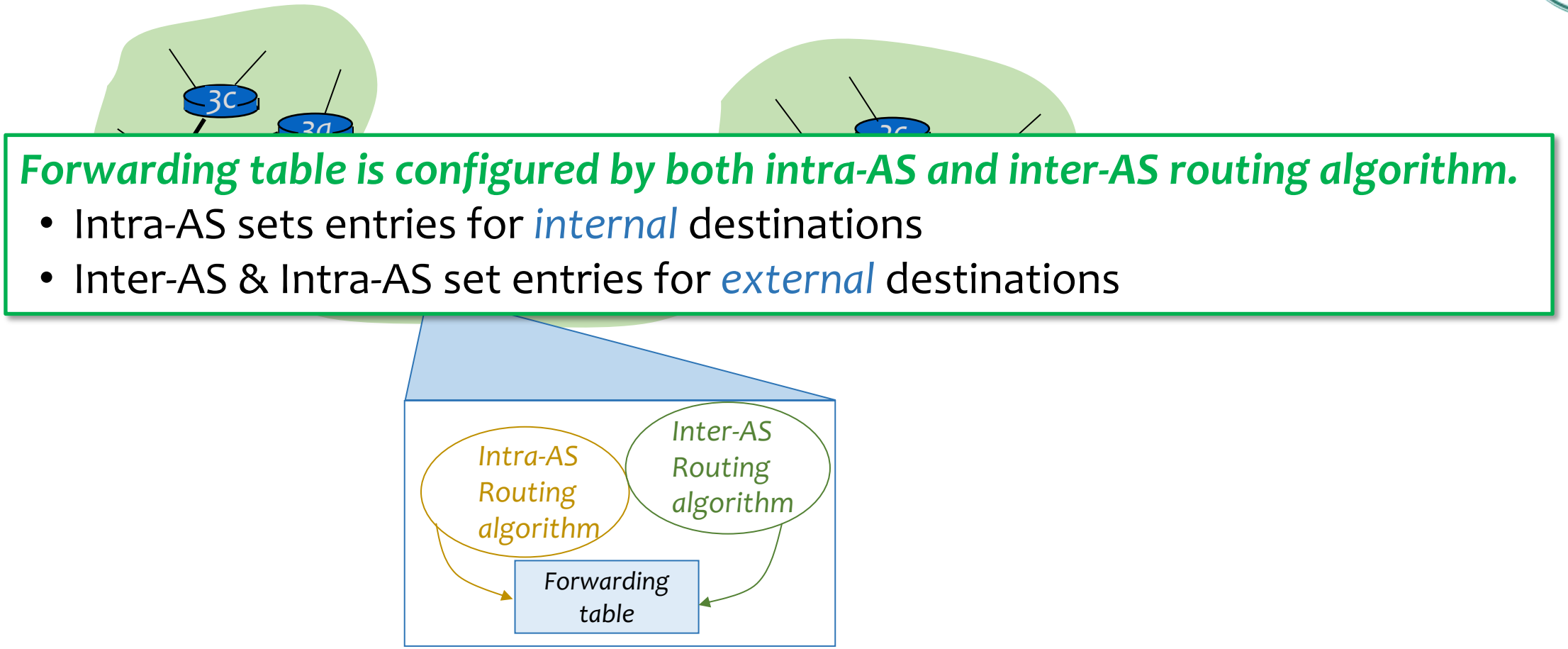
Network Layer
Routing: RIP & OSPF

Prof. Anja Feldmann, Ph.D.



Interconnected ASes



Forwarding table is configured by both intra-AS and inter-AS routing algorithm.

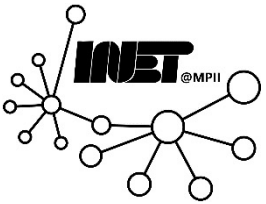
- Intra-AS sets entries for *internal* destinations
- Inter-AS & Intra-AS set entries for *external* destinations

Intra-AS routing

Also known as ***Interior Gateway Protocols (IGP)***

Most common Intra-AS routing protocols:

- *Routing Information Protocol (RIP)*
- ***Open Shortest Path First (OSPF)***



Intra-AS routing: OSPF

Open Shortest Path First (OSPF)

- *Link state* protocol (based on *Dijkstra*)
- Routers periodically *flood immediate reachability* info to all other routers
- Distance metric: *administrative weight*

Open Shortest Path First (OSPF)

State

- *Per router information about itself and attached networks*

OSPF advertisements

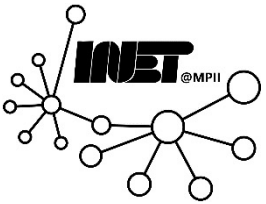
- *Propagates state*

Link state database

- *State of all routers*

Topology map

- *Derived from link state database*



OSPFv2: Components

Who is my neighbor?

- ***Hello*** Protocol

With whom I want to talk? (LAN!!!)

- ***Designated router*** or *Backup* designated router concept

What information am I missing?

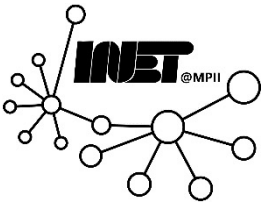
- Database synchronization

How do I distribute info?

- Advertisements disseminated to ***entire*** Autonomous System (via ***reliable flooding***)
- OSPF messages ***directly over IP*** (*rather than TCP or UDP*)

Route computation

- From link state database with Dijkstra's algorithm
- Supports equal-cost path routing



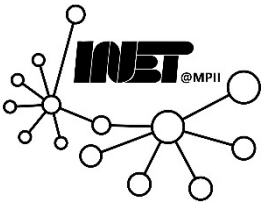
OSPF: Neighbor discovery & maintenance

Hello Protocol

- Ensures that neighbors can send packets to and receive packets from the other side: *bi-directional* communication
- Ensures that neighbors agree on parameters (*HelloInterval* and *RouterDeadInterval*)

How?

- ***Hello packet*** to fixed well-known multicast address
- ***Periodic*** *Hellos*
- Broadcast network: Electing designated router

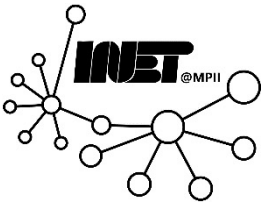


Some multicast addresses

- *224.0.0.5 AllSPFRouters OSPF-ALL.MCAST.NET*
- *224.0.0.6 AllDRouters OSPF-DSIG.MCAST.NET*

- FF02::5 and FF02::6, respectively for OSPFv3.

