OSPF (Open Shortest Path First)

- "Open": specification publicly available
  - RFC 1247, RFC 2328
  - Working group formed in 1988
  - Goals:
    - Large, heterogeneous internetworks
- Uses the Link State algorithm
  - Topology map at each node
  - Route computation using Dijkstra's algorithm

OSPF "Advanced" Features (not in RIP)

- Security: All OSPF messages are authenticated (to prevent malicious intrusion); UDP used
- Multiple same-cost paths allowed (only one path in RIP)
- For each link, multiple cost metrics for different TOS (e.g., satellite link cost set "low" for best effort; high for real time)
- Integrated uni- and multicast support:
  - Multicast OSPF (MOSPF) uses same topology data base as OSPF
- Hierarchical OSPF in large domains.

OSPFv2: Components

- Hello Protocol: “Who is my neighbor?”
- Designated router/Backup designated router (DR/BDR) election: “With whom I want to talk?”
- Database Synch: “What info am I missing?”
- Reliable flooding alg: “How do I distribute info?”
- Route computation
  - From link state database
  - Using Dijkstra’s algorithm
  - Supporting equal-cost path routing

Neighbor Discovery and 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

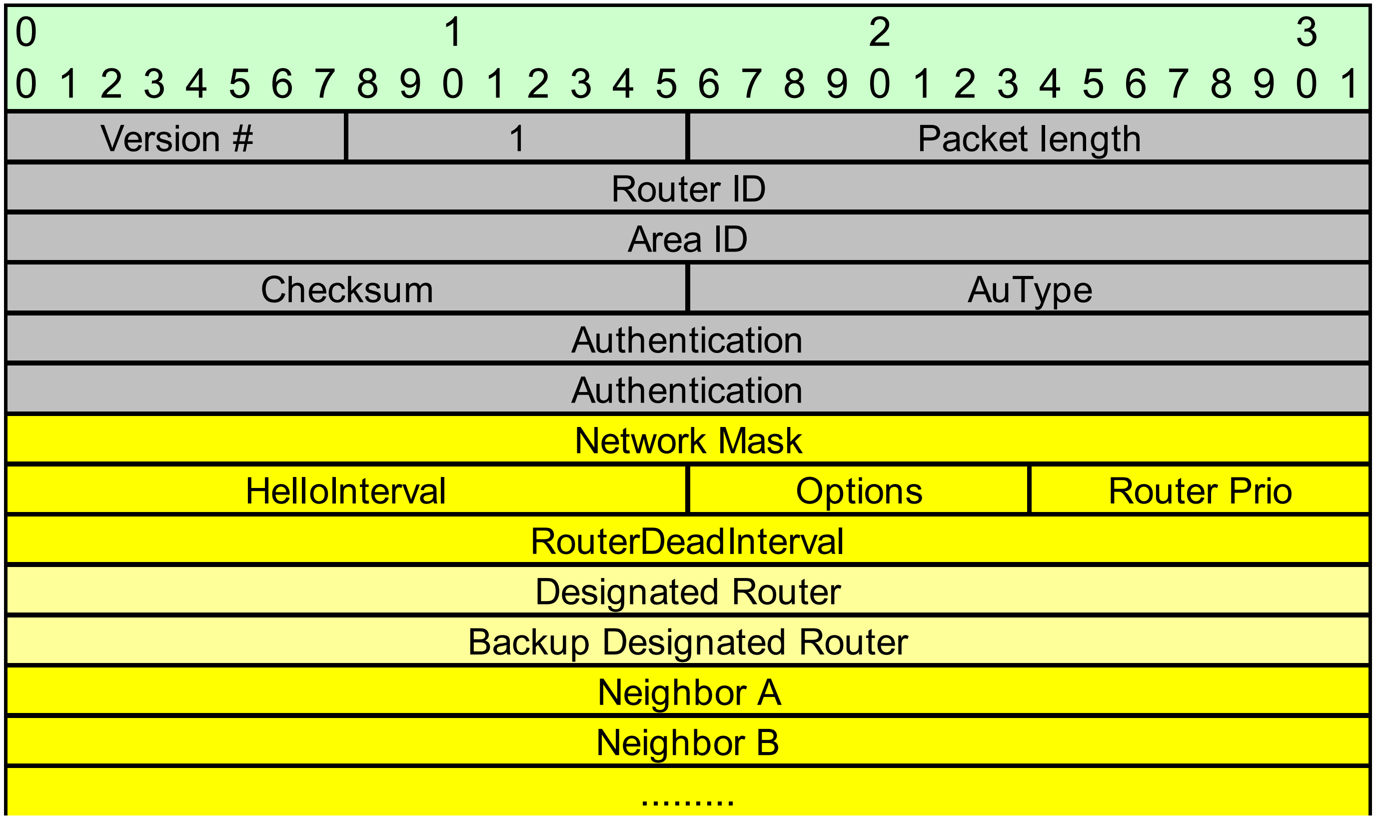
- FF02:: 5 and FF02:: 6, respectively for OSPFv3.

