

L09 - IP Routing Introduction

Introduction to IP Routing

Static-, Default-, Dynamic-Routing, RIP
Classless/Classful Routing, Internet Routing Overview

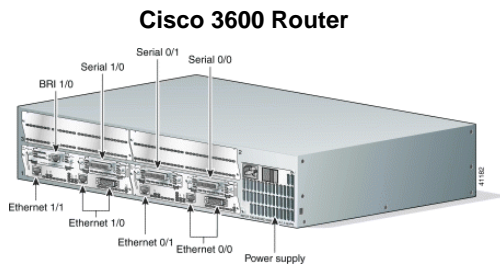
Agenda

- **Introduction to IP Routing**
 - Static Routing
 - Default Route
 - Dynamic Routing
- **RIP**
- **Classful versus Classless Routing**
- **Private Addresses and NAT**
- **Internet Routing**

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IP Router

- Initially Unix workstations with several network interface cards
- Today specialized hardware



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IP Routing

1

- **routing**
 - process of choosing a path over which to send IP datagram's
 - direct versus indirect delivery
 - depends on destination net-ID
 - net-ID equal to source net-ID -> direct delivery
 - net-ID unequal to source net-ID -> indirect delivery
 - IP hosts and routers take part in this process
 - IP hosts responsible for direct delivery of IP datagram's
 - IP hosts responsible for choosing a default router ("default gateway") as next hop in case of indirect delivery of IP datagram's
 - routers responsible for selecting the best path in a meshed network in case of indirect delivery of IP datagram's

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IP Routing

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- **indirect routing of IP datagram's**

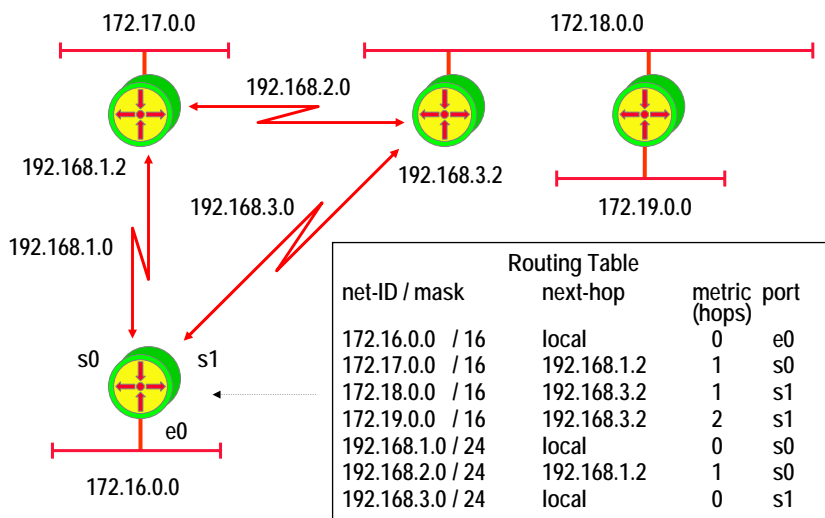
- is done by routers based on routing tables
 - routing table
 - database of known destinations
 - database contains
 - next hop router (and next hop MAC address in case of LAN)
 - outgoing port
 - metric (information how far away is a certain destination network)
 - time reference (information about the age of the table entry)
- for every known (or specified) destination network
- net-ID / subnet-mask

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Routing Table Example



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IP Routing Paradigm

- **Destination Based Routing**
 - source address is not taken into account for the forward decision
- **Hop by Hop Routing**
 - IP datagram's follow the path, which is pointed by the current state of the routing tables
- **Least Cost Routing**
 - normally only the best path is considered for forwarding of IP datagram's
 - alternate paths will not be used in order to reach a given destination
 - note:some methods allow load balancing if paths are equal

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IP Routing Types

- **routing can be either**
 - static
 - routing tables are preconfigured by network administrator
 - non-responsive to topology changes
 - can be labor intensive to set up and modify in complex networks
 - no overhead concerning CPU time and traffic
 - or dynamic
 - routing tables are dynamically updated with information received from other routers
 - responsive to topology changes
 - low maintenance labor cost
 - communication between routers is done by routing protocols using routing messages for their communication
 - routing messages need a certain percentage of bandwidth
 - dynamic routing need a certain percentage of CPU time of the router
 - that means overhead

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Static Routing

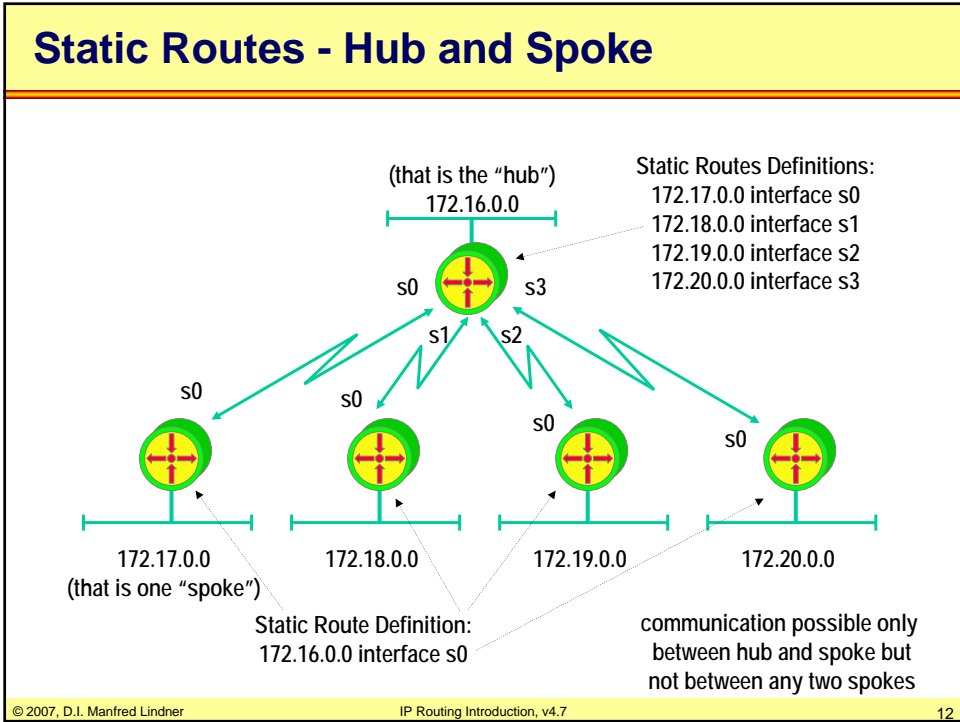
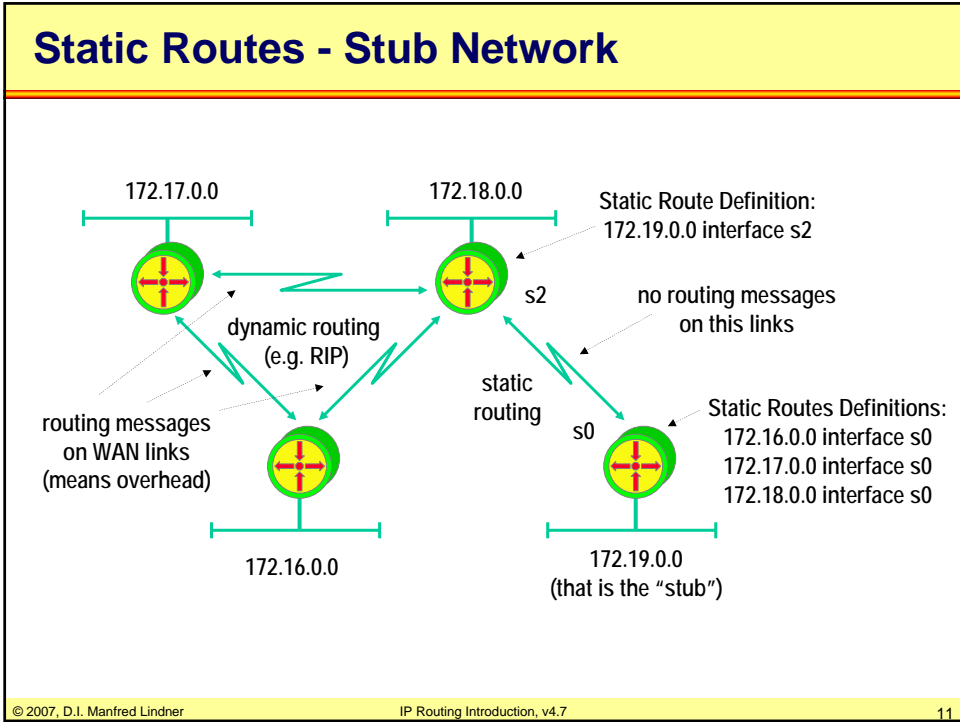
- **static routing**
 - preconfigured static routing tables
 - no overhead traffic
 - often sufficient in case of lack of any network redundancy
 - e.g. reaching stub networks
 - e.g. hub and spoke topology
 - but can be labor intensive to set up and modify in complex networks
 - overhead can be reduced by default route
 - sometimes only or preferred way in certain technologies
 - Dial on Demand Networks (e.g. X.25, ISDN, Frame Relay, ATM)
 - sometimes used for security reasons

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Default Route

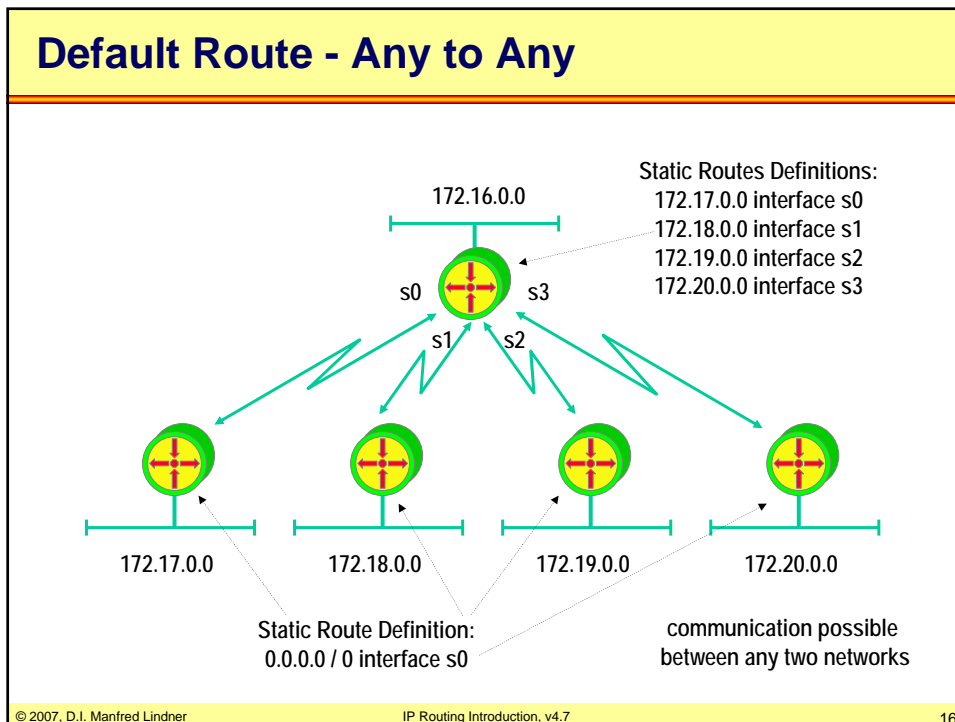
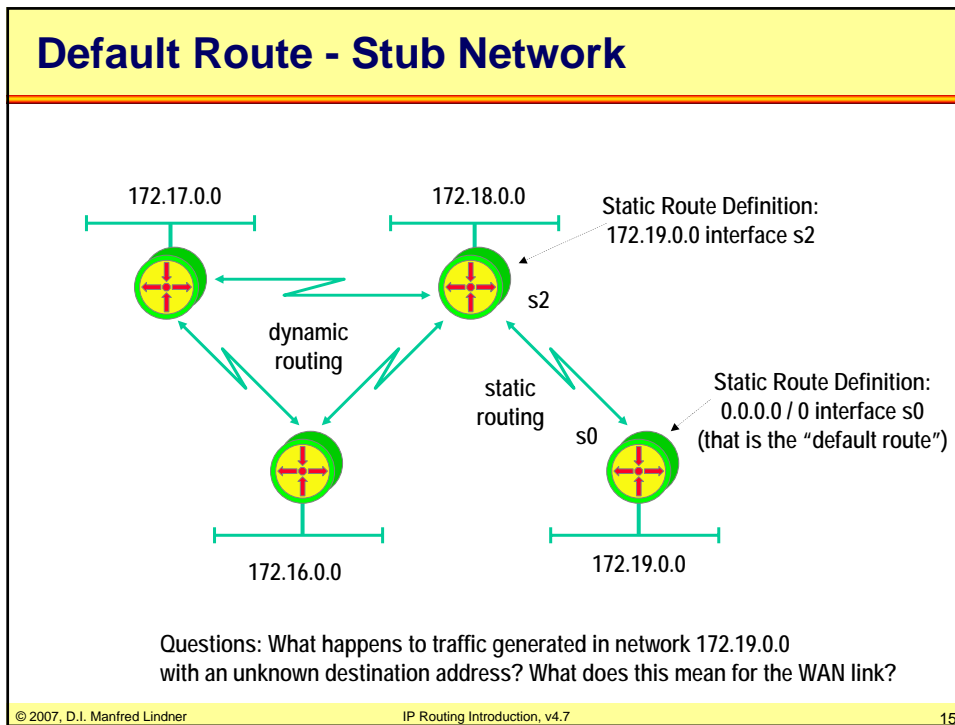
- **general routing principle**
 - traffic to destinations that are unknown to the router will be discarded by the router (ICMP message !!!)
 - behavior can be changed by default route
- **default routing principle**
 - traffic to destinations that are unknown to the router will be sent to a default route (default network)
 - implies that another router might know more networks
 - permits routers to carry less than full routing tables
 - default network marked with net-ID equal 0.0.0.0
 - in routing tables
 - in routing updates used by dynamic routing

