TCP/IP Network Essentials

Linux System Administration and IP Services

Layers

Layers

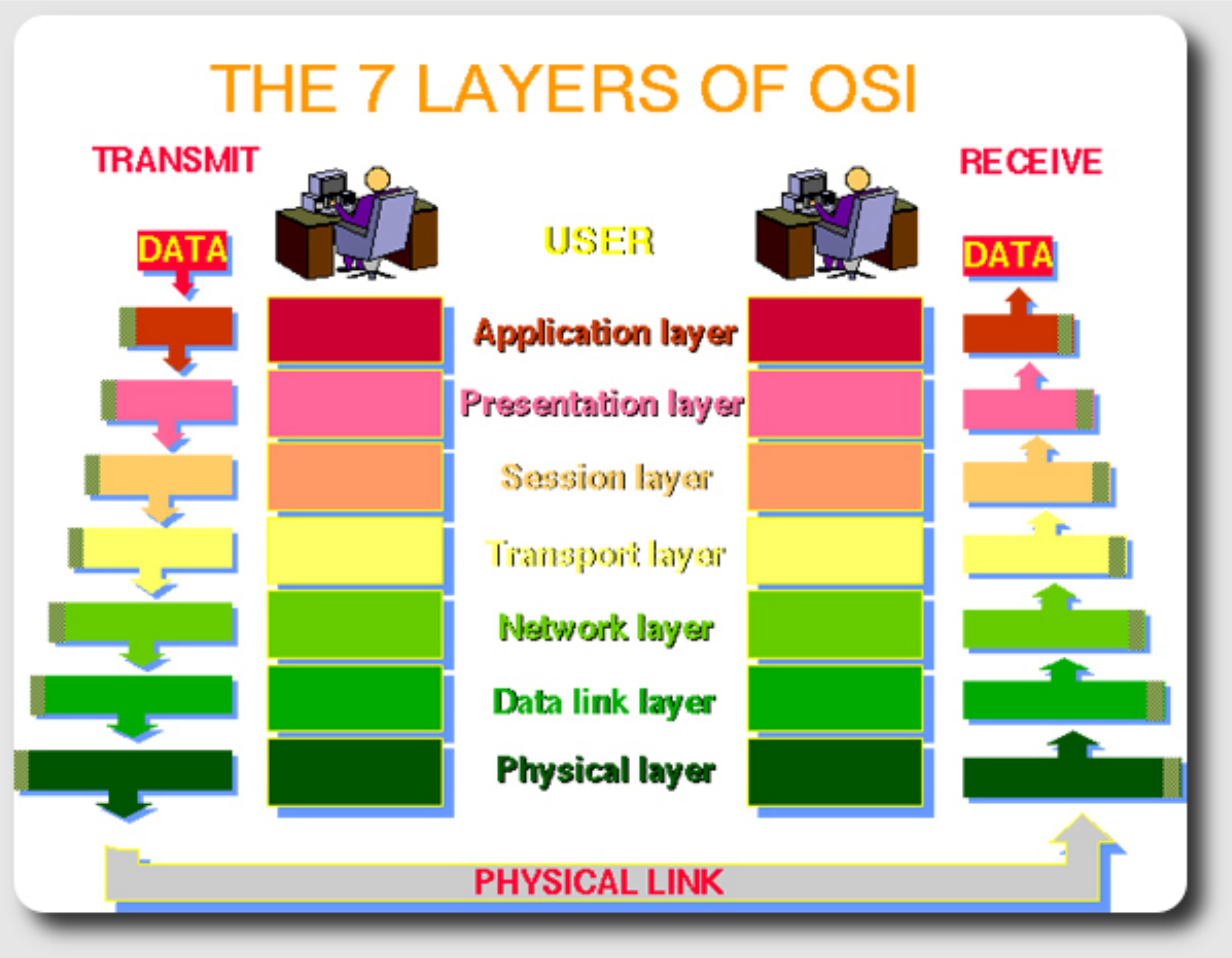
Complex problems can be solved using the common divide and conquer principle. In this case the internals of the Internet are divided into separate layers.

- Makes it easier to understand
- Developments in one layer need not require changes in another layer
- Easy formation (and quick testing of conformation to) standards

Two main models of layers are used:

- OSI (Open Systems Interconnection)
- TCP/IP

OSI Model



THE 7 LAYERS OF OSI
TRANSMIT
RECEIVE
DATA
USER
DATA
Application layer
Presentation layer
Session layer
Transport layer
Network layer
Data link layer
Physical layer
PHYSICAL LINK

OSI

Conceptual model composed of seven layers, developed by the International Organization for Standardization (ISO) in 1984.

Layer 7 – Application (servers and clients etc web browsers, httpd)
Layer 6 – Presentation (file formats e.g pdf, ASCII, jpeg etc)
Layer 5 – Session (conversation initialisation, termination,)
Layer 4 – Transport (inter host comm – error correction, QOS)
Layer 3 – Network (routing – path determination, IP[x] addresses etc)
Layer 2 – Data link (switching – media acces, MAC addresses etc)
Layer 1 – Physical (signalling – representation of binary digits)

