ISOTDAQ 2016
WEIZMANN INSTITUTE FOR SCIENCE
NIKO NEUFELD, CERN EP

PRACTICAL ASPECTS OF NETWORKS FOR DATA ACQUISITION

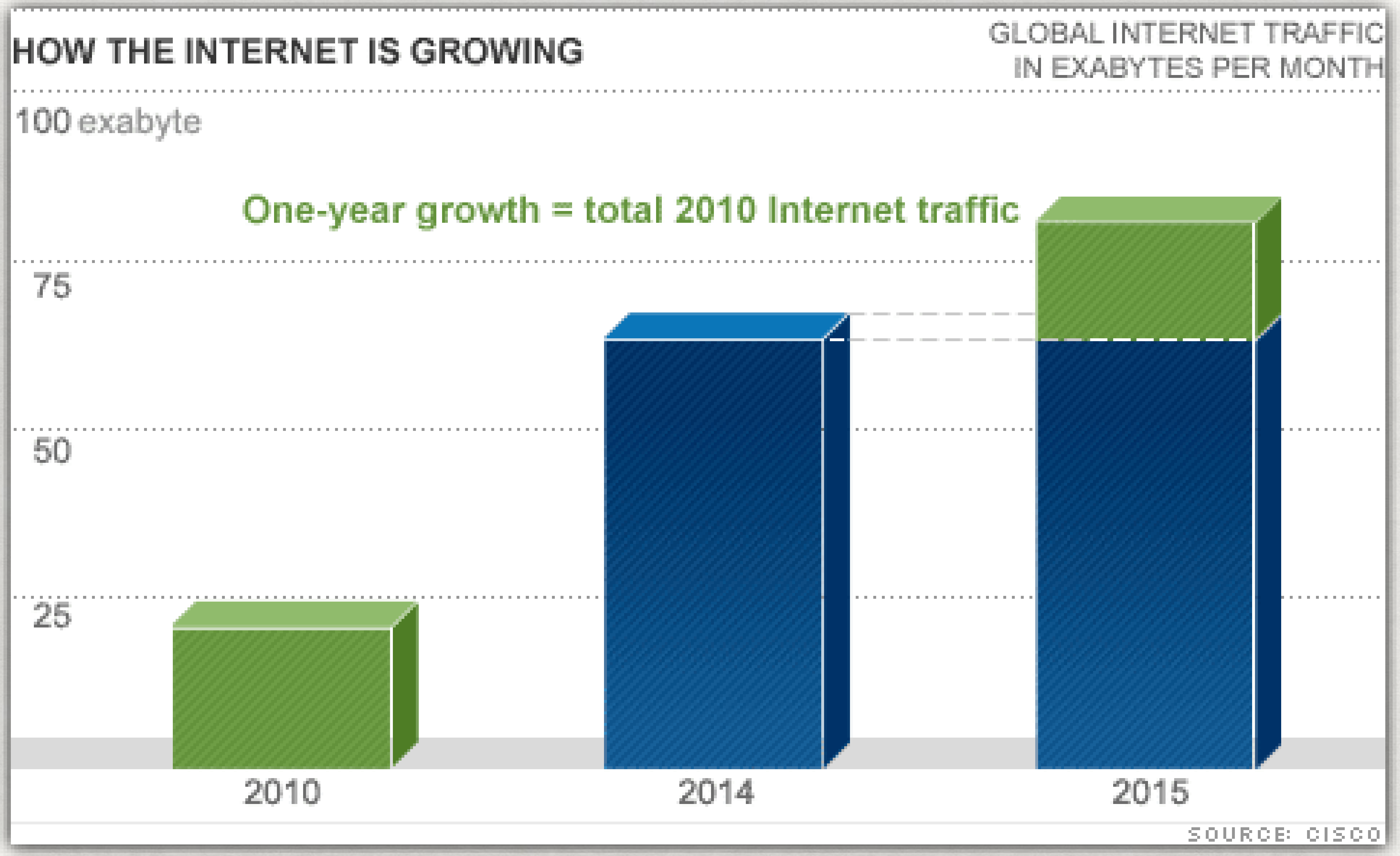
THE DATA TORRENT

EXPERIMENTS GENERATE “BIG” DATA

- LHC: (per experiment) about 100 GB/s(!) to the software trigger (HLT), about 1 GB/s to storage
- SKA: 68 Tbits/s (raw), 0.5 to 10 PB/day(!) of image data
- ESRF: > 8 GB/s for fast cameras, > 10 TB retained data (for a single beamline!)
- CTA: 4 GB/s to storage, 1.5 - 20 PB / year

THE DATA TORRENT

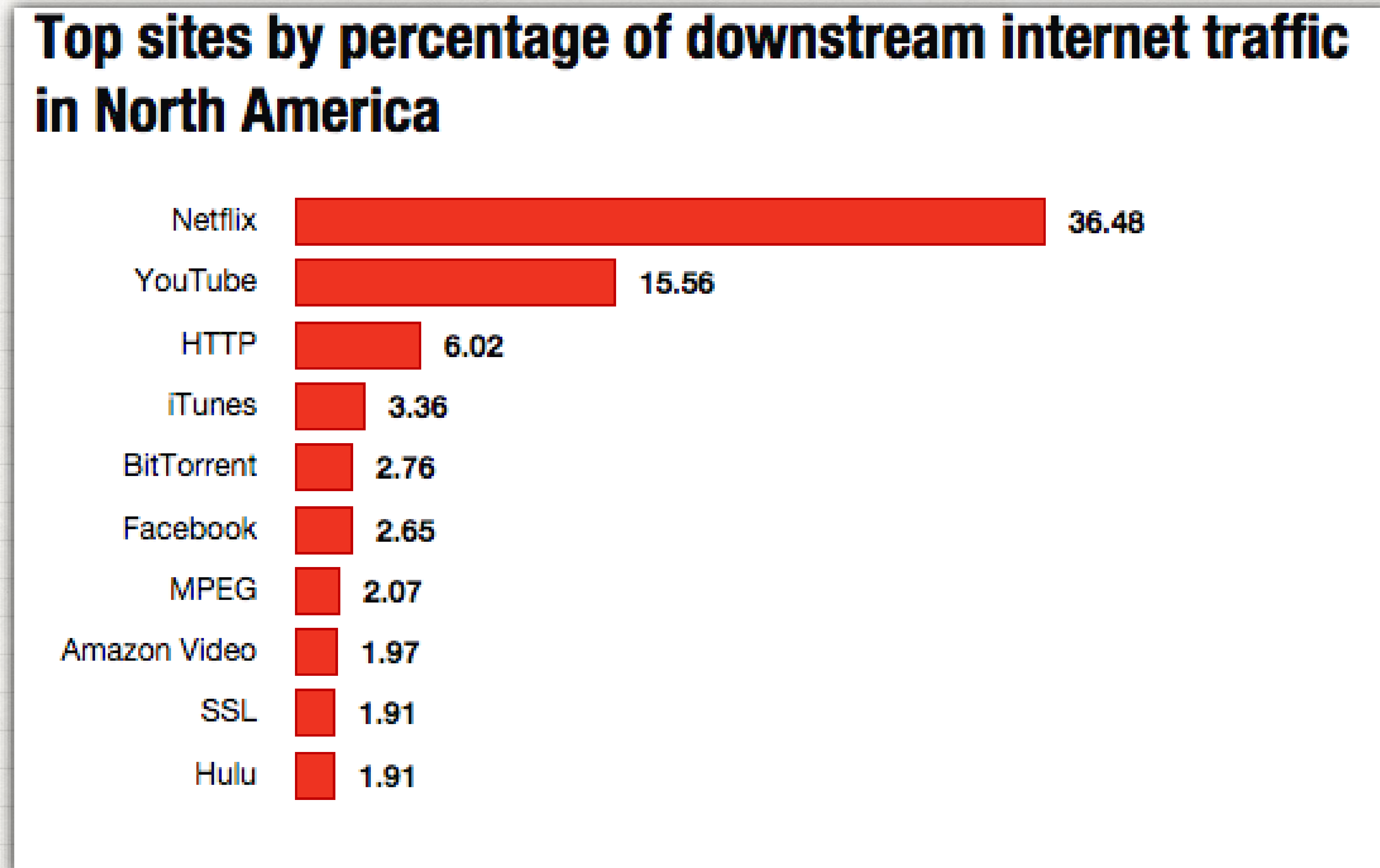
DATA GROWTH ON THE INTERNET



THE INTERNET IS NO LONGER FOR …

- It’s for Video and mobile
- 15 bytes become 3.5 MB

WHAT IS THE BANDWIDTH USED FOR?



HIGH DATA RATE REQUIRED?
NETWORKS ARE THE WAY TO GO!

NETWORKS

GENERAL

- Networks connect multiple devices over (large) distances
- In a network devices are equal (“peers") unlike in bus systems (VME, USB, PCI), which have “masters” and “slaves”
- In a network devices communicate directly with each other
- Data and control use the same path (again unlike in many bus-systems)
- At the signaling level network technologies are normally (multiple) serial, many can use multiple physical layers (—> later) including optical and radio-transmitted

NETWORKS

TECHNOLOGIES

- The telephone network (now being replaced by IP)
- Ethernet (IEEE 802.3)
- ATM (the backbone for 2G cell-phones), RapidIO (3G and 4G)
- InfiniBand, OmniPath
- and many, many more
- Network technologies are sometimes functionally grouped
  - Cluster interconnect (OmniPath, InfiniBand) 1 m - 150 m (in a data-centre)
  - Local area network (LAN), up to ~ 10 km (in and between buildings)
  - Wide area network (ATM, SONET) > 50 km (between cities, countries…)

WHAT MAKES A NETWORK?

- A network has two important aspects
  - A physical implementation: wires, optical fibres, devices, connectors, cables, radio-transmitters, etc…
  - A protocol defining how data are exchanged between nodes on the network

NETWORKS

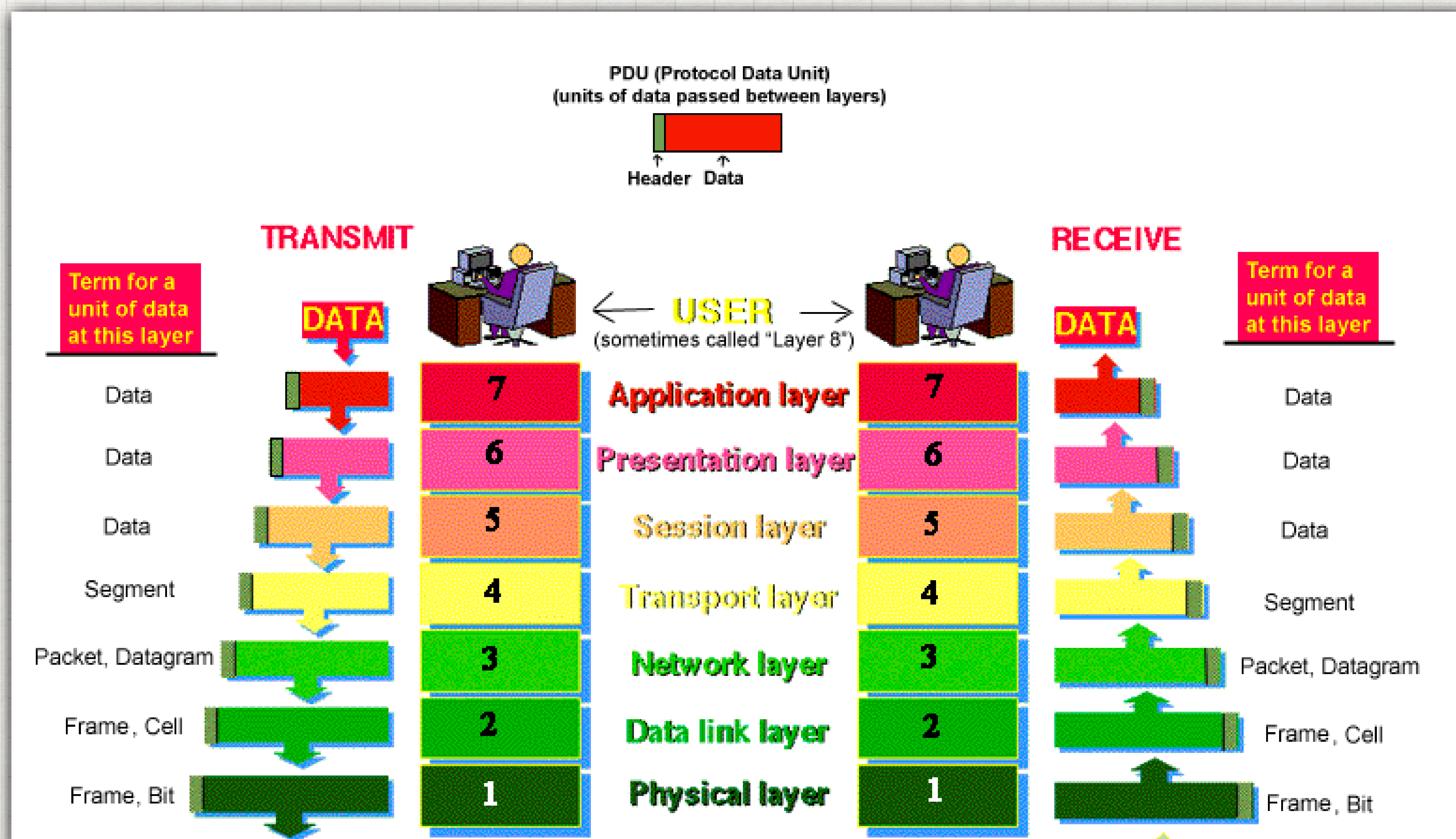
PROTOCOL STACK

OSI model

Layer	Name	Example protocols
7	Application Layer	HTTP, FTP, DNS, SNMP, Telnet
6	Presentation Layer	SSL, TLS
5	Session Layer	NetBIOS, PPTP
4	Transport Layer	TCP, UDP
3	Network Layer	IP, ARP, ICMP, IPSec
2	Data Link Layer	PPP, ATM, Ethernet
1	Physical Layer	Ethernet, USB, Bluetooth, IEEE802.11