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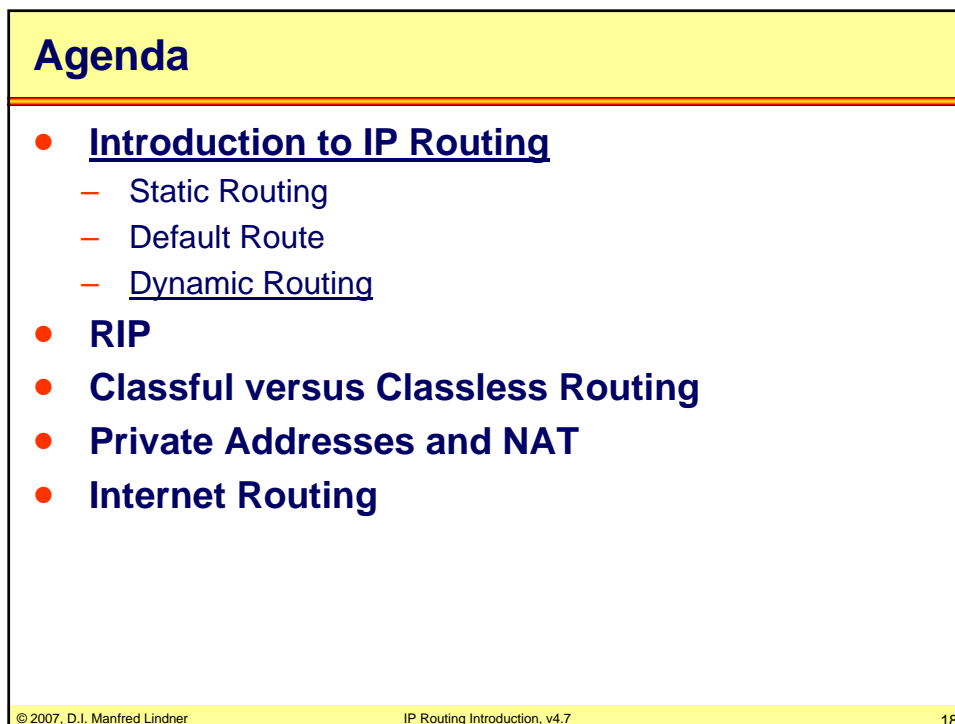
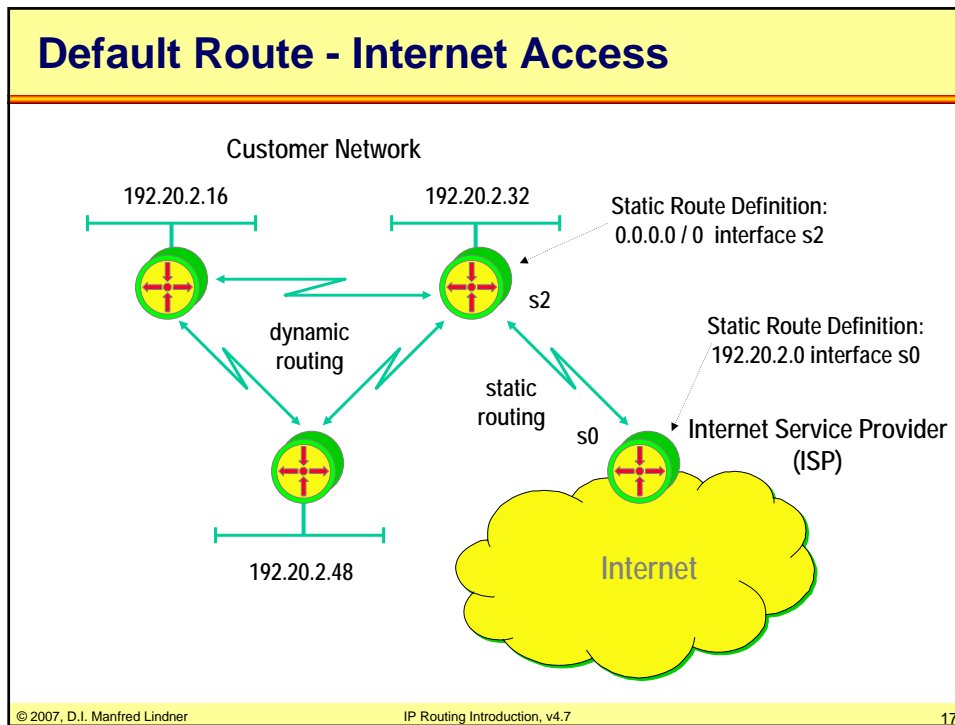
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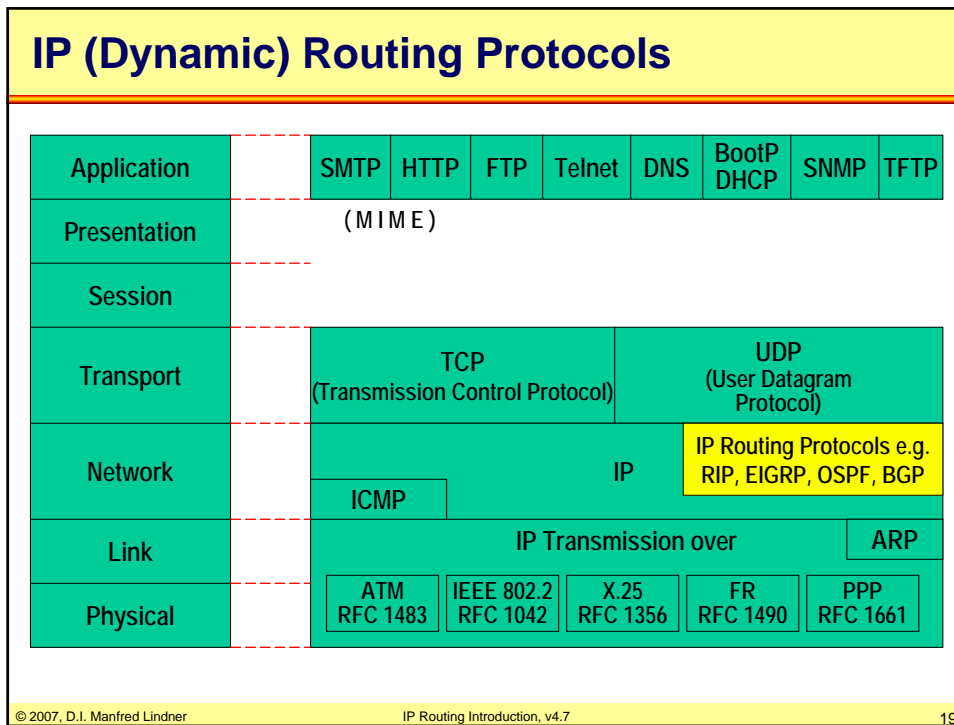
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Dynamic Routing

- **dynamic routing**
 - routing tables are dynamically updated with information from other routers done by routing protocols
 - routing protocol
 - discovers current network topology
 - determines the best path to every reachable network
 - stores information about best paths in the routing table
 - metric information is necessary for best path decision
 - in most cases summarization along the a given path of static preconfigured values
 - hops, interface cost, interface bandwidth, interface delay, etc.
 - two basic technologies
 - distance vector, link state

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Distance Vector Protocols

1

- **routing table is sent periodically to all immediately-neighboring routers (IP limited broadcast)**
 - after power-up routing table contains information about local attached networks only
- **incoming updates are checked for changes**
 - new networks, metric change of already known networks, etc.
- **own routing table is adapted accordingly**
 - changes announced by next periodic routing update

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Distance Vector Protocols

2

- **metric information based on hops (distance between hops)**
- **limited view of topology**
 - routers view is based on its routing table only
 - exact view how to reach local neighbors
 - but topology behind neighbors is hidden
 - based on signpost principle only
- **several procedures necessary**
 - to solve problems caused by limited view
 - e.g. count to infinity, routing loops
 - to reduce convergence time
 - time to reach consistent routing tables after topology change

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Distance Vector Protocols

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- **some usual procedures for to solve inherent problems**
 - maximum hop count
 - split horizon, poison reverse
 - triggered update
 - hold down, route poisoning
- **distance vector protocols examples**
 - RIP, RIPv2 (Routing Information Protocol)
 - IGRP (Cisco, Interior Gateway Routing Protocol)
 - IPX RIP (Novell)
 - AppleTalk RTMP (Routing Table Maintenance Protocol)

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Link State Protocols

1

- **routers have a global view of network topology**
 - exact knowledge about all routers, links and their costs (metric) of a network stored in topology database (“roadmap”)
 - roadmap principle
- **routing table entries are based**
 - on computation of own router-resident topology database
- **SPF computation**
 - Shortest-Path-First (Dijkstra) algorithm to find lowest cost path to every destination network
 - lowest cost path is stored in routing table

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Link State Protocols

2

- **topology changes (link up or down, link state)**
 - are recognized by routers responsible for supervising those links
 - are flooded by responsible routers to the whole network (**L**ink **S**tate **A**dvertisements, LSAs)
- **flooding**
 - is a controlled multicast procedure to guarantee that every router gets corresponding LSA information as fast as possible
 - is used to update network topology database and hence may lead to change of routing table

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Link State Protocols

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- **with the lack of topology changes**
 - local hello messages are used to supervise local links (to test reachability of immediate-neighbor routers)
 - therefore less routing overhead concerning link bandwidth than periodic updates of distance vector protocols
- **but more network load is caused by such a routing protocol**
 - during connection of former separate parts of the network
 - topology database synchronization

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L09 - IP Routing Introduction**Link State Protocols****4**

- **link state protocols examples**

- OSPF (Open Shortest Path First)
- Integrated IS-IS (IP world)
 - note: Integrated IS-IS takes another approach to handle large networks (topic outside the scope of this course)
- IS-IS (OSI world)
- PNNI (in the ATM world)
- APPN (IBM world),
- NLSP (Novell world)

Routing Protocol Comparison

Routing Protocol	Complexity	Max. Size	Convergence Time	Reliability	Protocol Traffic
RIP	very simple	16 Hops	High (minutes)	Not absolutely loop-safe	High
RIPv2	very simple	16 Hops	High (minutes)	Not absolutely loop-safe	High
IGRP	simple	X	High (minutes)	Medium	High
EIGRP	complex	X	Fast (seconds)	High	Medium
OSPF	very complex	Thousands of Routers	Fast (seconds)	High	Low
IS-IS	complex	Thousands of Routers	Fast (seconds)	High	Low
BGP-4	very complex	more than 100,000 networks	Middle	Very High	Low

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RIP - Routing Information Protocol

- **RIP is an Interior Gateway Protocol (IGP)**
 - due to inherent administrative traffic, RIP suits best for smaller networks
 - routing decisions are based upon hop count measure
- **RIP was initially released as part of BSD 4.2 UNIX**
 - hence RIP got wide-spread availability
- **RIP is specified in RFC 1058**
 - RFC category „historic“

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RIP Principles

1

- **RIP is a Distance Vector Protocol**
- **after booting the non-volatile configuration-memory tells a RIP router to which networks it is directly connected**
- **this information is loaded into the routing table**
- **basically the routing table contains**
 - the net-ID of the directly connected networks
 - and the associated distance (in hops) to them
directly connected networks have hop-count = 0

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RIP Principles

2

- **then, this routing table is distributed periodically (every 30 seconds) to all connected networks = routing update**
 - using a broadcast MAC-frame containing
 - an IP-broadcast datagram containing
 - an UDP-datagram with port number 520
 - metric entries of the routing table will be risen by the distance of the interface where transmitted-> in case of RIP -> distance is one -> hop count
- **directly reachable routers**
 - receive this message, update their own routing tables,
 - and hence generate their own routing updates reflecting any corresponding modifications

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RIP Principles

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- **after a specific time**
 - all routers know about all network addresses of the whole network
- **if different routing updates (from different routers) contain the same net-ID**
 - then there are redundant paths to this network
 - only the path with the lowest hop-count is stored in the routing-table
 - on receiving equal hop counts, the net-ID of the earlier one will be selected (and all other associated data)
- **hence, between each two networks exists exactly one active path**

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RIP Principles

4

- **all routing table's net-IDs are periodically refreshed by routing-update messages**
- **if a routing update tells a better metric than that one currently stored in the table**
 - the routing table must be updated with this new information
 - this update does not take care about if the sender of this routing-update is also the router which is currently selected as next hop
 - "good news" are quickly adapted
 - RIP trusts good news from any source ("trusted news")

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RIP Principles

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- **if a routing update tells a worse metric than that one currently stored in the table**
 - the routing table must be updated with this new information if the sender of this routing-update is the next-hop router for this network
 - that is: the actual VECTOR in the table is identical with the source address of the routing-update
 - routing-updates from other routers than that one currently registered in the table are ignored
- **summary: routing-updates with worse metric is only relevant if it comes from that router mentioned in the actual table entry**

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RIP Principles

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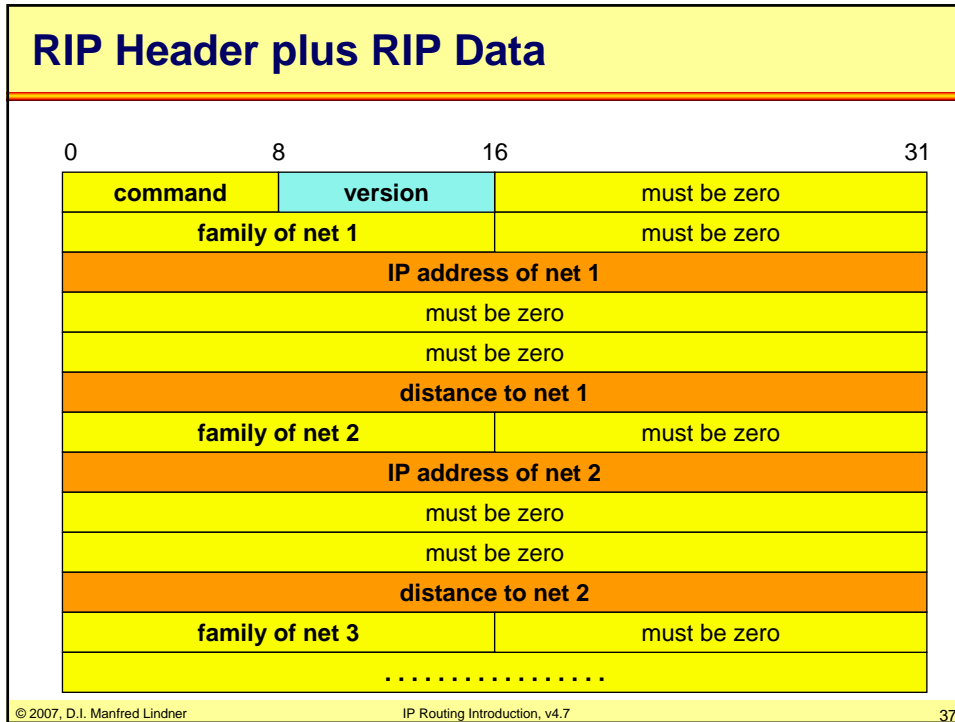
- **when a routing table entry is not refreshed within 180sec**
 - this entry is considered to be obsolete
 - possible reasons: router-failure, network not reachable
 - without special mechanism
 - we have to wait for 180sec at least in order that all routers have consistent routing tables again
 - improvement by a special network-unreachable message
 - which is distributed to all other routers
 - it takes 180sec in the worst case
 - slow adaptation of "bad news"
 - during these 180sec, forwarding of IP datagram's is done according to the routing table !!

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- ### RIP Header and Data Fields
- **command**
 - Request (1): Router or Host requests for a routing update
 - Response (2): response to a request but also used for periodic routing-updates
 - **version**
 - version number of the RIP protocol (= 1 for RIP)
 - **family of net x**
 - because RIP is not only build for IP (in the case of IP: 2)
 - **IP address of net x**
 - IP-address of the announced network x
 - **distance to net x**
 - = hop-count to net x
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RIP Summary

to give a clearer idea of the RIP method:

- every router holds a directory, pointing to other networks (VECTOR entries) without knowing the exact location of them
- datagram's follow these "signposts" and finally reach their targets
- information about these signposts is based upon rumours (routing-updates)

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Creating Routing Tables



Routing table A

Net	Hops	Hop-ID
1	0	direct
2	0	direct

Routing table B

Net	Hops	Hop-ID
2	0	direct
3	0	direct

Situation after booting

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Creating Routing Tables

Router A Router B

Net 1 Net 2 Net 3

Net	Hops
1	1
2	1

Router A: routing update to net 2

values used by router B to actualise its routing table

Routing table A

Net	Hops	Hop-ID
1	0	direct
2	0	direct

Routing table B

Net	Hops	Hop-ID
1	1	2.A
2	0	direct
3	0	direct

Situation after distribution of A's routing update

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Creating Routing Tables

Router A Router B

Net 1 Net 2 Net 3

Net	Hops
1	2
2	1
3	1

Router B: routing update to net 2

Routing table A

Net	Hops	Hop-ID
1	0	direct
2	0	direct
3	1	2.B

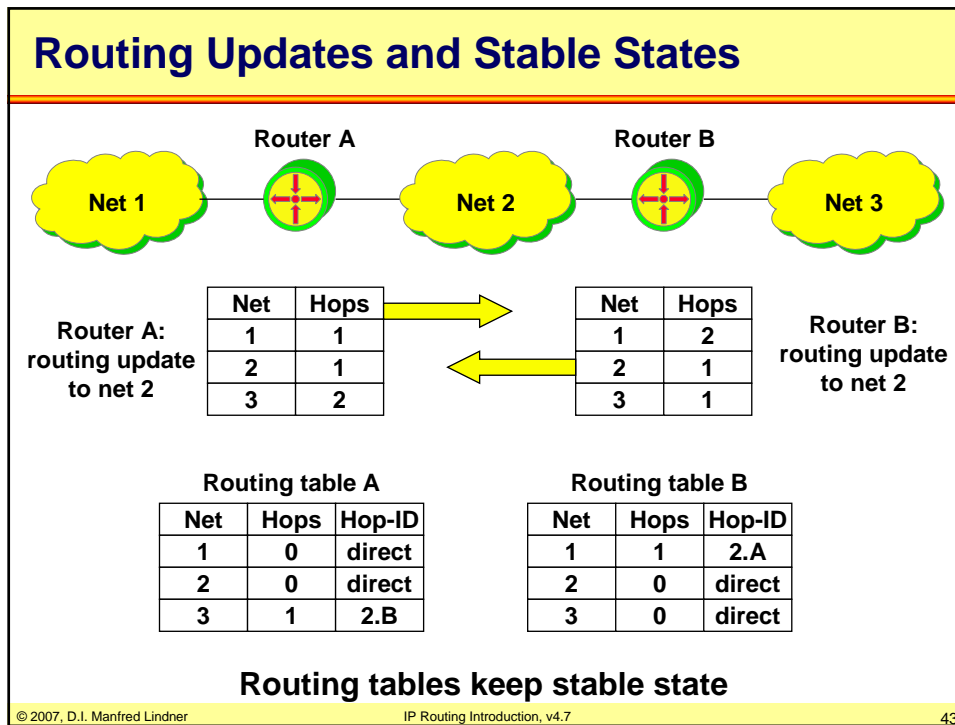
Routing table B

Net	Hops	Hop-ID
1	1	2.A
2	0	direct
3	0	direct

Situation after distribution of B's routing update

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- ### RIP-Problems
- **slow convergence**
 - due to 30s routing-update interval and 180s aging timeout
 - **routing-loops cannot be safely detected**
 - because routing updates are obligatory ("Trusted Information Principle" of RIP)
 - **so, failures and routing-loops keep large networks inconsistent for a long period of time**
 - datagram's circle around along redundant paths
 - "Count to Infinity" -problem
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Count to Infinity 1

Router A:
routing update
to net 2

Net	Hops
1	1
2	1
3	2

Router B:
routing update
to net 2

Net	Hops
1	2
2	1
3	1

Routing table A

Net	Hops	Hop-ID
1	0	direct
2	0	direct
3	1	2.B

Routing table B

Net	Hops	Hop-ID
1	1	2.A
2	0	direct
3	0	direct

Initial situation

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Count to Infinity 2

Router A

Router B

Net 1

Net 2

Net 3

Routing table A

Net	Hops	Hop-ID
1	0	direct
2	0	direct
3	1	2.B

Routing table B

Net	Hops	Hop-ID
1	1	2.A
2	0	direct
3	?	?