- While we are at it:
  - 224.0.0.1 ALL- SYSTEMS. MCAST. NET
  - 224.0.0.2 ALL- ROUTERS. MCAST. NET
  - 224.0.0.9 RIP2- ROUTERS. MCAST. NET
  - 224.0.0.10 IGRP- ROUTERS. MCAST. NET
  - Look up some more (with dig –x address)



Hello Protocol: Phases

Down

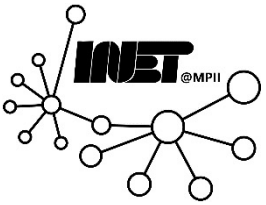
- Neighbor is supposed to be *"dead"*
- No communication at all

Init

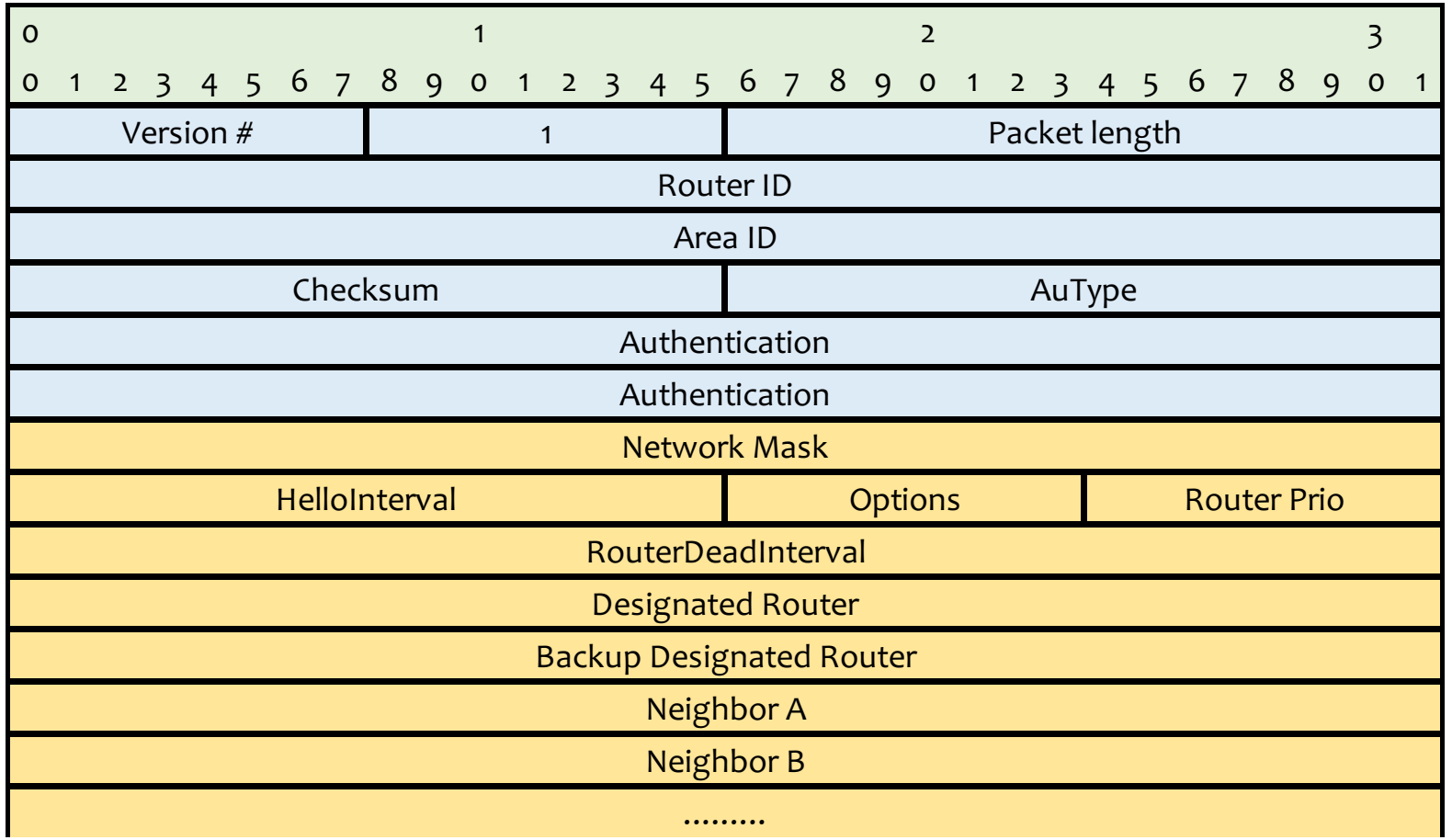
- *"I have heard of a Neighbor"*
- Uni-directional communication

ExStart or TwoWay

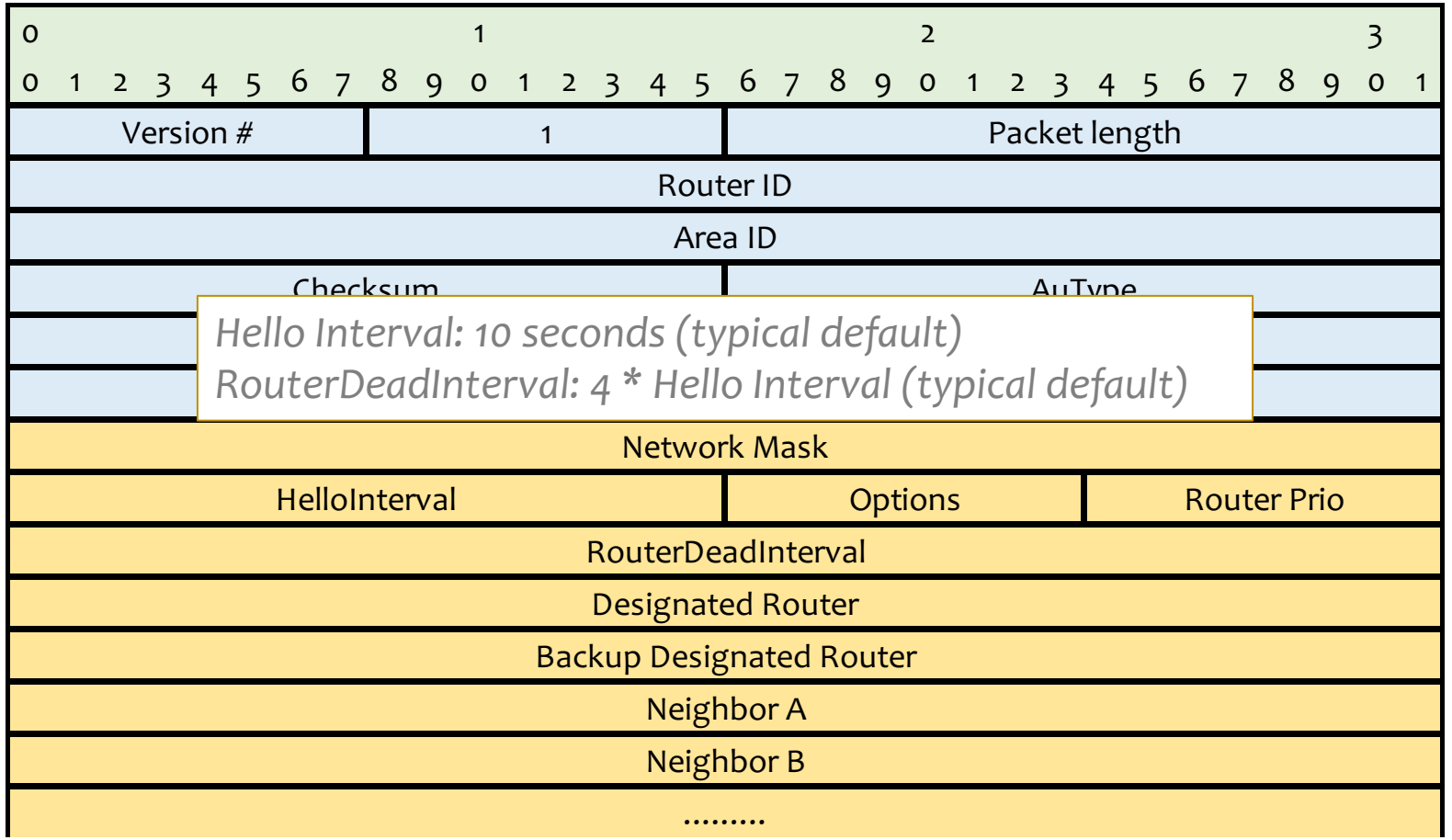
- Communication is bi-directional



Hello Protocol: Packet



Hello Protocol: Packet

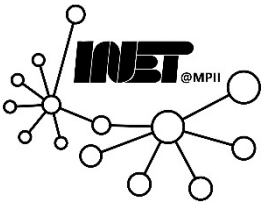


OSPF: Packet

- IP Protocol ***#89***
- Directly to neighbors using ***multicast*** address; ***TTL 1***

