Introduction to Computer Networks

Fundamentos de Redes

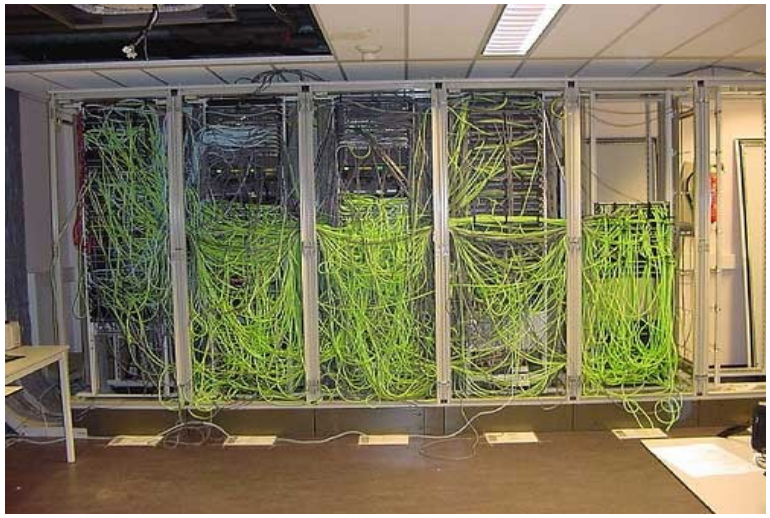
Mestrado Integrado em
Engenharia de Computadores e Telemática
DETI-UA

universidade de aveiro
deti.ua.pt

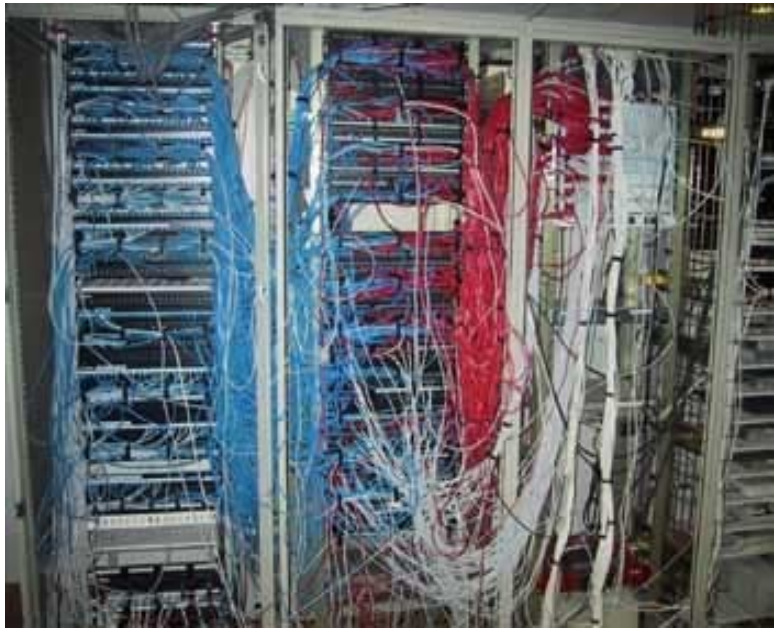
Computer Network

- Purpose: Transmit information/data from a sender to a receiver
  - Using multiple entities, equipment and services.
  - Constrained by the sender/receiver requirements
    - QoS, Security, ...

Different Implementations

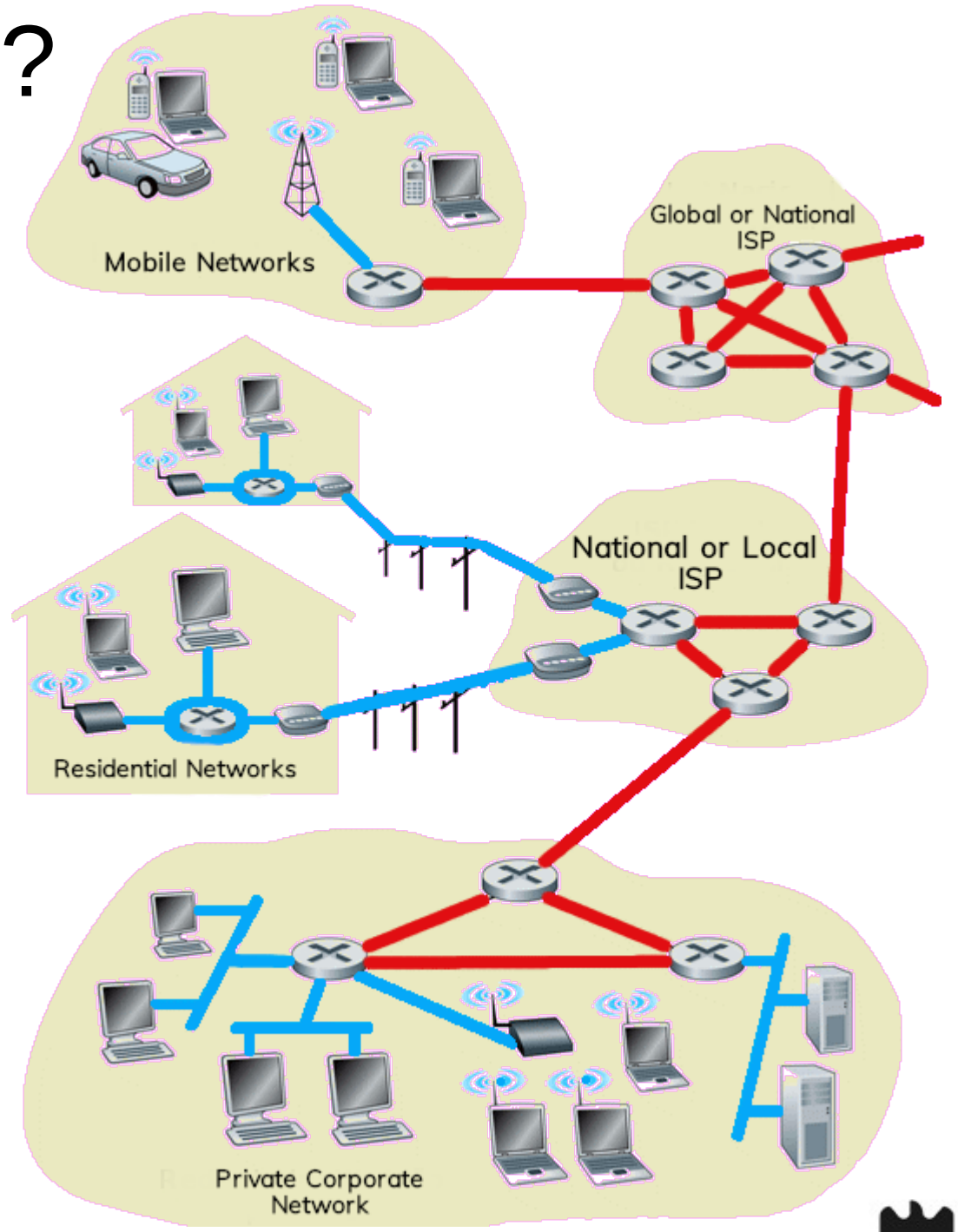


vs

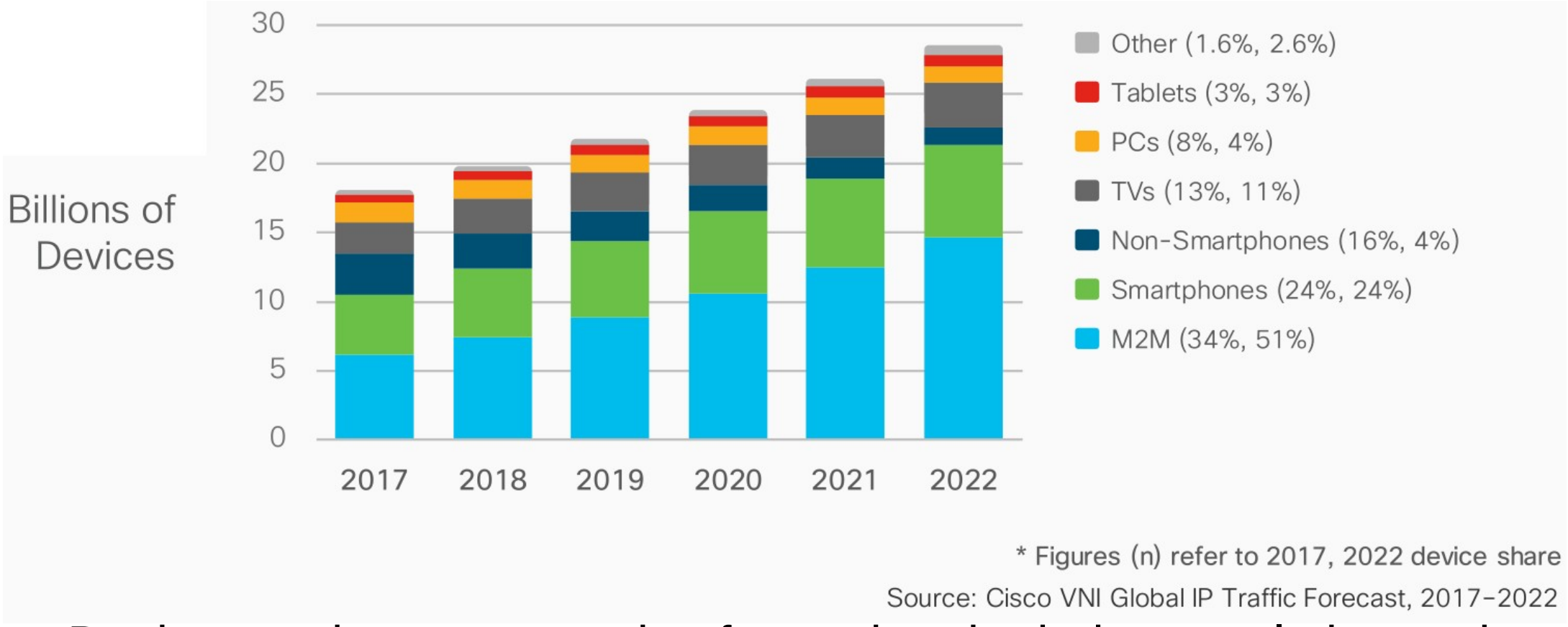


What's the Internet?

- Millions of interconnected devices: hosts or terminal
  - PCs, servers, phones, tablets, TVs, ...
  - Execute distributed actions.
- Physical connections
  - Optical fiber (light), copper (electrons), antennas/satellite (radio), ...
- Routers: devices that interconnect different networks.
- Protocols that control/define data exchange
  - e.g., TCP, IP, HTTP, FTP, PPP
- Internet: "*network of networks*"
  - Hierarchical (approximately)
  - Public vs. Private Internet
  - Internet neutrality (never existed!)
- Internet Standards
  - RFC: Request for comments
  - IETF: Internet Engineering Task Force

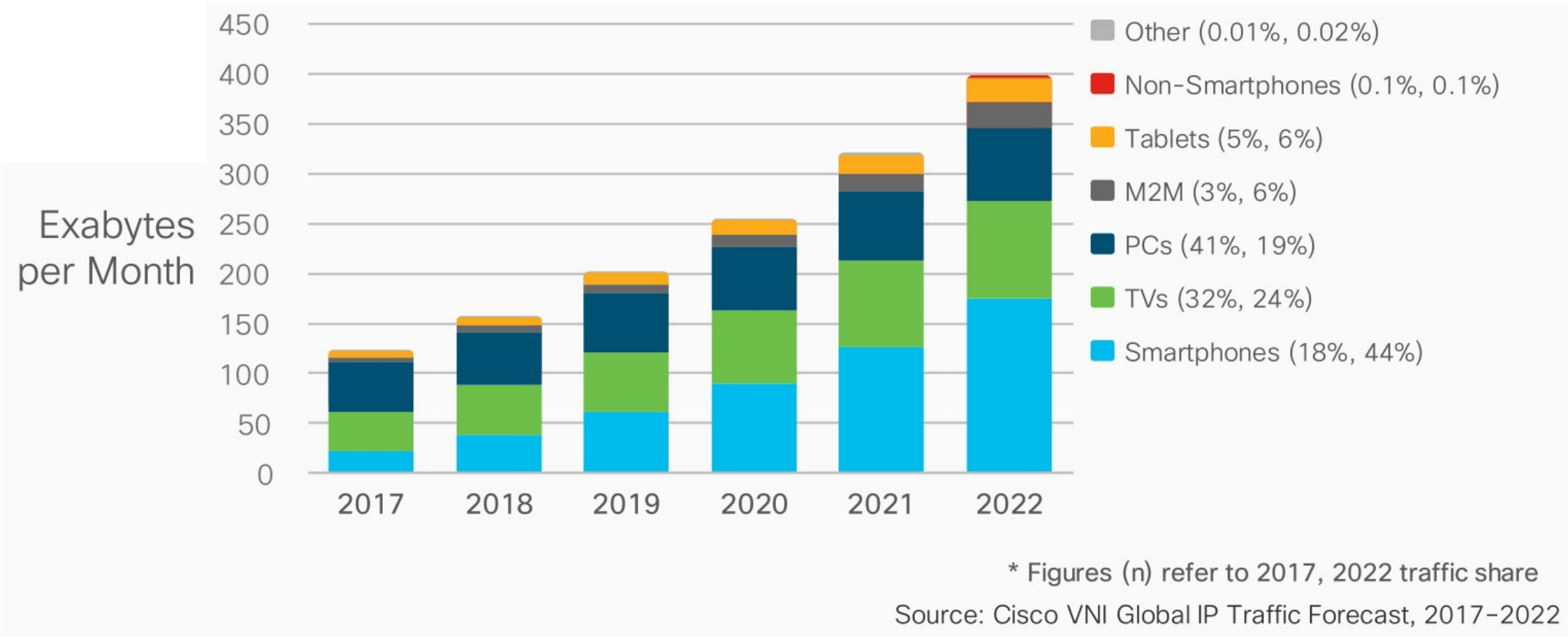


Global Devices Growth



- Device numbers are growing faster than both the population and Internet users.
- By 2022, M2M connections will be 51 percent of the total devices and connections.
  - Smart meters, video surveillance, healthcare monitoring, transportation, and package or asset tracking.

