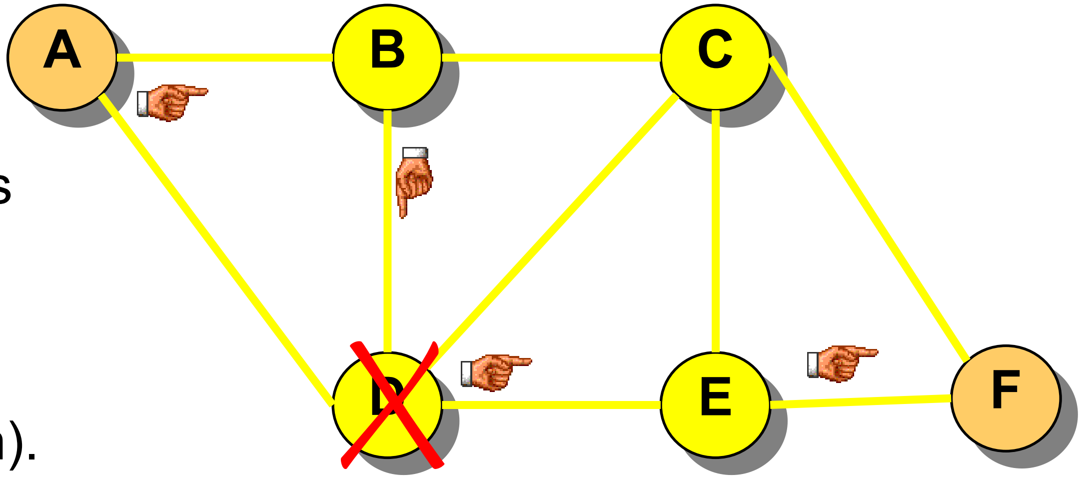
Dynamic Routing Protocols II
OSPF

Relates to Lab 4. This module covers link state routing and the Open Shortest Path First (OSPF) routing protocol.

Distance Vector vs. Link State Routing

- With distance vector routing, each node has information only about the next hop:
    - Node A: to reach F go to B
    - Node B: to reach F go to D
    - Node D: to reach F go to E
    - Node E: go directly to F

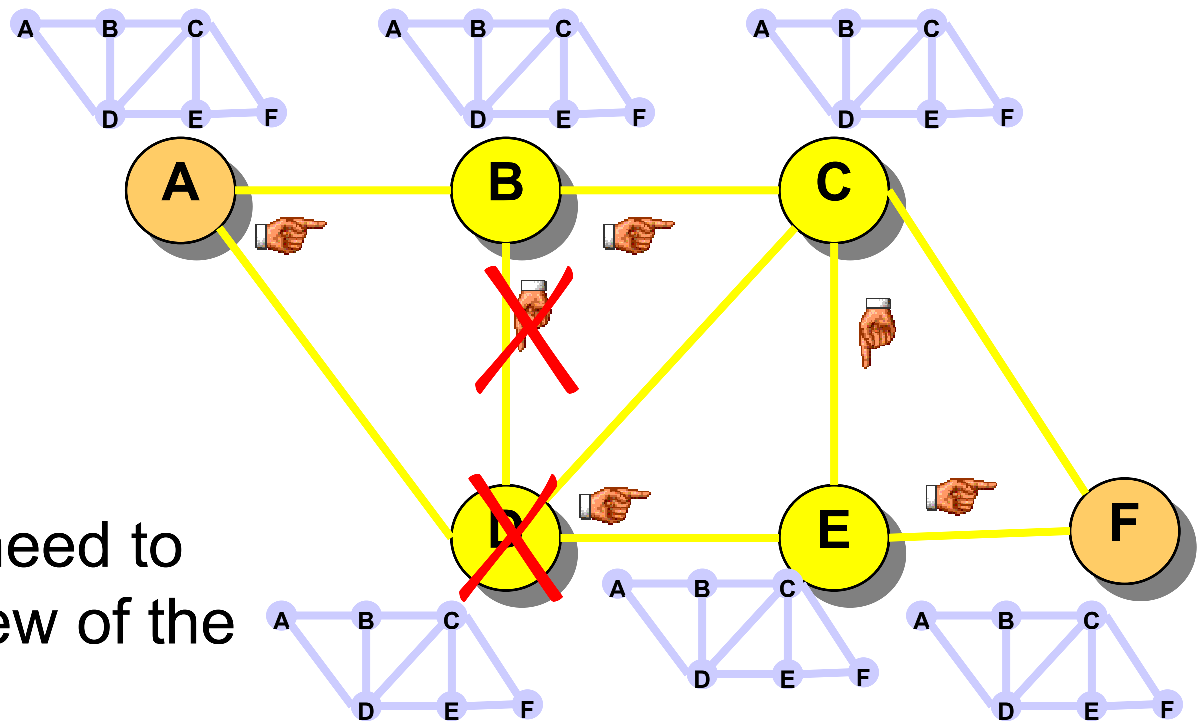


- Distance vector routing makes poor routing decisions if directions are not completely correct
(e.g., because a node is down).

- If parts of the directions incorrect, the routing may be incorrect until the routing algorithms has re-converged.

Distance Vector vs. Link State Routing

- In link state routing, each node has a complete map of the topology
- If a node fails, each node can calculate the new route
- Difficulty: All nodes need to have a consistent view of the network



Link State Routing: Properties

- *Each node requires complete topology information*
- *Link state information must be flooded to all nodes*
- *Guaranteed to converge*