Failure: net 3 unreachable

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Count to Infinity 3

Router A: routing update to net 2

Net	Hops
1	1
2	1
3	2

Net	Hops	Hop-ID
1	0	direct
2	0	direct
3	1	2.B

Net	Hops	Hop-ID
1	1	2.A
2	0	direct
3	2	2.A

Situation after sending A's routing update

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Count to Infinity 4

Router B: routing update to net 2

Net	Hops
1	2
2	1
3	3

Net	Hops	Hop-ID
1	0	direct
2	0	direct
3	3	2.B

Net	Hops	Hop-ID
1	1	2.A
2	0	direct
3	2	2.A

Situation after sending B's routing update

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Count to Infinity

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Router A:
routing update
to net 2

Net	Hops
1	1
2	1
3	4

→

problem: routing updates do not
contain explicit VECTOR-
information !!

(Vector is given only implicitly
through source address)

Routing table A

Net	Hops	Hop-ID
1	0	direct
2	0	direct
3	3	2.B

Routing table B

Net	Hops	Hop-ID
1	1	2.A
2	0	direct
3	4	2.A

Situation after sending A's next routing update

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Solutions against Count to Infinity

- **problem:** good news are distributed faster than bad news
 - the information of a path with lower hop-count is distributed every 30 seconds
 - the information of a network-failure is distributed at least after 180 (or later)
- **remedy:**
 - Maximum Hop Count
 - Split Horizon
 - Poison Reverse
 - Triggered Update
 - Hold Down

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Maximum Hop Count

- **maximal distance between each two subnets is limited to 16**
 - hop count between two end-systems cannot exceed 15
- **a DISTANCE-value of 16 in the routing-table means that the corresponding network is not reachable**
 - using hop count = 16 in a routing update allows a router to indicate the failure of a network
 - we have not to age out this entry in all routing tables hence waiting at least for 180 s
 - IP-datagram's with a net-ID pointing to such an entry are discarded by the router and additionally a ICMP message "network unreachable" is generated

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Split Horizon

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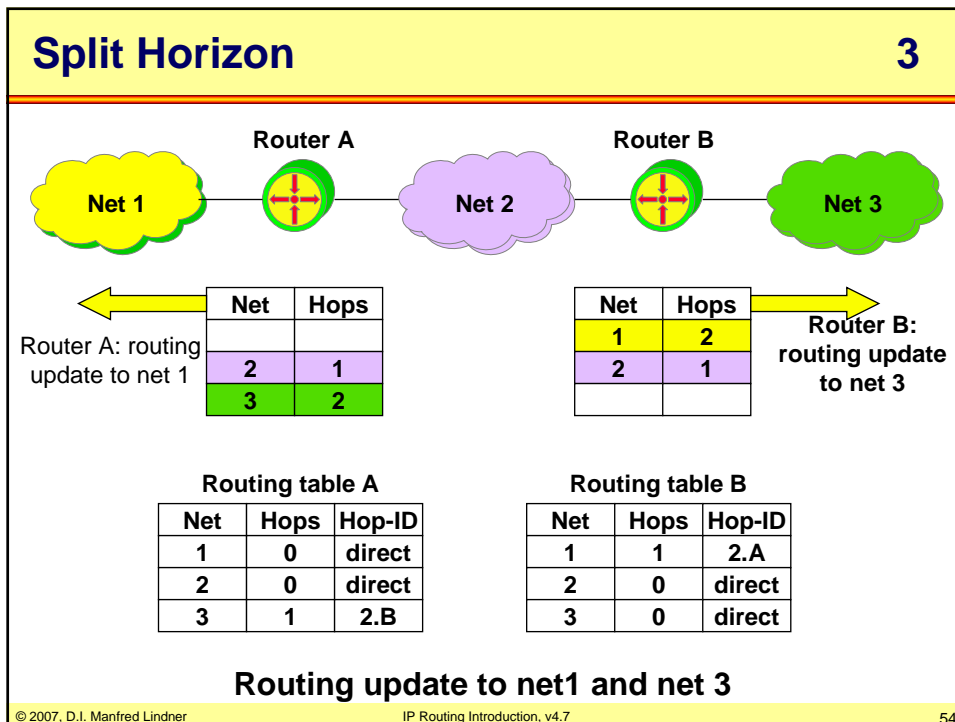
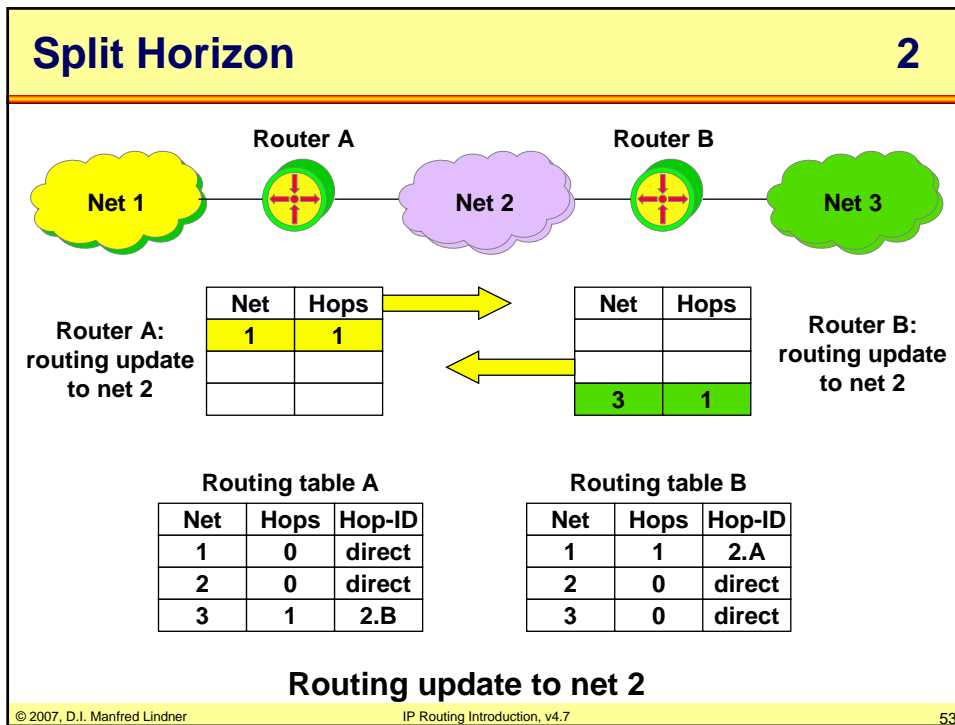
- **Maximum Hop Count technique alone (counting to 16) does not avoid routing-loops !**
- **to overcome routing-loops and also slow-convergence, Split-Horizon has been introduced**
 - prevents router from sending information about reachability of networks in that direction from where the information originally came
- **exception of this rule:**
 - if the router knows a better path

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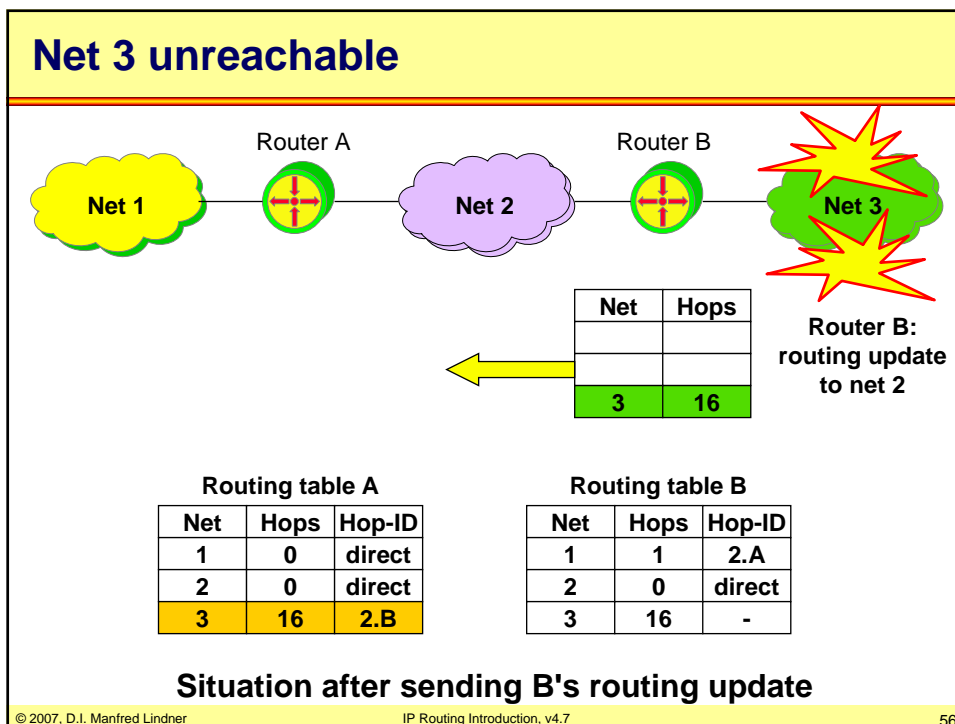
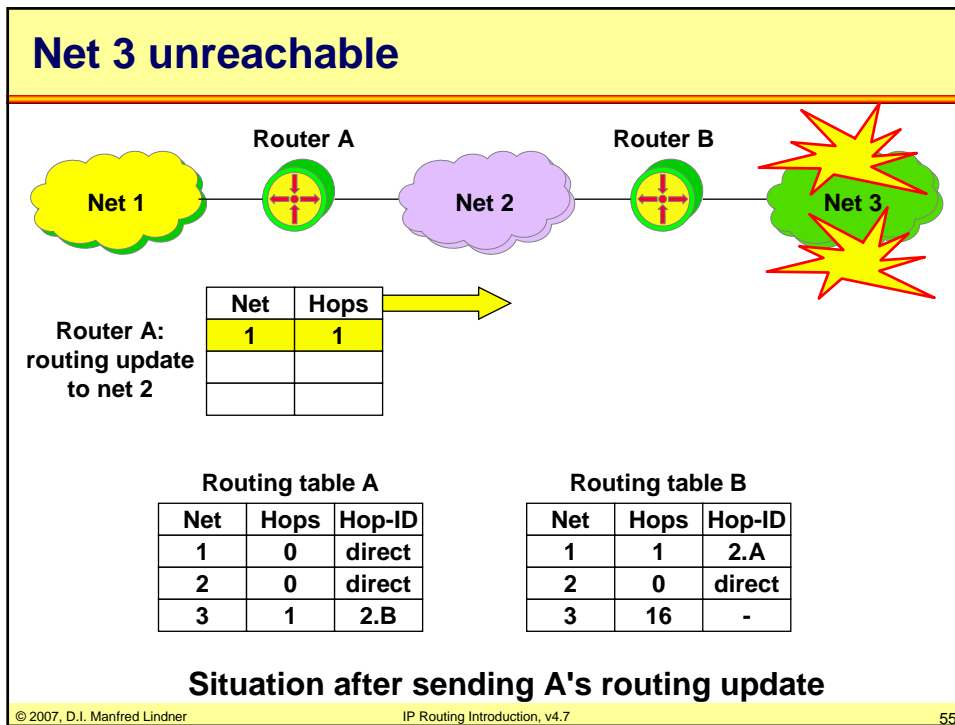
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Split Horizon Facts

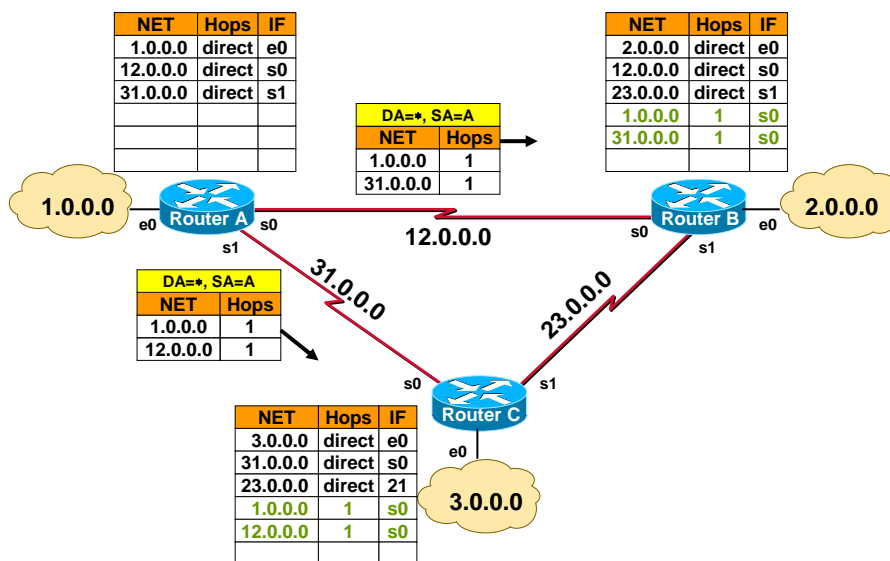
- Don't tell neighbour of routes that you learned from this neighbour
- That's what humans (almost) always do:
 - Don't tell me what I have told you!
- Using split horizon a router will not send information about routes he isn't really aware of
- the convergence time
 - is reduced to the time of failure-detection (180 s)
 - note: method of Maximum Hop Count alone would take 16 x 30 s = 480 s in the worst case

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RIP At Work (Update Router A)

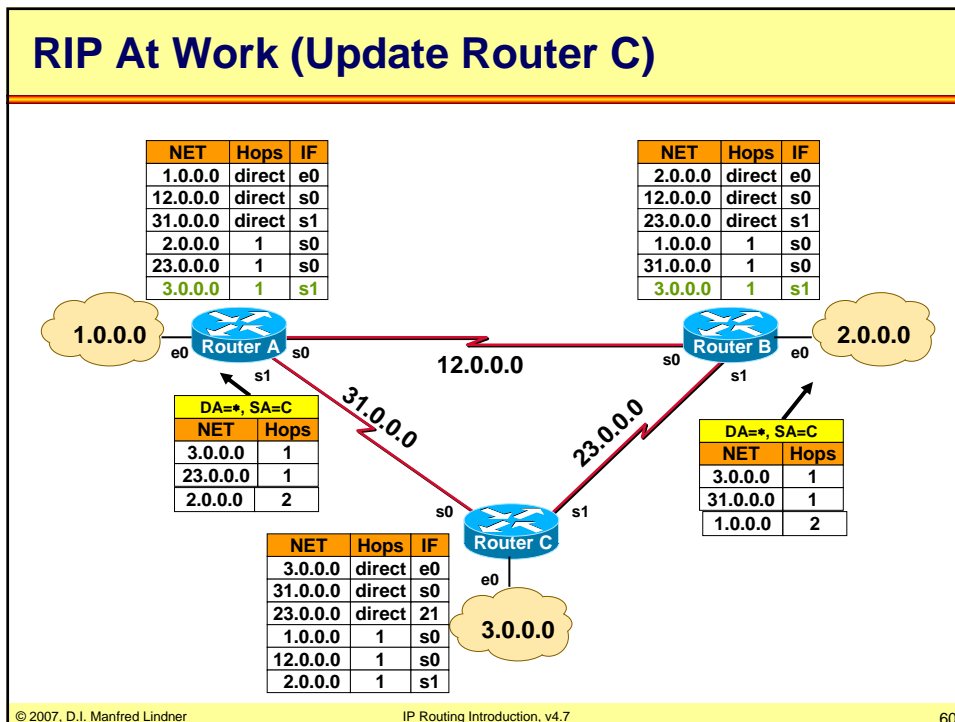
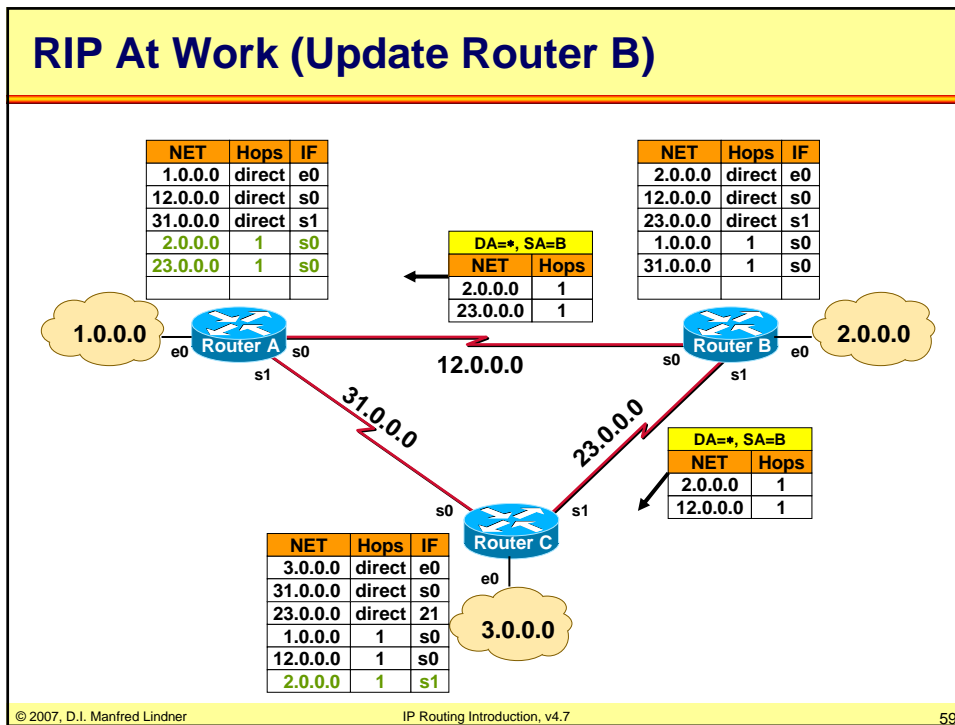


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Poison Reverse **1**

- **alternative method against routing loops and slow convergence: Poison Reverse**
- **router sends not-reachability messages (= "poison") via routing-updates in the direction from which the information about this network originally came**
- **so the convergence time is reduced to the time of failure-detection (180 s)**
 - method of Maximum Hop Count would take $16 \times 30 \text{ s} = 480 \text{ s}$!