Global IP Traffic by Devices

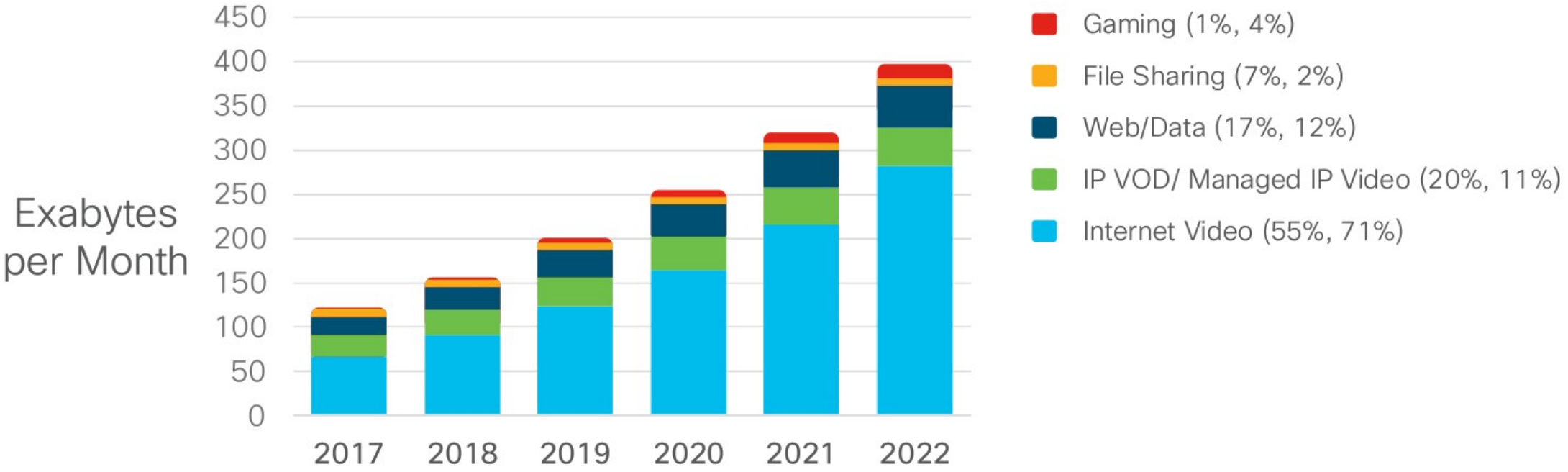


* Figures (n) refer to 2017, 2022 traffic share

Source: Cisco VNI Global IP Traffic Forecast, 2017–2022

- At the end of 2017, 59 percent of IP traffic originated from non-PC devices.
- By 2022, 81 percent of IP traffic will originate from non-PC devices.

IP Traffic by Application

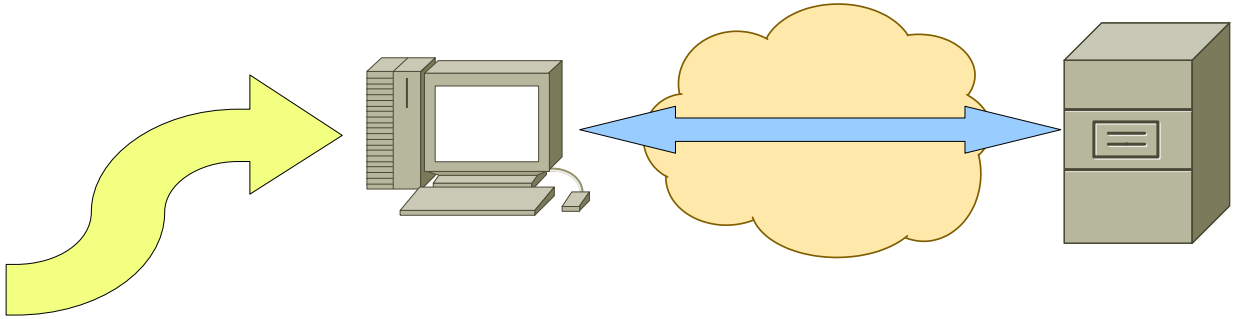


* Figures (n) refer to 2017, 2022 traffic share

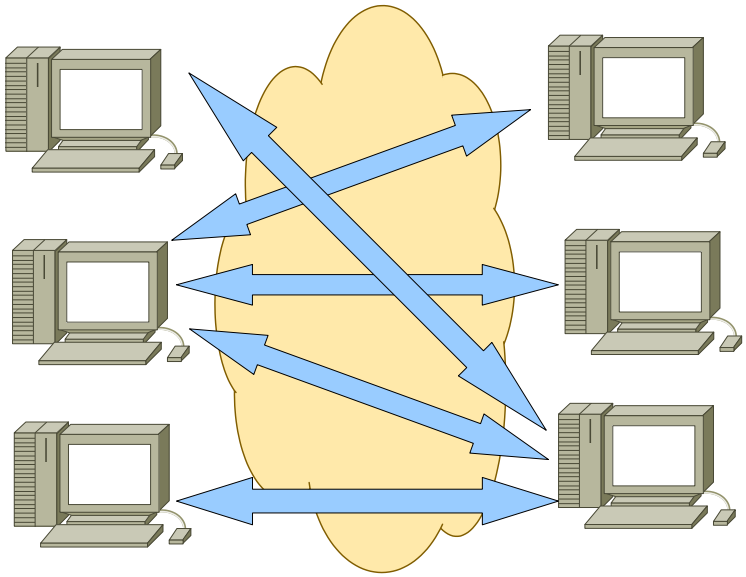
Source: Cisco VNI Global IP Traffic Forecast, 2017–2022

Internet Periphery

- Terminals (Hosts)
  - Run applications.
- Client/Server Model
  - Host requests data from an always on server.
  - E.g., browser/Web server; Email client/server.

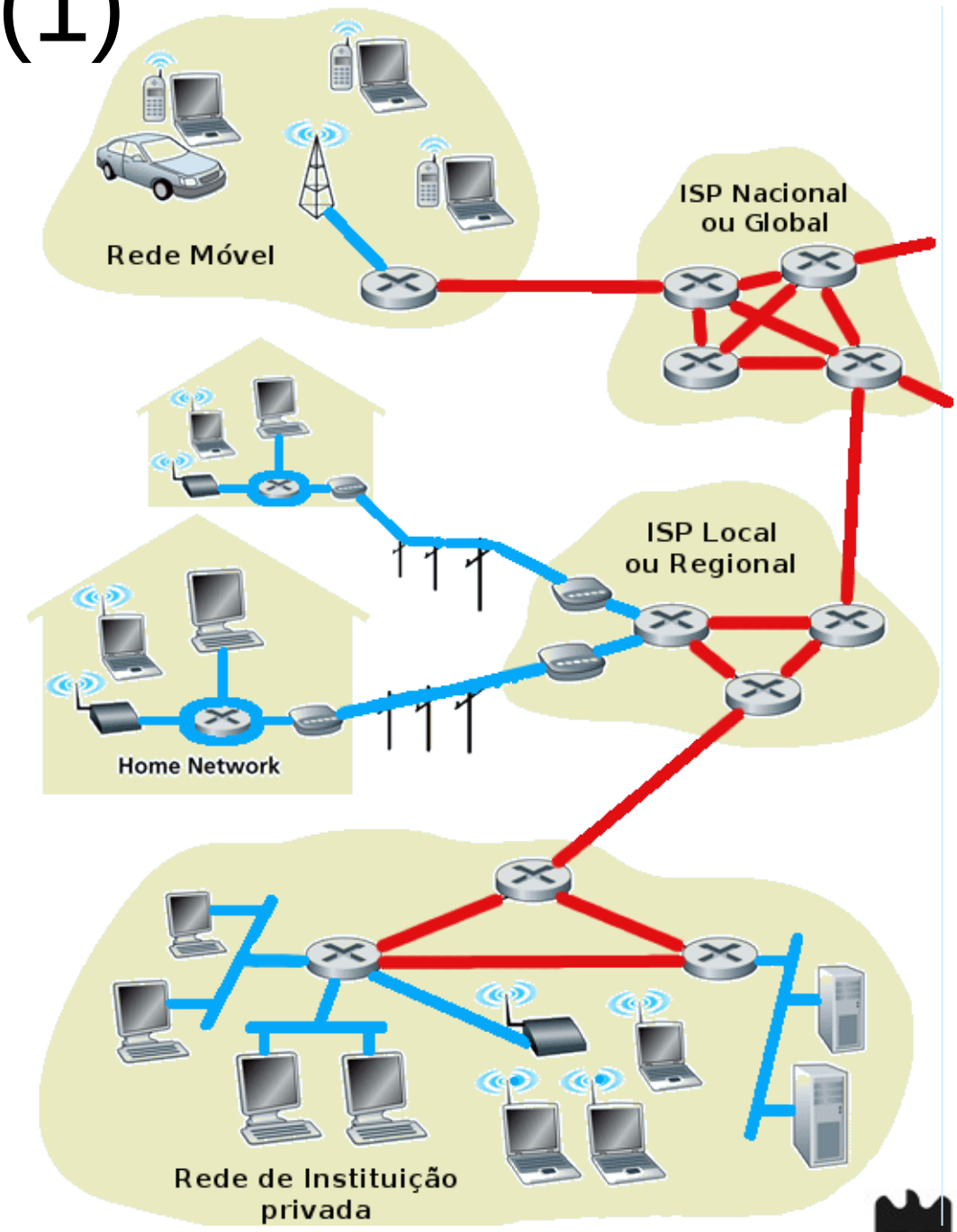


- Peer-to-Peer (P2P) Model
  - Minimal (or none) server utilization.
  - Hosts act as client and server.
  - E.g., eMule, BitTorrent.



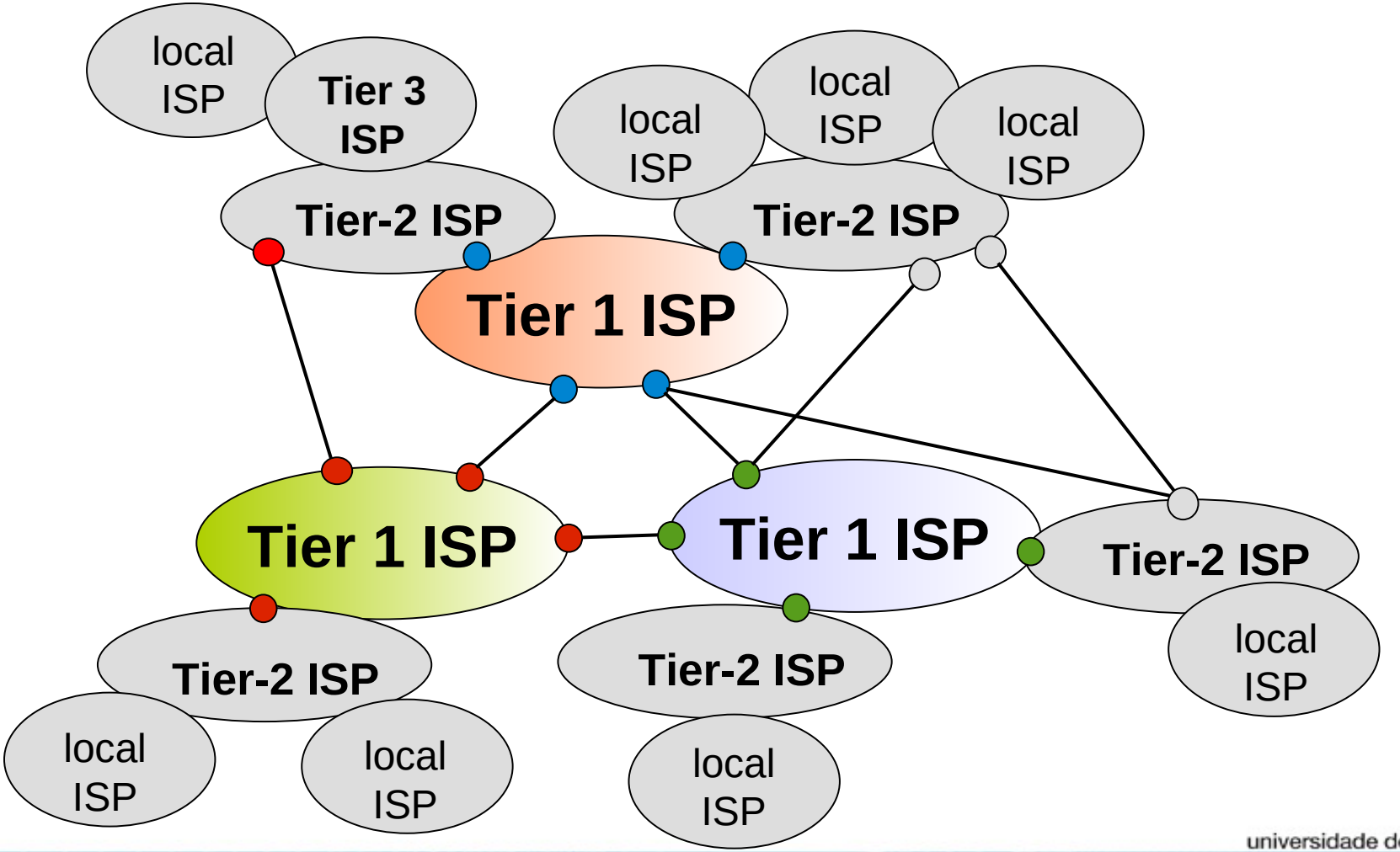
Internet Infrastructure (1)

- **Access Networks**
  - Interconnects hosts to the boundary of Internet.
  - May incorporate more than one technology.
    - e.g., Wireless+Ethernet+FFTB.
- **Core Network(s)**
  - Routers interconnect multiple access networks.
  - Multiple interconnected core networks are the Internet.



