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

Routing tasks: OSPF

- Neighbor?
  - Discovery
  - Maintenance
- Database?
  - Granularity
  - Maintenance – updates
  - Synchronization
- Routing table?
  - Metric
  - Calculation
  - Update

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

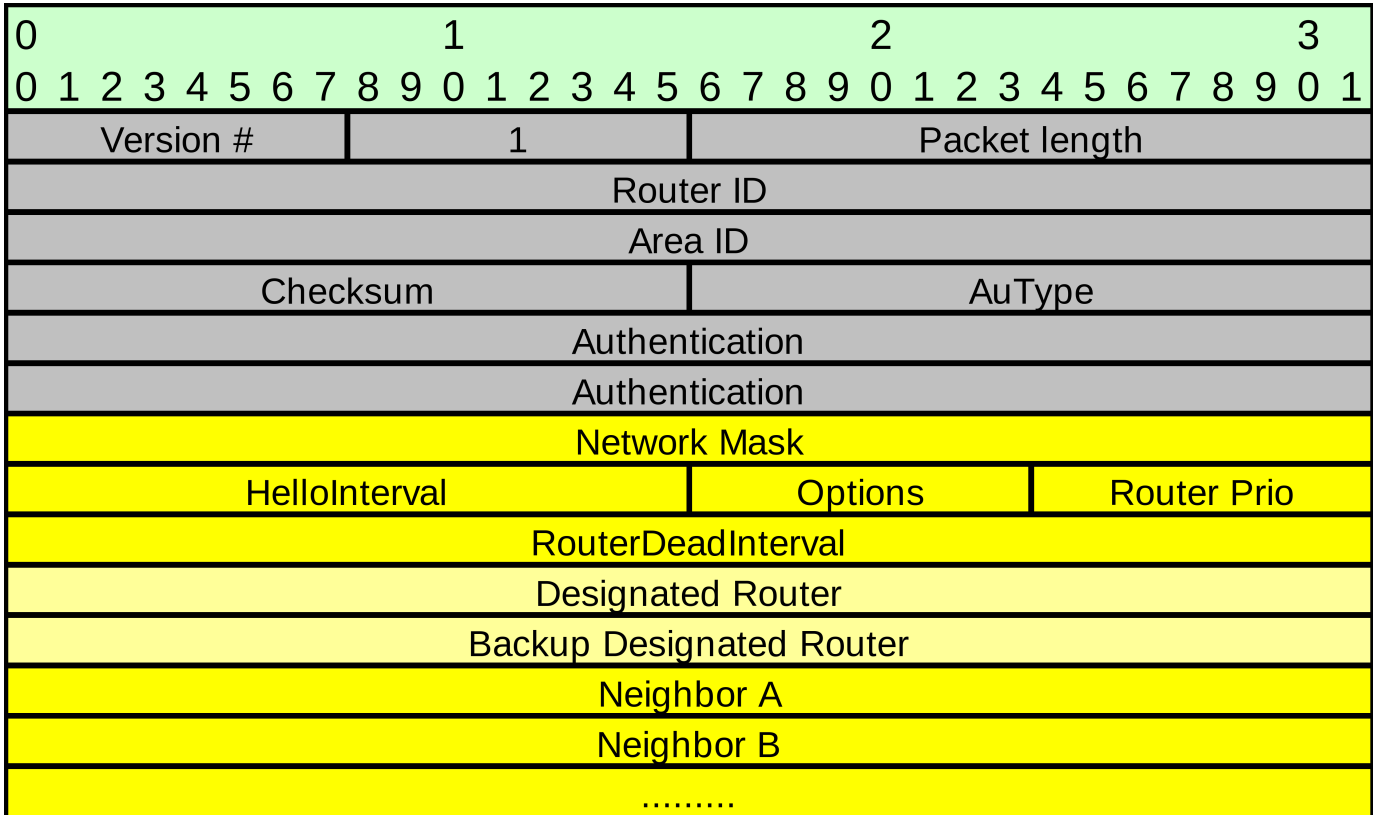
- FF02::5 and FF02::6, respectively for OSPFv3.

