CompSci 356: Computer Network Architectures

Lecture 12: Dynamic routing protocols: Link State Chapter 3.3.3

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Today

- Routing Information Protocol
- Link-state routing
  - Algorithm
  - Protocol: Open shortest path first (OSPF)

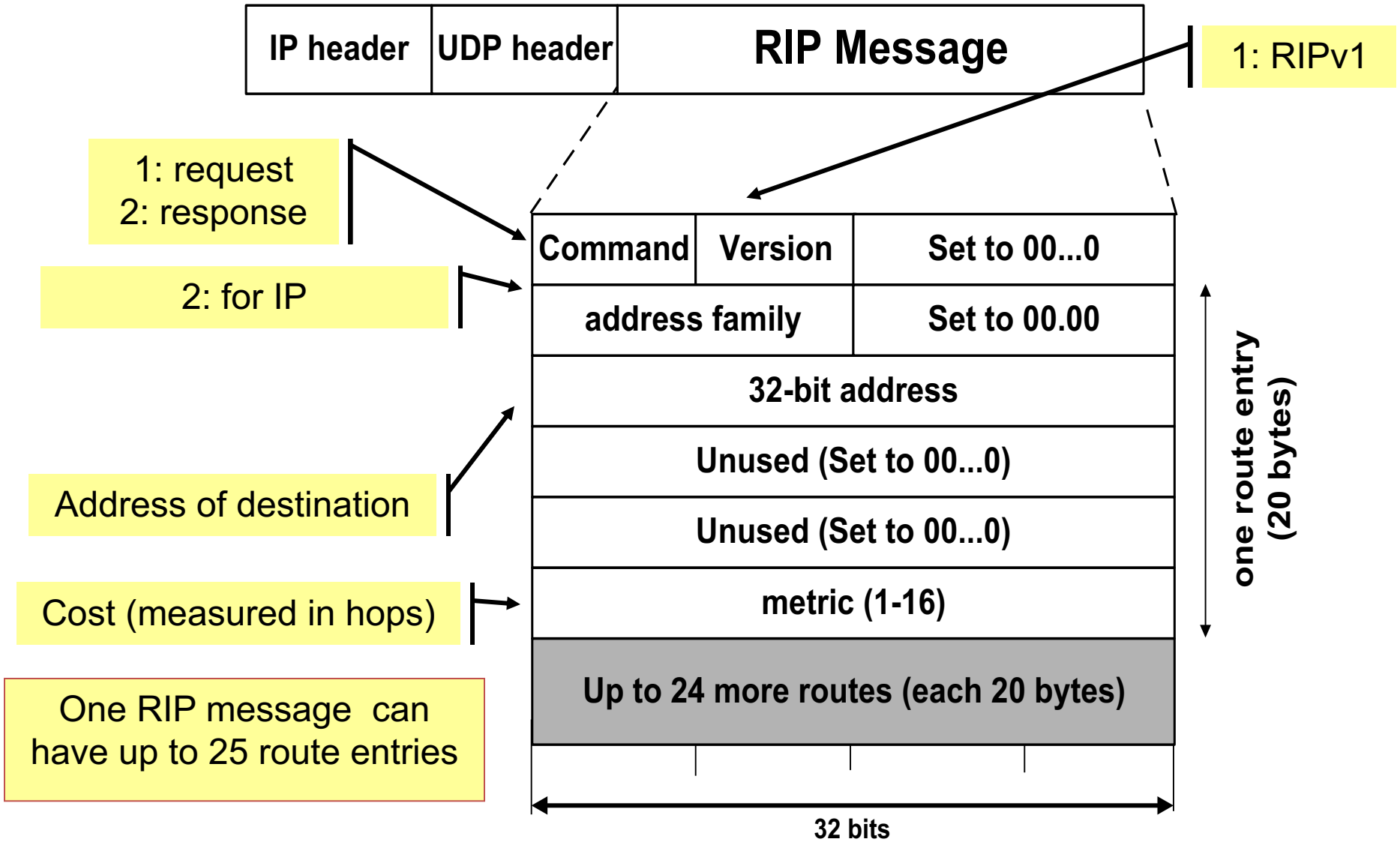
RIP - Routing Information Protocol

- A simple intra-domain protocol
- Straightforward implementation of Distance Vector Routing
- Each router advertises its distance vector every 30 seconds (or whenever its routing table changes) to all of its neighbors
- RIP always uses 1 as link metric
- Maximum hop count is 15, with “16” equal to “∞”
- Routes are timeout (set to 16) after 3 minutes if they are not updated

RIP - History

- Late 1960s : Distance Vector protocols were used in the ARPANET
- Mid-1970s: XNS (Xerox Network system) routing protocol is the ancestor of RIP in IP (and Novell's IPX RIP and Apple's routing protocol)
- 1982 Release of **routed** for BSD Unix
- 1988 RIPv1 (RFC 1058)
  - classful routing
- 1993 RIPv2 (RFC 1388)
  - adds subnet masks with each route entry
  - allows classless routing
- 1998 Current version of RIPv2 (RFC 2453)

