IP Technology Basics

TCP/IP Protocol Suite, RFC,
IP Addresses, IP Forwarding

Agenda

- **Introduction**
- **IP Address**
  - Address Classes
  - Subnetting
- **IP Forwarding**
  - Routing Basics
  - Forwarding and ARP
  - Forwarding and ICMP (Error Signaling)

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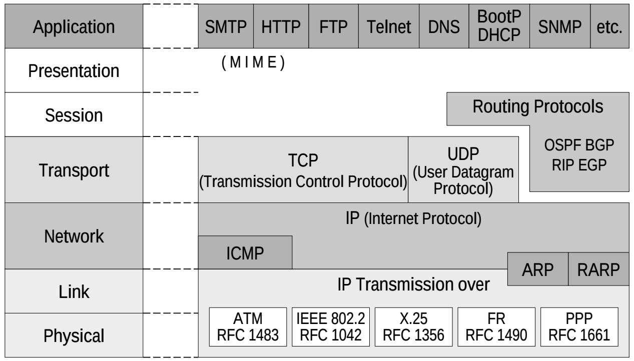
IP Technology

- **packet switching technology**
  - packet switch is called router or gateway (IETF terminology)
  - end system is called IP host
  - structured layer 3 address (IP address)
- **datagram service**
  - connectionless
    - datagrams are sent without establishing a connection in advance
  - best effort delivery
    - datagrams may be discarded due to transmission errors or network congestion

TCP Technology

- **shared responsibility between network and end systems**
  - routers responsible for delivering datagrams to remote networks based on structured IP address
  - IP hosts responsible for end-to-end control
- **end to end control**
  - is implemented in upper layers of IP hosts
  - TCP (Transmission Control Protocol)
    - connection oriented
    - sequencing, windowing
    - error recovery by retransmission
    - flow control

TCP/IP Protocol Suite



TCP/IP Story of Success

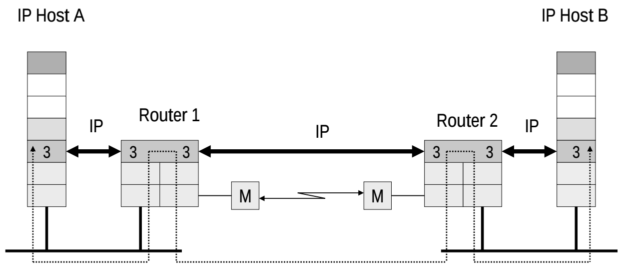
- **IP over everything**
  - technology independent
  - internetwork is built by layering a unique IP protocol on top of various network technologies
    - overlay technique
  - it is easy to adopt new network technologies
    - define how to transfer IP datagrams and how to use the possible switching capability of the new network
- **end-to-end principle**
  - avoids sophisticated tasks to be performed by network infrastructure (routers)
  - TCP takes care of reliability

TCP/IP Story of Success

- **TCP**
  - tolerant and adaptive to network operational conditions
    - robust against network failures
    - adapts to varying network delays
    - adapts to varying network load
- **right functionality partition between**
  - IP
    - knows nothing about end systems applications
    - makes best effort to route packets through the network
  - and TCP
    - takes care of end-to-end issues
    - end users know nothing about network internals
- **WWW**

IP and OSI Network Layer 3

Layer 3 Protocol = IP
Layer 3 Routing Protocols = RIP, OSPF, EIGRP, BGP



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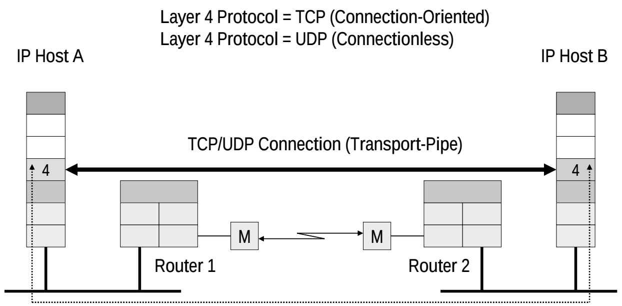
TCP/UDP and OSI Transport Layer 4



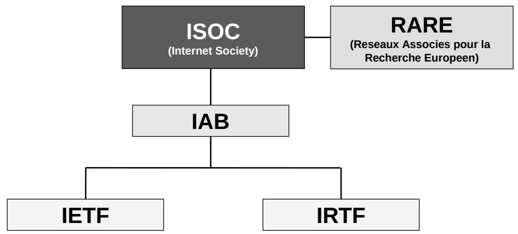
Key Players of Internet Technology

- **IAB (Internet Architecture Board)**
  - responsible for technical directions, coordination and standardization of the TCP/IP technology
  - the "Board" is highest authority and controls IETF, IRTF
- **IETF (Internet Engineering Task Force)**
  - provides solutions and extensions for TCP/IP
    - working groups organized in areas
    - area manager and IETF chairman form the IESG (Internet Engineering Steering Group)
- **IRTF (Internet Research Task Force)**
  - coordinates and prioritize research
    - research groups controlled by the IRSG (Internet Research Steering Group)

Key Players of Internet Technology

- **ISOC (Internet Society)**
  - highest Internet organization founded in 1992
- **RARE (Reseaux Associes pour la Recherche Europeen)**
  - founded 1986 to build and maintain a European high speed data network infrastructure
  - EBONE initiated by RARE
  - member of ISOC and ETSI (European Telecommunications Standards Institute)
  - close cooperation with RIPE (Reseaux IP Europeen)

Internet Organizations



Internet in Europe

- **RIPE NCC (Reséaux IP Européens Network Coordination Center)**
  - Internet Registry
    - assigning IP addresses
    - assigning AS numbers
  - Routing Registry
    - coordinating policies between Internet Service Providers (ISP)
  - how to contact?
    - RIPE NCC
    - Singel 258
    - 1016 AB Amsterdam
    - The Netherlands
    - Phone: +31 20 535 4444 , Fax: +31 20 535 4445
    - E-Mail: <ncc@ripe.net>, WWW: <http://www.ripe.net>

Standardization by RFCs

- **all documentation, standards, proposals for new protocols and enhancements for the Internet**
  - are published as "Requests for Comments" (RFC)
  - RFCs were the initial approach of engineers to discuss questions, suggestions via e-mail to speed up development
    - part of the success story of TCP/IP
  - IETF (Internet Engineering Task Force) decides, which RFCs will be adopted as a standard after rigorous review (e.g. two different implementations have to exist)
  - RFCs are numbered in sequence of publishing
  - adopted enhancements or changes to a protocol will result in a new RFC number

Standardization by RFCs

- **today's standardization process is best described**
  - in RFC-2026
    - The Internet Standards Process Revision3
- **not every RFC is an Internet Standard**
  - categories
    - Informational, Experimental, Historic
    - Proposed Standard
    - Draft Standard
    - Standard
- **IAB (Internet Architecture Board) publishes periodically a status list of all protocols:**
  - Official Protocol Standard RFC (currently RFC 3300).

