Computer Networks - *Xarxes de Computadors*

Outline

- Course Syllabus
- Unit 1. Introduction
- **Unit 2. IP Networks**
- Unit 3. LANs
- Unit 4. TCP
- Unit 5. Network applications

These slides are based on the set of slides provided by Llorenç Cerdà for this course. They include some modifications and some new slides.
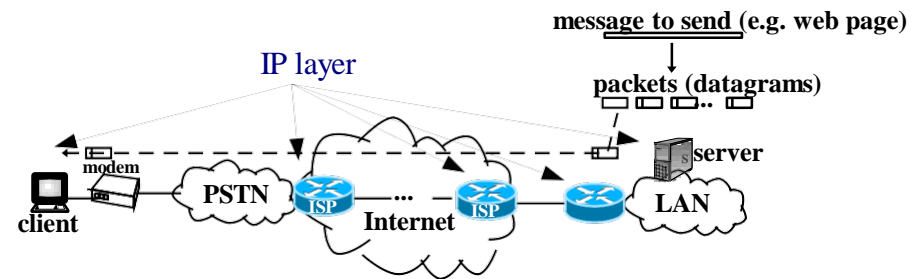
Unit 2: IP Networks

Outline

- **IP layer service**
- IP addresses
- Subnetting
- Routing tables
- ARP protocol
- IP header

- ICMP protocol
- DNS
- DHCP protocol
- NAT
- Routing algorithms
- Security in IP

IP Layer Service

- Internet Protocol (IP) goal is routing datagrams.

- IP main design goal was interconnecting hosts attached to LANs/WANs networks of different technologies.

- IP characteristics:

  - Connectionless
  - Stateless
  - Best effort

Commercial routers

Basic router architecture

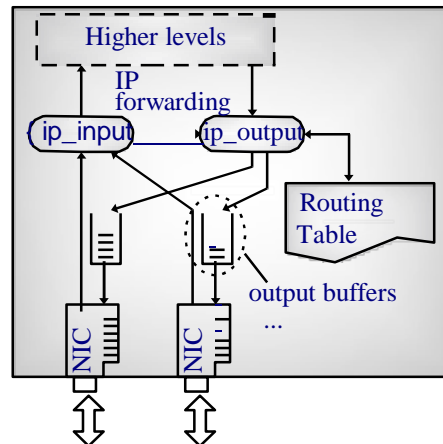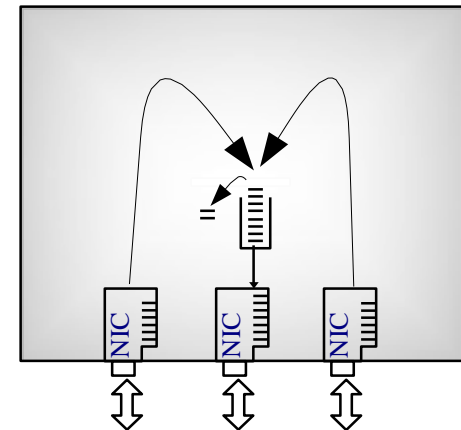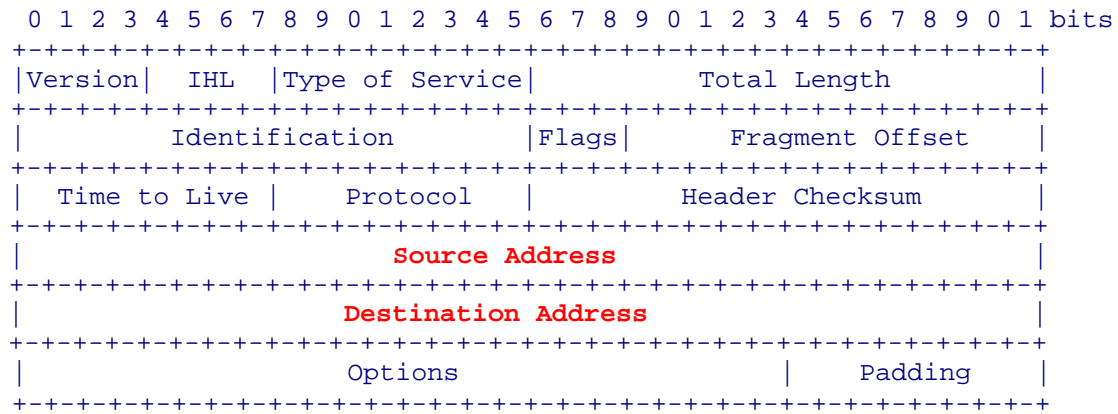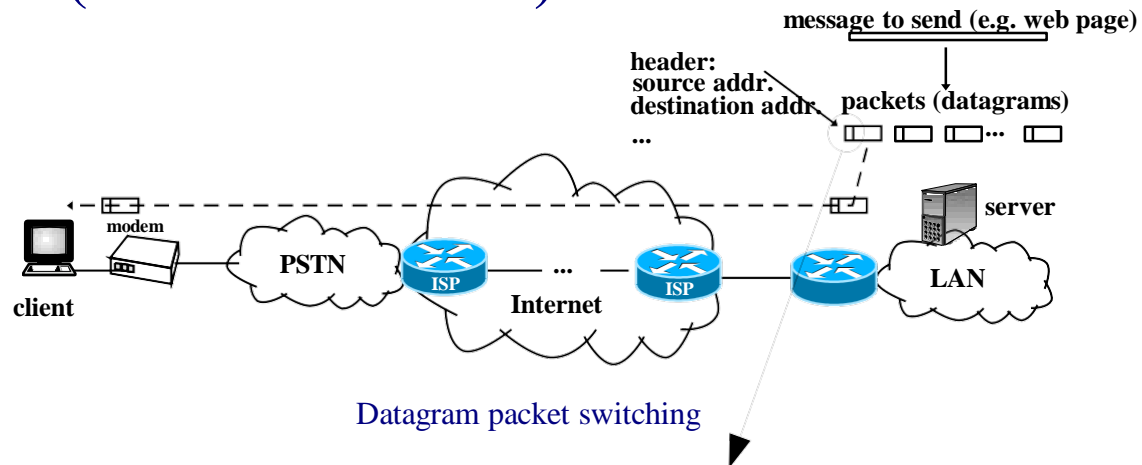Looses may occur due to buffer overflow
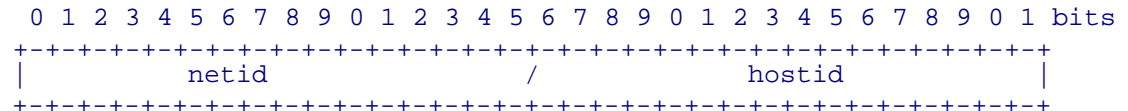
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IP Addresses (RFC 791 Y1981)

message to send (e.g. web page)

header:
source addr.
destination addr.

packets (datagrams)

modem

server

PSTN

ISP ... ISP

client

Internet

LAN

Datagram packet switching

```
 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 bits
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|Version|  IHL  |Type of Service|          Total Length         |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|        Identification         |Flags|      Fragment Offset    |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|  Time to Live |    Protocol   |         Header Checksum        |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                        Source Address                         |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                      Destination Address                      |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                    Options                    |    Padding     |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

IP datagram header

IP Addresses

```
0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 bits
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|            netid             /             hostid             |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

- 32 bits (4 bytes).

- Dotted point notation: Four bytes in decimal, e.g. 147.83.24.28

- netid identifies the network.

- hostid identifies the host within the network.

- An IP address identifies an *interface*: an attachment point to the network.

- All IP addresses in Internet must be different. To achieve this goal, Internet Assigned Numbers Authority, IANA (http://www.iana.net) assign address blocs to Regional Internet Registries, RIR:

  - RIPE: Europe, http://www.ripe.net.

  - ARIN: USA, http://www.arin.net.

  - APNIC: ASIA http://www.apnic.net.

  - LACNIC: Latin America, http://www.lacnic.net.

  - AFRINIC: Africa, http://www.afrinic.net.

  RIR assign addresses to ISPs, and ISPs to their customers.

IP Addresses - Classes

- The highest bits identify the class.
- The number of IP bits of netid/hostid varies in classes A/B/C.
- D Class is for multicast addresses (e.g. 224.0.0.2: "all routers")
- E Class are reserved addresses.

Classe	netid (bytes)	hostid (bytes)	Codification	range
A	1	3	0xxxx···x	0.0.0.0 ∼ 127.255.255.255
B	2	2	10xxx···x	128.0.0.0 ∼ 191.255.255.255
C	3	1	110xx···x	192.0.0.0 ∼ 223.255.255.255
D	-	-	1110x···x	224.0.0.0 ∼ 239.255.255.255
E	-	-	1111x···x	240.0.0.0 ∼ 255.255.255.255

2^7 (128)   class A networks with 2^{24} addresses
2^{14} (16.384)   class B networks with 2^{16} addresses
2^{21} (2.097.152) class C networks with 2^8 addresses
2^{28} class D (multicast) addresses
2^{28} class E (reserved) addresses

IP Addresses – Special Addresses

- Special addresses cannot be used for a physical interface.
- Each network has two special addresses: network and broadcast addresses.

netid	hostid	Meaning
xxx	all '0'	Identifies a network. It is used in routing tables.
xxx	all '1'	Broadcast in the net. xxx.
all '0'	all '0'	Identifies "this host" in "this net.". Used as source address in configuration protocols, e.g. DHCP.
all '1'	all '1'	broadcast in "this net.". Used as destination address in configuration protocols, e.g. DHCP.
127	xxx	host loopback: interprocess communication with TCP/IP.

- Example:

200.10.10.1
200.10.10.2
200.10.11.1
200.10.11.2
200.10.10.3
200.10.11.3
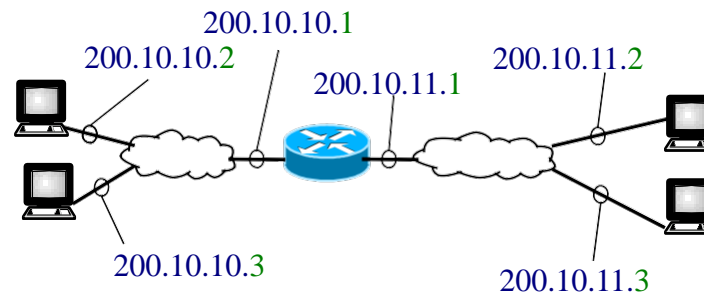
IP Addresses – Private Addresses (RFC 1918 Y1996)

- Commercial OSs include the TCP/IP stack.

- TCP/IP is used to network many kind of electronic devices:

PC   printer   labtop   GPRS phone   PDA   media player   IP camera   DVD player   GPS   balance   …

- Addresses assigned to RIRs by IANA are called *public, global* or *registered*.

- What if we arbitrarily assign a registered address to a host?
  - It may be filtered by our ISP or cause trouble to the right host using that address.

- **Private addresses** has been reserved for devices not using public addresses. These addresses are not assigned to any RIR (are not unique). There are addresses in each class:
  - 1 class A network: 10.0.0.0
  - 16 class B networks: 172.16.0.0 ~ 172.31.0.0
 - 256 class C networks: 192.168.0.0 ~ 192.168.255.0
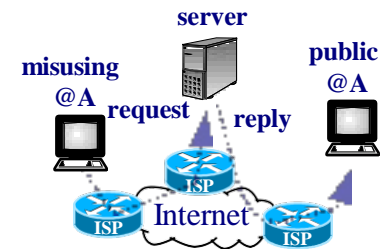
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Subnetting (RFC 950 Y1985)

- Initially the netid was given by the address class: A with 2^{24} addresses, B with 2^{16} addresses and C with 2^8 addresses.

- What if we want to divide the network?

class C
240 hosts
210.50.30.0
Internet
60 hosts
60 hosts
60 hosts
60 hosts
Internet
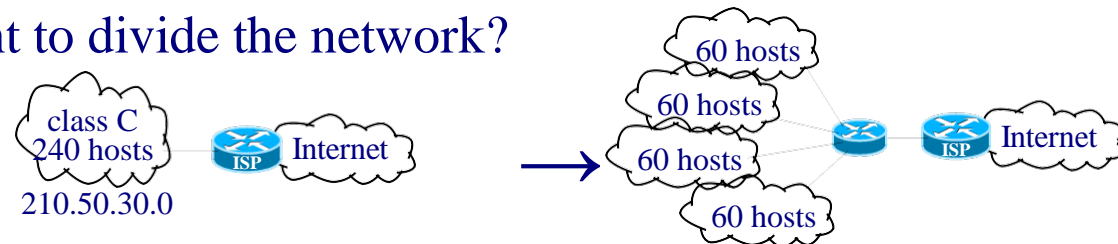
- Subnetting allows adding bits from the hostid to the netid (called subnetid bits).

- Example: For the ISP the network prefix is 24 bits. For the internal router the network prefix is 26 bits. The 2 extra bits allows 4 "subnetworks".

- A **mask** is used to identify the size of the netid+subnetid prefix.

- Mask notations:

  - dotted, as 255.255.255.192

  - giving the mask length (number of bits) as 210.50.30.0/26

IP Addresses – Subnetting Example

- We want to subnet the address 210.50.30.0/24 in 4 subnets
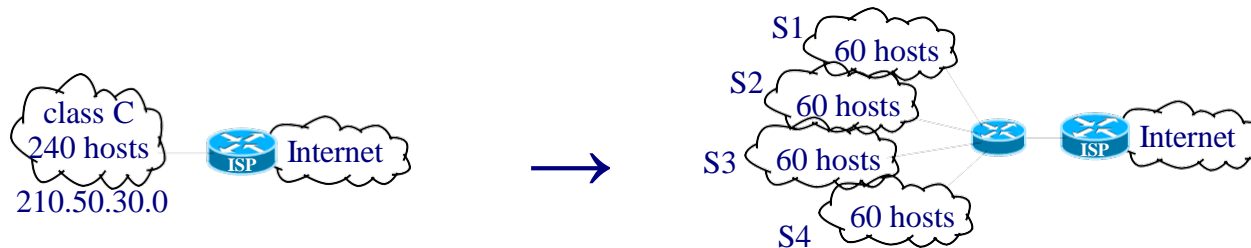
B = 210.50.30

subnet	subnetid	IP net. addr.	range	broadcast	available
S1	00	B.0/26	B.0 ~ B.63	B.63	$2^6 - 2 = 62$
S2	01	B.64/26	B.64 ~ B.127	B.127	$2^6 - 2 = 62$
S3	10	B.128/26	B.128 ~ B.191	B.191	$2^6 - 2 = 62$
S4	11	B.192/26	B.192 ~ B.255	B.255	$2^6 - 2 = 62$

# IP Addresses – Variable Length Subnet Mask (VLSM)

- Subnetworks of different sizes.
- Example, subnetting a class C address:
  - We have 1 byte for subnetid + hostid.
  - subnetid is green, chosen subnets addresses are underlined.

$$\frac{\mathbf{0000}}{\mathbf{1000}}\Big\} \longrightarrow \frac{\mathbf{1000}}{\mathbf{1100}}\Big\} \longrightarrow \frac{\mathbf{1100}}{\mathbf{1101}} \\ \frac{\mathbf{1110}}{\mathbf{1111}}$$

subnet	subnetid	IP net. addr.	range	broadcast	available
S1	0	B.0/25	B.0 ∼ B.127	B.127	$2^7 - 2 = 126$
S2	10	B.128/26	B.128 ∼ B.191	B.191	$2^6 - 2 = 62$
S3	1100	B.192/28	B.192 ∼ B.207	B.207	$2^4 - 2 = 14$
S4	1101	B.208/28	B.208 ∼ B.223	B.223	$2^4 - 2 = 14$
S5	1110	B.224/28	B.224 ∼ B.239	B.239	$2^4 - 2 = 14$
S6	1111	B.240/28	B.240 ∼ B.255	B.255	$2^4 - 2 = 14$

Classless Inter-Domain Routing, CIDR (RFC 1519 Y1993)

- Initially, Internet backbone routing tables did not use masks: netid was derived from the IP address class (default /8, /16, /24).