Five packet types

- ***Hello***
- ***Database Description***
- ***Link State Request***
- ***Link State Update***
- ***Link State Acknowledgement***



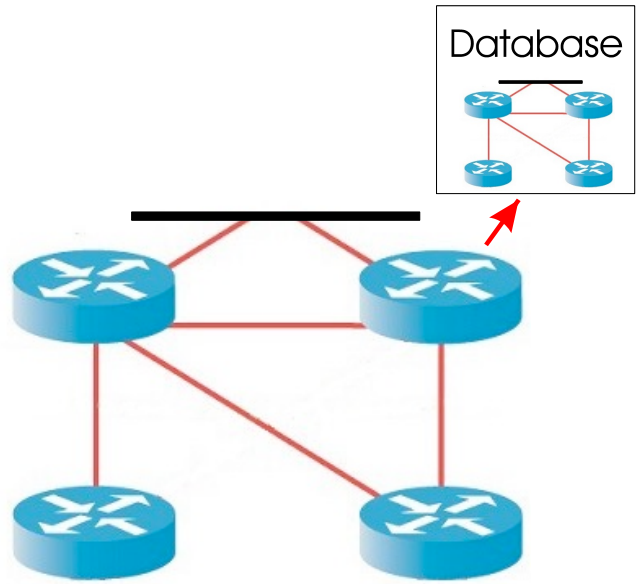
OSPF: Link state database

Based on link-state technology

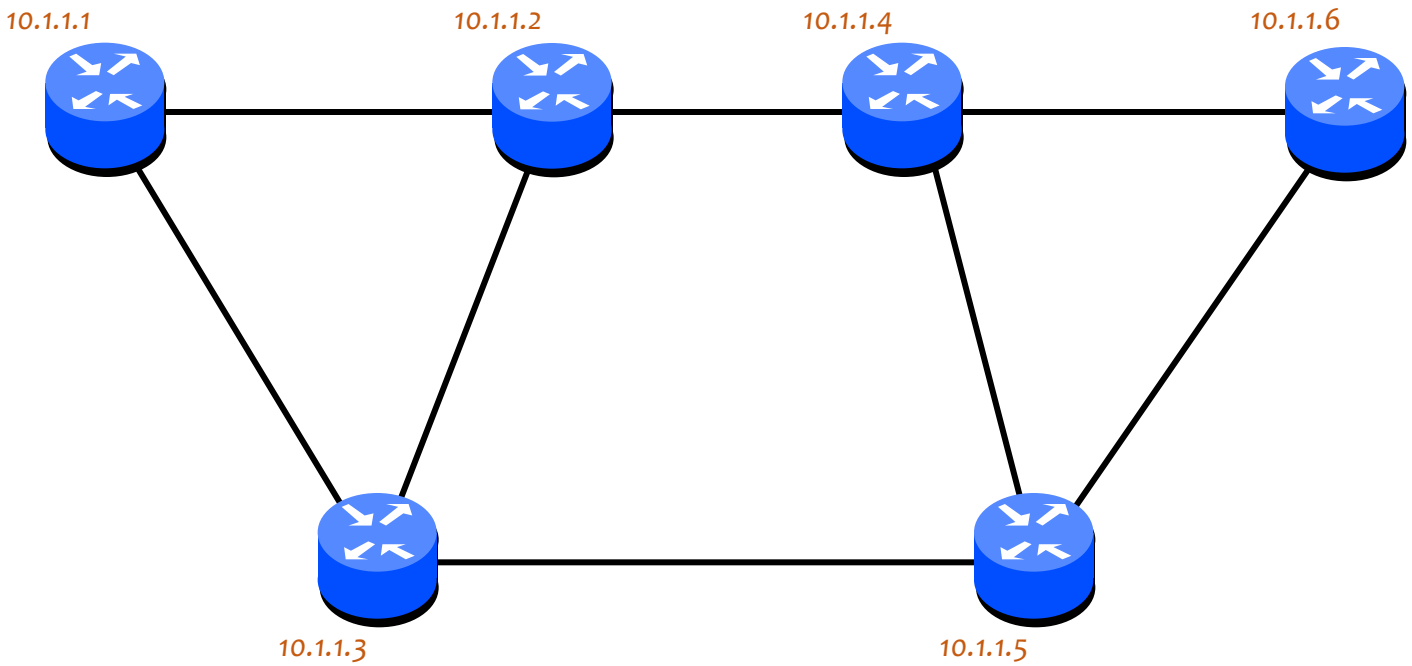
- Local view of topology in a database

Database

- Consists of ***Link State Advertisements (LSA)***
- ***LSA***: Data unit describing local state of a network/router
- *Must be kept synchronized* to react to routing failures