How to get RFCs ?

- **RFCs can be ordered from the NIC (Network Information Center) or retrieved through "anonymous FTP":**
  - ftp://ds.internic.net/rfc/
  - ftp://ftp.univie.ac.at/netinfo/rfc/

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  - Subnetting
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  - Routing Basics
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IP Address

- **IP address**
  - 32 bit , dotted decimal notation
  - identifies access to a network (network interface)
  - basic structure
    - network number (net-id)
    - host number (host-id)
  - two level hierarchy
  - net-id must be unique when a physical network with IP hosts is connected to the Internet
    - assignment controlled by Internet Registry
  - host-id is assigned by each local network manager

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Address notation

IP address (example):

1 0 0 0 0 0 0 0	1 1 1 1 0 0 0 0	0 0 0 0 0 0 0 1	0 1 1 0 1 1 0 1
0x80	0xF0	0x01	0x6D

each octet of an IP address is written as the decimal equivalent:

128	240	1	109

The resulting four numbers are delimited with dots (dotted decimal notation):

128.240.1.109

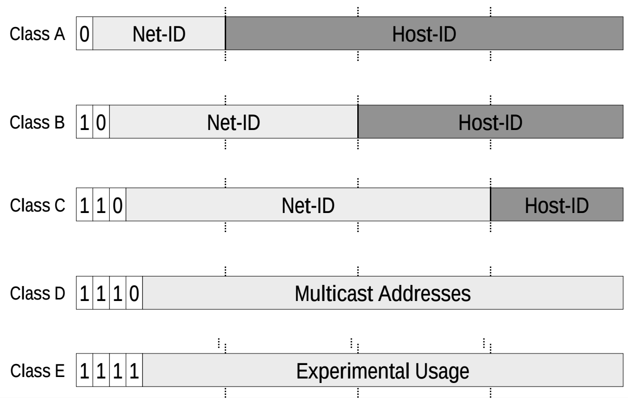
Binary vs Decimal Notation

2^7	2^6	2^5	2^4	2^3	2^2	2^1	2^0	
1	0	0	0	0	0	0	0	128
0	1	0	0	0	0	0	0	64
0	0	1	0	0	0	0	0	32
0	0	0	1	0	0	0	0	16
0	0	0	0	1	0	0	0	8
0	0	0	0	0	1	0	0	4
0	0	0	0	0	0	1	0	2
0	0	0	0	0	0	0	1	1
1	1	1	1	1	1	1	1	255

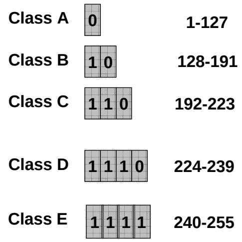
Classes

- **several classes of IP addresses**
  - A, B, C (unicast), D (multicast), E (experimental)
  - class defines numbers of address-bits to be used for net-id
    - class A — 7 bits of net-id, 24 bits of host-id; 126 nets / 16.777.214 hosts
    - class B — 14 bits of net-id, 16 bits of host-id; 16.384 nets / 65.534 hosts
    - class C — 21 bits of net-id, 8 bits of host-id; 2.097.512 nets / 254 hosts
    - class D — 28 bits multicast group number
  - first octet rule
    - class A range: 1 - 126
    - class B range: 128 - 191
    - class C range: 192 - 223
    - class D range: 224 - 239

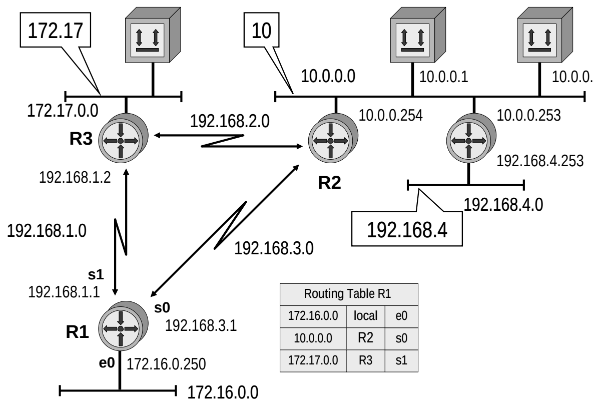
IP Address Classes



IP Address Classes First Octet Rule



IP Address (Net-ID) Example

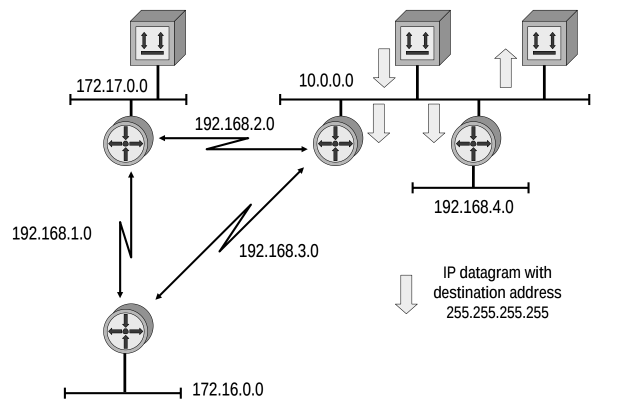


Routing Table R1		
172.16.0.0	local	e0
10.0.0.0	R2	s0
172.17.0.0	R3	s1

Special Addresses

- **basic IP address format**
  - { net-id, host-id }
- **special purpose addresses and rules**
  - { 0, 0 } this host on this network (0.0.0.0)
  - { 0, <host-id> } specified host on this network
  - { <net-id>, -1 } directed broadcast to specified network
  - { -1, -1 } limited broadcast on this network (255.255.255.255)
  - { 127, <any> } loopback address
  - { <net-id>, 0 } never used for a host number, identifies network itself
  - note:
    - 0 … means all corresponding bits = 0
    - -1 … means all corresponding bits = 1