- When the number of networks in Internet started growing exponentially, routing tables size started exploding.

- In order to reduce routing tables size, CIDR proposed a "rational" geographical-based distribution of IP addresses to be able to "aggegate routes", and use masks instead of classes.

- Aggregation example:

$$
\left.\begin{array}{l}
200.1.10.0/24 \\
\\
200.1.11.0/24
\end{array}\right\} \rightarrow 200.1.10.0/23
$$
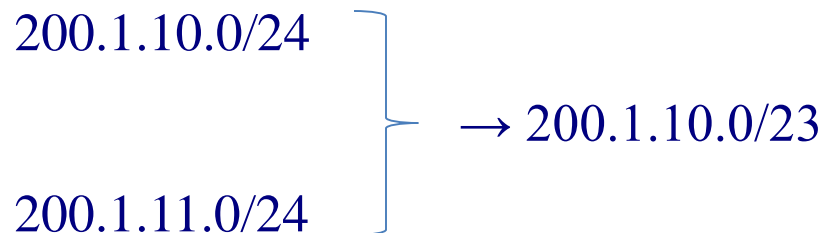
- The term summarization is normally used when aggregation is done at a class boundary (e.g. a groups of subnets is summarized with their classful base address).

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Routing Table

- ip_output() kernel function consults the routing table for each datagram.
- Routing can be:
  - Direct: The destination is directly connected to an interface.
  - Indirect: Otherwise. In this case, the datagram is sent to a router.
- Default route: Is an entry where to send all datagrams with a destination address to a network not present in the routing table. The default route address is 0.0.0.0/0.
- Hosts routing tables usually have two entries: The network where they are connected to and a default route.

Higher levels

IP forwarding

ip_input   ip_output

Routing Table

output buffers
...

NIC   NIC

Basic router architecture
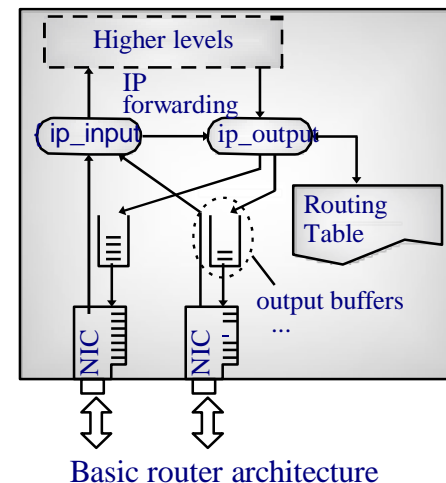
Routing Table – Unix Example
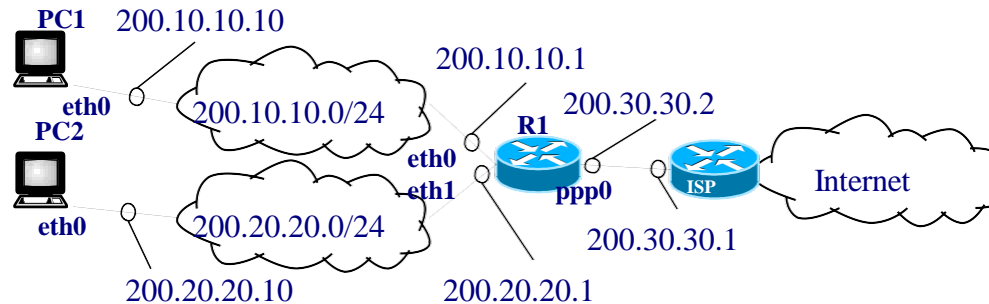
known destinations   how to reach the destinations

PC1 routing table:

Destination	Genmask	Gateway	Iface
200.10.10.0	255.255.255.0	0.0.0.0	eth0
0.0.0.0	0.0.0.0	200.10.10.1	eth0

PC2 routing table:

Destination	Genmask	Gateway	Iface
200.20.20.0	255.255.255.0	0.0.0.0	eth0
0.0.0.0	0.0.0.0	200.20.20.1	eth0

R1 routing table:

Destination	Genmask	Gateway	Iface
200.10.10.0	255.255.255.0	0.0.0.0	eth0
200.20.20.0	255.255.255.0	0.0.0.0	eth1
200.30.30.0	255.255.255.0	0.0.0.0	ppp0
0.0.0.0	0.0.0.0	200.30.30.1	ppp0

Routing Table – Datagram Delivery Algorithm

1. Check if the device itself is the destination:

```
if(Datagram Destination == address of any of the interfaces) {
    send the datagram to upper layers
}
```

2. Consult the routing table:

```
for each routing table entry ordered from longest to shortest mask
  (Longest Prefix Match) {
    if((Datagram Destination IP address & mask) == Destination
      table entry) {
        return (gateway, interface) ;
    }
```

3. Forward the datagram

```
if(it is a direct routing) {
    send the datagram to the Datagram Destination IP address
} else { /* it is an indirect routing */
    send the datagram to the gateway IP address
}
```

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Data Flow of the Internet Protocol Suite

Application Layer	SMTP		process to process		SMTP
Transport Layer	TCP		host to host		TCP
Internet Layer	IP	IP	IP		IP
Link Layer	LAN	LAN	WAN	WAN LAN	LAN

Outgoing E-mail Frame

Destination MAC Address	Source MAC Address	Destination IP Address	Source IP Address	Destination TCP Port	Source TCP Port	
00:0C:78:52:F3:A5	0E:11:81:F2:C3:98	216.93.82.9	172.16.20.57	25	58631	Hi Mom	101101
MAC address of default gateway router's interface	Your NIC's MAC address	IP address of the SMTP server at your mom's ISP	IP address of your PC	Standard port number for SMTP	Randomly generated by your PC's TCP/IP stack	

Address Resolution Protocol, ARP (RFC 826 Y1982)

- To send the datagram, IP layer may have to pass a "physical address" to the NIC driver. Physical addresses are also called MAC or hardware addresses.

- ARP translate IP addresses to "physical addresses" (used by the physical network).

- If needed, IP calls ARP module to obtain the "physical addresses" before the NIC driver call.

- Ethernet example:
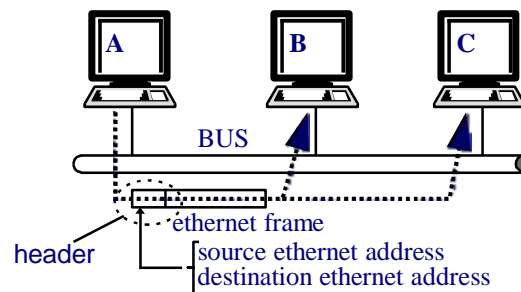
Address Resolution Protocol, messages - Example

- ARP messages (tcpdump):

147.83.34.125   147.83.34.123

```
A        B        C
```

1 broadcast:
   20:02:25.681331 arp who-has
    147.83.34.123 tell 147.83.34.125

2 unicast:
   20:02:25.681490 arp reply 147.83.34.123
   is-at 00:c0:49:d5:96:d8
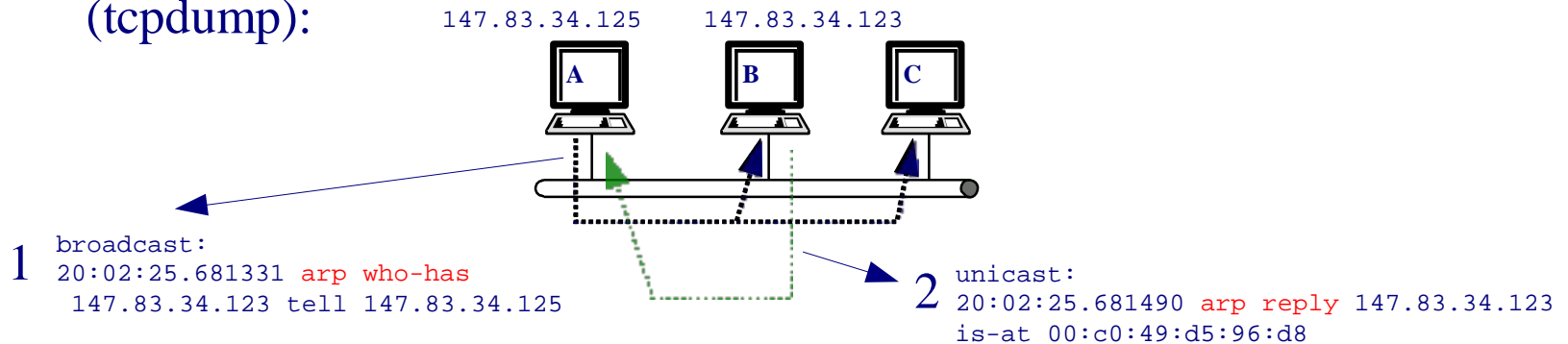
- ARP tables:

```
A> /sbin/arp -n
Address                 HWtype   HWaddress           Flags Mask         Iface
147.83.34.123           ether    00:c0:49:d5:96:d8   C                  eth0

B> /sbin/arp -n
Address                 HWtype   HWaddress           Flags Mask         Iface
147.83.34.125           ether    00:14:F1:CC:59:00   C                  eth0
```

"Completed" flag

Address Resolution Protocol

- ARP resolution in an ethernet network (broadcast network):
  - A broadcast "ARP Request" message is sent indicating the IP address.
  - The station having the requested IP address sends a unicast "ARP Reply", and stores the requesting address in the ARP table.
  - Upon receiving the "ARP Reply", the requesting station return the IP call with it.
  - ARP entries have a timeout refreshed each time a match occurs.

Address Resolution Protocol – Message format (ethernet)

- ARP messages are encapsulated directly in a data-link frame.

```
 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 bits
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
| Hardware Type (16)            |    Protocol Type (16)         |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|Hard. Length(8)|Prot. Length(8)|  Opcode (16)                 |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|         Sender Hardware                                       |
+         Address (48)                  +-+-+-+-+-+-+-+-+-+-+-+-+
|                                       | Sender Protocol Address (32)  |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
| Sender Protocol Address (cont)|    Target Hardware            |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+    Address (48)               +
|                                                              |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|         Target Protocol Address (32)                         |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```
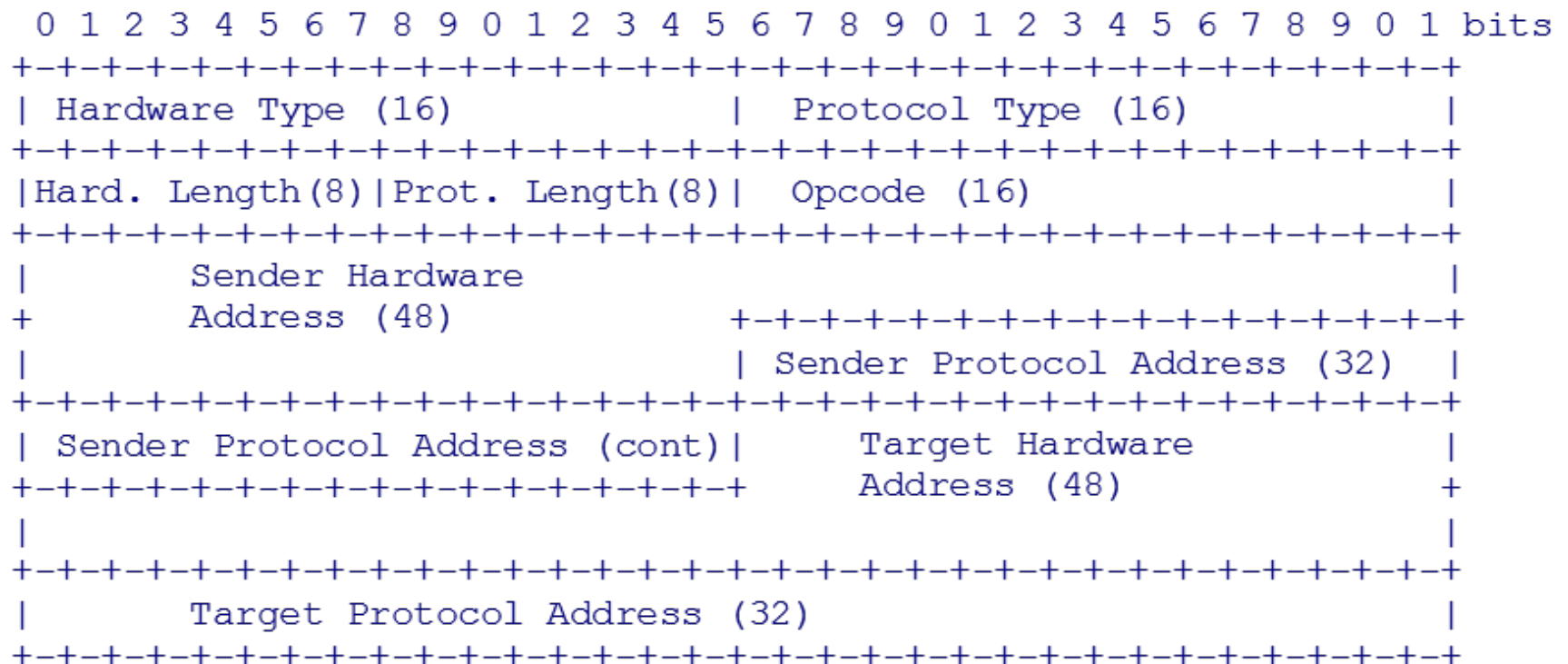
Address Resolution Protocol – Gratuitous ARP