Link State Routing: Basic princples

1. Each router establishes a relationship *(“adjacency”)* with its neighbors

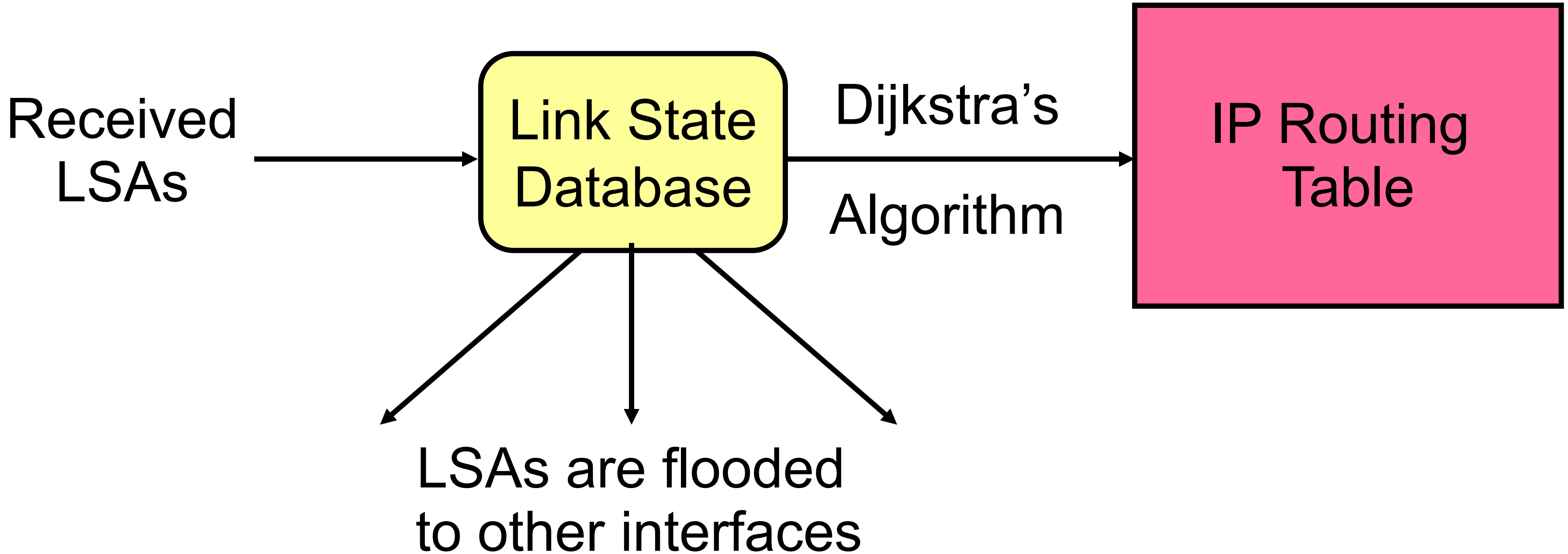
2. Each router generates *link state advertisements (LSAs)* which are distributed to all routers

   LSA = (link id, state of the link, cost, neighbors of the link)

3. Each router maintains a database of all received LSAs (*topological database* or *link state database*), which describes the network has a graph with weighted edges.

4. Each router ***uses its link state database to run a shortest path algorithm (Dijikstra’s algorithm)*** to produce the shortest path to each network.

Operation of a Link State Routing protocol



Dijkstra's Shortest Path Algorithm for a Graph

Input: Graph (N, E) with

N the set of nodes and $E \subseteq N \times N$ the set of edges

d_{vw} link cost (d_{vw} = infinity if $(v,w) \notin E$, $d_{vv} = 0$)

s source node.

Output: D_n cost of the least-cost path from node s to node n

```
M = {s};

for each  n ∉ M
      D_n  = d_sn;
while (M ≠ all nodes) do
      Find w ∉ M for which D_w = min{D_j ; j ∉ M};
      Add w to M;
      for each  n ∉ M
            D_n = min_w [ D_n, D_w + d_wn ];
            Update route;
enddo
```

OSPF

- OSPF = Open Shortest Path First
- The OSPF routing protocol is the most important link state routing protocol on the Internet
- The complexity of OSPF is significant

- History:
  - 1989: RFC 1131 OSPF Version 1
  - 1991: RFC1247 OSPF Version 2
  - 1994: RFC 1583 OSPF Version 2 (revised)
  - 1997: RFC 2178 OSPF Version 2 (revised)
  - 1998: RFC 2328 OSPF Version 2 (current version)

Features of OSPF

- ***Provides authentication of routing messages***

- ***Enables load balancing by allowing traffic to be split evenly across routes with equal cost***

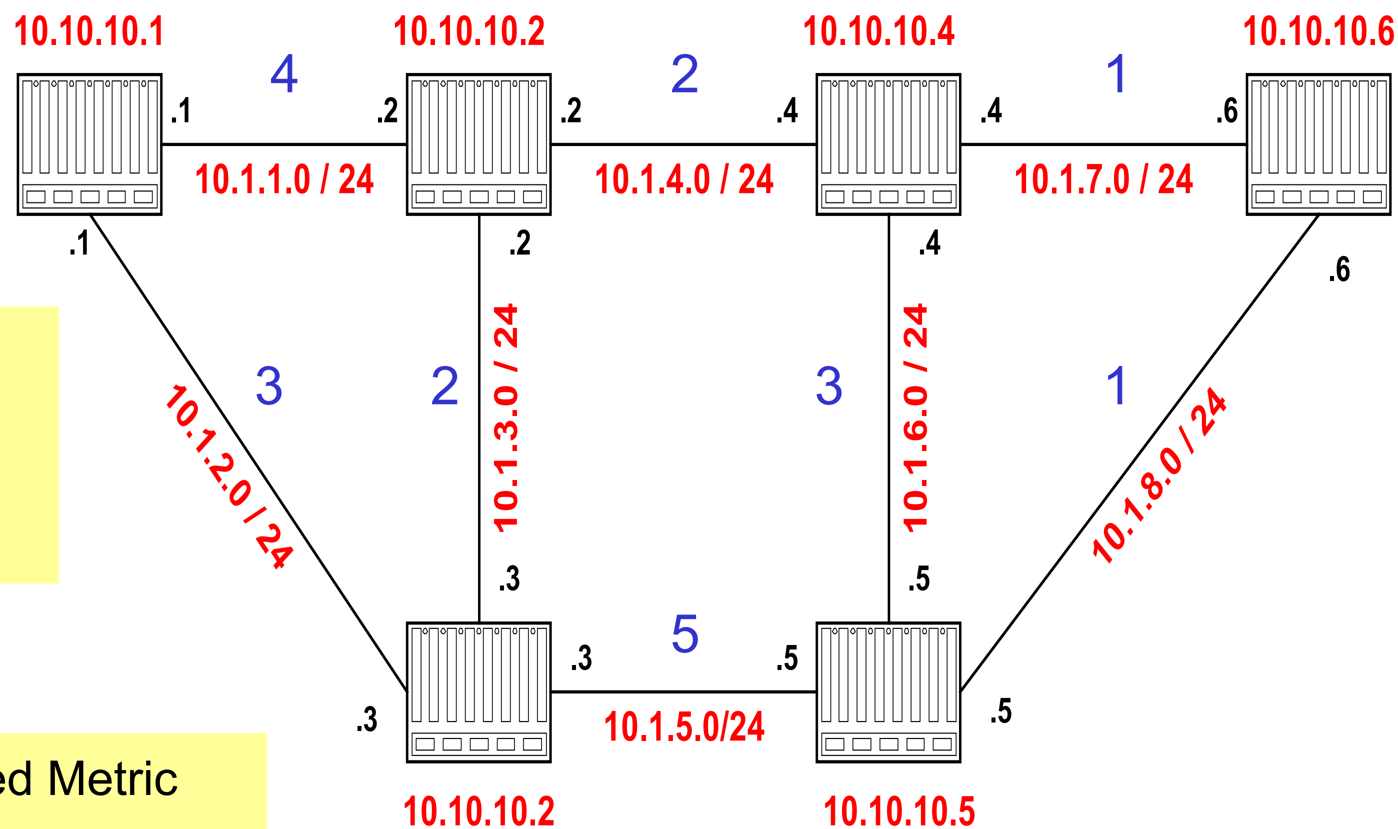
- ***Type-of-Service routing allows to setup different routes dependent on the TOS field***