IP Limited Broadcast



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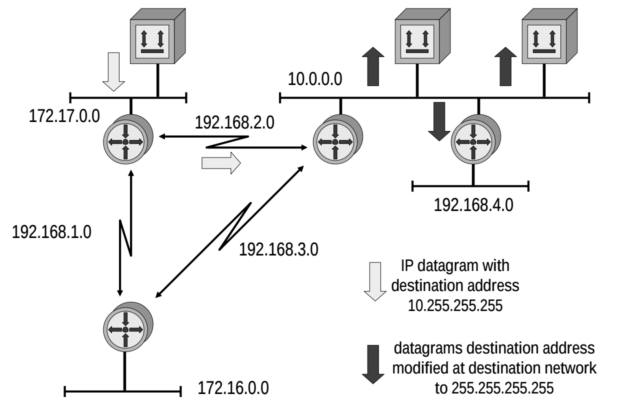
IP Directed Broadcast



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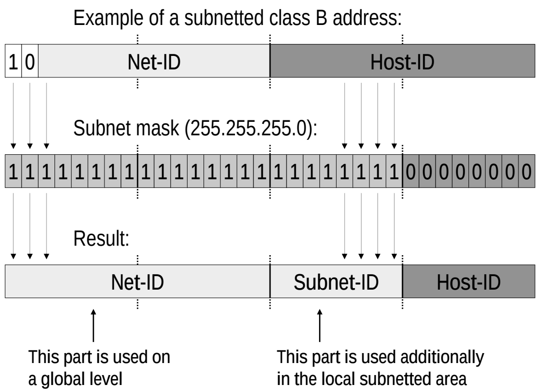
Subnetting

- **two level hierarchy was sufficient in the early days of the Internet**
- **with local area networks a third hierarchical level was introduced by subnetting**
- **subnetting**
  - some bits of the host-id can be used as subnet-id
  - subnet-id extends classful net-id meaning
    - subnet-id bits are only locally interpreted inside subnetted area
    - net-id bits are still globally seen outside the subnetted area
  - number of bits to be used for network identification are specified by subnet mask (written in dotted decimal notation)
    - ones portion represents network part (must be contiguous)
    - zeros portion represent the host part

Subnet addressing



Possible Subnet Mask Values

2^7	2^6	2^5	2^4	2^3	2^2	2^1	2^0	
1	0	0	0	0	0	0	0	128
1	1	0	0	0	0	0	0	192
1	1	1	0	0	0	0	0	224
1	1	1	1	0	0	0	0	240
1	1	1	1	1	0	0	0	248
1	1	1	1	1	1	0	0	252
1	1	1	1	1	1	1	0	254
1	1	1	1	1	1	1	1	255

Subnet Mask

- **natural subnet mask**
  - address classes without subnetting
    - class A … 255.0.0.0
    - class B … 255.255.0.0
    - class C … 255.255.255.0
- **old notation of IP addresses**
  - with subnetmask
    - 10.0.0.0 255.0.0.0 (Class A)
    - 176.16.0.0 255.255.0.0 (Class B)
- **new notation of IP addresses**
  - with prefix/length
    - 10.0.0.0 / 8 (Class A)
    - 176.16.0.0 / 16 (Class B)

Rules with Subnetting

- **IP address format with subnetting**
  - { net-id, subnet-id, host-id }
- **additional special purpose addresses and rules**
  - { <net-id>, <subnet-id>, -1 }
    - directed broadcast to specified subnet
  - { <net-id>, -1, -1 }
    - directed broadcast to all subnets of specified subnetted network
  - { <net-id>, 0, <host-id> }
    - subnet zero never used for a subnet number for classful routing (see RFC 950)
  - { <net-id>, -1, <host-id> }
    - subnet broadcast never used for a subnet number for classful routing (see RFC 950)

Subnet Mask Examples 1

- **class A ⇨ pseudo class B (8 bit subnetting)**
  - 10.0.0.0 with 255.255.0.0 (10.0.0.0 / 16)
  - subnetworks:
    - 10.0.0.0 subnet zero
    - 10.1.0.0
      - 10.1.0.1 first IP host in net 10.1.0.0
      - 10.1.255.254 last IP host in net 10.1.0.0
      - 10.1.255.255 directed broadcast in net 10.1.0.0
    - 10.2.0.0
    - 10.3.0.0
    - ……….
    - 10.254.0.0
    - 10.255.0.0 subnet broadcast
  - 254 subnets / 65534 hosts

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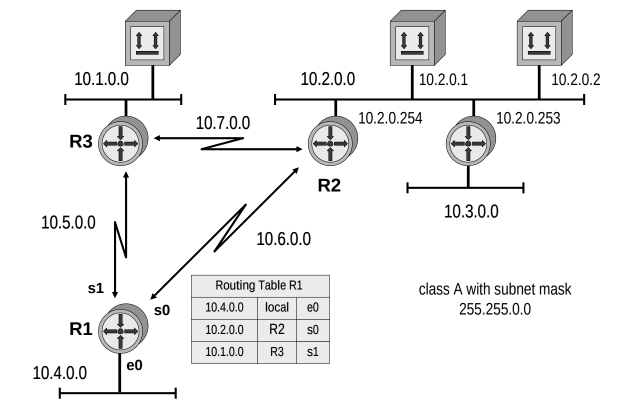
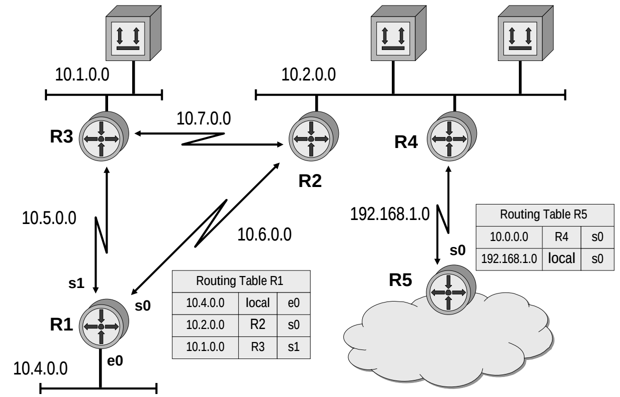
Subnet Zero / Subnet Broadcast

- **What is the problem?**
  - Does 10.0.0.0 mean net-ID of net 10 or of subnet 10.0 ?
  - Does 10.255.255.255 mean directed broadcast for the whole net 10 or for the subnet 10.255 ?
  - subnet zero and subnet broadcast are ambiguous

IP Address Example with Subnetting



Classful Routing



Subnet Mask Examples 2

- **class A ⇨ pseudo class C (16 bit subnetting)**
  - 10.0.0.0 with 255.255.255.0 (10.0.0.0 / 24)
  - subnetworks:
    - 10.0.0.0 subnet zero
    - 10.0.1.0
    - 10.0.2.0

      ……….
    - 10.0.255.0
    - 10.1.0.0
    - 10.1.2.0

      ………..
    - 10.255.254.0
    - 10.255.255.0 subnet broadcast
  - 65534 subnets / 254 hosts

Subnet Mask Examples 3

- **class B ⇨ pseudo class C (8 bit subnetting)**
  - 172.16.0.0 with 255.255.255.0 (172.16.0.0 / 24)
  - subnetworks:
    - 172.16.0.0 subnet zero
    - 172.16.1.0
    - 172.16.2.0

      ……….