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Poison Reverse **2**

Router A:
routing update
to net 2

Net	Hops
1	1
2	16
3	16

Router B:
routing update
to net 2

Net	Hops
1	16
2	16
3	1

Routing table A

Net	Hops	Hop-ID
1	0	direct
2	0	direct
3	1	2.B

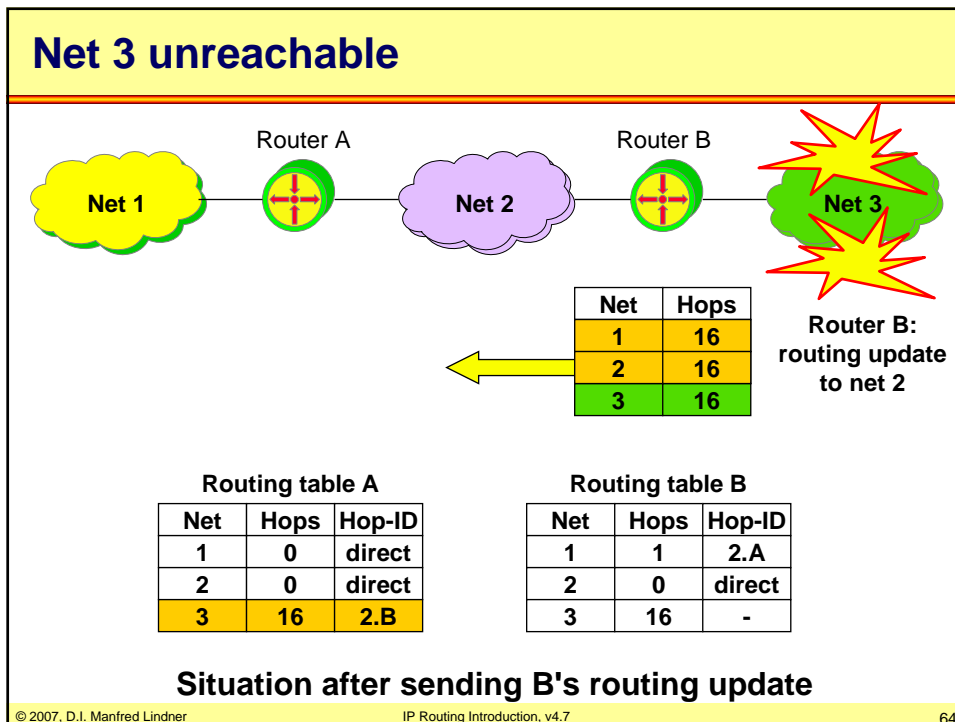
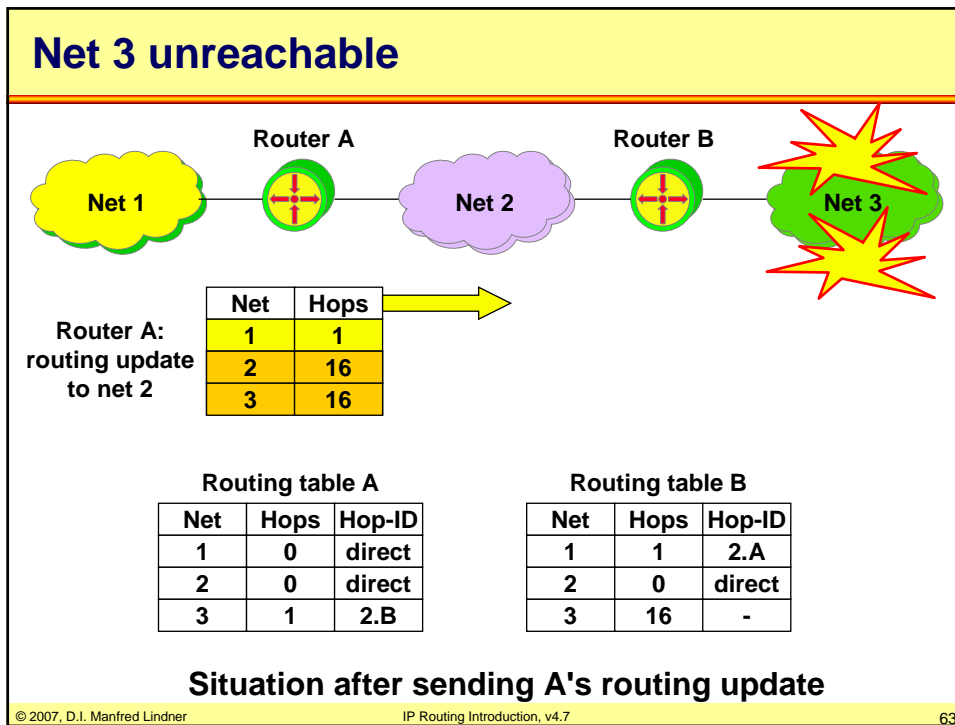
Routing table B

Net	Hops	Hop-ID
1	1	2.A
2	0	direct
3	0	direct

Routing update to net1 and net 2

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Triggered Update

- **Triggered Update has been introduced in order to speed up the convergence time**
- **after notice of a network-failure the router generates immediately a routing-update to indicate this failure**
 - setting hop-count = 16
 - note: the router does not wait for the expiration of the 30 s
- **Triggered Update can also be used when other events occur (e.g. additional links)**
- **Triggered Update without employing additional methods (like Split Horizon) cannot avoid routing-loops**

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Hold Down

- **Split Horizon is a good means to avoid temporary routing-loops and to improve the convergence time in simple network topologies**
- **complex network topologies require an additional tool to avoid temporary routing-loops:**
Hold Down
- **if a router gets information about a network failure, it ignores further information about that network from other routers for a specific duration of time**
 - typically 240 seconds

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Hold Down

- **basic idea:**

- network-failure message requires a specific amount of time to spread across the whole network (like a wave)
- with Hold Down, all routers get the chance to receive the network-failure message
- steady-state will be awaited to avoid inconsistent routing-tables and routing-loops

- **disadvantages of Hold Down**

- longer convergence time...
- ...can be a drawback at all (in special cases)

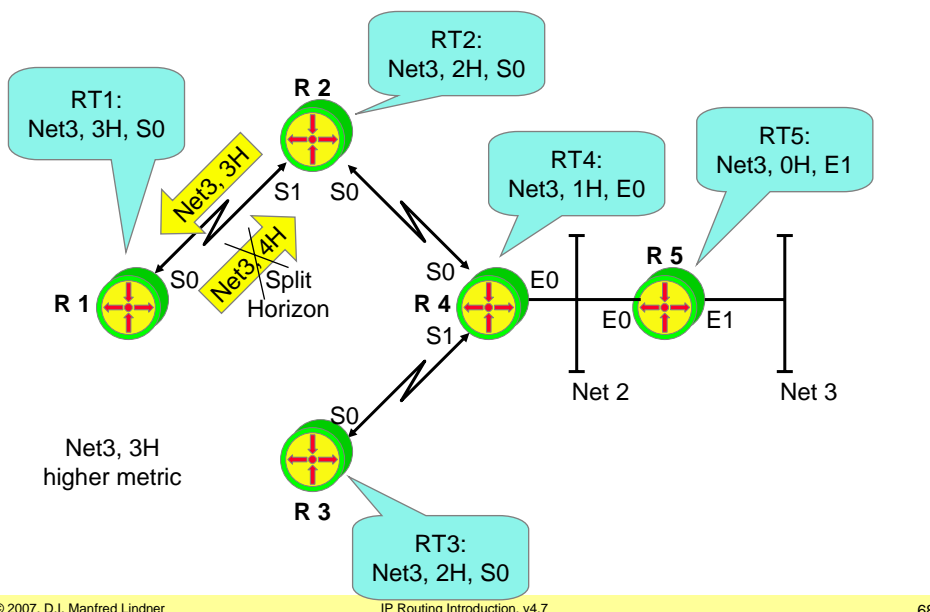
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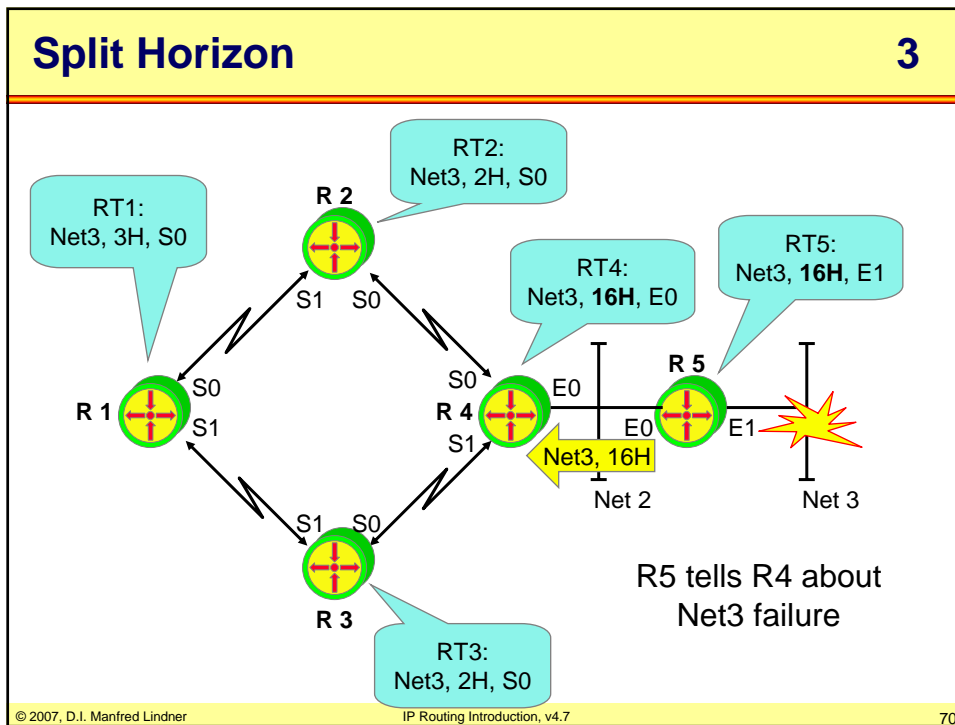
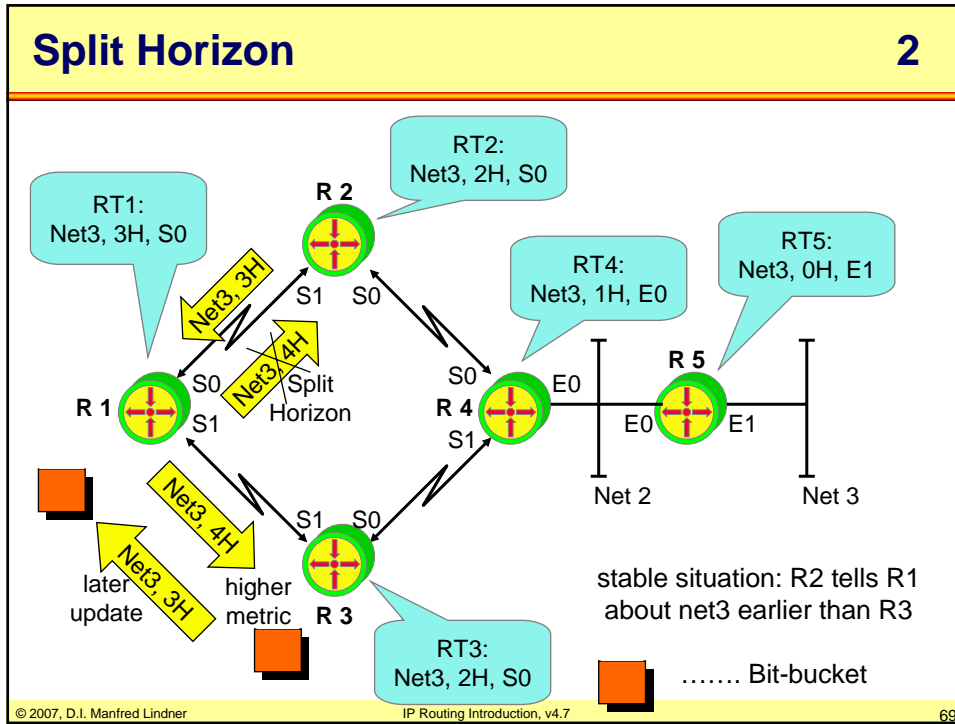
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Split Horizon