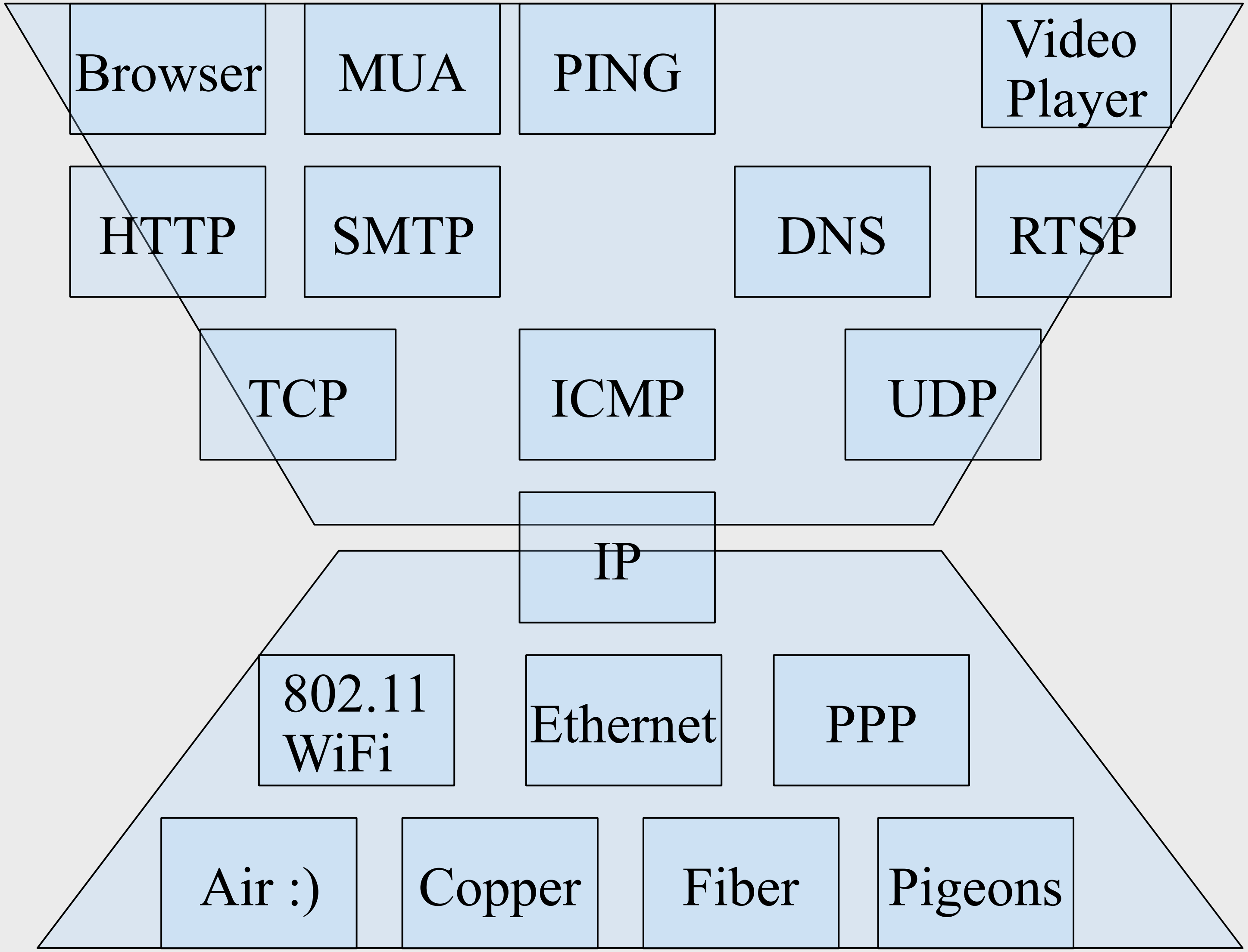
Acronym: All People Seem To Need Data Processing

TCP/IP

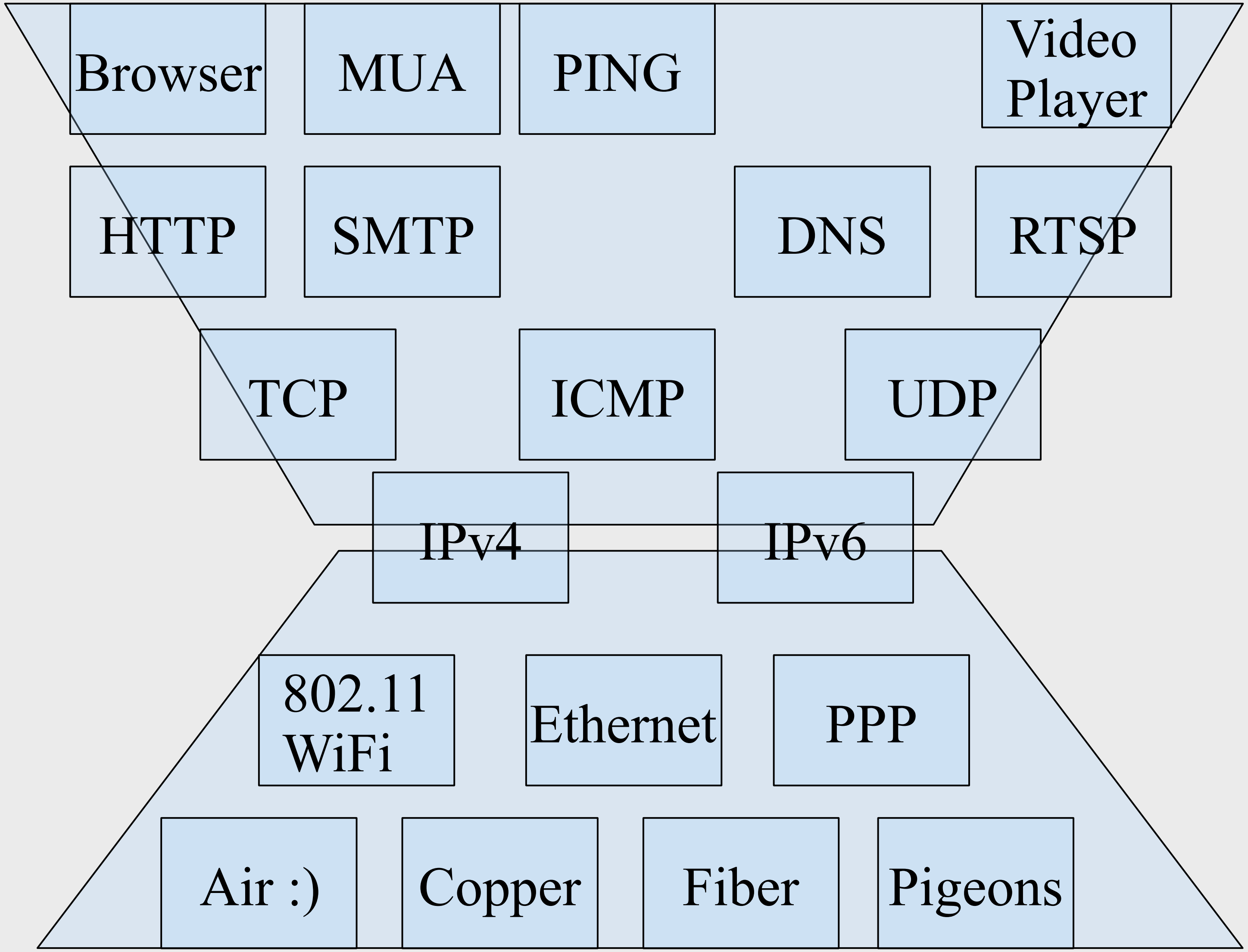
Generally, TCP/IP (Transmission Control Protocol/ Internet Protocol) is described using three to five functional layers. We have chosen the common DoD reference model, which is also known as the Internet reference model.