HOW TO CALL THINGS

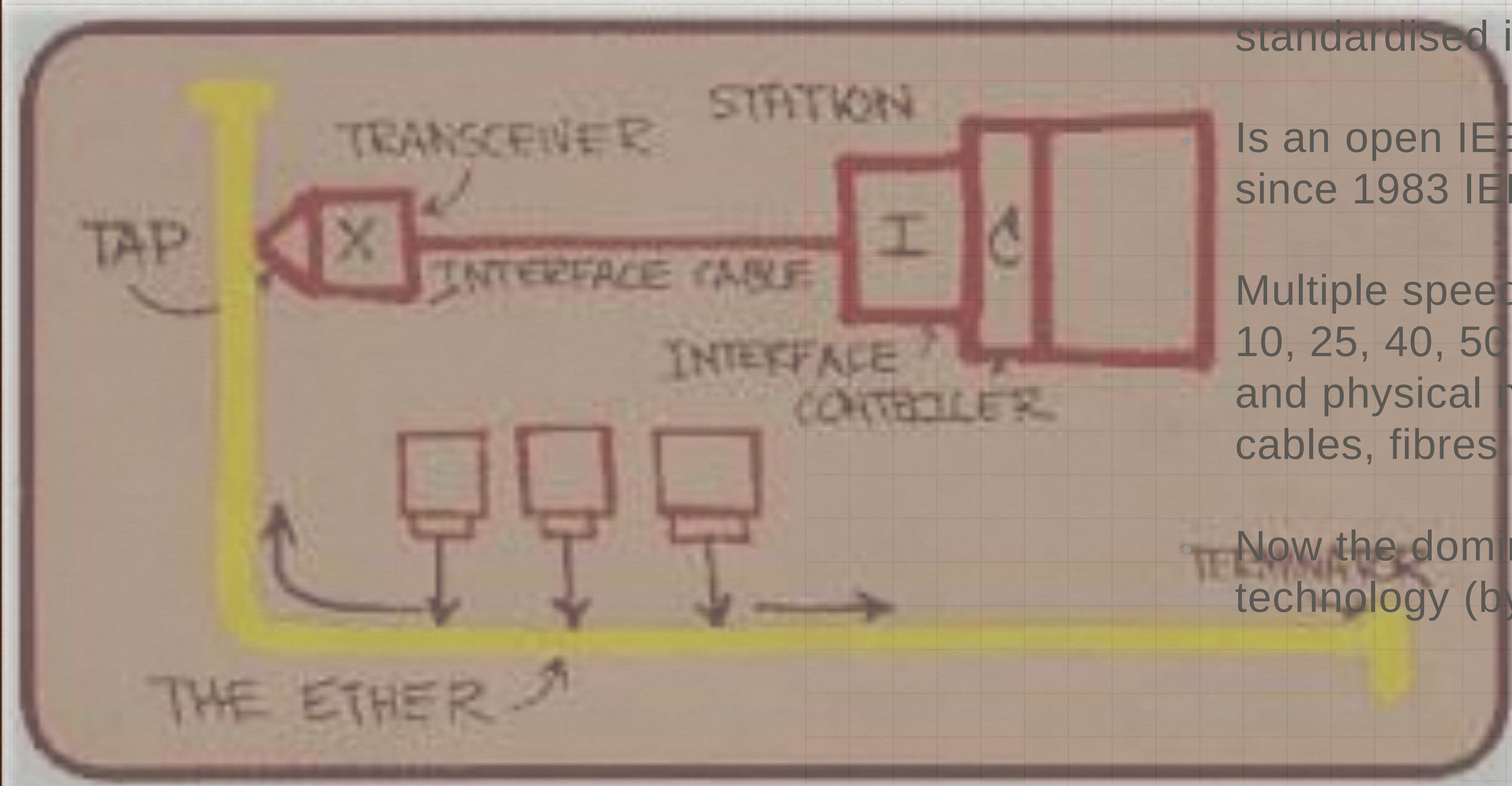
COMMON TERMINOLOGY HELPS



IN NETWORKING WE DO NOT TALK ABOUT BYTES BUT ABOUT OCTETS (8 BITS)

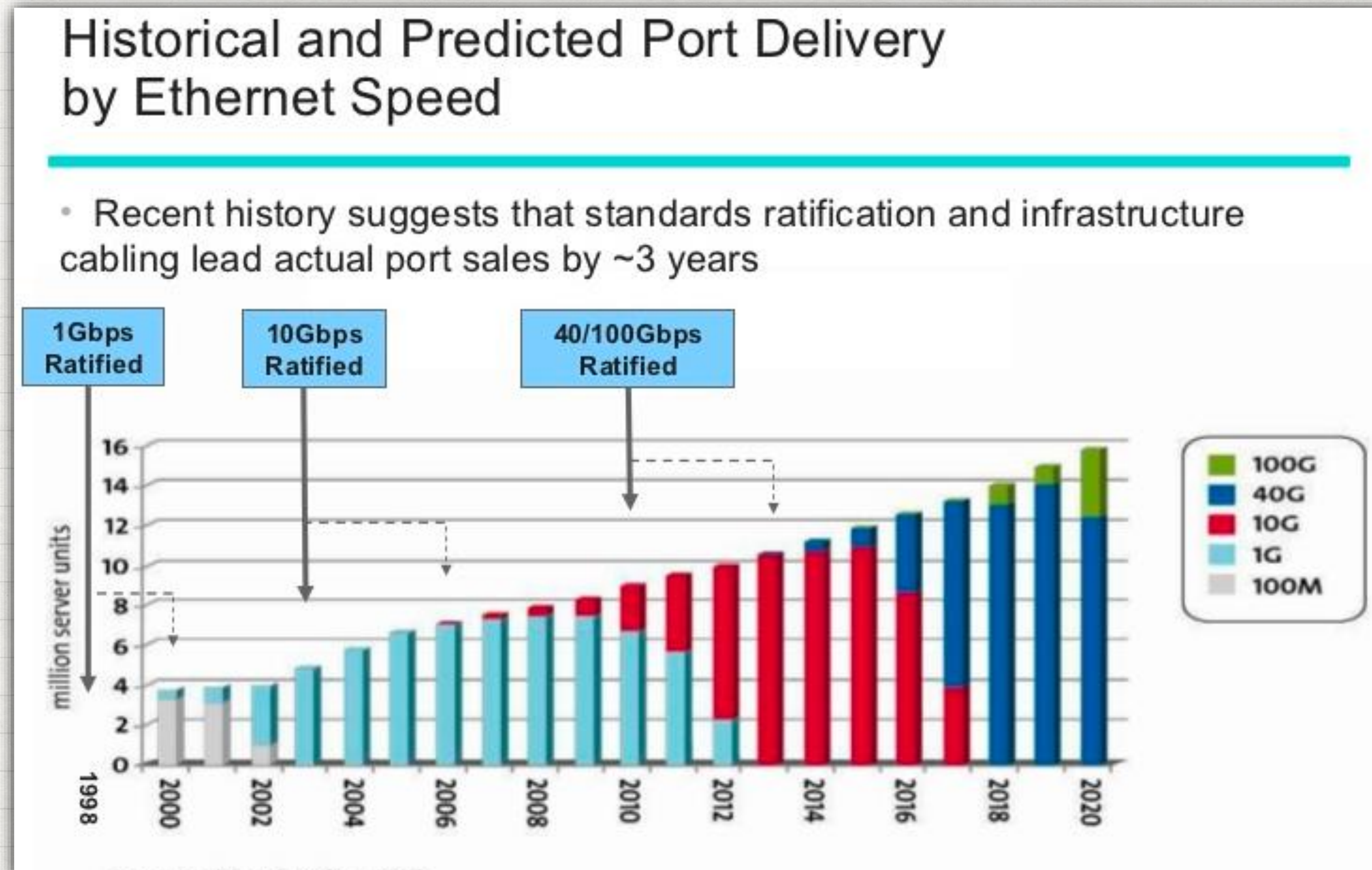
ETHERNET

ONE NETWORK TO RULE THEM ALL

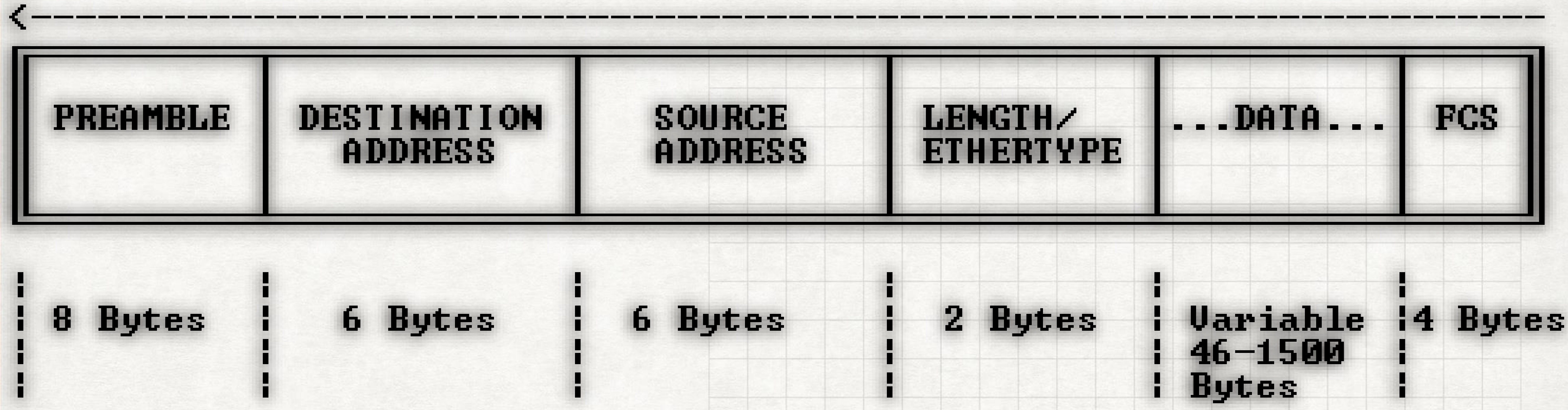


- Invented in 1973, standardised in 1980
- Is an open IEEE standard since 1983 IEEE 802.3
- Multiple speed grades (1, 10, 25, 40, 50, 100 Gb/s) and physical media: cables, fibres
- Now the dominant LAN technology (by far)

THE RISE OF ETHERNET



ETHERNET

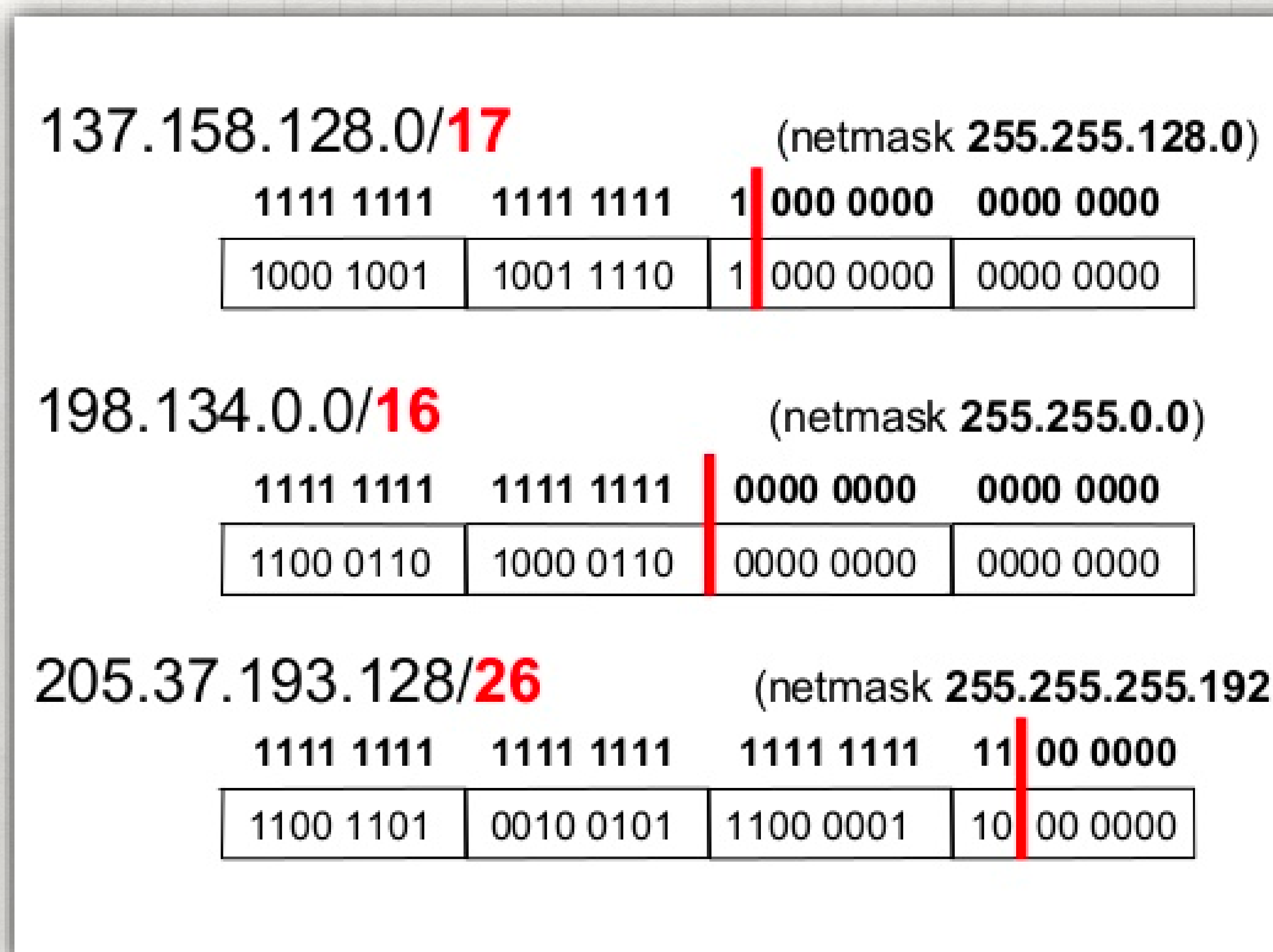


- 48 bit addresses, also called MAC addresses (Media Access Control)
- Payload: min 64 bytes, max 1518 bytes —> many but not all devices support “jumbo” frames up to 9000 bytes. The maximum number acceptable by a device is called the *Maximum Transmission Unit (MTU)*
- Source address usually “burnt” into a device (in practice read from an EEPROM or similar and set by software)
- You can override your source address (using ethtool(8) or ip(8) command)