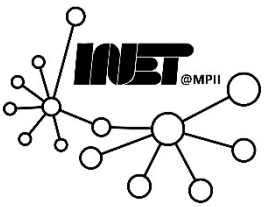


OSPF: Example network



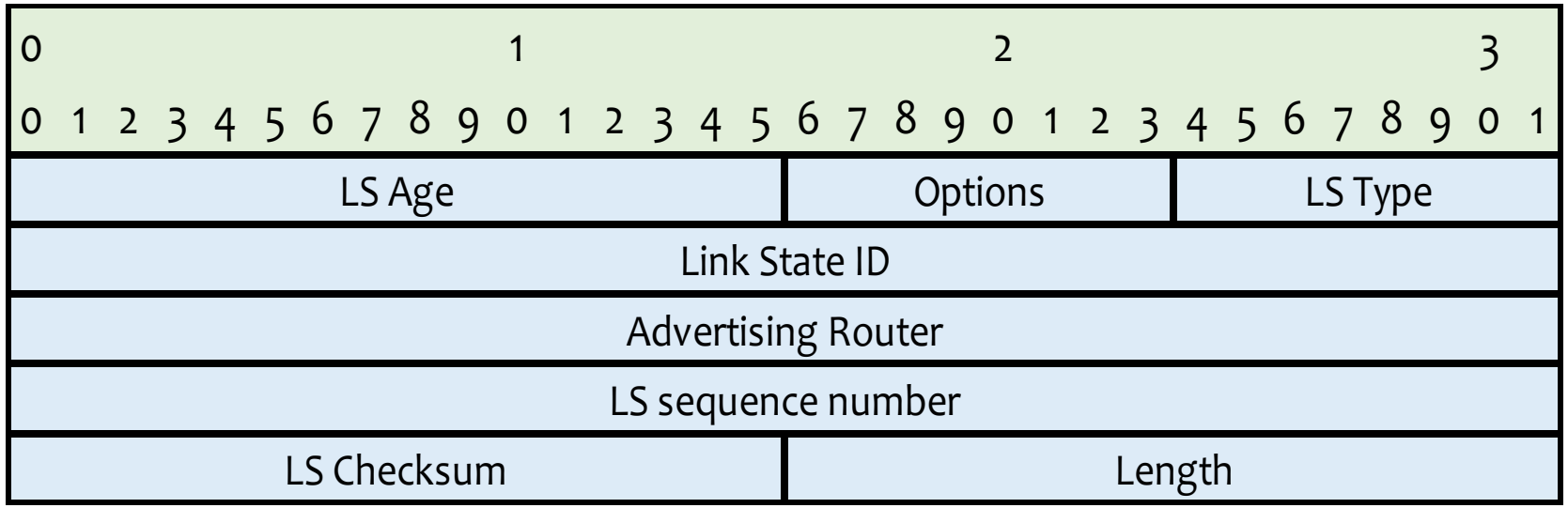
OSPF: Example link state database

LS-Type	Link State ID	Adv. Router	Checksum	Seq. No.	Age
Router-LSA	10.1.1.1	10.1.1.1	0x9b47	0x80000006	0
Router-LSA	10.1.1.2	10.1.1.2	0x219e	0x80000007	1618
Router-LSA	10.1.1.3	10.1.1.3	0x6b53	0x80000003	1712
Router-LSA	10.1.1.4	10.1.1.4	0xe39a	0x8000003a	20
Router-LSA	10.1.1.5	10.1.1.5	0xd2a6	0x80000038	18
Router-LSA	10.1.1.6	10.1.1.6	0x05c3	0x80000005	1680



OSPF: LSAs

- LSAs consist of a ***header*** and a ***body***
- Header size is *20 bytes*



OSPF: LSAs

Identifying LSAs

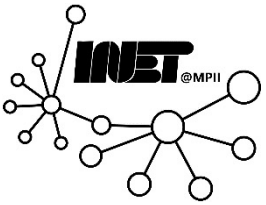
- LS Type Field
- Link State ID Field
- Advertising Router Field

Verifying LSA Contents

- LS Checksum Field

Identifying LSA Instances *(keeping in mind that the topology changes)*

- LS Sequence Number Field
- Linear sequence space
- Max. Seq.: New instance

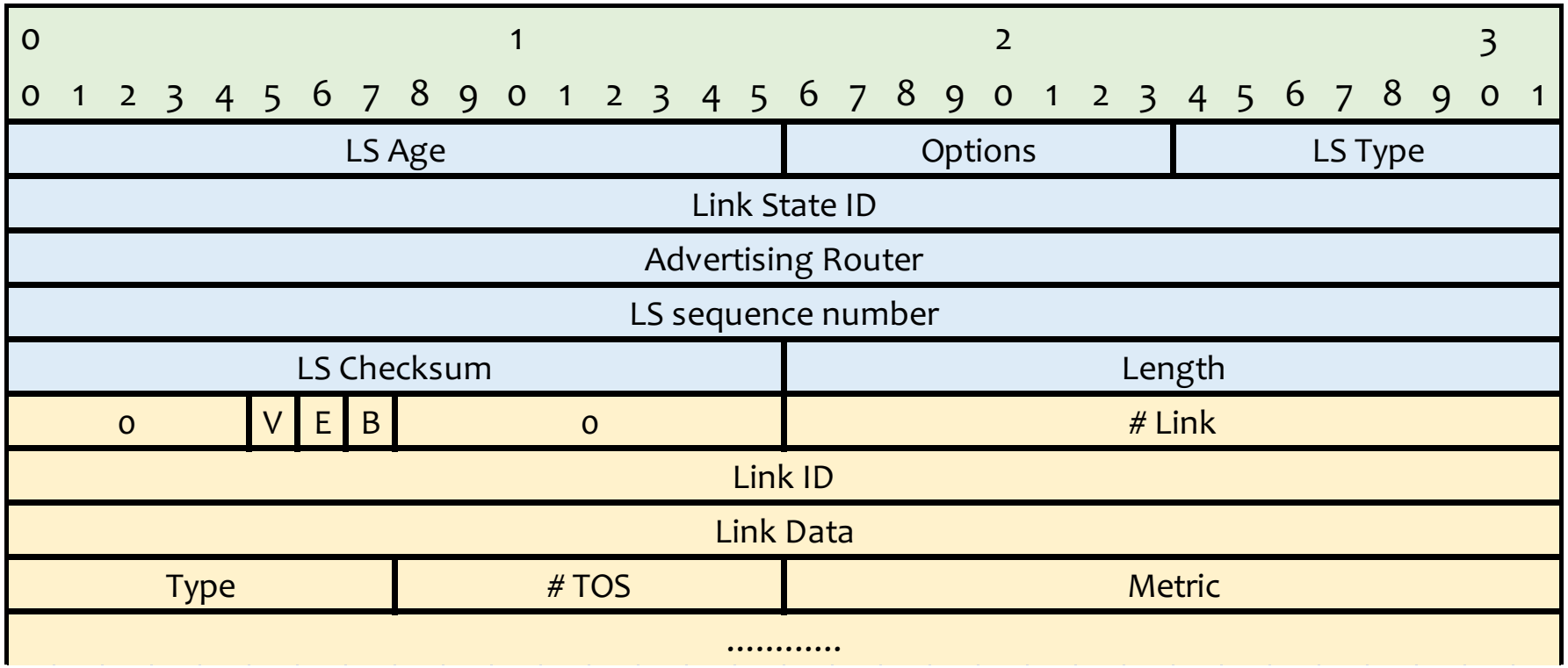


OSPF: LSAs

LS Age Field *(to ensure consistency)*

- Goal: New sequence number every *30 minutes*
- Maximum value 1 hour
- Age > 1 hour ⟹ invalid ⟹ removal
- Enables premature aging
- Ensures removal of outdated information

OSPF: Example Router-LSA



OSPF: Link state database

Is the database synchronized?

- Same number of LSAs?
- Sums of LSA LS Checksums are equal?

OSPF: Database synchronization

Central aspect: *all routers need to have identical databases!*

Two types of synchronization

- ***Initial*** synchronization
  - After hello
- ***Continuous*** synchronization
  - Flooding

OSPF: Initial synchronization

Explicit transfer of the database upon establishment of *neighbor-ship*

Once *bi-directional* communication exists

- Send *all LS headers* from database to neighbor
  - OSPF ***database description (DD)*** packets
  - Flood all future LSAs