- Process/Application Layer consists of applications and processes that use the network.
- Host-to-host transport layer provides end-to-end data delivery services.
- Internetwork layer defines the datagram and handles the routing of data.
- Network access layer consists of routines for accessing physical networks.

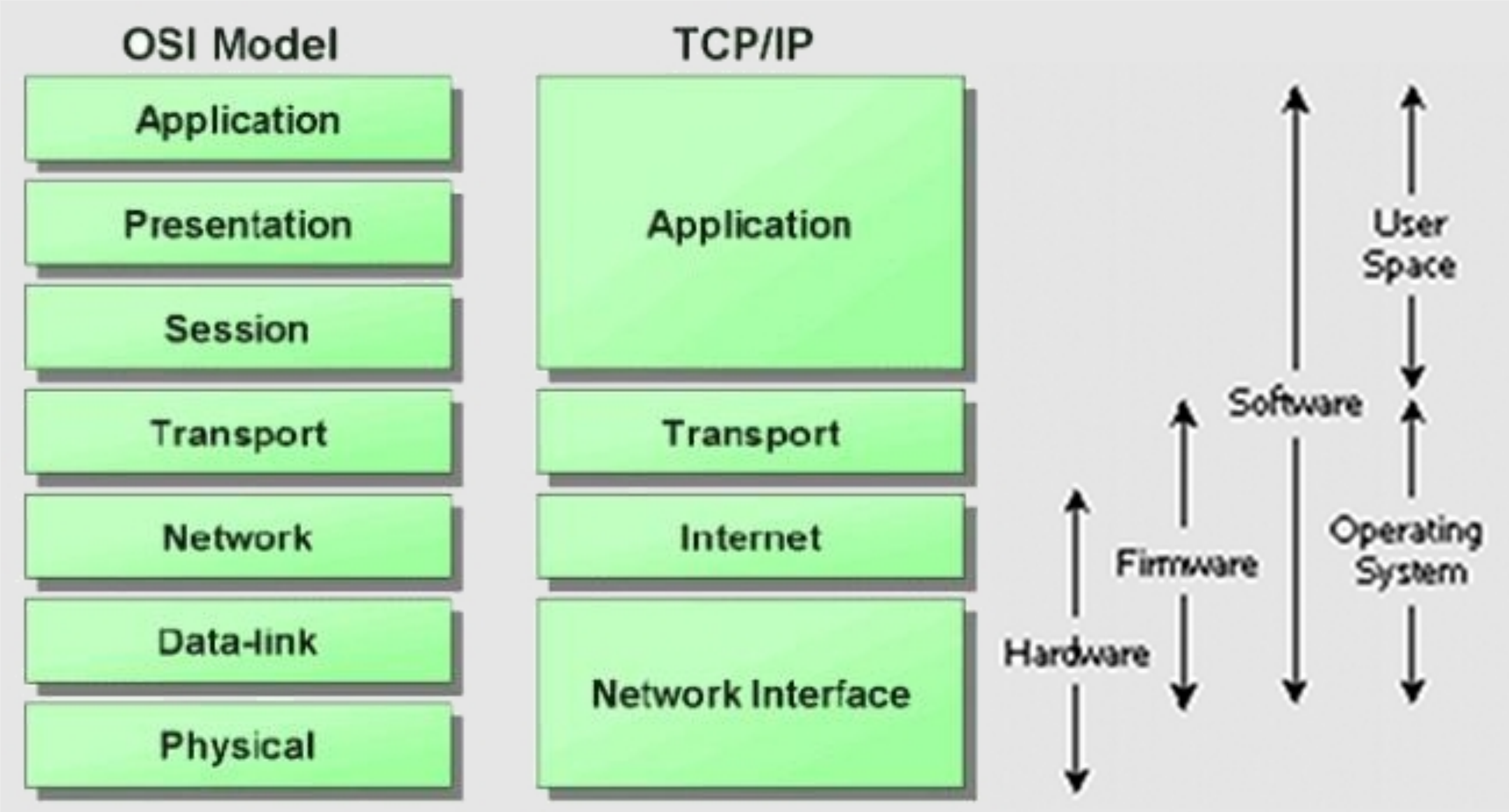
TCP/IP model – the "hourglass"