- 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



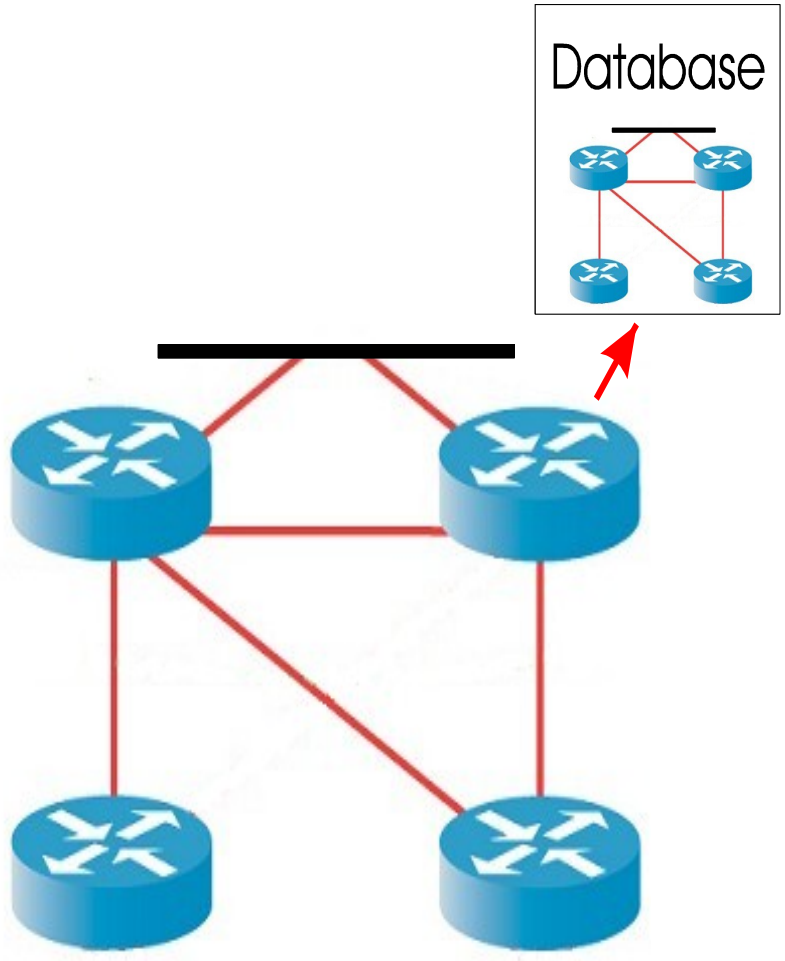
- Hello Interval: 10 seconds (typical default)
- RouterDeadInterval: 4 * Hello Interval (typical default)

OSPF packet

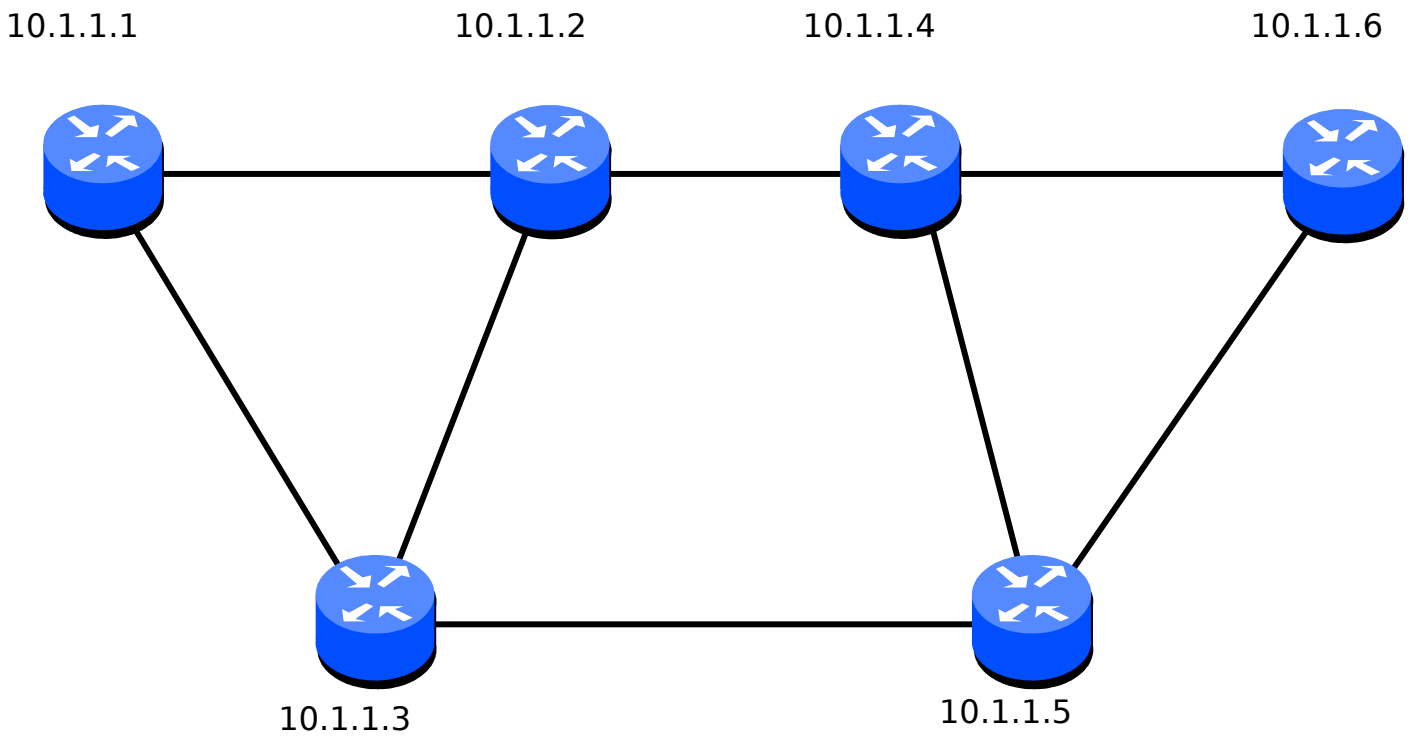
- IP Protocol #89
- Directly to neighbors using Multicast address TTL 1
- Five packet types
  - Hello
  - Database Description
  - Link State Request
  - Link State Update
  - Link State Acknowledgement