OSPF: Initial synchronization

Database description (DD) exchange

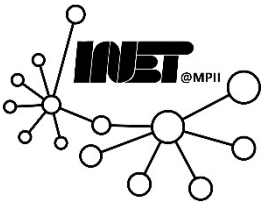
- Only one DD at a time
- Wait for Ack

Control of DD exchange

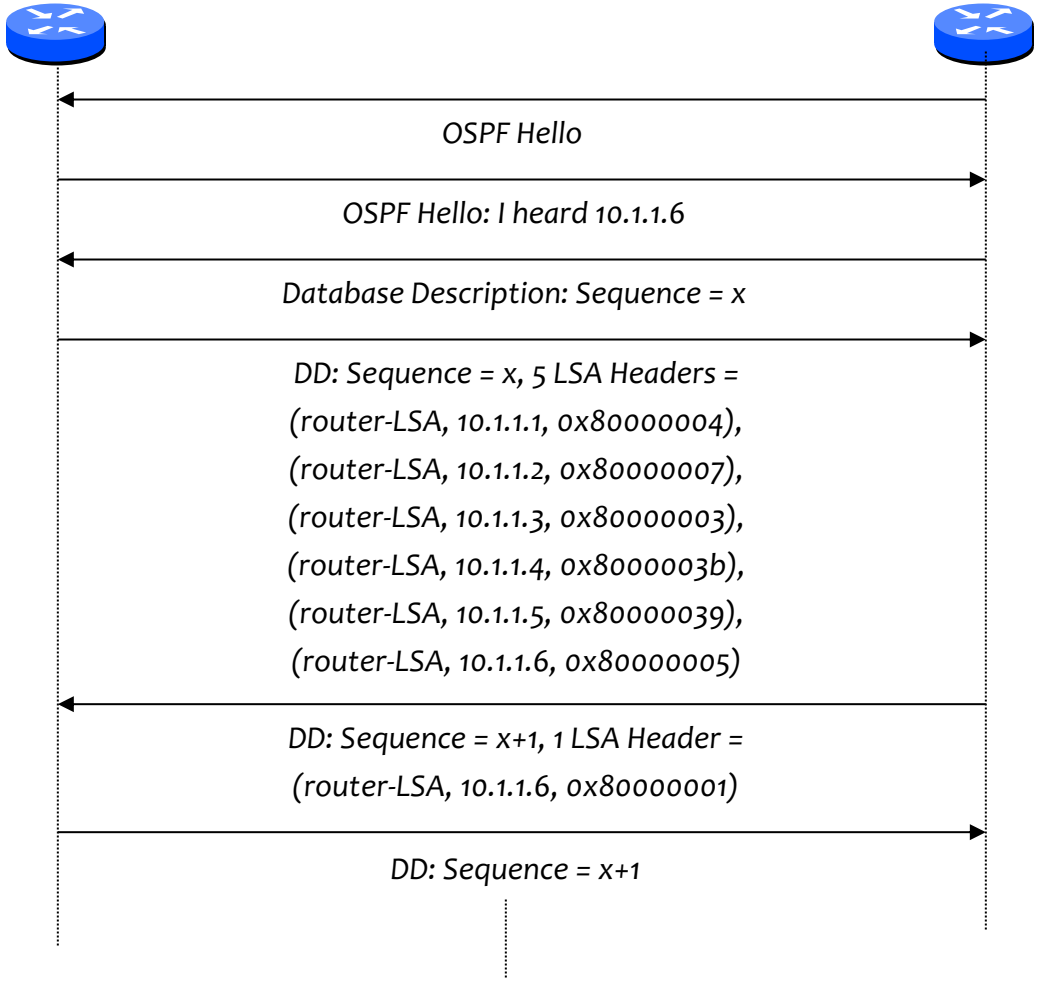
- Determine Master/Slave for DD exchange
- Determine which LSA's are missing in own DB
- Request those via link state request packets
- Neighbor sends these in link state update packets

Result:

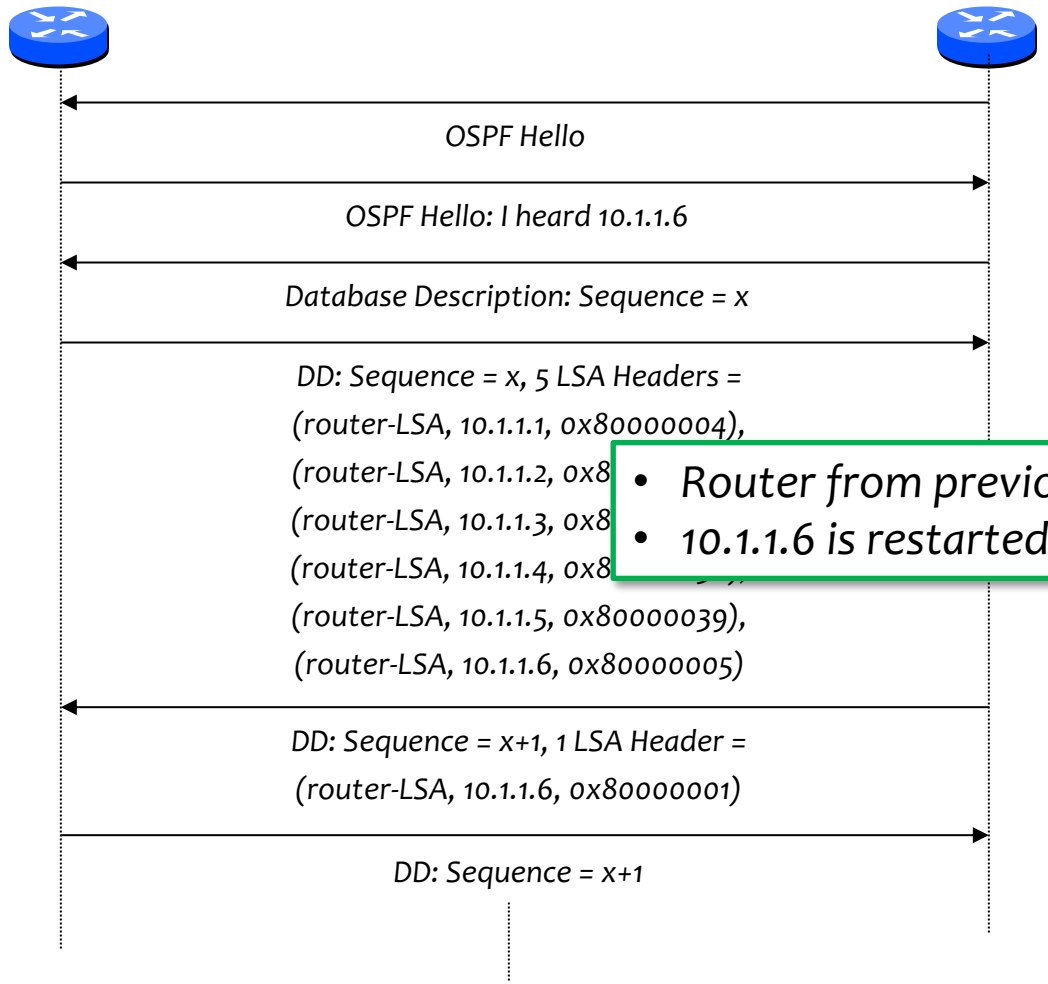
- Fully adjacent OSPF neighbors



OSPF: Example synchronization

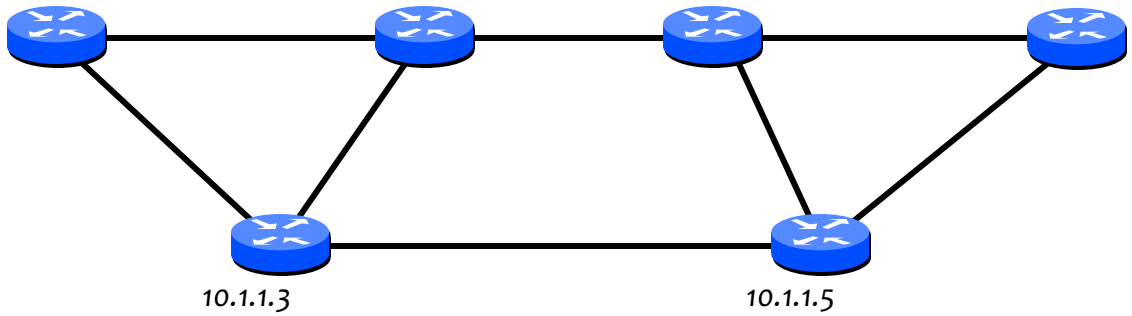


OSPF: Example synchronization



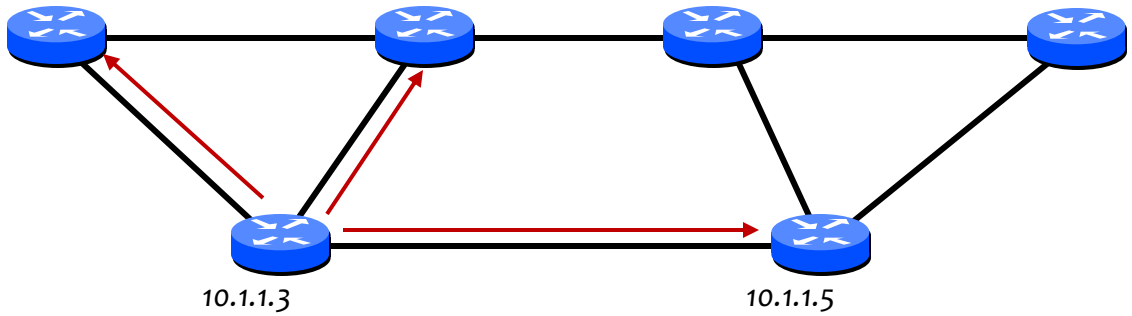
- *Router from previous example are synchronized*
- *10.1.1.6 is restarted*

OSPF: Reliable flooding



- *10.1.1.3* sends *LS Update*
- Same copy of an *LSA* is an ***implicit*** *ACK*
- Use ***delayed*** *ACKs*
- All *LSAs must* be acknowledged either *implicitly* or *explicitly*

OSPF: Reliable flooding



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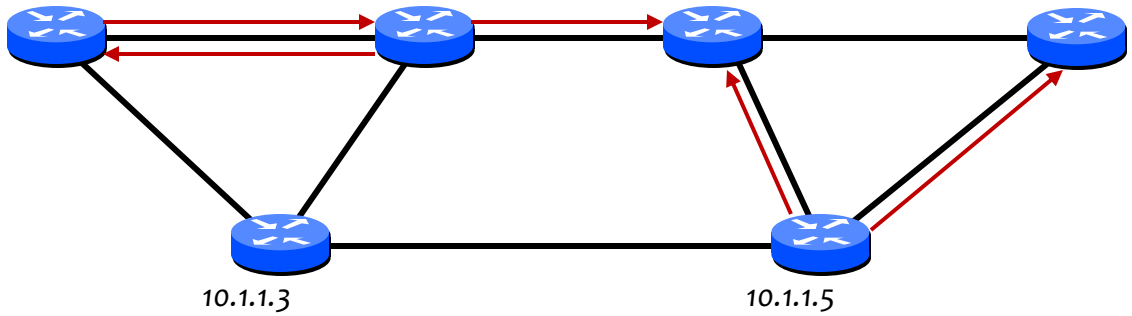

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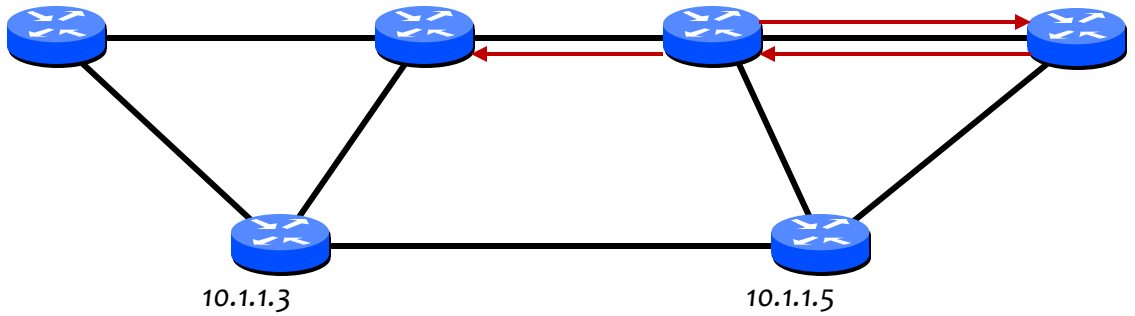

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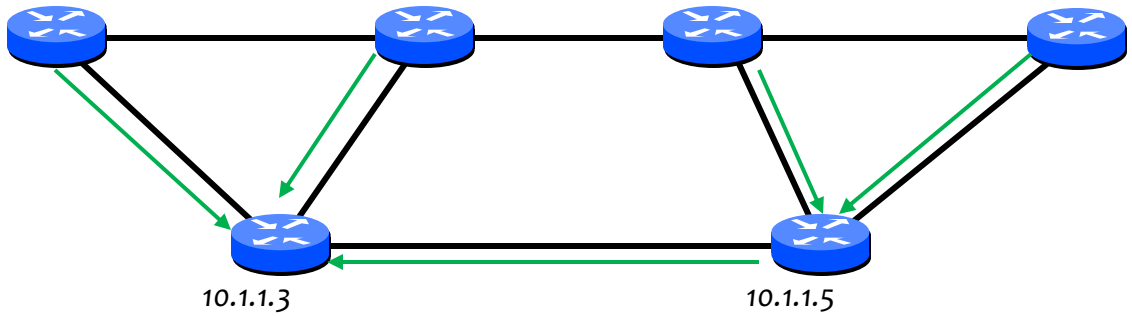

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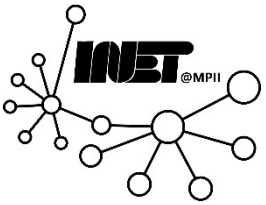
OSPF: Robustness of flooding

- More robust than a *spanning tree*
- LSA refreshes every *30 minutes*
- LSAs …
  - Have checksums
  - Are aged
  - Cannot be send at arbitrary rate: There are *timers!*

OSPF: LSA timers

MinLSArrival	*1 second*
MinLSInterval	*5 seconds*
CheckAge	*5 minutes*
MaxAgeDiff	*15 minutes*
LSRefreshTime	*30 minutes*
MaxAge	*1 hour*