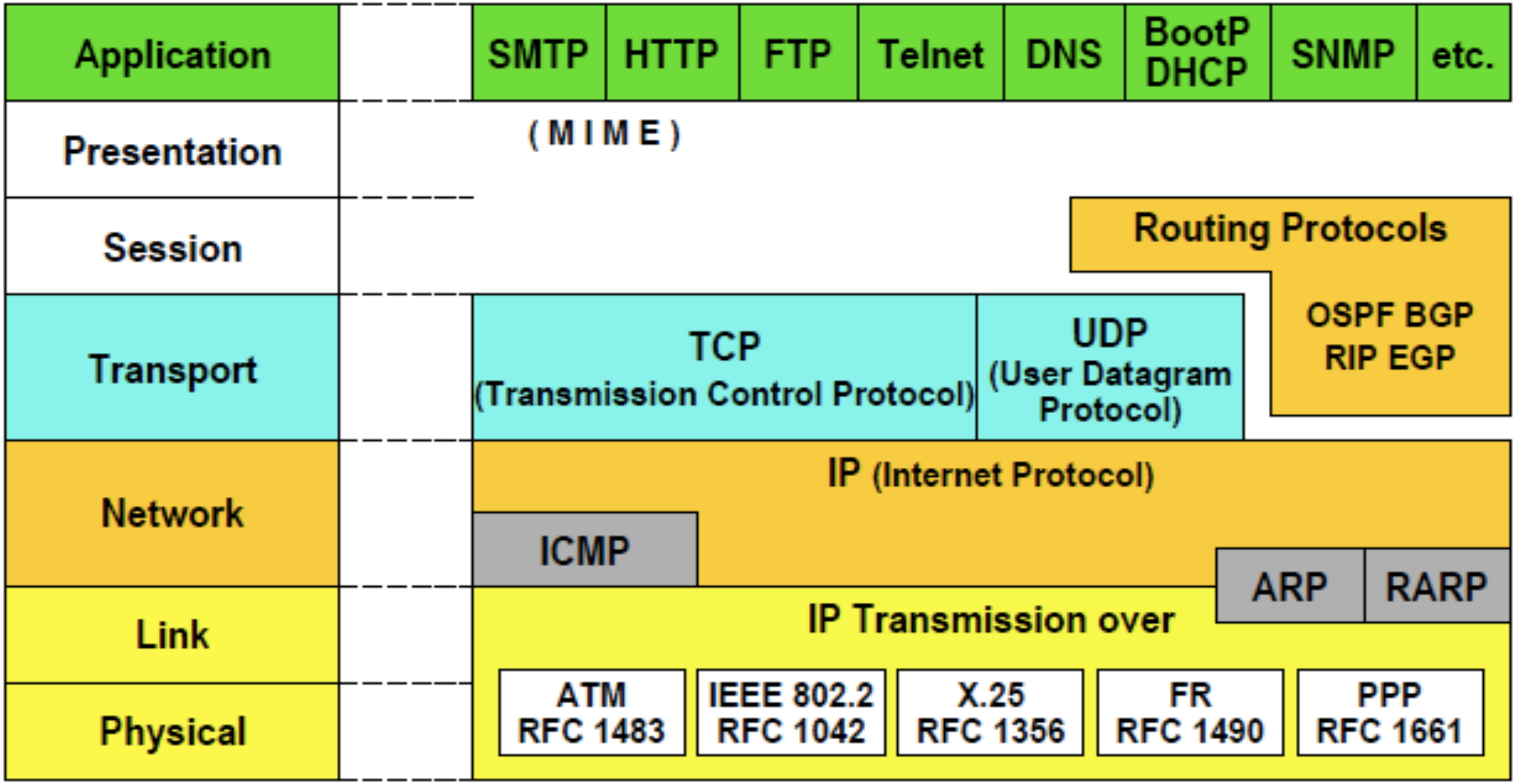
TCP/IP model – IPv4 and IPv6



OSI and TCP/IP

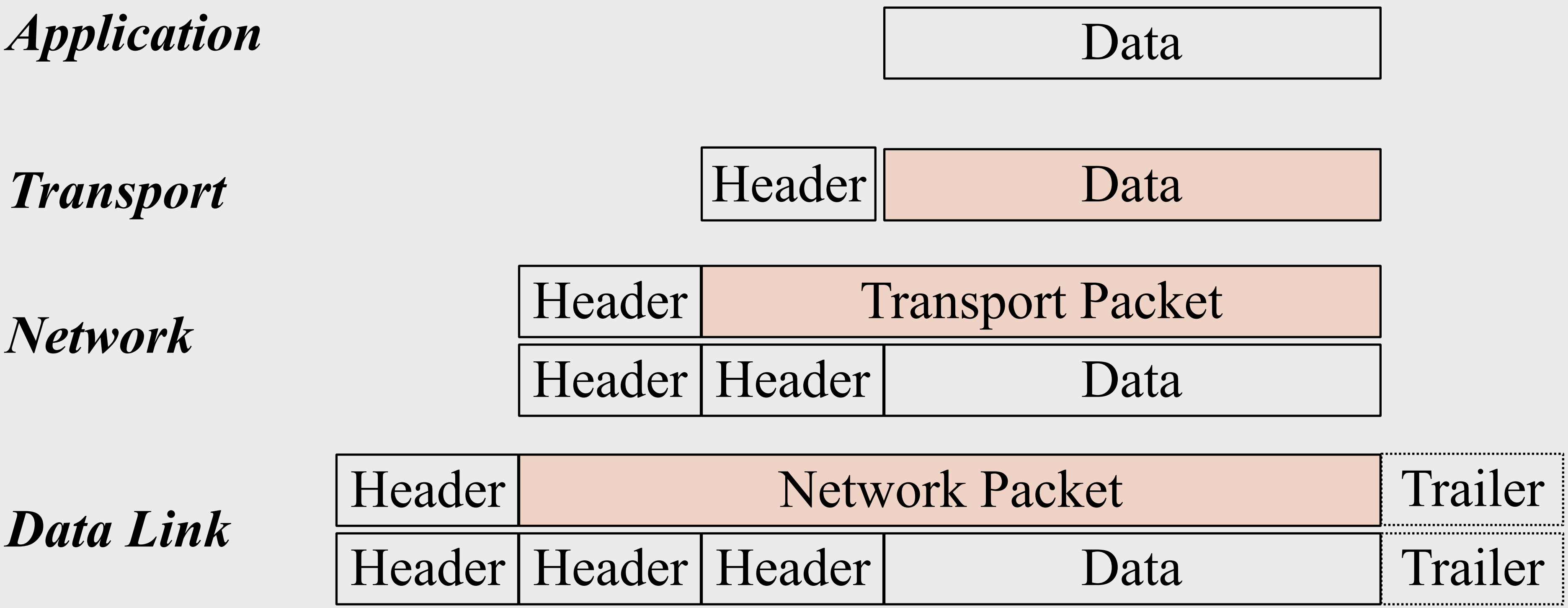


TCP/IP Protocol Suite



Encapsulation & Decapsulation

Lower layers add headers (and sometimes trailers) to upper layers packets



Frame, Datagram, Segment, Packet

Different names for packets at different layers

- Ethernet (link layer) frame
- IP (network layer) datagram
- TCP (transport layer) segment

Terminology is not strictly followed

- we often just use the term “packet” at any layer

Summary

Networking is a problem approached in layers.

- OSI Layers
- TCP/IP Layers

Each layer adds headers to the packet of the previous layer as the data leaves the machine (encapsulation) and the reverse occurs on the receiving host (decapsulation)

Addressing

So what is an IPv4 address anyway?

32 bit number (4 octet number) can be represented in lots of ways:

133	27	162	125

10000101	00011011	10100010	01111101

85	1B	A2	7D

Calculating dec, hex, bin

Some useful Linux command line tools:

ipcalc – try:

$ ipcalc 41.93.45.1

Bc – binary calculator

$ echo 'ibase=10;obase=16;27' | bc
1B

$ echo 'ibase=10;obase=2;27' | bc

11011

$ echo 'ibase=16;obase=A;1B' | bc
27

More to the structure

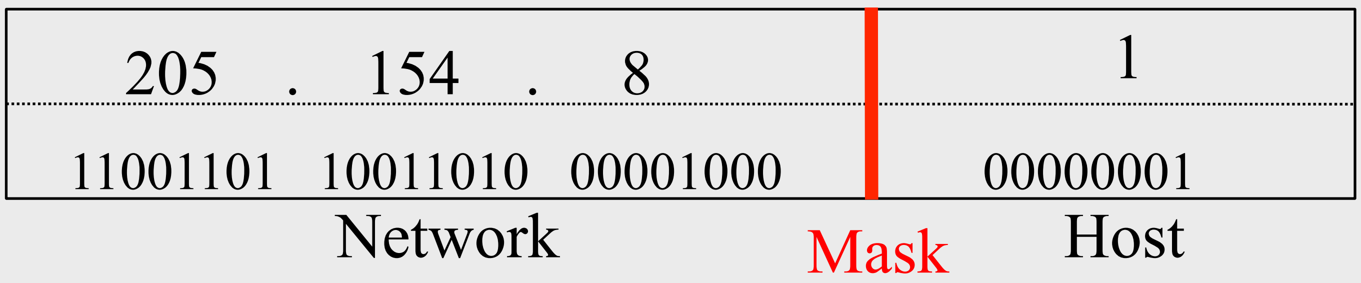
Hierarchical Division in IP Address:

Network Part (Prefix)

describes which network

Host Part (Host Address)

describes which host on that network



Boundary can be anywhere

used to be a multiple of 8 (/8, /16/, /24), but not usual today

Network Masks

Network Masks help define which bits are used to describe the Network Part and which for hosts

Different Representations:

- decimal dot notation: 255.255.224.0 (128+64+32 in byte 3)
- binary: 11111111 11111111 111 00000 00000000
- hexadecimal: 0xFFFFE000
- number of network bits: /19 (8 + 8 + 3)

Binary AND of 32 bit IP address with 32 bit netmask yields network part of address

Sample Netmasks

137.158.128.0/**17** (netmask **255.255.128.0**)

1111 1111	**1111 1111**	**1 | 000 0000**	**0000 0000**
1000 1001	1001 1110	1 | 000 0000	0000 0000

198.134.0.0/**16** (netmask **255.255.0.0**)

1111 1111	**1111 1111**	**0000 0000**	**0000 0000**
1100 0110	1000 0110	0000 0000	0000 0000

205.37.193.128/**26** (netmask **255.255.255.192**)

1111 1111	**1111 1111**	**1111 1111**	**11 | 00 0000**
1100 1101	0010 0101	1100 0001	10 | 00 0000

Allocating IP addresses

The subnet mask is used to define size of a network

E.g a subnet mask of 255.255.255.0 or /24 implies 32-24=8 host bits

2^8 minus 2 = 254 possible hosts

Similarly a subnet mask of 255.255.255.224 or /27 implies 32-27=5 host bits

2^5 minus 2 = 30 possible hosts

Special IP Addresses

All 0's in host part: Represents Network

e.g. 193.0.0.0/24

e.g. 138.37.128.0/17

e.g. 192.168.2.128/25 (WHY?)

All 1's in host part: Broadcast (all hosts on net)

e.g. 137.156.255.255 (network = 137.156.0.0/16)

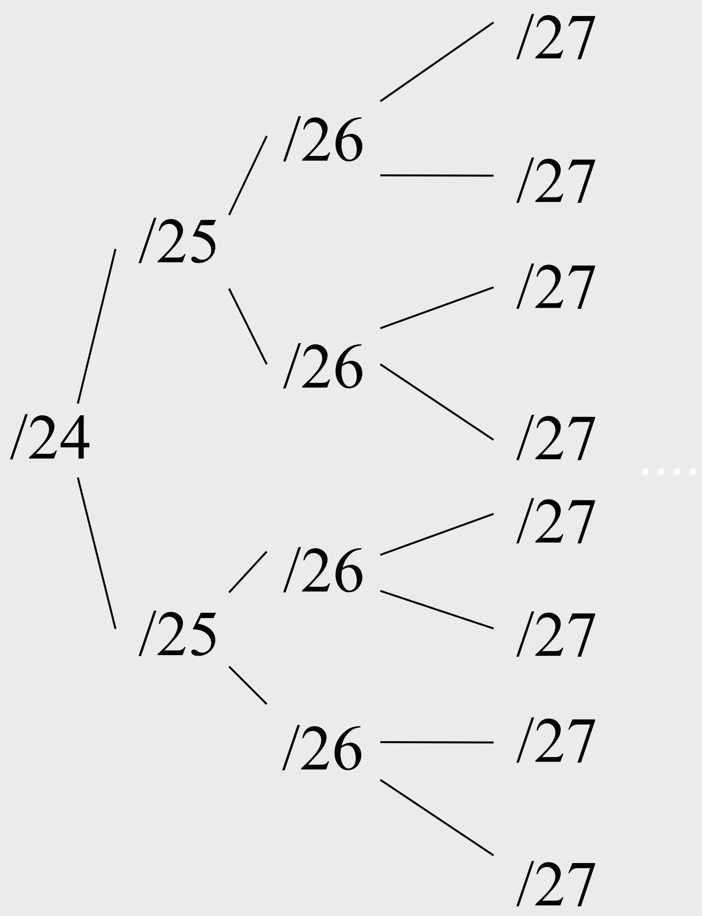
e.g. 134.132.100.255 (network = 134.132.100.0/24)

e.g. 192.168.2.127/25 (network = 192.168.2.0/25) (WHY?)

127.0.0.0/8: Loopback address (127.0.0.1)

0.0.0.0: Various special purposes (DHCP, etc.)

Networks – super- and subnetting

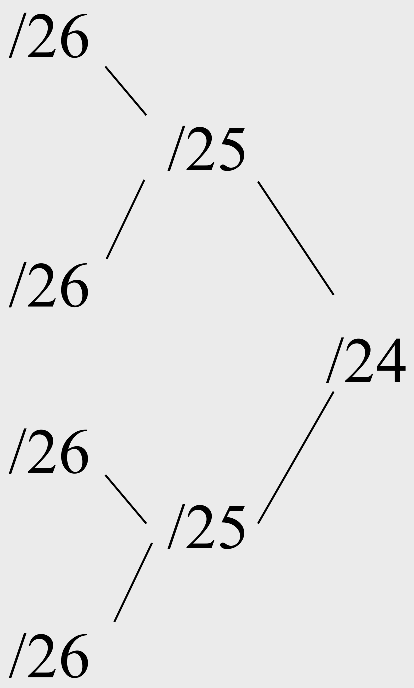


By adding one bit to the netmask, we subdivide the network into two smaller networks. This is *subnetting*.

i.e.: If one has a /26 network (32 – 26 = 6 => 2^6 => 64 addresses), that network can be subdivided into two subnets, using a /27 netmask, where the state of the last bit will determine which network we are addressing (32 – 27 = 5 => 2^5 => 32 addresses). This can be done recursively (/27 => 2 x /28 or 4 x /29, etc...).

Example: 192.168.10.0/25 (.0 - .127) can be subnetted into 192.168.10.0 / 26 and 192.168.10.64 / 26

Networks – super- and subnetting



Inversely, if two networks can be "joined" together under the same netmask, which encompasses both networks, then we are *supernetting*.