RIPv1 Packet Format

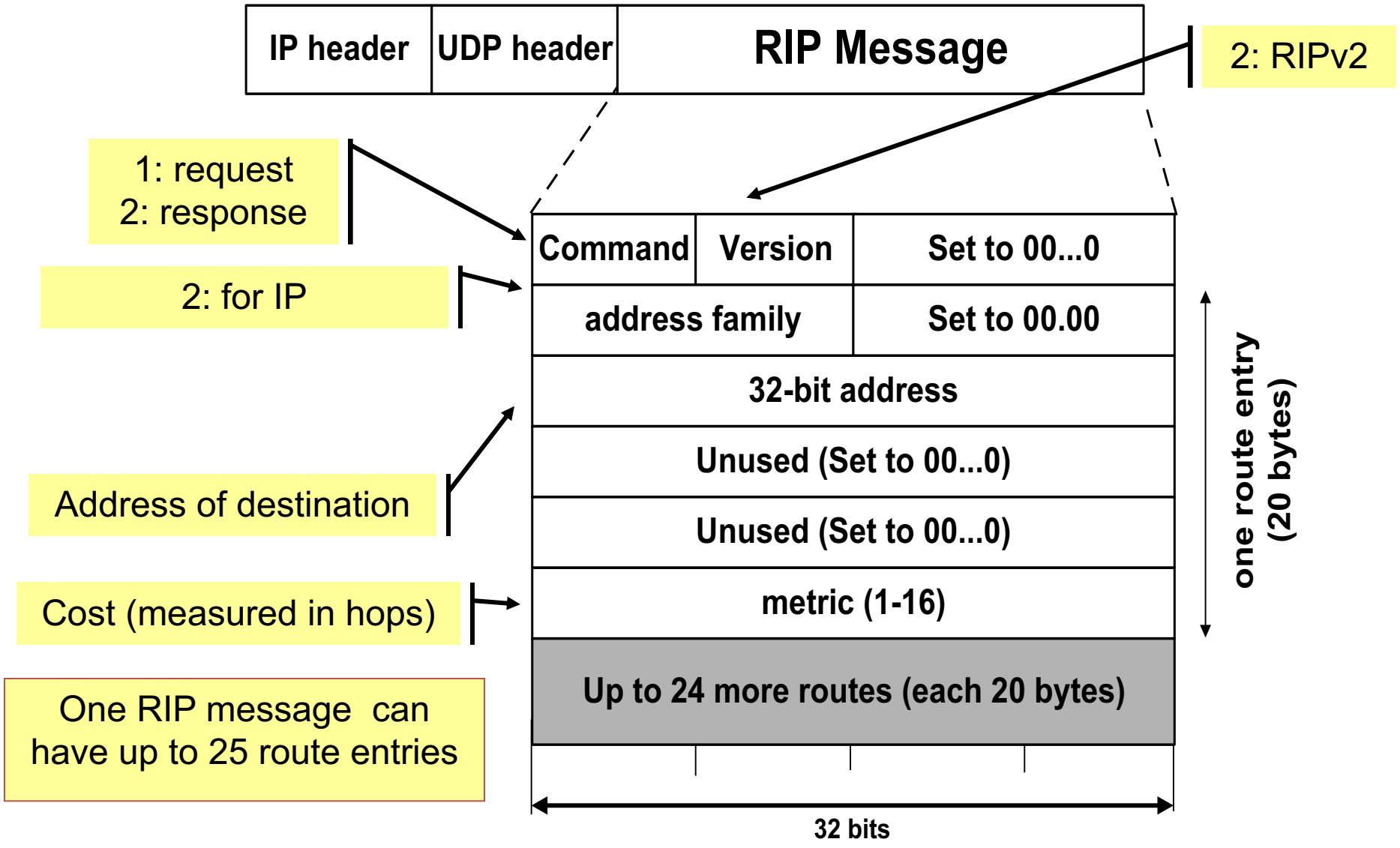


RIPv2

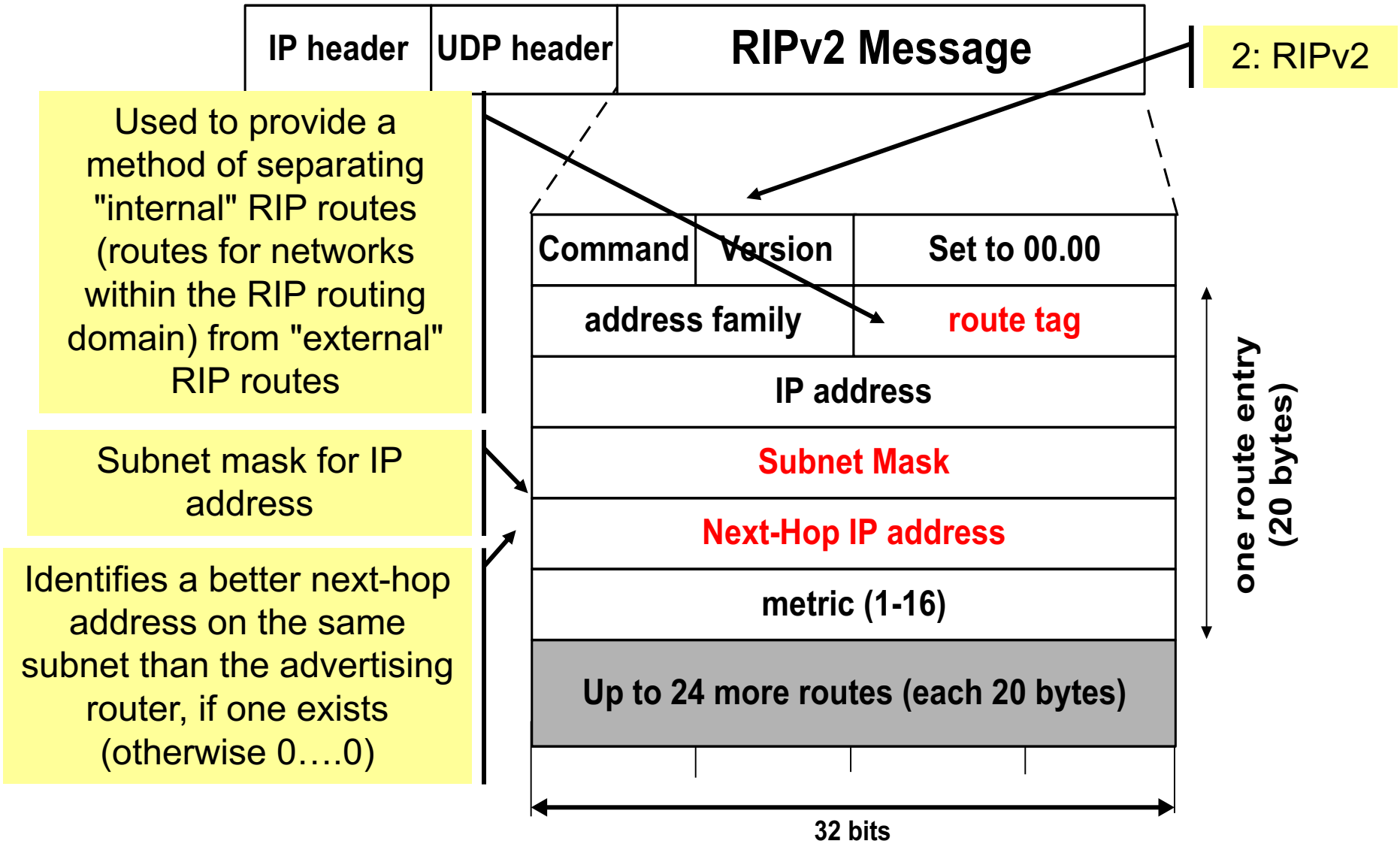
- RIPv2 extends RIPv1:
  - Subnet masks are carried in the route information
  - Authentication of routing messages
  - Route information carries next-hop address
  - Uses IP multicasting to send routing messages

- Extensions of RIPv2 are carried in unused fields of RIPv1 messages

RIPv2 Packet Format



RIPv2 Packet Format



RIP Messages

- This is the operation of RIP in **`routed`**. Dedicated port for RIP is UDP port 520.