      ………..
    - 172.16.254.0
    - 172.16.255.0 subnet broadcast
  - 254 subnets / 254 hosts

Subnet Mask -> Net-ID, Host-ID

- **class A address**

subnet mask 255.255.0.0

IP- Address 10.3.49.45

? net-id, ? host-id

net-id = 10.3.0.0

host-id = 0.0.49.45

65534 IP hosts

range: 10.3.0.1 -> 10.3.255.254

10.3.0.0 -> network itself

10.3.255.255 -> directed broadcast for this network

Subnet Mask Examples 4

- **class B address**

  subnet mask 255.255.255.192
  IP- Address 172.16.3.144
  ? net-id, ? host-id

address binary	1010 1100 . 0001 0000 . 0000 0011 . 1001 0000
mask (binary)	1111 1111 . 1111 1111 . 1111 1111 . 1100 0000

----

logical AND (bit by bit)	
net-id	1010 1100 . 0001 0000 . 0000 0011 . 1000 0000

net-id = 172.16.3.128

host-id = 0.0.0.16

Subnet Mask Examples 5

- **class B ⇨ 10 bit subnetting**
  - 172.16.0.0 with 255.255.255.192 (172.16.0.0 / 26)
  - subnetworks:

	net-ID | host-ID
• 172.16.0.0 subnet zero	172.16.0. 00 | xx xxxx
• 172.16.0.64	172.16.0. 01 | xx xxxx
– 172.16.0.65 first IP host	172.16.0. 01 | 00 0001
– 172.16.0.66 second IP host	172.16.0. 01 | 00 0010
………..	
– 172.16.0.126 last IP host	172.16.0. 01 | 11 1110
– 172.16.0.127 directed broadcast	172.16.0. 01 | 11 1111
• 172.16.0.128	172.16.0. 10 | xx xxxx
• 172.16.0.192	172.16.0. 11 | xx xxxx

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Subnet Mask Examples 5

- subnetworks (cont.):

• 172.16.1.0	172.16.1. 00 | xx xxxx
• 172.16.1.64	172.16.1. 01 | xx xxxx
• 172.16.1.128	172.16.1. 10 | xx xxxx
• 172.16.1.192	172.16.1. 11 | xx xxxx
• 172.16.2.0	172.16.2. 00 | xx xxxx
• 172.16.2.64	172.16.2. 01 | xx xxxx
………..	
• 172.16.255.0	172.16.255. 00 | xx xxxx
• 172.16.255.64	172.16.255. 01 | xx xxxx
• 172.16.255.128	172.16.255. 10 | xx xxxx
• 172.16.255.192 subnet broadcast	172.16.255. 11 | xx xxxx

- 1022 subnets / 62 hosts

Subnet Mask Examples 6

- **class C ⇨ 2 bit subnetting**
  - 192.168.16.0 with 255.255.255.192 (192.168.16.0 / 26)
  - subnetworks:

	net-ID | host-ID
• 192.168.16.0 subnet zero	192.168.16. 00 | xxxxxx
• 192.168.16.64	192.168.16. 01 | xxxxxx
• 192.168.16.128	192.168.16. 10 | xxxxxx
• 192.168.16.192 subnet broadcast	192.168.16. 11 | xxxxxx

  - 2 subnets / 62 hosts

Subnet Mask Examples 7

- **class C ⇨ 3 bit subnetting**
  - 192.168.16.0 with 255.255.255.224 (192.168.16.0 / 27)
  - subnetworks: net-ID host-ID
    - 192.168.16.0 subnet zero 192.168.16. 000 | xxxxx
    - 192.168.16.32 192.168.16. 001 | xxxxx
    - 192.168.16.64 192.168.16. 010 | xxxxx
    - 192.168.16.96 192.168.16. 011 | xxxxx
    - 192.168.16.128 192.168.16. 100 | xxxxx
    - 192.168.16.160 192.168.16. 101 | xxxxx
    - 192.168.16.192 192.168.16. 110 | xxxxx
    - 192.168.16.224 subnet broadcast 192.168.16. 111 | xxxxx
  - 6 subnets / 30 hosts

Subnet Mask Examples 8

- **class C ⇨ 4 bit subnetting**
  - 192.168.16.0 with 255.255.255.240 (192.168.16.0 / 28)
  - subnetworks: net-ID host-ID
    - 192.168.16.0 subnet zero 192.168.16. 0000 | xxxx
    - 192.168.16.16 192.168.16. 0001 | xxxx
      - 192.168.16.17 1st IP host 192.168.16. 0001 | 0001
      - 192.168.16.18 2nd IP host 192.168.16. 0001 | 0010

        ………..
      - 192.168.16.30 14th IP host 192.168.16. 0001 | 1110
      - 192.168.16.31 directed broadcast 192.168.16. 0001 | 1111
    - 192.168.16.32 192.168.16. 0010 | xxxx
    - 192.168.16.48 192.168.16. 0011 | xxxx

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Subnet Mask Examples 8

- subnetworks (cont.): net-ID host-ID
  - 192.168.16.64 192.168.16. 0100 | xxxx
  - 192.168.16.80 192.168.16. 0101 | xxxx
  - 192.168.16.96 192.168.16. 0110 | xxxx
  - 192.168.16.112 192.168.16. 0111 | xxxx
  - 192.168.16.128 192.168.16. 1000 | xxxx
  - 192.168.16.144 192.168.16. 1001 | xxxx
  - 192.168.16.160 192.168.16. 1010 | xxxx
  - 192.168.16.176 192.168.16. 1011 | xxxx
  - 192.168.16.192 192.168.16. 1100 | xxxx
  - 192.168.16.208 192.168.16. 1101 | xxxx
  - 192.168.16.224 192.168.16. 1110 | xxxx
  - 192.168.16.240 subnet broadcast 192.168.16. 1111 | xxxx
- 14 subnets / 14 hosts