Example:

Networks 10.254.4.0/24 and 10.254.5.0/24 can be "joined" together into one network expressed: 10.254.4.0/23.

Note: for this to be possible, the networks must be *contiguous*, i.e. it is not possible to supernet 10.254.5.0/24 and 10.254.6.0/24

Numbering Rules

Private IP address ranges (RFC 1918)

- 10/8 (10.0.0.0 – 10.255.255.255)
- 192.168/16 (192.168.0.0 – 192.168.255.255)
- 172.16/12 (172.16.0.0 – 172.31.255.255)

- Public Address space available from AfriNIC
- Choose a small block from whatever range you have, and subnet your networks (to avoid problems with broadcasts, and implement segmentation policies – DMZ, internal, etc...)

Network related settings

Files

```
/etc/network/interfaces
/etc/hosts
/etc/resolv.conf
```

Commands

```
# ifconfig eth0 10.10.0.X/24
# route add default gw 10.10.0.254
# hostname pcX.ws.nsrc.org
```

Network related settings

Files

/etc/network/interfaces - excerpt:

```
auto eth0
iface eth0 inet dhcp

auto eth1
iface eth1 inet static
   address 10.10.0.X
   gateway 10.10.0.254
   netmask 255.255.255.0
```

/etc/resolv.conf - example:

```
domain mydomain.org
search mydomain.org
nameserver 41.93.45.3
```

Network related settings

Commands

In addition to the “ifconfig” command, “ip” is also used:

#ip

Try

#ip addr show
#ip route show
#ip addr add 10.10.10.10 eth0
#ip route add default ....

For details:

#man ip

Routing and forwarding

Routing

Every host on the internet needs a way to get packets to other hosts outside its local network.

This requires special hosts called **routers** that can move packets between networks.

Packets may pass through many routers before they reach their destinations.

The route table

All hosts (including routers) have a **route table** that specifies which networks it is connected to, and how to forward packets to a gateway router that can talk to other networks.

Linux routing table from "`netstat -rn46`"

```
Kernel IP routing table

Destination     Gateway         Genmask         Flags   MSS Window  irtt Iface
0.0.0.0         128.223.157.1   0.0.0.0         UG        0 0          0 eth0
128.223.157.0   0.0.0.0         255.255.255.128 U         0 0          0 eth0

Kernel IPv6 routing table
Destination                    Next Hop                   Flag Met Ref Use If
2001:468:d01:103::/64          ::                         UAe  256 0     0 eth0
fe80::/64                      ::                         U    256 0     0 eth0
::/0                           fe80::2d0:1ff:fe95:e000    UGDAe 1024 0   0 eth0
::/0                           ::                         !n   -1  1     7 lo
::1/128                        ::                         Un   0   1  1125 lo
2001:468:d01:103:3d8c:b867:f16d:efed/128 ::               Un   0   1     0 lo
2001:468:d01:103:a800:ff:fe9c:4089/128 ::                 Un   0   1     0 lo
fe80::a800:ff:fe9c:4089/128    ::                         Un   0   1     0 lo
ff00::/8                       ::                         U    256 0     0 eth0
::/0                           ::                         !n   -1  1     7 lo
```

What do route table entries mean?

Destination	Gateway	Genmask	Flags	MSS	Window	irtt	Iface
0.0.0.0	128.223.157.1	0.0.0.0	UG	0	0	0	eth0
128.223.157.0	0.0.0.0	255.255.255.128*	U	0	0	0	eth0

- The **destination** is a network address.
- The **gateway** is an IP address of a router that can forward packets (or 0.0.0.0, if the packet doesn't need to be forwarded).
- **Flags** indicate various attributes for each route:
  - **U Up**: The route is active.
  - **H Host**: The route destination is a single host.
  - **G Gateway**: Send anything for this destination on to this remote system, which will figure out from there where to send it.
  - **D Dynamic**: This route was dynamically created by something like gated or an ICMP redirect message.
  - **M Modified**: This route is set if the table entry was modified by an ICMP redirect message.
  - **! Reject**: The route is a reject route and datagrams will be dropped.
- **MSS** is the Maximum Segment Size. Largest datagram kernel will construct for transmission via this route.
- **Window** is maximum data host will accept from a remote host.
- **irtt** initial round trip time.
- **Iface** the network inferface this route will use

**What size network is 255.255.255.128?*

How the route table is used

A packet that needs to be sent has a destination IP address.

For each entry in the route table (starting with the first):

1. Compute the logical AND of the destination IP and the **genmask** entry.
2. Compare that with the **destination** entry.
3. If those match, send the packet out the **interface**, and we're done.
4. If not, move on to the next entry in the table.

Reaching the local network

Suppose we want to send a packet to 128.223.143.42 using this route table.

Destination	Gateway	Genmask	Flags	Interface
128.223.142.0	0.0.0.0	255.255.254.0	U	eth0
0.0.0.0	128.223.142.1	0.0.0.0	UG	eth0

- In the first entry 128.223.143.42 AND 255.255.254.0 = 128.223.142.0
- This matches the **destination** of the first routing table entry, so send the packet out **interface** eth0.
- That first entry is called a **network route**.

Do you notice anything different about this routing table?

Reaching other networks

Suppose we want to send a packet to 72.14.213.99 using this route table.

Destination	Gateway	Genmask	Flags	Interface
128.223.142.0	0.0.0.0	255.255.254.0	U	eth0
0.0.0.0	128.223.142.1	0.0.0.0	UG	eth0

1. 72.14.213.99 AND 255.255.254.0 = 72.14.212.0
2. This does not match the first entry, so move on to the next entry.
3. 72.14.213.99 AND 0.0.0.0 = 0.0.0.0
4. This does match the second entry, so forward the packet to 128.223.142.1 via bge0.

The default route

Note that this route table entry:

Destination	Gateway	Genmask	Flags	Interface
0.0.0.0	128.223.142.1	0.0.0.0	UG	eth0

matches every possible destination IP address. This is called the **default route**. The gateway has to be a router capable of forwarding traffic.

More complex routing

Consider this route table:

Destination	Gateway	Genmask	Flags	Interface
192.168.0.0	0.0.0.0	255.255.255.0	U	eth0
192.168.1.0	0.0.0.0	255.255.255.0	U	eth1
192.168.2.0	0.0.0.0	255.255.254.0	U	eth2
192.168.4.0	0.0.0.0	255.255.252.0	U	eth3
0.0.0.0	192.168.1.1	0.0.0.0	UG	eth0

This is what a router's routing table might look like. Note that there are multiple interfaces for multiple local networks, and a gateway that can reach other networks.

