Dynamic Routing Protocols I
RIP

The first module on dynamic routing protocols. This module provides an overview of routing, introduces terminology (interdomain, intradomain, autonomous system),

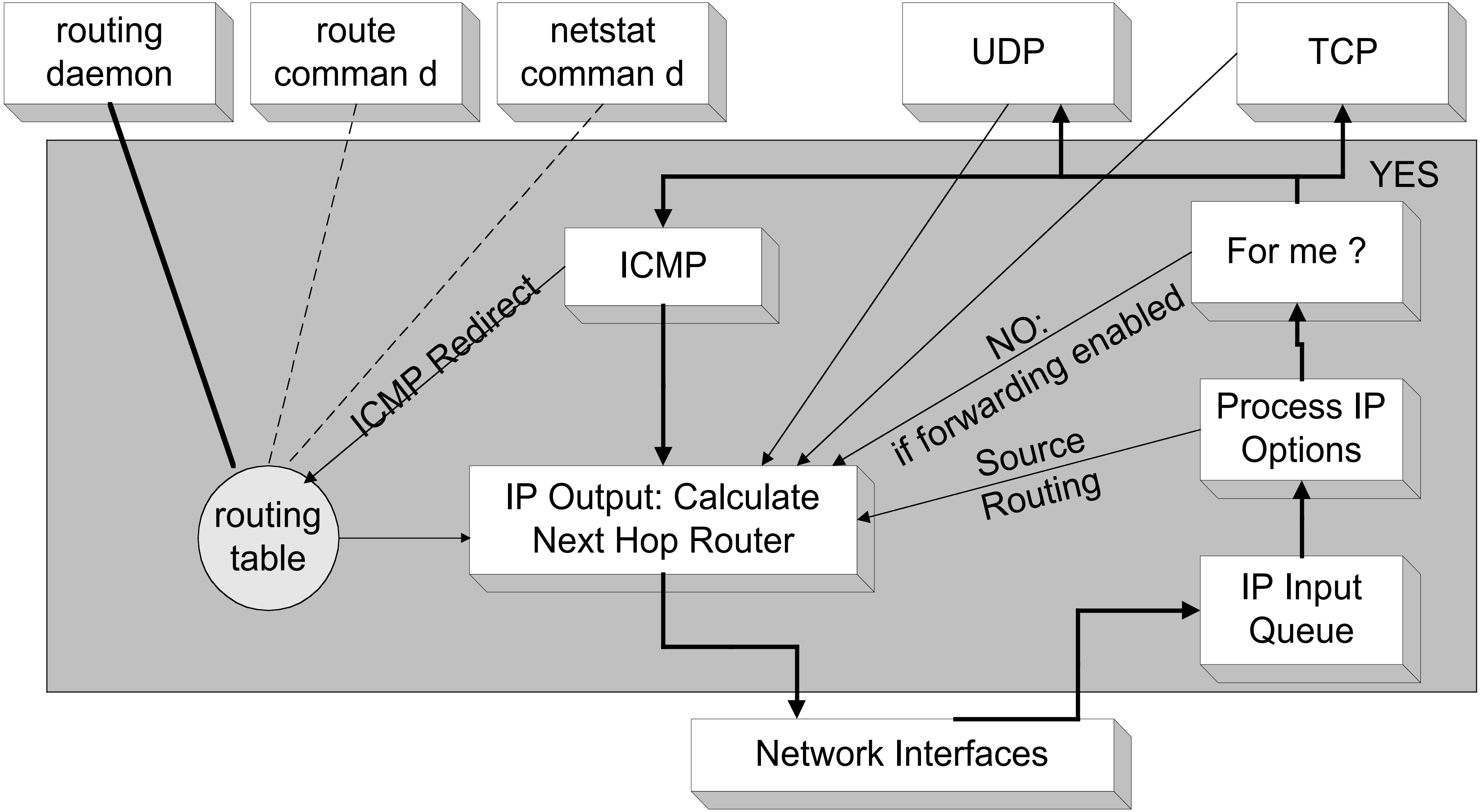
Routing

- **Recall:** There are two parts to routing IP packets:
  1. How to pass a packet from an input interface to the output interface of a router (packet forwarding) ?
  2. How to find and setup a route ?

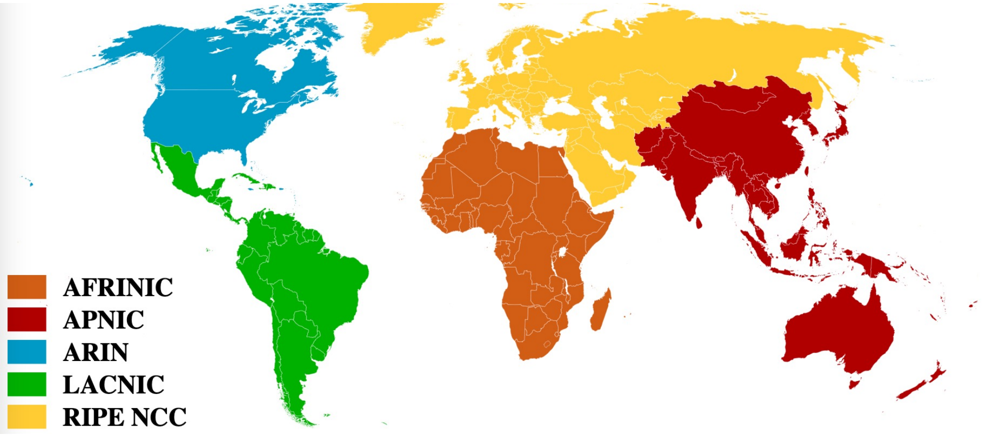
- We already discussed the packet forwarding part

- There are two approaches for calculating the routing tables:
  - Static Routing
  - Dynamic Routing: Routes are calculated by a routing protocol

IP Routing


routing daemon
route comman d
netstat comman d
UDP
TCP
YES
ICMP
For me ?
ICMP Redirect
NO:
if forwarding enabled
Process IP Options
Source Routing
routing table
IP Output: Calculate Next Hop Router
IP Input Queue
Network Interfaces