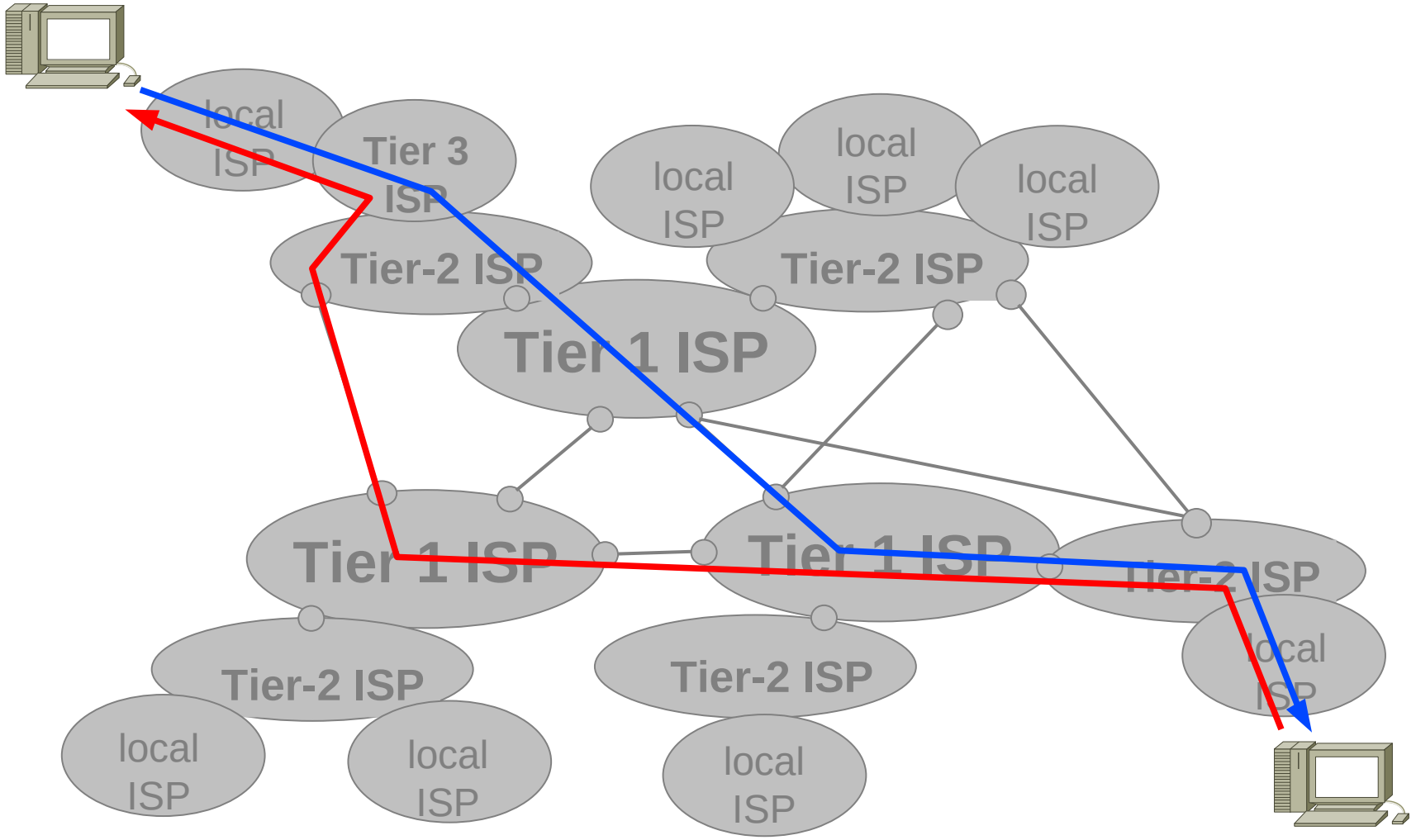
Internet Infrastructure (2)

- Hierarchical (approximately)
- Tier 1 ISP (Global ISPs, e.g Sprint e AT&T), Tier 2 ISP (smaller,nation or region wide), Tier 3 ISP and Local ISP (provide local accesses)



Internet Infrastructure (3)

- Data transverses multiple ISP.
- Paths may not be symmetric (usually are not).

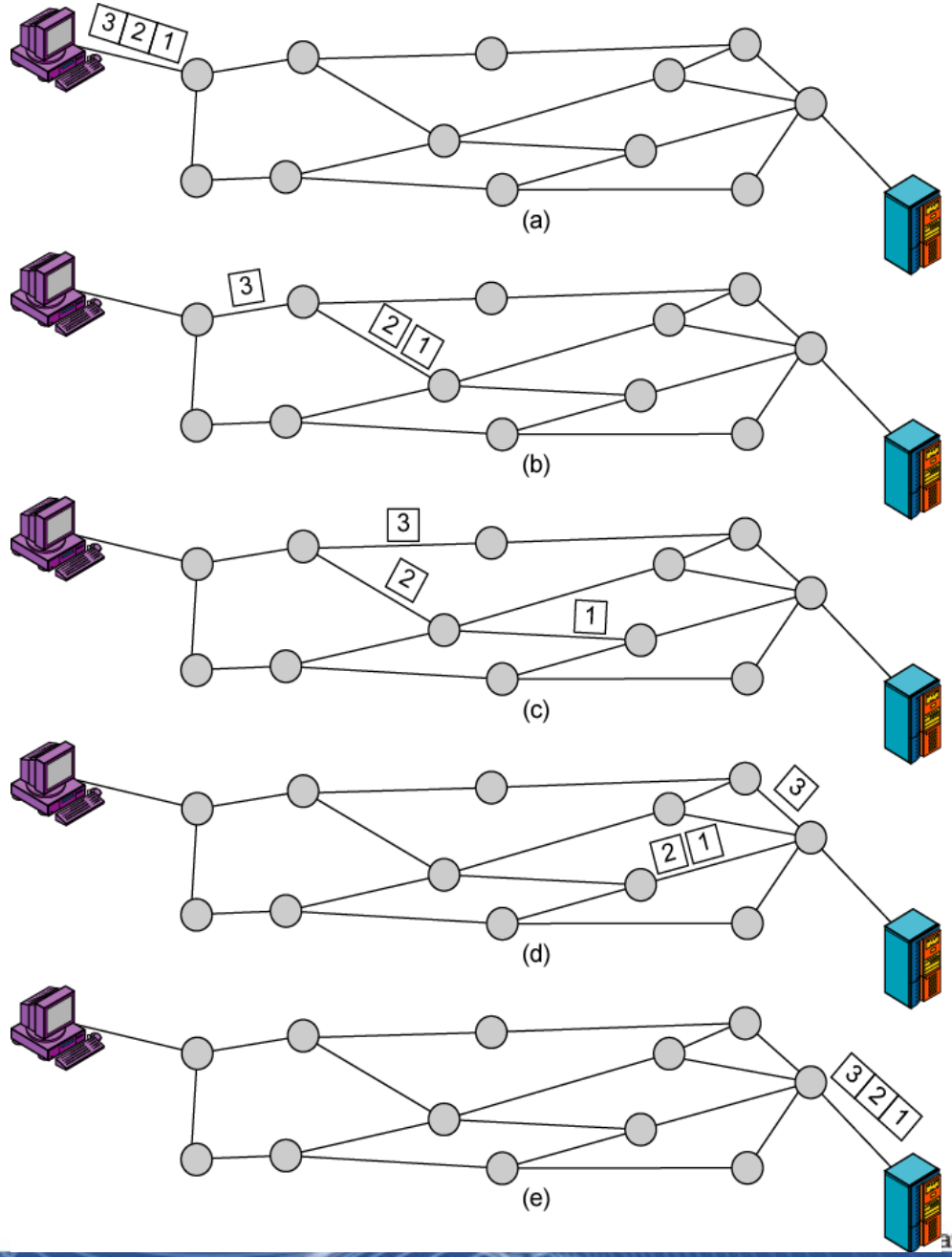


Core Networks

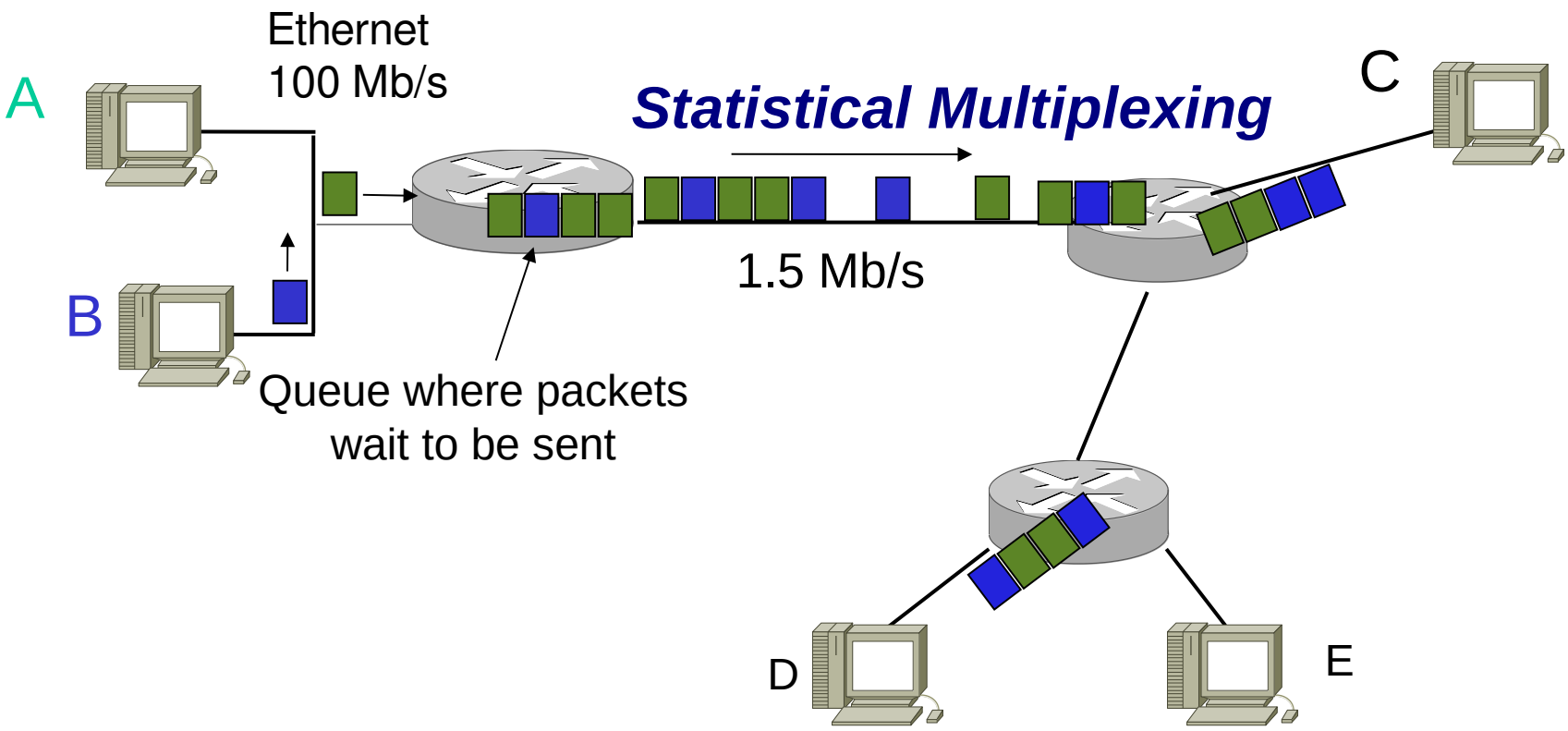
- Datagram Networks
  - Networks that provide only a connection-less service.
  - Packets reach their intended destination in a different order in which they were sent.
  - There if no reservation of resources as there is no dedicated path for a connection session.
  - No easy way to guarantee QoS per client.
- Virtual Circuits Networks
  - Networks that provide only a connection service at the network layer.
  - Packets always reach their intended destination in the same order in which they were sent.
  - There is a reservation of resources like buffers, CPU, bandwidth, etc for the time in which the VC is going to be used by a data transfer session.
  - Evolved from the Phone call concept.
  - Is being revived with the advent of virtualization of network functions and services.
  - Allows to implement per-client QoS.
  - Nowadays operate (virtually) over Datagram networks.

Routing in Datagram Networks

- Each packet is handled independently.
- Packets may take any route.
- Packets may arrive out of order.
- Packets may be lost.
- The receiver has the responsibility to order the packets.
- In some applications, the receiver has the responsibility to recover any lost packet.