- ***Supports subnetting***

- ***Supports multicasting***

- ***Allows hierarchical routing***

Example Network

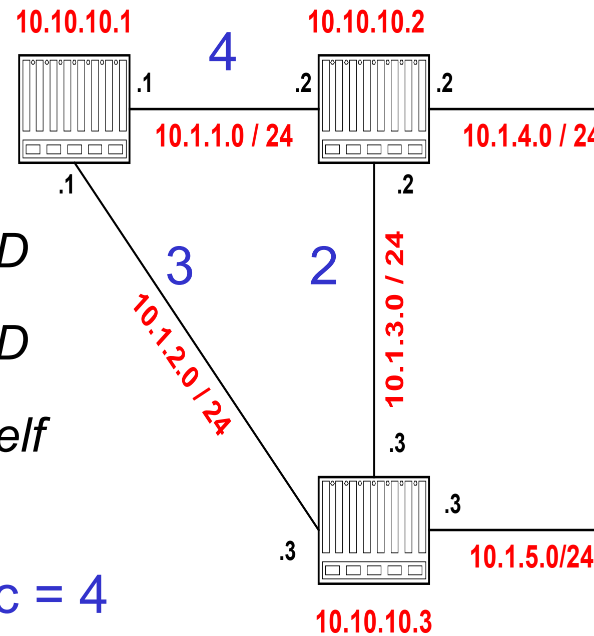


Router IDs are selected independent of interface addresses

- Link costs are called Metric
- Metric is in the range [0 , 2^{16}]
- Metric can be asymmetric

Link State Advertisement (LSA)

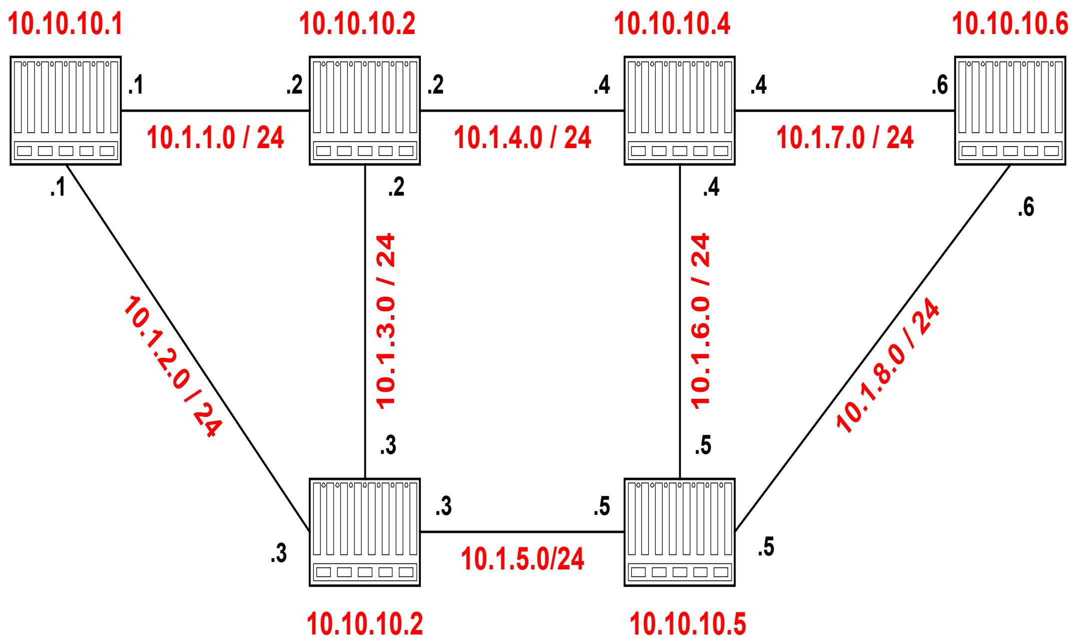
- **The LSA of router 10.10.10.1 is as follows:**
- **Link State ID:** 10.10.10.1 = *Router ID*
- **Advertising Router:** 10.10.10.1 = *Router ID*
- **Number of links:** 3 = *2 links plus router itself*
- **Description of Link 1:** Link ID = 10.1.1.1, Metric = 4
- **Description of Link 2:** Link ID = 10.1.2.1, Metric = 3
- **Description of Link 3:** Link ID = 10.10.10.1, Metric = 0



Each router sends its LSA to all routers in the network (using a method called reliable flooding)