Autonomous Systems

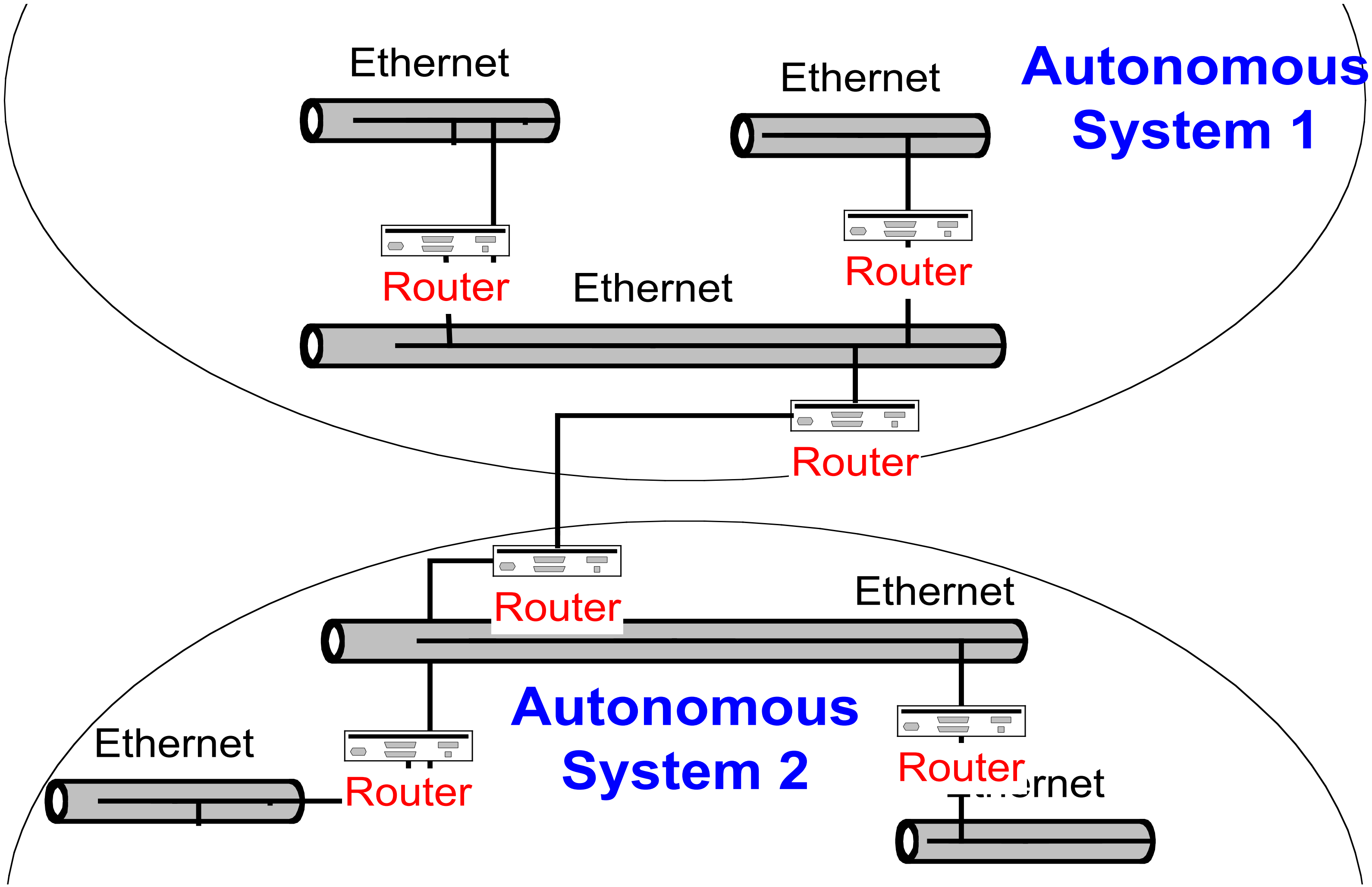


- An **Autonomous System** is

a region of the Internet that is Administered by a single entity.

- Space of Internet distribution: IANA → RIR → LIR → End-user
  - Regional Internet Registry: AFRINIC, APNIC, ARIN, LACNIC,RIPE NCC.
  - Local Internet Registry: Extra Large, Large, Medium, Small и Extra Small.
  - LIR content 1 or many AS
  - Have 4 types of AS: multihomed, stub, transit, private (64512 - 65534)
  - IANA make a listing of ASN (16bit use in IGP and EGP).
  - AS List http://www.iana.org/assignments/as-numbers/as-numbers.xhtml
  - Examples of autonomous regions see on https://www.robtex.com/
- Routing is done differently within an autonomous system (**intradomain routing**) and between autonomous system **(interdomain routing**).

Autonomous Systems (AS)



Interdomain and Intradomain Routing

Intradomain Routing

- Routing within an AS
- Ignores the Internet outside the AS
- Protocols for Intradomain routing are also called **Interior Gateway Protocols** or **IGP' s**.
- Popular protocols are
  - RIP (simple, old)
  - OSPF (better)

Interdomain Routing

- Routing between AS' s
- Assumes that the Internet consists of a collection of interconnected AS' s
- Normally, there is one dedicated router in each AS that handles interdomain traffic.
- Protocols for interdomain routing are also called **Exterior Gateway Protocols** or **EGP' s.**
- Routing protocols:
  - EGP
  - BGP (more recent)

Components of a Routing Algorithm

- A procedure for sending and receiving reachability information about network to other routers

- A procedure for calculating optimal routes
  - Routes are calculated using a shortest path algorithm:
    - **Goal:** Given a network were each link is assigned a cost. Find the path with the least cost between two networks with minimum cost.

- A procedure for reacting to and advertising topology changes

Approaches to Shortest Path Routing

- There are two basic routing algorithms found on the Internet.

1. Distance Vector Routing

- Each node knows the distance (=cost) to its directly connected neighbors
- A node sends periodically a list of routing updates to its neighbors.
- If all nodes update their distances, the routing tables eventually converge
- New nodes advertise themselves to their neighbors

2. Link State Routing

- Each node knows the distance to its neighbors
- The distance information (=link state) is broadcast to all nodes in the network
- Each node calculates the routing tables independently

Routing Algorithms in the Internet

Distance Vector

- **Routing Information Protocol (RIP)**
- Gateway-to-Gateway Protocol (GGP)
- Exterior Gateway Protocol (EGP)
- Interior Gateway Routing Protocol (IGRP)

Link State

- Intermediate System - Intermediate System (IS-IS)
- **Open Shortest Path First (OSPF)**

Dynamic IP Routing Protocols

- In Unix systems, the dynamic setting of routing tables is done by the **routed** or **gated** daemons
- The routing daemons execute the following intradomain and interdomain routing protocols

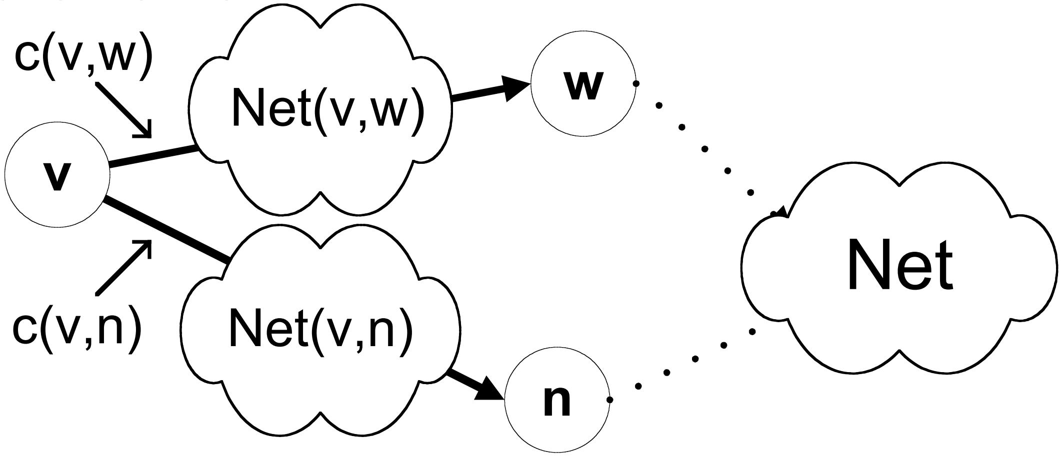
intradomain *interdomain*

Daemon	*Hello*	*RIP*	*OSPF*	*EGP*	*BGP*
`routed`		V1			
`Gated` **`(Version 3)`**	Yes	V1 V2	V2	Yes	V2, V3