Forwarding packets

Any UNIX-like (and other) operating system can function as a gateway:

- In Ubuntu /etc/sysctl.conf set:

```
# Uncomment the next line to enable
# packet forwarding for IPv4
#net/ipv4/ip_forward=1

  # Uncomment the next line to enable
  # packet forwarding for IPv6
  #net/ipv6/ip_forward=1
```

Forwarding packets

Important

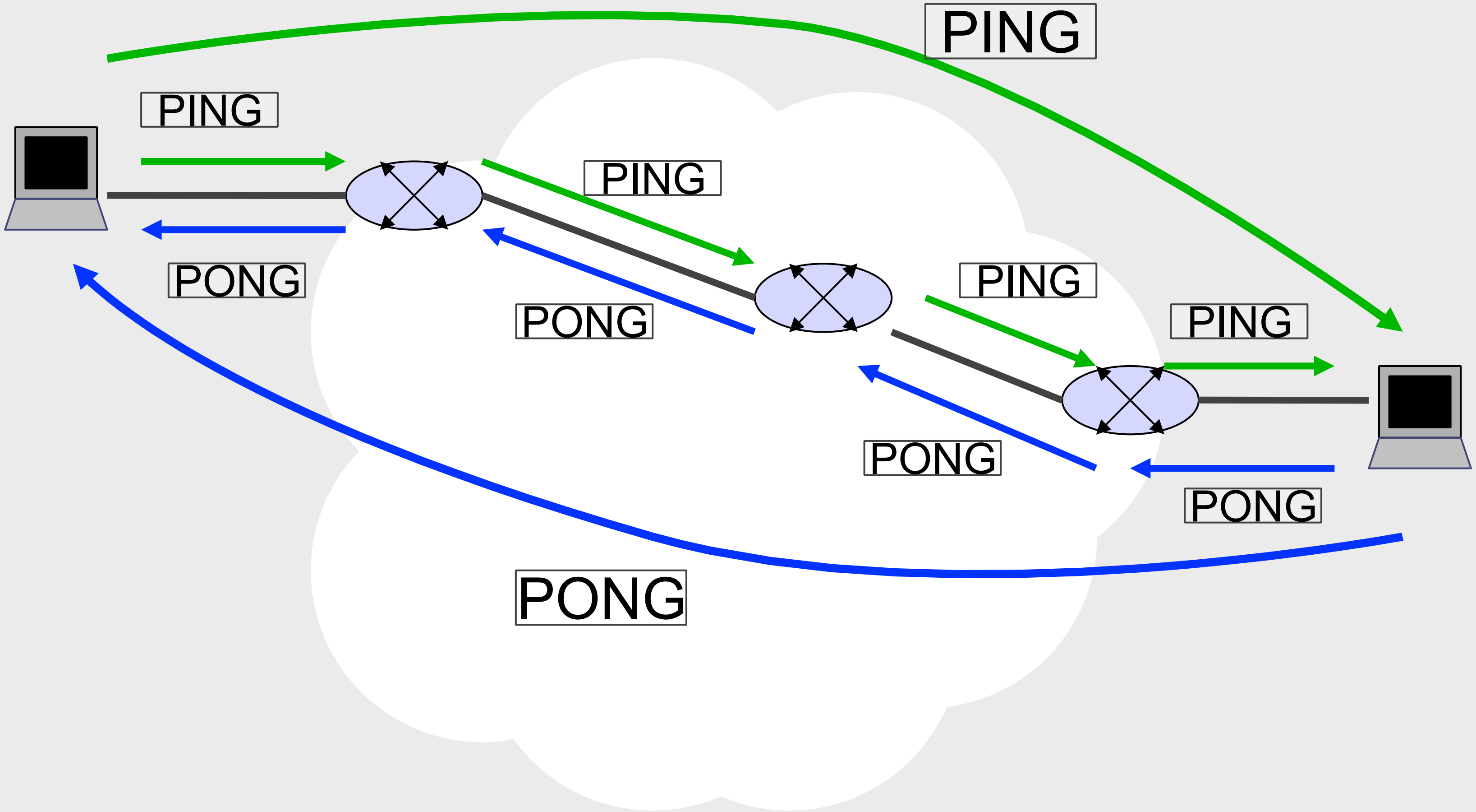
Without forwarding enabled, the box will not forward packets from one interface to another: it is simply a host with multiple interfaces.

The IP end-to-end principle

IP is an end-to-end protocol
The network doesn't keep track of connections
The host takes a decision on where to send *each packet*
The network equipment takes a decision on where to forward packets *every time*
The path is not necessarily symmetric
Cost constraints, reconfiguration of the network, network failures can make the IP packets