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

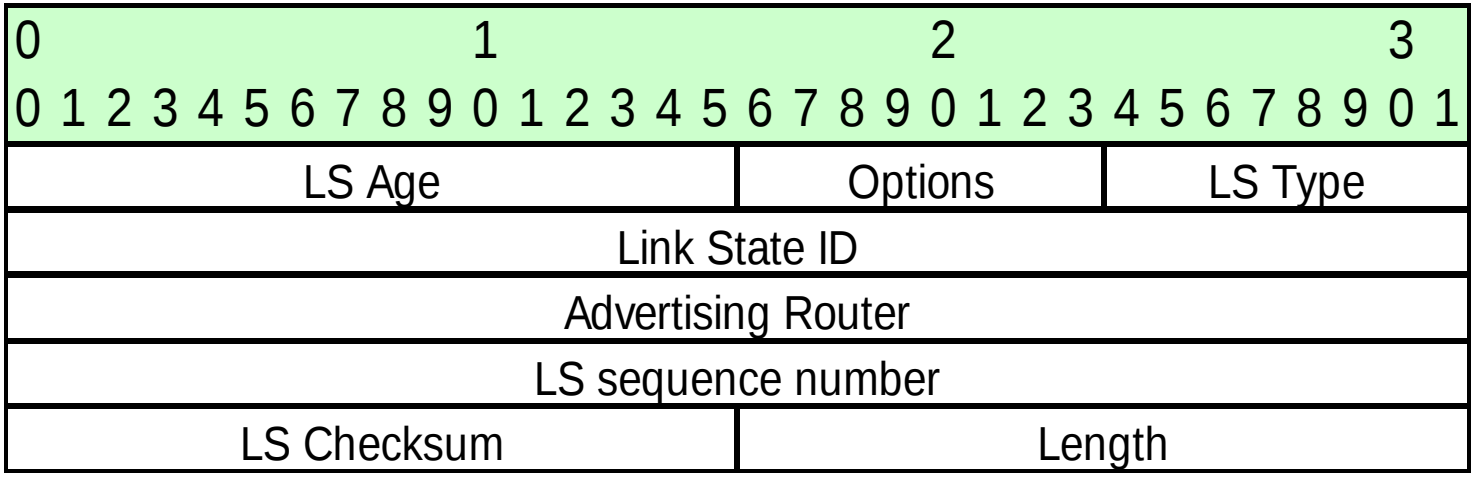


Link state database: Example

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



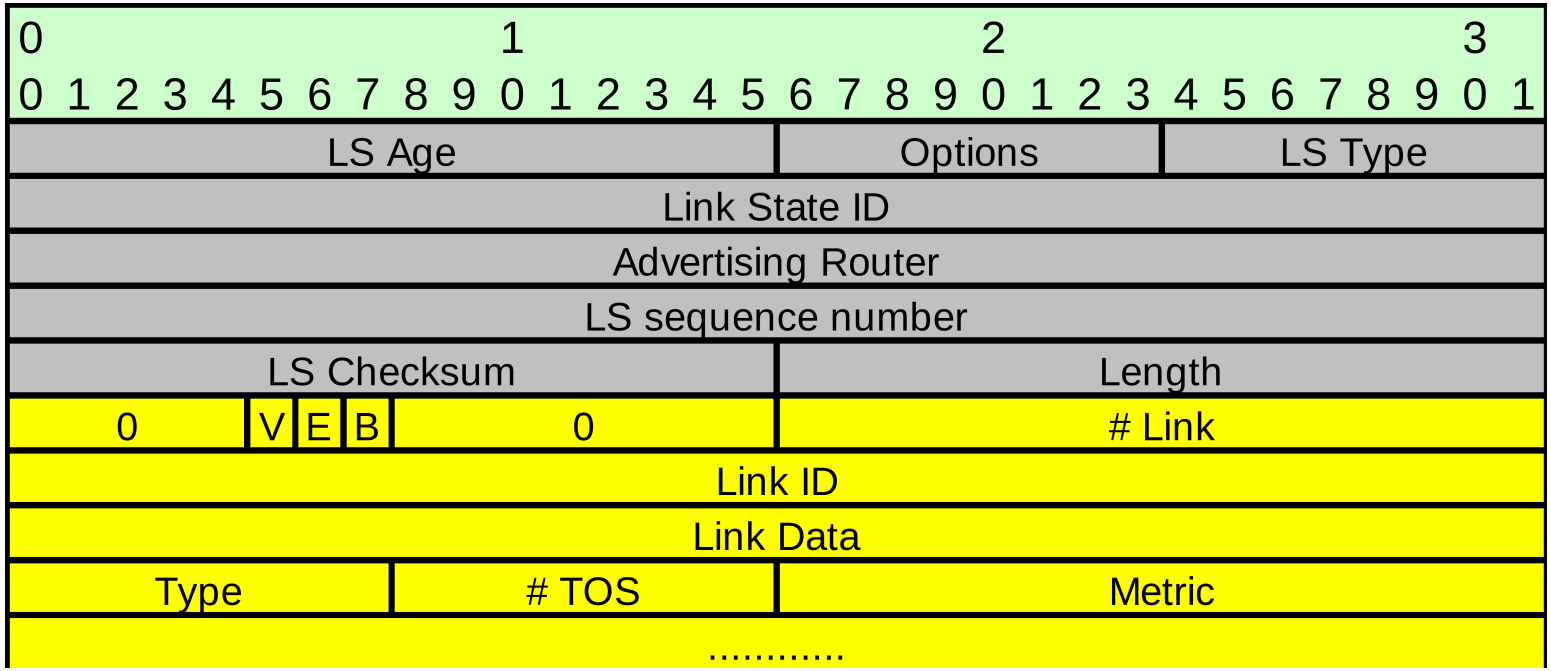
LSAs (2.)