A network as a graph

- **In the following, networks are represented as a network graph**:
  - nodes are connected by networks
    - network can be a link or a LAN
  - network interface has cost
  - networks are destinations
  - Net(v,w) is an IP address of a network

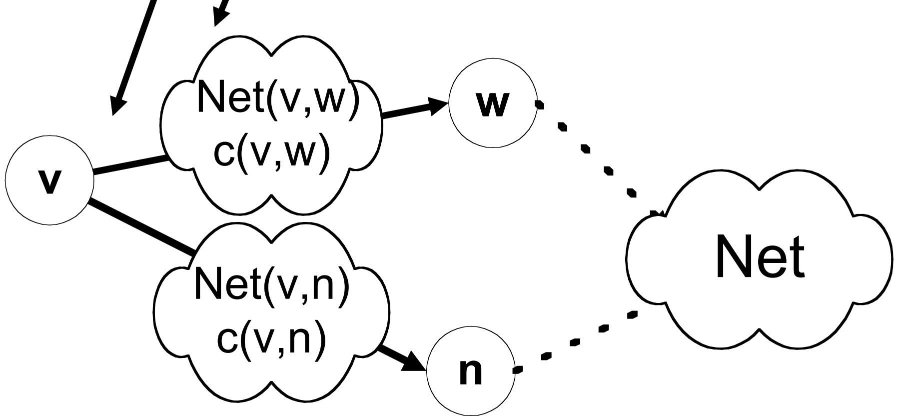
- For ease of notation, we often replace the clouds between nodes by simple links.



Distance Vector Algorithm: Routing Table

c(v,w): cost to transmit on the interface to network Net(v,w)

Net(v,w): Network address of the network between v and w
The network can be a link, but could also be a LAN



RoutingTable of node v

Dest	via (next hop)	cost
Net	n	D(v,Net)

Distance Vector Algorithm: Messages

RoutingTable of node v

Dest	via (next hop)	cost
Net	n	D(v,Net)

- Nodes send messages to their neighbors which contain routing table entries

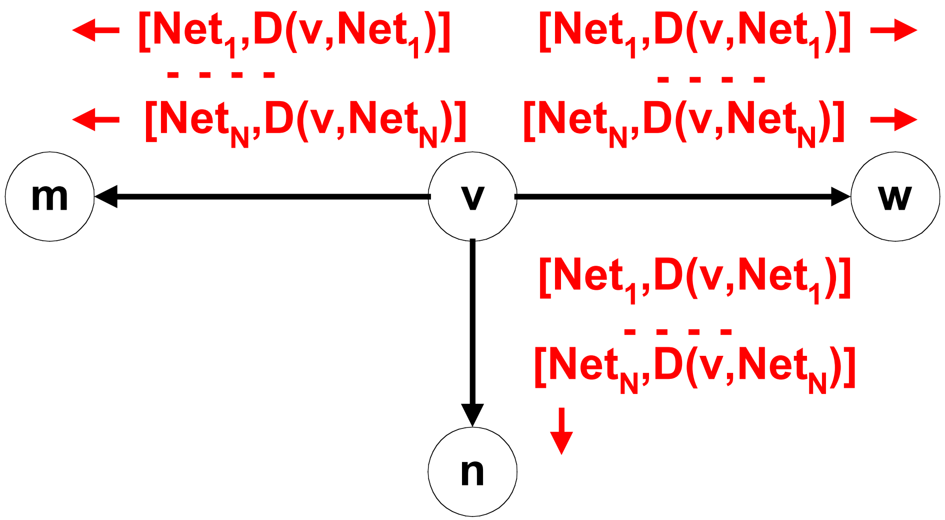
- A message has the format: **[Net , D(v,Net)]** means ***"My cost to go to Net is D (v,Net) "***

Distance Vector Algorithm: Sending Updates

RoutingTable of node v

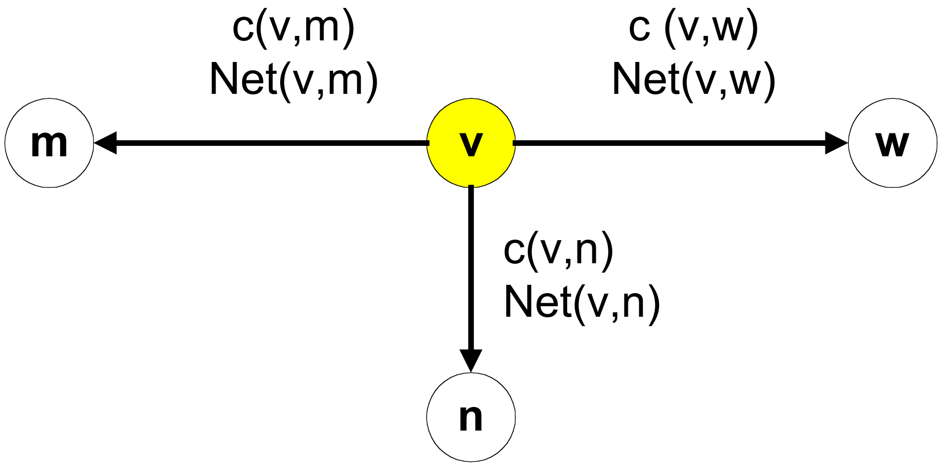
Dest	via (next hop)	cost
Net_1	m	$D(v,Net_1)$
Net_2	n	$D(v,Net_2)$
- - -	- - -	- - -
Net_N	w	$D(v,Net_N)$

Periodically, each node v sends the content of its routing table to its neighbors:



Initiating Routing Table I

- Suppose a new node v becomes active.
- The cost to access directly connected networks is zero:
  - D (v, Net(v,m)) = 0
  - D (v, Net(v,w)) = 0
  - D (v, Net(v,n)) = 0