- Two types of messages:
  - **Request messages**
    - used to ask neighboring nodes for an update
  - **Response messages**
    - contains an update

Routing with RIP

- **Initialization:** Send a **request packet** (command = 1, address family=0..0) on all interfaces:
    - RIPv1 uses broadcast if possible,
    - RIPv2 uses multicast address 224.0.0.9, if possible

  requesting routing tables from neighboring routers

- **Request received**: Routers that receive above request send their entire routing table

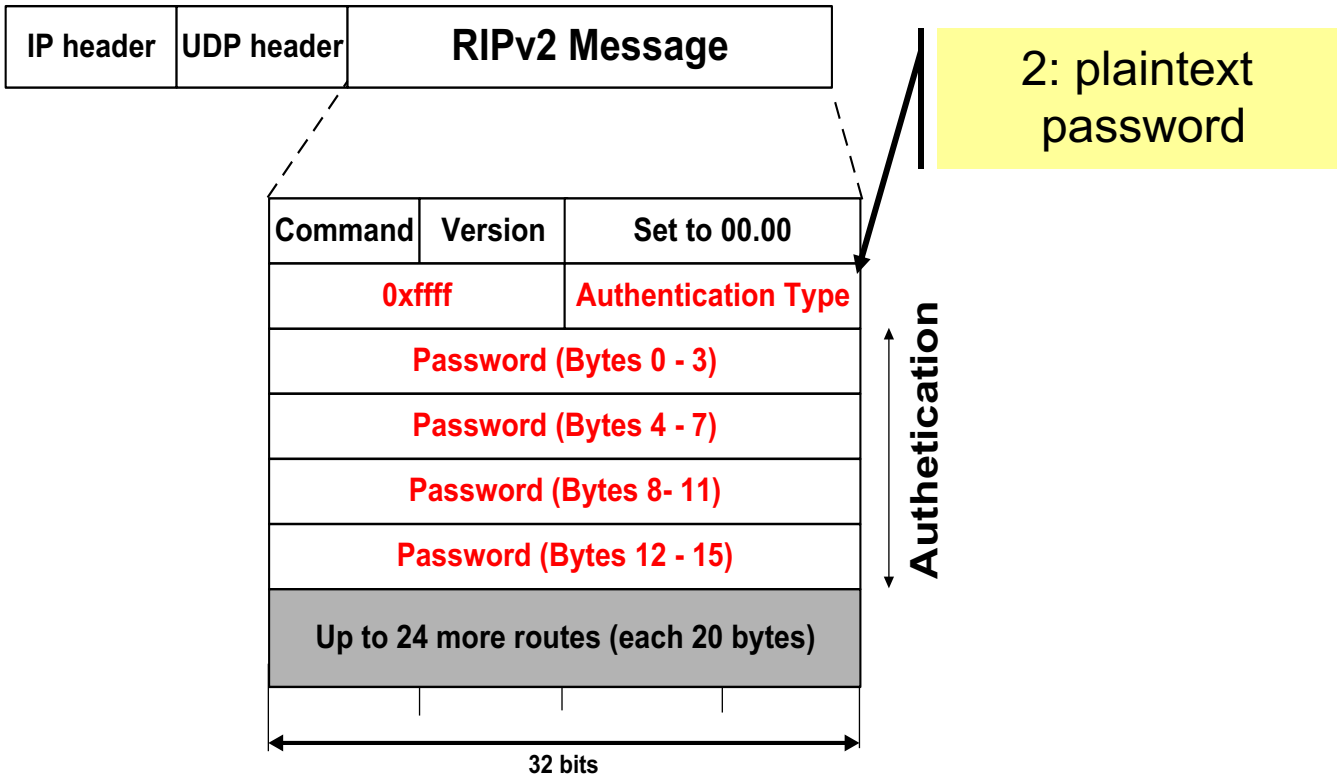
- **Response received**: Update the routing table

- **Regular routing updates**: Every 30 seconds, send all or part of the routing tables to every neighbor in an response message

- **Triggered Updates:** Whenever the metric for a route change, send the entire routing table.

RIP Security

- Issue: Sending bogus routing updates to a router
- RIPv1: No protection
- RIPv2: Simple authentication scheme



RIP Problems

- RIP takes a long time to stabilize
  - Even for a small network, it takes several minutes until the routing tables have settled after a change
- RIP has all the problems of distance vector algorithms, e.g., count-to-Infinity
    - » RIP uses split horizon to avoid count-to-infinity
- The maximum path in RIP is 15 hops

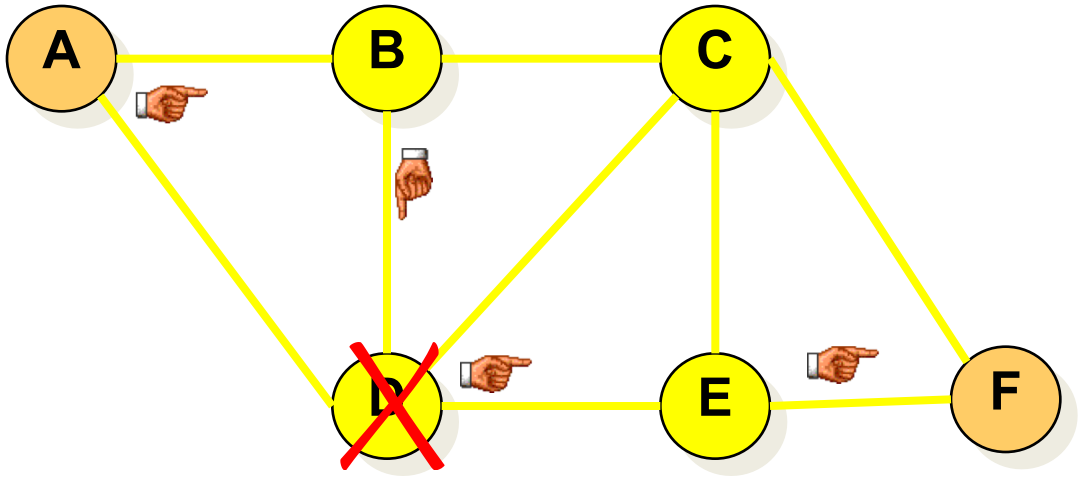
Today

- RIP
- Link-state routing
  - Algorithm
  - Protocol: Open shortest path first (OSPF)