- 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.)

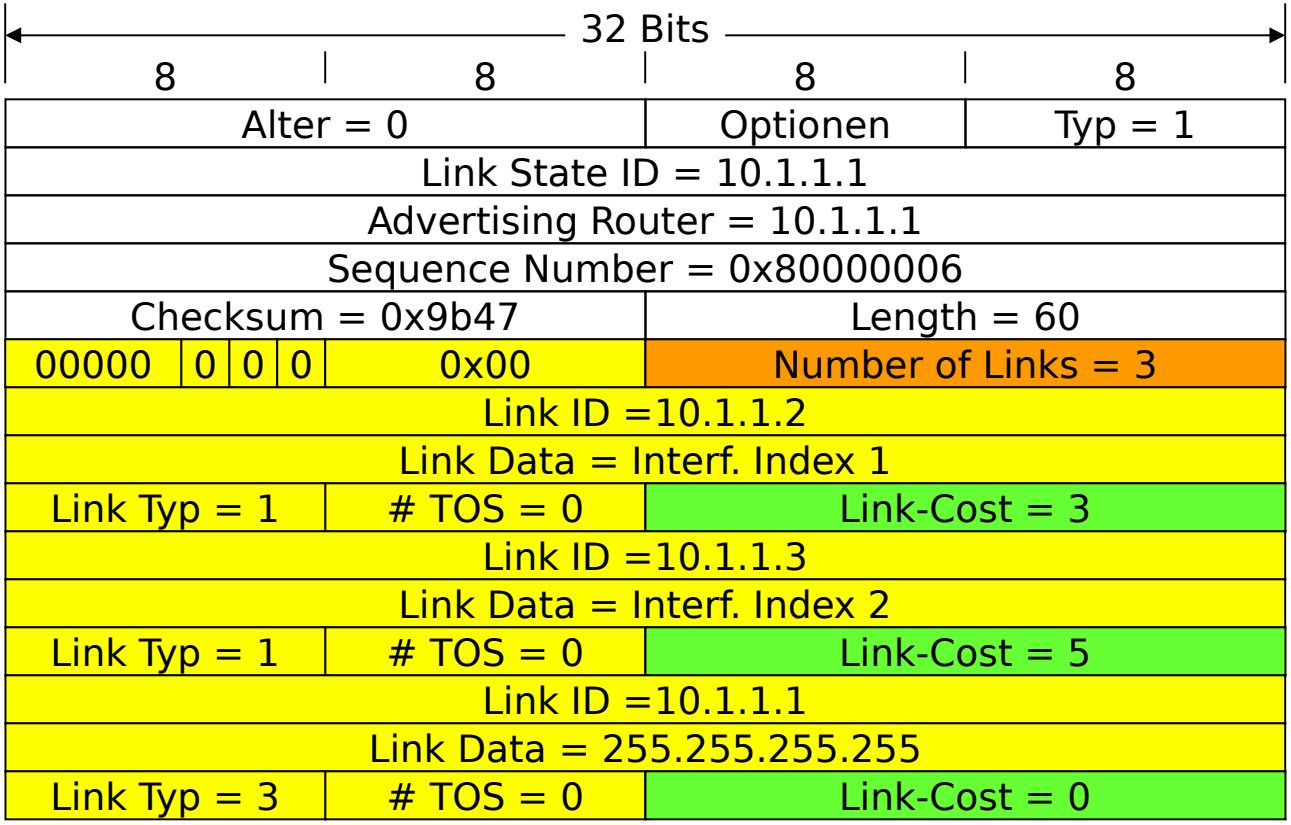
- LS Age Field
  (to ensure consistency)
  - Goal: new sequence number every 30 minutes
  - Maximum value 1 hour
  - Age > 1 hour ⇒ invalid ⇒ removal
  - Enables premature aging
  - Ensures removal of outdated information