Network and Link State Database

Each router has a database which contains the LSAs from all other routers



LS Type	Link StateID	Adv. Router	Checksum	LS SeqNo	LS Age
Router-LSA	10.1.10.1	10.1.10.1	0x9b47	0x80000006	0
Router-LSA	10.1.10.2	10.1.10.2	0x219e	0x80000007	1618
Router-LSA	10.1.10.3	10.1.10.3	0x6b53	0x80000003	1712
Router-LSA	10.1.10.4	10.1.10.4	0xe39a	0x8000003a	20
Router-LSA	10.1.10.5	10.1.10.5	0xd2a6	0x80000038	18
Router-LSA	10.1.10.6	10.1.10.6	0x05c3	0x80000005	1680

Link State Database

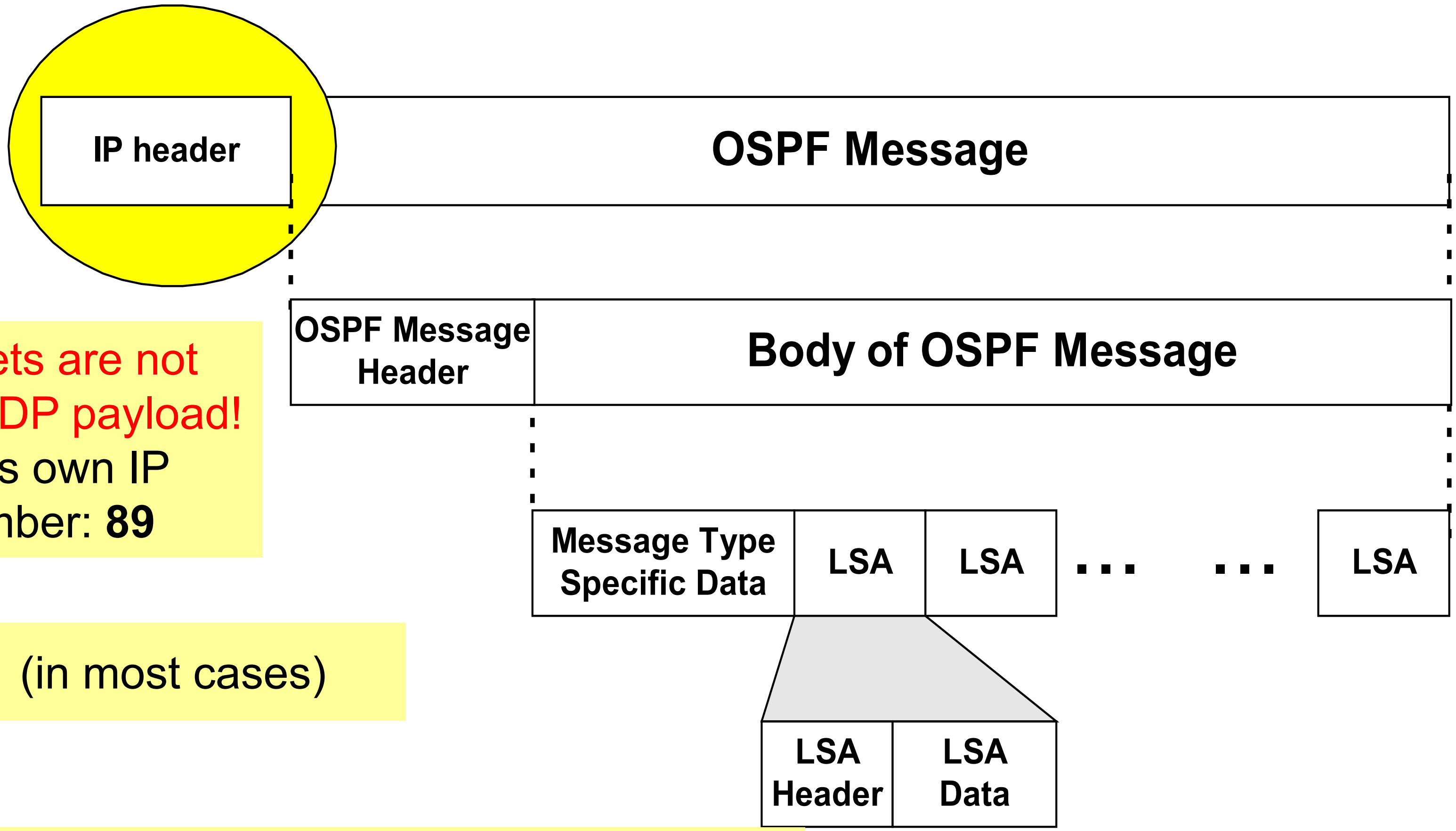
- The collection of all LSAs is called the link-state database

- Each router has an identical link-state database
  - Useful for debugging: Each router has a complete description of the network

- If neighboring routers discover each other for the first time, they will exchange their link-state databases