RoutingTable

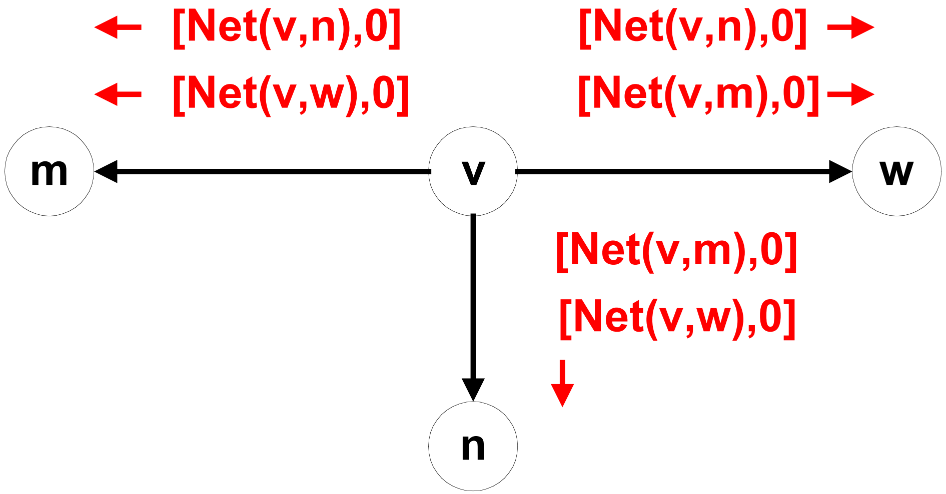
Dest	via (next hop)	cost
Net(v,m)	m	0
Net(v,w)	w	0
Net(v,n)	n	0

Initiating Routing Table II

RoutingTable

Dest	via (next hop)	cost
Net(v,m)	m	0
Net(v,w)	w	0
Net(v,n)	n	0

- New node v sends the routing table entry to all its neighbors:



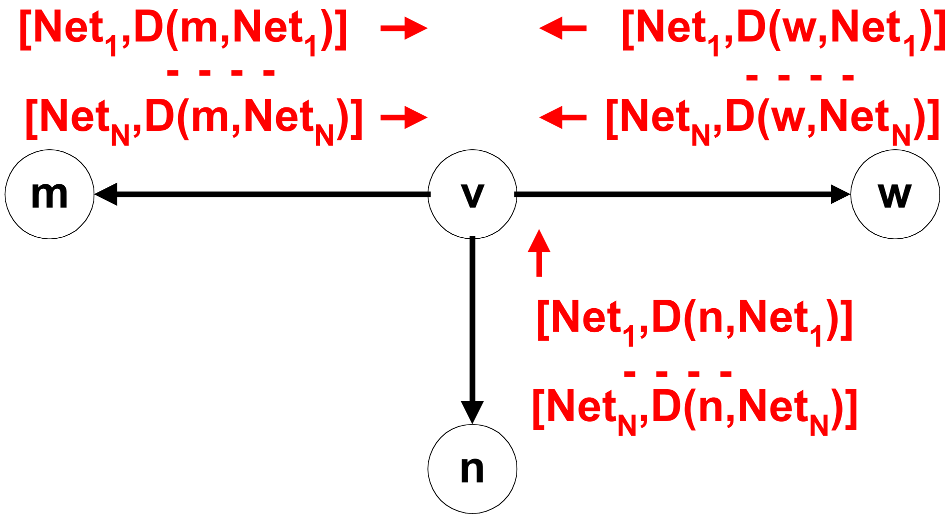
← [Net(v,n),0]
← [Net(v,w),0]

[Net(v,n),0] →
[Net(v,m),0] →

[Net(v,m),0]
[Net(v,w),0]
↓

Initiating Routing Table III

- Node v receives the routing tables from other nodes and builds up its routing table



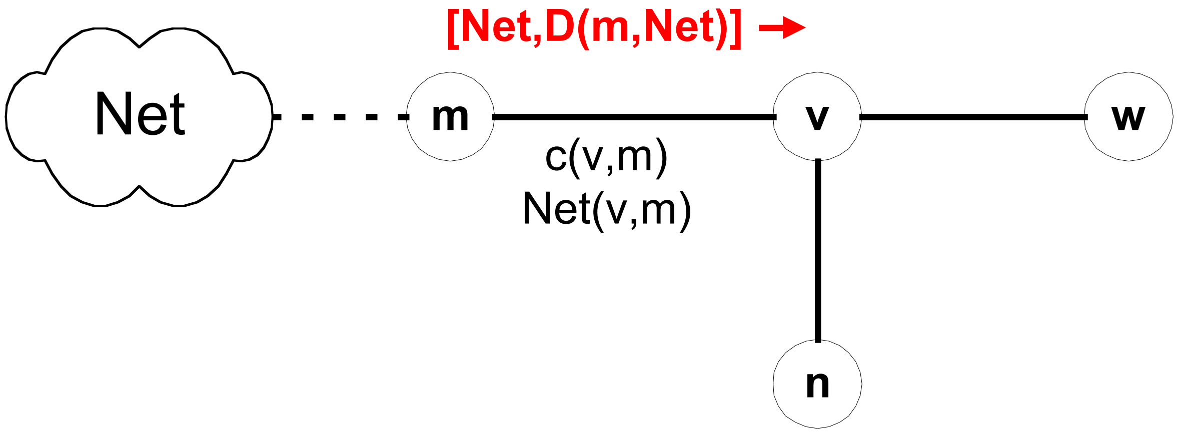
$[Net_1,D(m,Net_1)]$ →
\- - - -
$[Net_N,D(m,Net_N)]$ →

← $[Net_1,D(w,Net_1)]$
\- - - -
← $[Net_N,D(w,Net_N)]$

$[Net_1,D(n,Net_1)]$
\- - - -
$[Net_N,D(n,Net_N)]$

Updating Routing Tables I

- Suppose node v receives a message from node m: **[Net,D(m,Net)]**

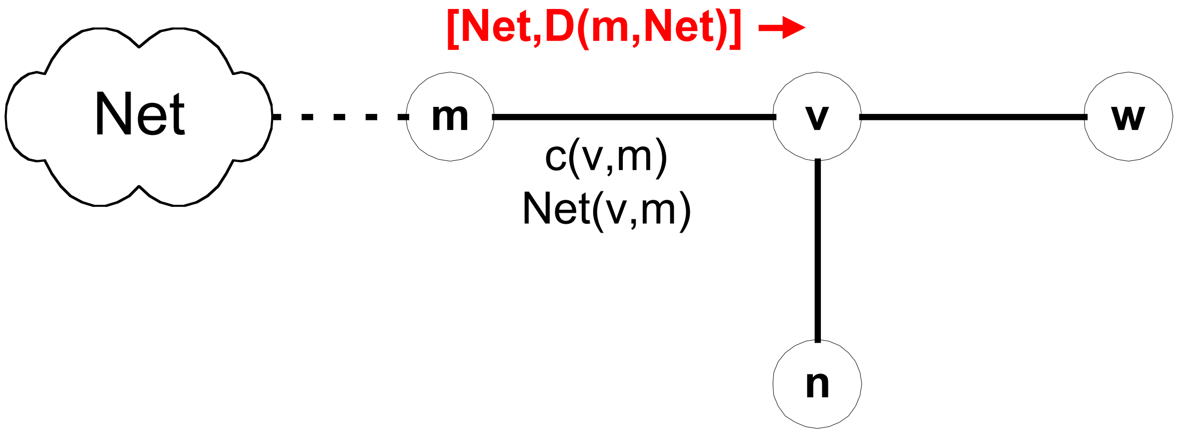


Node v updates its routing table and sends out further messages if the message reduces the cost of a route:

```
if ( $D(m,Net) + c(v,m) < D(v,Net)$ ) {
    $D^{new}(v,Net) := D(m,Net) + c(v,m)$;
    Update routing table;
    send message [Net, $D^{new}(v,Net)$] to all neighbors
}
```