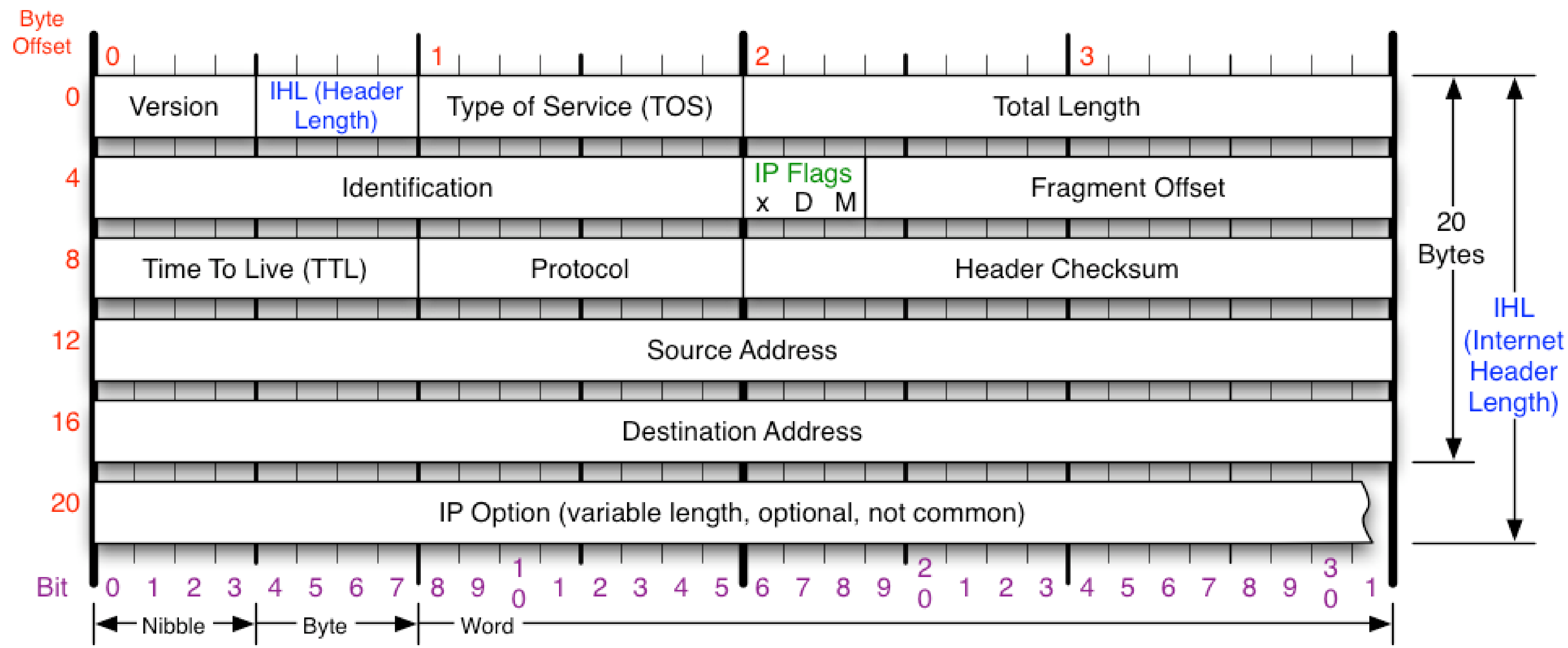
NETWORK PROTOCOLS

IP

- Two major versions
  - IPv4 and IPv6 (focus on v4 for the rest of this)
- In IP devices carry a 32-bit address written as 4 decimals separated by dots
- IP groups several devices into a network / subnet using the net mask
  - Net mask
    - 8, 16, 24 bit wide net masks have special names (Class A, Class B and Class C)
  - The network itself has an address (all unmasked bits 0) e.g. 137.158.0.0
  - There is a broad-cast address (all unmasked bits 1) e.g. 137.158.255.255



THE IPV4 HEADER



Version

Version of IP Protocol. 4 and 6 are valid. This diagram represents version 4 structure only.

Header Length

Number of 32-bit words in TCP header, minimum value of 5. Multiply by 4 to get byte count.

Protocol

IP Protocol ID. Including (but not limited to):

1 ICMP	17 UDP	57 SKIP
2 IGMP	47 GRE	88 EIGRP
6 TCP	50 ESP	89 OSPF
9 IGRP	51 AH	115 L2TP

Total Length

Total length of IP datagram, or IP fragment if fragmented. Measured in Bytes.

Fragment Offset

Fragment offset from start of IP datagram. Measured in 8 byte (2 words, 64 bits) increments. If IP datagram is fragmented, fragment size (Total Length) must be a multiple of 8 bytes.

Header Checksum

Checksum of entire IP header

IP Flags

x D M

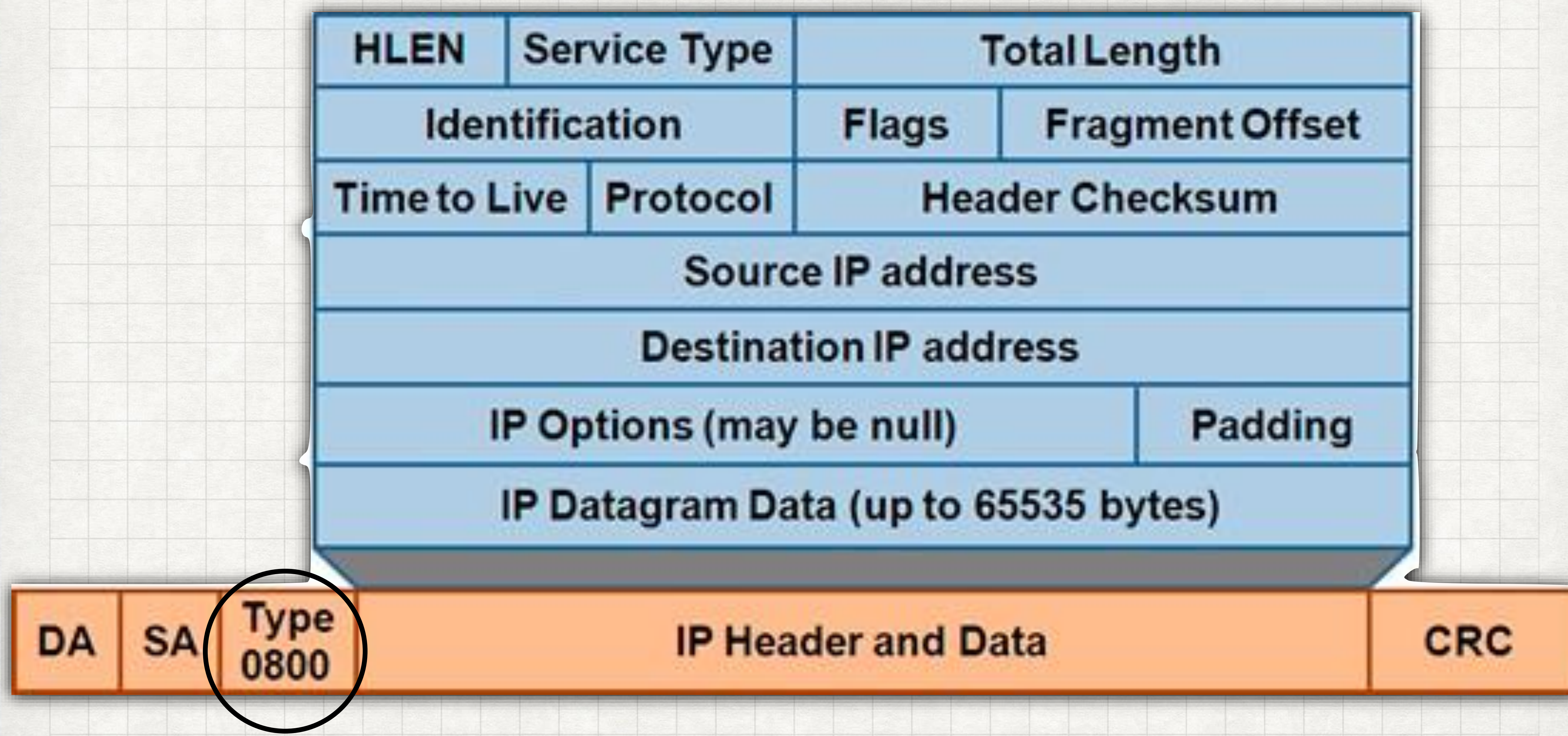
x 0x80 reserved (evil bit)
D 0x40 Do Not Fragment
M 0x20 More Fragments follow

RFC 791

Please refer to RFC 791 for the complete Internet Protocol (IP) Specification.