Example LSA: Router-LSA



Example: Router LSA

- Link-Cost: Integers (configured)



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

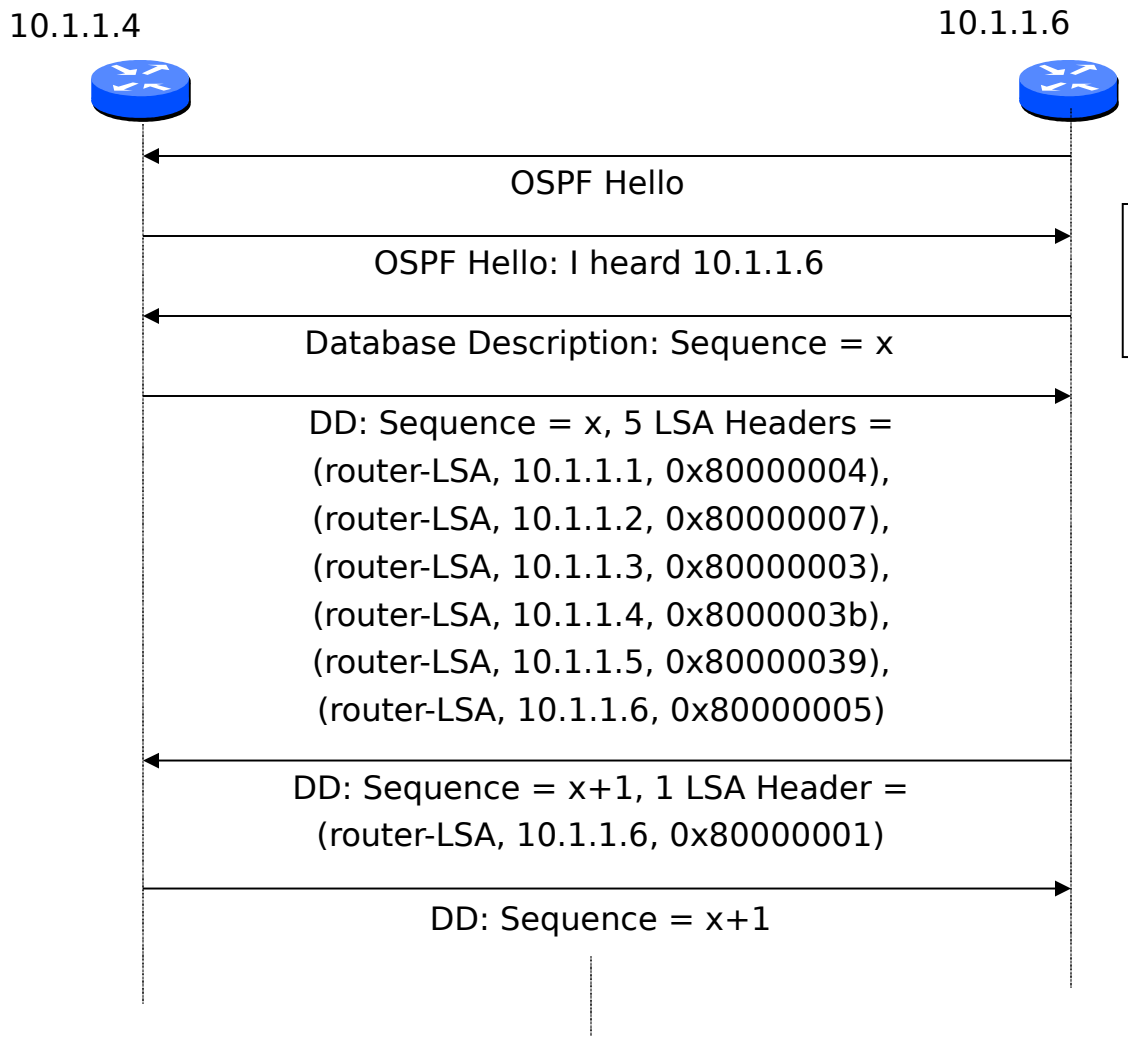
Initial synchronization

- 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.)