Subnet Mask Examples 9

- **class C ⇨ 5 bit subnetting**
  - 192.168.16.0 with 255.255.255.248 (192.168.16.0 / 29)
  - subnetworks: net-ID host-ID
    - 192.168.16.0 subnet zero 192.168.16. 00000 | xxx
    - 192.168.16.8 192.168.16. 00001 | xxx
    - 192.168.16.16 192.168.16. 00010 | xxx
    - 192.168.16.24 192.168.16. 00011 | xxx

      ………..
    - 192.168.16.240 192.168.16. 11110 | xxx
    - 192.168.16.248 subnet broadcast 192.168.16. 11111 | xxx
  - 30 subnets / 6 hosts

Subnet Mask Examples 10

- **class C ⇨ 6 bit subnetting**
  - 192.168.16.0 with 255.255.255.252 (192.168.16.0 / 30)
  - subnetworks:

	net-ID	host-ID
• 192.168.16.0 subnet zero	192.168.16. 000000	xx
• 192.168.16.4	192.168.16. 000001	xx
– 192.168.16.5 1st IP host	192.168.16. 000001	01
– 192.168.16.6 2nd IP host	192.168.16. 000001	10
– 192.168.16.7 directed broadcast	192.168.16. 000001	11
• 192.168.16.8	192.168.16. 000010	xx
………..		
• 192.168.16.248	192.168.16. 111110	xx
• 192.168.16.252 subnet broadcast	192.168.16. 111111	xx

  - 62 subnets / 2 hosts

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  - <u>Routing Basics</u>
  - Forwarding and ARP
  - Forwarding and ICMP (Error Signaling)

IP Routing

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

IP Routing

- **indirect routing of IP datagrams**
  - is done by routers based on routing tables
  - routing table
    - database of known destinations in form of “signposts”
    - contains next hop router, outgoing port (and metric) to every specified (or known) destination network (net-ID, subnet mask)
- **routing can be either**
  - static
    - non-responsive to topology changes
  - or dynamic
    - responsive to topology changes
    - requires special communication protocols among routers (routing protocol)

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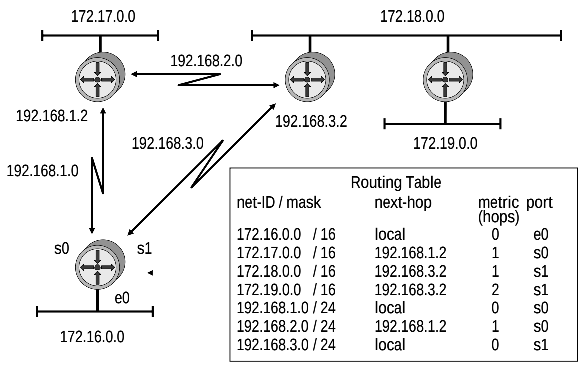
Routing Table Example



Routing Table

net-ID / mask	next-hop	metric (hops)	port
172.16.0.0 / 16	local	0	e0
172.17.0.0 / 16	192.168.1.2	1	s0
172.18.0.0 / 16	192.168.3.2	1	s1
172.19.0.0 / 16	192.168.3.2	2	s1
192.168.1.0 / 24	local	0	s0
192.168.2.0 / 24	192.168.1.2	1	s0
192.168.3.0 / 24	local	0	s1

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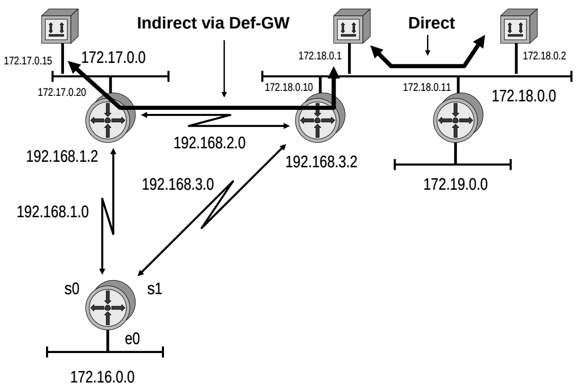
Direct versus Indirect Delivery



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Agenda

- Introduction
- IP Address
  - Address Classes
  - Subnetting
- IP Forwarding
  - Routing Basics
  - Forwarding and ARP
  - Forwarding and ICMP (Error Signaling)

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Principle

- **IP Forwarding is done by routers in case of indirect routing**
  - based on the destination address of a given IP datagram
  - following the path to the destination hop by hop
- **routing tables**
  - have information about which next hop router a given destination network can be reached
- **L2 header must be changed hop by hop**
  - if LAN then physical L2 address (MAC addresses) must be adapted for direct communication on LAN
- **mapping between IP and L2 address**
  - is done by Address Resolution Protocol (ARP)

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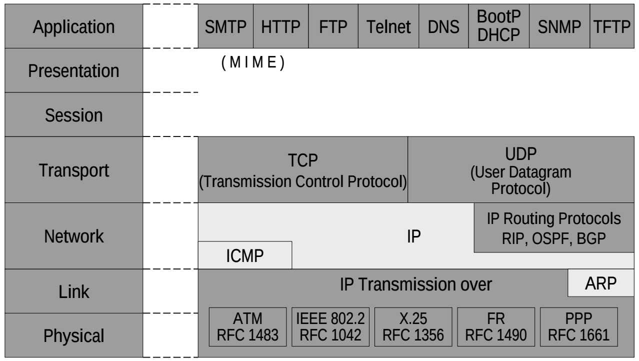
IP Related Protocols



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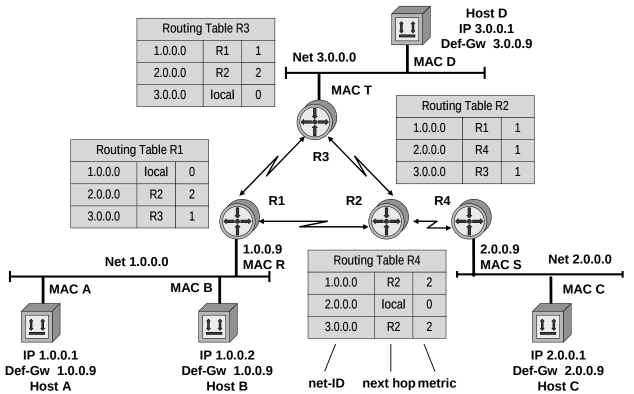
Example Topology