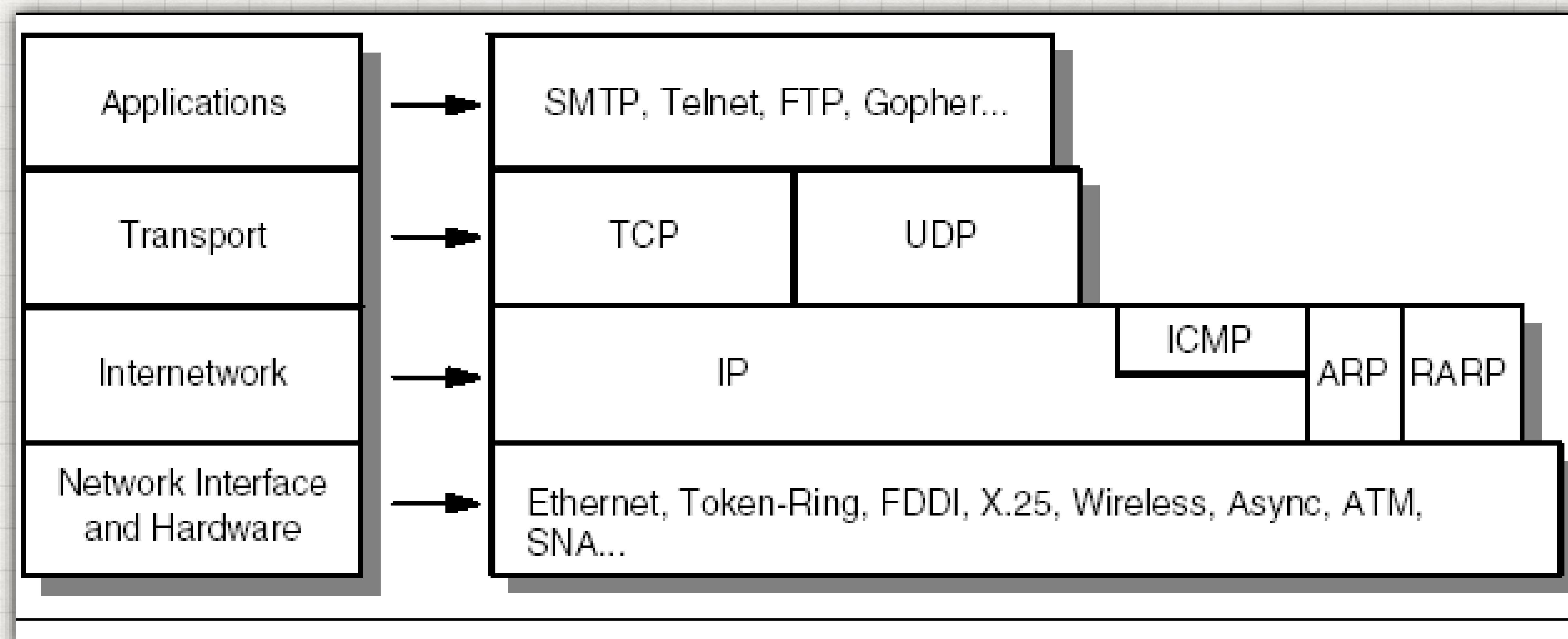
NETWORK PROTOCOLS

IP OVER ETHERNET

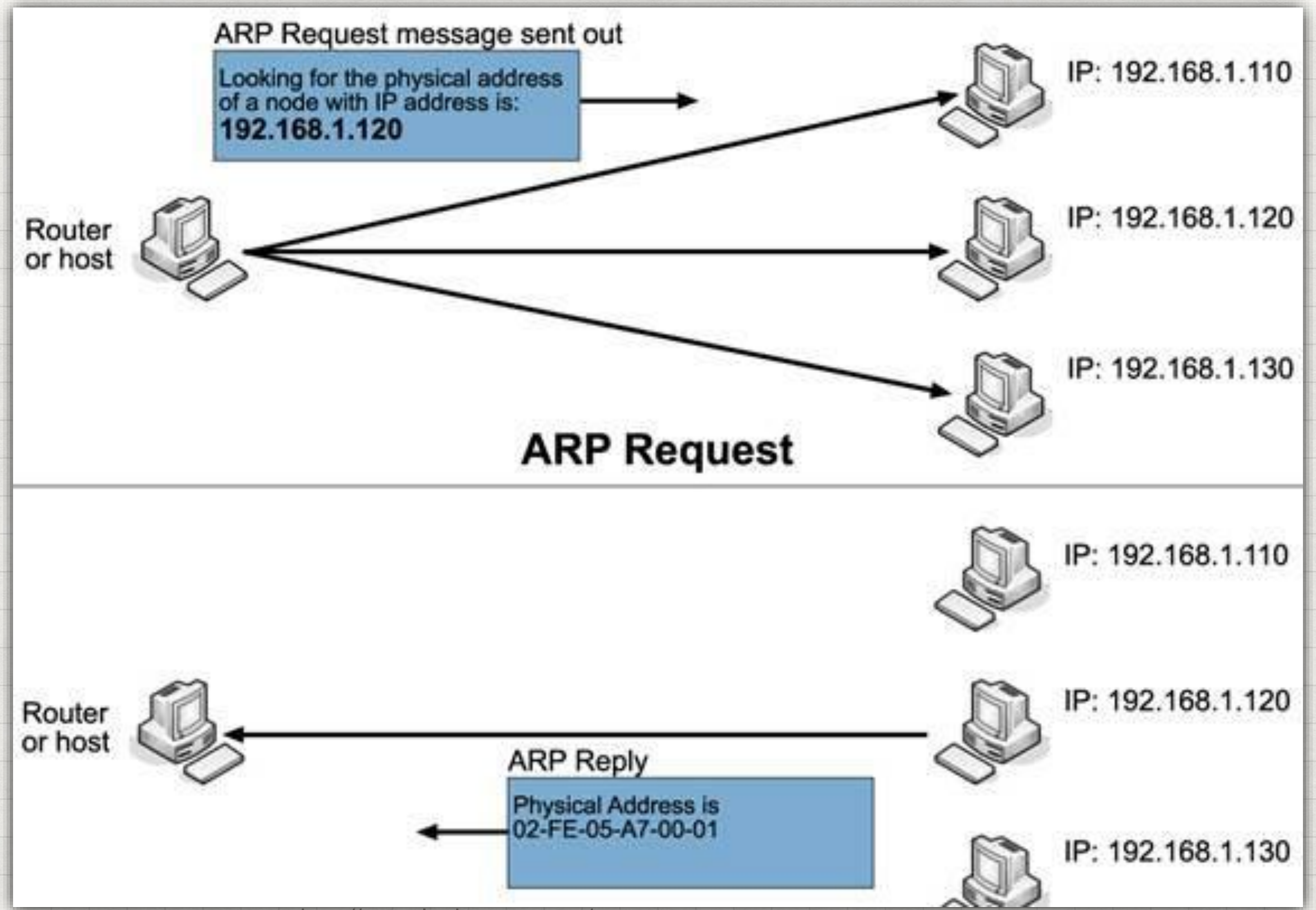


THE INTERNET PROTOCOLS

A SIMPLIFIED STACK



RELATING IP AND ETHERNET: ARP



source: http://www.louiewong.com/

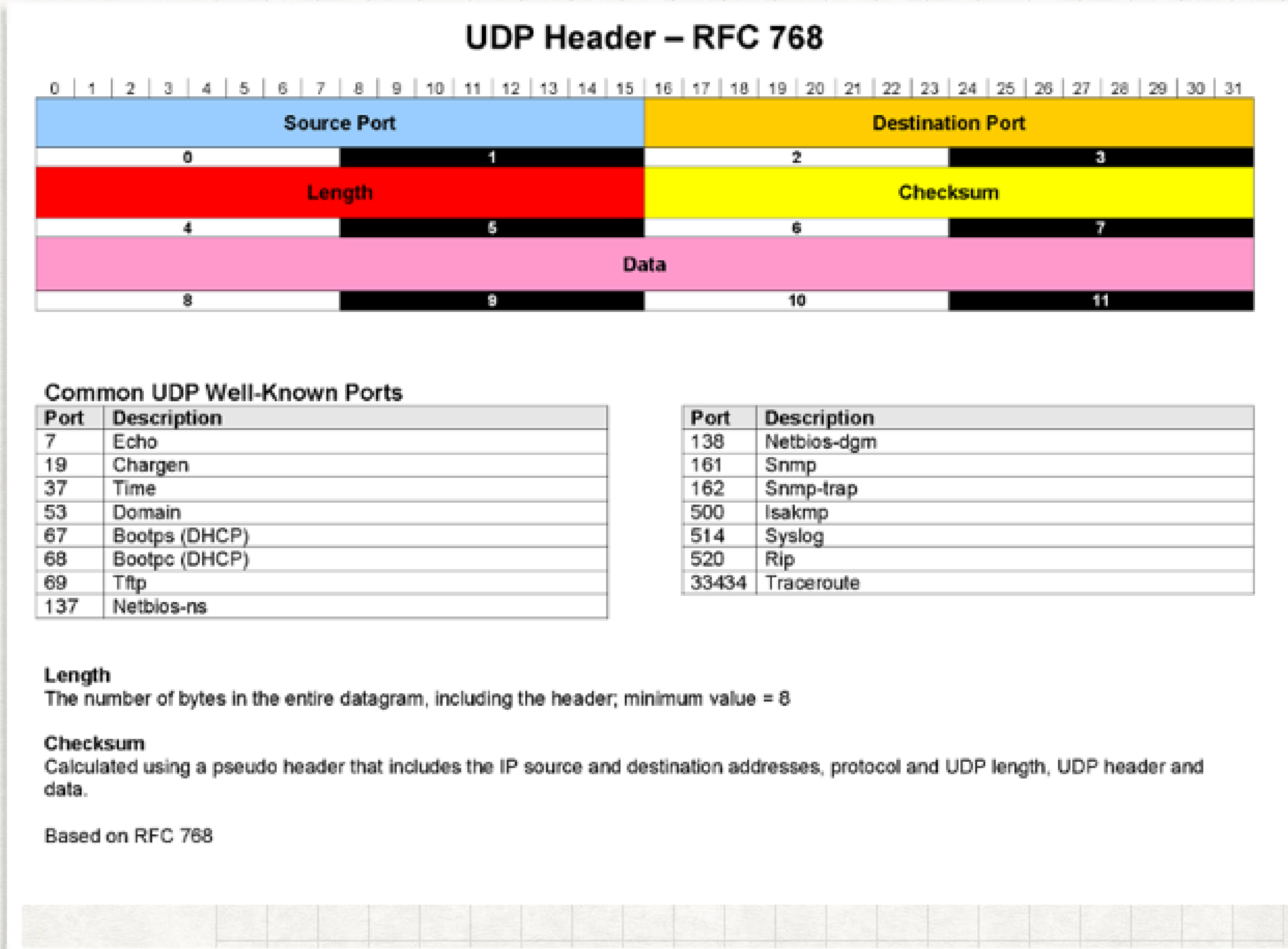
ARP

- ARP requests are Ethernet broadcasts
- They are sent to and received by all members of a Virtual LAN (VLAN). A VLAN is a arbitrary selection of ethernet devices (hosts or switches). Broadcasts are only forwarded within a VLAN - VLANs are so-called “broadcast domains”.
- Because the protocol is relatively costly, ARP replies are cached
  - With all the usual problems of caches
- On Linux you can look at the cache using `ip neighbour show`
- You can also manipulate this table / sometimes it is useful to fix an Ethernet / IP relation

NETWORK PROTOCOLS

UDP

- Adds concept of "port" to IP
- Unreliable datagrams == messages
  - Can get lost
  - Can arrive out of sending order(!)
- Sent in one go
- Maximum size 64 kB



UDP Header – RFC 768

Common UDP Well-Known Ports

Port	Description
7	Echo
19	Chargen
37	Time
53	Domain
67	Bootps (DHCP)
68	Bootpc (DHCP)
69	Tftp
137	Netbios-ns

Port	Description
138	Netbios-dgm
161	Snmp
162	Snmp-trap
500	Isakmp
514	Syslog
520	Rip
33434	Traceroute

Length
The number of bytes in the entire datagram, including the header; minimum value = 8

Checksum
Calculated using a pseudo header that includes the IP source and destination addresses, protocol and UDP length, UDP header and data.

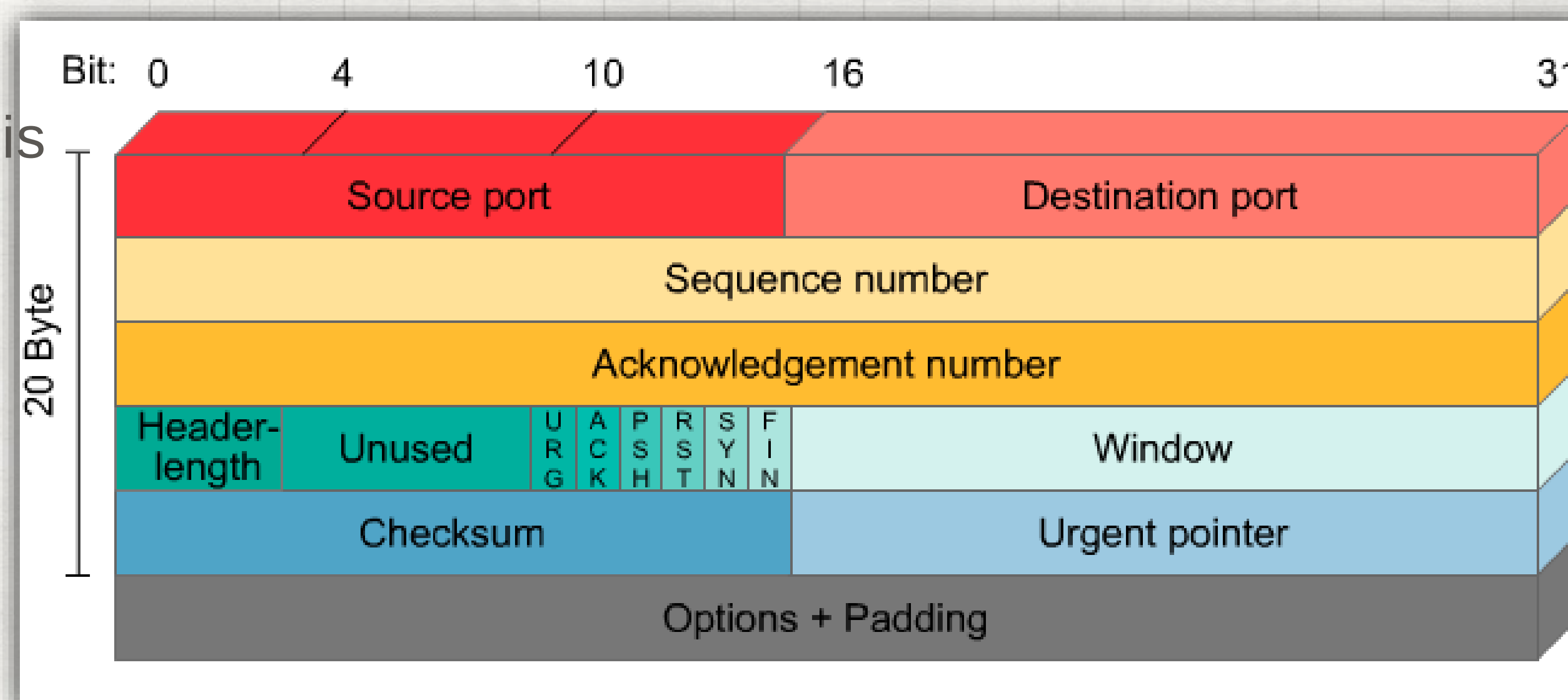
Based on RFC 768

Source: optimus5.com

NETWORK PROTOCOLS

TCP/IP

- TCP/IP is a child of Unix:
  - everything is a file and what is not a file looks like a file
  - sockets, byte-streams, there is no “maximum” size
  - TCP is a connected protocol
- TCP also has ports which are distinct from UDP ports
- TCP is reliable - packets do not get lost and arrive in sending order



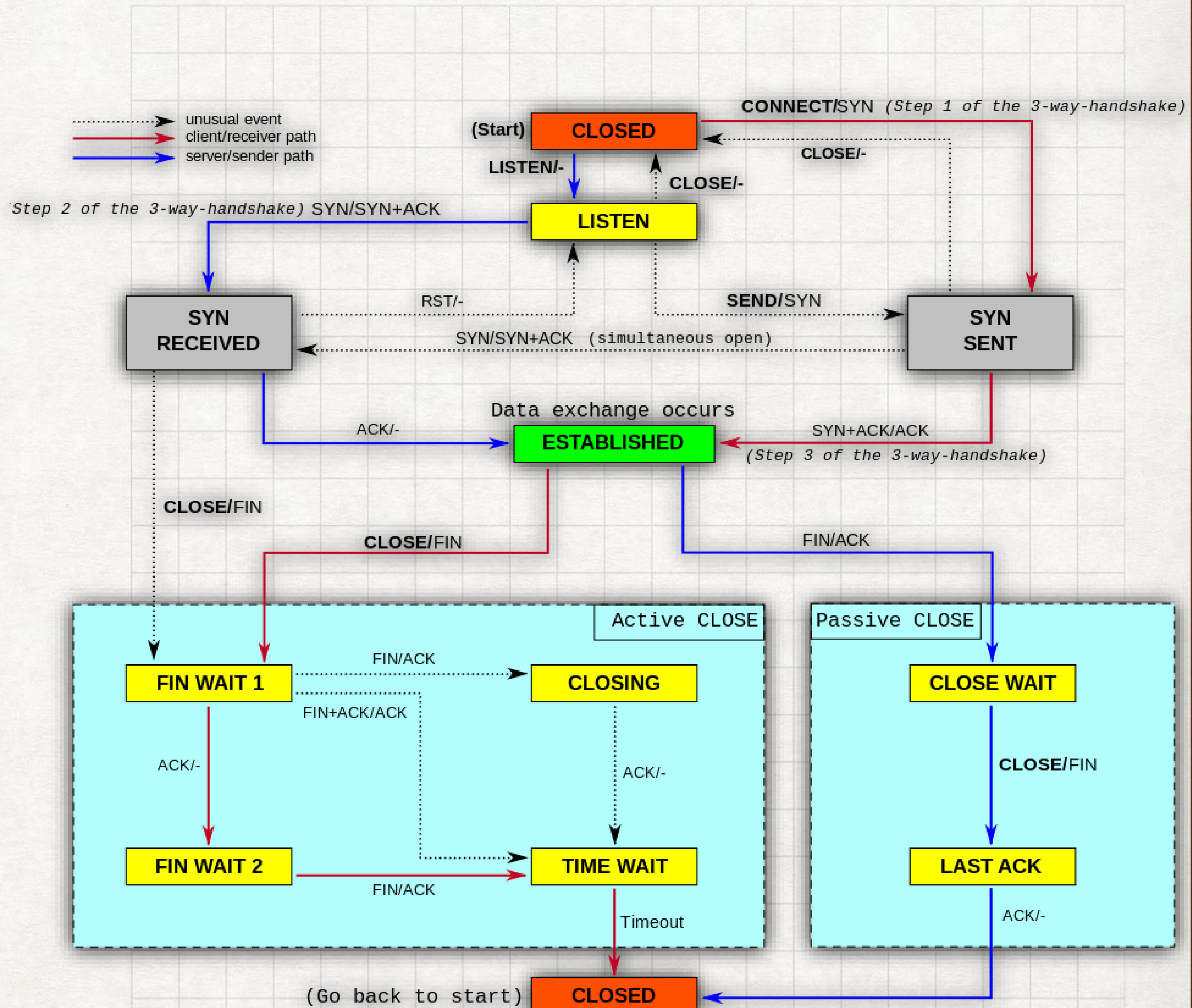
Source: www.kaderali.de

- Data are sent in chunks called “segments” the maximum segment size is abbreviated to MSS

TCP/IP

STATE DIAGRAM (SIMPLIFIED)

- This needs meditation and a good book (or wikipedia)
- Key points are that every attempt is made that sender and receiver are synchronised throughout the communication (handshakes)
- When used properly - also during shutdown, no data should be lost or corrupted (ever)
- But all this is not quick! For DAQ applications the connection needs to remain.



"Tcp state diagram fixed new" by Scil100. Licensed under CC BY-SA 3.0 via Commons - https://commons.wikimedia.org/wiki/File:Tcp_state_diagram_fixed_new.svg#/media/File:Tcp_state_diagram_fixed_new.svg

NETWORK PROTOCOLS

SOME FEATURES OF TCP/IP 1)

- MSS and MTU path discovery
  - TCP uses an algorithm to determine the maximum allowed segment size which fits into the least common MTU along the path - this is even dynamic but requires ICMP (not in UDP)
- Nagle algorithm
  - Normally TCP waits a bit to collect small messages into a single segment to be close to the MSS.
  - This can be very bad for latency and can be switched off by setting the TCP_NODELAY option (setsockopt)

NETWORK PROTOCOLS

MORE FEATURES OF TCP/IP

- TCP/IP was conceived to work well over long distance, unreliable lines

- There is a lot(!) of literature and algorithms to achieve good performance under such conditions (“slow start”, “window scaling”, “bandwidth delay product”, …). Many socket options (tcp(7)) allow to influence this

- In DAQ (usually) a reliable LAN is used and none of this is relevant, as there should be no appreciable packet-loss. This should be verified of course using counters and tools such as wireshark, etc…

RELIABLE DATAGRAMS

- In DAQ we normally want to send reliable datagrams
  - Can use UDP with homemade re-transmission
  - Or TCP with NO_DELAY
- POSIX has a few more little pitfalls, e.g. read and recv can return fewer bytes than requested(!). You will see therefore code like this

```
int i = 0;

while (i < len) {
    int n = recv(socket, buf, len, 0);
    if (n < 0) {
        // error
        break;
    } else {
        i += n;
}
```

- Lots of boring boilerplate code has been omitted
- Error-checking is of course (even more) vital in network programming

PROTOCOLS

RELIABLE MESSAGES: 0MQ

- Message libraries such as 0MQ or DIM take away some of the pain of dealing with sockets directly
- They encapsulate error-handling and some oddities of the socket semantics (like the boring while loop on recv) and the setup of the addresses
- Why reinvent the wheel? If you can use them!

```python
# receiver
import zmq
context = zmq.Context()
socket = context.socket(zmq.REP)
socket.bind("tcp://127.0.0.1:5000")

while True:
    msg = socket.recv()
    print "Got", msg
    socket.send(msg)
# sender
import zmq
context = zmq.Context()
socket = context.socket(zmq.REQ)
socket.connect("tcp://127.0.0.1:5000")
for i in range(10):
    msg = "msg %s" % i
    socket.send(msg)
    print "Sending", msg
    msg_in = socket.recv()
```