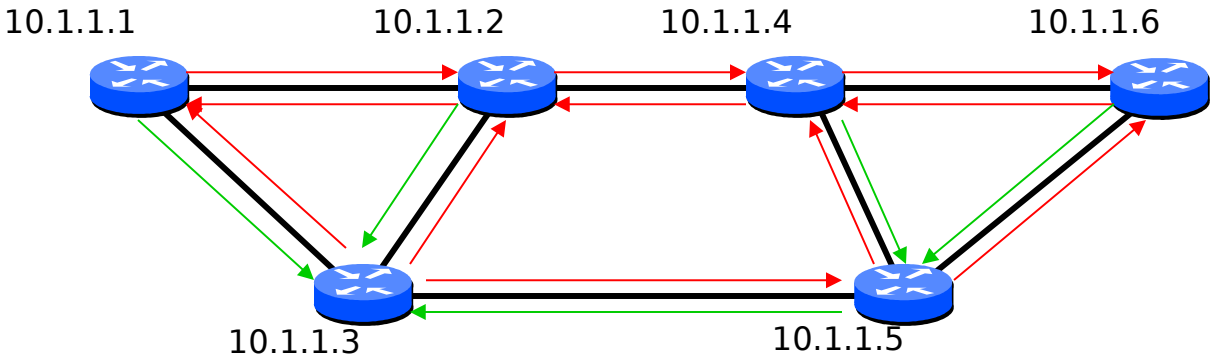
- Database description (DD) exchange
  - Only one DD at a time
  - Wait for Ack
- Control of DD exchange
  - Determine Master/Slave for DD exchange
  - Determine which LSA’s are missing in own DB
  - Request those via link state request packets
  - Neighbor sends these in link state update packets
- Result:
  - Fully adjacent OSPF neighbors

Example: Database synchronization



- 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 Ack‘s
- All LSA‘s 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

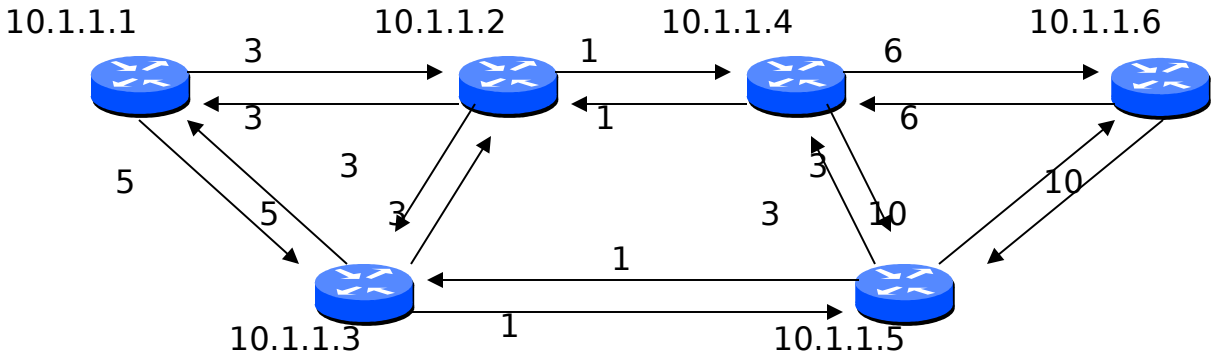
OSPF LSA timers

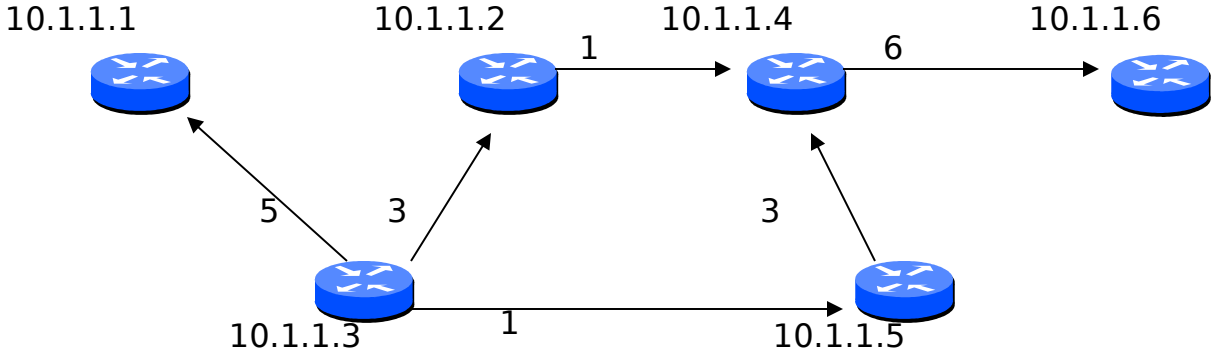
- MinLSArrival 1 second
- MinLSInterval 5 seconds
- CheckAge 5 minutes
- MaxAgeDiff 15 minutes
- LSRefreshTime 30 minutes
- MaxAge 1 hour