- 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: 3 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



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<tr><td colspan="8">Version #</td><td colspan="8">1</td><td colspan="16">Packet length</td></tr>
<tr><td colspan="32">Router ID</td></tr>
<tr><td colspan="32">Area ID</td></tr>
<tr><td colspan="16">Checksum</td><td colspan="16">AuType</td></tr>
<tr><td colspan="32">Authentication</td></tr>
<tr><td colspan="32">Authentication</td></tr>
<tr><td colspan="32">Network Mask</td></tr>
<tr><td colspan="16">HelloInterval</td><td colspan="8">Options</td><td colspan="8">Router Prio</td></tr>
<tr><td colspan="32">RouterDeadInterval</td></tr>
<tr><td colspan="32">Designated Router</td></tr>
<tr><td colspan="32">Backup Designated Router</td></tr>
<tr><td colspan="32">Neighbor A</td></tr>
<tr><td colspan="32">Neighbor B</td></tr>
<tr><td colspan="32">.........</td></tr>
</table>

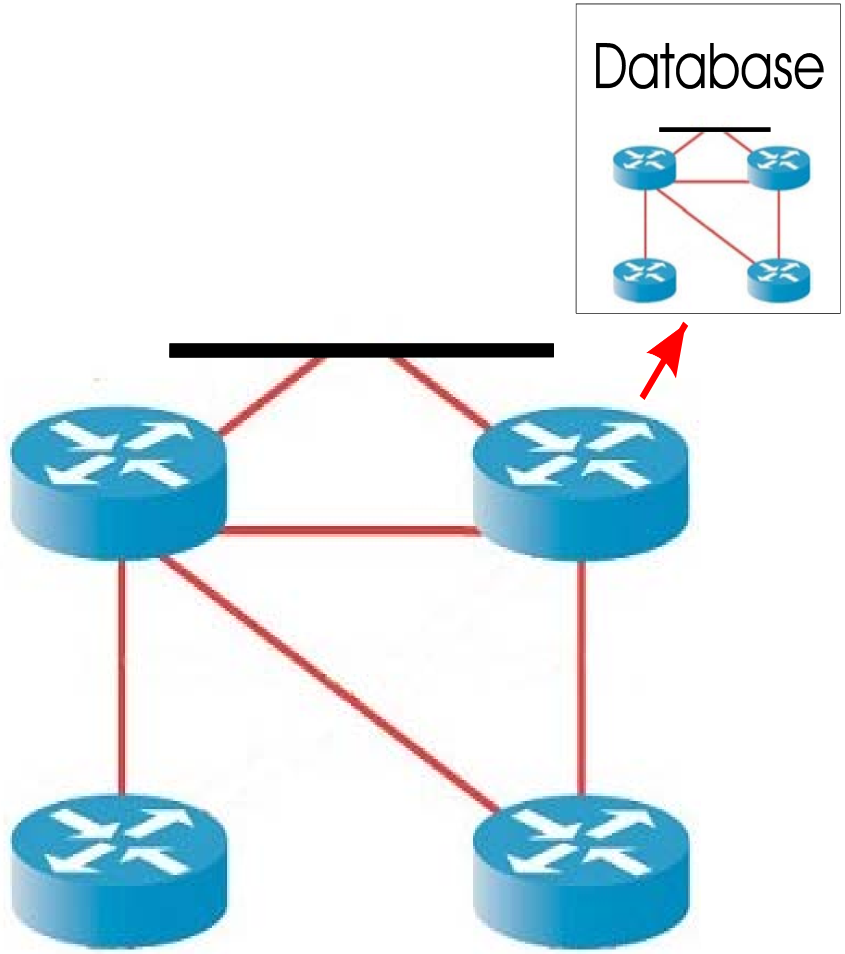
- Hello Interval: 10 seconds (typical default)
- RouterDeadInterval: 4 * Hello Interval (typical default)