Distance Vector vs. Link State Routing

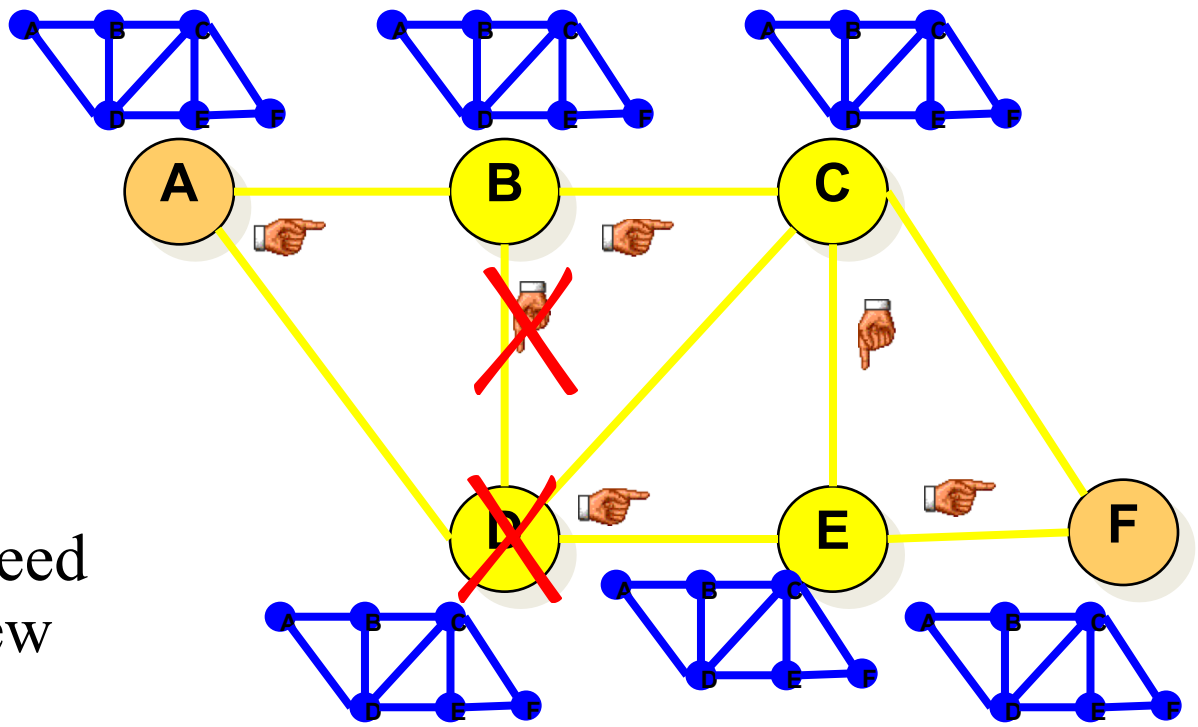
- DV only sees next hop "direction"
  - Node A: to reach F go to B
  - Node B: to reach F go to D
  - Node D: to reach F go to E
  - Node E: go directly to F

- Wrong directions lead to wrong routes
  - Count to infinity



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
- Challenge: All nodes need to have a consistent view of the network



Link State Routing: Basic operations

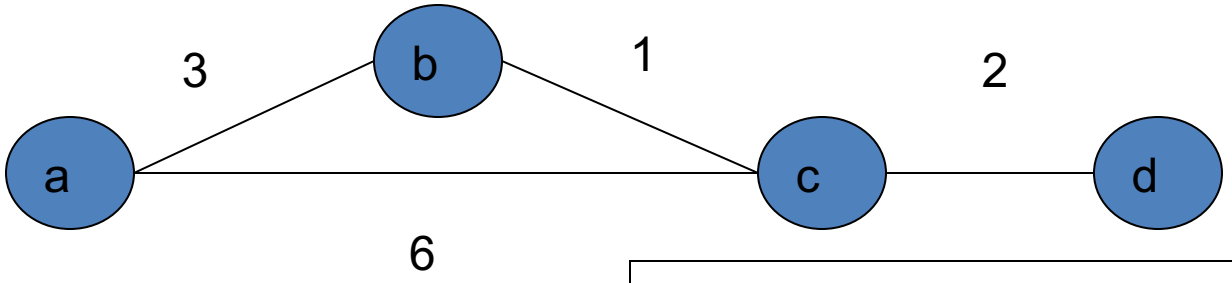
1. Each router establishes *link adjacency*

2. Each router generates a *link state advertisement (LSA)*

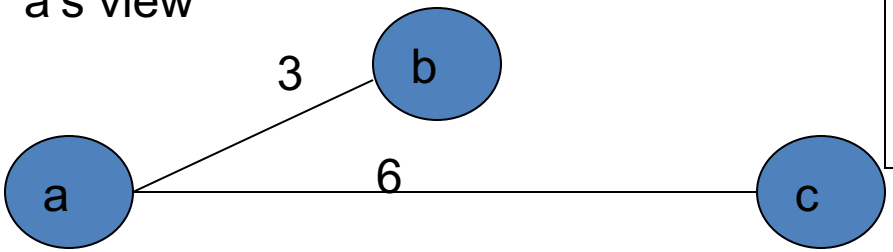
3. Each router maintains a database of all received LSAs (*topological database* or *link state database*

4. Each router runs the Dijkstra's algorithm

Link state routing: graphical illustration

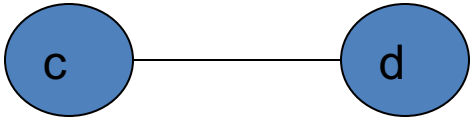


a's view

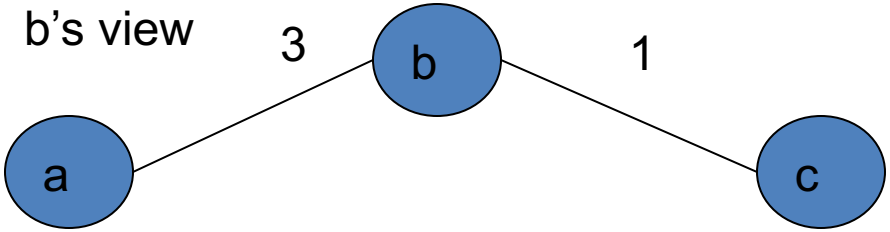


Collecting all pieces yield
a complete view of the network!