PROTOCOL OVERHEADS

SOME NUMBERS AND WISDOM

- "In protocol design, perfection is achieved not when nothing can be added, but when nothing can be taken away"
- "Any technology can be two out of the following three: cheap, fast, reliable"
  - Every layer a adds a header:
    - Ethernet 14 octets
    - IP 20 octets
    - TCP 20 octets

In addition protocols add packet over heads (acknowledgments for TCP for example)

A SIDENOTE ON DOCUMENTATION

BEFORE GOOGLE THERE WAS MAN

- The man pages come in several sections
  - Section 7 contains all the protocols (man 7 ip, man 7 tcp)
  - Section 2 contains the sys-calls (man 2 setsockopt)
  - Section 8 contains the configuration tool (man 8 ip)
- It takes a bit of practice to read them, but understanding them means understanding sockets, protocols, etc…
- Wikipedia is usually an excellent complement

```
NAME

baby -- create new process from two parents
SYNOPSIS

baby -sex [m|f] [-name name]
DESCRIPTION

baby is initiated when one parent process polls
another server process through a socket connection
in the BSD ver- sion or through pipes in the
System V implementation. baby runs at low priority
for approximately forty weeks and then terminates
with a heavy system load. Most systems require
constant monitoring when baby reaches its final
stages of execution.
Older implementations of baby did not require both
initiating processes to be present at the time of
completion.
```

NETWORK TOOLS TO KNOW

ICMP PING

- Internet Control Message Protocol (ICMP) is a suite of utility messages to notify network devices about various problems and status of other devices
- The most well known is the Echo Request message which is used by the Ping command
- Watch out for the latency (round-trip time) and its stability

Why the game "PONG-PING" never caught on.

```
gw22:~>ping lab14
PING lab14.lbdaq.cern.ch (10.128.210.114) 56(84) bytes of data.
64 bytes from lab14.lbdaq.cern.ch (10.128.210.114): icmp_seq=1 ttl=60 time=1.11 ms
64 bytes from lab14.lbdaq.cern.ch (10.128.210.114): icmp_seq=2 ttl=60 time=1.17 ms
64 bytes from lab14.lbdaq.cern.ch (10.128.210.114): icmp_seq=3 ttl=60 time=1.20 ms
```

NETWORK UTILITIES TO KNOW

IPERF

- Standard tool
- URL: https://iperf.fr/
- Use only iperf v3
  - v2 has known bugs, in particular for bi-direction tests
- It can use multiple streams in parallel (important at high speeds)

```
<perf-3.1.1plus02:~/devel/iperf-3.1.1>./src/iperf3 -c localhost
Connecting to host localhost, port 5201
[  4] local ::1 port 43530 connected to ::1 port 5201
[ ID] Interval           Transfer     Bandwidth       Retr  Cwnd
[  4]   0.00-1.00   sec  1.79 GBytes  15.4 Gbits/sec    0   1.12 MBytes
[  4]   1.00-2.00   sec  1.84 GBytes  15.8 Gbits/sec    0   1.12 MBytes
[  4]   2.00-3.00   sec  1.82 GBytes  15.6 Gbits/sec    0   1.25 MBytes
[  4]   3.00-4.00   sec  1.87 GBytes  16.0 Gbits/sec    0   1.37 MBytes
[  4]   4.00-5.00   sec  1.83 GBytes  15.8 Gbits/sec    0   1.62 MBytes
[  4]   5.00-6.00   sec  1.84 GBytes  15.8 Gbits/sec    0   1.75 MBytes
[  4]   6.00-7.00   sec  1.77 GBytes  15.2 Gbits/sec    0   1.81 MBytes
[  4]   7.00-8.00   sec  1.86 GBytes  15.9 Gbits/sec    0   1.87 MBytes
[  4]   8.00-9.00   sec  1.86 GBytes  16.0 Gbits/sec    0   1.87 MBytes
[  4]   9.00-10.00  sec  1.87 GBytes  16.0 Gbits/sec    0   1.87 MBytes
- - - - - - - - - - - - - - - - - - - - - - - - -
[ ID] Interval           Transfer     Bandwidth       Retr
[  4]   0.00-10.00  sec  18.3 GBytes  15.8 Gbits/sec    0             sender
[  4]   0.00-10.00  sec  18.3 GBytes  15.8 Gbits/sec                  receiver

iperf Done.
```

NETWORK TOOLS TO KNOW

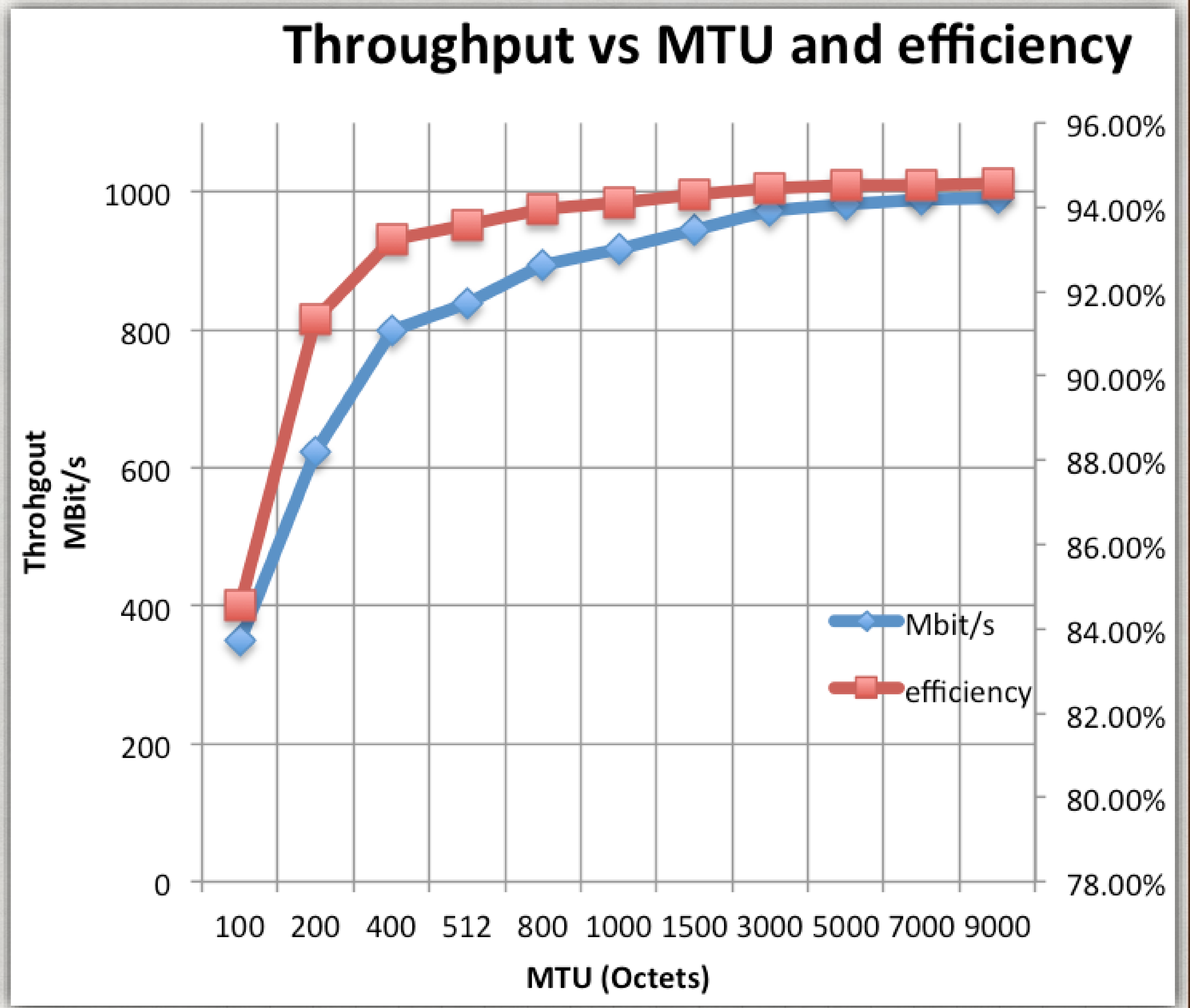
IPTRAF

- Needs root privs (“sudo”) or CAP_NET_ADMIN (man capabilities)
- Good & quick overview on how much “stuff” is going on
- Detailed analysis needs other tools

```
IPTraf
┌ Statistics for eth0 ─────────────────────────────────────────────

               Total      Total   Incoming  Incoming   Outgoing   Outgoing
             Packets      Bytes    Packets     Bytes    Packets      Bytes
 Total:          987     174243        504     41811        483     132432
 IPv4:           987     160419        504     34749        483     125670
 IPv6:             0          0          0         0          0          0
 TCP:            966     158586        494     33878        472     124708
 UDP:             10        846          4       304          6        542
 ICMP:            11        987          6       567          5        420
 Other IP:         0          0          0         0          0          0
 Non-IP:           0          0          0         0          0          0


 Total rates:         66.6 kbits/sec        Broadcast packets:          0
                      50.0 packets/sec      Broadcast bytes:            0

 Incoming rates:      18.4 kbits/sec
                      25.6 packets/sec
                                            IP checksum errors:         0
 Outgoing rates:      48.2 kbits/sec
                      24.4 packets/sec
```

THE EFFECT OF THE MTU

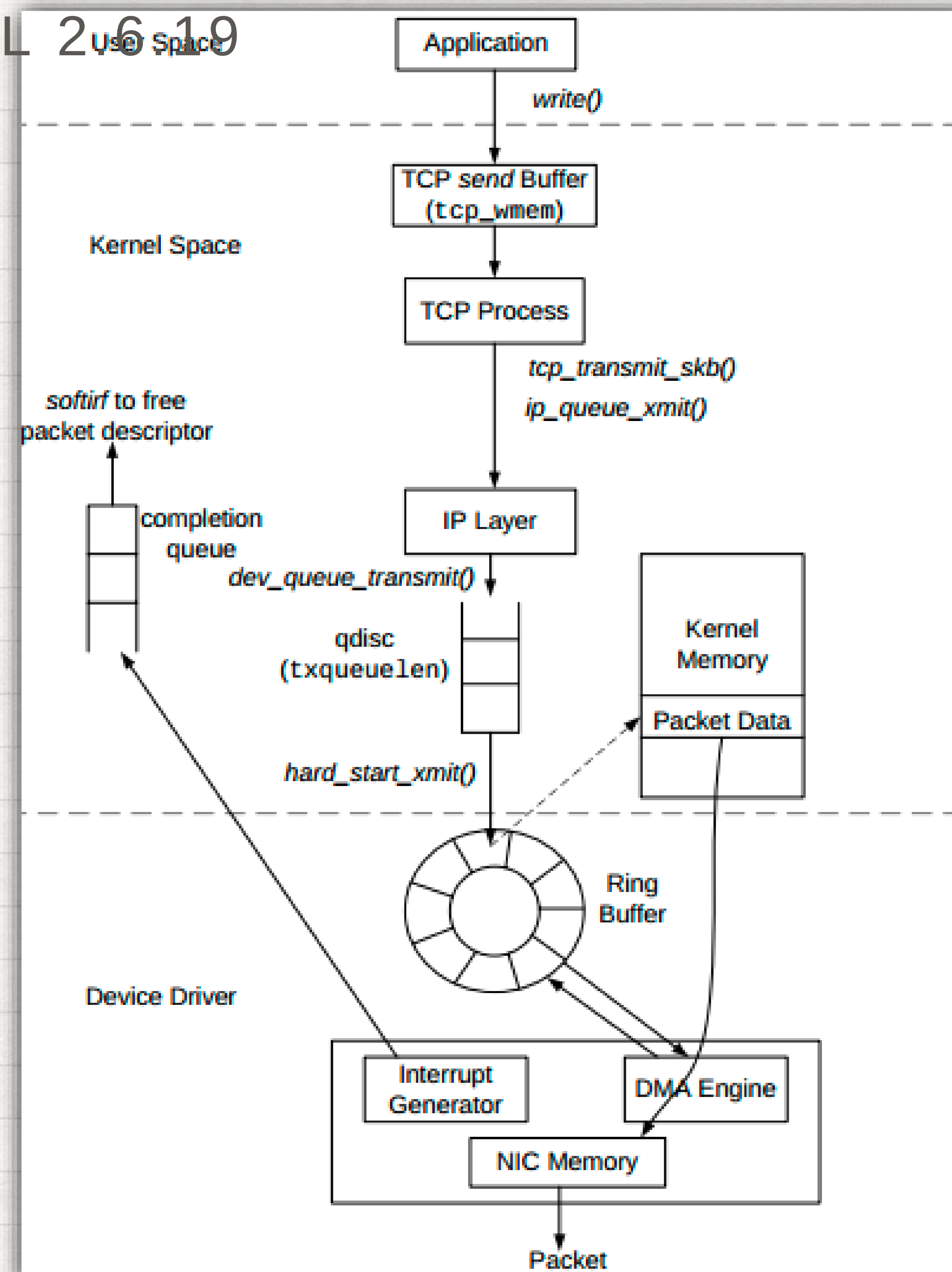
- Measured on I350 network controller
- iperf3 TCP/IP no special tunings
- CPU Intel 2630v3 (8 core)
- Note that standard MTU 1500 does not give line-rate even though efficiency is already high. This effect is stronger on weaker CPUs
- eff = (MTU - 54) / MTU



THE LINUX NETWORK STACK

KERNEL 2.6.19

- The NIC DMAs the packets from/to buffers managed by the kernel sk_buff
- Protocol verification and handling done in the kernel
- Read/Write calls from user-space applications normally entail a copy from/to kernel space
  - Standard Linux IP protocols do not support zero-copy
- Sizes of many of these buffers can be influenced by kernel parameters