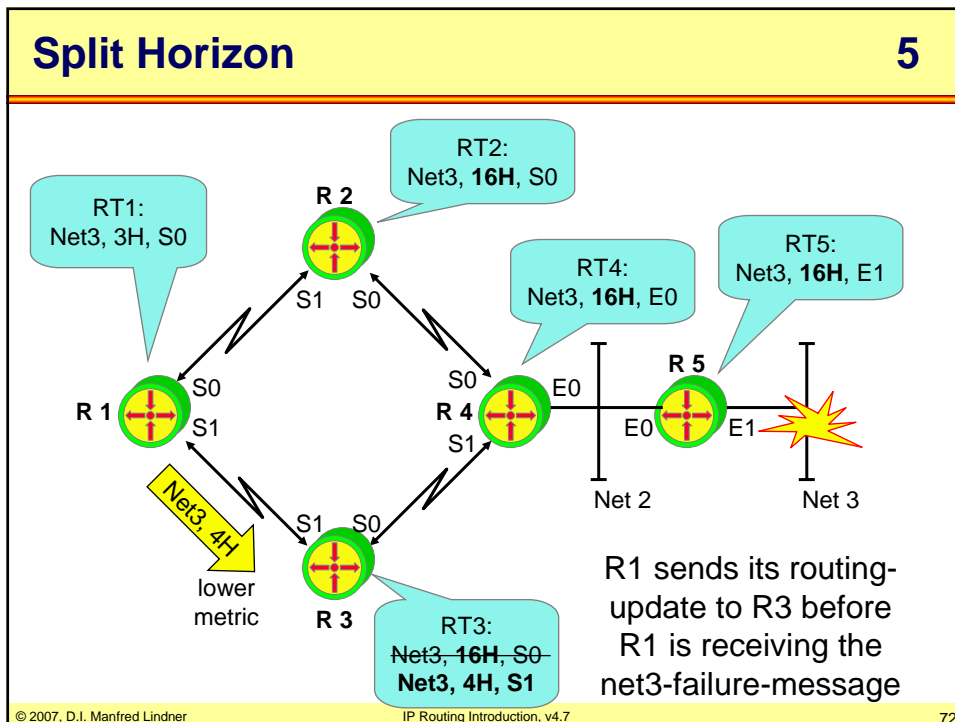
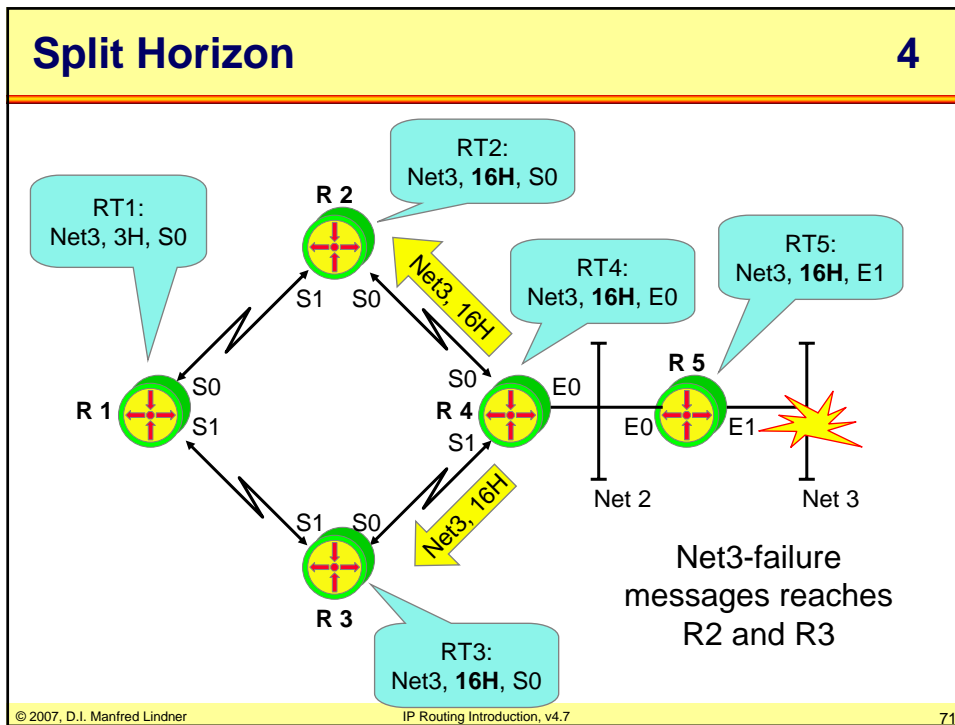
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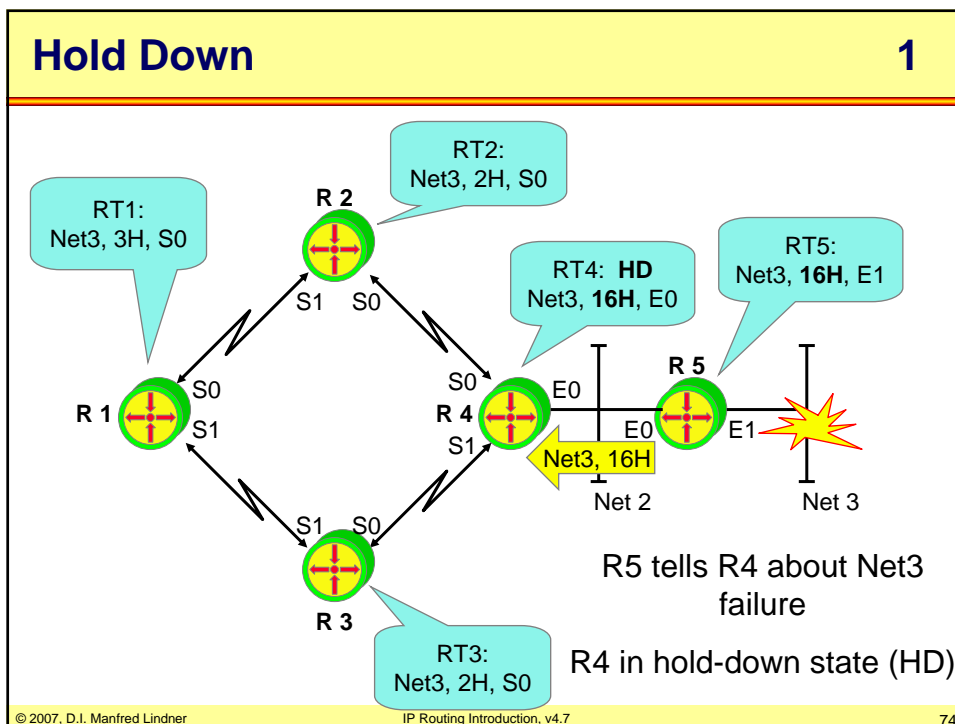
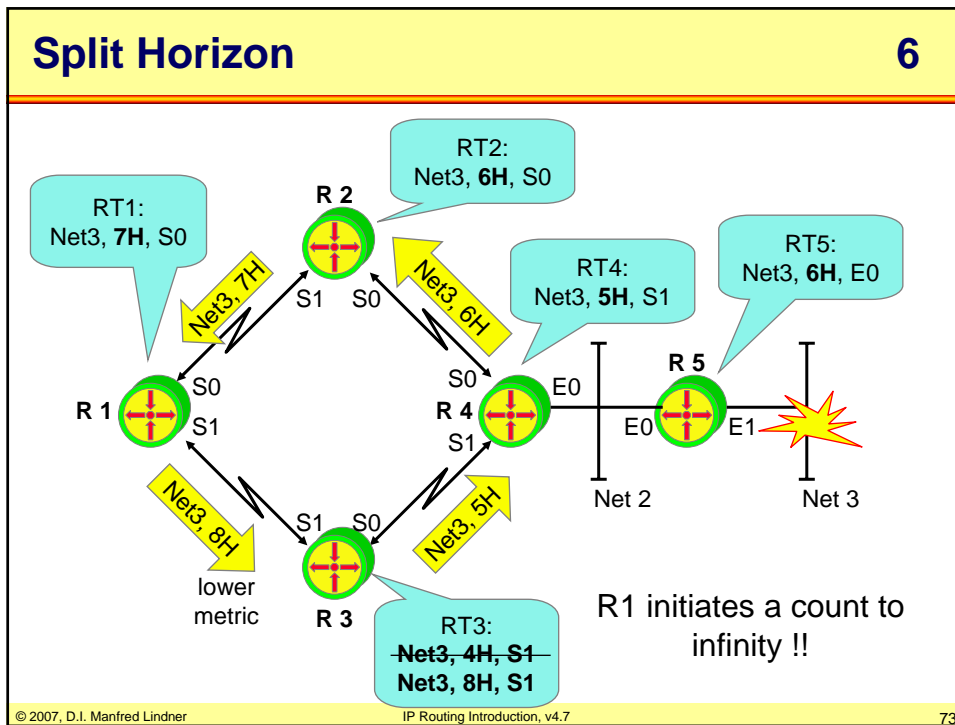
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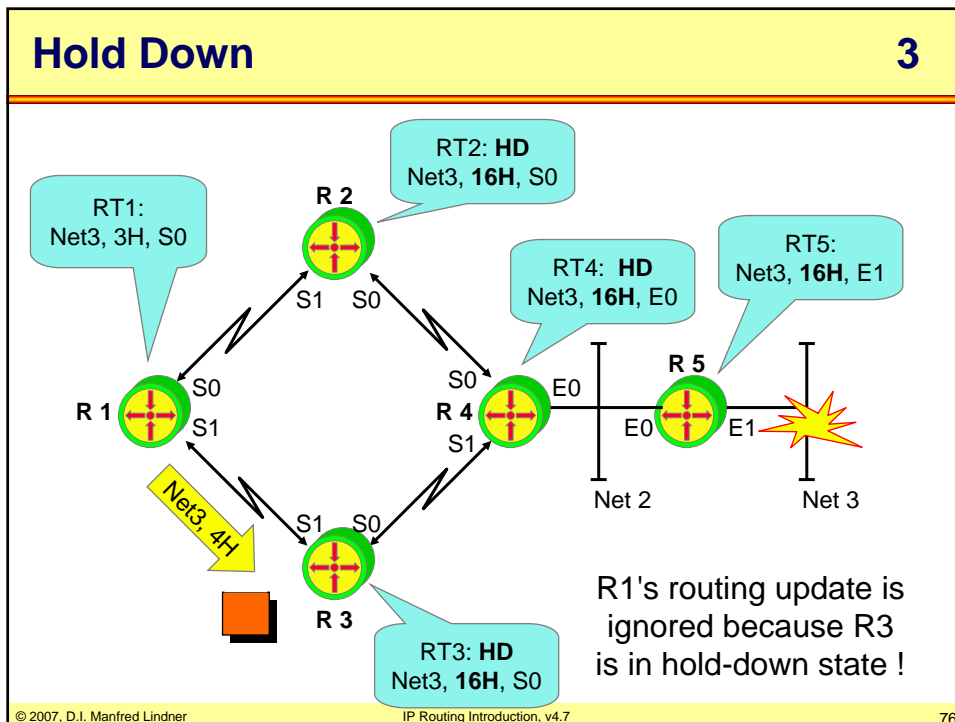
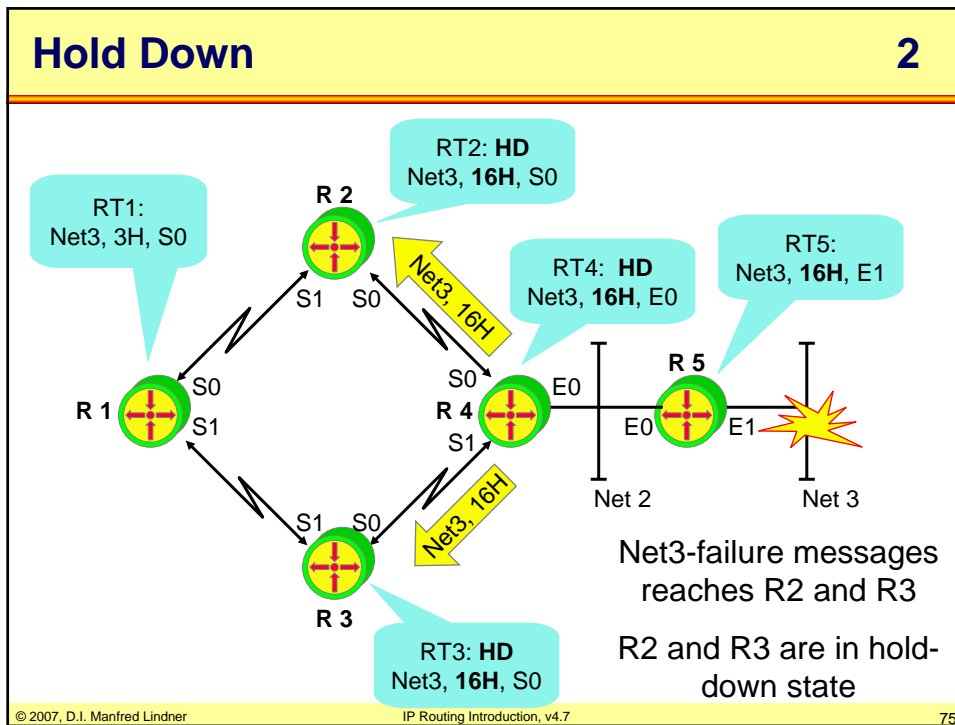
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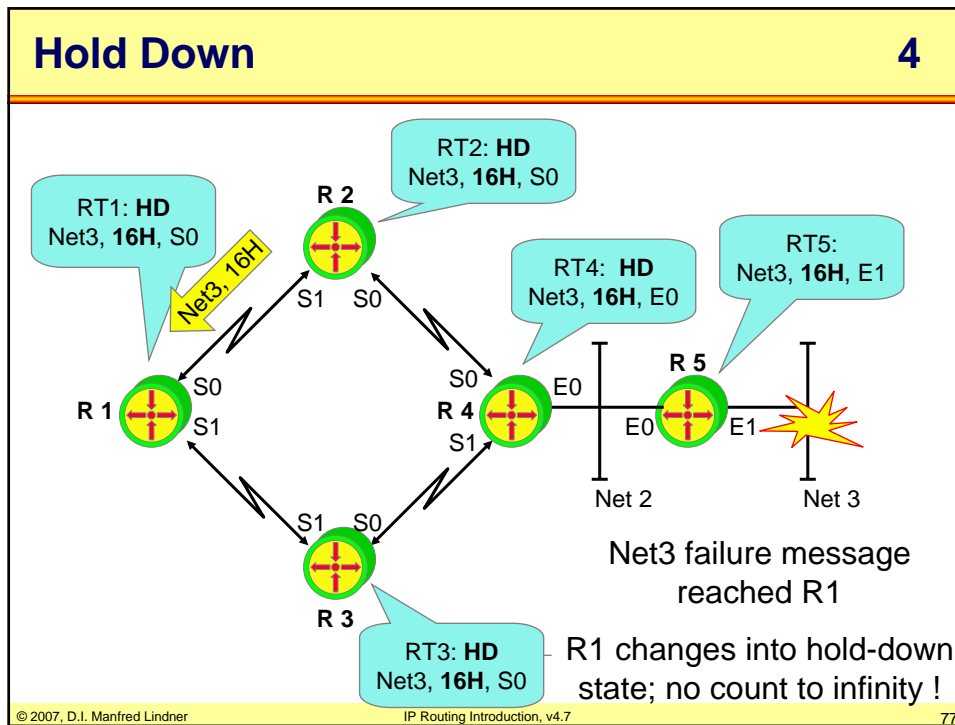
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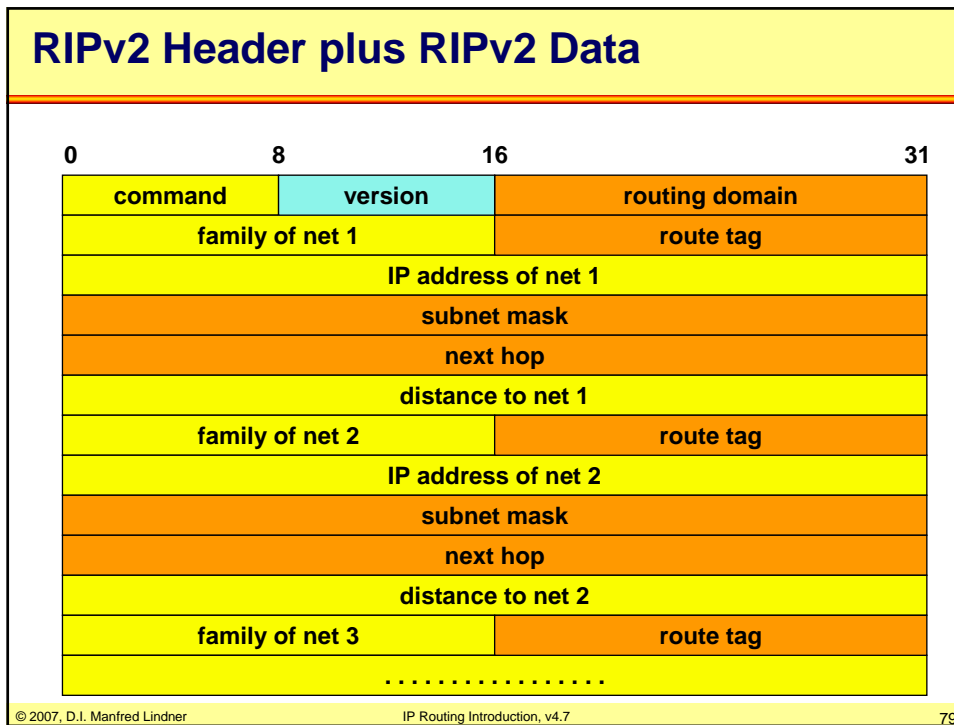


RIP Version 2

- **RFC 2453 specifies a new, extended RIP version:**
 - RIPv2 is RFC category “Standard”
 - RIPv1 is RFC category “Historic”
- **RIPv2 is an alternative choice to OSPF**
- **RIPv2 utilizes the unused fields of the RIPv1 message-format**
- **several new features are supported:**
 - routing domains and route tags
 - transmission of subnet-masks
 - transmission of next hop redirect information
 - authentication

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Message Fields of RIPv2 1

- **version = 2 (RIPv2)**
- **IP address of net x, distance to net x, command fields**
 - have the same meaning as for RIPv1
- **subnet mask**
 - contains the subnet-mask to the "IP address"-field
 - now discontinuous subnetting and variable length subnet masks (VLSM) are supported
- **RIPv2 is a classless routing protocol**

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Message Fields of RIPv2

2

- **routing domain**
 - indicates the routing-process for which the routing-update is destined
 - now routers can support several domains within the same subnet
- **route tag**
 - contains the autonomous system number for EGP and BGP
 - on receiving a routing-update with a routing tag unequal zero, the associated path must be distributed to other routers; so interior routers notice the existence of exterior networks (tagging exterior routes)

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Message Fields of RIPv2

3

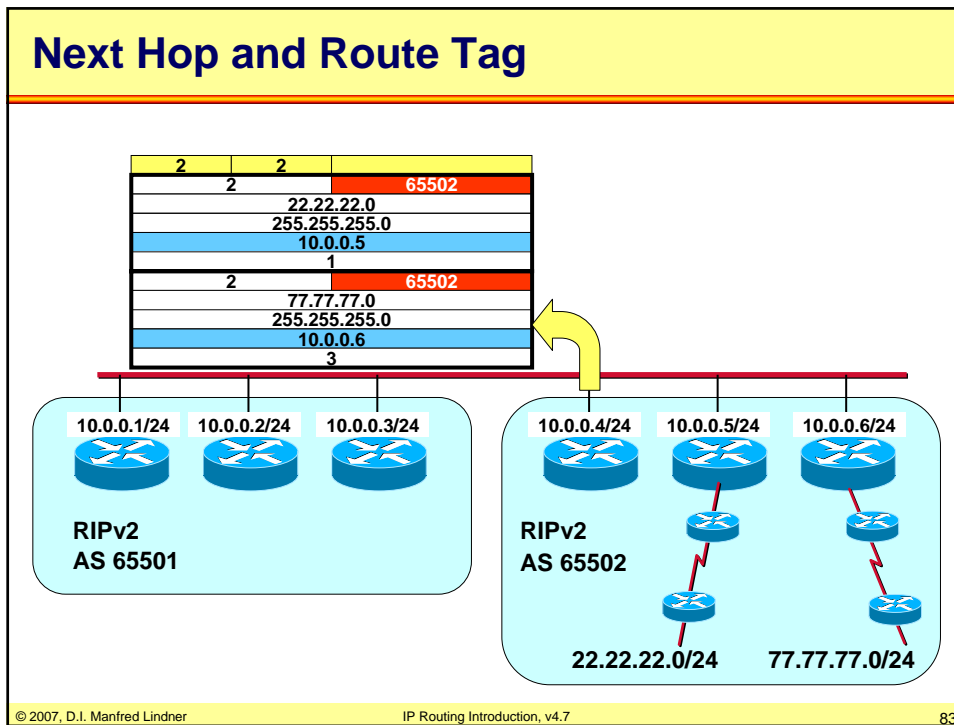
- **next hop**
 - datagram's for the network specified in the "IP address" - field have to be redirected to that router whose IP address is specified in the "next hop" field
 - this next-hop router must be located in the same subnet as the sender of the routing-update
 - a next hop value of 0.0.0.0 indicates, that the sender-router acts as next hop itself for the given network
 - so in cases when there are several routers in a subnet, just one router needs to send a routing-update
 - using RIPv2 this router announces which networks can be reached over other routers