```
10.0.0.10                    10.0.0.20
00:00:39:7e:06:3b            00:00:39:7f:16:a0
```

A   B

1   broadcast:
     20:02:25.681331 arp who-has
      10.0.0.20 tell 10.0.0.20
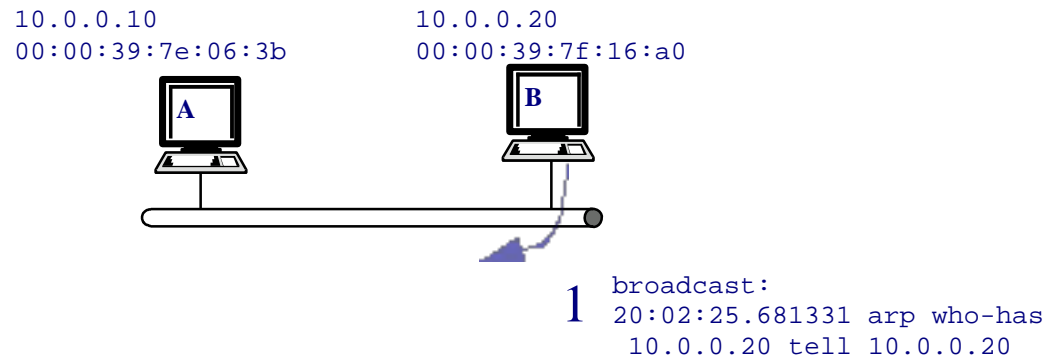
- Goals:
  - Detect duplicated IP addresses.
  - Update MAC addresses in ARP tables after an IP or NIC change.
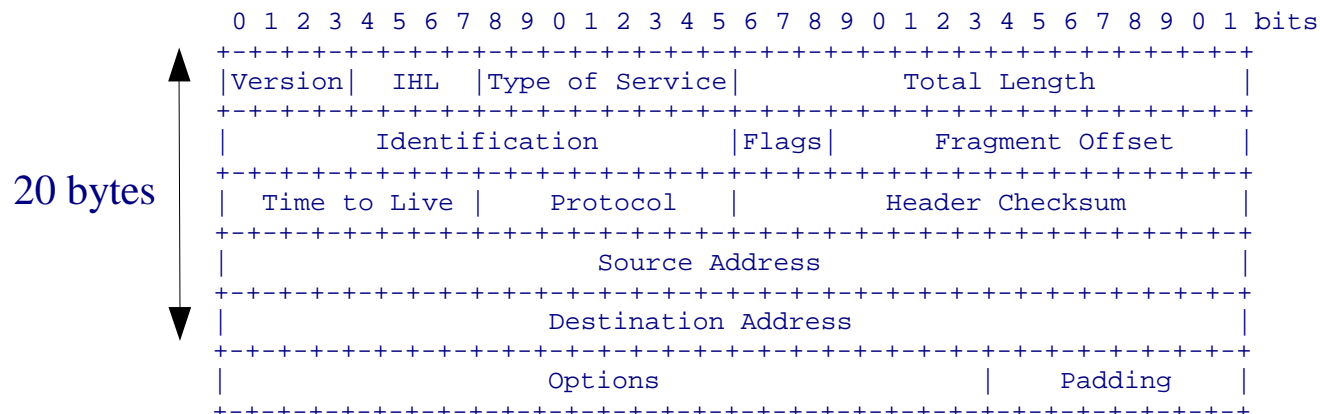
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IP Header (RFC 791 Y1981 updated by 1349 Y1992, 2474 Y1998, 6864 Y2013)

- Version: 4
- IP Header Length (IHL): Header size in 32 bit words.
- Type of Service: (ToS): *xxxdtrc0*.
- Total Length: Datagram size in bytes.
- Identification/Flags/Fragment Offset: used in fragmentation.
- Time to Live (TTL): if(--TTL==0) { discard ; }.
- Protocol: Encapsulated protocol (/etc/protocols in unix).
- Header Checksum: Header error detection.
- Source and Destination Addresses: End node addresses.
- Options: Record Route, Loose Source Routing, Strict Source Routing.

```
          0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 bits
         +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
         |Version|  IHL  |Type of Service|          Total Length         |
         +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
         |         Identification        |Flags|      Fragment Offset    |
         +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
 20 bytes|  Time to Live |    Protocol   |         Header Checksum        |
         +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
         |                       Source Address                          |
         +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
         |                     Destination Address                       |
         +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
         |                    Options                    |    Padding    |
         +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

IP Fragmentation

- Fragmentation may occur:
    - Router: Fragmentation may be needed when two networks with different *Maximum Transfer Unit* (MTU) are connected.
    - Host: Fragmentation may be needed using UDP. TCP segments are ≤ MTU.
- Datagrams are reconstructed at the destination.
- Fields:
    - Identification (16 bits): identify fragments from the same datagram.
    - Flags (3 bits):
        - D, don't fragment. Used in MTU path discovery
        - M, More fragments: Set to 0 only in the last fragment
   - Offset (13 bits): Position of the fragment first byte in the original datagram in 8 byte words (indexed at 0).

ethernet, MTU=1500bytes

token ring, MTU=4464bytes

MTU examples:
Ethernet: 1500
WiFi: 2312
Token Ring 4M: 4464
FDDI: 4352
PPP: 250
X.25: 576

IP Fragmentation - Example

- Original datagram = 4464 bytes (4Mbps Token Ring): 20 header + 4444 payload.

- Fragment size = $\left\lfloor \frac{1500-20}{8} \right. = 185$ 8-byte-words (1480 bytes)

  - 1st fragment: offset = 0 , M = 1. 0~1479 payload bytes.

  - 2nd fragment: offset = 185, M = 1. 1480~2959 payload bytes.

  - 3rd fragment: offset = 370, M = 1 . 2960~4439 payload bytes.

  - 4th fragment: offset = 555, M = 0 . 4440~4443 payload bytes.
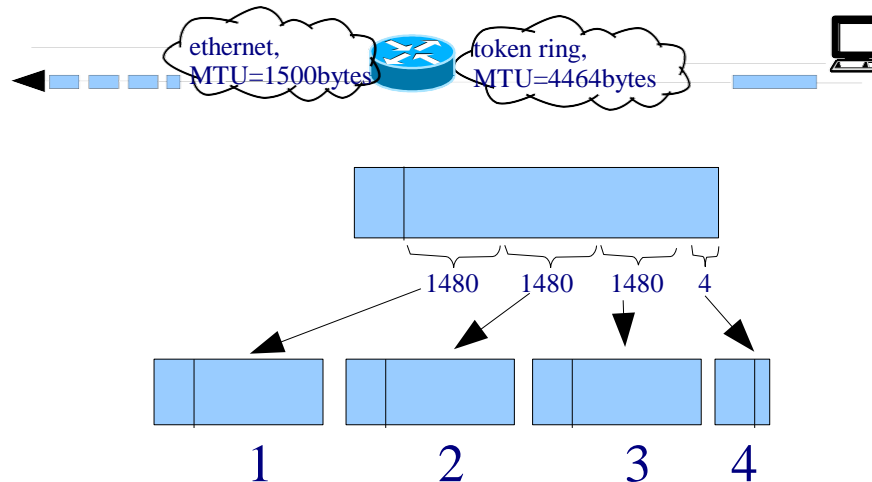
ethernet, MTU=1500bytes

token ring, MTU=4464bytes

1480   1480   1480   4

1   2   3   4
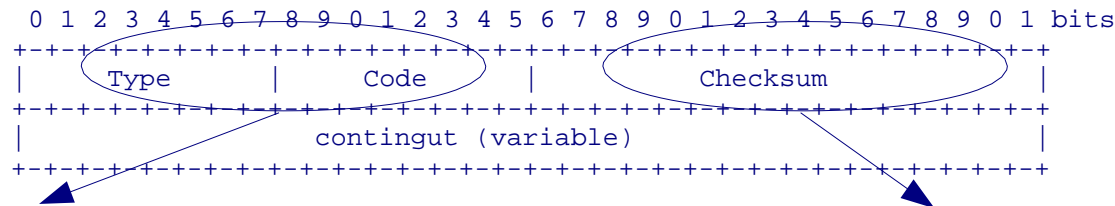
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Internet Control Message Protocol, ICMP (RFC 792 Y1981)

- Used for attention and error messages.
- Can be generated by IP, TCP/UDP, and application layers. ICMP
- Messages are encapsulated into an IP datagram (protocol = 1)
- Messages can be: (i) query, (ii) error.
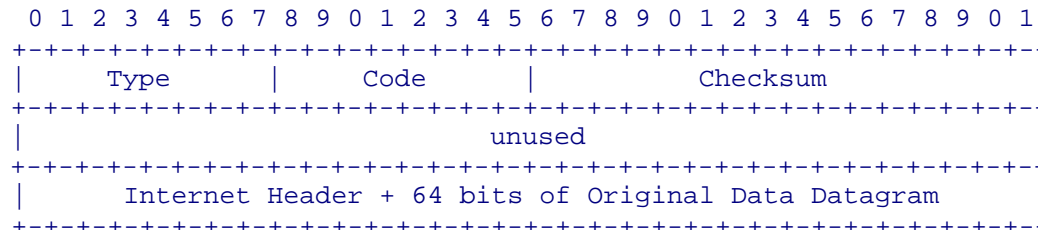- An ICMP error message cannot generate another ICMP error message (to avoid loops).

ICMP general format message (RFC 792 Y1981)

```
0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 bits
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|     Type      |     Code      |          Checksum             |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                    contingut (variable)                       |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

Identifies the message   It is computed using all the message

- Query type messages have an identifier field, for request-reply correspondence.

- Error messages have a field where the first 8 bytes of the datagram payload causing the error are copied. These bytes capture the TCP/UDP ports. E.g. Destination Unreachable Message:

```
0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|     Type      |     Code      |          Checksum             |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                             unused                            |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|      Internet Header + 64 bits of Original Data Datagram      |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

Common ICMP messages

Type	Code	query/error	Name	Description
0	0	query	echo reply	Reply an echo request
3	0	error	network unreachable	Network not in the RT.
	1	error	host unreachable	ARP cannot solve the address.
	2	error	protocol unreachable	IP cannot deliver the payload
	3	error	port unreachable	TCP/UDP cannot deliver the payload
	4	error	fragmentation needed but DF set	MTU path discovery
4	0	error	source quench	Sent by a congested router.
5	0	error	redirect for network	When the router send a datagram by the same interface it was received.
8	0	query	echo request	Request for reply
11	0	error	TTL=0 during transit	Sent by a router when `--TTL=0`

MTU Path Discovery

- Used in modern TCP implementations.

- TCP by default chooses the maximum segment size, to avoid headers overhead (segment efficiency = TCP payload / (TCP payload + Σ TCP,IP,Data-link,Physical headers)

- Goal: avoid fragmentation: The DF flag is set to one, segment size is reduced upon receiving ICMP error message "fragmentation needed but DF flag set"
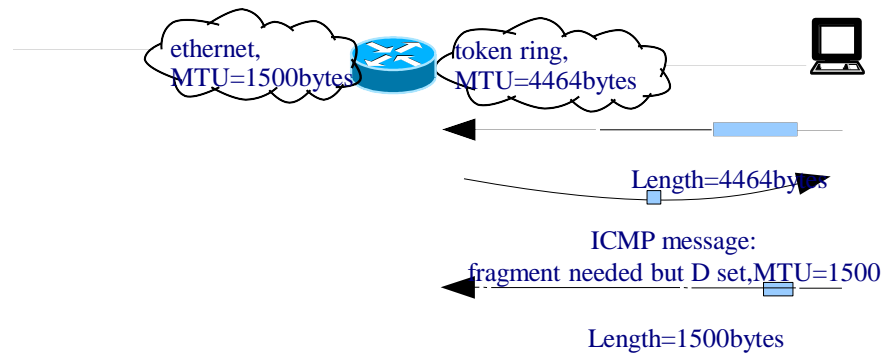
ethernet,
MTU=1500bytes

token ring,
MTU=4464bytes

Length=4464bytes

ICMP message:
fragment needed but D set,MTU=1500

Length=1500bytes
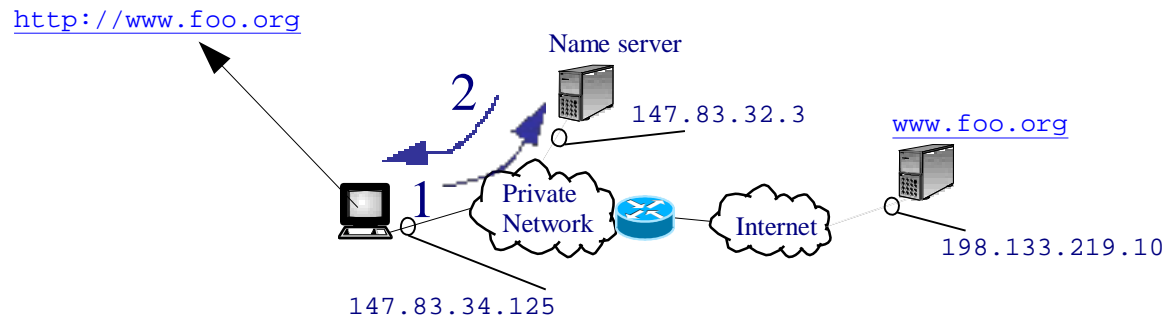
Unit 2: IP Networks

Outline

- IP layer service
- IP addresses
- Subnetting
- Routing tables
- ARP protocol
- IP header

- ICMP protocol
- DNS
- DHCP protocol
- NAT
- Routing algorithms
- Security in IP

Domain Name System DNS (RFC 1034, 1035 Y1987)

- Allows users to use names instead of IP addresses: e.g. rogent.ac.upc.edu instead of 147.83.31.7, www.upc.edu instead of 147.83.194.21, etc.
- Names consists of a node-name and a domain-mane: rogent.ac.upc.edu, www.upc.edu
- DNS consists of a worldwide distributed data base.
- DNS data base entries are referred to as *Resource Records* (RR).
- The information associated with a name is composed of 1 or more RRs.
- Names are case insensitive (e.g. www.upc.edu and WWW.UPC.EDU are equivalent).