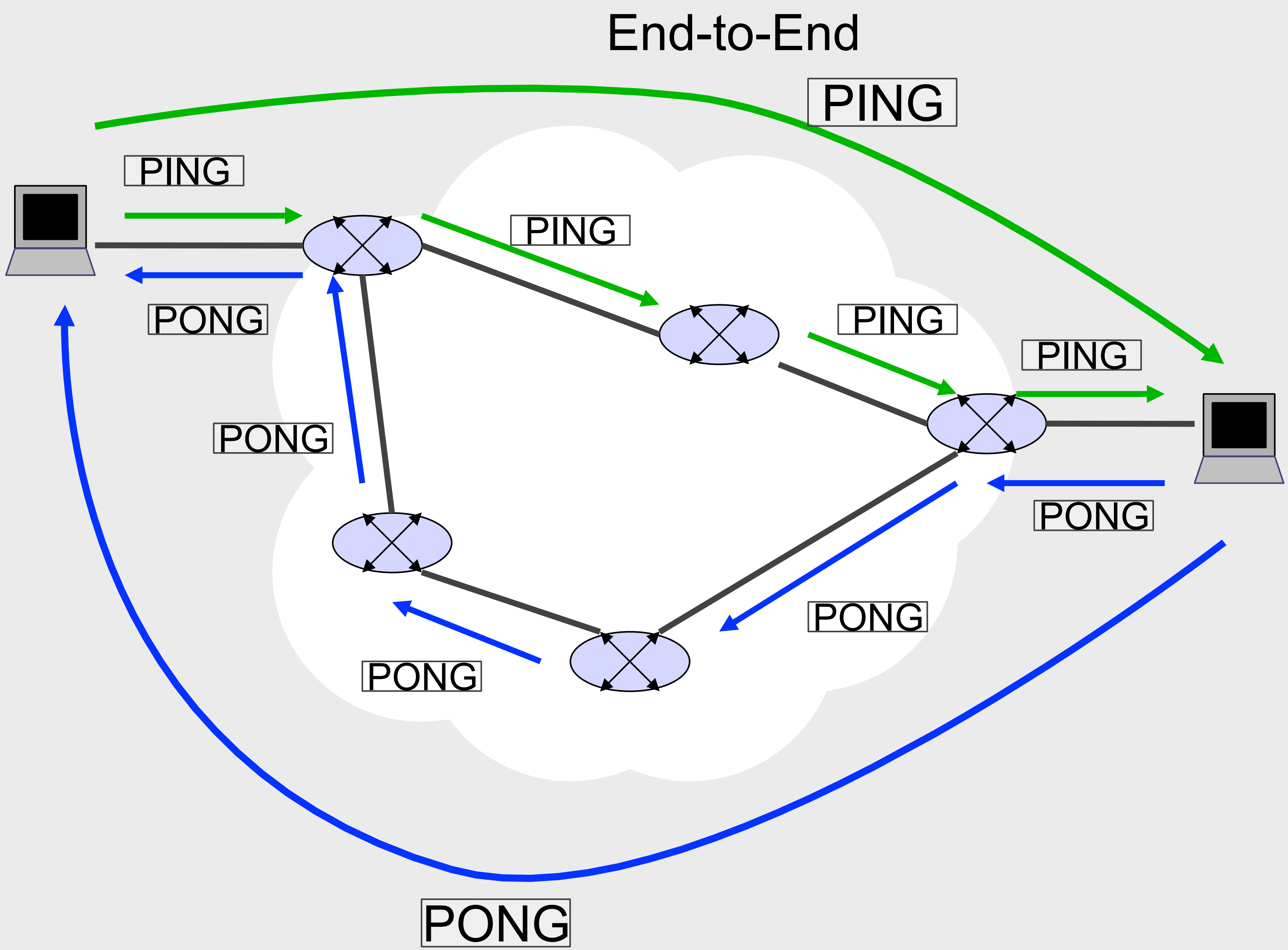
IP path

End-to-End



AfNOG

IP path


End-to-End
PING
PING
PING
PING
PING
PONG
PONG
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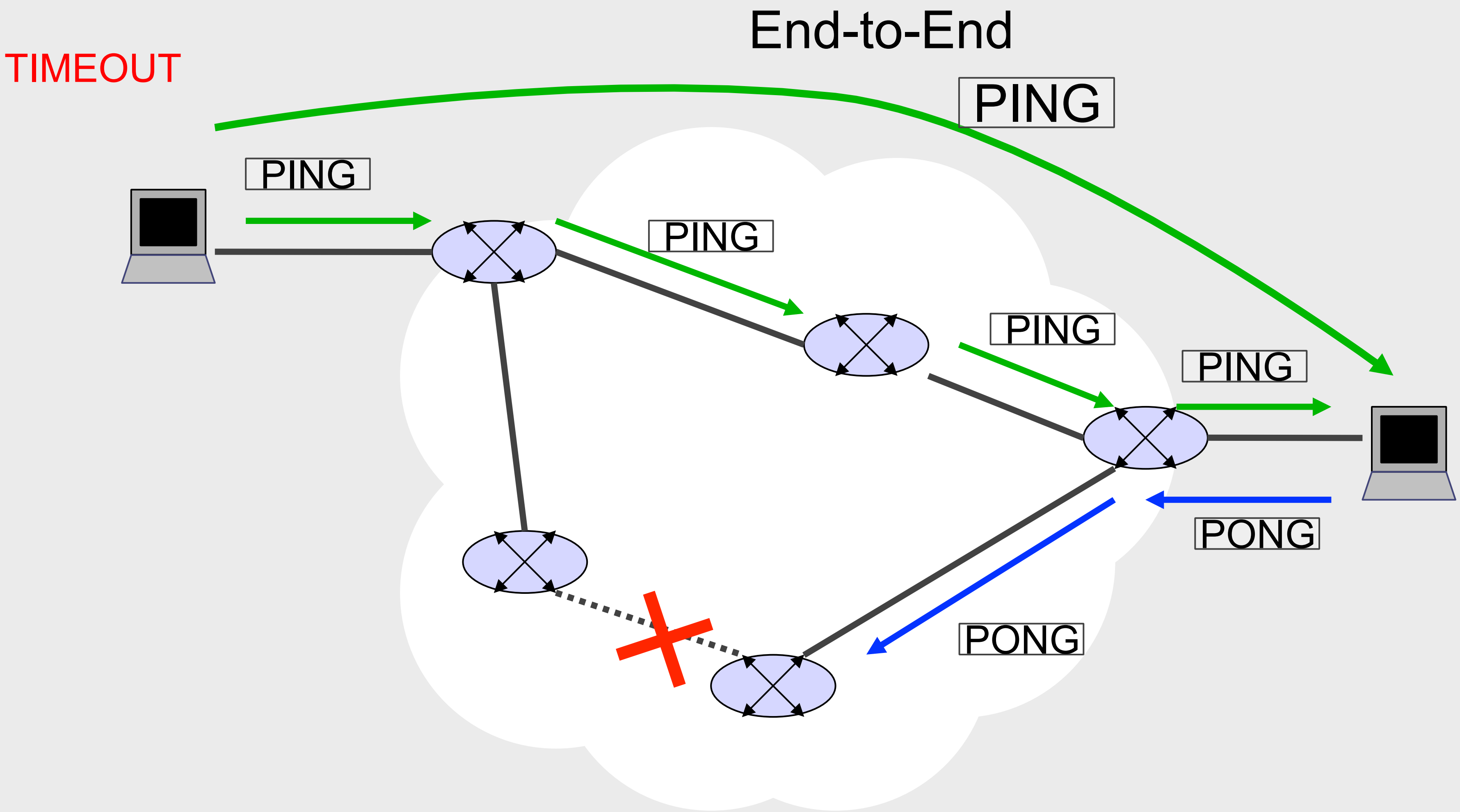
PONG

IP path



AfNOG

Network tools

What network tools can we use to troubleshoot ?

ping – requests echo reply from a computer
traceroute – show path taken by IP packets through a network
tcpdump – show network traffic
netstat – show routing entries and listening/active sockets
arp – show/modify the IP <-> MAC address table
route – show/modify the routing table
mtr – combines ping & traceroute