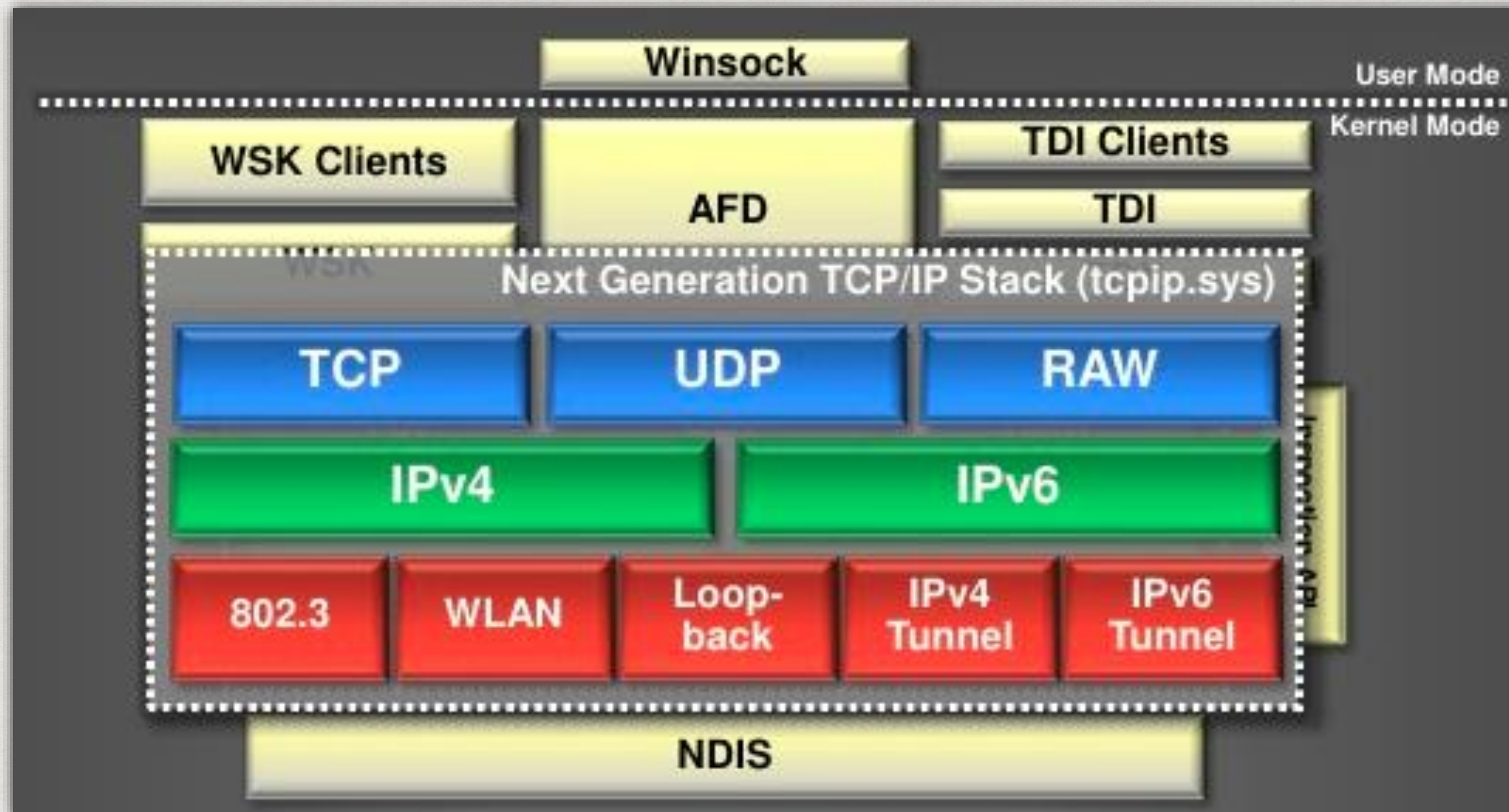
source: http://www.ece.virginia.edu/cheetah/documents/papers/TCPlinux.pdf

PERFORMANCE

LINUX TUNING - KERNEL PARAMETERS

- net.core.rmem_max: upper limit for buffer in sockets for reading
  - increase if you loose a lot of messages (UDP) or performance is bad (TCP) - note you also need to adapt the TCP options
- net.core.wmem_max: same for writing
- net.core.netdev_max_backlog: how many packets can be waiting to be handled
  - increase if you loose messages, can be caused by competing applications or hardware (IRQ sharing!)
- To change use
  - sysctl -w <parametername> <value>
- To read use
  - sysctl <parametername>
- Documentation in every kernel source tree in the doc folder or https://www.kernel.org/doc/Documentation/kernel-parameters.txt

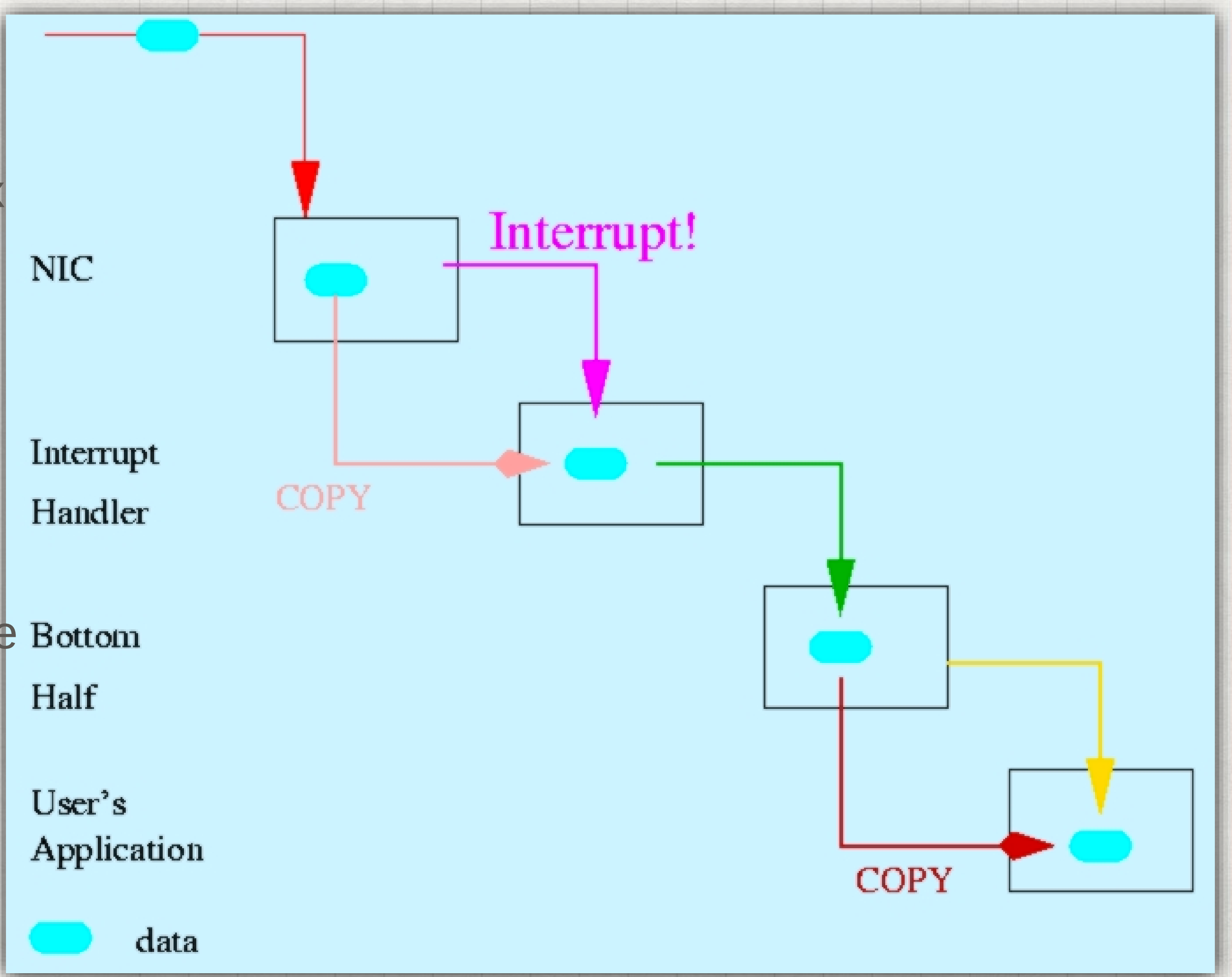
THE WINDOWS NETWORK STACK



- The good news: winsock is an exact copy of the Berkeley socket interface

NETWORK ADAPTERS & DRIVERS

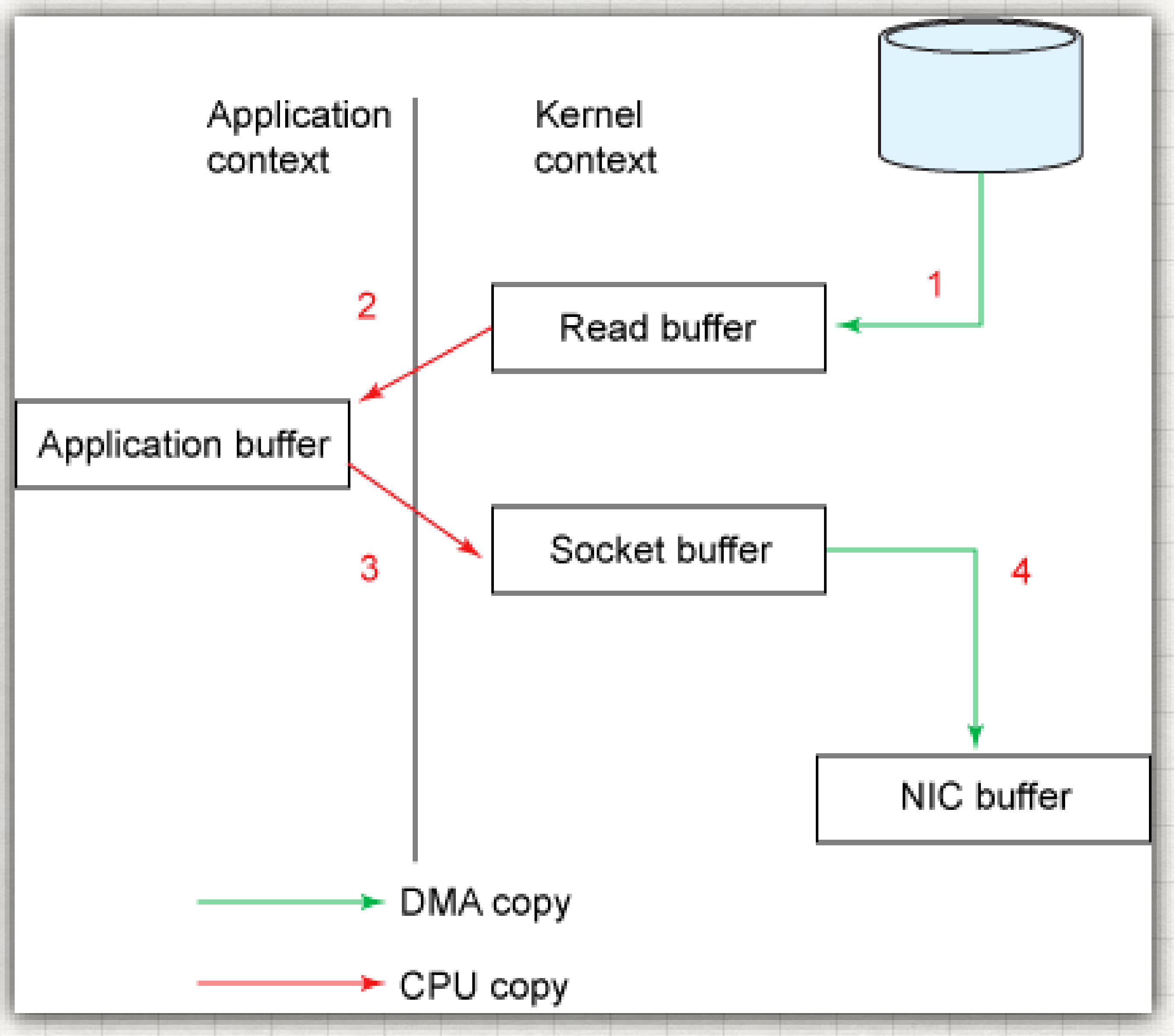
- Main manufacturers are today: Intel, Broadcom, in the high end you find also Chelsio, Solarflare, Mellanox
- Watch out for difference between “desktop” and “server” adapter
    - desktop adapters can have very small on-chip memory and be vulnerable to packet loss



ZERO-COPY

THE PROBLEM

- Buffering is crucial in networking because you never know when data will arrive
- But (shared) buffers are risky from a security and stability point of view
- This is avoided by copying to private buffers
- Copy operations however need CPU cycles and memory bandwidth

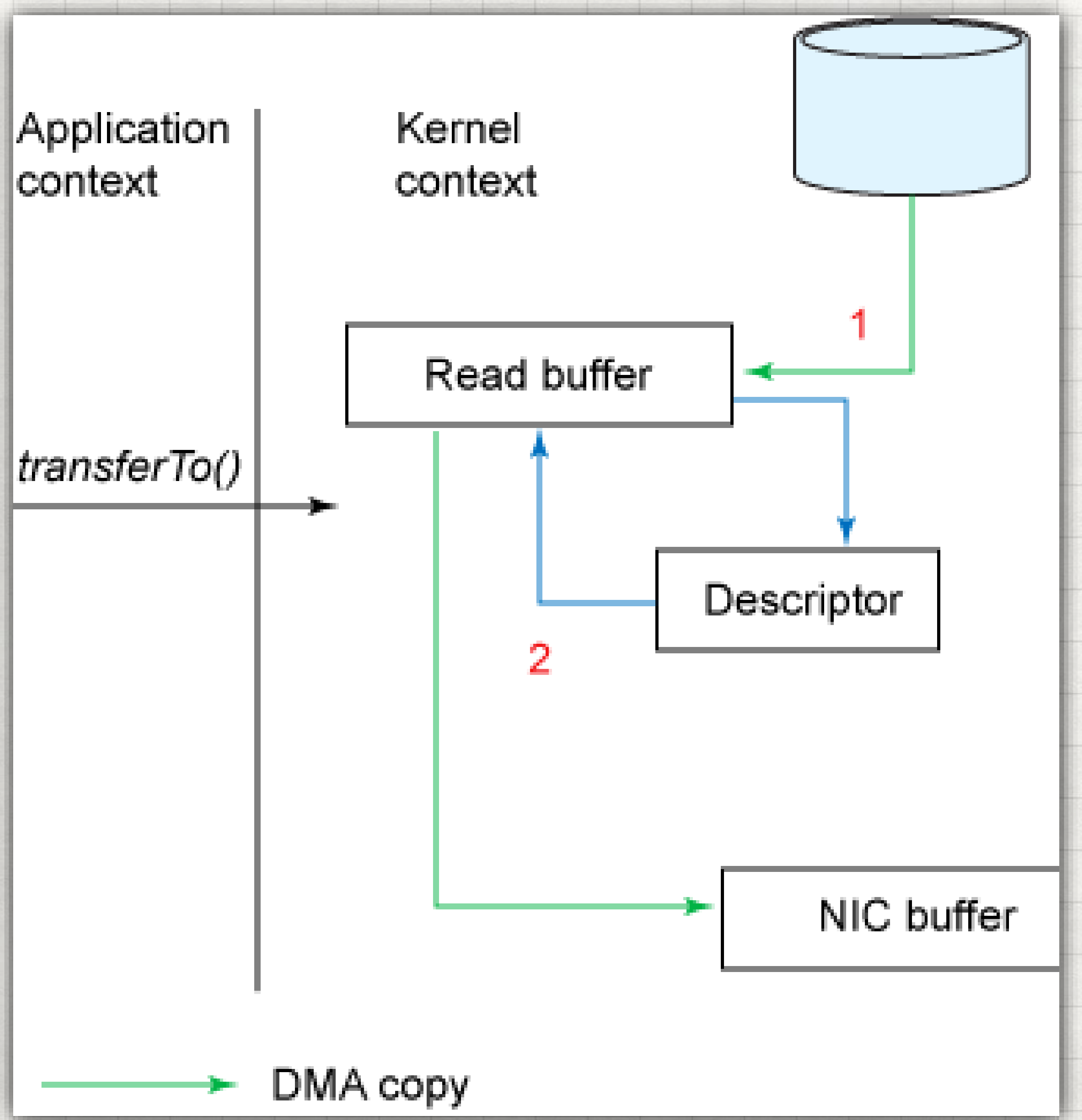


Traditional copy-model in a file-server (source IBM)