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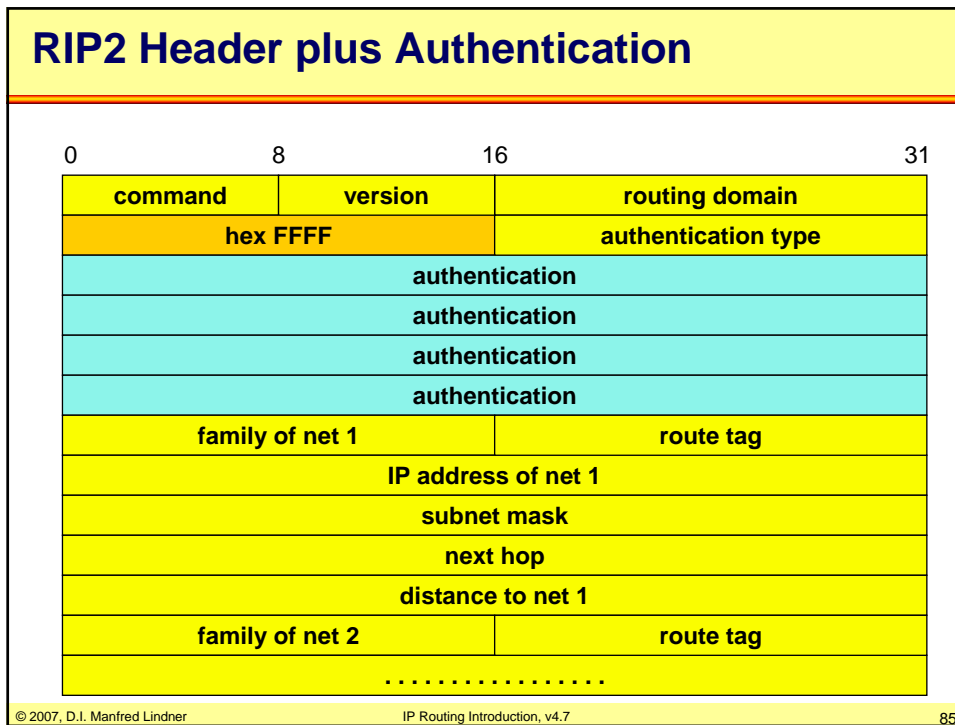


Authentication

- **family of net = hex FFFF**
 - this value registered in the first family of net entry announces 16 authentication octets to follow
 - currently only a single type (type = 2) defined with a simple (clear text) password protection
 - Cisco supports also type 3 based on Message Digest 5 (MD5)
 - routing updates without valid authentication are ignored by the receiving router (only trusted router are accepted)
- **family of net unequal hex FFFF**
 - has the same meaning as for RIP1

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Treatment of Routing Updates

- **RIPv2 uses a class D multicast-address (224.0.0.9)**
 - no use of broadcast messages (like RIPv1 does)
 - only a router who is member of this group will receive and must process this routing update
- **remember:**
 - RIPv1 used broadcast addresses
 - Seen by each IP host
 - Slows down stations

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Agenda

- **Introduction to IP Routing**
 - Static Routing
 - Default Route
 - Dynamic Routing
- **RIP**
- **Classful versus Classless Routing**
- **Private Addresses and NAT**
- **Internet Routing**

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Classful Routing

- **routing protocols like RIP, IGRP cannot carry subnetmask information in routing updates**
- **this has several consequences**
 - if a given class A, B or C address is subnetted the subnetmask must be constant in the whole area
 - no variable length subnet mask (VLSM) can be used
 - if a routing update is sent to an interface with an network number different to the subnetted network
 - only the major class A, B or C network number will be announced
 - route summarization will be performed on class boundaries
 - hence a subnetted area must be contiguous
 - classful routing

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Routing Table Lookup (Classful)

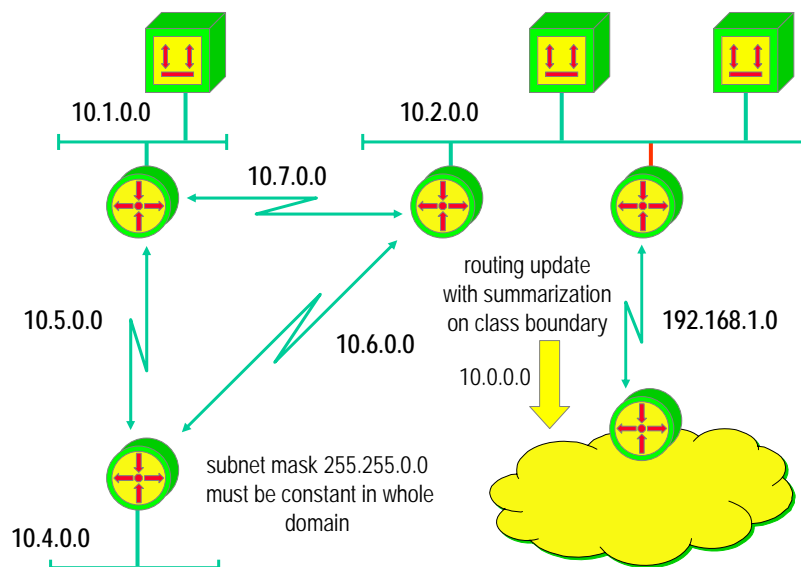
- **assumption:**
 - IP datagram with a given IP address is received by a classful router
- **IP address is interpreted as class A, B or C**
 - the major net is determined
- **next the a lookup in the routing table for the major net is performed**
 - if there is no entry the IP datagram will be discarded
- **if there is a match the IP address is compared to every known subnet of this major network**
 - if there is no such subnet the IP datagram will be discarded

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Classful Routing

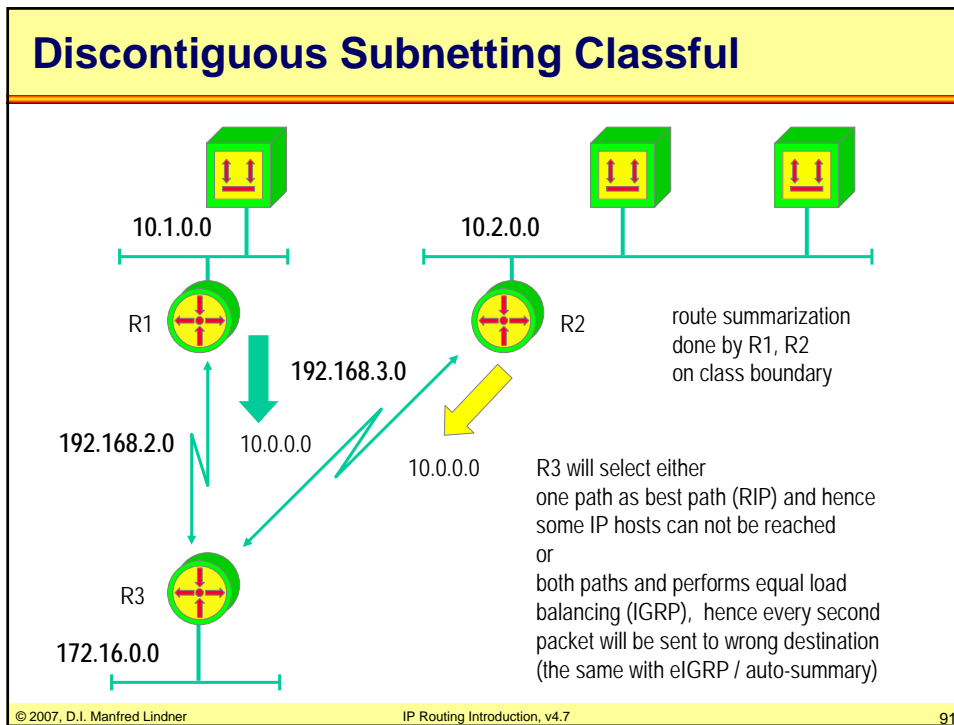


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- ### Classless Routing
- **routing protocols like RIPv2, OSPF, eIGRP can carry subnet mask information in routing updates**
 - **this has several advantages**
 - variable length subnet mask (VLSM) can be used
 - subnetting of a given address can be done according to the number of hosts required on a certain subnet
 - more efficient use of address space ⇒ sub-subnetting
 - route summarization can be performed on any address boundary and not only on class boundaries
 - a routing update contains prefix (relevant part of IP address) and length (number of ones used in subnetmask)
 - supernetting
 - actual subnetmask is smaller than natural subnetmask of given class
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Routing Table Lookup (Classless)

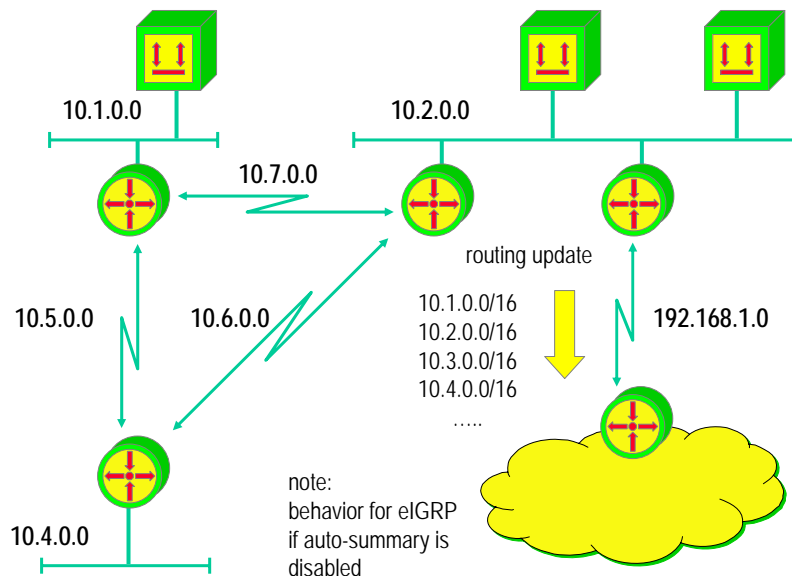
- **assumption:**
 - IP datagram with a given IP address is received by a classful router
- **IP address is not interpreted as class A, B or C**
- **a lookup in the routing table for the best match for this IP address is performed**
 - IP prefixes of the routing table are compared with the given IP address bit by bit from left to right
 - IP datagram is passed on to the network which matches best
 - “Longest Match Routing Rule”
 - result: IP addresses with any kind of subnetting can be used independently of the underlying network topology

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Classless Routing

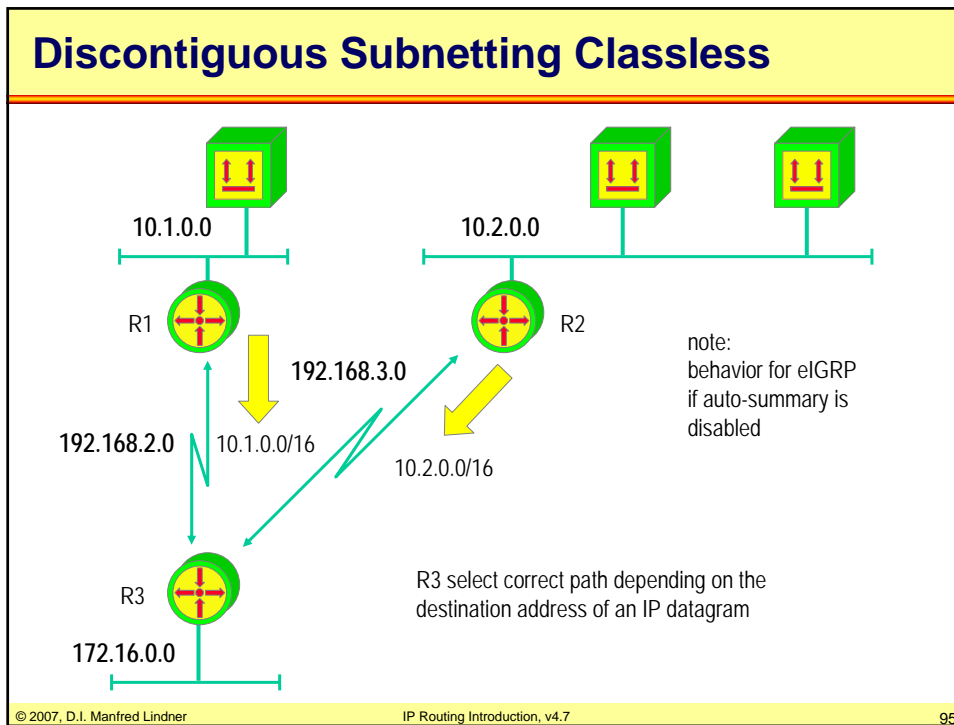


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- ### VLSM Example (1)
- **First step 6 bit subnetting of 172.16.0.0**
 - 172.16.0.0 with 255.255.252.0 (172.16.0.0 / 22)
 - subnetworks:
 - 172.16.0.0
 - 172.16.4.0
 - 172.16.8.0
 - 172.16.12.0
 - 172.16.16.0
 -
 - 172.16.248.0
 - 172.16.252.0
 - subnetworks capable of addressing 1022 IP systems
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VLSM Example (2)

- **next step sub-subnetting**
 - basic subnet 172.16.4.0 255.255.252.0 (172.16.4.0 / 22)
 - sub-subnetworks with mask 255.255.255.252 (/ 30):
 - 172.16.4.0 / 30
 - 172.16.4.4 / 30
 - 172.16.4.4 net-ID
 - 172.16.4.5 first IP host of subnet 172.16.4.4
 - 172.16.4.6 last IP host of subnet 172.16.4.4
 - 172.16.4.7 directed broadcast of subnet 172.16.4.4
 - 172.16.4.8 / 30
 - 172.16.4.12 / 30
 -
 - 172.16.4.252 / 30
 - sub-subnetworks capable of addressing 2 IP systems

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VLSM Example (3)

- **next step sub-subnetting**
 - basic subnet 172.16.8.0 255.255.252.0 (172.16.8.0 / 22)
 - sub-subnetworks with mask 255.255.255.0 (/ 24):
 - 172.16.8.0 / 24
 - 172.16.9.0 / 24
 - 172.16.9.0 net-ID
 - 172.16.9.1 first IP host of subnet 172.16.9.0
 -
 - 172.16.9.254 last IP host of subnet 172.16.9.0
 - 172.16.9.255 directed broadcast of subnet 172.16.9.0
 - 172.16.10.0 / 24
 - 172.16.11.0 / 24
 - sub-subnetworks capable of addressing 254 IP systems