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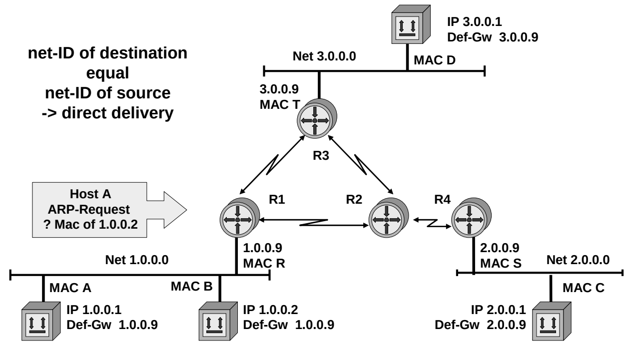
L30 - IP Technology Basics

Direct Delivery 1.0.0.1 - > 1.0.0.2

net-ID of destination equal net-ID of source -> direct delivery



ARP ... Address Resolution Protocol

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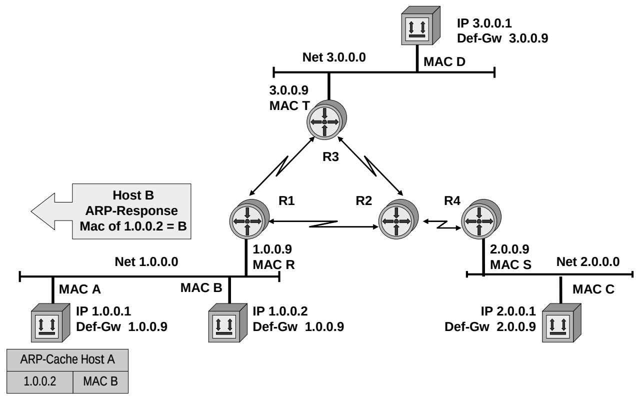
Direct Delivery 1.0.0.1 - > 1.0.0.2



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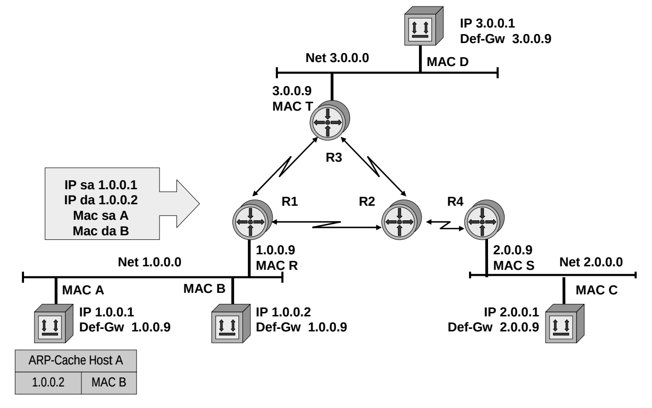
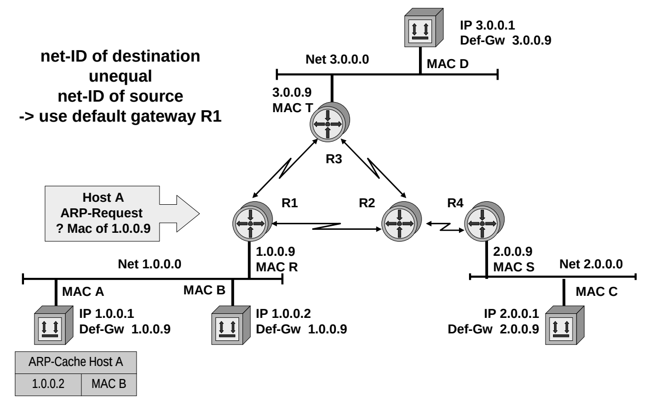
Direct Delivery 1.0.0.1 - > 1.0.0.2