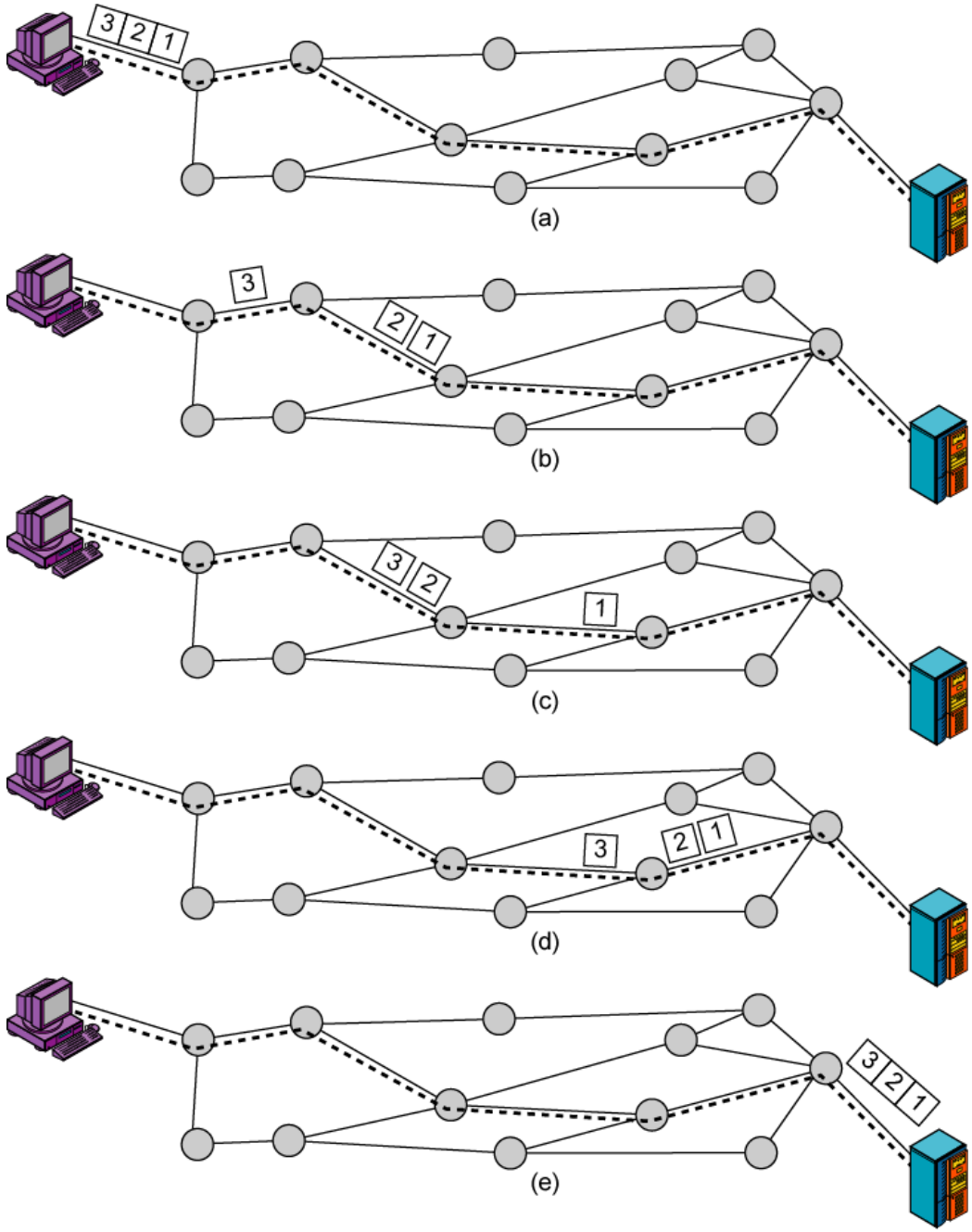


Datagram Networks: Statistical Multiplexing



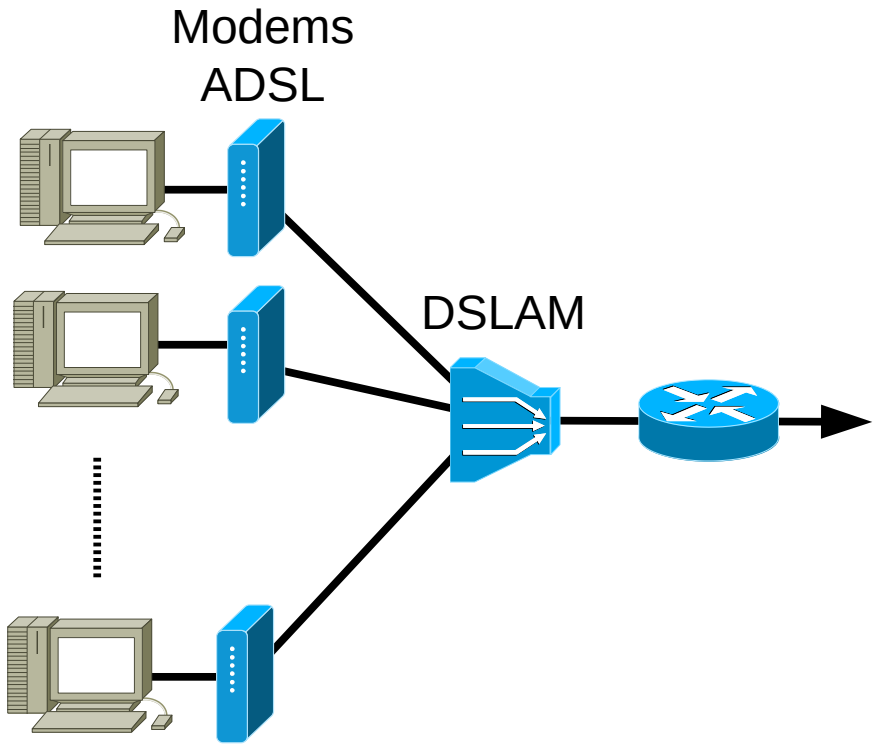
The sequence of packets (A or B) does not have a fixed statistical multiplexing pattern

Routing in Virtual Circuits Networks



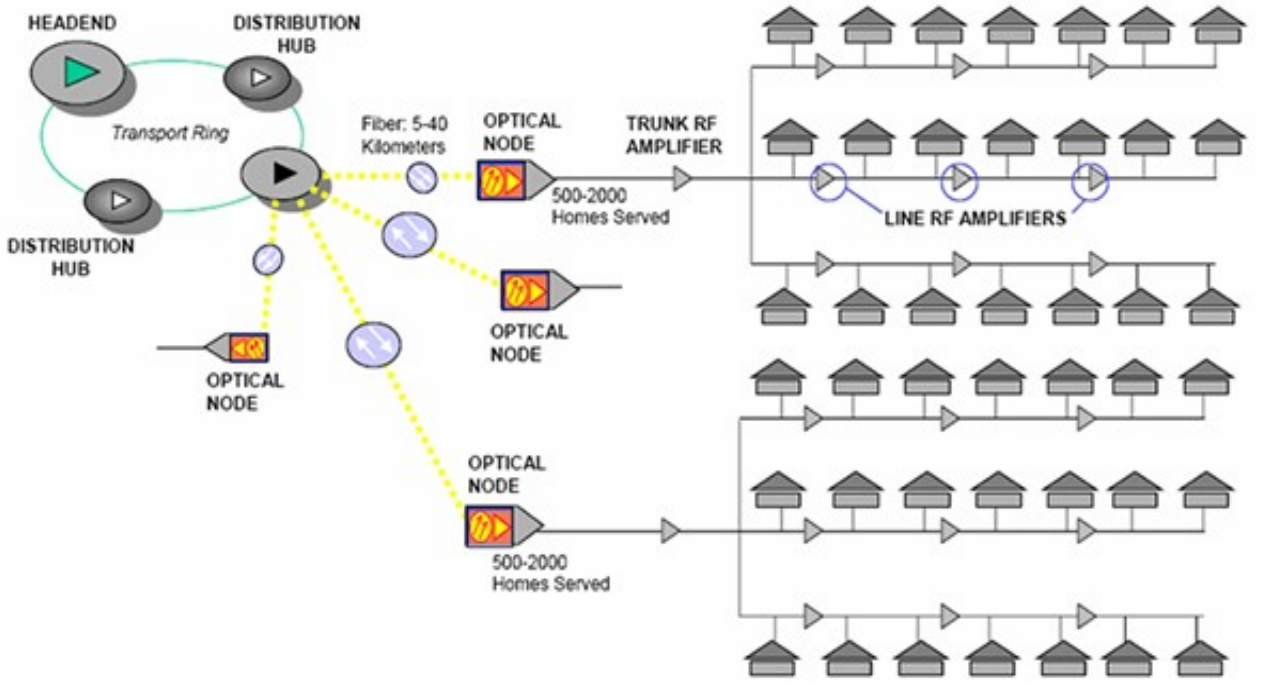
Residential Access Networks: Point-to-Point

- PSTN Modem
  - Até 56Kb/s de acesso directo ao router
  - Não era possível telefonar e aceder à Internet ao mesmo tempo
- ADSL: asymmetric digital subscriber line
  - Até 8Mbps downstream/1Mbps upstream
  - FDM:
    - 50 kHz - 1 MHz para downstream
    - 4 kHz - 50 kHz para upstream
    - 0 kHz - 4 kHz para telefone tradicional
- ADSL2: 12Mbps/1Mbps
- ADSL2+: 24Mbps/1Mbps
- VDSL: 55Mbps/15Mbps
- VDSL2 (long range): 55Mbps/30Mbps
- VDSL2 (short range): 100Mbps/100Mbps

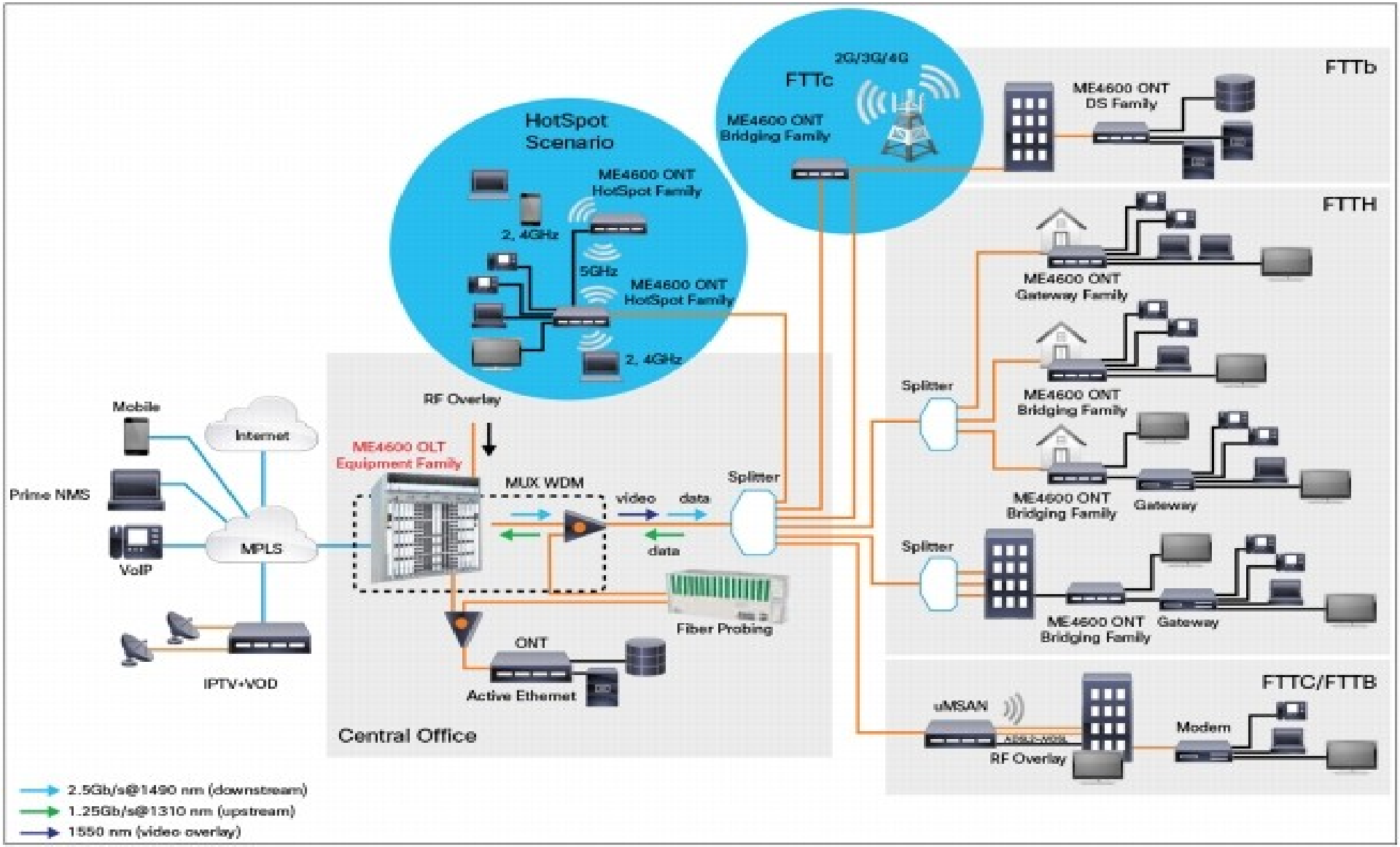


Residential Access Networks: CATV Network

- Rede de cabo e fibra liga habitações ao router do ISP
- HFC: Hybrid Fiber Coax
  - Assimétrico: até 10Mbps/1 Mbps
- DOCSIS: Data Over Cable Service Interface Specification
  - Versão 2 - assimétrico: até 50Mbps/27Mbps
  - Versão 3 (4 canais) - assimétrico: até 200Mbps/108Mbps



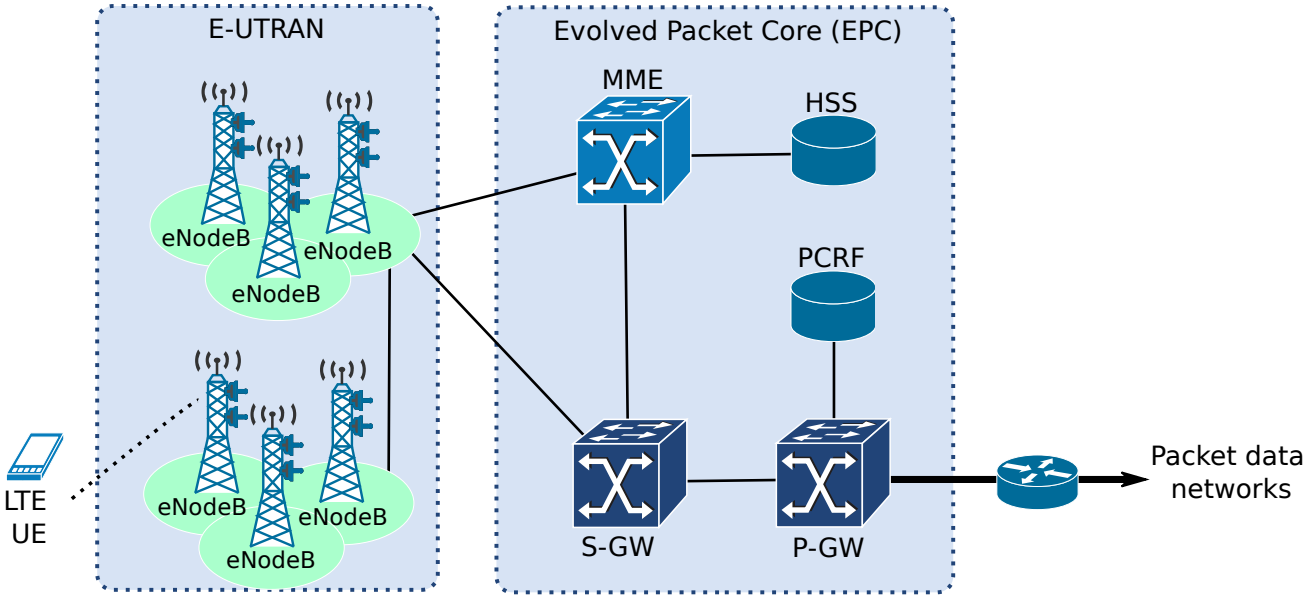
Residential and Corporate Access Networks: Fiber to the X (FTTx)



X=Terminal, Home, Building, Closet/Curb, ...