- The link-state databases are synchronized using reliable flooding

OSPF Packet Format

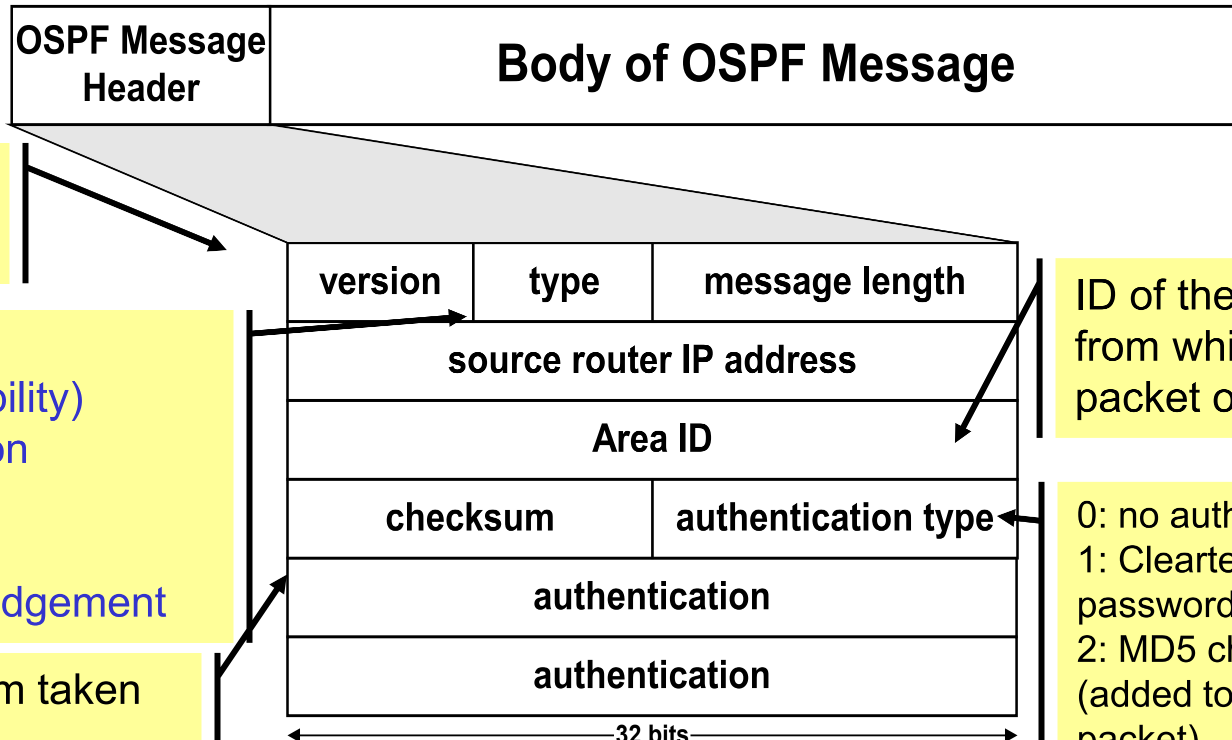


OSPF packets are not carried as UDP payload! OSPF has its own IP protocol number: **89**

TTL: set to 1 (in most cases)

Destination IP: neighbor's IP address or 224.0.0.5 (ALLSPFRouters) or 224.0.0.6 (AllDRouters)

OSPF Packet Format



2: current version is OSPF V2

Message types:
1: Hello (tests reachability)
2: Database description
3: Link Status request
4: Link state update
5: Link state acknowledgement

Standard IP checksum taken over entire packet

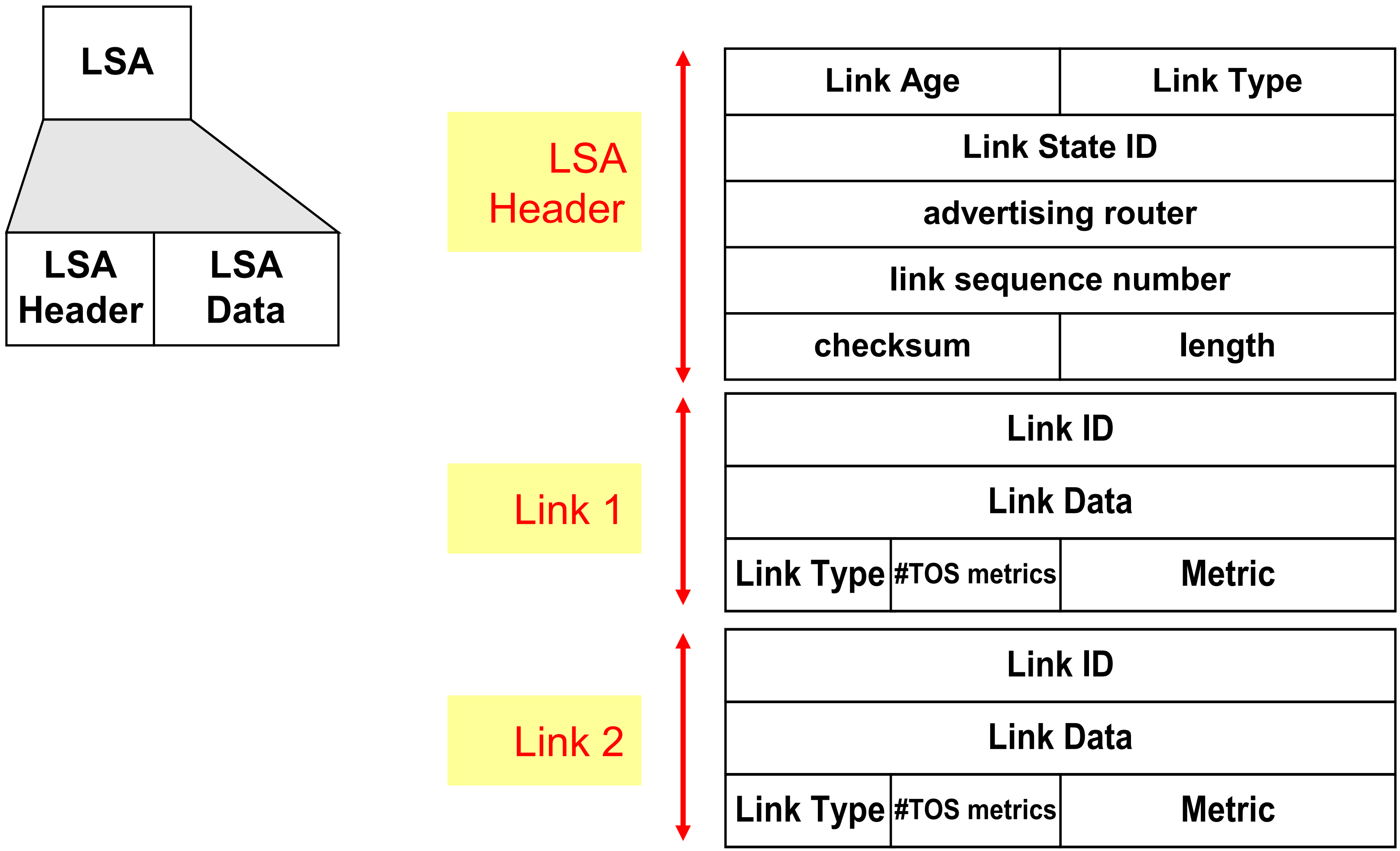
ID of the Area from which the packet originated

0: no authentication
1: Cleartext password
2: MD5 checksum (added to end packet)

Authentication passwd = 1: 64 cleartext password
Authentication passwd = 2: 0x0000 (16 bits)
KeyID (8 bits)
Length of MD5 checksum (8 bits)
Nondecreasing sequence number (32 bits)