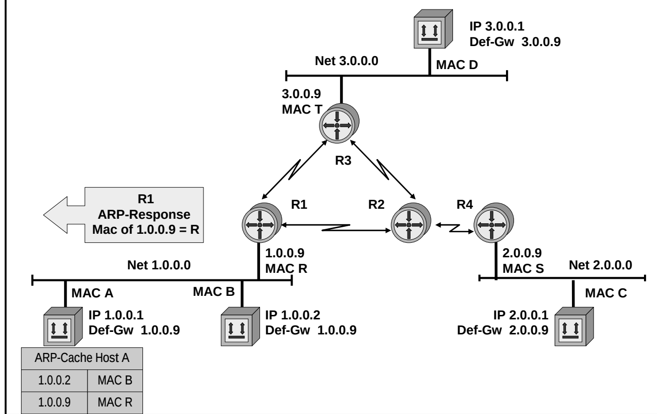
ARP-Cache Host A	
1.0.0.2	MAC B

Indirect Delivery 1.0.0.1 - > 2.0.0.1



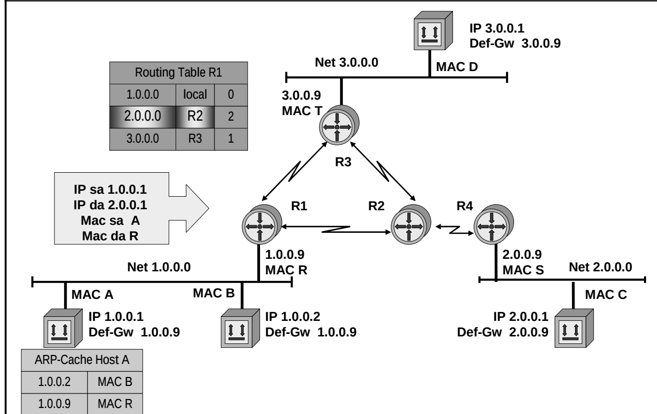
ARP-Cache Host A	
1.0.0.2	MAC B

Indirect Delivery 1.0.0.1 - > 2.0.0.1



ARP-Cache Host A	
1.0.0.2	MAC B
1.0.0.9	MAC R

Indirect Delivery 1.0.0.1 - > 2.0.0.1

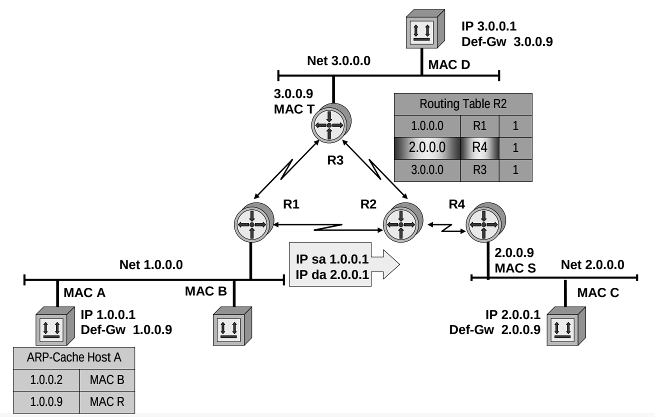


Routing Table R1		
1.0.0.0	local	0
2.0.0.0	R2	2
3.0.0.0	R3	1

ARP-Cache Host A	
1.0.0.2	MAC B
1.0.0.9	MAC R

L30 - IP Technology Basics

Indirect Delivery 1.0.0.1 - > 2.0.0.1



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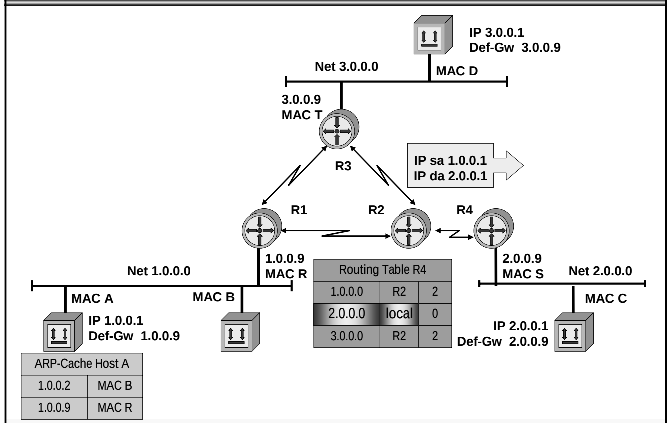
Indirect Delivery 1.0.0.1 - > 2.0.0.1



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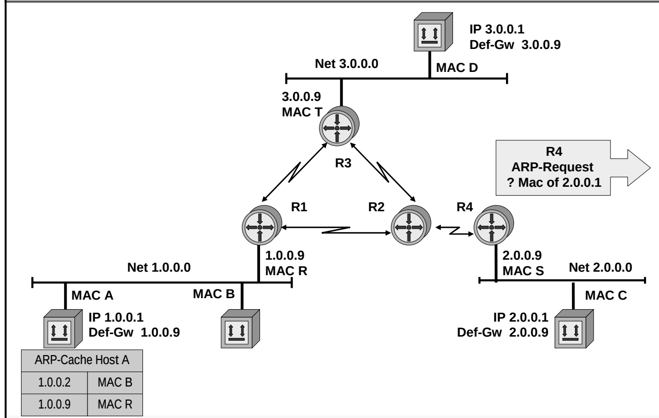
L30 - IP Technology Basics

Indirect Delivery 1.0.0.1 - > 2.0.0.1



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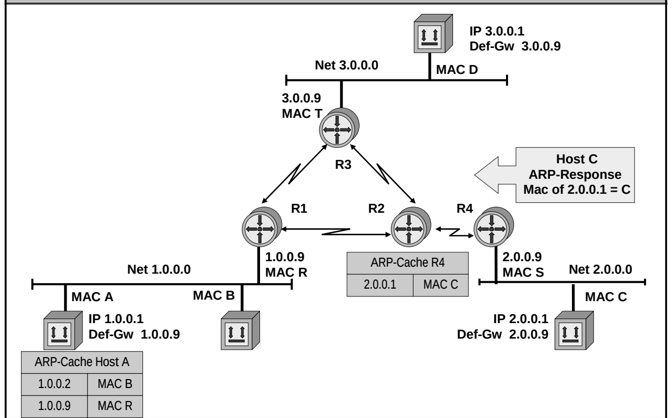
Indirect Delivery 1.0.0.1 - > 2.0.0.1



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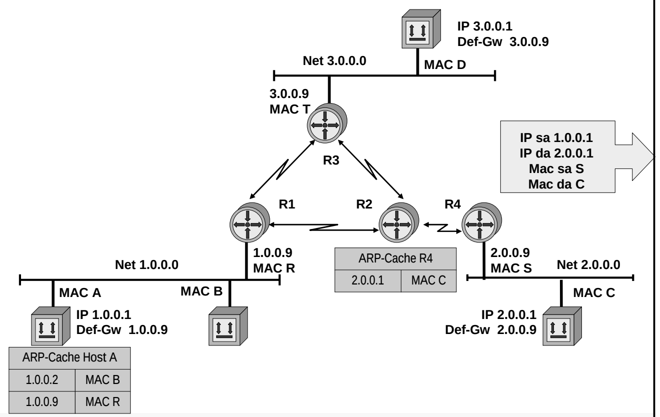
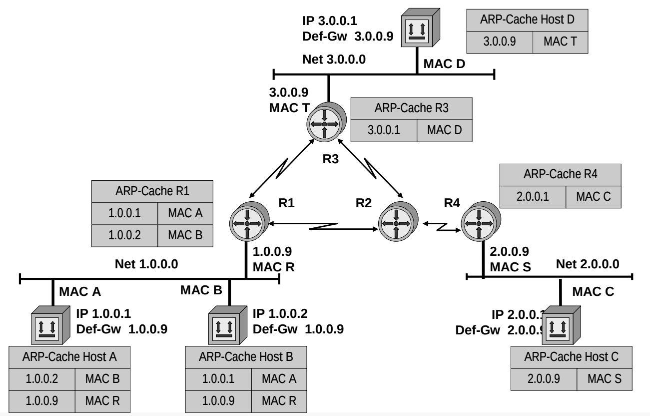
Indirect Delivery 1.0.0.1 - > 2.0.0.1