Mobile Access Network

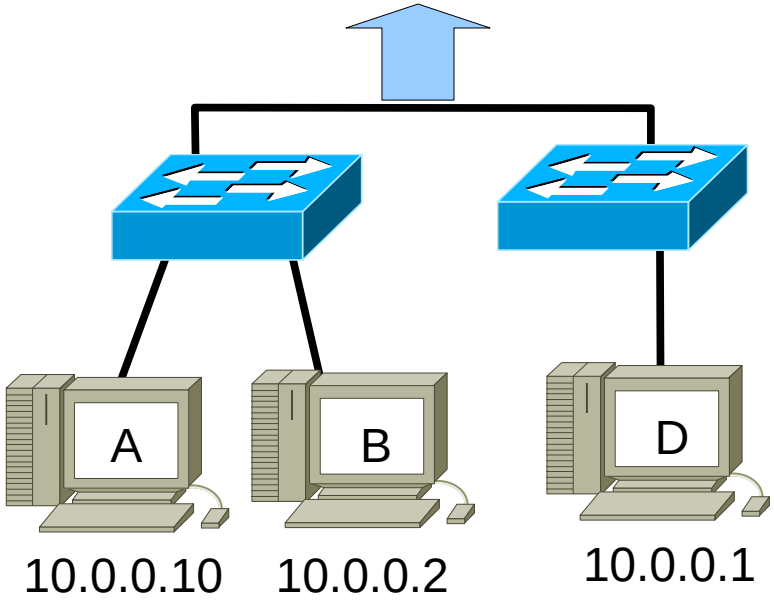
- Provided by an ISP.
- Technologies:
  - LTE Advanced: até 1Gbps/500Mbps
  - LTE: até 100Mbps/50Mbps
  - WiMax: até 128Mbps/56Mbps
  - 3G HSPA+: até 42Mbps/11Mbps
  - 3G HSUPA: upload até 5.7Mbps
  - 3G HSDPA: download até 14.4Mbps
  - 3G UMTS: até 384kbps/384kbps
  - WAP/GPRS na Europa: até 114kbps



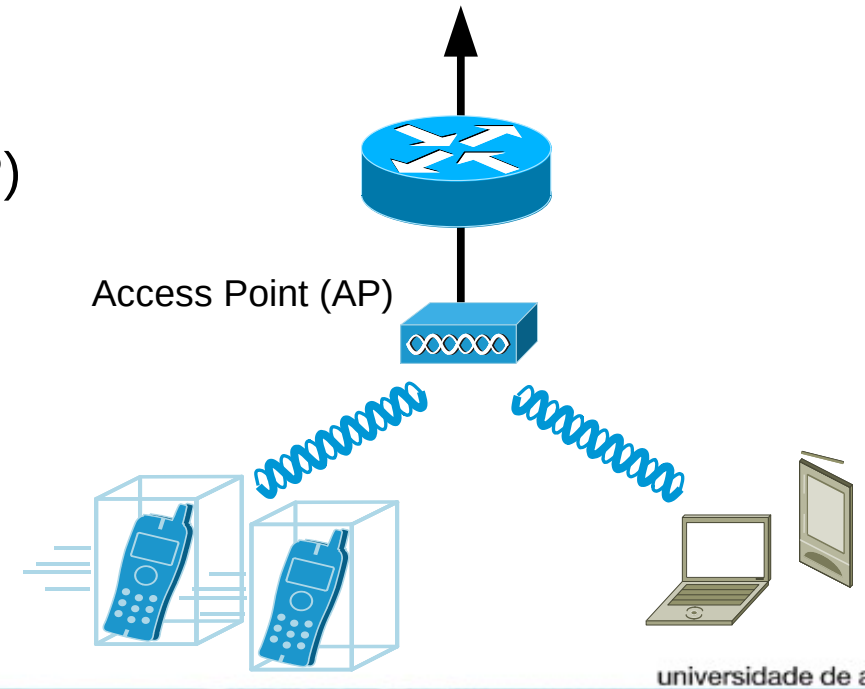
S-GW - Serving Gateway
P-GW - Packet data network Gateway
MME - Mobility Management Entity
HSS - Home Subscriber Server
PCRF - Policy and Charging Rules Function

Local Area Network (LAN)

- Commonly implemented using:
  - Ethernet
    - Cabled technology.
    - Hosts interconnected using switches.



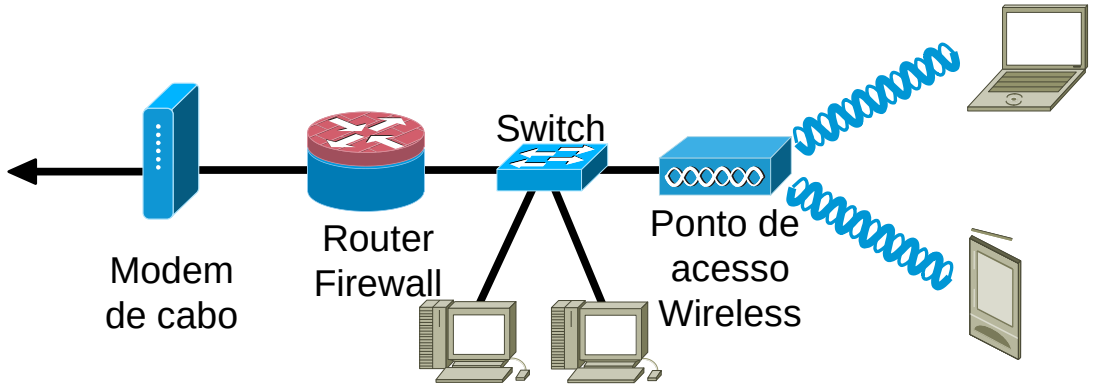
  - Wi-Fi (802.11)
    - Wireless technology
    - Hosts connect to Acces Points (AP)
    - Versions:
      - 802.11b (WiFi 1): 11 Mbps
      - 802.111 (WiFi 2): 11 Mbps
      - 802.11g (Wi-Fi 3): 54 Mbps
      - 802.11n (Wi-Fi 4): ~300 Mbps
      - 802.11ac (Wi-Fi 5): ~1Gbps
      - 802.11ax (Wi-Fi 6): > 1Gbps



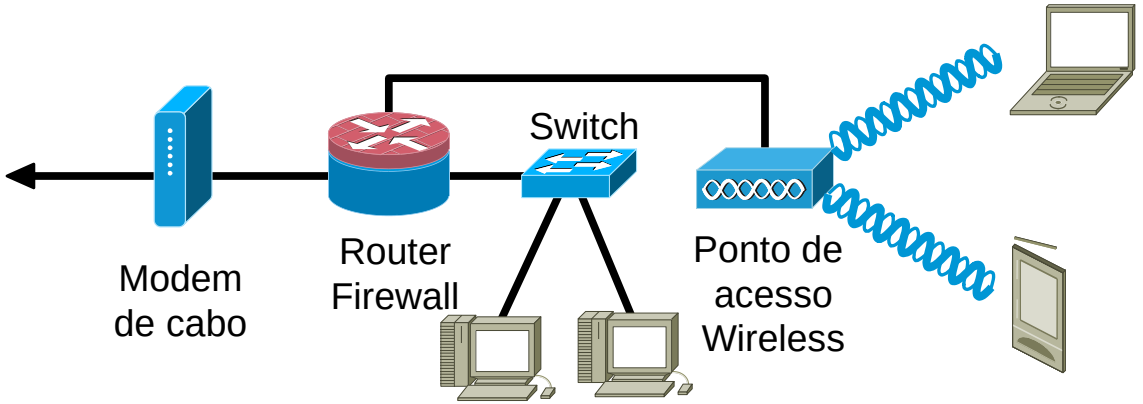
universidade de aveiro

Residential Access Networks: Home LAN

- Modem
  - Fibre, 4G/5G Mobile netwok, CATV, ADSL, ...
- Router/firewall/NAT
- (Switched) Ethernet
- Wireless network (Wi-Fi)
  - Wireless access point.

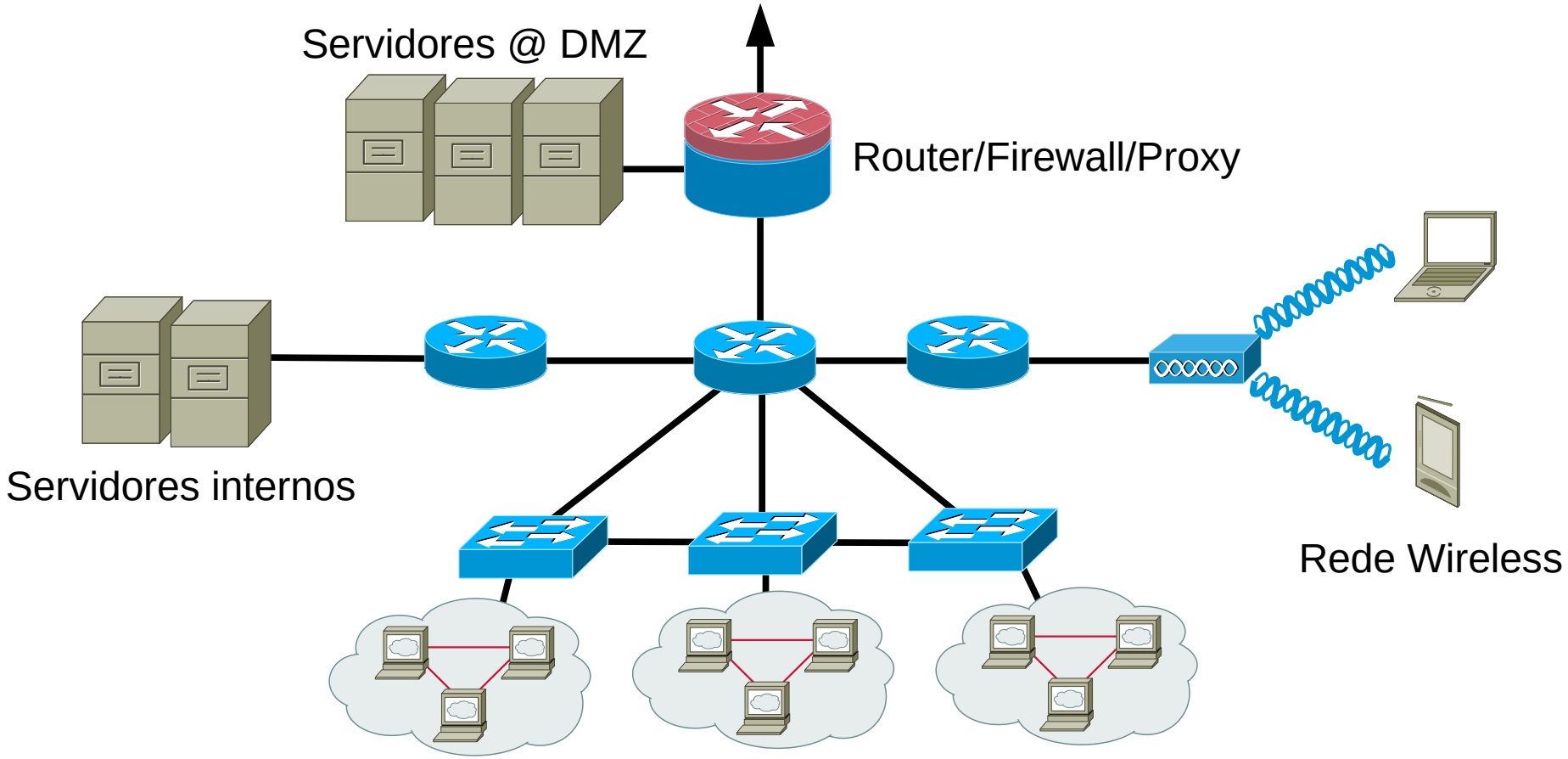


Ethernet (cabled) and Wireless networks on the same IP network



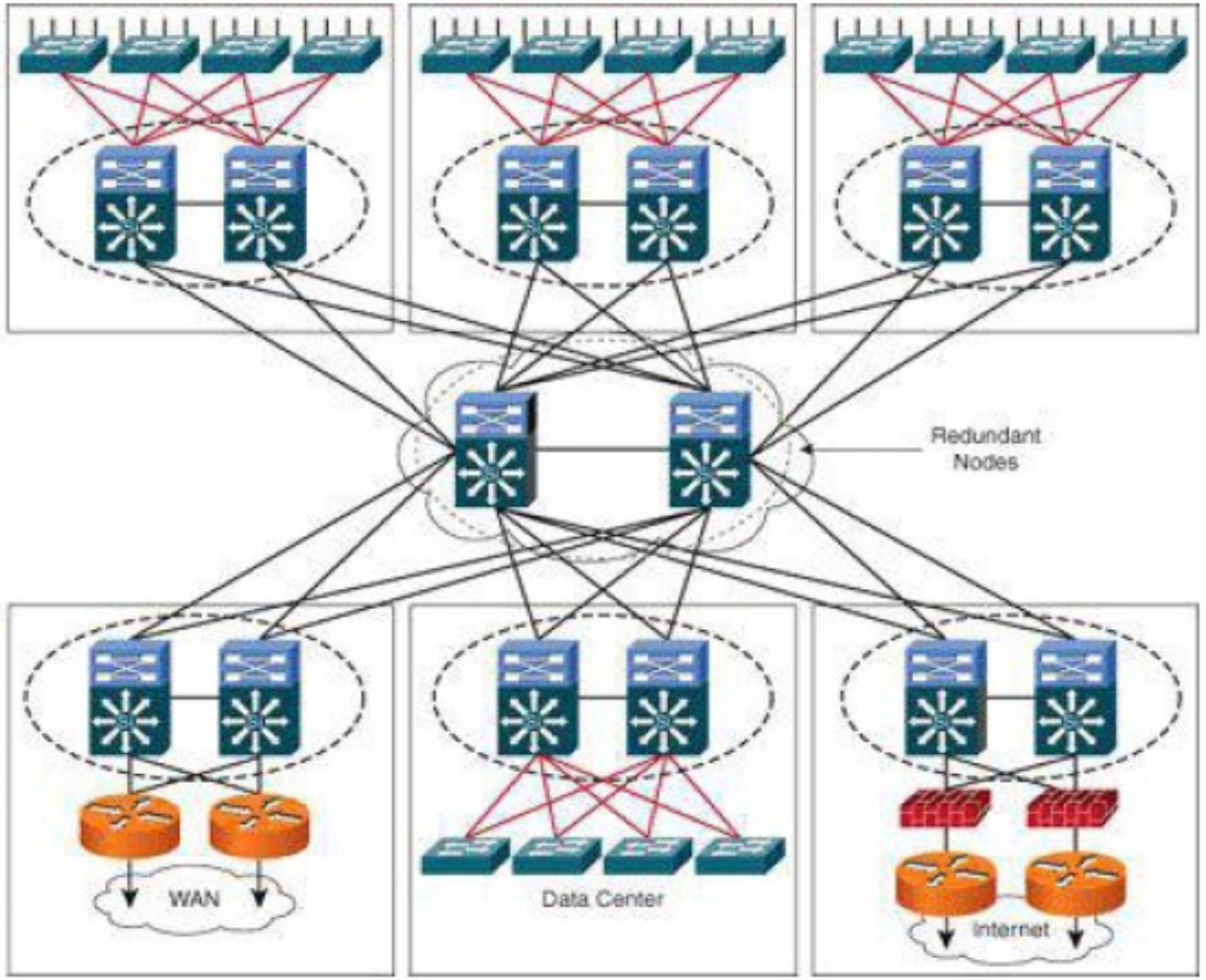
Ethernet (cabled) and Wireless networks on different IP networks