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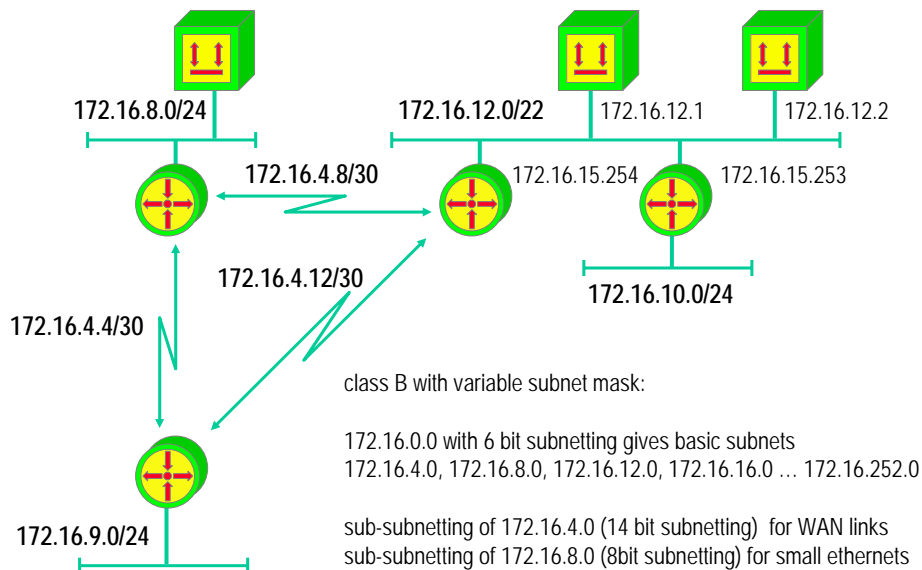
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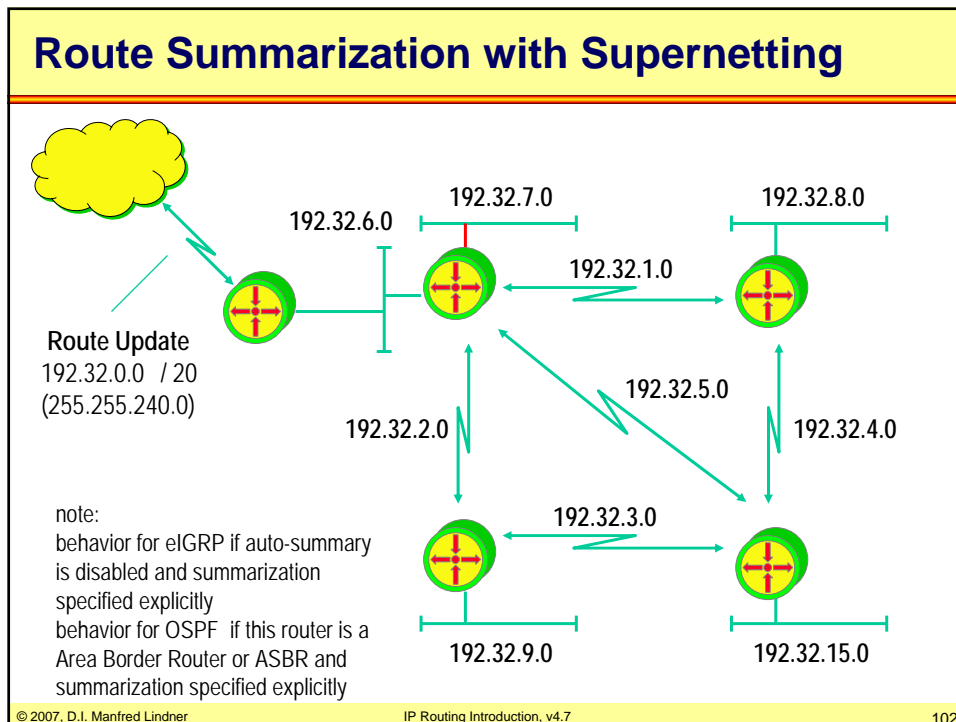
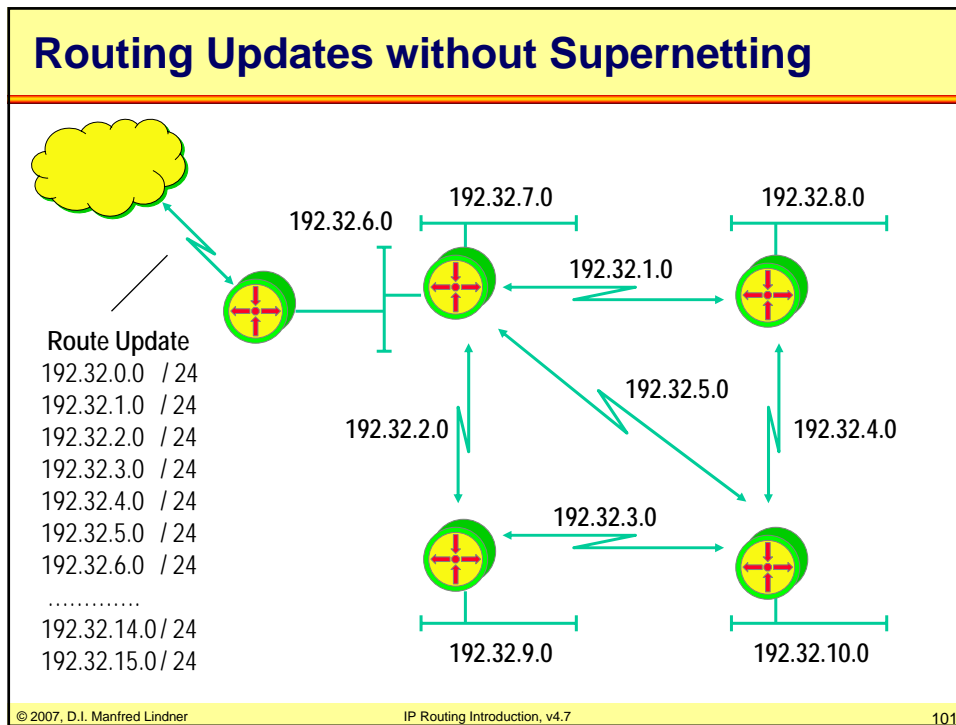
VLSM Example (4)

- **no sub-subnetting for basic subnet 172.16.12.0**
 - 172.16.12.0 with 255.255.252.0 (172.16.12.0 / 22)
 - 172.16.12.0 net-ID
 - 172.16.12.1 first IP host of subnet 172.16.12.0
 -
 - 172.16.15.254 last IP host of subnet 172.16.12.0
 - 172.16.15.255 directed broadcast of subnet 172.16.12.0
- subnetwork capable of addressing 1022 IP systems

VLSM Classless



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IP Address Space Depletion

- **the growing demand of IP addresses**
 - has put a strain on the classful model
 - class B exhaustion
 - class C are too small for most organizations
 - many class C addresses given to a certain organization leads to explosion of routing table entries in the Internet core routers
- **measures to handle these problems**
 - CIDR (Classless Interdomain Routing)
 - private IP addresses and network address translation (NAT)
 - IPv6

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CIDR

- **Classless Interdomain Routing (CIDR)**
 - address assignment and aggregation (route summarization) strategy
- **basic ideas**
 - classless routing (prefix, length)
 - supernetting
 - coordinated address allocation
 - until 1992 IP addresses had no relation at all to the network's topology
- **in order to implement CIDR**
 - classless routing protocols between routing domains must be used
 - BGP-4 as interdomain routing protocol
 - classless routing within a routing domain
 - RIPv2, OSPF, eIGRP

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CIDR

- **CIDR address allocation**

- addressing plan for class C addresses by continents
 - 192.0.0.0 - 193.255.255.255 ... Multiregional
 - 194.0.0.0 - 195.255.255.255 ... Europe
 - 198.0.0.0 - 199.255.255.255 ... North America
 - 200.0.0.0 - 201.255.255.255 ... Central/South America
- provider addressing strategy
 - Internet Service Providers (ISP) are given contiguous blocks of class C addresses which in turn are granted to their customers
 - consequence: change of provider means renumbering
- class C network numbers are allocated in such a way that route summarization (or sometimes called route aggregation) into supernets is possible

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Agenda

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Private Address Range - RFC 1918

- **Three blocks of address ranges are reserved for addressing of private networks**
 - 10.0.0.0 - 10.255.255.255 (10/8 prefix)
 - 172.16.0.0 - 172.31.255.255 (172.16/12 prefix)
 - 192.168.0.0 - 192.168.255.255 (192.168/16 prefix)
 - Note:
 - In pre-CIDR notation the first block is nothing but a single class A network number, while the second block is a set of 16 contiguous class B network numbers, and third block is a set of 256 contiguous class C network numbers.
- **Translation between private addresses and globally unique addresses -> NAT**

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Reasons for Network Address Translation

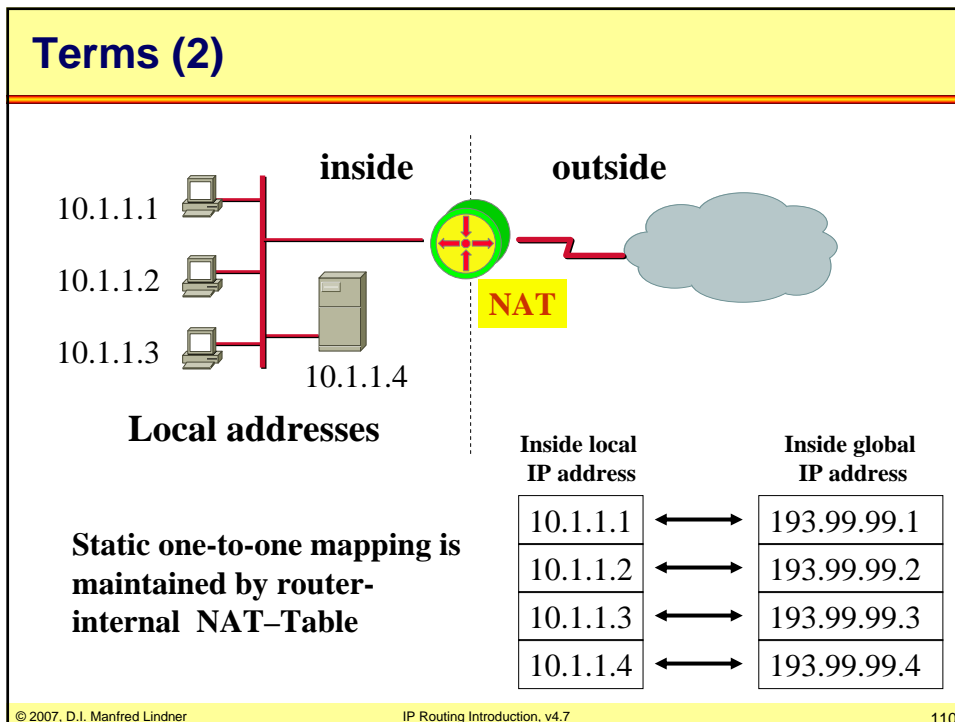
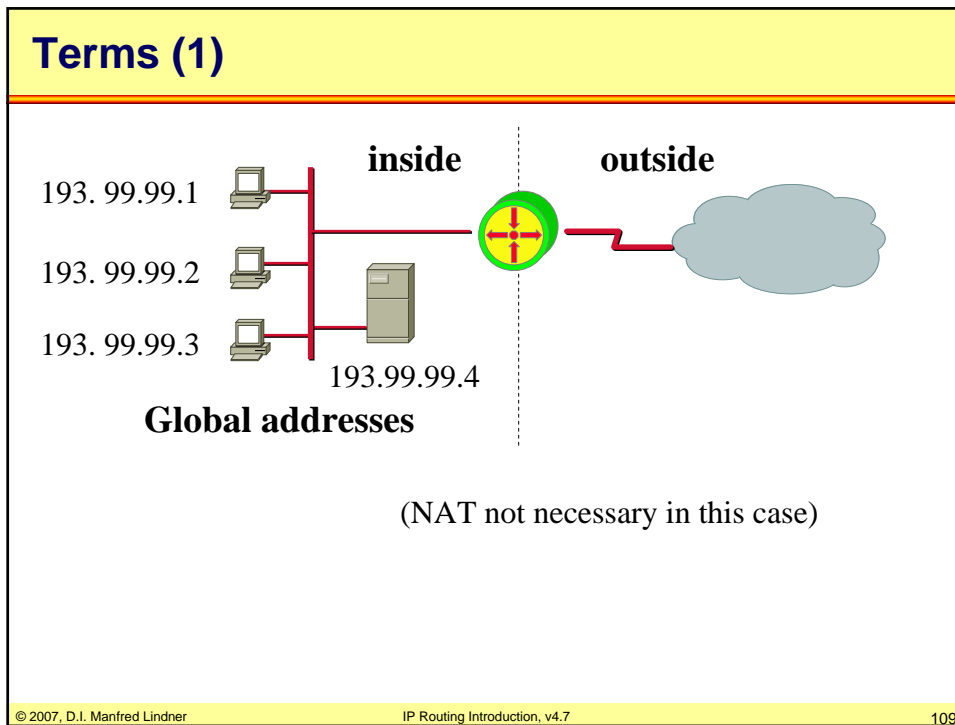
- **Mitigate Internet address depletion**
 - NAT was originally developed as an interim solution to combat IPv4 address depletion by allowing globally registered IP addresses to be reused or shared by several hosts (RFC 1631)
- **Save global addresses (and money)**
 - NAT is most often used to map IPs from the nonroutable private address spaces defined by RFC 1918
 - 10.0.0.0/8, 172.16.0.0/16, 192.168.0.0/16
- **Conserve internal address plan**
- **TCP load sharing**
- **Hide internal topology**

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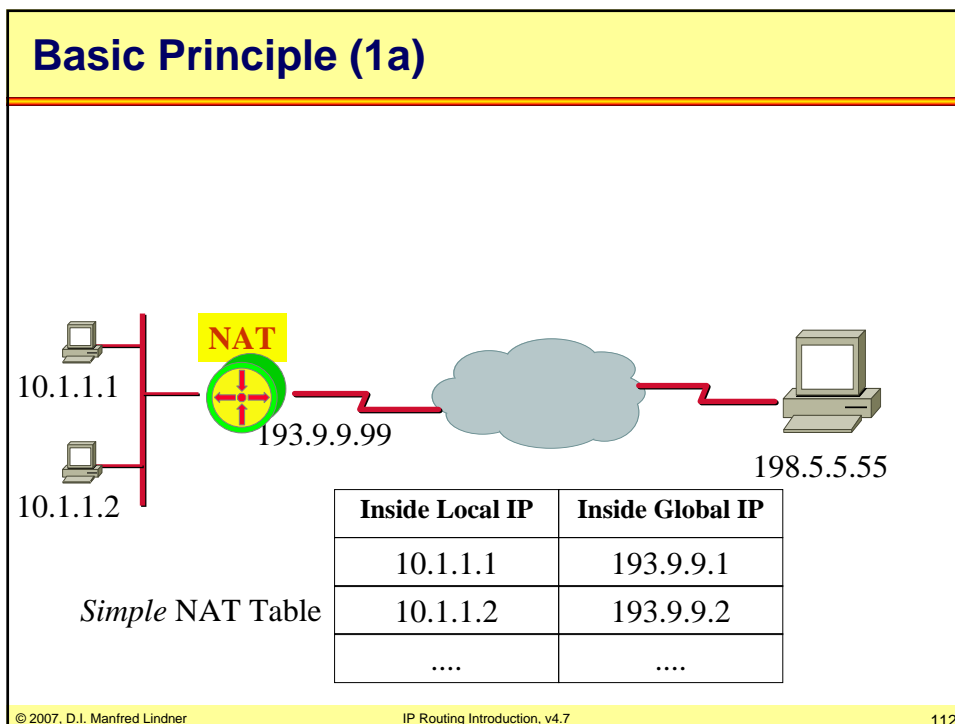
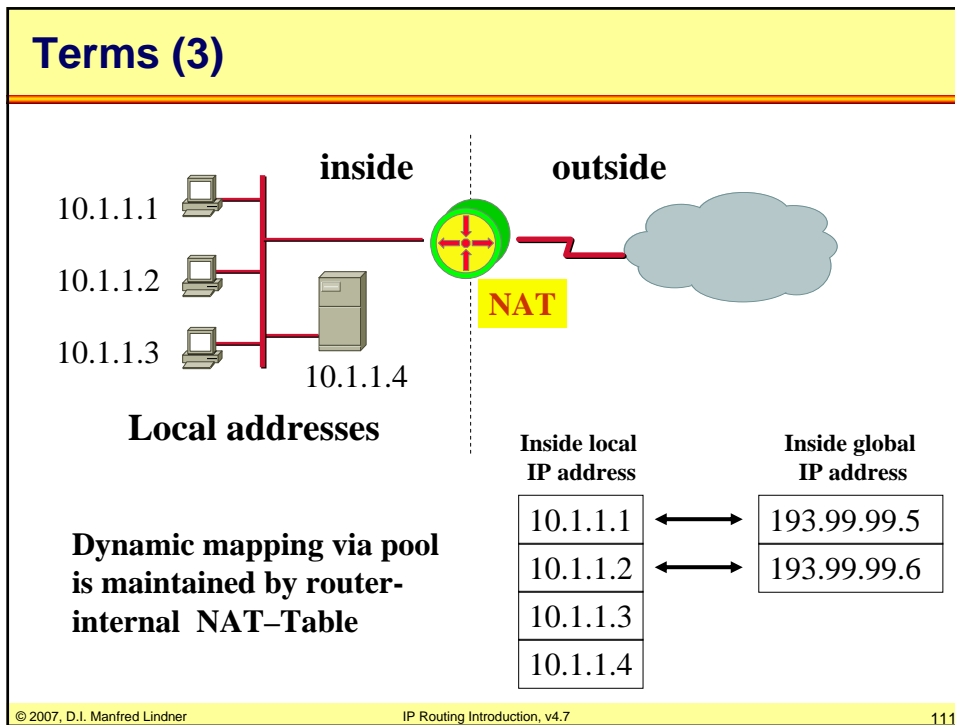
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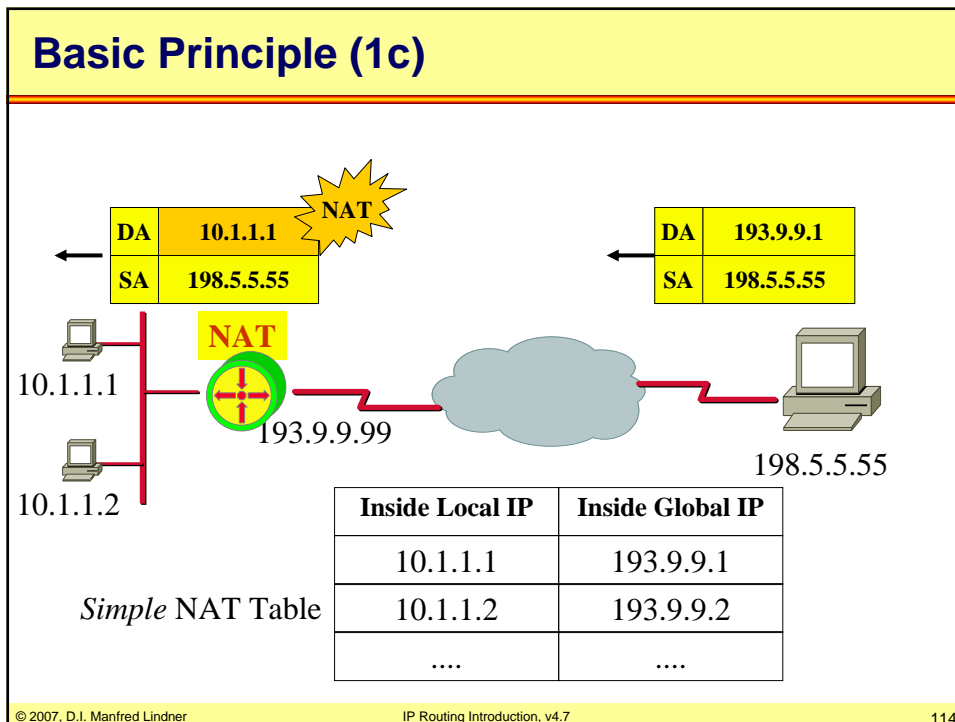
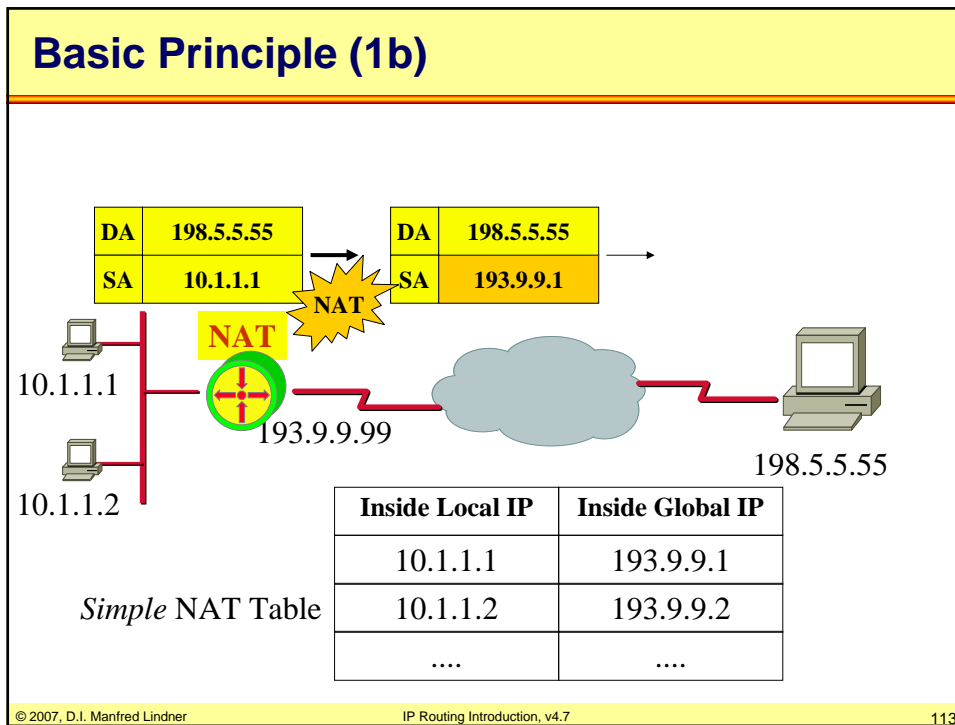
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Routing in Small Networks