DNS - Protocol

- Client-server paradigm
- UDP/TCP. For short messages it uses UDP.
- Well-known port: 53

http://www.foo.org

Name server
147.83.32.3

www.foo.org

2

1

Private
Network

Internet

198.133.219.10

147.83.34.125

1 18:36:00.322370 IP (proto: UDP) 147.83.34.125.1333 >
      147.83.32.3.53: 53040+ A? www.foo.org. (31)

2 18:36:00.323080 IP (proto: UDP) 147.83.32.3.53 > 147.83.34.125.1333:
      53040 1/2/2 www.foo.org. A 198.133.219.10 (115)

Unit 2: IP Networks

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Dynamic Host Configuration Protocol, DHCP (RFC 2131 Y1997)
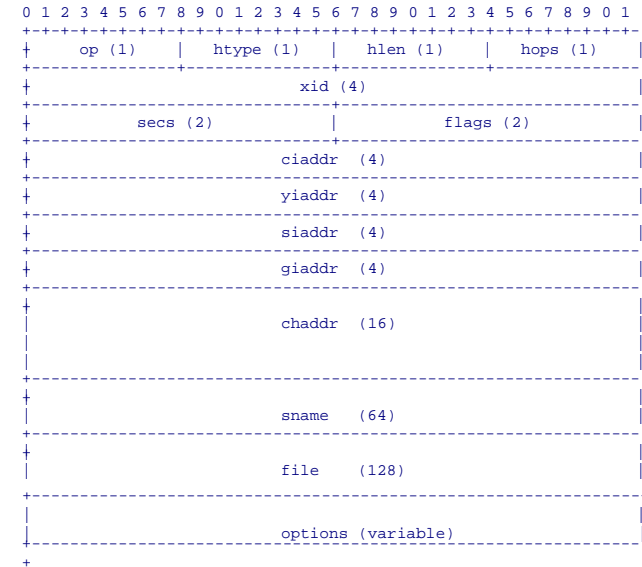
- Improves and can interoperate with previous BOOTP protocol.

- Used for automatic network configuration:

  - Assign IP address and mask

  - Default route

  - Configure DNS servers

  - Hostname

  - DNS domain

- IP address configuration can be:

  - Dynamic: During a leasing time.

  - Automatic: Unlimited leasing time.

  - Manual: IP addresses are assigned to specific MAC addresses.

DHCP – Protocol Messages (RFC 2131 Y1997)

```
DHCPDISCOVER -  Client broadcast to locate available servers.

DHCPOFFER    -  Server to client in response to DHCPDISCOVER with
                offer of configuration parameters.

DHCPREQUEST  -  Client message to servers either (a) requesting
                offered parameters from one server and implicitly
                declining offers from all others, (b) confirming
                correctness of previously allocated address after,
                e.g., system reboot, or (c) extending the lease on a
                particular network address.

DHCPACK      -  Server to client with configuration parameters,
                including committed network address.

DHCPNAK      -  Server to client indicating client's notion of network
                address is incorrect (e.g., client has moved to new
                subnet) or client's lease as expired

DHCPDECLINE  -  Client to server indicating network address is already
                in use.

DHCPRELEASE  -  Client to server relinquishing network address and
                cancelling remaining lease.

DHCPINFORM   -  Client to server, asking only for local configuration
                parameters; client already has externally configured
                network address.
```
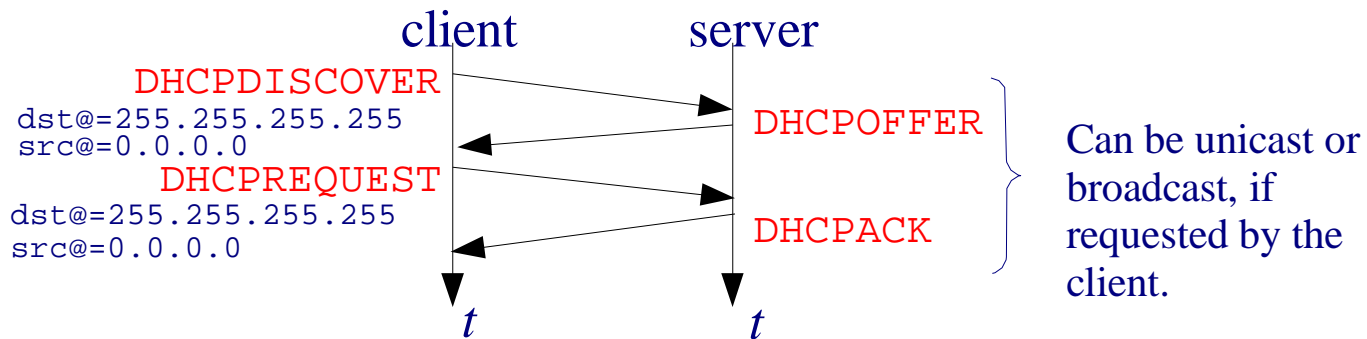
DHCP – Message Fields (RFC 2131)

```
FIELD       OCTETS        DESCRIPTION
op            1   Message op code / message type. 1 = BOOTREQUEST, 2 = BOOTREPLY.
htype         1   Hardware address type.
hlen          1   Hardware address length.
hops          1   Client sets to zero, optionally used by relay agents
                  when booting via a relay agent.
xid           4   Transaction ID, a random number chosen by the
                  client, used by the client and server to associate
                  messages and responses between a client and a
                  server.
secs          2   Filled in by client, seconds elapsed since client
                  began address acquisition or renewal process.
flags         2   Flags.
ciaddr        4   Client IP address; only filled in if client is in
                  BOUND, RENEW or REBINDING state and can respond
                  to ARP requests.
yiaddr        4   'your' (client) IP address. Set by the server in
                  a DHCPOFFER message.
siaddr        4   IP address of next server to use in bootstrap;
                  returned in DHCPOFFER, DHCPACK by server.
giaddr        4   Relay agent IP address, used in booting via a
                  relay agent.
chaddr       16   Client hardware address.
sname        64   Optional server host name, null terminated string.
file        128   Boot file name, null terminated string; "generic"
                  name or null in DHCPDISCOVER, fully qualified
                  directory-path name in DHCPOFFER.
options     var   Optional parameters field.
```
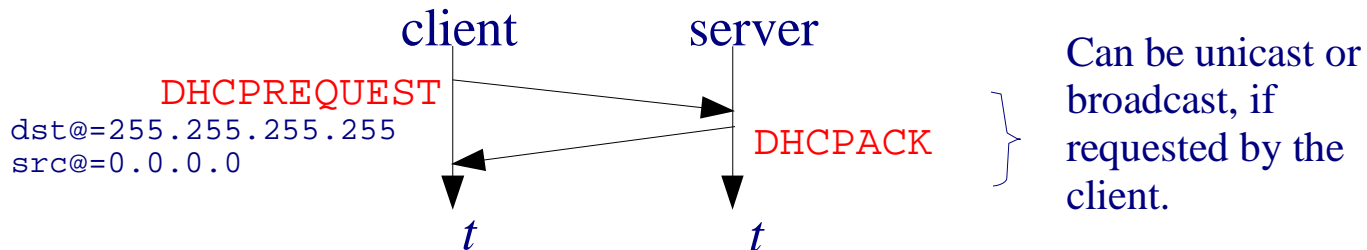
```
 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
+   op (1)      |   htype (1)   |   hlen (1)    |   hops (1)    |
+---------------+---------------+---------------+---------------+
+                            xid (4)                            |
+-------------------------------+-------------------------------+
+           secs (2)            |           flags (2)           |
+-------------------------------+-------------------------------+
+                          ciaddr  (4)                          |
+---------------------------------------------------------------+
+                          yiaddr  (4)                          |
+---------------------------------------------------------------+
+                          siaddr  (4)                          |
+---------------------------------------------------------------+
+                          giaddr  (4)                          |
+                                                               |
|                          chaddr  (16)                         |
|                                                               |
|                                                               |
+                                                               |
|                          sname   (64)                         |
+                                                               |
|                          file    (128)                        |
+---------------------------------------------------------------+
|                                                               |
|                          options (variable)                   |
+
```

DHCP – Client-server interaction (RFC 2131)

- UDP, server port = 67, client port = 68.


```
                          client        server

DHCPDISCOVER
dst@=255.255.255.255                     DHCPOFFER
src@=0.0.0.0
DHCPREQUEST
dst@=255.255.255.255                     DHCPACK
src@=0.0.0.0

                            t              t
```

Can be unicast or broadcast, if requested by the client.

- The client can directly send DHCPREQUEST:
    - After rebooting if it remembers and wishes to reuse a previously allocated network address.
    - Extending the lease on a particular network address.


```
                          client        server

DHCPREQUEST
dst@=255.255.255.255                     DHCPACK
src@=0.0.0.0

                            t              t
```

Can be unicast or broadcast, if requested by the client.

DHCP – Example: tcpdump/dhcpdump capture

```
linux # tcpdump -lenx -s 1500 -i eth0 port bootps or port bootpc | dhcpdump
    TIME: 17:09:24.616312
      IP: 0.0.0.0.68 (00:30:1b:b4:6d:78) > 255.255.255.255.67 (ff:ff:ff:ff:ff:ff)
      OP: 1 (BOOTPREQUEST)
   HTYPE: 1 (Ethernet)
     XID: 181f0139
   FLAGS: 0
  CIADDR: 0.0.0.0
  YIADDR: 0.0.0.0
  SIADDR: 0.0.0.0
  GIADDR: 0.0.0.0
  CHADDR: 00:30:1b:b4:6d:78:00:00:00:00:00:00:00:00:00:00
  OPTION:   53 (   1) DHCP message type          3 (DHCPREQUEST)
  OPTION:   57 (   2) Maximum DHCP message size 576
  OPTION:   50 (   4) Request IP address         192.168.1.100
  OPTION:   51 (   4) IP address leasetime       -1 ()
  OPTION:   55 ( 21) Parameter Request List       1 (Subnet mask)
                                                   3 (Routers)
                                                   6 (DNS server)
                                                  12 (Host name)
                                                  15 (Domainname)
                                                  23 (Default IP TTL)
                                                  28 (Broadcast address)
                                                  29 (Perform mask discovery)
                                                  42 (NTP servers)
                                                   9 (LPR server)
                                                 119 (Domain Search)
                                                 ...
  --------------------------------------------------------------------
    TIME: 17:09:24.619312
      IP: 192.168.1.1.67 (00:18:39:5d:74:9d) > 192.168.1.100.68 (00:30:1b:b4:6d:78)
      OP: 2 (BOOTPREPLY)
   HTYPE: 1 (Ethernet)
     XID: 181f0139
   FLAGS: 0
  CIADDR: 0.0.0.0
  YIADDR: 192.168.1.100
  SIADDR: 192.168.1.1
  GIADDR: 0.0.0.0
  CHADDR: 00:30:1b:b4:6d:78:00:00:00:00:00:00:00:00:00:00
  OPTION:   53 (   1) DHCP message type          5 (DHCPACK)
  OPTION:   54 (   4) Server identifier          192.168.1.1
  OPTION:   51 (   4) IP address leasetime       86400 (24h)
  OPTION:    1 (   4) Subnet mask                255.255.255.0
  OPTION:    3 (   4) Routers                    192.168.1.1
  OPTION:    6 (   4) DNS server                 192.168.0.1
  OPTION:   15 (   3) Domainname                 lan
```

Configuración DHCP IPv4

Dirección IPv4 (LOCAL):	192.168.1.1
Máscara de subred	255.255.255.0

DHCP

Estado	ACTIVADO
Dirección IPv4 inicio rango	192.168.1.33
Dirección IP fin de rango	192.168.1.199

Configuración de servidores DNS (se recomienda no modificar)

Servidor DNS 1	80.58.61.250
Servidor DNS 2	80.58.61.254

LAN IP Setup

IP Address : `192.168.1.1`

Subnet Mask : `255.255.255.0`

RIP Version : `RIP1` ▾   Direction : `None` ▾

Multicast : `IGMP v1/IGMP v2/IGMP v3` ▾

IGMP Snooping : ○ Disabled ● Enabled

IGMP Quickleave : ○ Disabled ● Enabled

DHCP Server State

DHCP : ○ Disable ● Enable ○ DHCP Relay

IP Addressing Values

IP Pool Starting Address : `192.168.1.33`

Pool Size : `167`

DHCP Conditional Serving Pool

State : ○ Disabled ● Enabled

Gateway : `192.168.1.1`

Subnet Mask : `255.255.255.0`

Pool Start : `192.168.1.200`

Pool End : `192.168.1.223`

DNS Server 1 : `80.58.61.250`

DNS Server 2 : `80.58.61.254`

VendorID : `[IAL]`

VendorID Mode : ○ Exact ○ Prefix ○ Suffix ● Substring

VendorID Exclude : ● Disabled ○ Enabled

Option240 State: ○ Disabled ● Enabled

Option240 Value: `:::::239.0.2.29:2222`

DHCP Server Lease Time

Lease Time : `43000` seconds

DNS Values

DNS Server 1 : `Obtained From ISP` ▾ `80.58.61.250`

DNS Server 2 : `Obtained From ISP` ▾ `80.58.61.254`

Detalles de la conexión de red:

Propiedad	Valor
Sufijo DNS específico para...	Home
Descripción	D-Link DWA-171 AC600 MU-MIMO Wi-Fi USB
Dirección física	C4-E9-0A-07-21-3A
Habilitado para DHCP	Sí
Dirección IPv4	192.168.1.69
Máscara de subred IPv4	255.255.255.0
Concesión obtenida	jueves, 04 de marzo de 2021 11:47:34
La concesión expira	viernes, 05 de marzo de 2021 23:38:33
Puerta de enlace predeter...	192.168.1.1
Servidor DHCP IPv4	192.168.1.1
Servidores DNS IPv4	80.58.61.250
	80.58.61.254
Servidor WINS IPv4	192.168.1.1
Habilitado para NetBios a t...	Sí
Vínculo: dirección IPv6 local	fe80::a023:3477:5ab2:81b9%12
Puerta de enlace predeter...	
Servidor DNS IPv6	

Unit 2: IP Networks

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Network Address Translation, NAT (RFCs 1631, 2663 3022)

- Typical scenario: Private addresses (internal addresses) are translated to public addresses (external addresses).

- A NAT table is used for address mapping.