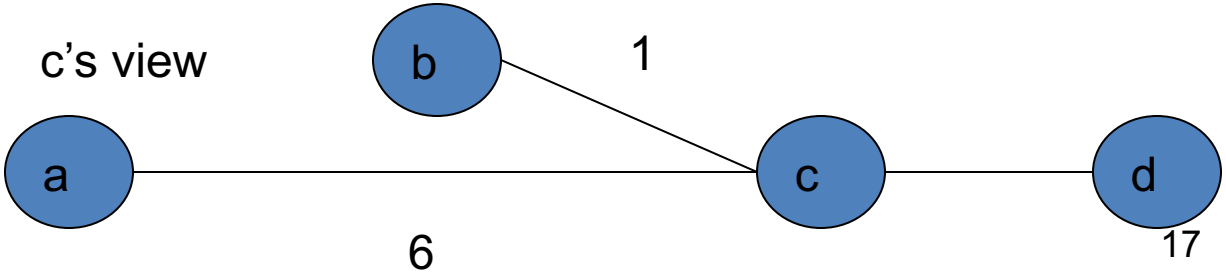
d's view



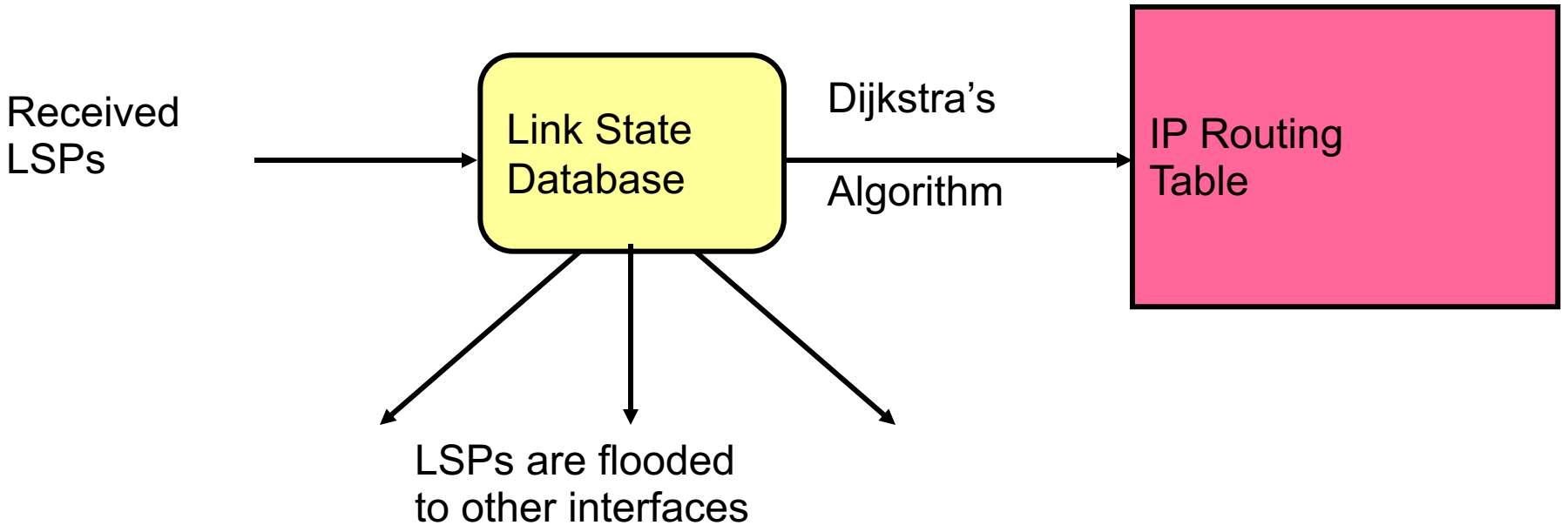
b's view



c's view



Operation of a Link State Routing protocol



Reliable flooding

- We've learned a flooding algorithm used by Ethernet switches

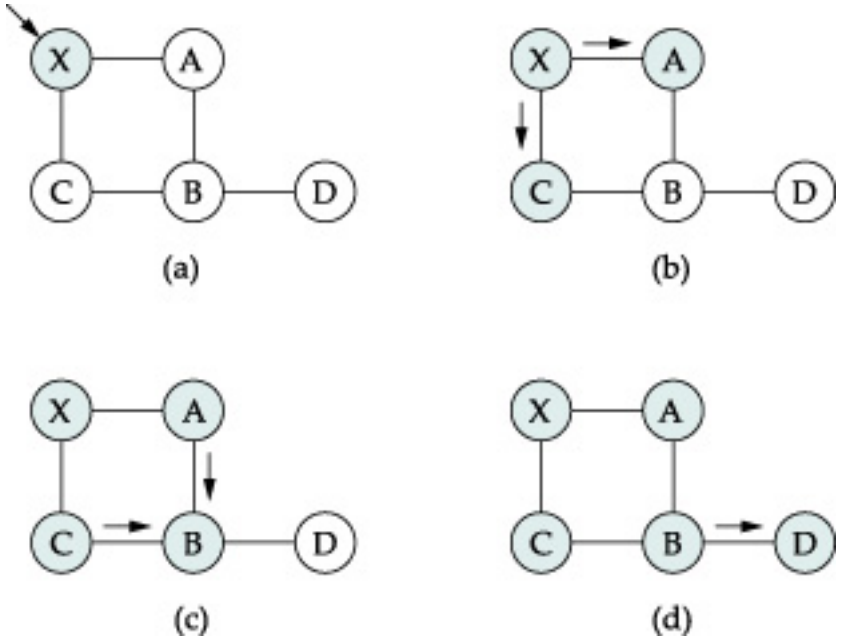
- Question: why is it insufficient for link-state routing?
  - Lost LSAs may result in inconsistent topologies at different routers
  - Inconsistent topologies may lead to routing loops

Reliable flooding

- LSPs are transmitted reliably between adjacent routers
  - ACK and retransmission

- For a node x, if it receives an LSA sent by y
  - Stores LSA(y) if it does not have a copy
  - Otherwise, compares SeqNo. If newer, store; otherwise discard
  - If a new LSA(y), floods LSA(y) to all neighbors except the incoming neighbor

An example of reliable flooding



When to flood an LSP

- Triggered if a link's state has changed
  - Detecting failure
    - Neighbors exchange hello messages
    - If not receiving hello, assume dead
- Periodic generating a new LSA
  - Fault tolerance (what if LSA in memory is corrupted?

Path computation

Dijkstra's Shortest Path Algorithm for a Graph

Input: Graph (N,E) with

N the set of nodes and E the set of edges

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

s source node.

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

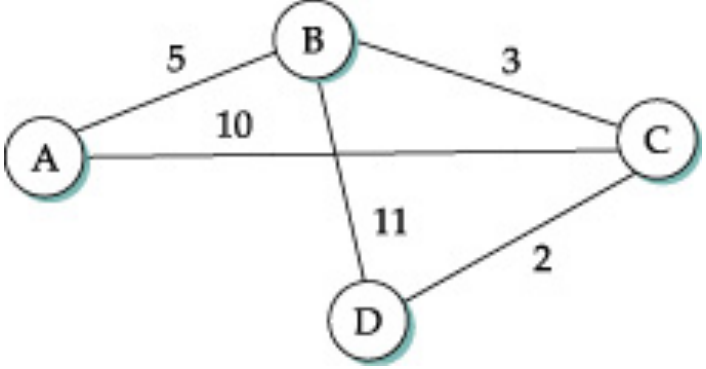
```
M = {s};
for each  n ∉ M
        D_n  = c_sn;
while (M ≠ all nodes) do
        Find w ∉ M for which D_w = min{D_j ; j ∉ M};
        Add w to M;
        for each neighbor n of w and n ∉ M
                D_n = min[ D_n, D_w + c_wn ];
                Update route;
enddo
```

Practical Implementation: forward search algorithm

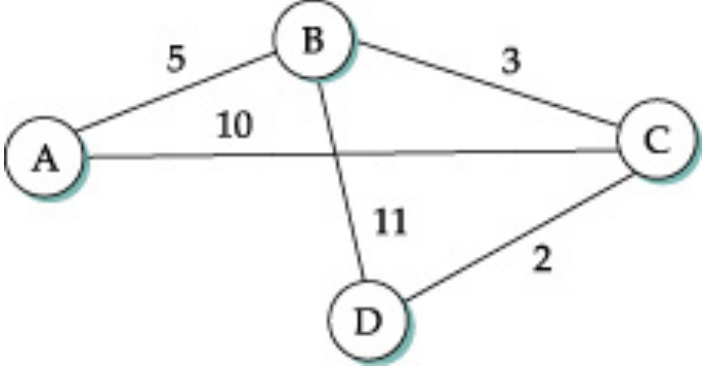
- More efficient: extracting min from a smaller set rather than the entire graph