OSPF Packet

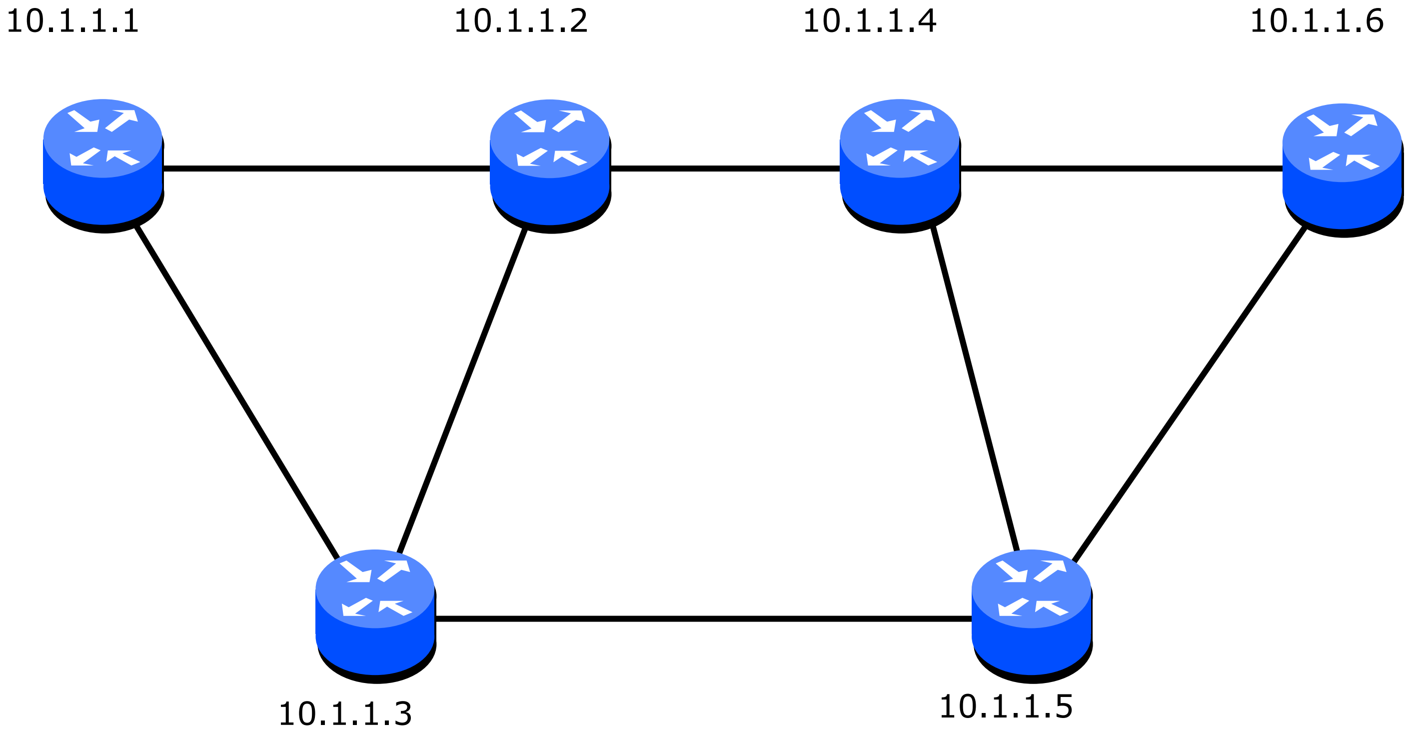
- IP Protocol #89
- Directly to neighbors using Multicast address
  ⇨ TTL 1
- Five packet types
  - Hello
  - Database Description
  - Link State Request
  - Link State Update
  - Link State Acknowledgement

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 kept synchronized to react to routing failures



Example Network



Link State Database: Example

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

LSAs

- Consists of a Header and a Body
- Header size is 20 Byte and consists of

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<tr><td colspan="16">LS Age</td><td colspan="8">Options</td><td colspan="8">LS Type</td></tr>
<tr><td colspan="32">Link State ID</td></tr>
<tr><td colspan="32">Advertising Router</td></tr>
<tr><td colspan="32">LS sequence number</td></tr>
<tr><td colspan="16">LS Checksum</td><td colspan="16">Length</td></tr>
</table>

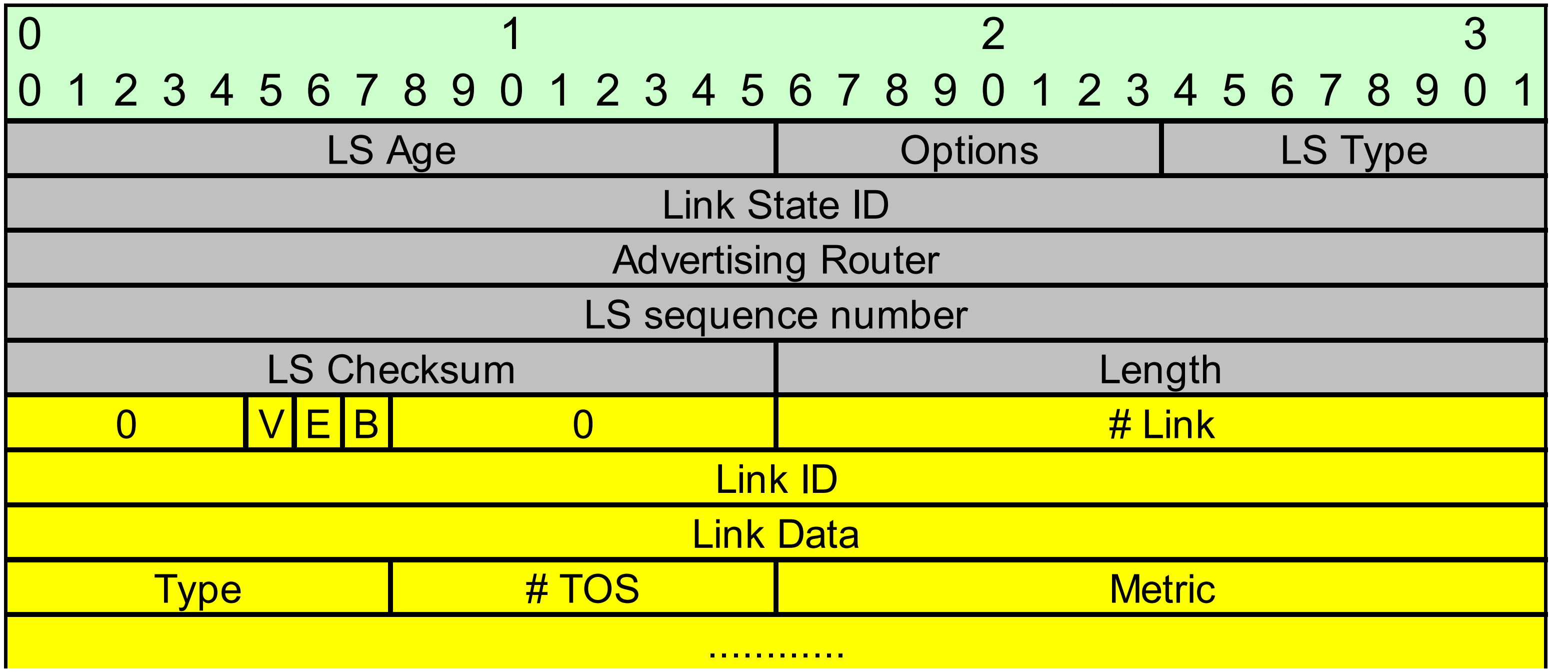
LSAs (2.)