- Advantages:
  - Save public addresses.
  - Security.
  - Administration, e.g. changing ISP does not imply changing private network addressing.
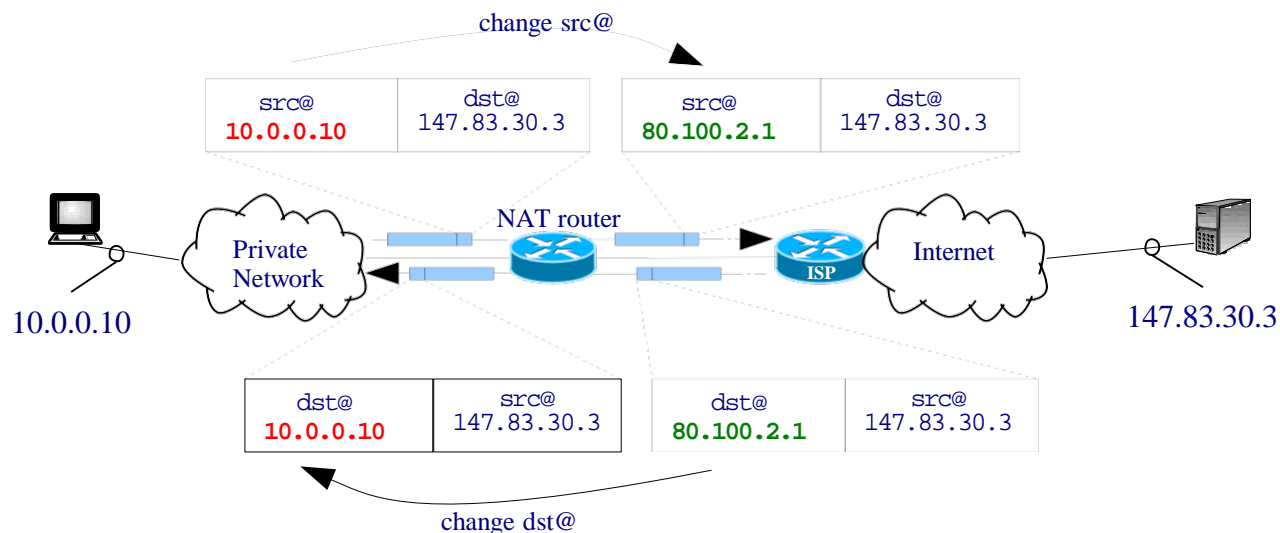
NAT – Types of translations

- NOTE: NAT is a technique, not a protocol. Implementations and terminology may change from one manufacturer to another.
- Basic NAT:
  - A different external address is used for each internal address → a different public IP address is needed for each hosts accessing Internet.
  - Each NAT table entry has the tuple: (internal address, external address).
  - Each host requires one NAT table entry.
- Port and Address Translation, PAT (PNAT, NAPT):
  - The same external address can be used for each internal address → a unique public IP address can be used for all hosts accessing Internet.
  - Each NAT table entry has the tuple: (int. address/port, ext. address/port)
  - Each connection requires one NAT table entry.
- The NAT table entries can be:
  - Static: Manually added.
  - Dynamic:
    – Entries are automatically added when an internal connection is initiated.
    – External addresses are chosen from a pool.
    – Table entries have a timeout.

Port and Address Translation (PAT)
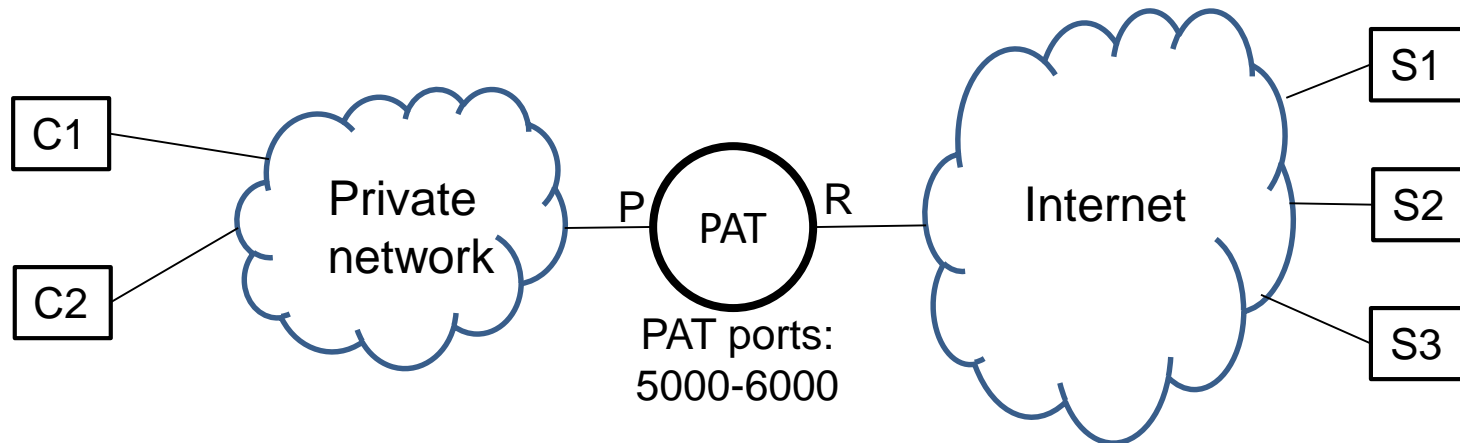
C1, C2, P are private IP addresses   R, S1, S3, S3 are public IP addresses

connection

src		dst	
C1	P1	S1	80
S1	80	C1	P1
C1	P2	S1	53
S1	53	C1	P2

C2	P1	S1	80
S1	80	C2	P1

C2	P2	S2	80
S2	80	C2	P2

Inside		Outside		Foreign/remote	
C1	P1	R	5000	S1	80
C1	P2	R	5001	S1	53
C2	P1	R	5002	S1	80
C2	P2	R	5003	S2	80

connection

src		dst	
R	5000	S1	80
S1	80	R	5000
R	5001	S1	53
S1	53	R	5001
R	5002	S1	80
S1	80	R	5002
R	5003	S2	80
S2	80	R	5003

PAT ports: 5000-6000

DNAT (Destination NAT)

- What if we want external connections to internal servers? (DNAT in linux-iptables terminology).

- The address translation is exactly the same as NAT, but, the connection is initiated from an external client.

- Typically, some static configuration is needed to configure the server IP/port.

```
Static entry in the NAT router:
Inside-address:Port  Outside-address:Port
192.168.1.10:22      80.102.9.91:22
```

change dst@

| dst@ 192.168.1.10:22 | src@ 147.83.30.3 | | dst@ 80.102.9.91:22 | src@ 147.83.30.3 |

NAT router

Private Network

ISP

Internet

192.168.1.10

147.83.30.3

| src@ 192.168.1.10:22 | dst@ 147.83.30.3 | | src@ 80.102.9.91:22 | dst@ 147.83.30.3 |

change src@
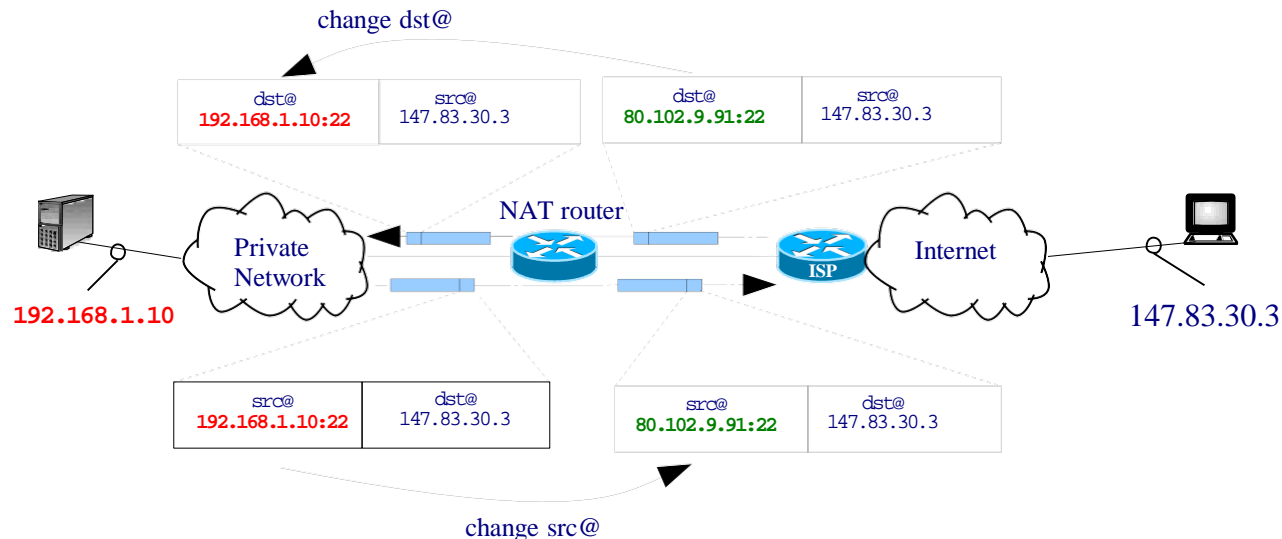
NAT – ADSL commercial router example

- NAT outgoing packets to 80.102.191.191
- DNAT incoming packets, port 22 (ssh) to 192.168.1.100
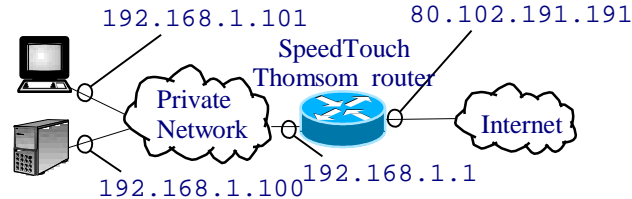

```
linux # telnet 192.168.1.1
Trying 192.168.0.1...
Connected to 192.168.1.1.
=>nat
[nat]=>list
       Indx Prot  Inside-address:Port    Outside-address:Port   Foreign-address:Port Flgs   Expir   State  Control
DNAT {  2    6    192.168.1.100:22        80.102.191.191:22          0.0.0.0:0       instance
       { 6    6    192.168.1.101:1420      80.102.191.191:10079    83.60.122.22:45730    1    14m48     1
       { 11   6    192.168.1.101:1337      80.102.191.191:10060    85.56.136.231:16000   1    14m30     1
SNAT {  12   6    192.168.1.101:1402      80.102.191.191:10064    82.159.8.187:1755     1     14s      5
       { ...
```

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Routing algorithms

- Objective: add entries to routing tables:
  - Static: Manual, scripts, DHCP.
  - Dynamic: Automatically update table entries, e.g. when a topology change occurs.

- Internet is organized in Autonomous Systems (AS). In terms of ASs, routing algorithms are classified as:
  - Interior Gateway Protocols (IGPs): Inside the same AS. Examples:
    - RFC standards: RIP, OSPF.
    - Proprietary: CISCO IGRP.
  - Exterior Gateway Protocols (EGPs): Between different ASs. Currently BGPv4.

Routing algorithms - Autonomous Systems (AS)

- AS definition (RFC 1930): "An AS is a connected group of one or more IP prefixes run by one or more network operators which has a SINGLE and CLEARLY DEFINED routing policy".

- Each AS is identified by a 16 bits AS Number (ASN) assigned by IANA.

- ASs facilitate Internet routing by introducing a two-level hierarchy: "IGP and EGP domains".

Internet

ASN1 ASN2 ASN5

ASN3 ASN4

ASN3

IP1 IP2 IP5

IP3 IP4

"EGP domain": Each domain is identified by a ASN. AS paths are used instead of metrics. Advertised AS paths depend on the routing preferences between ASs.

"IGP domain": metrics are used to find the set of "best paths" between IGP networks.
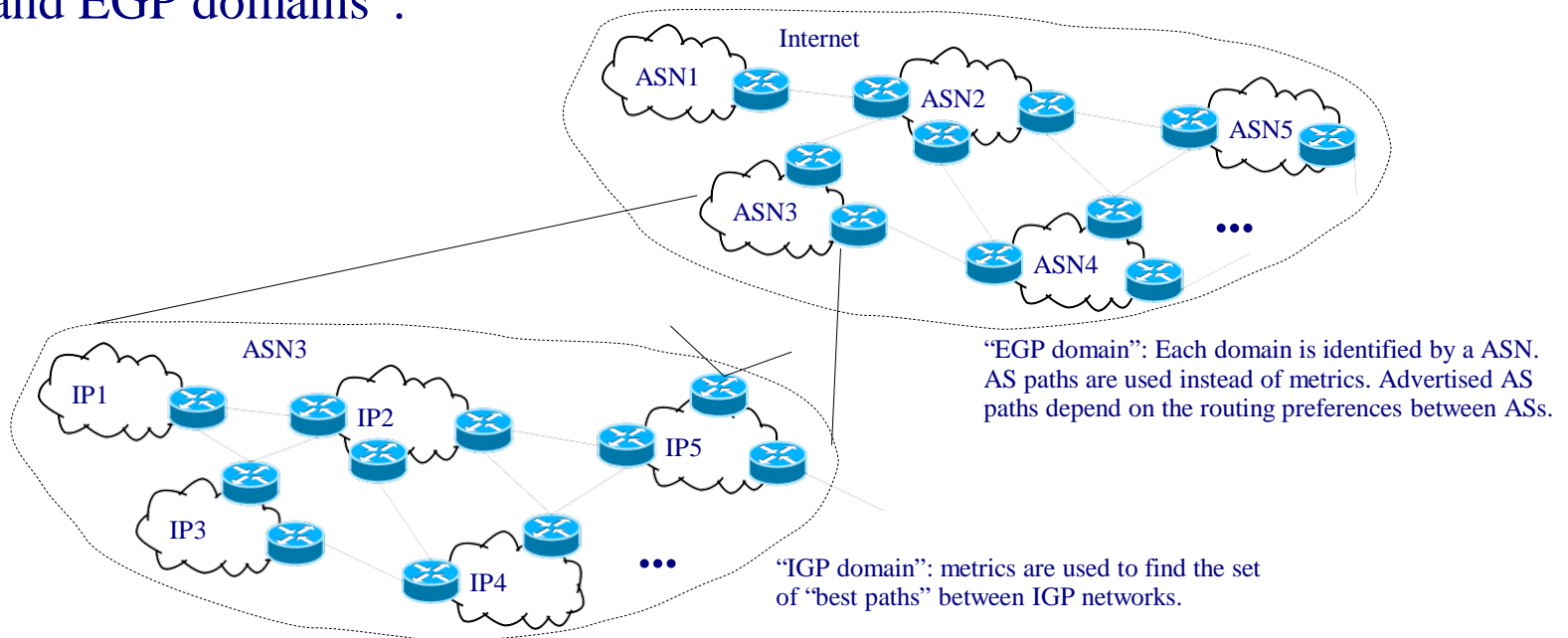
Routing Information Protocol, RIP (RFC 2453 RIPv2 Y1998)

- The metric (distance) to a destination is the number of hops (i.e. transmissions) to reach the destination: 1 if the destination is attached to a directly connected network, 2 if 1 additional router is needed ...