- Two lists: Tentative and Confirmed
- Each entry: (destination, cost, nextHop)

1. Confirmed = {(s,0,s)}
2. Let Next = Confirmed.last
3. For each Nbr of Next
   - Cost = my→Next + Next → Nbr
     - If Neighbor not in Confirmed or Tentative
       - Add (Nbr, Cost, my.Nexthop(Next)) to Tentative
   - If Nbr is in Tentative, and Cost is less than Nbr.Cost, update Nbr.Cost to Cost
4. If Tentative not empty, pick the entry with smallest cost in Tentative and move it to Confirmed, and return to Step 2
   - Pick the smallest cost from a smaller list Tentative, rather than the rest of the graph



Step	Confirmed	Tentative
1	(D,0,-)	
2		
3		
4		
5		
6		
7		



Step	Confirmed	Tentative
1	(D,0,-)	
2	(D,0,-)	(B,11,B), (C,2,C)
3	(D,0,-), (C,2,C)	(B,11,B)
4	(D,0,-), (C,2,C)	(B,5,C) (A,12,C)
5	(D,0,-), (C,2,C), (B,5,C)	(A,12,C)
6	(D,0,-),(C,2,C),(B,5,C)	(A,10,C)
7	(D,0,-),(C,2,C),(B,5,C), (A,10,C)	

OSPF

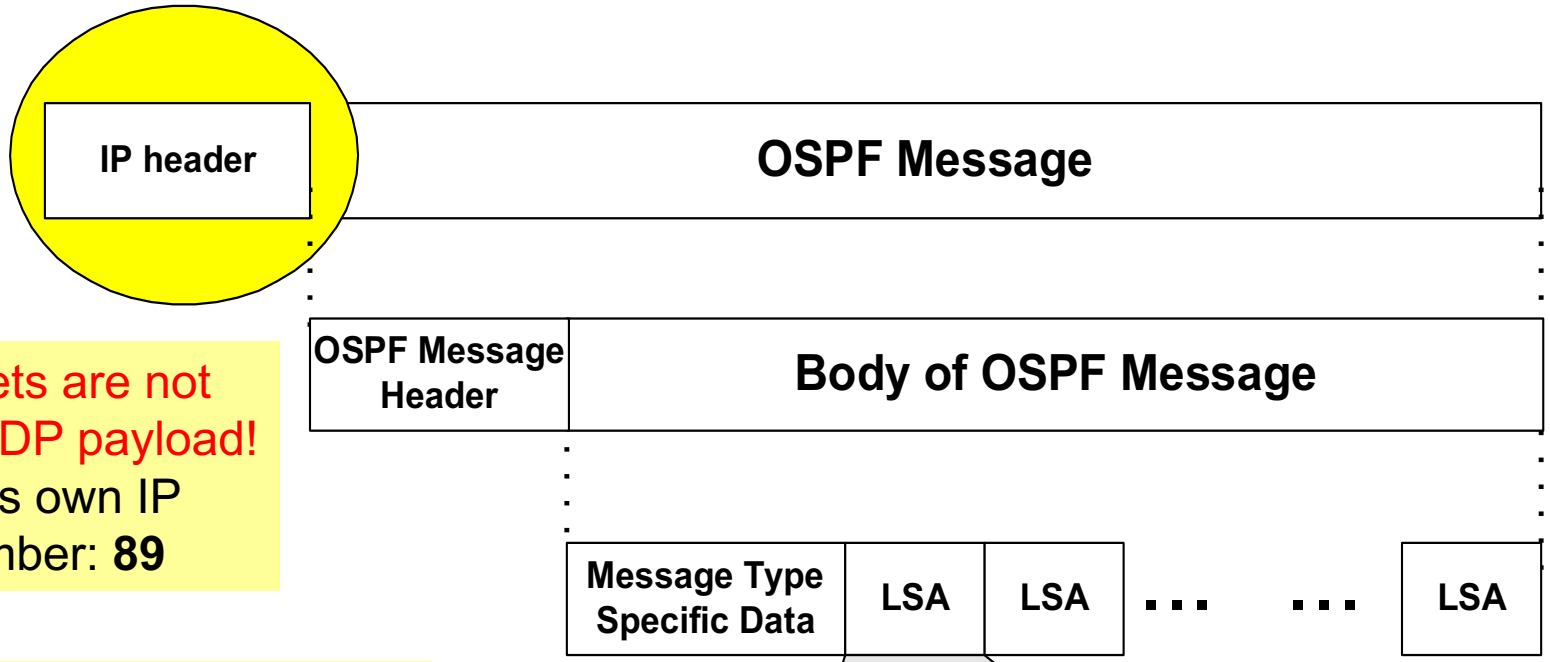
- OSPF = Open Shortest Path First
  - Open stands for open, non-proprietary

- A link state routing protocol
- The complexity of OSPF is significant
  - RIP (RFC 2453 ~ 40 pages)
  - OSPF (RFC 2328 ~ 250 pages)
- 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
  - Similar to RIP 2
- Allows hierarchical routing
  - Divide a domain into sub-areas
- Enables load balancing by allowing traffic to be split evenly across routes with equal cost