- 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

LSAs (3.)

- 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

Example LSA: Router-LSA



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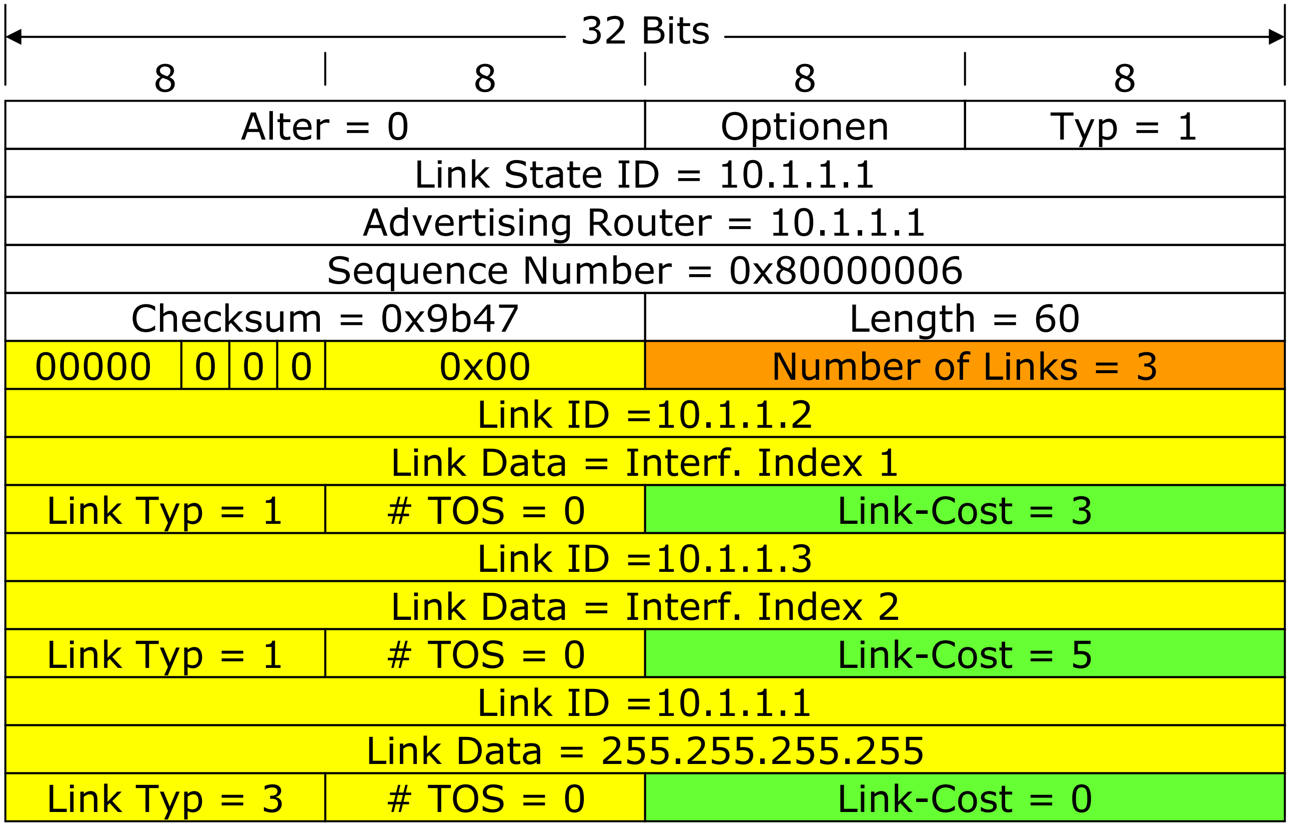
<tr><td colspan="32">LS sequence number</td></tr>
<tr><td colspan="16">LS Checksum</td><td colspan="16">Length</td></tr>
<tr><td colspan="5">0</td><td>V</td><td>E</td><td>B</td><td colspan="8">0</td><td colspan="16"># Link</td></tr>
<tr><td colspan="32">Link ID</td></tr>
<tr><td colspan="32">Link Data</td></tr>
<tr><td colspan="8">Type</td><td colspan="8"># TOS</td><td colspan="16">Metric</td></tr>
<tr><td colspan="32">............</td></tr>
</table>

Example: Router LSA

- Link-Cost: integers (configured)