- Routers send RIP updates every 30 seconds to the neighbors.

- RIP updates use UDP, well-known port = 520, to broadcast IP address.

- RIP updates include destinations and metrics tuples.

- A neighbor is considered down if no RIP messages are seen during 180 seconds.

- Infinite metric is 16.

- RIP Version 2 allows variable masks and uses the multicast destination address 244.0.0.9 (all RIPv2 routers).

- The routing algorithm is known as "distance-vector" or "Bellman-Ford algorithm".

RIP – Routing Table (RT) Update Example

- Example: When Ri receives an update message from Rj:
  - Increase the message metrics.
  - Add new destinations.
  - Change entries with other routers with larger metrics.
  - Update metrics using Rj's gateway.
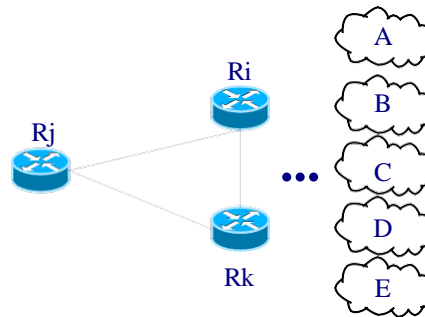
D	G	M
A	Rk	4
B	Rj	3
C	Rk	5
D	Rj	2

Ri's RT

D	M
A	1
B	4
C	5
D	1
E	3

Ri receives
Rj's update
message

D	M
A	2
B	5
C	6
D	2
E	4

Rj's metrics
increased

D	G	M
A	Rj	2
B	Rj	5
C	Rk	5
D	Rj	2
E	Rj	4

Ri's RT
updated

RIP – Count to Infinity

- Depending on the route update message order, convergence problems may arise:

D	G	M
N1	*	1
N2	*	1
N3	R2	2
N4	R2	3

R1's RT

D	G	M
N1	R1	2
N2	*	1
N3	*	1
N4	R3	2

R2's RT

D	G	M
N1	R2	3
N2	R2	2
N3	*	1
N4	*	1

R3's RT

- Example: Evolution of D=N4 entry when R3 fails:

	G	M	R3 fails	G	M	R1 upd	G	M	R2 upd	G	M	R1 upd	G	M		G	M
R1:	R2	3	→	R2	3	→	R2	3	→	R2	5	→	R2	5	...	R2	16
R2:	R3	2	→	R3	16	→	R1	4	→	R1	4	→	R1	6	...	R1	16

RIP – Count to Infinity Solutions

- Split horizon: When the router sends the update, removes the entries having a gateway in the interface where the update is sent:

D	G	M
N1	R1	2
N2	*	1
N3	*	1
N4	R3	2

R2's RT

D	M
N1	2
N2	1

update sent by R2
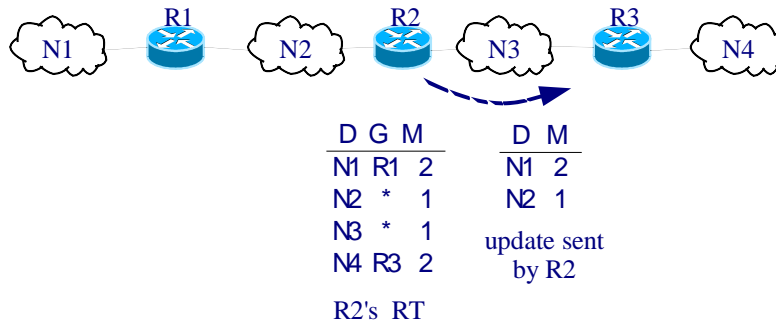
- Split horizon with Poisoned Reverse: Consists of adding the entries having a gateway with metric M=16.
- Triggered updates: Consists of sending the update before the 30 seconds timer expires when a metric change in the routing table.
- Hold down timer (CISCO): When a route becomes unreachable (metric = 16), the entry is placed in *holddown* during 280 seconds. During this time, the entry is not updated.

Open Shortest Path First, OSPF (RFC 2328, OSPF v2 Y1998)

- IETF standard for high performance IGP routing protocol.

- *Link State* protocol: Routers monitor neighbor routers and networks and send this information to all OSPF routers (*Link State Advertisements*, LSA).

- LSA are encapsulated into IP datagrams with multicast destination address 224.0.0.5, and routed using *flooding*.

- LSA are only sent when changes in the neighborhood occur, or when a LSA Request is received.

- Neighbor routers are monitored using a *hello protocol*.

- OSPF routers maintain a LS database with the information received with LSA. The Shortest Path First algorithm (Dijkstra algorithm) is used to optimal build routing table entries.

- The metric is computed taking into account link bitrates, delays etc.

- The infinite metric is the maximum metric value.

- There is no convergence (count to infinity) problems.

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Security in IP

- Goals:
    - Confidentiality: Who can access.
    - Integrity: Who can modify the data.
    - Availability: Access guarantee.

- Vulnerabilities:
    - Technological: Protocols (e.g. ftp and telnet send messages in "clear text") and networking devices (routers...)
    - Configuration: Servers, passwords, ...
    - Missing security policies: Secure servers, encryption, firewalls, ...

Security in IP – Attacks

- Detection: Previous to an attack.
    - Available IP addresses.
    - Available servers and ports.
    - Types of OSs, versions, devices...
    - Eavesdropping
- Access: Unauthorized access to an account or service.
- Denial of Service: Disables or corrupts networks, systems, or services.
- Viruses, worms , trojan horses...: Malicious software that replicates itself.

Security in IP – Basic Solutions

- Firewalls.
- Virtual Private Networks (VPN).

**An end-to-end connection is univocally defined by:**

source IP address (source device),
destination IP address (destination device),
source port number (application at source device),
destination port number (application at destination device) and
the protocol used in the communication

An end-to-end connection is univocally defined by:

	Header
source IP address (source device),	IP
destination IP address (destination device),	IP
source port number (application at source device),	TCP/UDP
destination port number (application at destination device) and	TCP/UDP
the protocol used in the communication	IP

Transport SAP:
TCP/UDP port number

Network SAP:
IP address
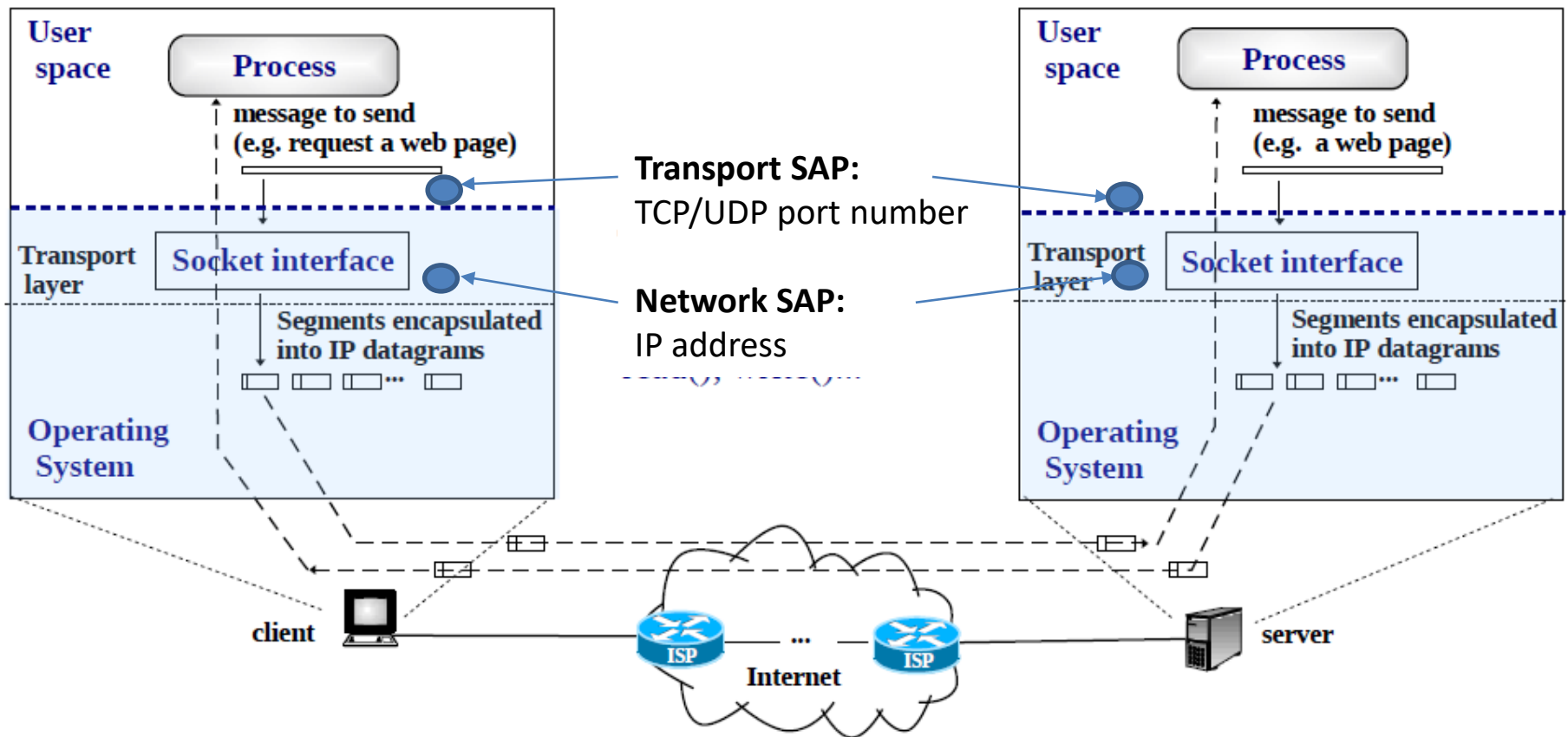
Example

Connection between an email client and an email server:

IP of the client device
Transport Protocol: TCP
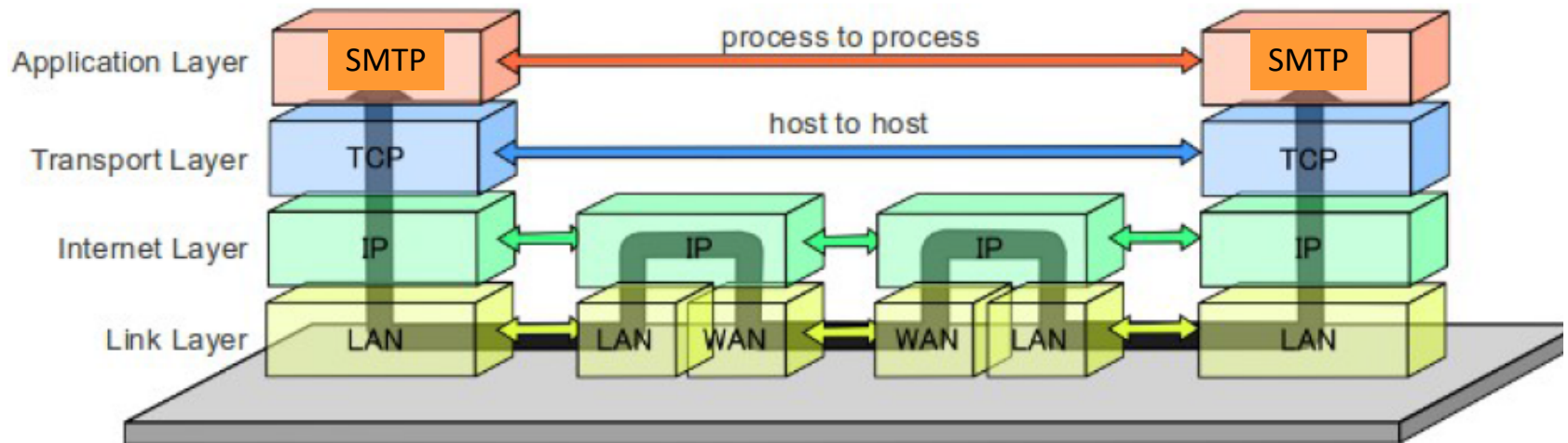Port number assigned to the email client by the client device

IP of the email server
Standard port number for email (SMTP): 25

The set of five fields identify a connection (flow)

Example

Connection between an email client and an email server:

              Client to Server

IP of the client device	Source IP header
Transport Protocol: TCP	Source IP header
Port number assigned to the email client by the email client	Source TCP header
IP of the email server	Destination IP header
Standard port number for email (SMTP): 25	Destination TCP header

The set of five fields identify a connection (flow)

Example

Server to Client

Connection between an email client and an email server:

IP of the client device	Destination IP header
Transport Protocol: TCP	Destination IP header
Port number assigned by the email client	Destination TCP header
IP of the email server	Source IP header
Standard port number for email (SMTP): 25	Source TCP header

The set of five fields identify a connection (flow)

Data Flow of the Internet Protocol Suite

| Application Layer | SMTP | process to process | SMTP |
Transport Layer	TCP	host to host	TCP
Internet Layer	IP	IP	IP	IP
Link Layer	LAN	LAN	WAN	WAN	LAN	LAN

Outgoing E-mail Frame

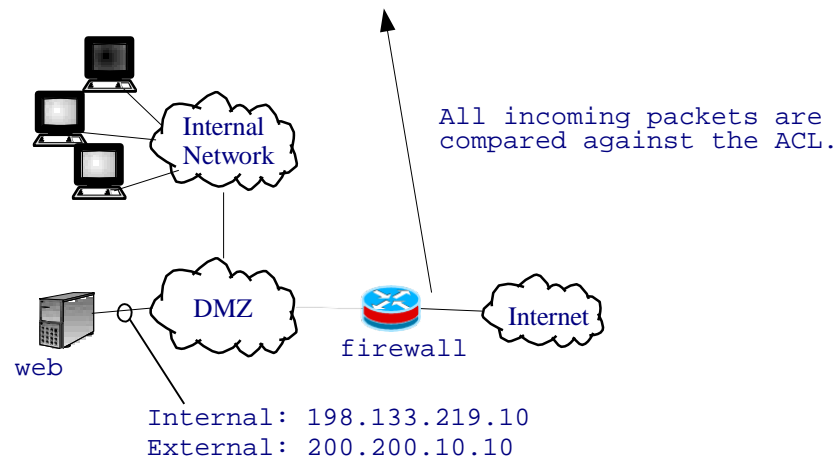| Destination MAC Address	Source MAC Address	Destination IP Address	Source IP Address	Destination TCP Port	Source TCP Port		
00:0C:78:52:F3:A5	0E:11:81:F2:C3:98	216.93.82.9	172.16.20.57	25	58631	Hi Mom	101101
MAC address of default gateway router's interface	Your NIC's MAC address	IP address of the SMTP server at your mom's ISP	IP address of your PC	Standard port number for SMTP	Randomly generated by your PC's TCP/IP stack		

Security in IP – Firewalls

- Firewall: System or group of systems that enforces an access control policy to a network.