Updating Routing Tables II

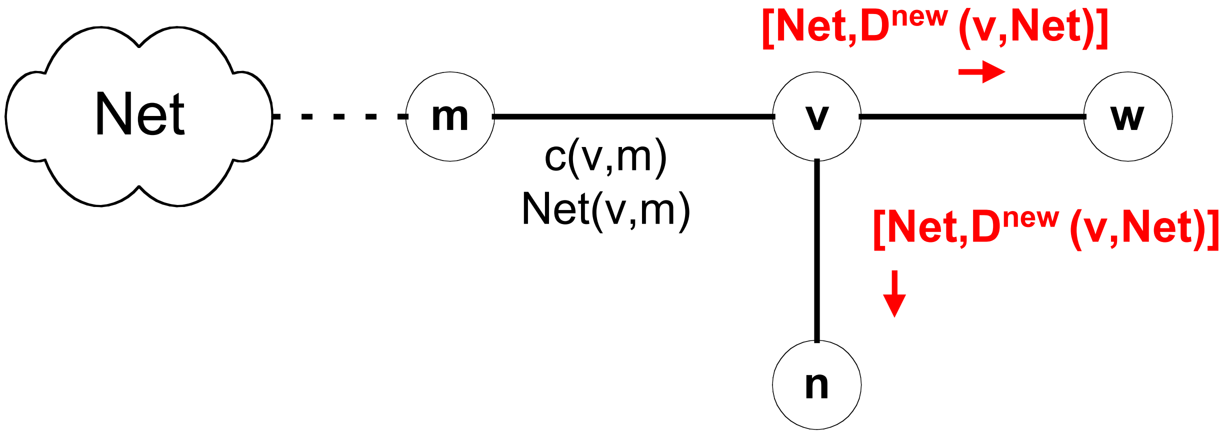
- Before receiving the message:



RoutingTable

Dest	via (next hop)	cost
Net	??	D(v,Net)

- Suppose $D(m,Net) + c(v,m) < D(v,Net)$:

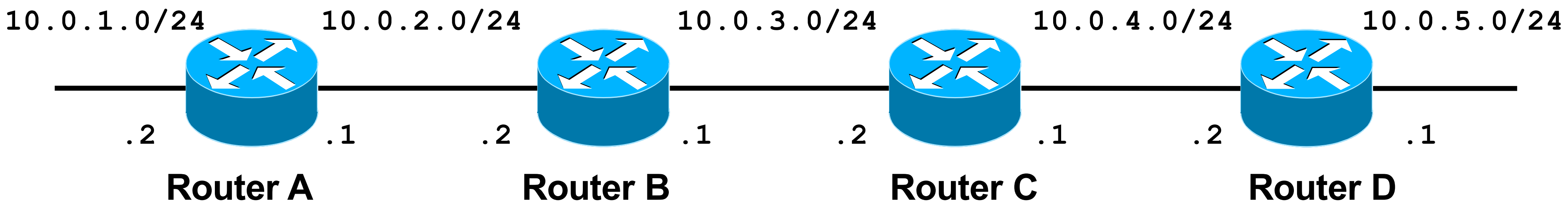


RoutingTable

Dest	via (next hop)	cost
Net	m	$D^{new}(v,Net)$

Example

Assume:
- link cost is 1, i.e., c(v,w) = 1
- all updates, updates occur simultaneously
- Initially, each router only knows the cost of connected interfaces



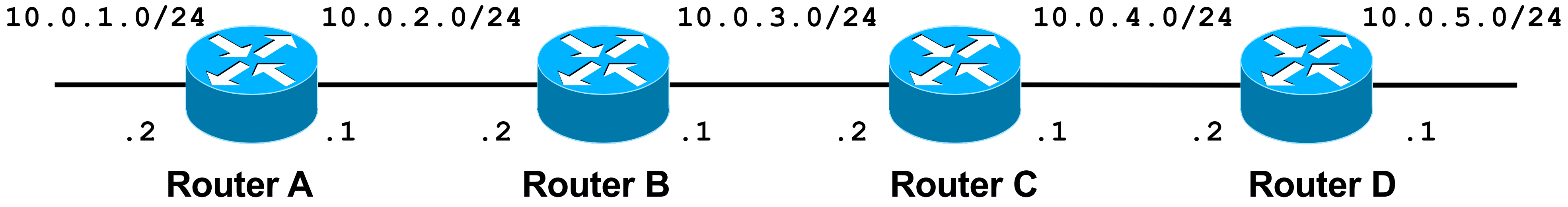
Net	via	cost
t=0:		
10.0.1.0	-	0
10.0.2.0	-	0
t=1:		
10.0.1.0	-	0
10.0.2.0	-	0
10.0.3.0	10.0.2.2	1
t=2:		
10.0.1.0	-	0
10.0.2.0	-	0
10.0.3.0	10.0.2.2	1
10.0.4.0	10.0.2.2	2

Net	via	cost
t=0:		
10.0.2.0	-	0
10.0.3.0	-	0
t=1:		
10.0.1.0	10.0.2.1	1
10.0.2.0	-	0
10.0.3.0	-	0
10.0.4.0	10.0.3.2	1
t=2:		
10.0.1.0	10.0.2.1	1
10.0.2.0	-	0
10.0.3.0	-	0
10.0.4.0	10.0.3.2	1
10.0.5.0	10.0.3.2	2

Net	via	cost
t=0:		
10.0.3.0	-	0
10.0.4.0	-	0
t=1:		
10.0.2.0	10.0.3.1	1
10.0.3.0	-	0
10.0.4.0	-	0
10.0.5.0	10.0.4.2	1
t=2:		
10.0.1.0	10.0.3.1	2
10.0.2.0	10.0.3.1	1
10.0.3.0	-	0
10.0.4.0	-	0
10.0.5.0	10.0.4.2	1

Net	via	cost
t=0:		
10.0.4.0	-	0
10.0.5.0	-	0
t=1:		
10.0.3.0	10.0.4.1	1
10.0.4.0	-	0
10.0.5.0	-	0
t=2:		
10.0.2.0	10.0.4.1	2
10.0.3.0	10.0.4.1	1
10.0.4.0	-	0
10.0.5.0	-	0

Example



Net	via	cost
t=2:		
10.0.1.0	*-*	*0*
10.0.2.0	*-*	*0*
10.0.3.0	*10.0.2.2*	*1*
10.0.4.0	*10.0.2.2*	*2*
t=3:		
10.0.1.0	-	0
10.0.2.0	-	0
10.0.3.0	10.0.2.2	1
10.0.4.0	10.0.2.2	2
10.0.5.0	10.0.2.2	3