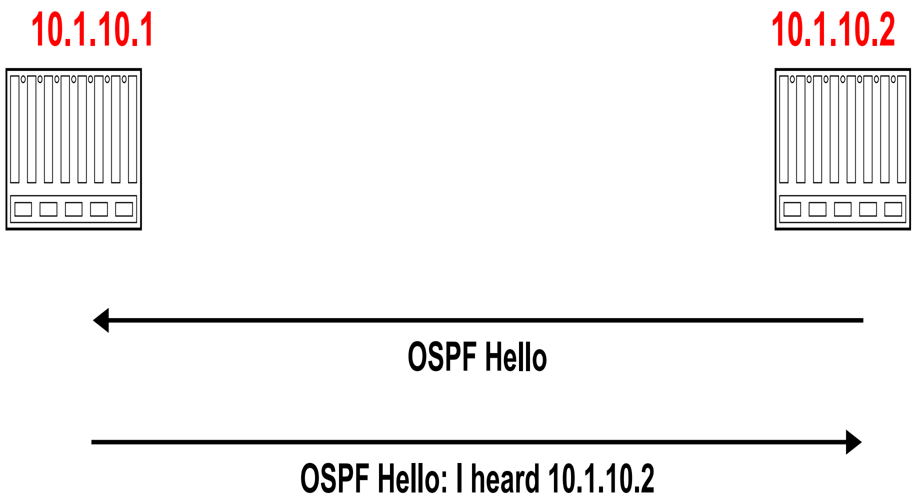
Prevents replay attacks

OSPF LSA Format



Discovery of Neighbors

- Routers multicasts OSPF Hello packets on all OSPF-enabled interfaces.
- If two routers share a link, they can become neighbors, and establish an adjacency



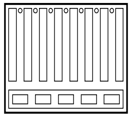
Scenario:
Router 10.1.10.2 restarts

- After becoming a neighbor, routers exchange their link state databases

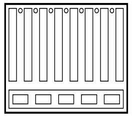
Neighbor discovery and database synchronization

Scenario:
Router 10.1.10.2 restarts

10.1.10.1



10.1.10.2



Discovery of adjacency

OSPF Hello (10.1.10.2 → 10.1.10.1)

OSPF Hello: I heard 10.1.10.2 (10.1.10.1 → 10.1.10.2)

After neighbors are discovered the nodes exchange their databases

Database Description: Sequence = X (10.1.10.2 → 10.1.10.1)

Sends empty database description

Database Description: Sequence = X, 5 LSA headers = (10.1.10.1 → 10.1.10.2)
Router-LSA, 10.1.10.1, 0x80000006
Router-LSA, 10.1.10.2, 0x80000007
Router-LSA, 10.1.10.3, 0x80000003
Router-LSA, 10.1.10.4, 0x8000003a
Router-LSA, 10.1.10.5, 0x80000038
Router-LSA, 10.1.10.6, 0x80000005

Sends database description. (description only contains LSA headers)

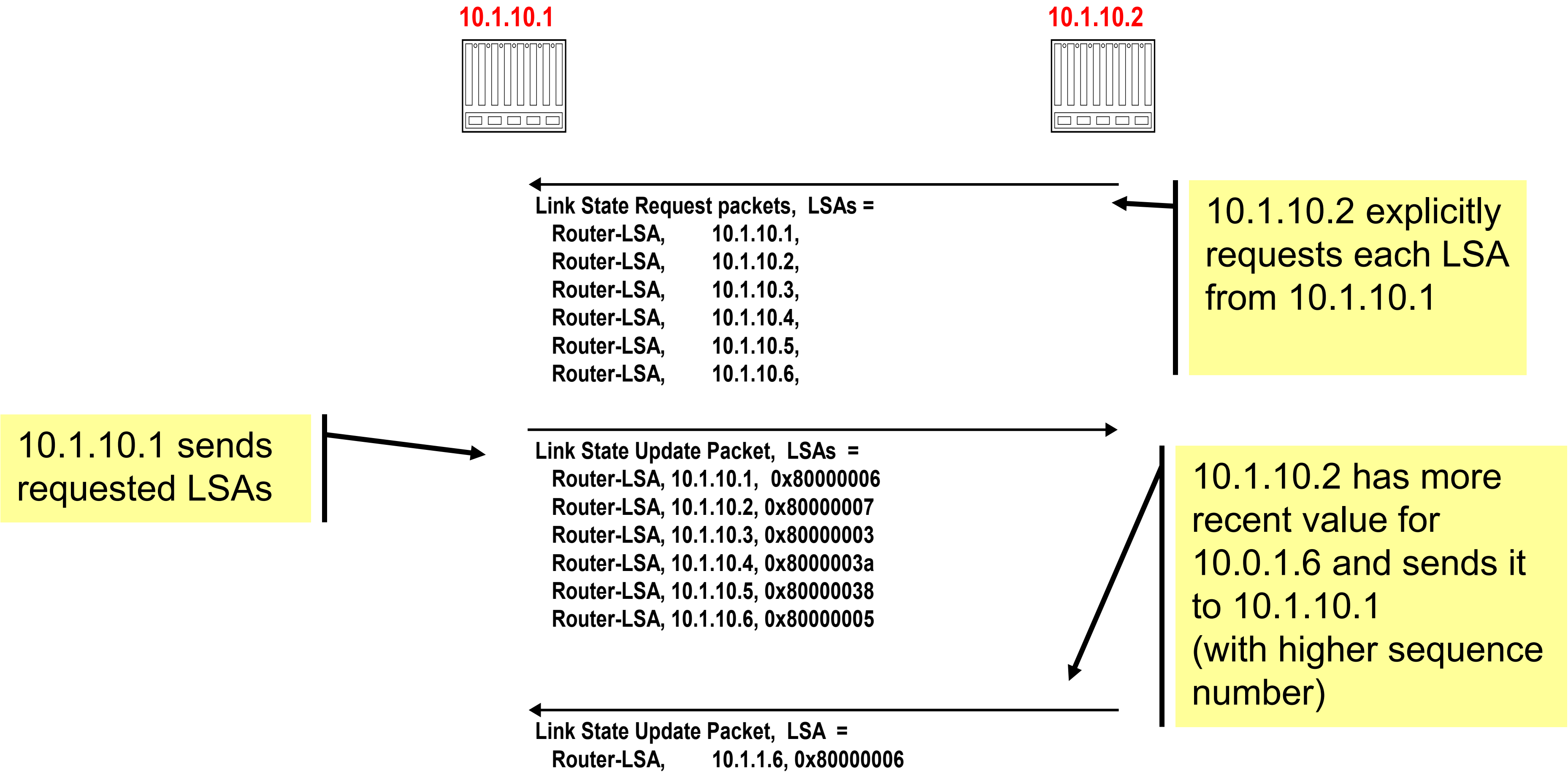
Database Description: Sequence = X+1, 1 LSA header= (10.1.10.2 → 10.1.10.1)
Router-LSA, 10.1.10.2, 0x80000005