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<tr><th colspan="7">32 Bits</th></tr>
<tr><th colspan="4">8</th><th>8</th><th>8</th><th>8</th></tr>
<tr><td colspan="5">Alter = 0</td><td>Optionen</td><td>Typ = 1</td></tr>
<tr><td colspan="7">Link State ID = 10.1.1.1</td></tr>
<tr><td colspan="7">Advertising Router = 10.1.1.1</td></tr>
<tr><td colspan="7">Sequence Number = 0x80000006</td></tr>
<tr><td colspan="5">Checksum = 0x9b47</td><td colspan="2">Length = 60</td></tr>
<tr><td>00000</td><td>0</td><td>0</td><td>0</td><td>0x00</td><td colspan="2">Number of Links = 3</td></tr>
<tr><td colspan="7">Link ID =10.1.1.2</td></tr>
<tr><td colspan="7">Link Data = Interf. Index 1</td></tr>
<tr><td colspan="4">Link Typ = 1</td><td># TOS = 0</td><td colspan="2">Link-Cost = 3</td></tr>
<tr><td colspan="7">Link ID =10.1.1.3</td></tr>
<tr><td colspan="7">Link Data = Interf. Index 2</td></tr>
<tr><td colspan="4">Link Typ = 1</td><td># TOS = 0</td><td colspan="2">Link-Cost = 5</td></tr>
<tr><td colspan="7">Link ID =10.1.1.1</td></tr>
<tr><td colspan="7">Link Data = 255.255.255.255</td></tr>
<tr><td colspan="4">Link Typ = 3</td><td># TOS = 0</td><td colspan="2">Link-Cost = 0</td></tr>
</table>

Link Typ 1: Peer-to-peer
Link Typ 3: Stub Network

Link-State Database (2.)

- Is the database synchronized?
  - Same number of LSAs?
  - Sums of LSA LS Checksums are equal?

Database Synchronization

- Central aspect:
  all routers need to have identical databases!
- 2 types of synchronization
  - Initial synchronization
    - After hello
  - Continuous synchronization
    - Flooding

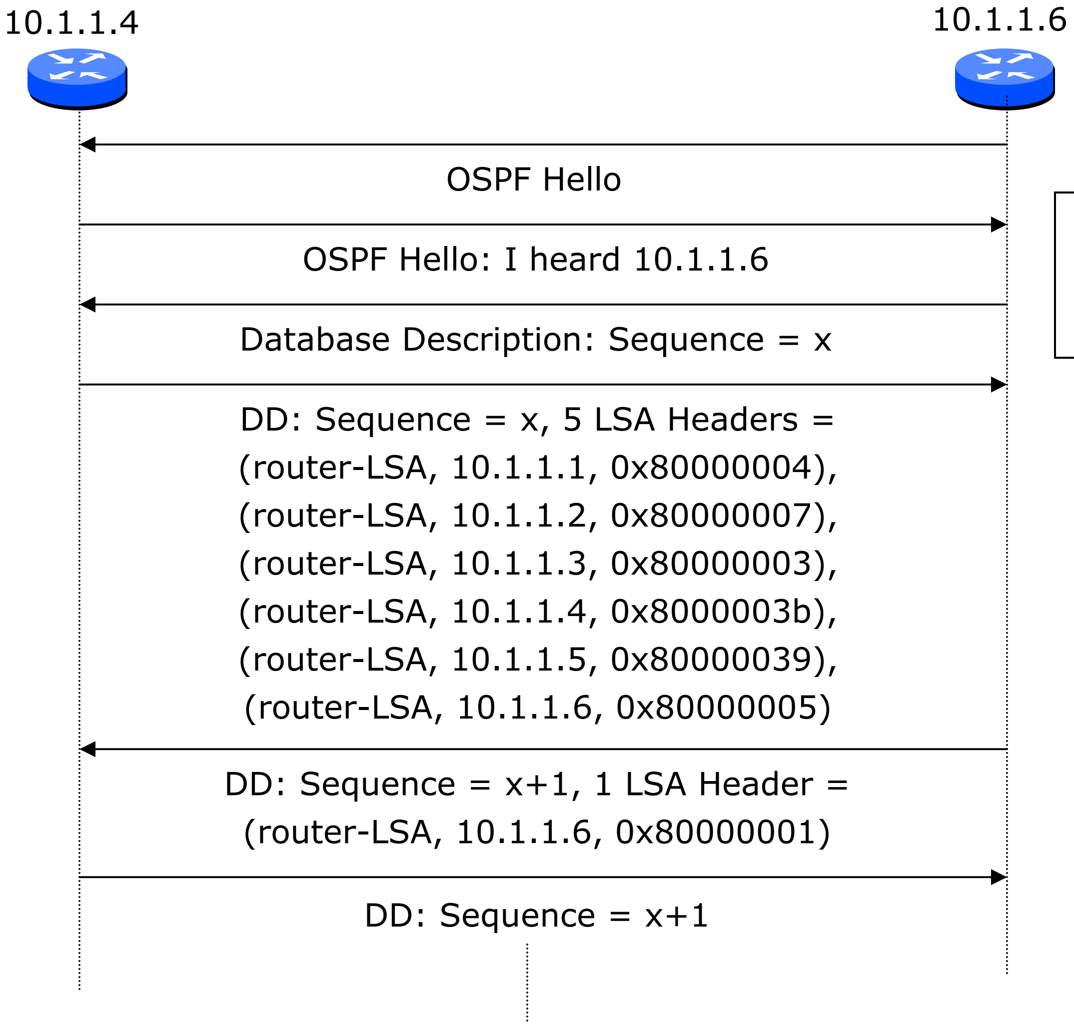
Initial Synchronization

- Explicit transfer of the database upon establishment of neighbor ship
- Once bi-directional communication exists
- Send all LS header from database to neighbor
  - OSPF database description packets (DD pkt)
  - Flood all future LSA's

Initial Synchronization (2.)