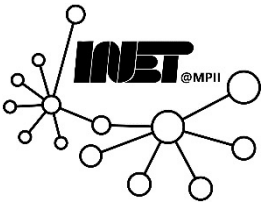


OSPF: Routing table calculation

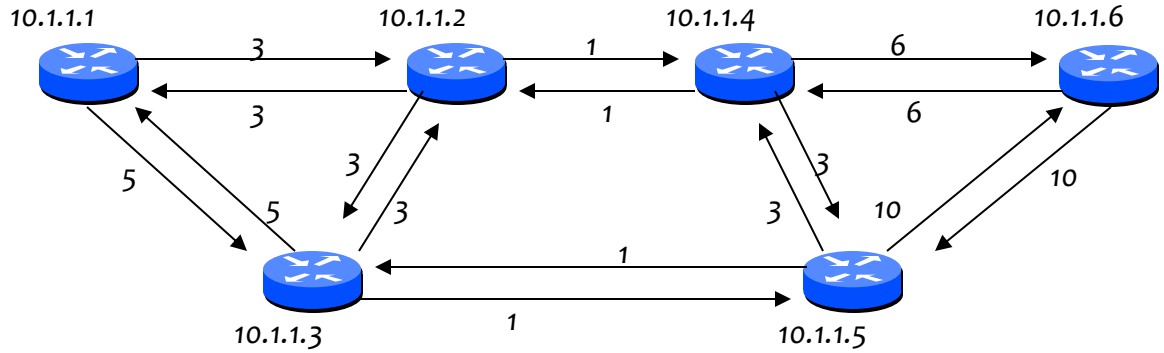
Link state database is a *directed graph with costs* for each link

Dijkstra's SPF algorithm

- Add all routers to shortest-path-tree
- Add all neighbors to candidate list
- Add routers with the smallest cost to tree
- Add neighbors of this router to candidate list
  - If not yet on it
  - If cost smaller
- Continue until candidate list empty



OSPF: Example routing table calc.



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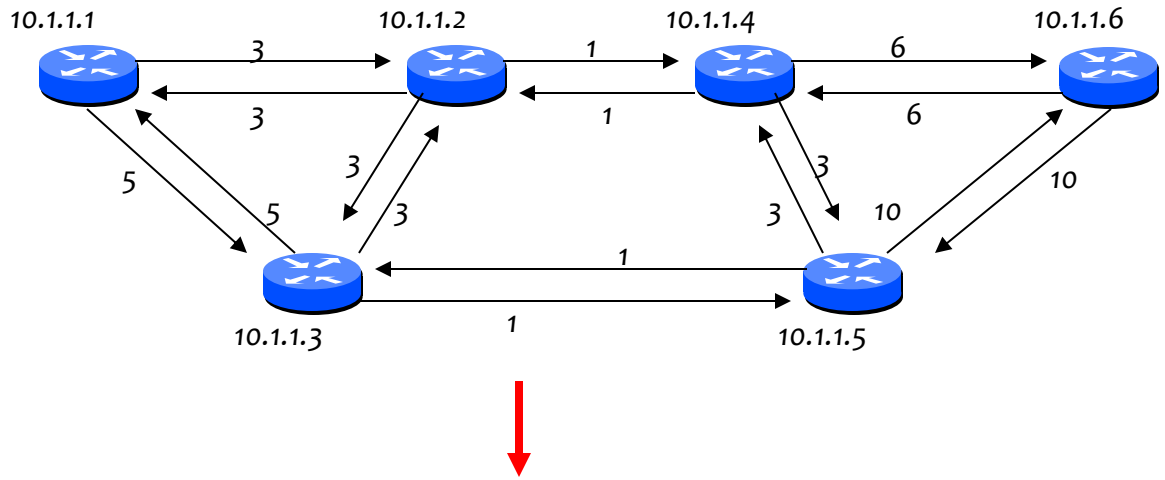

10.1.1.5 (1, 10.1.1.5)
10.1.1.2 (3, 10.1.1.2)
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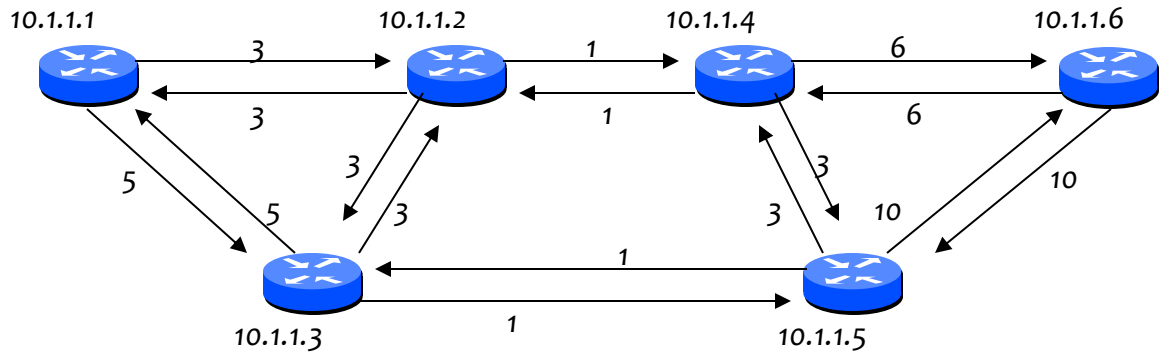

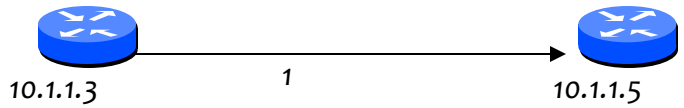

10.1.1.2 (3, 10.1.1.2)
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10.1.1.6 (11, 10.1.1.5)

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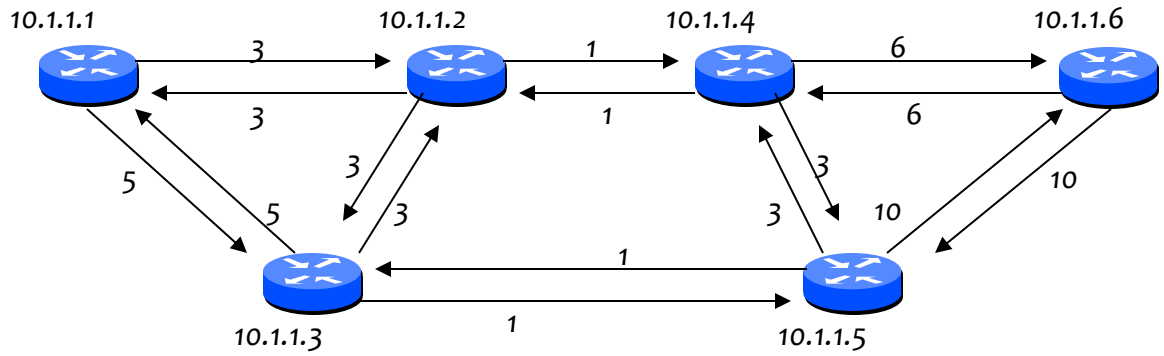