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





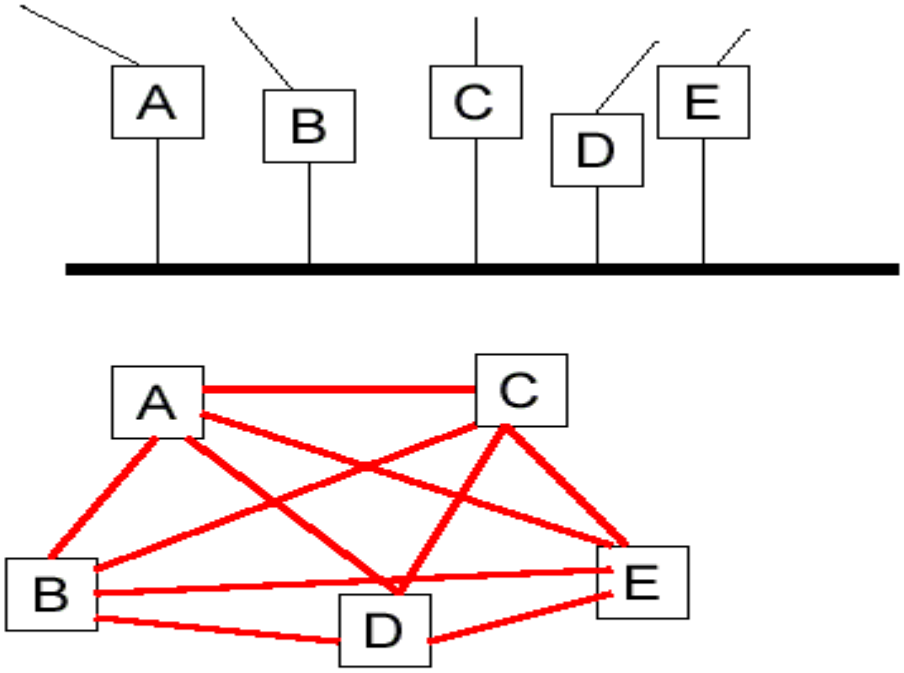
10.1.1.4 (4, 10.1.1.5/2)
10.1.1.1 (5, 10.1.1.1)
10.1.1.6 (11, 10.1.1.5)

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)

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*-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