ZERO-COPY

A SOLUTION

- The key is to let the DMA engines talk to each other
- For this application has to own the buffer (and lock the pages in RAM)
- Kernel safety functions are bypassed
- This is partially possible in Linux for fileserver using the sendfile system call
- In general this is a problem only for data-transfers > 10 Gbit/s and (on Linux at least) requires not using the standard TCP/IP stack



CONNECTING MANY DEVICES

SWITCHES

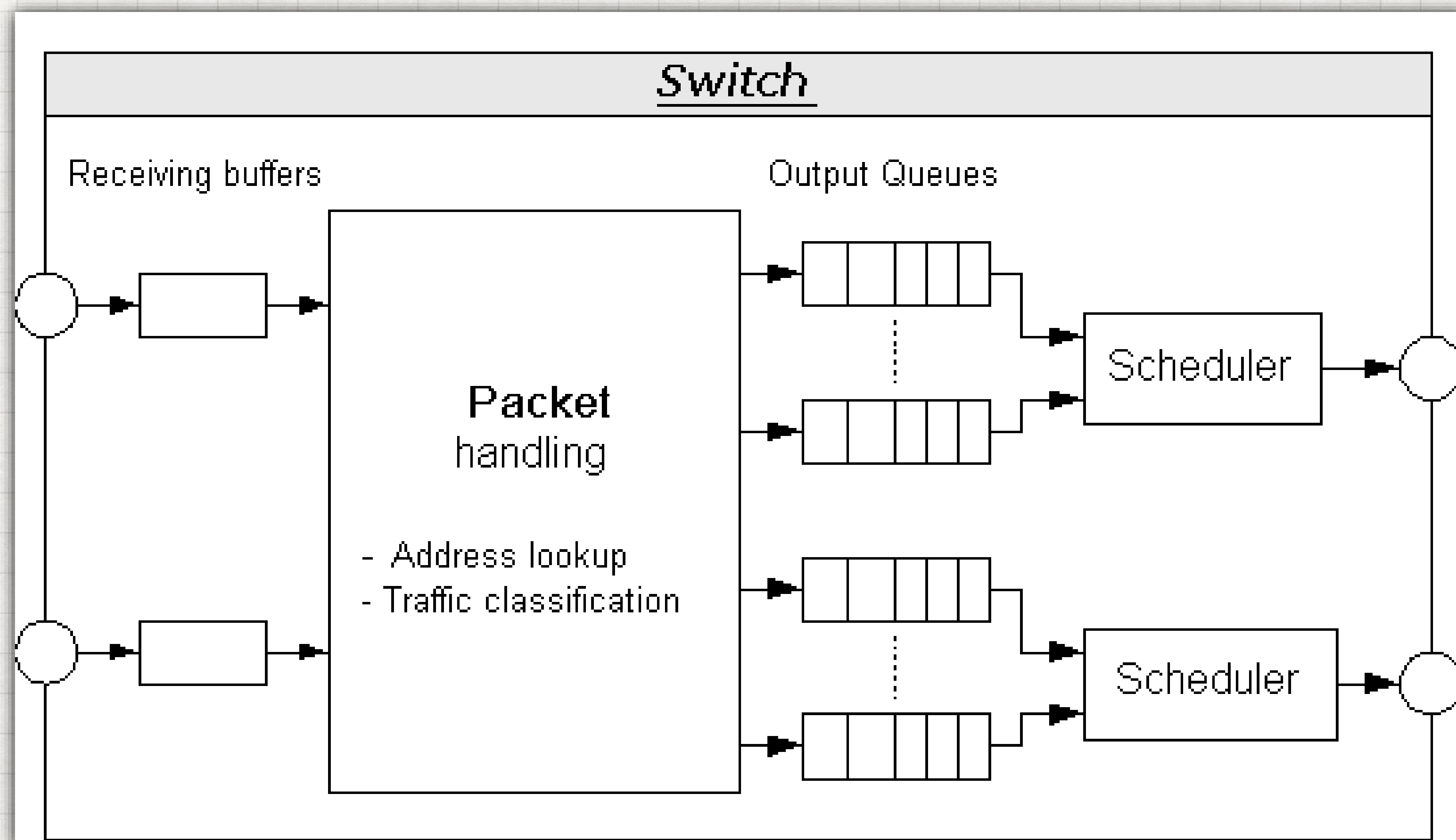
- Switches normally operate at the Ethernet level (Layer 2)
- There are managed switches, which allow configuration and monitoring and unmanaged switches which are fully automatic and not configurable
- Monitoring is usually done via SNMP (a UDP based protocol)
  - From linux use snmpwalk
- For DAQ buffer-sizes should be configured as large as possible
  - Often space can be made available by reducing the number of traffic classes (used for priority)
- Configuration is using a web-interface or a Command Line Interface (CLI) which is usually a variant of the CLI invented by Cisco (if you know one, you will be annoyed but not stopped by any other)

NETWORK TOOLS TO KNOW

ETHTOOL

- ethtool allows you to manipulate the Ethernet layer and your NIC
- It shows very useful information , eg:
  - #link status
    sudo ethtool eth1 | grep Link
    Link detected: yes
  - #link statistics
    sudo ethtool eth1 -S
    # loads of numbers defined by 802.3 (watch out for errors)
    Even a small amount of errors usually means a serious problem (cable, optics, etc…)
- It can be used to set important parameters, eg:
  - # set number of DMA descriptors for receiving to 4000
    sudo ethtool eth1 -G rx 4000

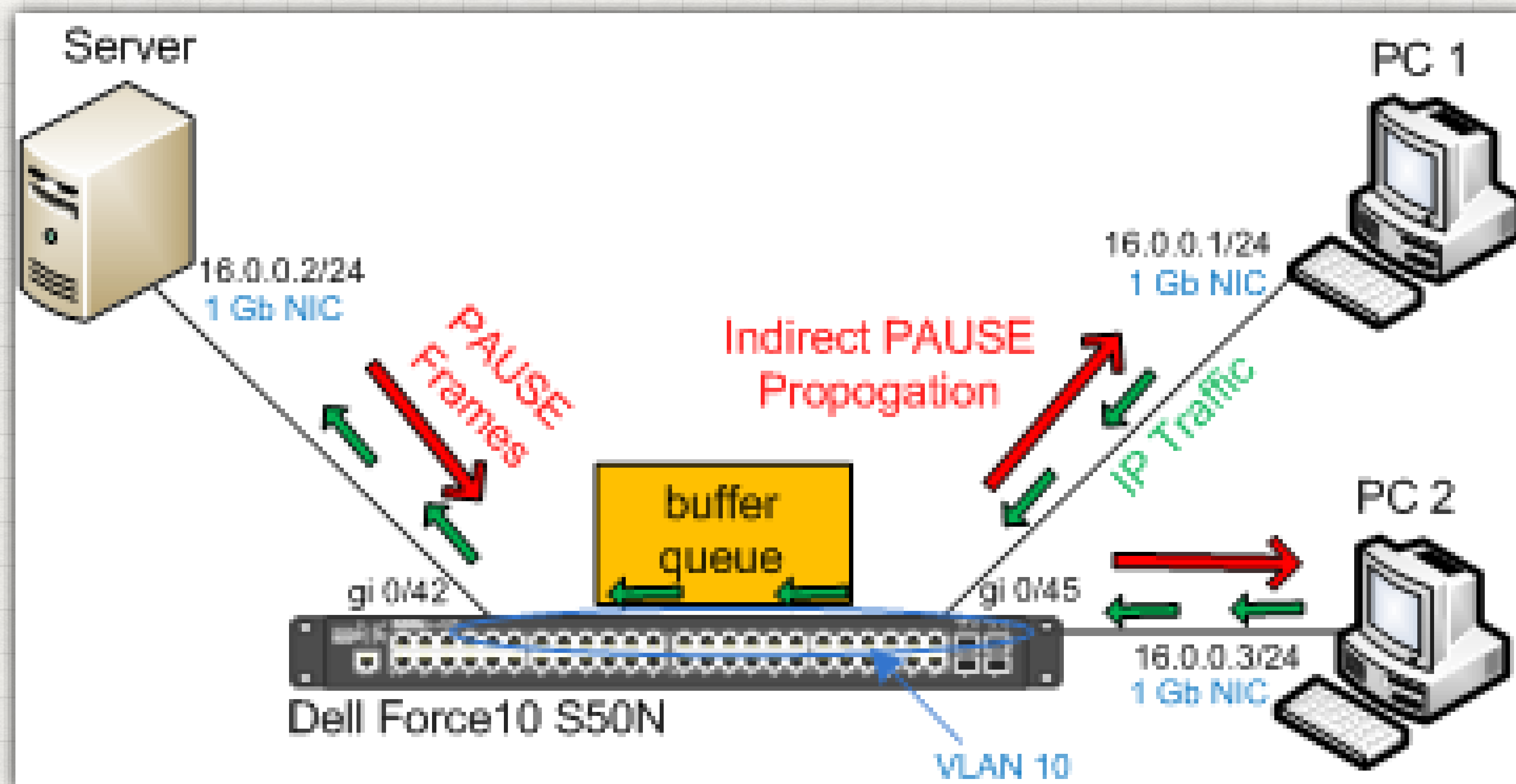
ETHERNET SWITCH INSIDE



source: www.iecstfa.org

ETHERNET FLOW CONTROL

AND IT'S PROBLEMS



CONNECTING NETWORKS

ROUTERS

- In DAQ we tend to use private LANs
- For larger or multistage systems, it is almost always better to use layer 3 (IP). A layer-3 switch is called a router.
  - IP addresses are easier to manage, they have symbolic names, there is a (simple) loop protection
- Routers offer many, many features, most of which are not needed in a LAN for DAQ
- A static setup eases debugging, the failover features of internet routing protocols are usually too slow to be of big help in DAQ

NETWORK TOOLS TO KNOW

TRACEROUTE

- traceroute (tracert on M$-Windows)
- Checks the connectivity between nodes. It shows all (many) of the intermediate devices.
  - If you loose packets any of them are a candidate
- It can show you if things go the way you think they would

```
hltb1001:~>traceroute -n www.cern.ch
traceroute to www.cern.ch (188.184.9.235), 30 hops max, 60 byte packets
 1  10.130.122.254  1.061 ms  1.067 ms  1.099 ms
 2  172.16.1.1  0.357 ms  0.407 ms 172.16.1.5  0.447 ms
 3  137.138.18.241  2.460 ms  2.456 ms  2.626 ms
 4  172.24.2.145  0.361 ms  0.387 ms  0.381 ms
 5  172.24.3.17  0.457 ms 172.24.3.81  0.454 ms  0.493 ms
 6  172.24.3.178  0.517 ms 172.24.3.158  0.404 ms 172.24.3.178  5.135 ms
 7  188.184.9.235  0.564 ms  0.572 ms  0.548 ms
```

NETWORK TOOLS TO KNOW

LIBPCAP

- Filtering lets you focus on what's interesting
- It is much more efficient to filter at the libpcap ("capture") level than using the display filter in wireshark
- This is shared by many tools: dumpcap, tcpdump, etc..

Capture only traffic to or from IP address 172.18.5.4:

```
host 172.18.5.4
```

Capture traffic to or from a range of IP addresses:

```
net 192.168.0.0/24
```

or

```
net 192.168.0.0 mask 255.255.255.0
```

Capture traffic from a range of IP addresses:

```
src net 192.168.0.0/24
```

or

```
src net 192.168.0.0 mask 255.255.255.0
```

Capture traffic to a range of IP addresses:

```
dst net 192.168.0.0/24
```

or

```
dst net 192.168.0.0 mask 255.255.255.0
```

Capture only DNS (port 53) traffic:

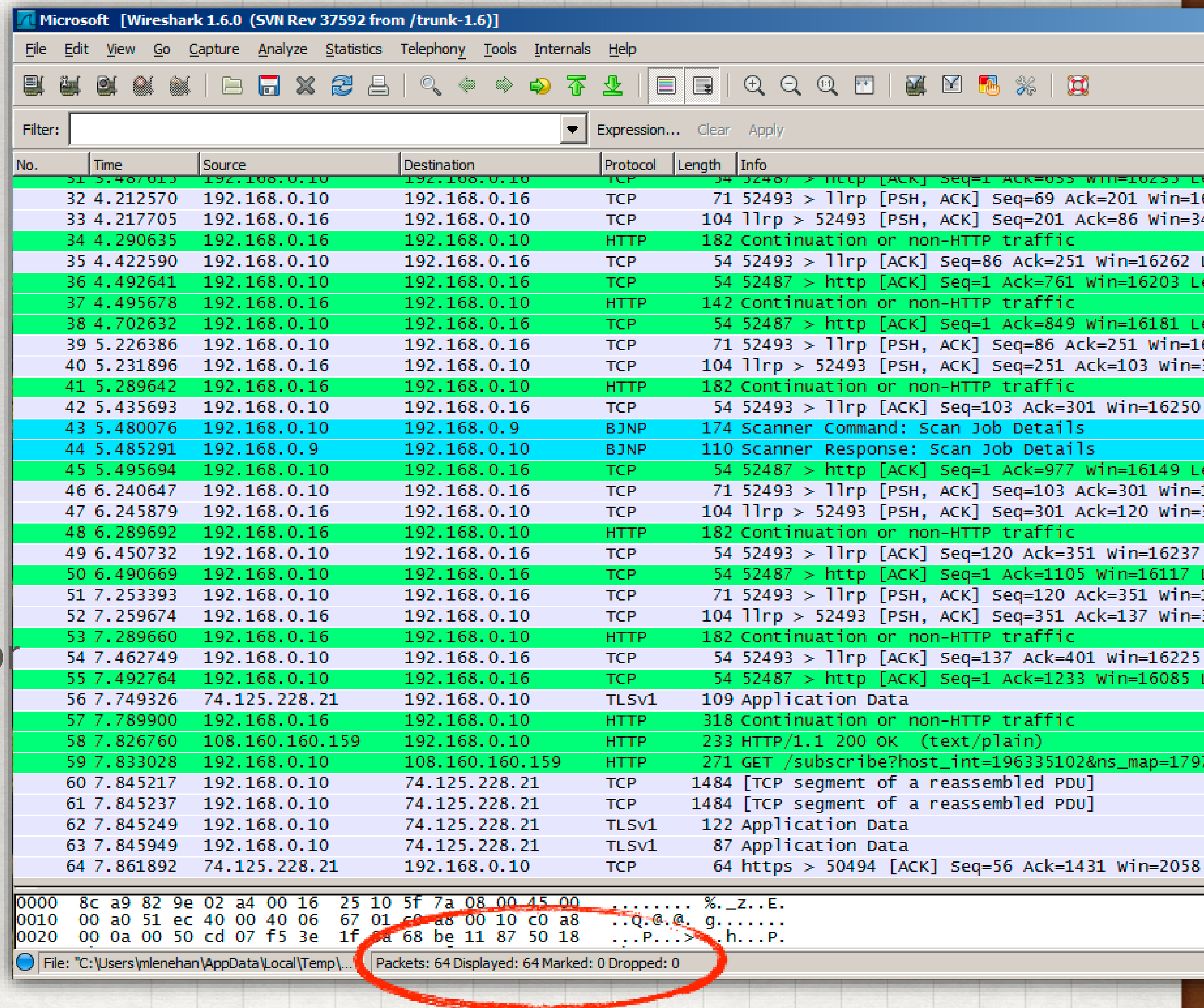
```
port 53
```

From the wireshark wiki

NETWORK TOOLS TO KNOW

WIRESHARK

- A super-powerful tool
- Comes in a gui and a console version (tshark)
- Is built on top of libpcap
- It understands virtually all known network protocols
- Packet processing at high speed is tricky, watch out for dropped packets —> not seen does not mean not received