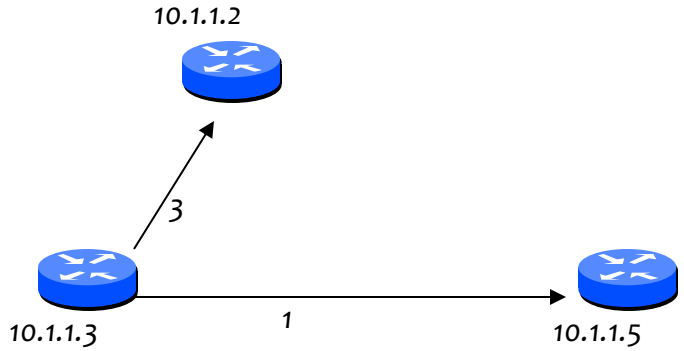

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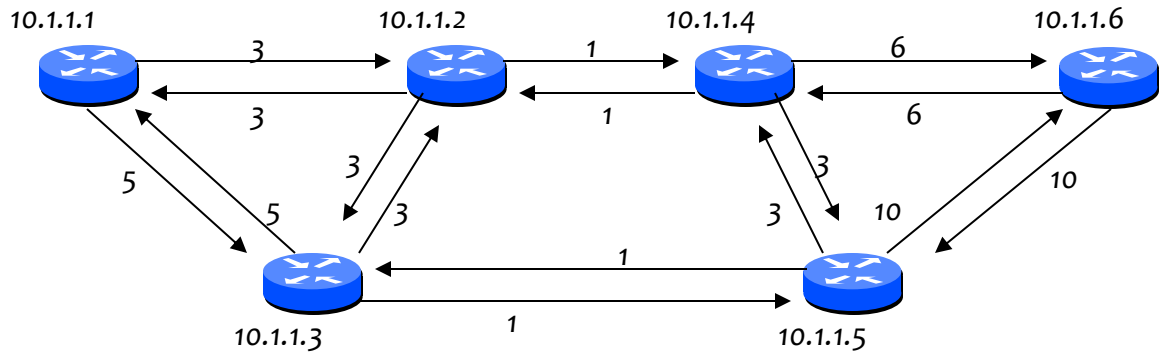

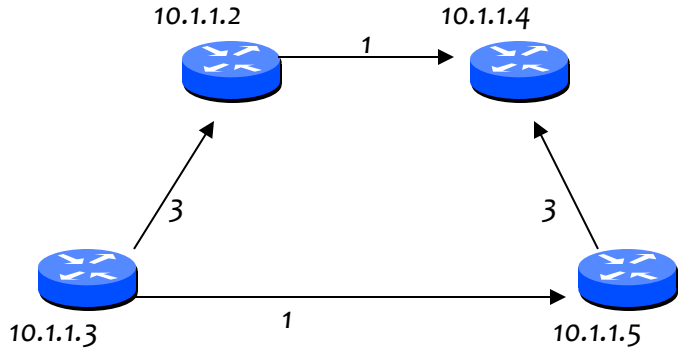

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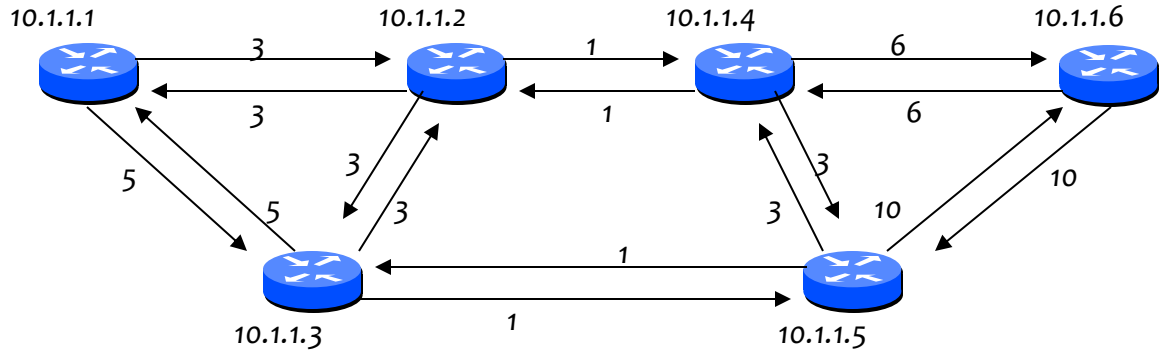

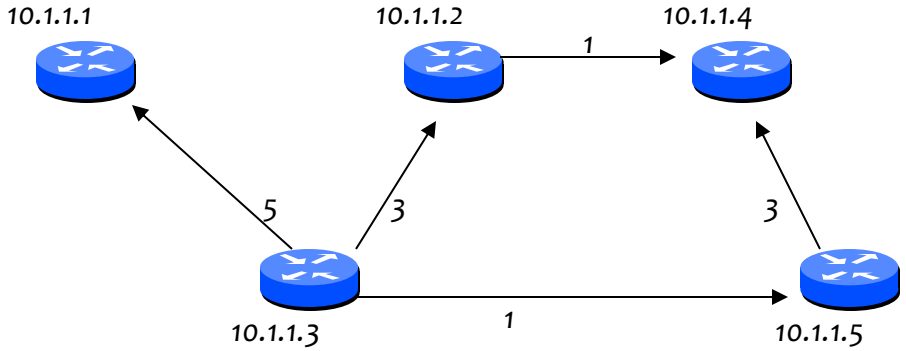

10.1.1.6 (10, 10.1.1.5/2)

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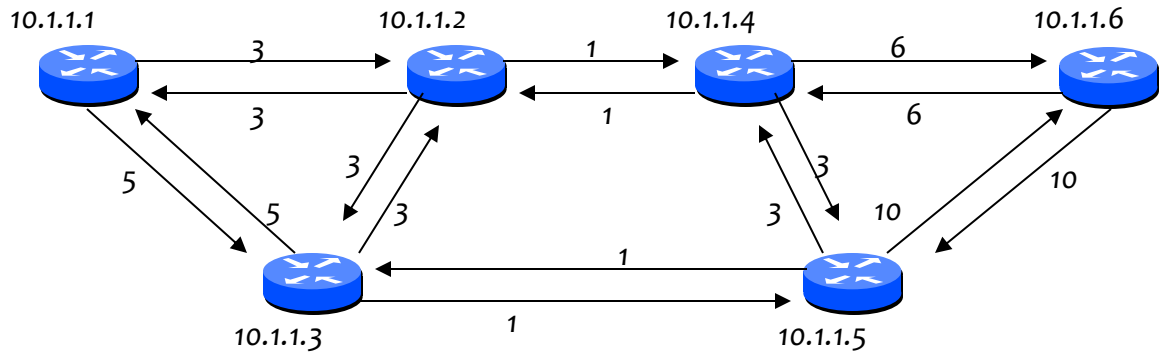

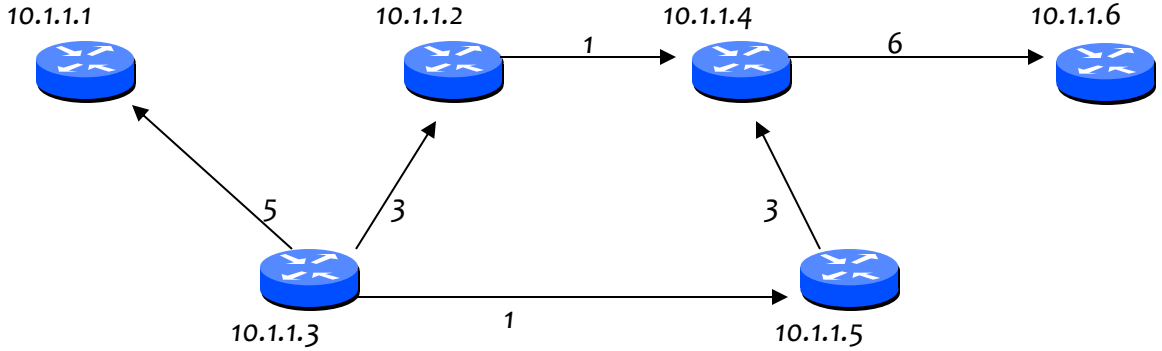

List empty