Net	via	cost
t=2:		
10.0.1.0	*10.0.2.1*	*1*
10.0.2.0	*-*	*0*
10.0.3.0	*-*	*0*
10.0.4.0	*10.0.3.2*	*1*
10.0.5.0	*10.0.3.2*	*2*
t=3:		
10.0.1.0	10.0.2.1	1
10.0.2.0	-	0
10.0.3.0	-	0
10.0.4.0	10.0.3.2	1
10.0.5.0	10.0.3.2	2

Net	via	cost
t=2:		
10.0.1.0	*10.0.3.1*	*2*
10.0.2.0	*10.0.3.1*	*1*
10.0.3.0	*-*	*0*
10.0.4.0	*-*	*0*
10.0.5.0	*10.0.4.2*	*1*
t=3:		
10.0.1.0	10.0.3.1	2
10.0.2.0	10.0.3.1	1
10.0.3.0	-	0
10.0.4.0	-	0
10.0.5.0	10.0.4.2	1

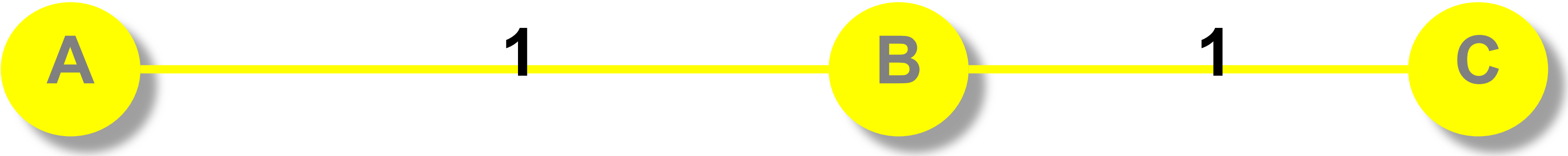
Net	via	cost
t=2:		
10.0.2.0	*10.0.4.1*	*2*
10.0.3.0	*10.0.4.1*	*1*
10.0.4.0	*-*	*0*
10.0.5.0	*-*	*0*
t=3:		
10.0.1.0	10.0.4.1	3
10.0.2.0	10.0.4.1	2
10.0.3.0	10.0.4.1	1
10.0.4.0	-	0
10.0.5.0	-	0

Now, routing tables have converged !

Characteristics of Distance Vector Routing

- **Periodic Updates:** Updates to the routing tables are sent at the end of a certain time period. A typical value is 90 seconds.
- **Triggered Updates:** If a metric changes on a link, a router immediately sends out an update without waiting for the end of the update period.
- **Full Routing Table Update**: Most distance vector routing protocols send their neighbors the entire routing table (not only entries which change).
- **Route invalidation timers:** Routing table entries are invalid if they are not refreshed. A typical value is to invalidate an entry if no update is received after 3-6 update periods.

The Count-to-Infinity Problem



A's Routing Table				B's Routing Table		
to	via (next hop)	cost		to	via (next hop)	cost
C	B	2		C	C	1

now link B-C goes down

C	B	2		C	-	oo
	C	2 →		← C	oo	
C	-	oo		C	A	3
	C	oo →		← C	3	
C	B	4		C	-	oo
	C	4 →		← C	oo	

Count-to-Infinity

- The reason for the count-to-infinity problem is that each node only has a “next-hop-view”
- For example, in the first step, A did not advertise that its route (with cost 2) to C went through node B

- How can the Count-to-Infinity problem be solved?

Count-to-Infinity

- The reason for the count-to-infinity problem is that each node only has a “next-hop-view”
- For example, in the first step, A did not realize that its route (with cost 2) to C went through node B

- How can the Count-to-Infinity problem be solved?
- **Solution 1:** Always advertise the entire path in an update message (**Path vectors**)
    - If routing tables are large, the routing messages require substantial bandwidth
    - BGP uses this solution

Count-to-Infinity

- The reason for the count-to-infinity problem is that each node only has a “next-hop-view”
- For example, in the first step, A did not realize that its route (with cost 2) to C went through node B

- How can the Count-to-Infinity problem be solved?
- **Solution 2:** Never advertise the cost to a neighbor if this neighbor is the next hop on the current path **(Split Horizon)**
  - Example: A would not send the first routing update to B, since B is the next hop on A’s current route to C
  - Split Horizon does not solve count-to-infinity in all cases!