- 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

Example: Database Synchronization



OSPF Hello

OSPF Hello: I heard 10.1.1.6

Database Description: Sequence = x

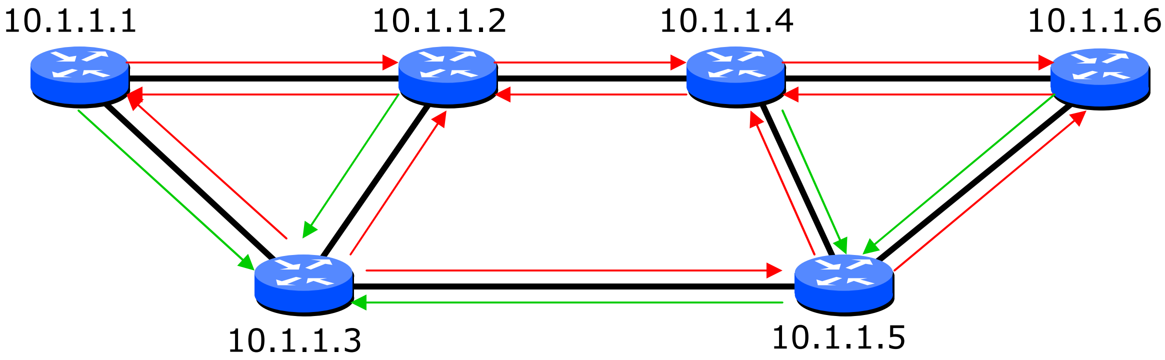
DD: Sequence = x, 5 LSA Headers =
(router-LSA, 10.1.1.1, 0x80000004),
(router-LSA, 10.1.1.2, 0x80000007),
(router-LSA, 10.1.1.3, 0x80000003),
(router-LSA, 10.1.1.4, 0x8000003b),
(router-LSA, 10.1.1.5, 0x80000039),
(router-LSA, 10.1.1.6, 0x80000005)

DD: Sequence = x+1, 1 LSA Header =
(router-LSA, 10.1.1.6, 0x80000001)

DD: Sequence = x+1

- Router from previous example are synchronized
- 10.1.1.6 is restarted

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 implicit or explicit

Robustness of Flooding

- More robust than a spanning tree
- LSA refreshes every 30 minutes
- LSAs have checksums
- LSAs are aged
- LSAs cannot be send at arbitrary rate: there are timers