OSPF Packet Format



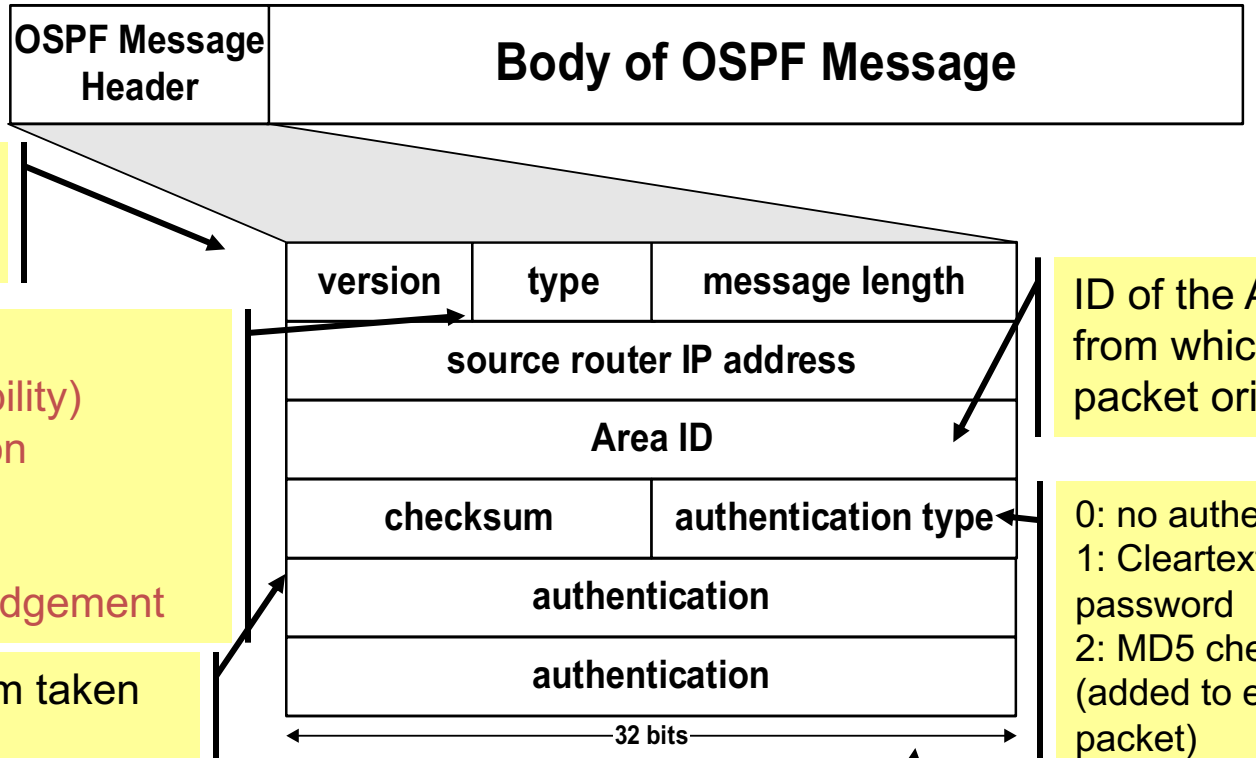
OSPF packets are not carried as UDP payload!
OSPF has its own IP protocol number: **89**

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)

Link state advertisement

OSPF Common header



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

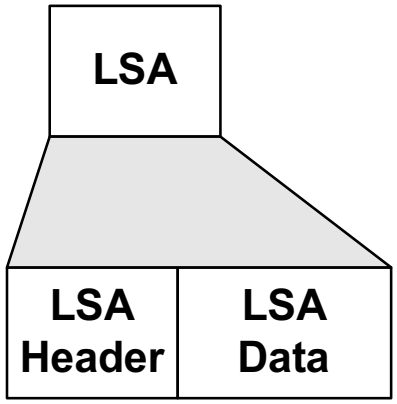
ID of the Area from which the packet originated

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)

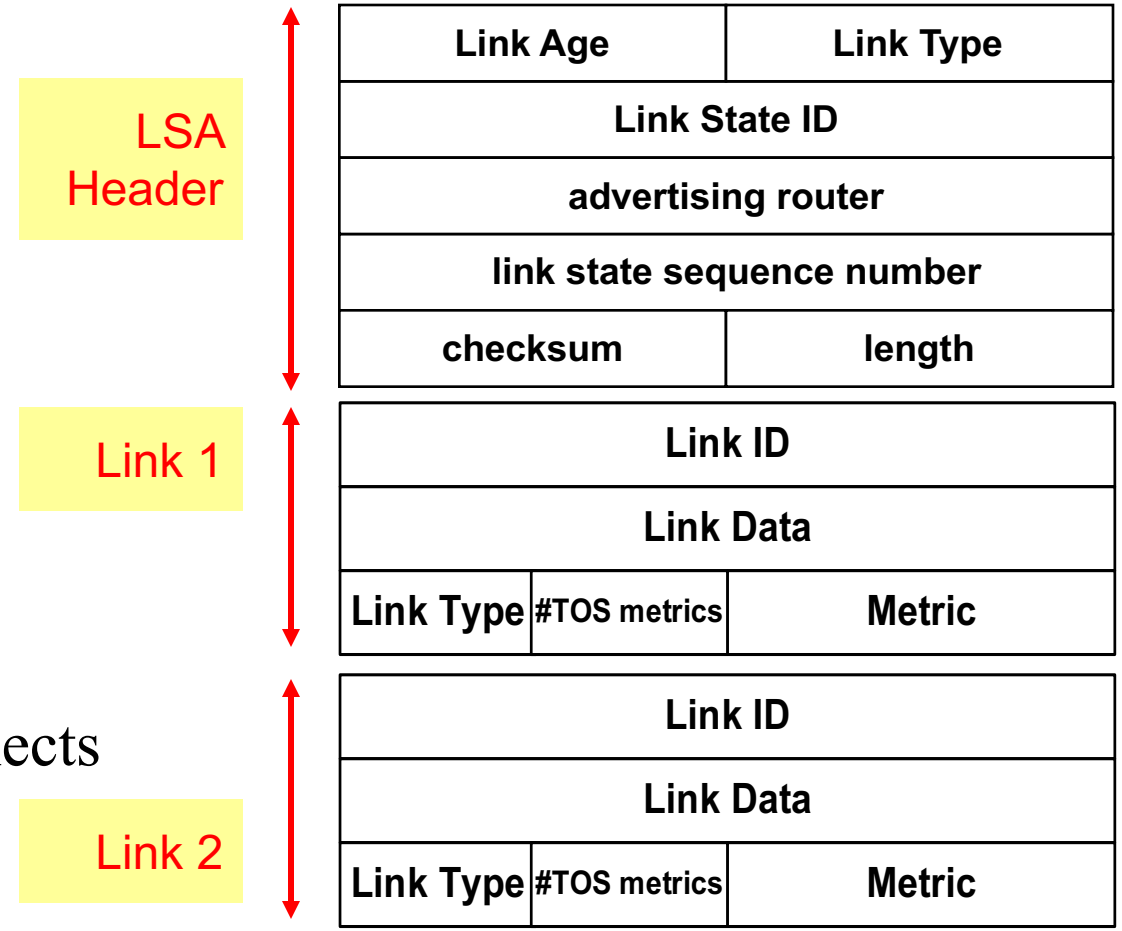
Prevents replay attacks

OSPF LSA Format



LSAs

- Type 1: cost of links between routers
- Type 2: networks to which the router connects
- Others: hierarchical routing