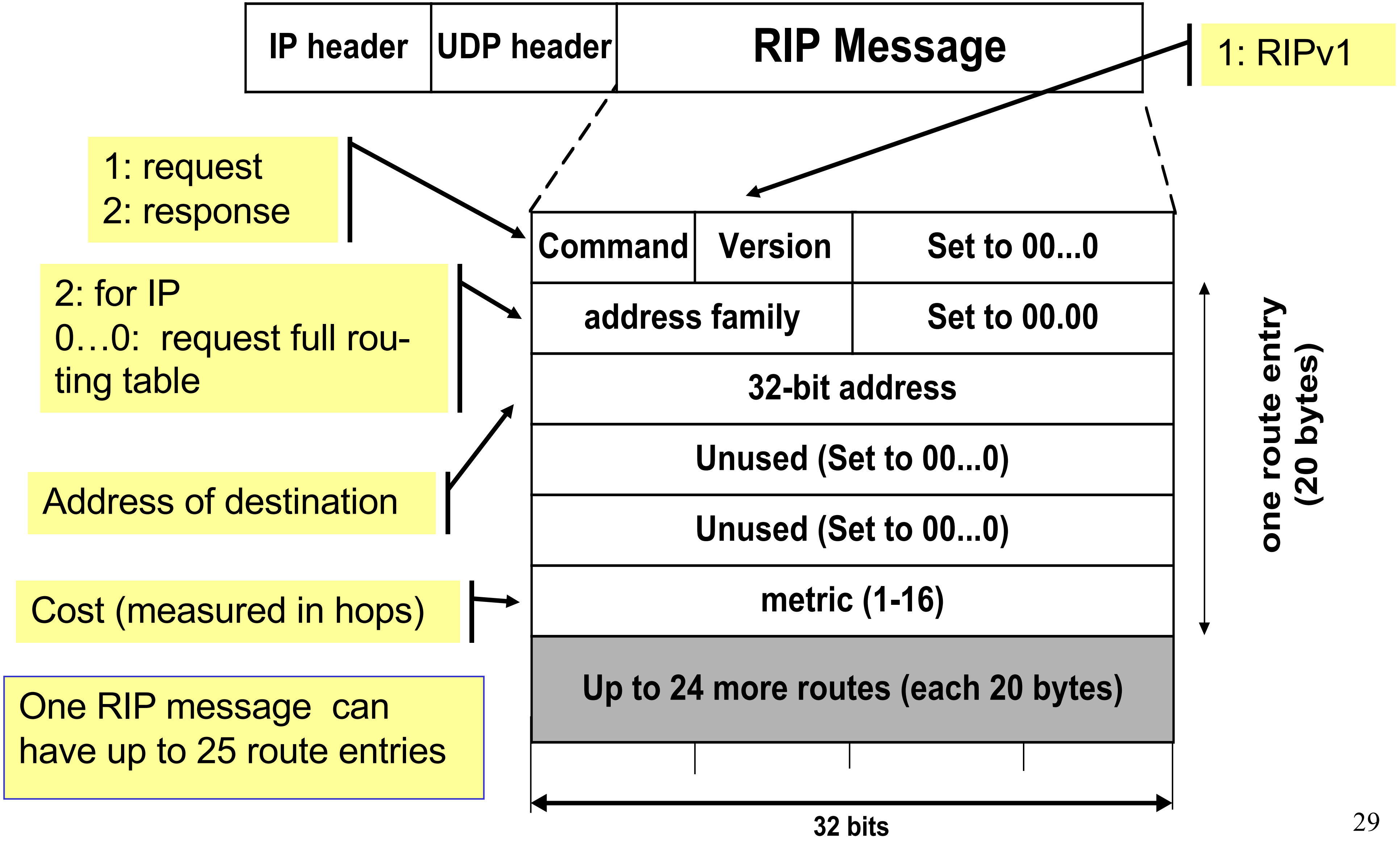
RIP - Routing Information Protocol

- A simple intradomain 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 precursor 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



1: RIPv1

1: request
2: response

2: for IP
0…0: request full routing table

Address of destination

Cost (measured in hops)

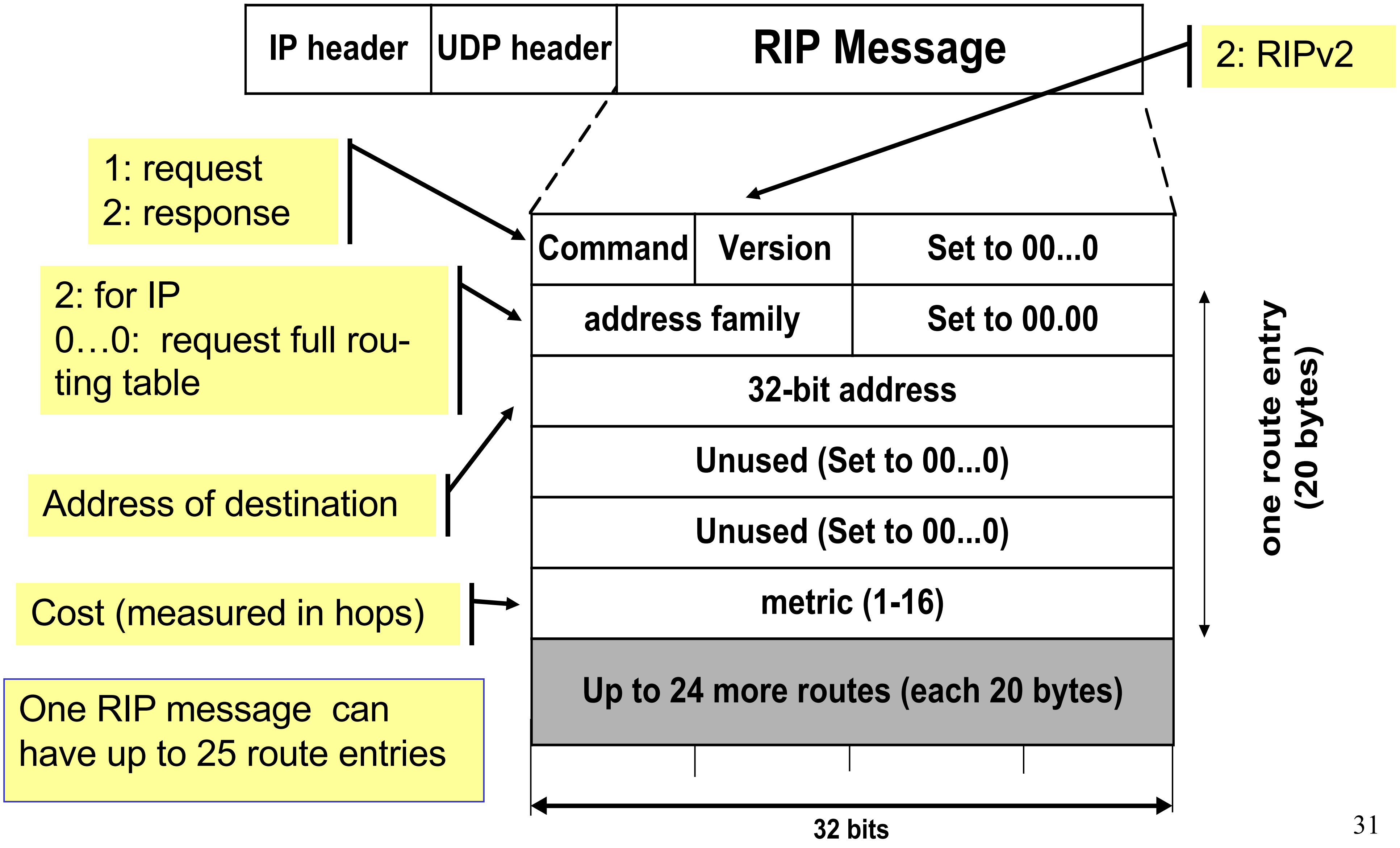
One RIP message can have up to 25 route entries

RIPv2

- RIPv2 is an extends RIPv1:
  - Subnet masks are carried in the route information
  - Authentication of routing messages
  - Route information carries better next-hop address if it exists
  - Exploites IP multicasting