Database description of 10.1.10.2

Database Description: Sequence = X+1 (10.1.10.1 → 10.1.10.2)

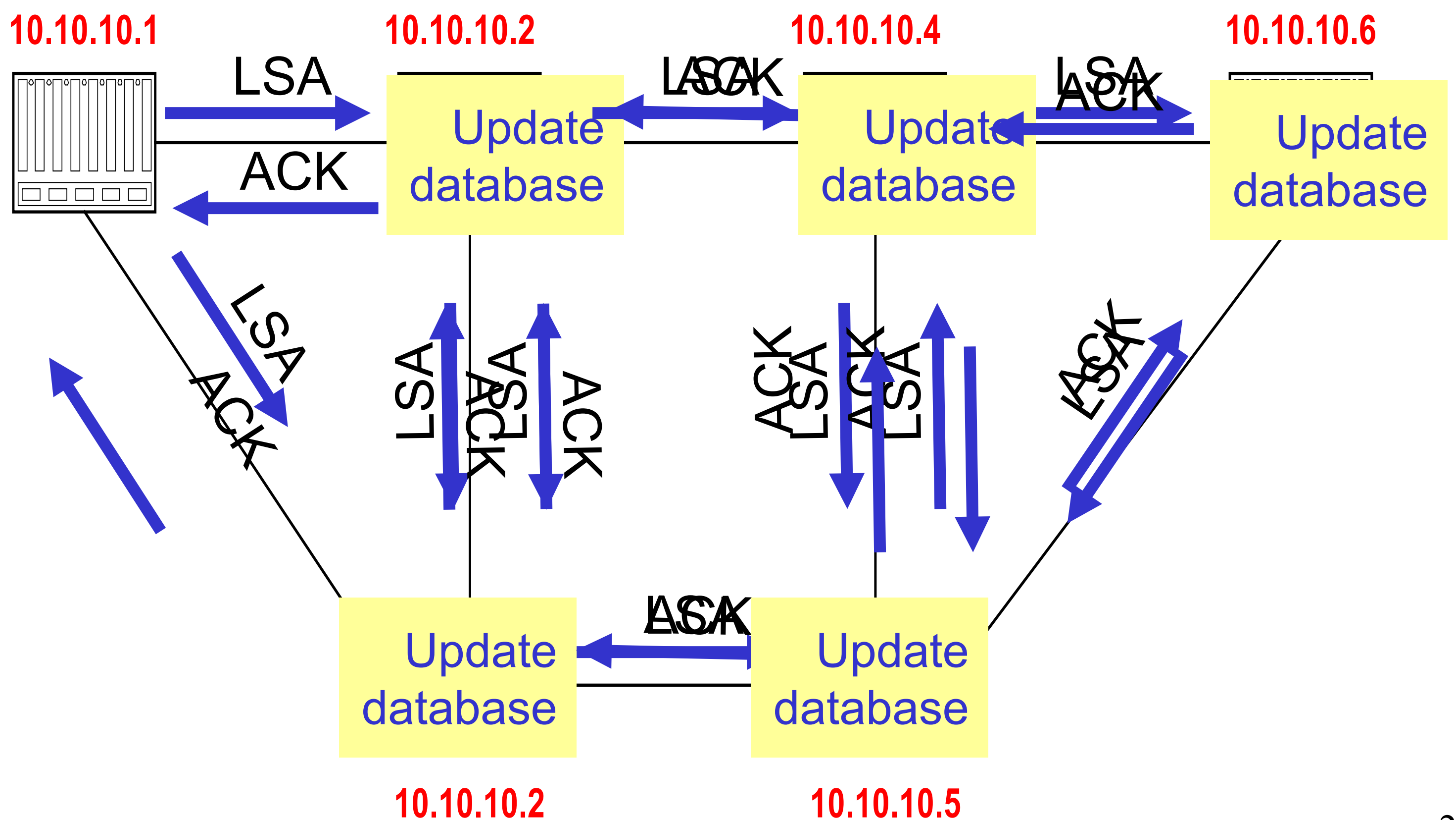
Acknowledges receipt of description

Regular LSA exchanges



Routing Data Distribution

- LSA-Updates are distributed to all other routers via **Reliable Flooding**
- **Example:** Flooding of LSA from 10.10.10.1



Dissemination of LSA-Update

- **A router sends and refloods LSA-Updates, *whenever the topology or link cost changes.*** (If a received LSA does not contain new information, the router will not flood the packet)

- Exception: Infrequently (every 30 minutes), a router will flood LSAs even if there are not new changes.

- Acknowledgements of LSA-updates:
  - explicit ACK, or
  - implicit via reception of an LSA-Update

OSPF versus RIP

- The rapid growth and expansion of modern networks has pushed Routing Information Protocol (RIP) to its limits.

- RIP has certain limitations that can cause problems in large networks

- ***RIP has a limit of 15 hops.*** A network that spans more than 15 hops (15 routers) is considered unreachable.

- ***RIP cannot handle Variable Length Subnet Masks (VLSM).*** Given the shortage of IP addresses and the flexibility VLSM gives in the efficient assignment of IP addresses, this is considered a major flaw.

OSPF versus RIP

- ***Periodic broadcasts of the full routing table consume a large amount of bandwidth.*** This is a major problem with large networks especially on slow links and WAN clouds.

- ***RIP converge is slower than OSPF.*** In large networks convergence gets to be in the order of minutes.

- RIP routers go through a period of a hold-down and garbage collection and slowly time-out information that has not been received recently. This is inappropriate in large environments and could cause routing inconsistencies.