- **in small networks**
 - distance vector or link state protocols like RIP or OSPF can be used for dynamic routing
 - it is possible that every router of the network knows about all destinations
 - all destination networks will appear in the routing tables
 - routing decisions are based on technical parameters
 - e.g. hop count, link bandwidth, link delay, interface costs
 - it is sufficient that routing relies only on technical parameters
 - small networks will be administered by a single authority
 - non-technical parameter like traffic contracts have no importance

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Routing in Large Networks

- **with increasing network size limitations of these protocols can be recognized**
 - some limitations for example
 - maximum hop count (RIP)
 - time to transmit routing tables (RIP) on low speed links
 - CPU time for SPF calculation (OSPF)
 - memory used for storing routing table (RIP, OSPF)
 - memory used for storing topology database (OSPF)
 - two level hierarchy centered around a core network (OSPF)
 - route fluctuation caused by link instabilities (OSPF)
 - routing based on non-technical criteria like financial contracts or legal rules is not possible

Routing in the Internet

- **limitations prevent using routing protocols like RIP or OSPF for routing in the Internet**
 - note: routing tables of Internet-core routers have about 220.000 net-ID entries
- **routing in the Internet**
 - is based on non-technical criteria like financial contracts or legal rules
 - policy routing
 - e.g. Acceptable Use Policy (AUP) in parts of the Internet
 - e.g. contracts between Internet Service Providers (ISP)

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Routing Hierarchy, Autonomous Systems

- **routing hierarchy is necessary for large networks**
 - to control expansion of routing tables
 - to provide a more structured view of the Internet
- **routing hierarchy used in the Internet**
 - based on concept of autonomous system (AS)
- **AS concept allows**
 - segregation of routing domains into separate administrations
 - note:
 - routing domain is a set of networks and routers having a single routing policy running under a single administration

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IGP, EGP

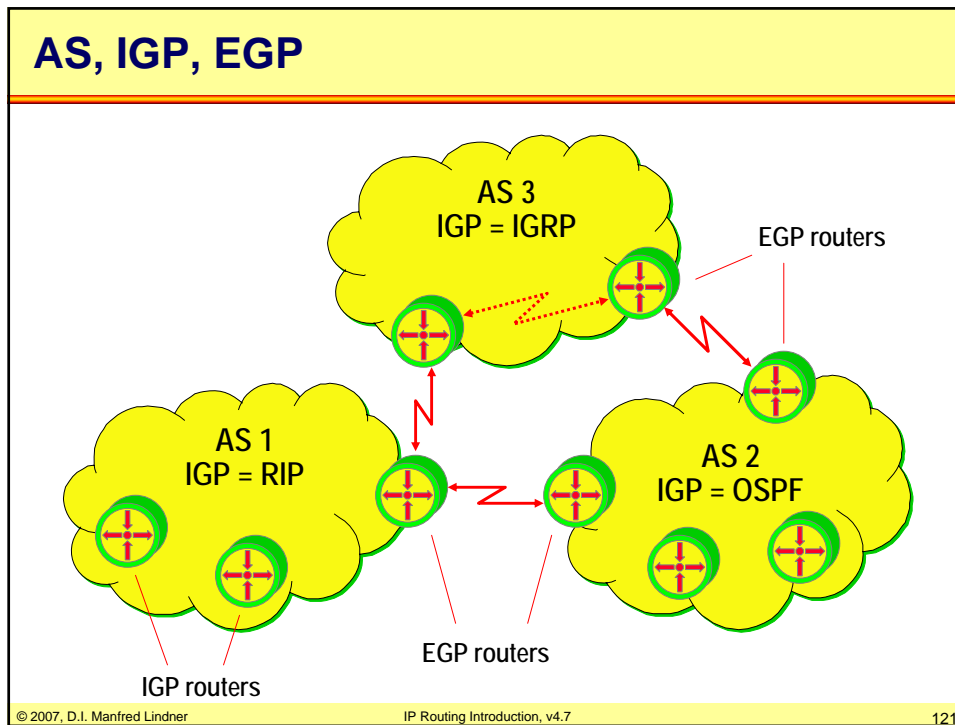
- **within an AS one or more IGP protocols provide interior routing**
 - IGP - Interior Gateway Protocol
 - IGP examples
 - RIP, RIPv2, OSPF, IGRP, eIGRP, Integrated IS-IS
 - IGP router responsible for routing to internal destinations
- **routing information between ASs is exchanged via EGP protocols**
 - EGP - Exterior Gateway Protocols)
 - EGP examples
 - EGP-2, BGP-3, BGP-4
 - EGP router knows how to reach destination networks of other ASs

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- ### AS Numbers
- **hierarchy based on ASs allows forming of a large network**
 - by dividing it into smaller and more manageable units
 - every unit may have its own set of rules and policies
 - **AS are identified by a unique number**
 - can be obtained like IP address from an Internet Registry
 - e.g. RIPE NCC (reséaux IP Européens Network Coordination Center)
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BGP-4

- **Border Gateway Protocol (BGP)**

- is the Exterior Gateway Protocol used in the Internet nowadays
- was developed to overcome limitations of EGP-2
- RFC 1267 (BGP-3) older version
 - classful routing only
- RFC 1771 (BGP-4) current version, DS
 - classless routing
- is based on relationship between neighboring BGP-routers
 - peer to peer
 - called BGP session or BGP connection

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BGP-4 Concepts 1

- **Border Gateway Protocol (cont.)**

- primary function
 - exchange of network reachability information with other autonomous systems via external BGP sessions
 - but also within an autonomous system between BGP border routers via internal BGP sessions
- BGP session runs on top of TCP
 - reliable transport connection
 - well known port 179
 - TCP takes care of fragmentation, sequencing, acknowledgement and retransmission
 - hence these procedures need not be done by the BGP protocol itself

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BGP-4 Concepts 2

- **basic ideas**

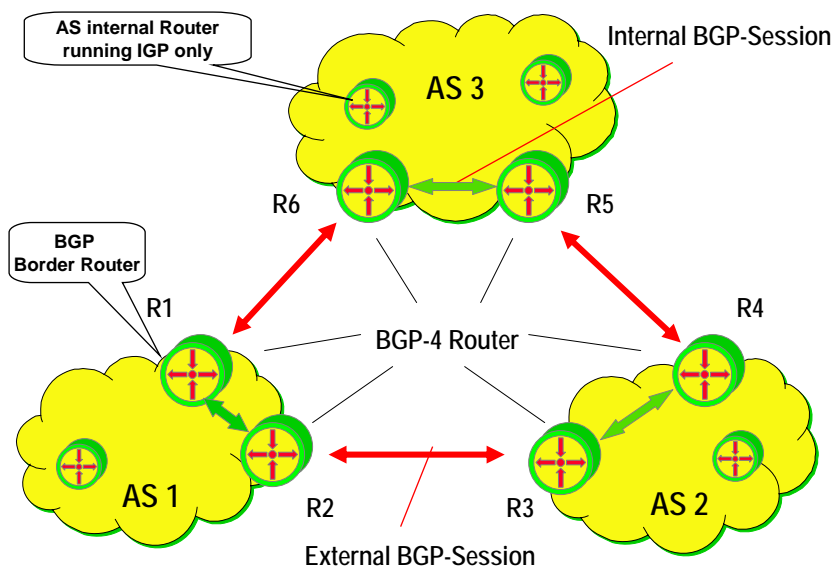
- reachability information exchanged between BGP routers carries a sequence of AS numbers
 - indicates the path of ASs a route has traversed
- path vector protocol
- this allows BGP to construct a graph of autonomous systems
 - loop prevention
 - no restriction on the underlying topology
- the best path
 - minimum number of AS hops
- incremental update
 - after first full exchange of reachability information between BGP routers only changes are reported

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BGP-4 Basic Example (1)

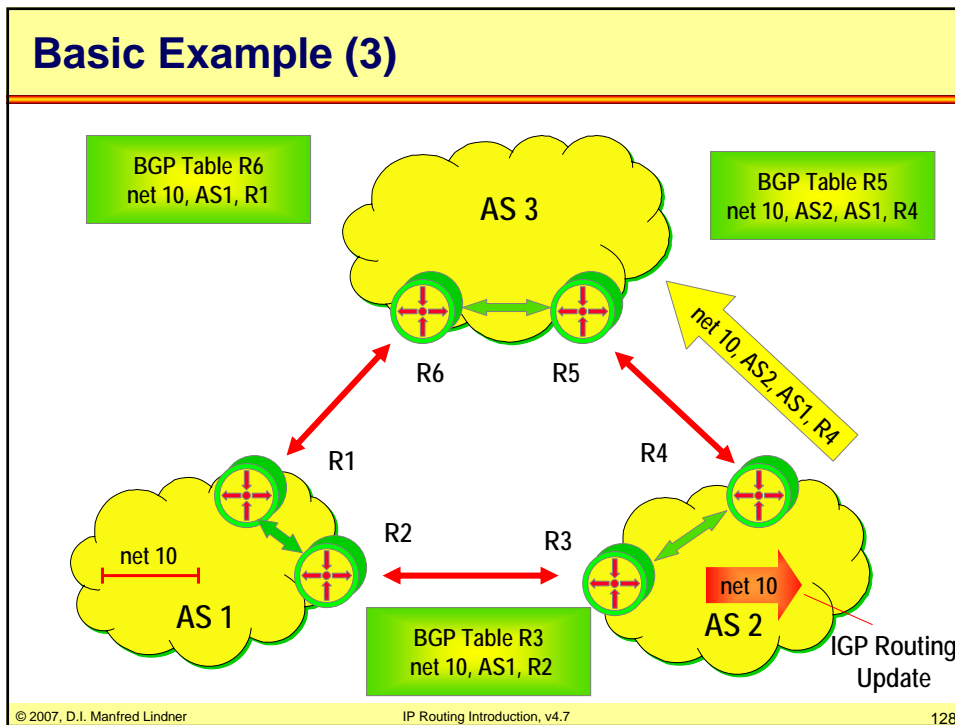
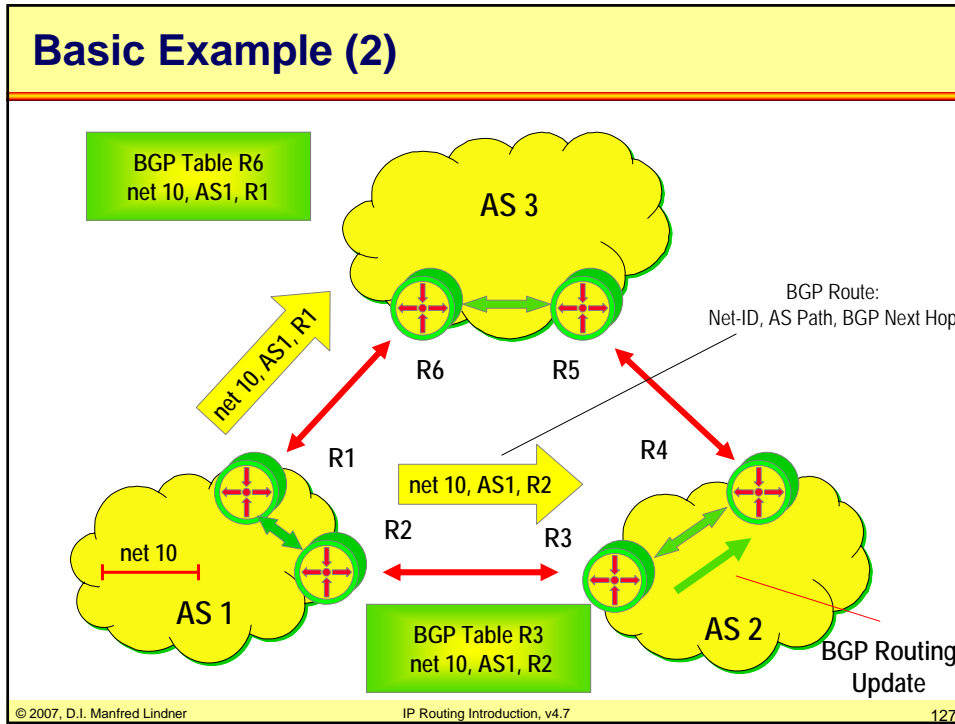


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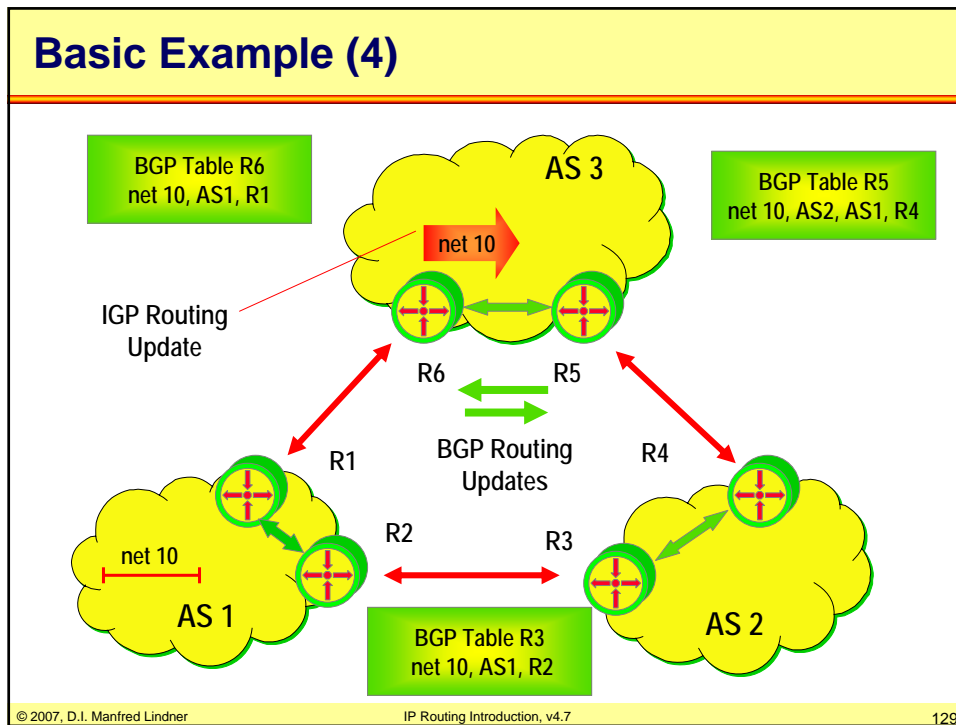
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BGP-4 Concepts 3

- **basic ideas (cont.)**
 - description of reachability information by BGP attributes
 - for BGP routing
 - for establishing of routing policy between ASs
 - BGP-4 advertises so called BGP routes
 - a BGP route is unit of information that pairs a destination with the path attributes to that destination
 - AS Path is one among many BGP attributes
 - IP prefix and mask notation
 - supports VLSM
 - supports aggregation (CIDR) and supernetting
 - routes can be filtered using attributes, attributes can be manipulated
 - > routing policy can be established

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