Corporate Access Networks: Small LAN



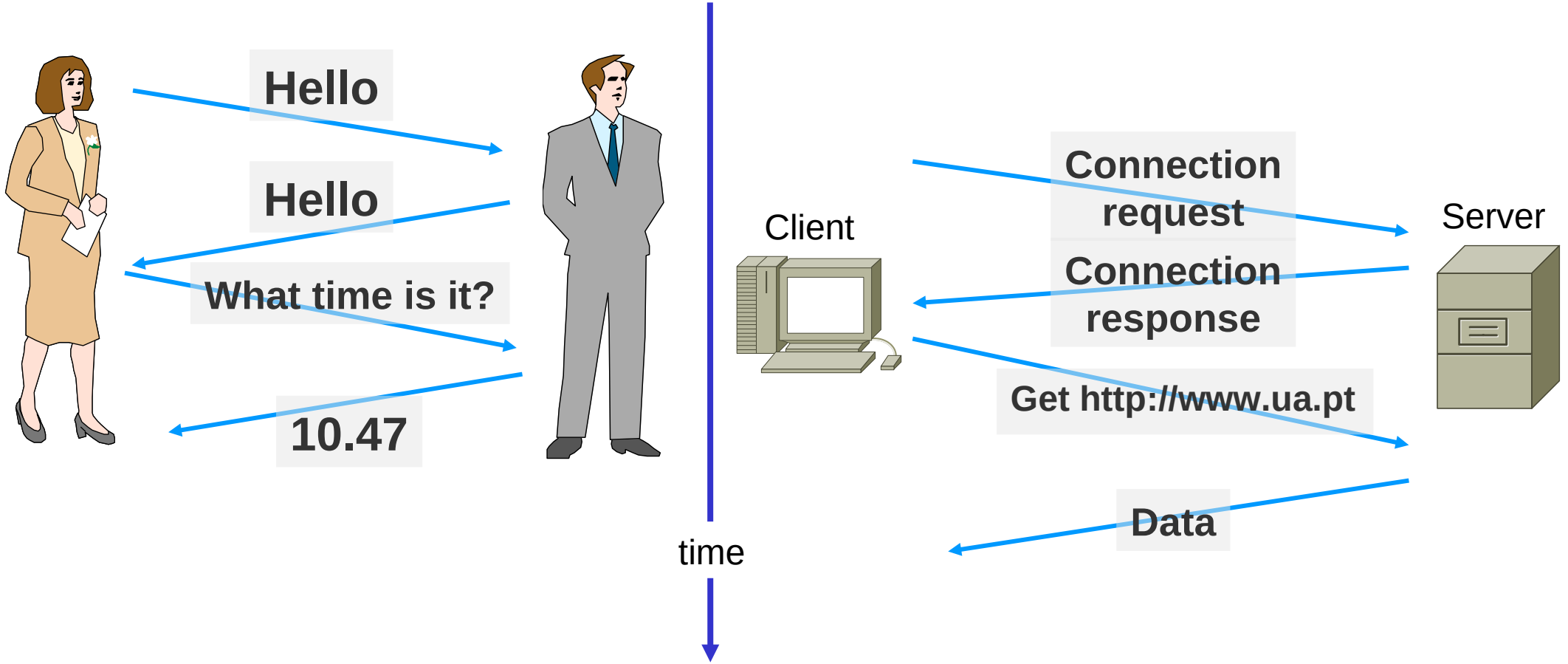
Corporate Access Networks: Medium/Large LAN

- Hierarchical architecture



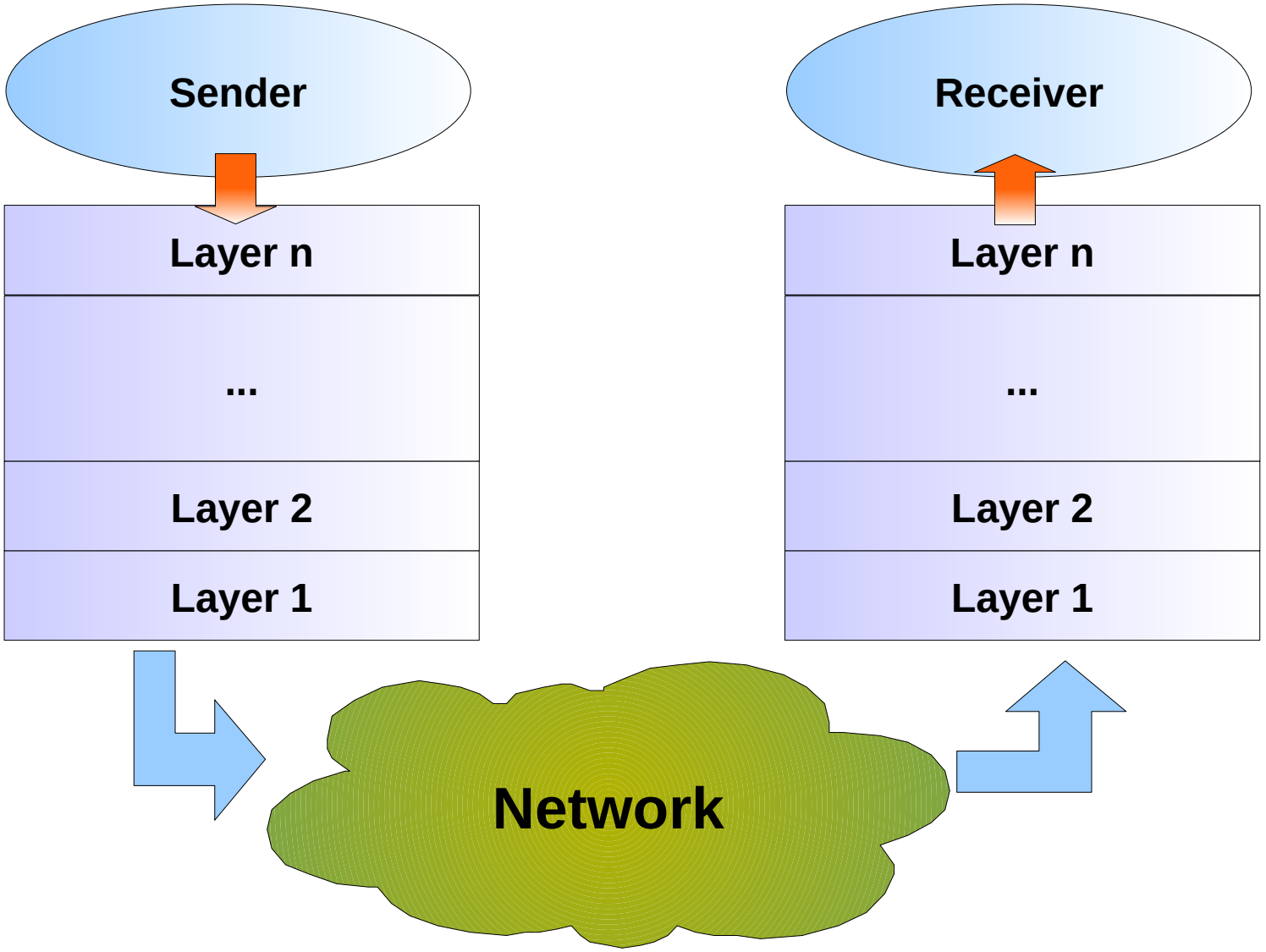
What's a Protocol?

- Human protocol vs. Network protocol

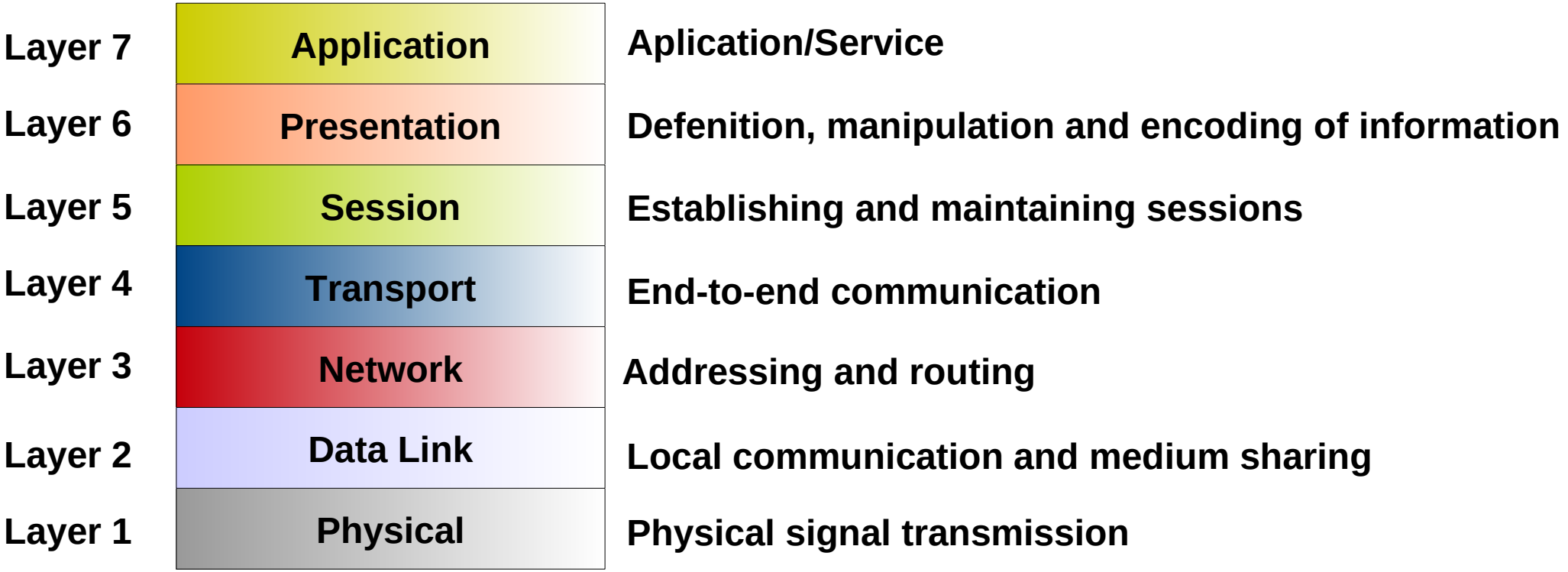


- Network protocols define:
  - Format and order of the messages,
  - Actions to execute on sending, receiving and relaying messages.

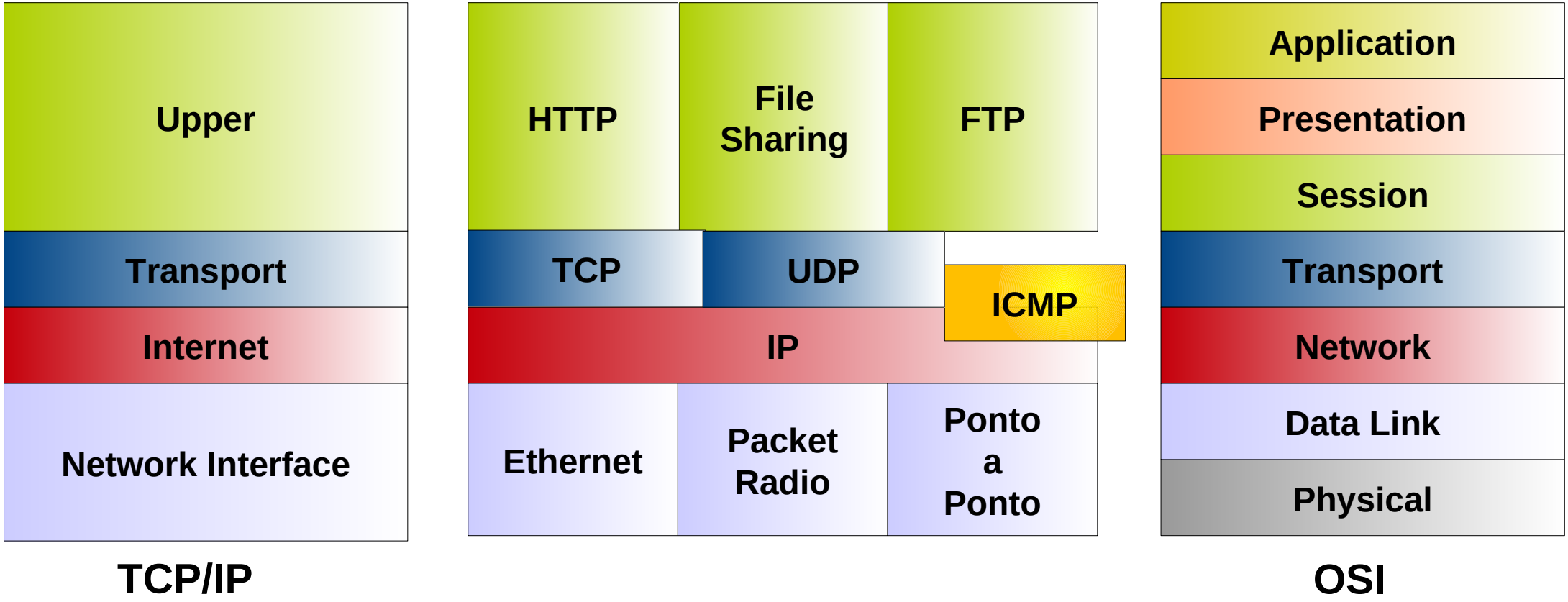
Functionalities are Organized in Layers



Modelo OSI
(Open Systems Interconnection)