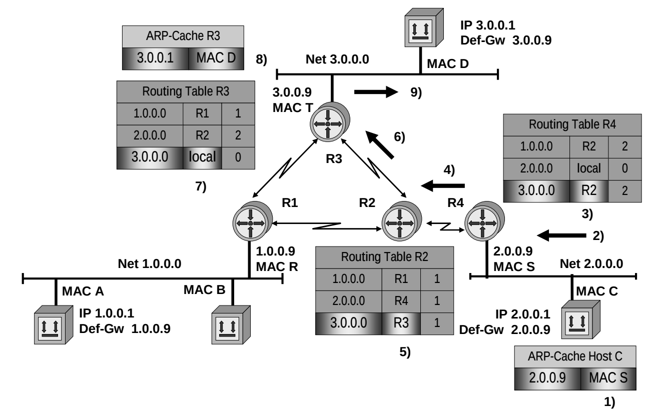
ARP Cache - Final Picture



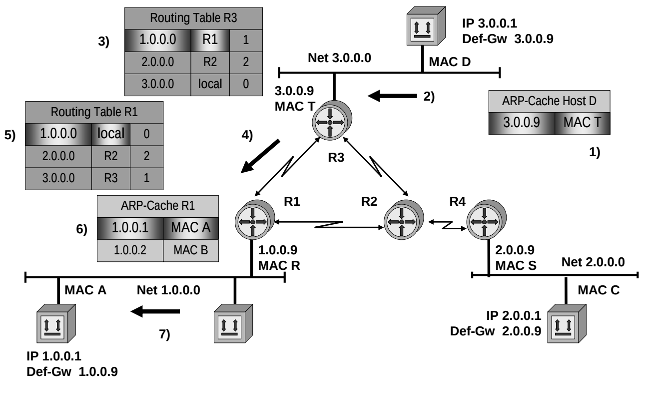
IP Routing Paradigm

- **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

Delivery 2.0.0.1 -> 3.0.0.1



Delivery 3.0.0.1 -> 1.0.0.2



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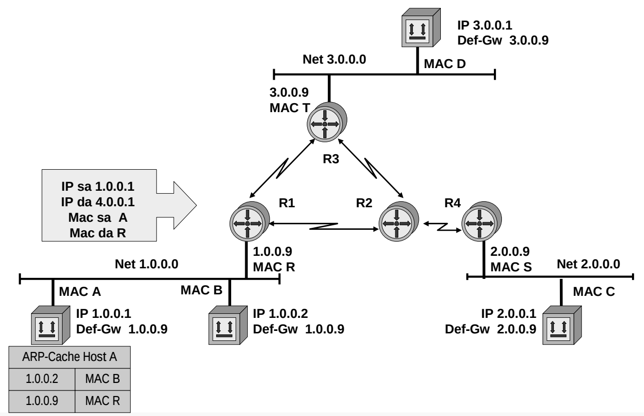
L30 - IP Technology Basics

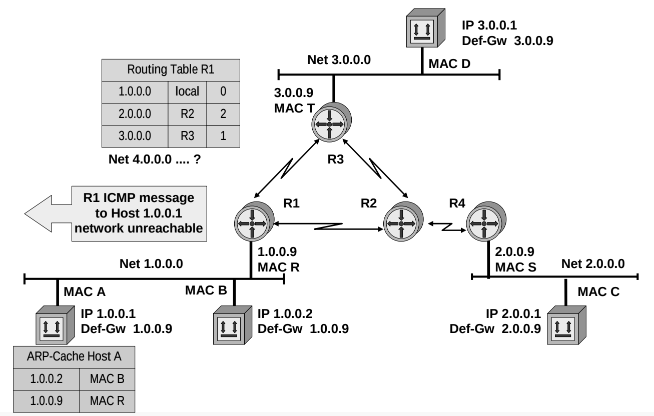
ICMP

- **datagram service of IP**
  - best effort -> IP datagram's can be lost
- **ICMP**
  - Internet Control Message Protocol generates error messages to enhance the reliability and to provide information about errors and packet loss in the network
- **principle of ICMP operation**
  - IP station (router or destination), which detects any transmission problems, generates an ICMP message
  - ICMP message is addressed to the originating station (sender of the original IP packet)
- **most famous ICMP message: PING**

Delivery 1.0.0.1 - > 4.0.0.1



ICMP network unreachable



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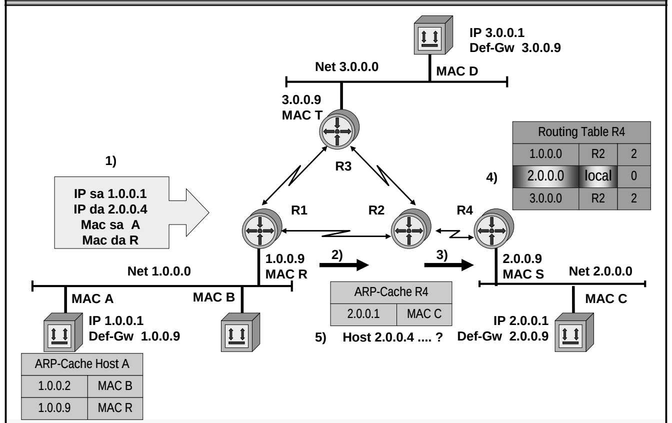
Delivery 1.0.0.1 - > 2.0.0.4



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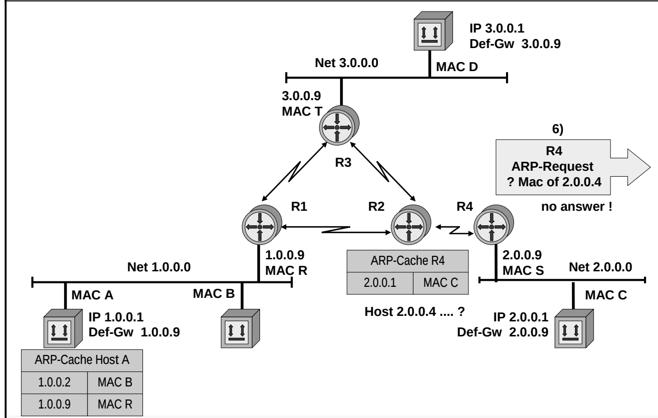
Delivery 1.0.0.1 - > 2.0.0.4



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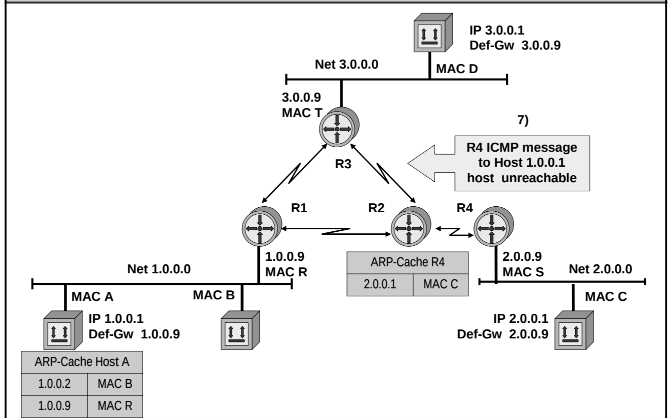
ICMP host unreachable



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