OSPF versus RIP

- ***RIP has no concept of network delays and link costs. Routing decisions are based on hop counts.***

- ***RIP networks are flat networks.*** There is no concept of areas or boundaries. With the introduction of classless routing and the intelligent use of aggregation and summarization, RIP networks have fallen behind.

- Enhancements were introduced in a new version of RIP called RIP2. RIP2 addresses the issues of VLSM, authentication, and multicast routing updates.

OSPF versus RIP

- RIP2 is not a big improvement over RIP (now called RIP1) because it still has the limitations of hop counts and slow convergence which are essential in large networks.

OSPF versus RIP

- OSPF, on the other hand, addresses most of the issues previously presented:

- With OSPF, there is no limitation on the hop count.

- The intelligent use of VLSM is very useful in IP address allocation.

- **OSPF uses IP multicast to send link-state updates**.

- OSPF has better convergence than RIP.

OSPF versus RIP

- OSPF allows for better load balancing.

- OSPF allows for a logical definition of networks where routers can be divided into areas. This limits the explosion of link state updates over the whole network. This also provides a mechanism to aggregate routes and decrease the unnecessary propagation of subnet information.

- **OSPF allows for routing authentication through different methods of password authentication.**

OSPF versus RIP

- OSPF allows for the transfer and tagging of external routes injected into an Autonomous System. This keeps track of external routes injected by exterior protocols such as BGP.

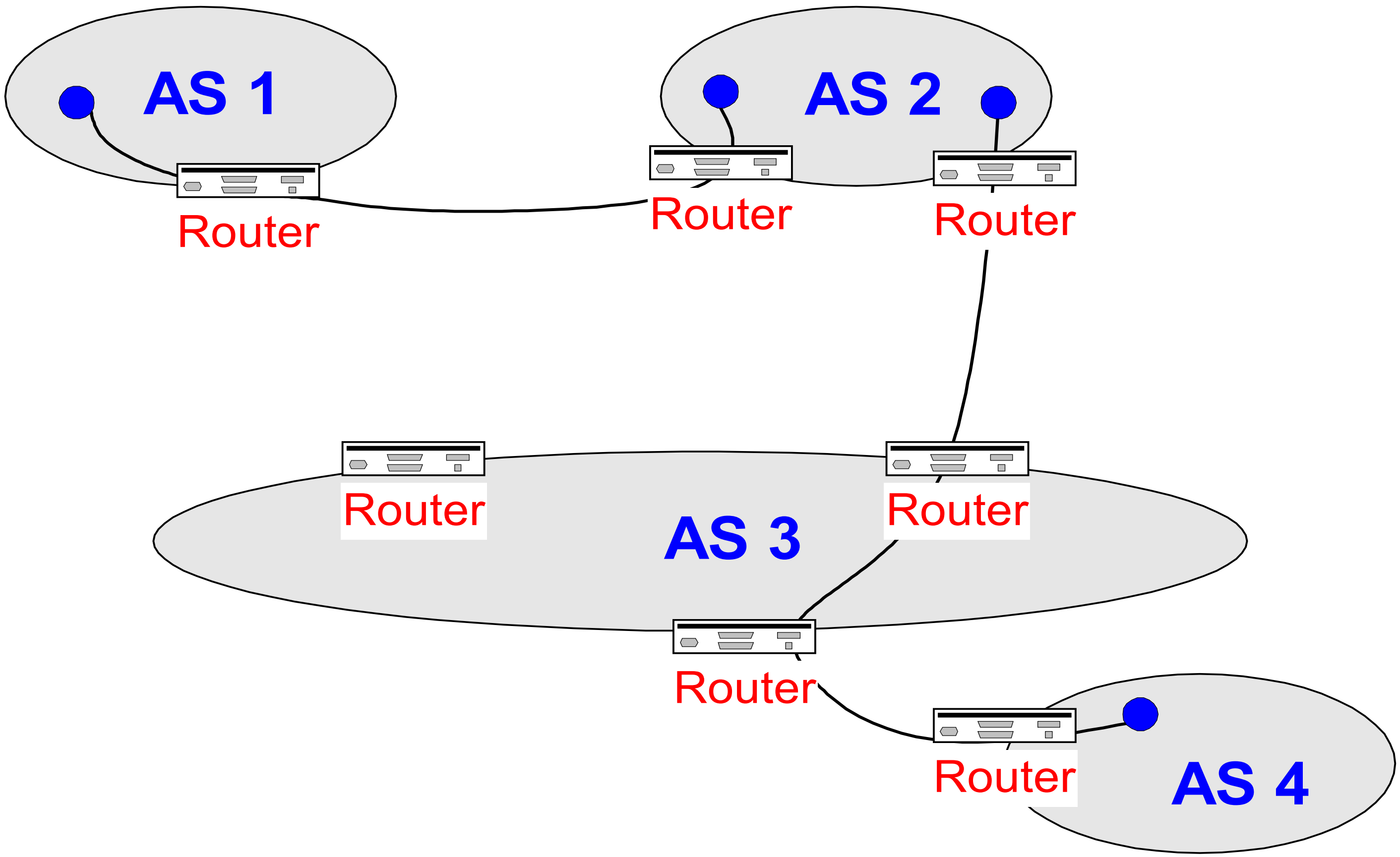
BGP

- BGP = Border Gateway Protocol
- Currently in version 4
- Note: In the context of BGP, a gateway is nothing else but an IP router that connects autonomous systems.
- Interdomain routing protocol for routing between autonomous systems
- Uses TCP to send routing messages
- BGP is neither a link state, nor a distance vector protocol. Routing messages in BGP contain complete routes.
- Network administrators can specify routing policies

BGP

- BGP’s goal is to find any path (not an optimal one). Since the internals of the AS are never revealed, finding an optimal path is not feasible.
- For each autonomous system (AS), BGP distinguishes:
  - **local traffic** = traffic with source or destination in AS
  - **transit traffic** = traffic that passes through the AS
  - **Stub AS** = has connection to only one AS, only carry local traffic
  - **Multihomed AS** = has connection to >1 AS, but does not carry transit traffic
  - **Transit AS** = has connection to >1 AS and carries transit traffic

BGP


AS 1
Router
AS 2
Router
Router
Router
AS 3
Router
Router
Router
AS 4