- There are many firewall types: From simple packet filtering based on IP/TCP/UDP header rules, to state-full connection tracking and application-based filtering, defense against network attacks, ...
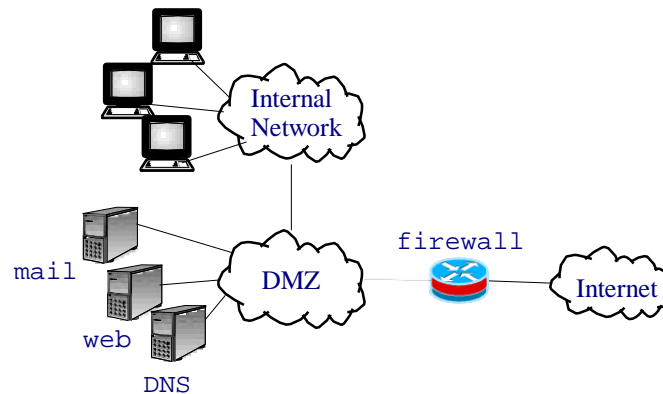
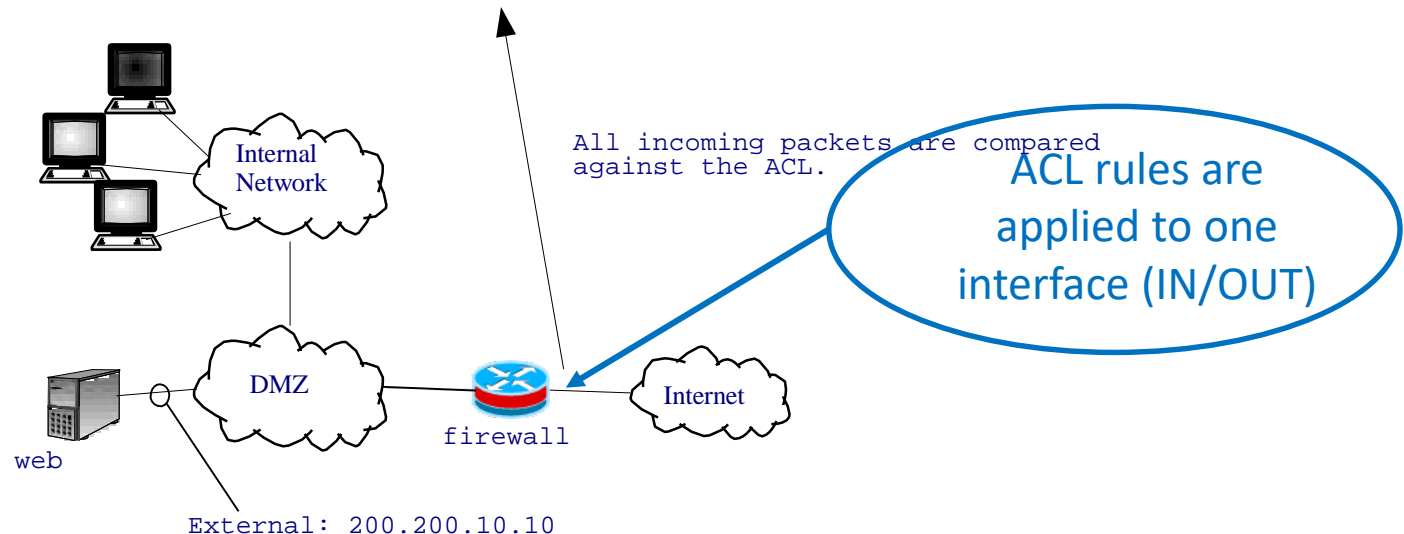# Security in IP – Basic Firewall Configuration

- Access Control List, ACL

Protocol	IP-src	IP-dst	Port-src	Port-dst	Action
TCP	*any*	200.200.10.10/32	*any*	80	*accept*
TCP	*any*	*any*	< 1024	≥ 1024	*accept*
ICMP	*any*	*any*	–	–	*accept*
IP	*any*	*any*	–	–	*deny*

Internal
Network

All incoming packets are
compared against the ACL.

web

DMZ

firewall

Internet

Internal: 198.133.219.10
External: 200.200.10.10

Security in IP/TCP/UDP – Basic Firewall Configuration

- Access Control List, ACL

Protocol	IP-src	IP-dst	Port-src	Port-dst	Action
TCP	*any*	200.200.10.10/32	*any*	80	*accept*
TCP	*any*	*any*	< 1024	≥ 1024	*accept*
ICMP	*any*	*any*	–	–	*accept*
IP	*any*	*any*	–	–	*deny*

Internal Network

All incoming packets are compared against the ACL.

ACL rules are applied to one interface (IN/OUT)

DMZ

Internet

firewall

web

External: 200.200.10.10

Security in IP/TCP/UDP – Basic Firewall Configuration

- Access Control List, ACL

Protocol	IP-src	IP-dst	Port-src	Port-dst	Action
TCP	any	200.200.10.10/32	any	80	accept
TCP	any	any	< 1024	≥ 1024	accept
ICMP	any	any	–	–	accept
IP	any	any	–	–	deny

Internal Network

All incoming packets are compared against the ACL.

DMZ

Internet

firewall

web

External: 200.200.10.10

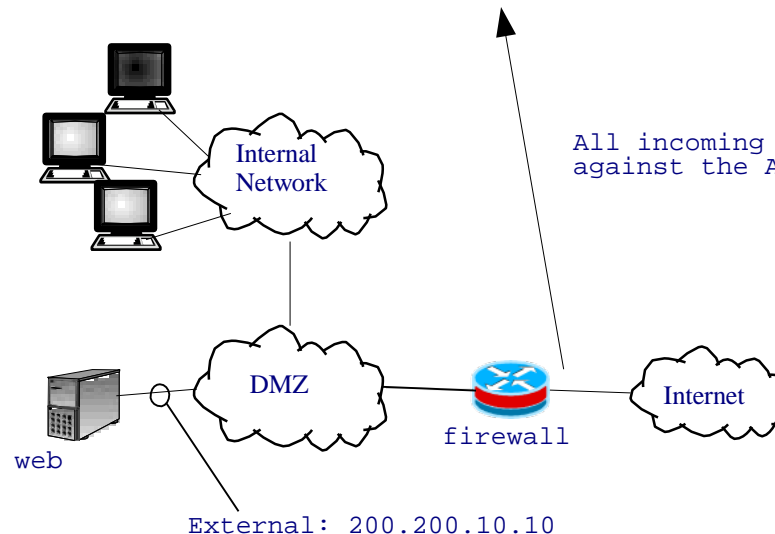incoming

FROM

TO

ONLY the Web server accepts connections from an external web client

Security in IP/TCP/UDP – Basic Firewall Configuration

- NAT
- Access Control List, ACL

Protocol	IP-src	IP-dst	Port-src	Port-dst	Action
TCP	*any*	200.200.10.10/32	*any*	80	*accept*
TCP	*any*	*any*	< 1024	≥ 1024	*accept*
ICMP	*any*	*any*	–	–	*accept*
IP	*any*	*any*	–	–	*deny*

Internal Network

All incoming packets are compared against the ACL.

incoming

FROM

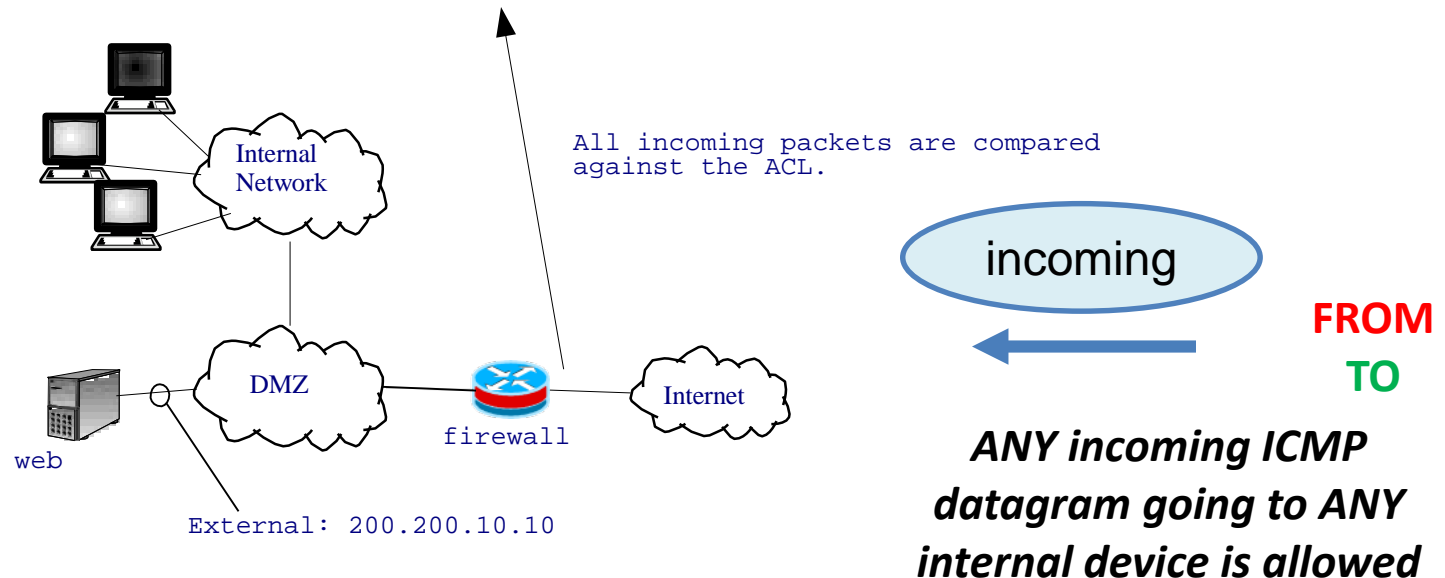**TO**

DMZ

firewall

Internet

web

External: 200.200.10.10

ANY internal client accepts connections from any external server

Security in IP/TCP/UDP – Basic Firewall Configuration
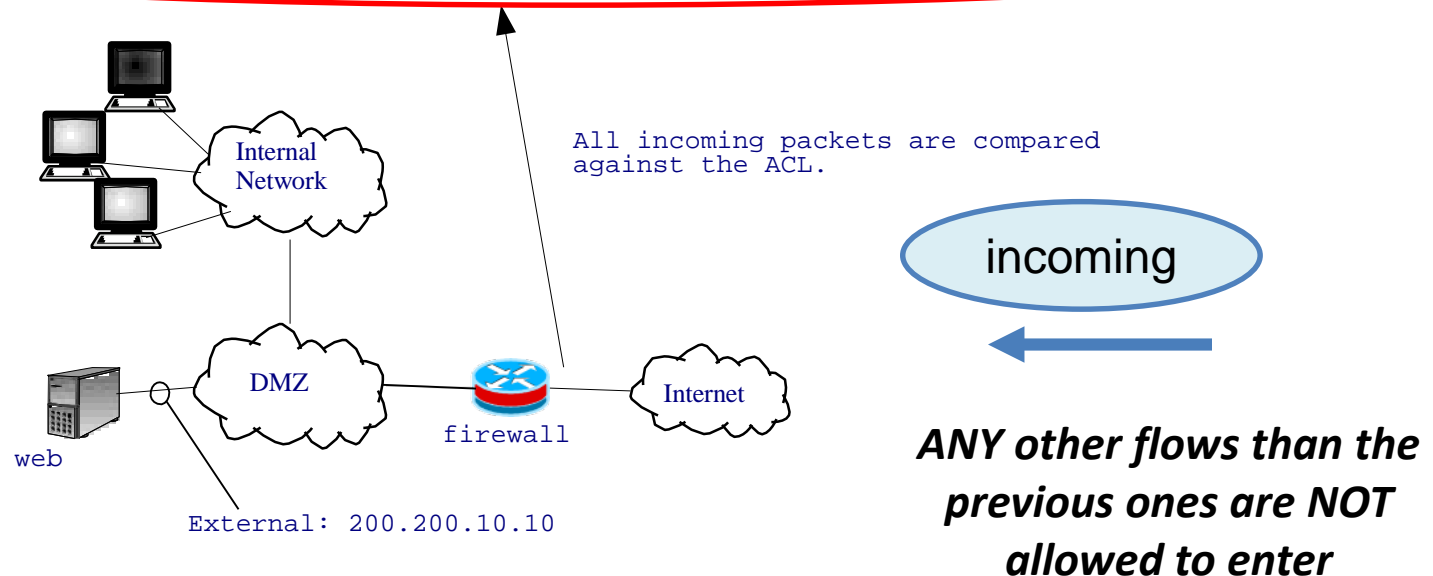
- NAT

- Access Control List, ACL

Protocol	IP-src	IP-dst	Port-src	Port-dst	Action
TCP	any	200.200.10.10/32	any	80	accept
TCP	any	any	< 1024	> 1024	accept
ICMP	any	any	–	–	accept
IP	any	any	–	–	deny

All incoming packets are compared against the ACL.

Internal Network

DMZ

Internet

firewall

web

External: 200.200.10.10

incoming

FROM

TO

ANY incoming ICMP datagram going to ANY internal device is allowed

Security in IP/TCP/UDP – Basic Firewall Configuration

- NAT

- Access Control List, ACL

Protocol	IP-src	IP-dst	Port-src	Port-dst	Action
TCP	*any*	200.200.10.10/32	*any*	80	*accept*
TCP	*any*	*any*	< 1024	≥ 1024	*accept*
ICMP	*any*	*any*	–	–	*accept*
IP	*any*	*any*	–	–	*deny*

All incoming packets are compared against the ACL.