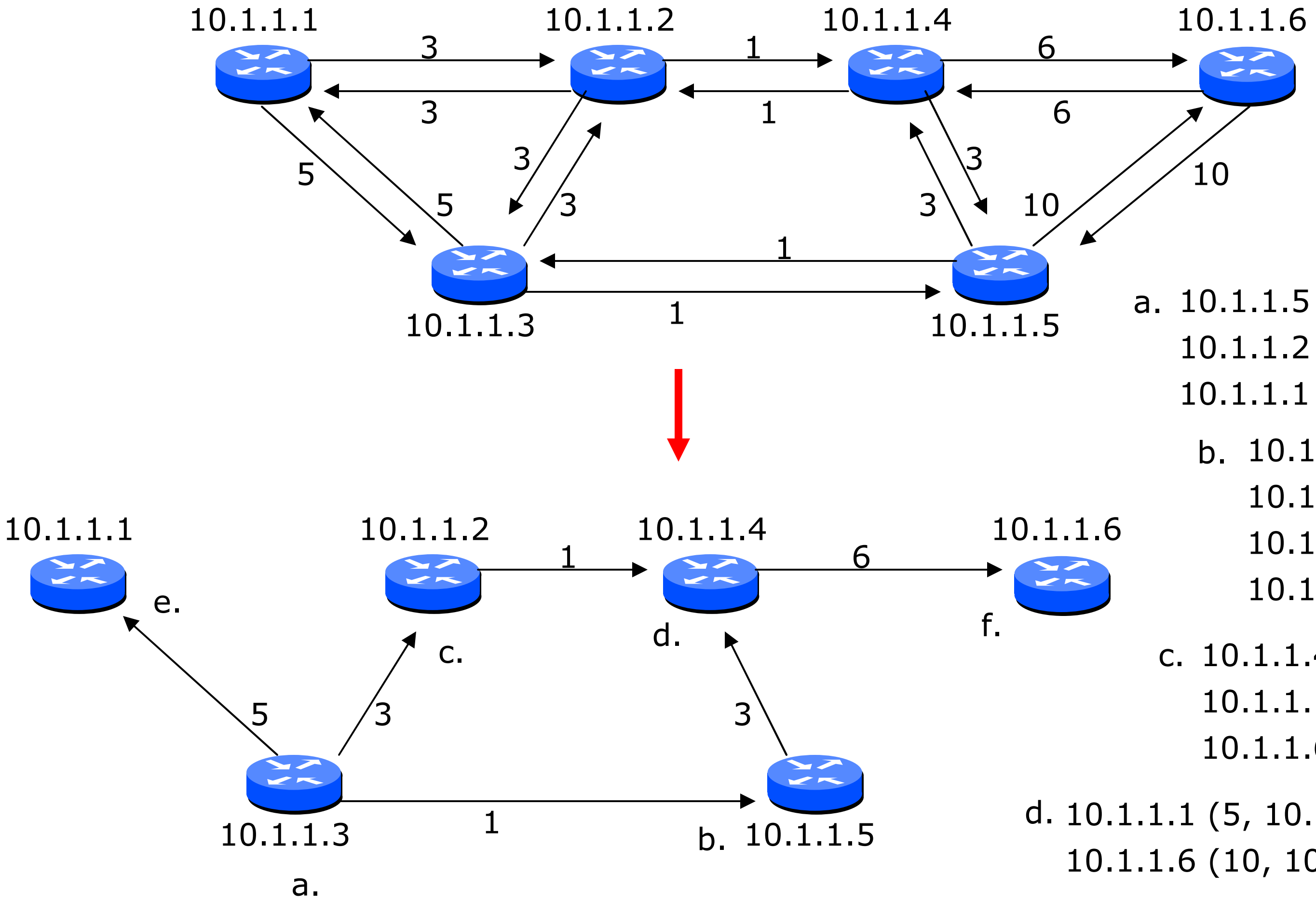
OSPF LSA Timers

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

Calculation of routing table

- Link state database is a directed graph with costs for each link
- Dijkstra’s SPF algorithms
  - 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

Example



a. 10.1.1.5 (1, 10.1.1.5)
10.1.1.2 (3, 10.1.1.2)
10.1.1.1 (5, 10.1.1.1)

b. 10.1.1.2 (3, 10.1.1.2)
10.1.1.4 (4, 10.1.1.5)
10.1.1.1 (5, 10.1.1.1)
10.1.1.6 (11, 10.1.1.5)

c. 10.1.1.4 (4, 10.1.1.5/2)
10.1.1.1 (5, 10.1.1.1)
10.1.1.6 (11, 10.1.1.5)

d. 10.1.1.1 (5, 10.1.1.1)
10.1.1.6 (10, 10.1.1.5/2)

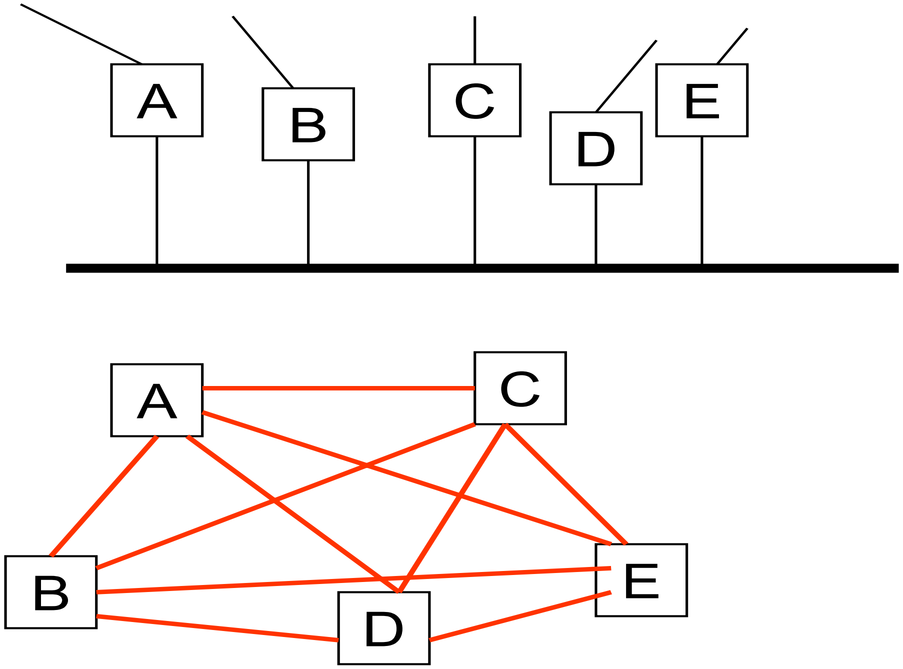
e. 10.1.1.6 (10, 10.1.1.5/2)

f. Liste leer.

Network Types

- So far only point-to-point
- Many other technologies
- Specific requirements for OSPF
  - Neighbor relations
  - Synchronization
  - Representation in DB
- Kinds
  - Point-to-point
  - Broadcast
  - Nonbroadcast multiaccess
  - Point-to-multipoint

Adjacencies on Broadcast Networks



- If *n* routers are on a broadcast link, $n(n\text{-}1)/2$ adjacencies can be formed.

Adjacencies (2.)

- If routers formed pair wise adjacencies:
  - Each would originate $(n-1)+1=n$ LSAs for the link.
  - Out of the network, n^2 LSAs would be emanating.
- Routers also send received LSAs to their neighbors
  - $(n-1)$ copies of each LSA present on the network
  - Even with multicast: $(n-1)$ responses
- Solution: elect Designated Router (DR)
  - Routers form adjacencies only with DR:
  - Link acts as a (multi-interface) virtual router to the rest of the area