Type 1 LSA

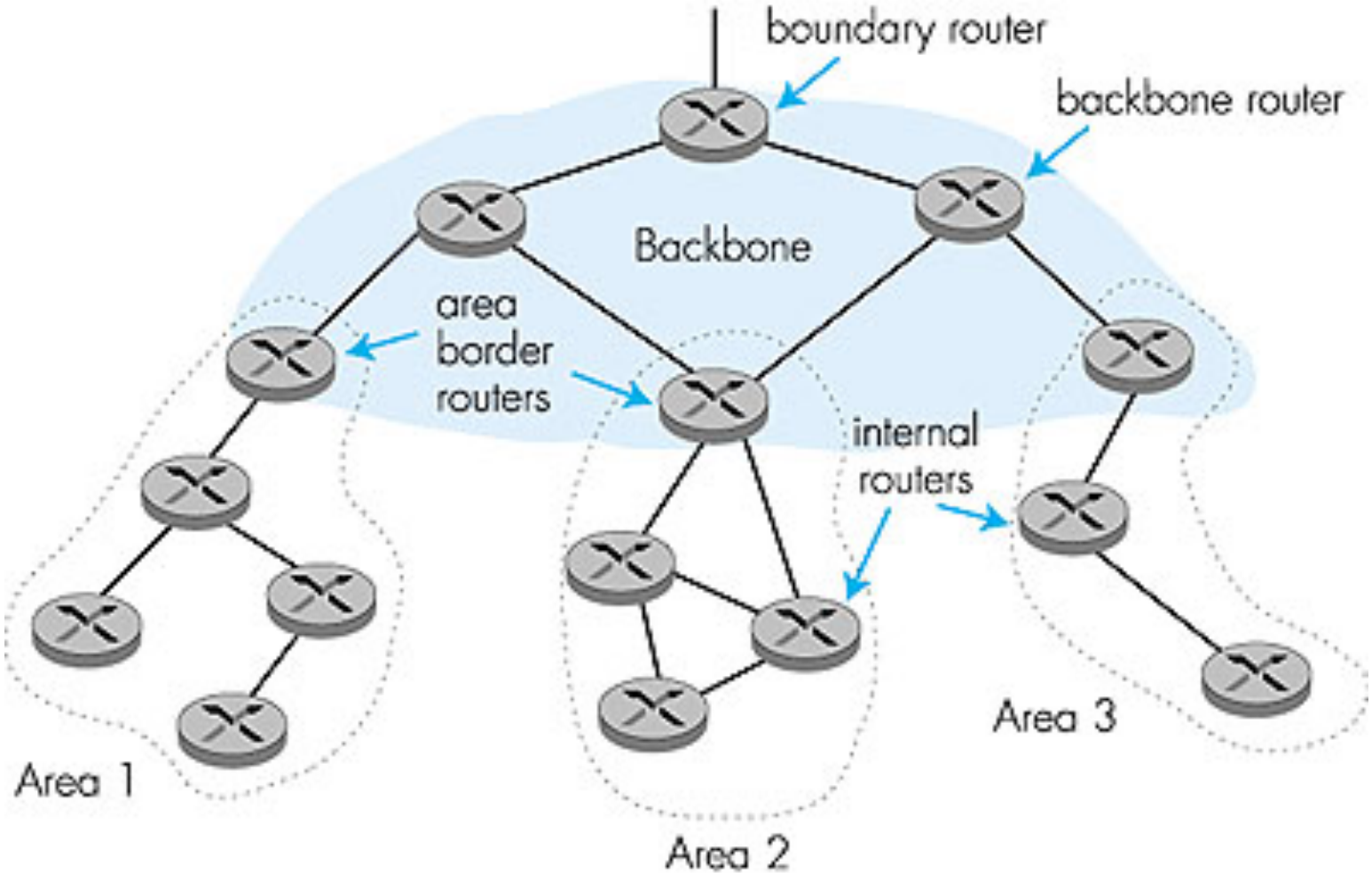
- Link state ID and Advertising router are the same, 32-bit router ID

- Link ID: router ID at the other end of the link
- Link Data: identify parallel links
- Metric: cost of the link
- Type: types of the link e.g., point-to-point

Open question

- How to set link metrics?
- Design choice 1: all to 1
- Design choice 2: based on load
  - Problems?
- In practice: static

Hierarchical OSPF

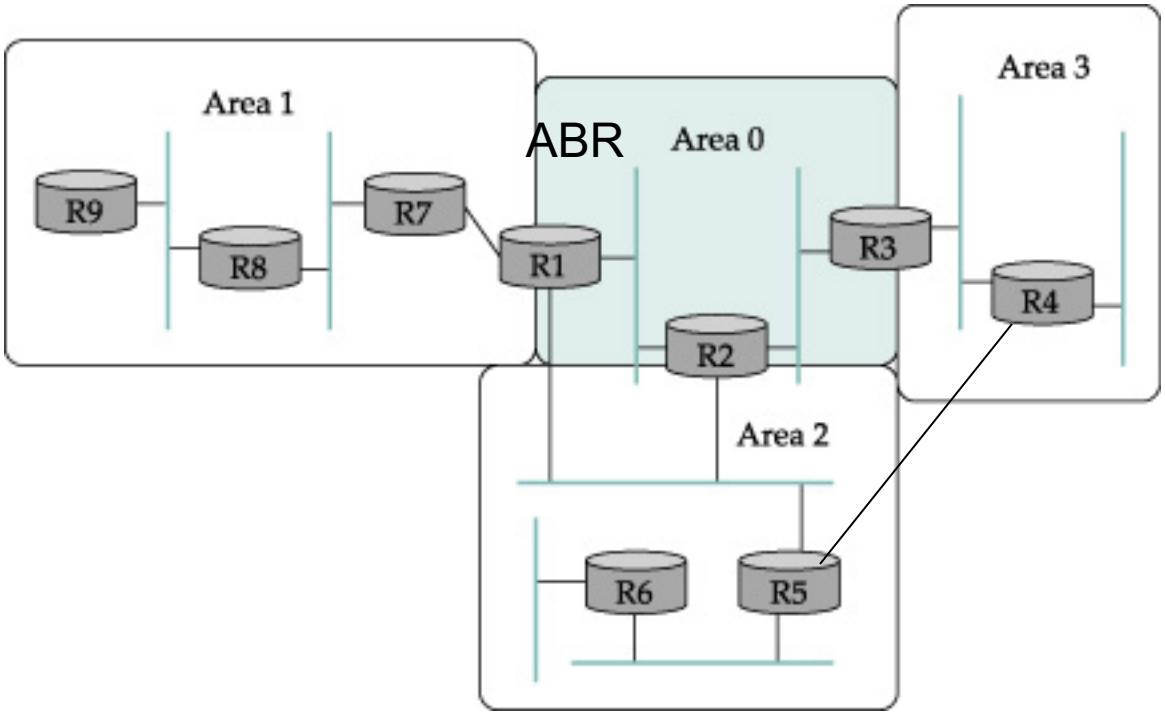


Hierarchical OSPF

- Two-level hierarchy: local area, backbone.
  - Link-state advertisements only in area
  - Each nodes has detailed area topology; only know direction (shortest path) to nets in other areas.
- **Area border routers:** "summarize" distances to nets in own area, advertise to other Area Border routers.
- **Backbone routers:** run OSPF routing limited to backbone.

Scalability and Optimal Routing

- A frequent tradeoff in network design
- Hierarchy introduces information hiding



OSPF summary

- A link-state routing protocol
- Each node has a map of the network and uses Dijkstra to compute shortest paths
- Nodes use reliable flooding to keep an identical copy of the network map

Summary

- Routing information protocol (RIP)
- Link-state routing
  - Algorithm
  - Protocol: Open shortest path first (OSPF)