Internal Network

DMZ

firewall

Internet

web

External: 200.200.10.10

incoming

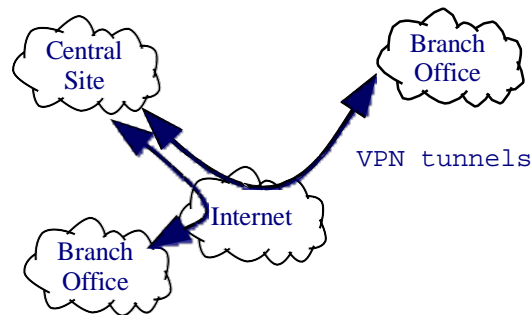*ANY other flows than the previous ones are NOT allowed to enter*

Security in IP – Virtual Private Network, VPN

- Provides connectivity for remote users over a public infrastructure, as they would have over a private network.
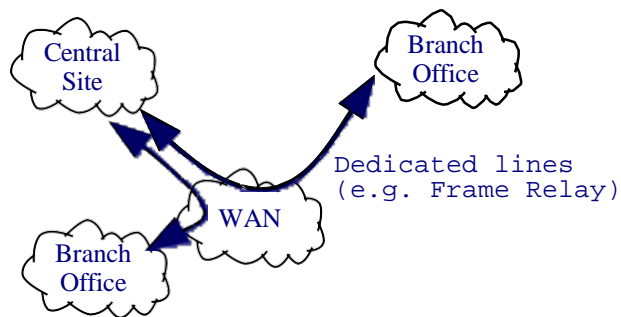
Conventional Private Network
- More cost.
- Less flexible.
- WAN management.

Virtual Private Network (VPN)
- Less cost.
- More flexible.
- Simple management.
- Internet availability.

Security in IP – VPN Security

- Authentication
- Cryptography
- Tunneling

tunnel: 192.168.0.0/24

160.0.0.1
160.0.0.20

180.0.0.30
180.0.0.1

Private
Network

R1

Internet

R2

Private
Network

10.0.0.30/24

10.0.1.12/24

encapsulation

decapsulation

src@ 10.0.0.30	dst@ 10.0.1.12	src@ 160.0.0.20	dst@ 180.0.0.30

internal header

external header

tunnel: 192.168.0.0/24

160.0.0.1
160.0.0.20

180.0.0.30
180.0.0.1

Private
Network

R1

Internet

Private
Network

R2

10.0.0.30/24

10.0.1.12/24

encapsulation

decapsulation

src@ 10.0.0.30	dst@ 10.0.1.12	src@ 160.0.0.20	dst@ 180.0.0.30

internal header

external header

Routing tables before the tunnel configuration

Destination	Gateway	Genmask	Iface	Destination	Gateway	Genmask	Iface
10.0.0.0	0.0.0.0	255.255.255.0	eth0	10.0.1.0	0.0.0.0	255.255.255.0	eth0
160.0.0.1	0.0.0.0	255.255.255.255	ppp0	180.0.0.1	0.0.0.0	255.255.255.255	ppp0
0.0.0.0	160.0.0.1	0.0.0.0	ppp0	0.0.0.0	180.0.0.1	0.0.0.0	ppp0

R1 Routing Table

R2 Routing Table
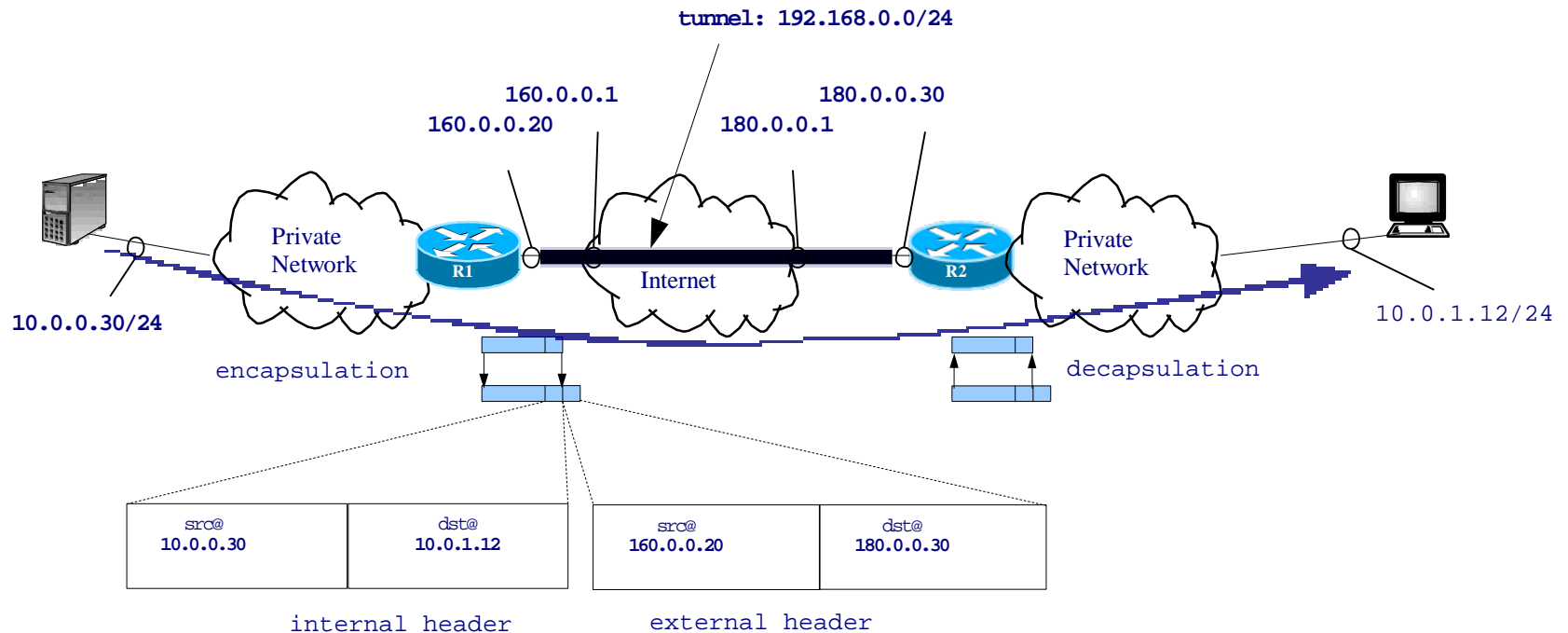
tunnel: 192.168.0.0/24

160.0.0.1   180.0.0.30
160.0.0.20   180.0.0.1

Private   Private
Network   R1   Network
                      Internet   R2

10.0.0.30/24   10.0.1.12/24

encapsulation   decapsulation

src@ 10.0.0.30	dst@ 10.0.1.12	src@ 160.0.0.20	dst@ 180.0.0.30

internal header   external header

```
Example: creating a tunnel in linux: R1#
ip tunnel add tun0 mode gre remote 180.0.0.30 local 160.0.0.20 ttl 255
```

Tunnel configuration

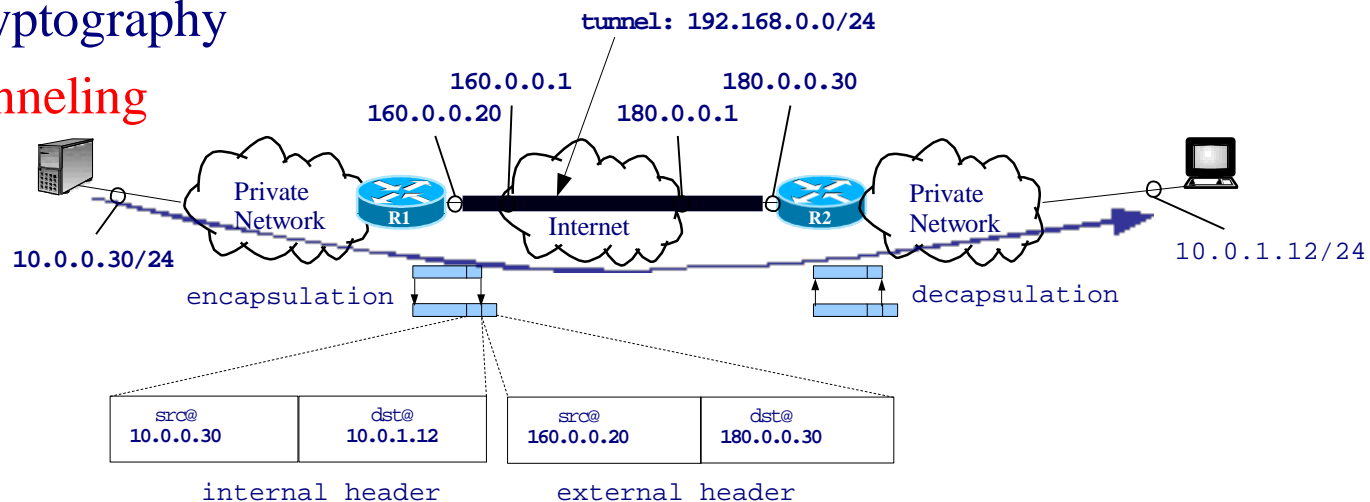| Destination	Gateway	Genmask	Iface		Destination	Gateway	Genmask	Iface
10.0.0.0	0.0.0.0	255.255.255.0	eth0		10.0.1.0	0.0.0.0	255.255.255.0	eth0
160.0.0.1	0.0.0.0	255.255.255.255	ppp0		180.0.0.1	0.0.0.0	255.255.255.255	ppp0
0.0.0.0	160.0.0.1	0.0.0.0	ppp0		0.0.0.0	180.0.0.1	0.0.0.0	ppp0
192.168.0.0	0.0.0.0	255.255.255.0	tun0		192.168.0.0	0.0.0.0	255.255.255.0	tun0
10.0.1.0	192.168.0.2	255.255.255.0	tun0		10.0.0.0	192.168.0.1	255.255.255.0	tun0

R1 Routing Table   Virtual interface for the tunnel   R2 Routing Table
                        Static route to remote network

Security in IP – VPN Security

- Authentication
- Cryptography
- Tunneling

tunnel: 192.168.0.0/24

160.0.0.1
160.0.0.20

180.0.0.30
180.0.0.1

10.0.0.30/24

10.0.1.12/24

encapsulation

decapsulation

src@ 10.0.0.30	dst@ 10.0.1.12	src@ 160.0.0.20	dst@ 180.0.0.30

internal header   external header

Example: creating a tunnel in linux:
R1# ip tunnel add tun0 mode gre remote 180.0.0.30 local 160.0.0.20 ttl 255

Destination	Gateway	Genmask	Iface
10.0.0.0	0.0.0.0	255.255.255.0	eth0
160.0.0.1	0.0.0.0	255.255.255.255	ppp0
0.0.0.0	160.0.0.1	0.0.0.0	ppp0
192.168.0.0	0.0.0.0	255.255.255.0	tunl0
10.0.1.0	192.168.0.2	255.255.255.0	tunl0

R1 Routing Table

Destination	Gateway	Genmask	Iface
10.0.1.0	0.0.0.0	255.255.255.0	eth0
180.0.0.1	0.0.0.0	255.255.255.255	ppp0
0.0.0.0	180.0.0.1	0.0.0.0	ppp0
192.168.0.0	0.0.0.0	255.255.255.0	tunl0
10.0.0.0	192.168.0.1	255.255.255.0	tunl0

R2 Routing Table

Security in IP – VPN Tunneling Issues

- Fragmentation inside the tunnel will use the external header, thus, the exit router of the tunnel should reassemble fragmented datagrams.

- ICMP messages sent inside the tunnel are addressed to the tunnel entry.

- MTU path discovery may fail (may not detect small MTU in the tunnel).

- Solution: the router entry maintains a "tunnel state", e.g. the tunnel MTU, and generate ICMP messages that would be generated inside the tunnel. Furthermore, the tunnel entry router typically fragments the datagrams before encapsulation, if needed, to avoid the exit router having to reassemble fragmented datagrams.

160.0.0.20   tunnel   180.0.0.30

Internet

Private Network   R1   R2   Private Network

10.0.0.30

10.0.1.12

encapsulation   decapsulation

src@ 10.0.0.30	dst@ 10.0.1.12	src@ 160.0.0.20	dst@ 180.0.0.30

internal header   external header
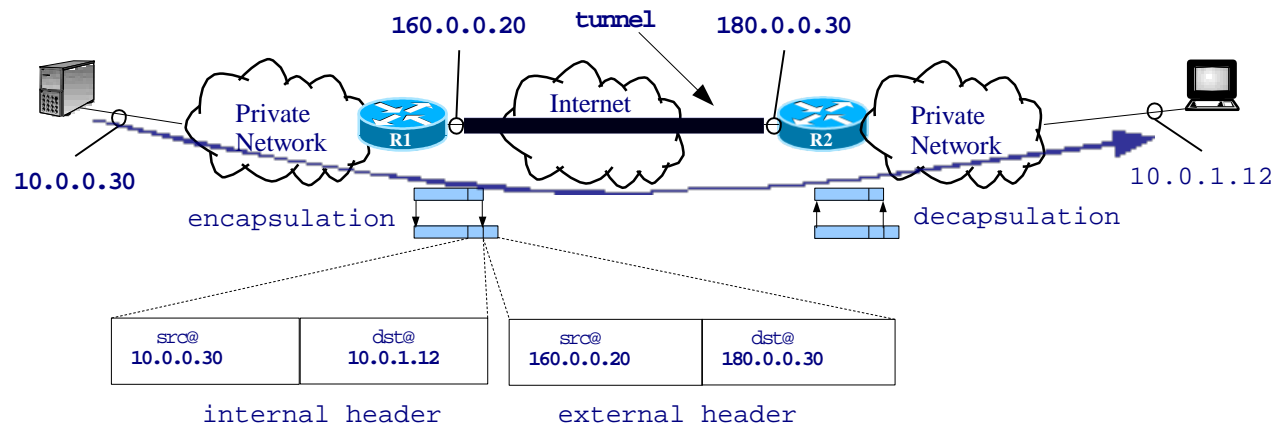
Security in IP – VPN Tunneling

- IP over IP (RFC 2003): Basic encapsulation.

- Generic Routing Encapsulation, GRE (RFC 1701):
  There is an additional GRE header: different protocol encapsulation (not only IP).

- Point-to-Point Tunneling Protocol (RFC 2637):
  Add the ppp functionalities.

- IPsec (RFC 2401): Standards to introduce authentication and encryption and tunneling to IP layer.

IP Networks

Outline

- IP layer service
- IP addresses
- Subnetting
- Routing tables
- ARP protocol
- IP header

- ICMP protocol
- DNS
- DHCP protocol
- NAT
- Routing algorithms
- Security in IP