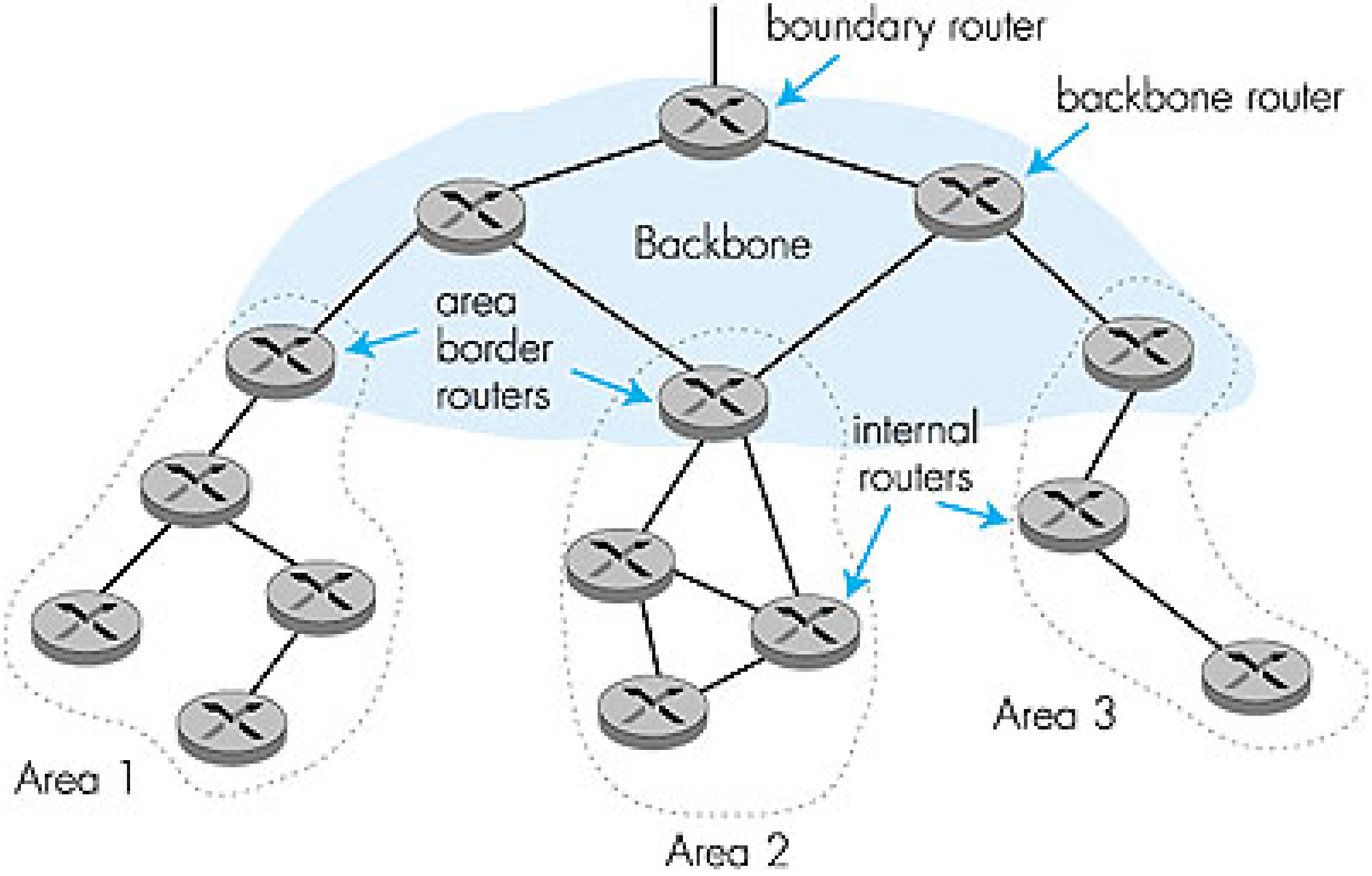
Designated Router Election

- When router joins:
  - Listen to hellos; if DR and BDR advertised, accept them
    - All Hello packets agree on who the DR and BDR are
    - Status quo is not disturbed
- If there is no elected BDR, router with highest priority becomes BDR
- Ties are broken by highest RouterID
  - RouterIDs are unique (IP address of interface)
- If there is no DR, BDR is promoted to DR
- Elect new BDR

Network LSA‘s

- A network LSA represents a broadcast subnet
- Router LSA‘s have links to network LSA
- Reduction of links
- DR responsible for network LSA
- Link State ID = IP-address of DR

Hierarchical OSPF



Hierarchical OSPF

- Two-level hierarchy: local area and backbone.
  - Link-state advertisements do not leave respective areas.
  - Nodes in each area have detailed area topology; they only know direction (shortest path) to networks in other areas.
- Area Border routers: “summarize” distances to networks in the area and advertise them to other Area Border routers.
- Backbone routers: run an OSPF routing algorithm limited to the backbone.
- Boundary routers: connect to other ASs.

Areas

- An AS (or Routing Domain) is divided into areas.
- Group of routers
- “Close” to each other.
- Reduce the extend of LSA flooding
- Intra-area traffic
- Inter-area traffic
- External traffic: injected from a different AS
- OSPF requires a backbone area (Area 0)
  - Routing between areas only via backbone area
  - Strict area hierarchy (no loops allowed)

Area Partitions

- Link and router failures can cause areas to be partitioned
- Some partitions are healed automatically
- Some need manual intervention.
  - Virtual Links.
- Isolated area: link failure results in no path to the rest of the network
  - Obviously, cannot be healed at all.
  - Redundancy is important!

OSPF: Summary

Neighbors	
Discovery	Multicast group
Maintenance	Hello protocol
Database	
Granularity	Link state advertisements (LSA)
Maintenance	LSA-updates flooding protocol
Synchronization	Synchronization protocol
Routing table	
Metric	Fixed values
Calculation	Local shortest path calculation