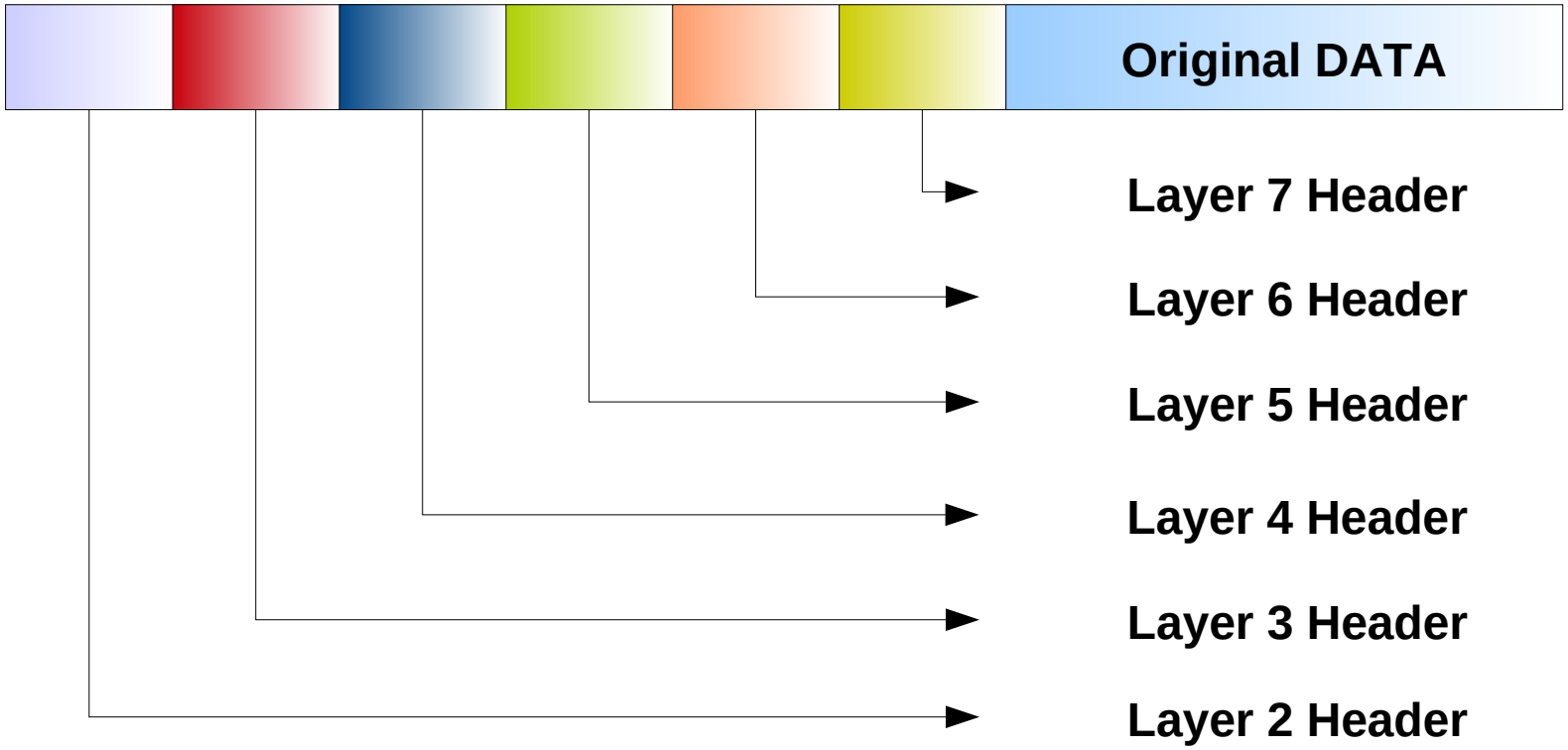


TCP/IP Reference Model

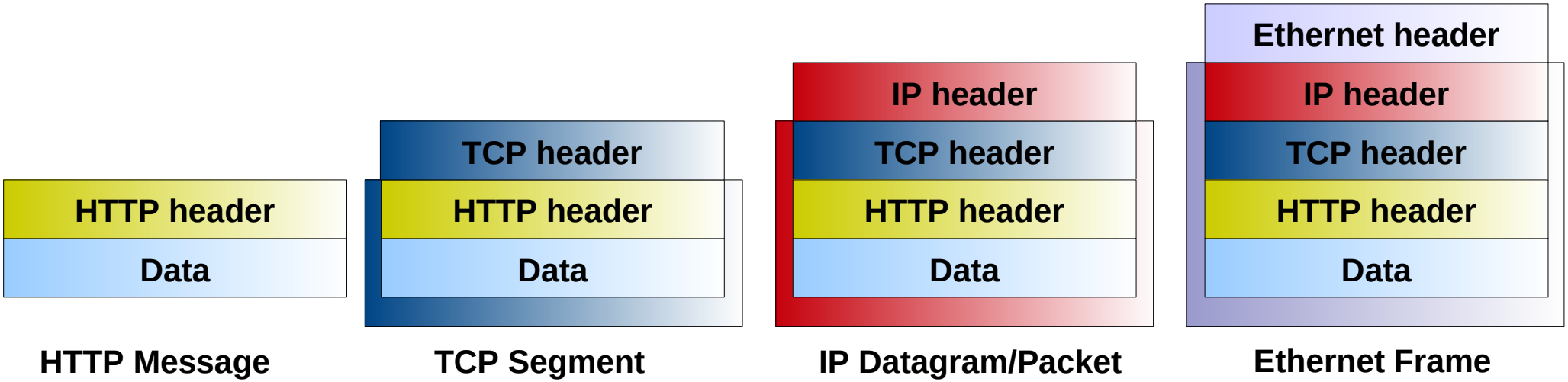


Header Concatenation

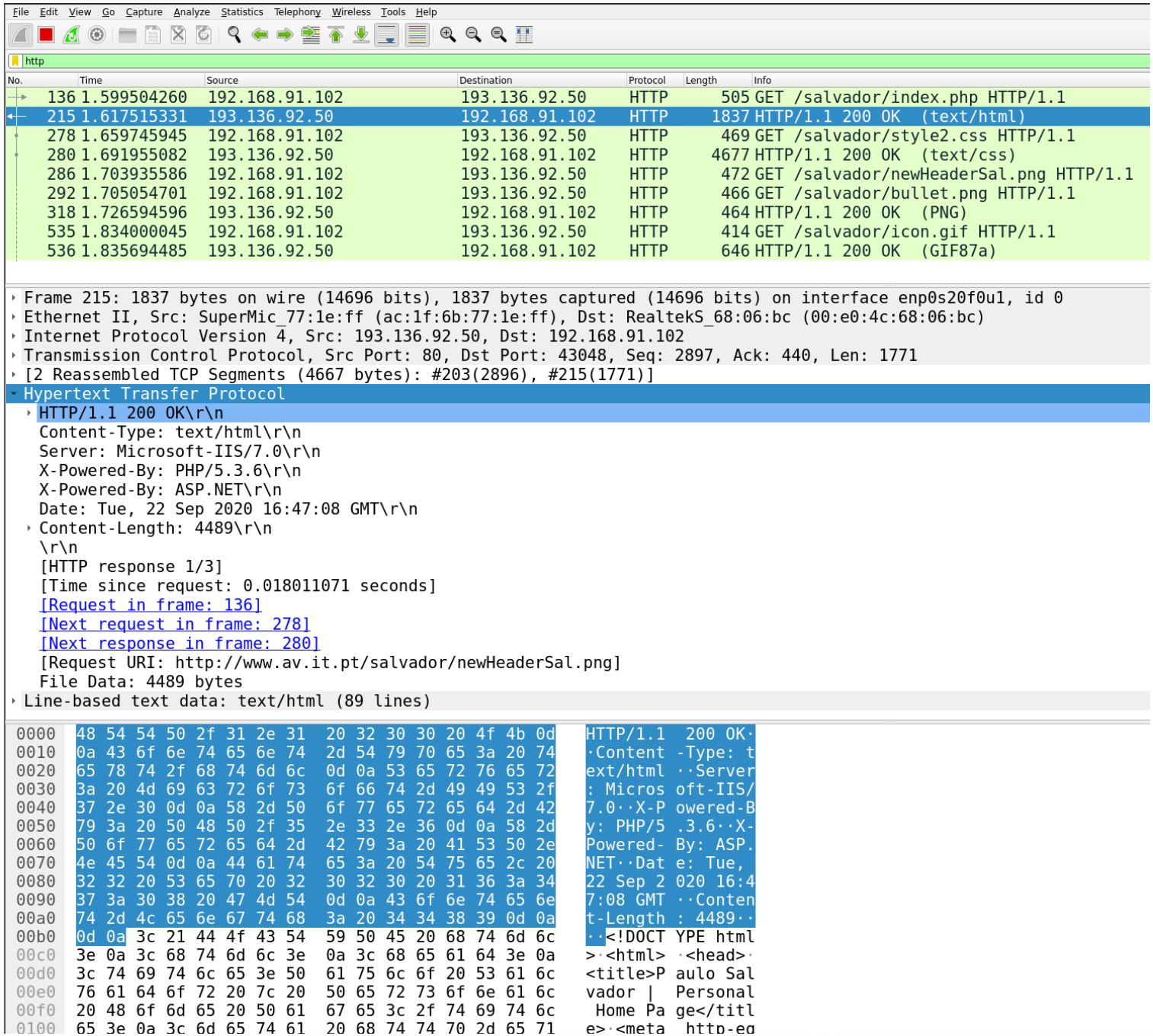
- Packets that travel through a network may have multiple concatenated headers
  - May be from protocols from all OSI layers.
  - May have more than one header from the same OSI layer.



Example
HTTP (HyperText Transfer Protocol)

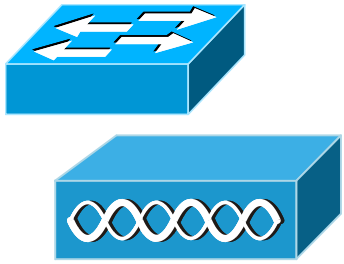


HTTP Example with Wireshark

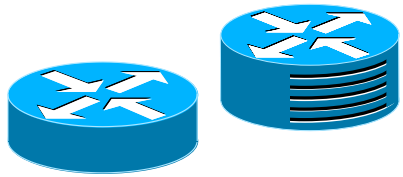


Equipment Types

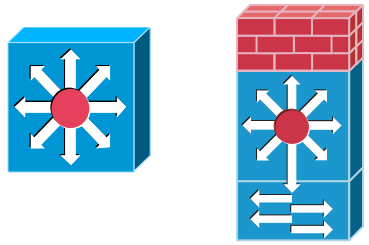
- **Switch**
  - OSI Layer 2 inter-connection,
  - Implements VLAN,
  - Forwarding based on Spanning-tree,
    - STP, RSTP, MSTP
  - Wireless access points (AP).



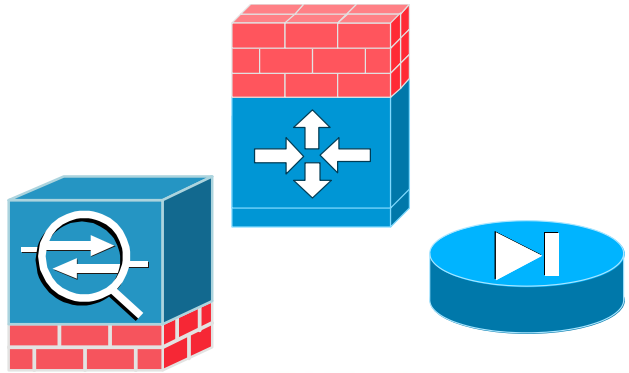
- **Router**
  - OSI Layer 3 inter-connection
  - Has extra functionalities such as: QoS, Security, VPN gateway, monitoring, etc...



- **L3 Switch**
  - Switch+Router.
  - Limited routing functionalities (lower/medium end models).
  - Full routing functionalities (high end models).
  - Many have Layer 3 dedicated hardware for switching.



- **Router with switching modules**
  - Full Layer 3 functionalities
  - Limited Layer 2 functionalities.
- **Security Appliance**
  - Firewall
  - IDS/IPS (Intrusion Detection/Prevention System)
  - NAT/PAT
  - VPN Gateway



Introduction to Network Addresses

- Physical (MAC) in Ethernet and Wi-Fi
  - MAC (Physical, Ethernet or LAN) Address:
  - Function: Allow the exchange of data between network interfaces connected using a Layer 2 network.
  - Have 6 bytes/48 bits.
  - Are unique.
  - Each network card has its own address.
  - Defined by manufacturer
    - Some hardware allows change.
    - First 24-, 28-, or 36-bits assign to manufacturer.

  Hexadecimal notation

  Broadcast: FF-FF-FF-FF-FF-FF

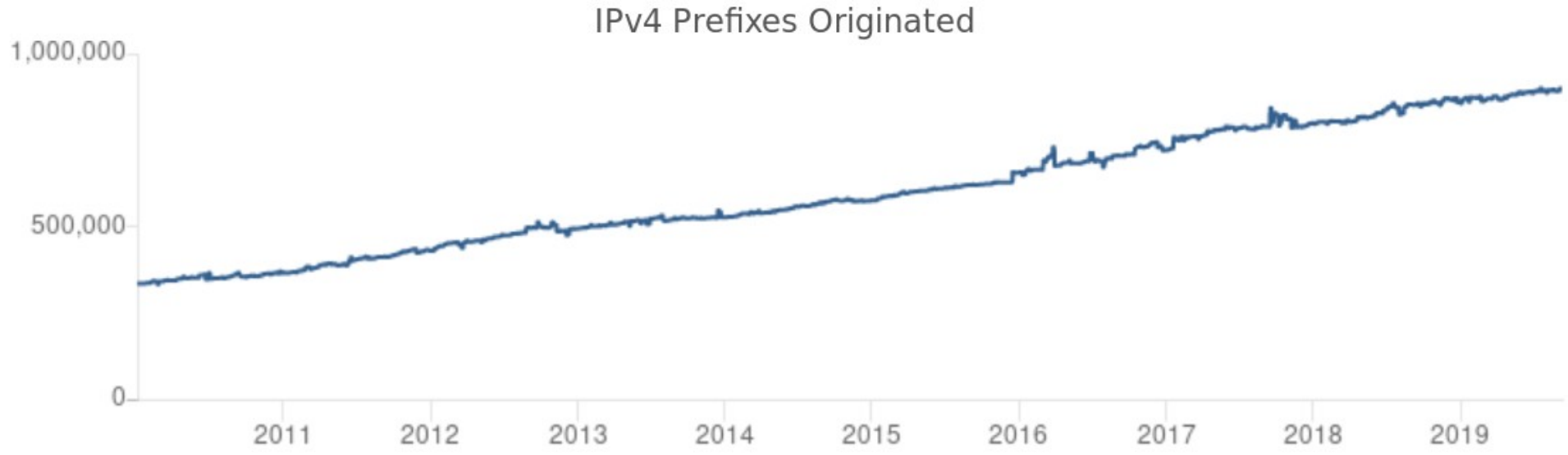
- IPv4
  - 4 bytes = 32 bits
  - 4 decimal numbers separated by dots (.)
    - e.g.: 10.0.0.1, 192.156.1.4, 253.1.3.7
    - 1 byte: 0 to 255
- IPv6
  - 16 bytes = 128 bits
  - 8 groups of 4 hexadecimal digits separated by colons (:)
    - Can be simplified, by merging sequential zeros!
    - e.g.: 2001:ABCD:1346:0011:ABFE:3478:A4B5:CC10
    - 2 hexadecimal digits represent a byte: 00 to FF