INTERPRETING THE HEX DUMP

NETWORK BYTE ORDER

Low address — High address

Address	0	1	2	3	4	5	6	7
Little-endian	Byte 0	Byte 1	Byte 2	Byte 3	Byte 4	Byte 5	Byte 6	Byte 7
Big-endian	Byte 7	Byte 6	Byte 5	Byte 4	Byte 3	Byte 2	Byte 1	Byte 0
Memory content	0x11	0x22	0x33	0x44	0x55	0x66	0x77	0x88

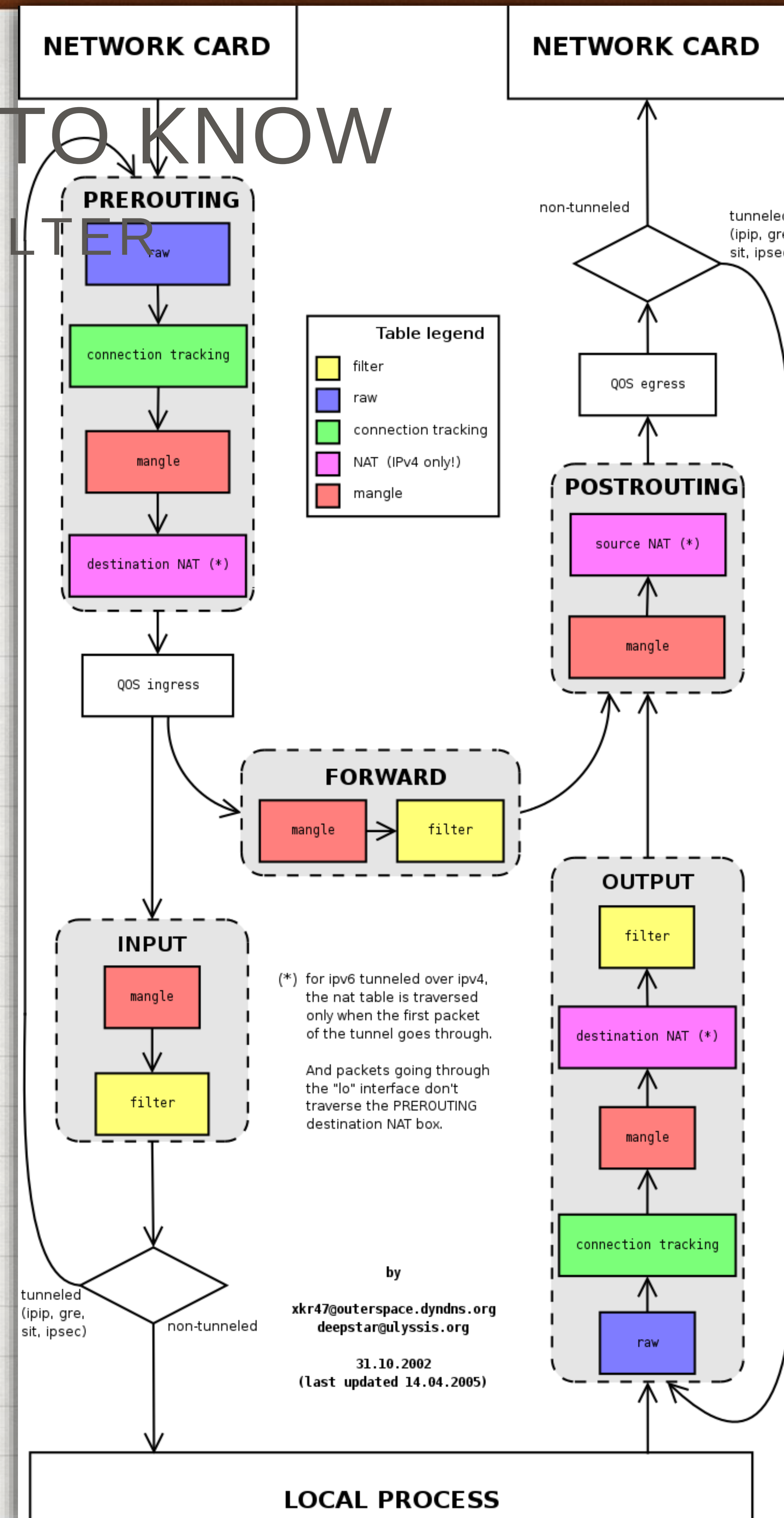
64 bit value on Little-endian	64 bit value on Big-endian
0x8877665544332211	0x1122334455667788

- Historically network byte order is big-endian
- In the 21st century almost all processors are little-endian
- POSIX has portable conversion functions (`man htons`)
  - `htons, ntohs, htonl, ntohl h … host, n … network`

NETWORK TOOLS TO KNOW

IPTABLES / NETFILTER

- “Firewall” used for counting
- Monitoring independent of running application
- No copy from kernel space —> efficient



WIFI FOR DAQ?

NOT A GOOD IDEA

- WiFi is a shared medium (like the original Ethernet)
- Bandwidth is erratic
- Stability is poor
  - Check latencies with ping or throughput with iperf
- Your mileage may vary of course, if you're needs are far below the effective speed

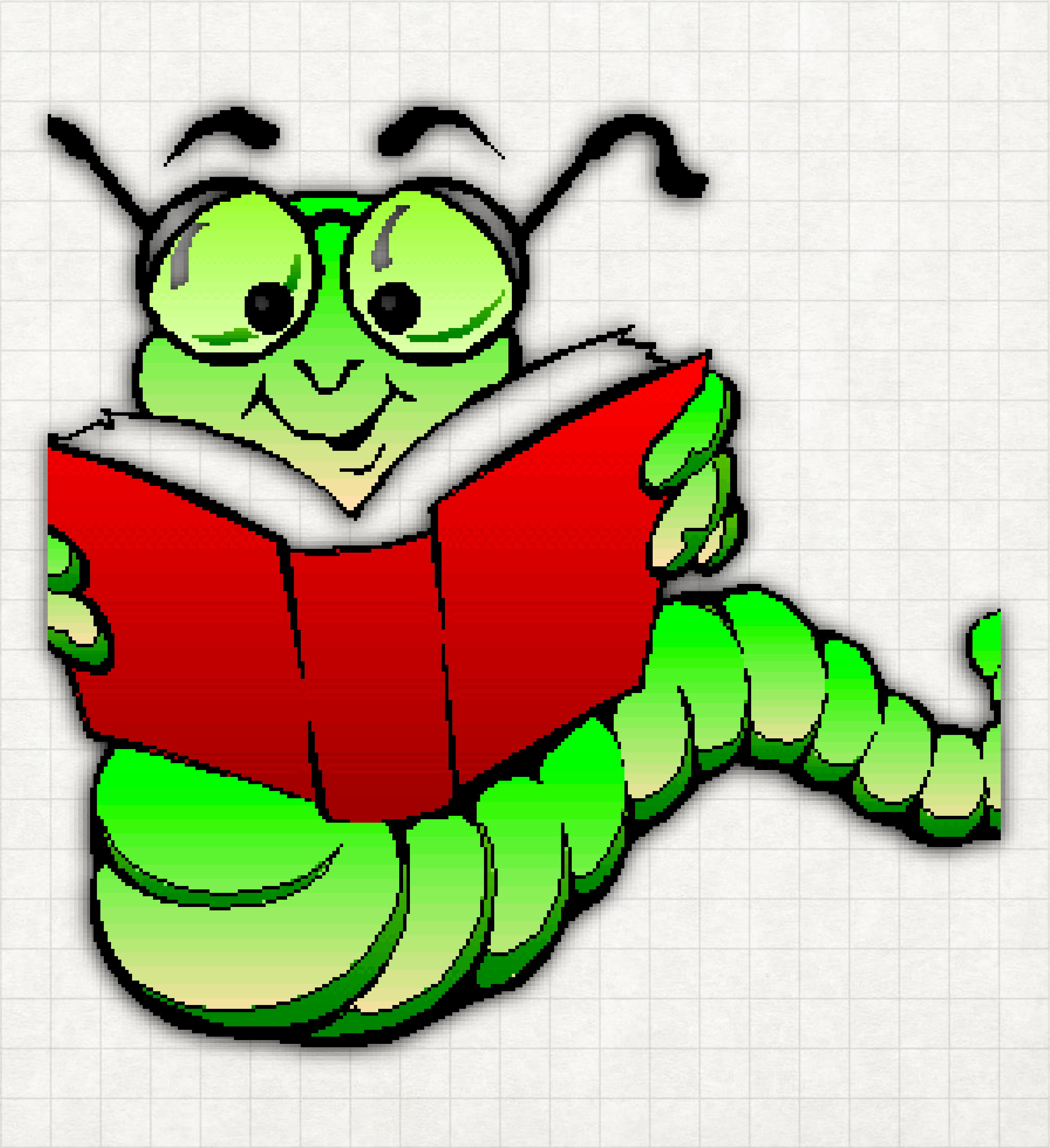
Standard	eff. speed
802.11 b	2 Mbit/s
802.11 g	20 Mbit/s
802.11 n	40 Mbit/s
802.11 ac	60 Mbit/s

source: www.speedguide.net

source: www.dumbblog.com

FURTHER READING

- Best is simply to try out
- man-pages and wikipedia have practically all info which is needed
- For book-worms there is “Unix Network Programming, Volume 1: The Sockets Networking API (3rd Edition)”

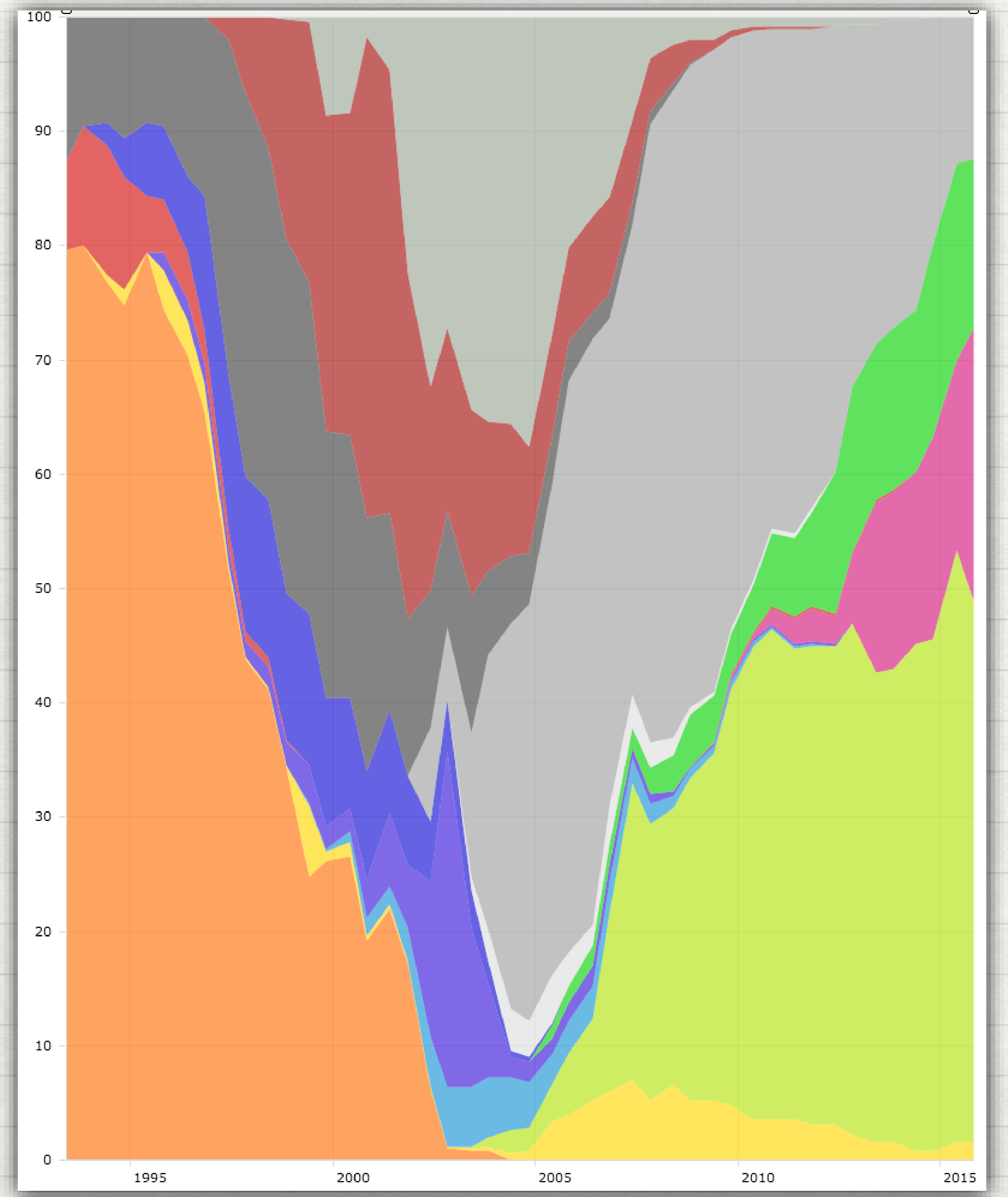


APPENDIX

THE CASE FOR CLUSTER-INTERCONNECTS

COST, COST AND COST

- Per unit of bandwidth InfiniBand and OmniPath are more cost-effective than Ethernet (at least at the top-speeds)
- They tend also to use less CPU power than the TCP/IP stack (only relevant at speeds > 10 Gbit/s)
- Using them is *much* more difficult in practice - believe me - I’ve been there :-)



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ANOTHER STACK