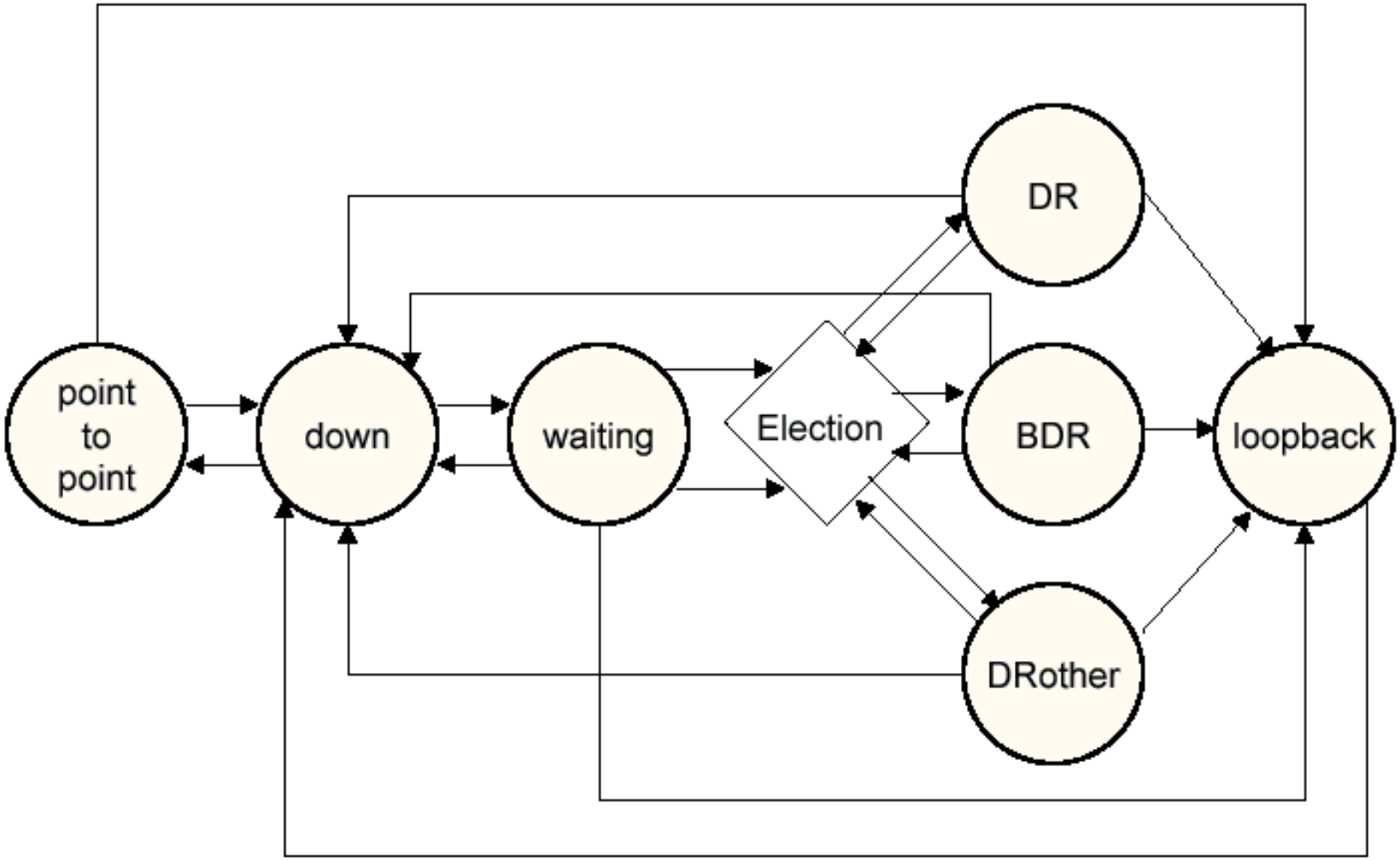
Designated router election

- 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

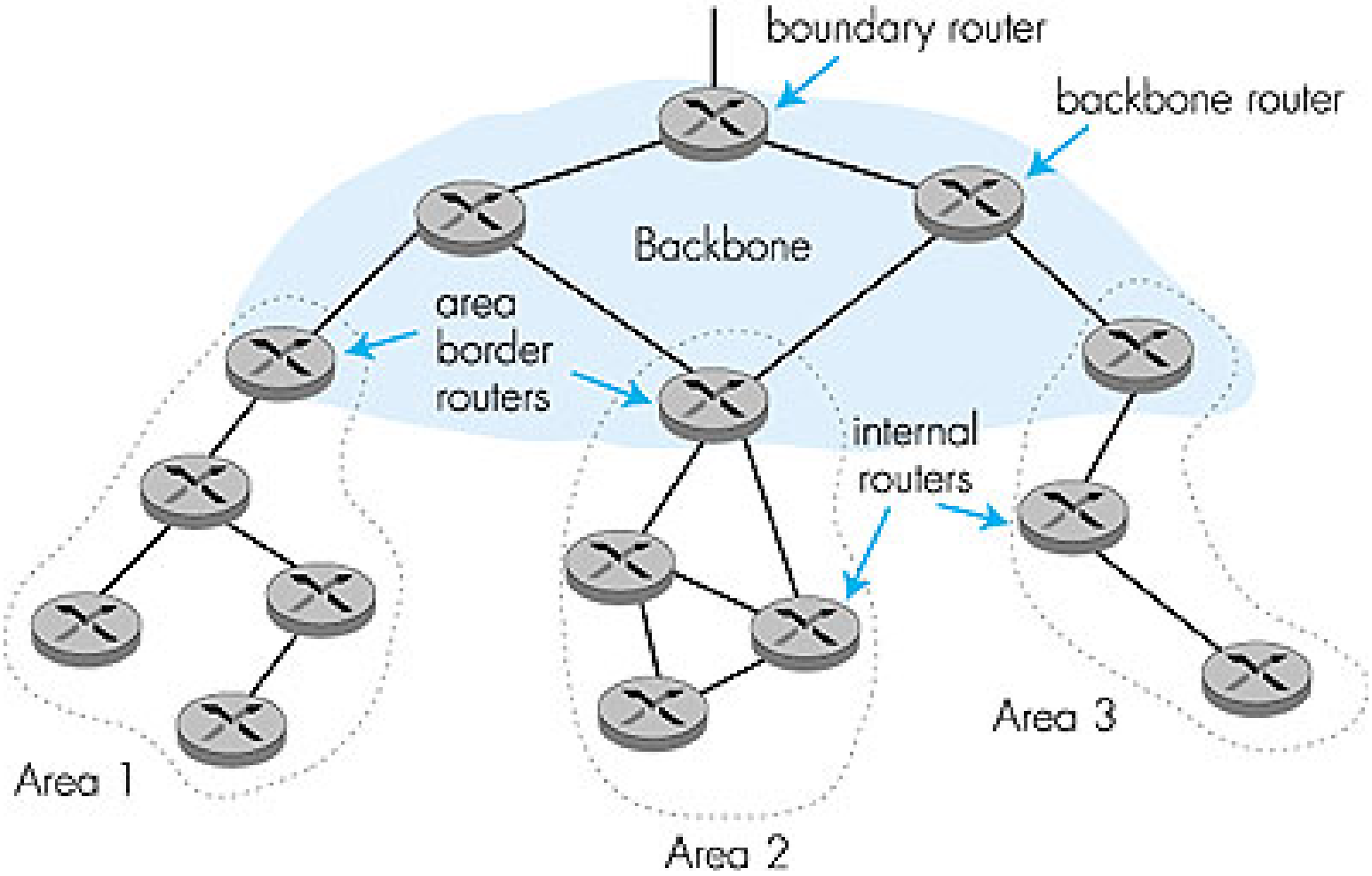
Network LSA‘s

- 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

OSPF interface state machine



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 “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 for large domains

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

How to set link weights?

Oscillations possible:

- E.g., link cost = amount of carried traffic