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

RIPv2 Packet Format



IP header	UDP header	RIP Message

2: RIPv2

1: request
2: response

2: for IP
0…0: request full routing table

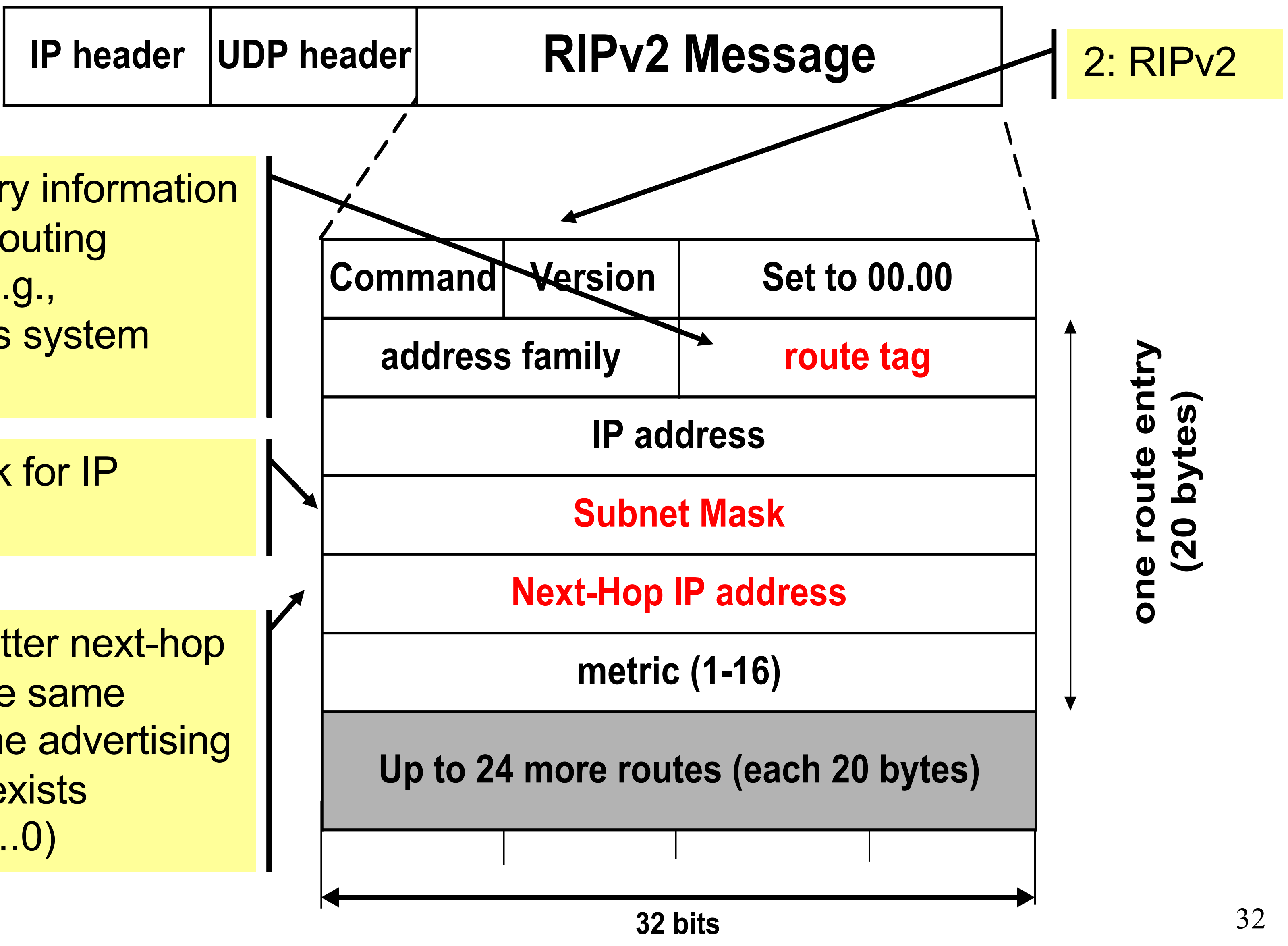
Address of destination

Cost (measured in hops)

One RIP message can have up to 25 route entries

Command	Version	Set to 00...0
address family		Set to 00.00
32-bit address		
Unused (Set to 00...0)		
Unused (Set to 00...0)		
metric (1-16)		
Up to 24 more routes (each 20 bytes)		

RIPv2 Packet Format



IP header | UDP header | RIPv2 Message

2: RIPv2

Command | Version | Set to 00.00

address family | route tag

IP address

Subnet Mask

Next-Hop IP address

metric (1-16)

Up to 24 more routes (each 20 bytes)

one route entry (20 bytes)

32 bits

Used to carry information from other routing protocols (e.g., autonomous system number)

Subnet mask for IP address

Identifies a better next-hop address on the same subnet than the advertising router, if one exists (otherwise 0….0)

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

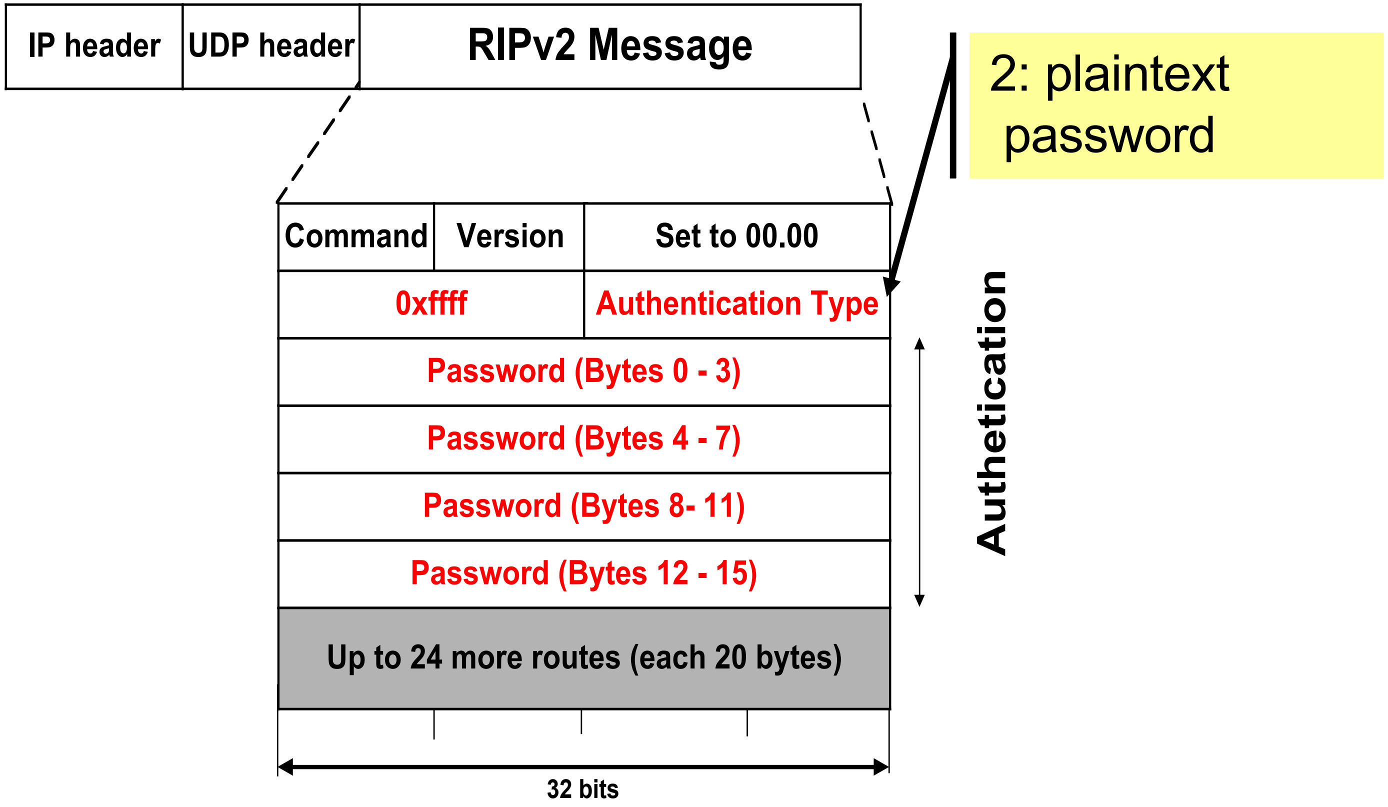
- **Initialization:** Send a **request packet** (command = 1, address family=0..0) on all interfaces:
    - RIPv1 uses broadcast if possible,
    - RIPv2 uses multicast address 224.0.0.9, if possible

  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 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