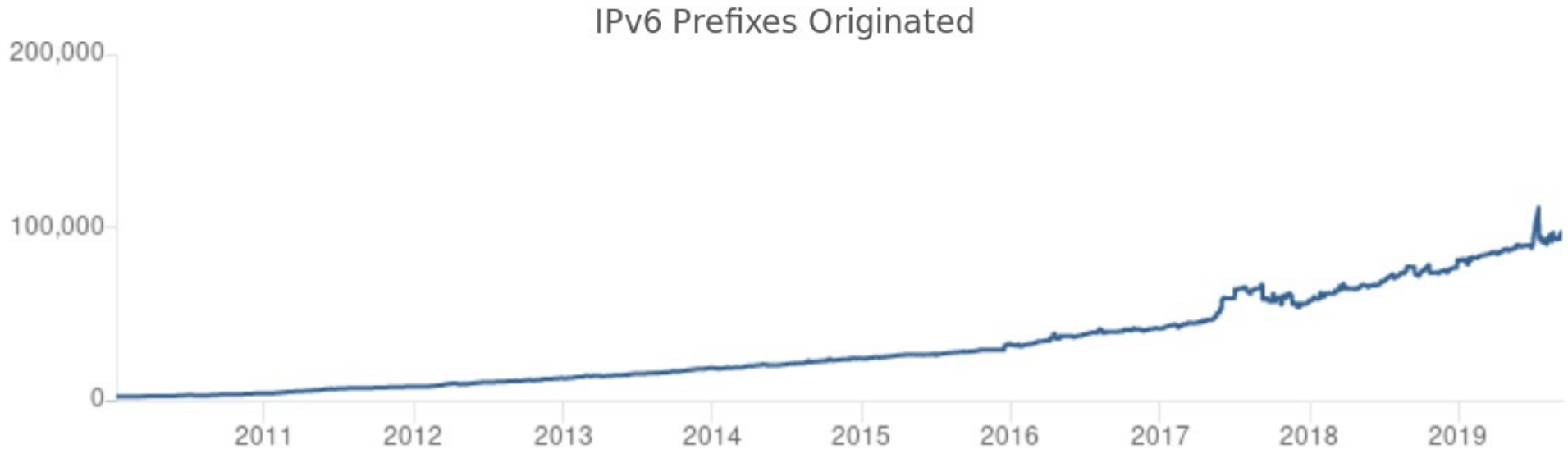
```
Ethernet adapter Ethernet:

   Connection-specific DNS Suffix  . :
   Description . . . . . . . . . . . : Intel(R) PRO/1000 MT Desktop Adapter
   Physical Address. . . . . . . . . : 08-00-27-F7-59-07
   DHCP Enabled. . . . . . . . . . . : Yes
   Autoconfiguration Enabled . . . . : Yes
   Link-local IPv6 Address . . . . . : fe80::c84:e2a0:88ad:a538%10(Preferred)
   IPv4 Address. . . . . . . . . . . : 10.0.2.15(Preferred)
   Subnet Mask . . . . . . . . . . . : 255.255.255.0
   Lease Obtained. . . . . . . . . . : Tuesday, September 15, 2020 2:56:00 PM
   Lease Expires . . . . . . . . . . : Wednesday, September 23, 2020 4:28:24 PM
   Default Gateway . . . . . . . . . : 10.0.2.2
   DHCP Server . . . . . . . . . . . : 10.0.2.2
   DHCPv6 IAID . . . . . . . . . . . : 34078759
   DHCPv6 Client DUID. . . . . . . . : 00-01-00-01-22-0B-6E-F8-08-00-27-F7-59-07
   DNS Servers . . . . . . . . . . . : 193.136.92.73
                                       193.136.92.74
   NetBIOS over Tcpip. . . . . . . . : Enabled
```

```
3: wlp59s0: <NO-CARRIER,BROADCAST,MULTICAST,UP> mtu 1500 qdisc noqueue state
    link/ether 6e:c2:ce:46:d1:9b brd ff:ff:ff:ff:ff:ff permaddr 9c:b6:d0:c1:c
59: enp0s20f0u1: <BROADCAST,MULTICAST,UP,LOWER_UP> mtu 1500 qdisc fq_codel st
    link/ether 00:e0:4c:68:06:bc brd ff:ff:ff:ff:ff:ff
    inet 192.168.91.102/25 brd 192.168.91.127 scope global dynamic noprefixro
       valid_lft 38824sec preferred_lft 38824sec
    inet6 fe80::6583:5450:64c3:94a3/64 scope link noprefixroute
       valid_lft forever preferred_lft forever
```

IPv4/IPv6 Prefixes

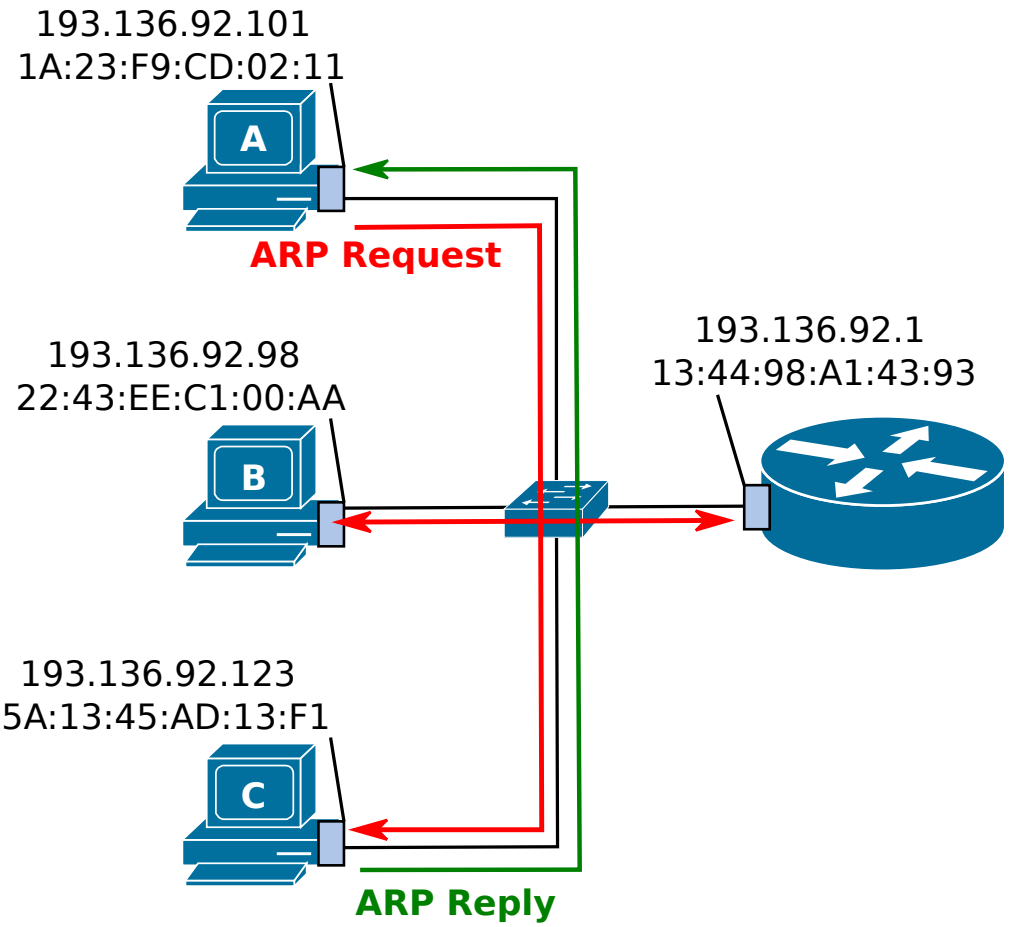




Updated 10 Sep 2019 20:45 PST © 2019 Hurricane Electric

Resolution of Physical Addresses

- IPv4: Address Resolution Protocol (ARP)
- IPv6: Neighbor Discovery (ICMPv6)
- ARP Example:
  - When “A” wants to contact “C” by IPv4:
    - “A” requires “C” MAC address.
    - Only knows IPv4 address.
    - If “C” IPv4 address is not present in the ARP table, then:
      - “A” send an “ARP Request” in broadcast to the local network (destination MAC: FF:FF:FF:FF:FF:FF) with the IPv4 address of “C”,
      - All machines receive this packet,
      - “C” verifies that is IPv4 addess is on the the “ARP request”, responds directly to “A” with a “ARP reply” (destination MAC==MAC of “A”) with it’s on MAC address.
- MAC address resolution only happens in a the local network.
  - ARP packets to not pass through routers.

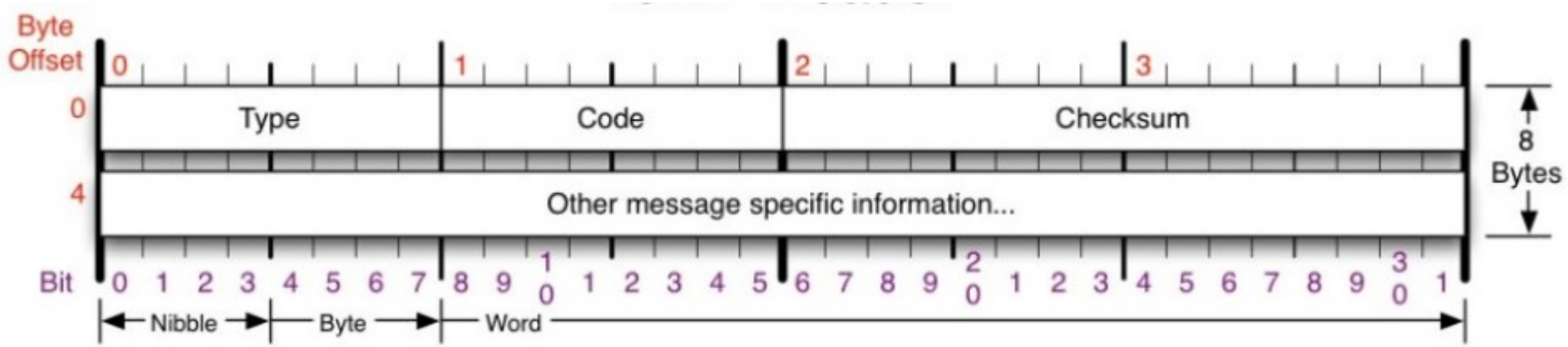


Hosts Connectivity

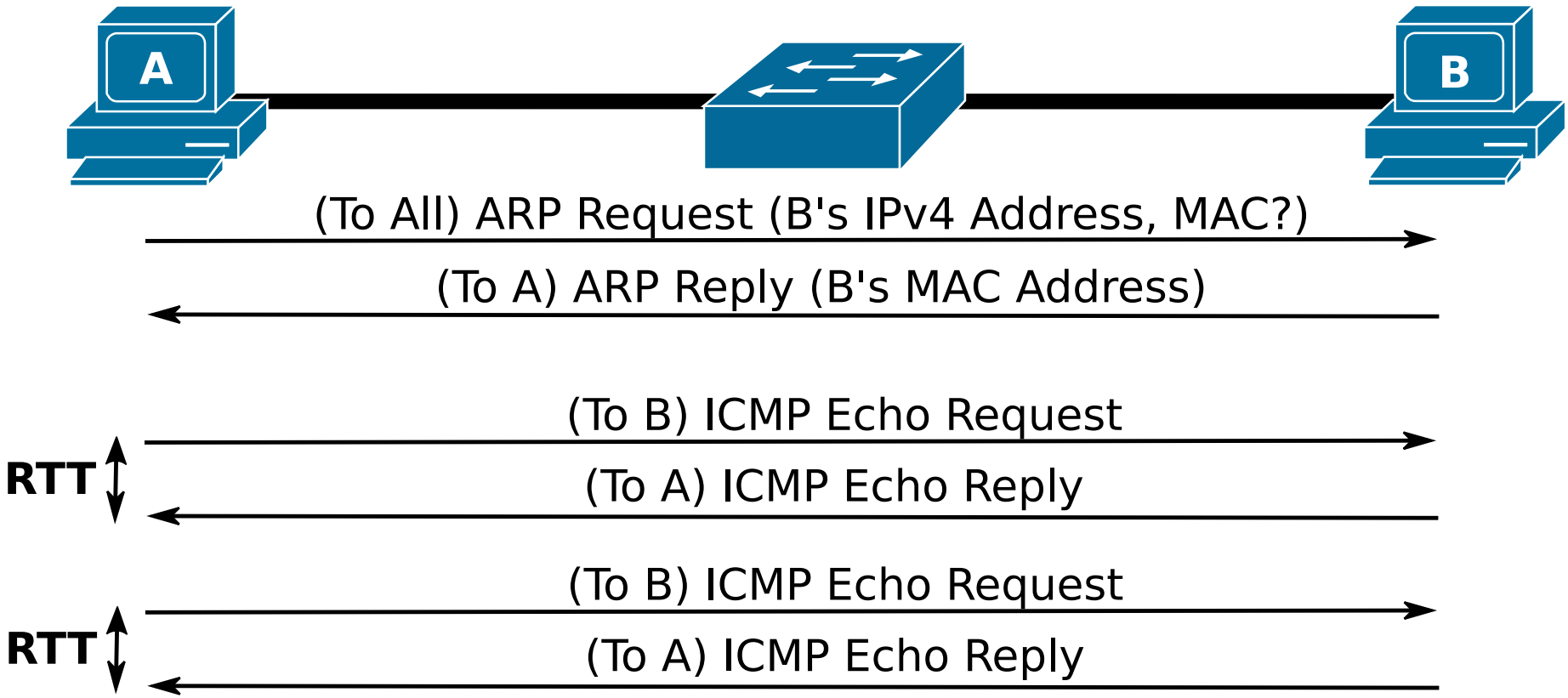
- Two hosts are considered connected if both can send packets to the other, and the packets are correctly received.
  - This is called **Full Connectivity**.
  - It is possible to measure the quality of the connectivity:
    - Measuring the number of **lost packets**,
    - Measuring **Round Trip Time (RTT).**
      - Time it takes for a network packet to go from a starting point to a destination and back again to the starting point.
      - Does not require clock synchronization
    - Lack of full connectivity may be caused by routing problems, lack of connections between sender and receiver, and/or security constraints.
- When connectivity is only achieved in one direction (not both ways), this is called partial connectivity.

Internet Control Message Protocol (ICMP)

- Used to notify events and perform network operations
  - Notification of unreachable network,
  - Notification of unavailable UDP ports,
  - Routing redirection,
  - Connectivity tests and path identification,
  - Etc...
- Header with a fixed size of 8 bytes:



IPv4 Connectivity Test with PING



RTT: Round Trip Time

End-to-End Path Identification

- Usually called “Trace Route” or “Trace Path”
- Rely on the usage of the IP TTL header field
  - Uses ICMP, UDP or TCP packets
- TTL is reduced by one when reaches a router
  - If reaches 0 the packet is discarded,
  - And, the router notifies the sender with a ICMP “TTL expired in transit “ message.
- Sender starts with TTL equal to 1, and progressively increases the sent TTL, until it reaches the destination.
  - TTL=1 → packet “expires” in first router on path, sender discovers first router.
  - TTL=2 → packet “expires” in second router on path, sender discovers second router.
  - And so on… until the sender receives an answer from the destination.