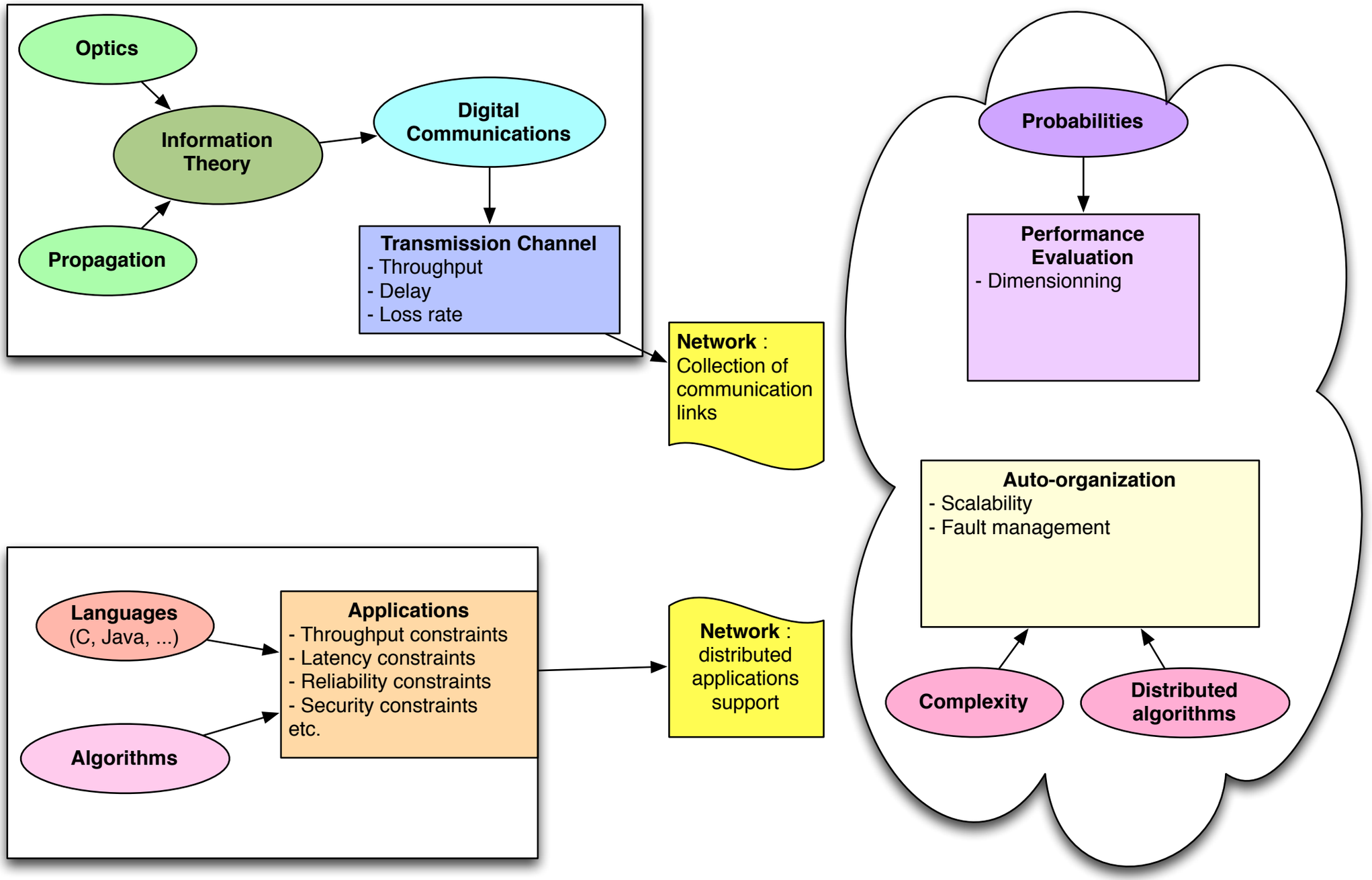
TELECOM ParisTech

# Computer Networks — Introduction

Claude Chaudet

# Perimeter of the course



# Computer network - a definition

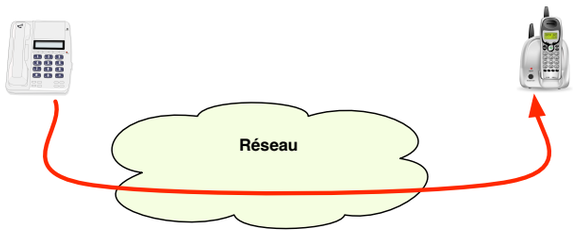
- Communication links
- Interconnection devices

- Peers identification
- Communication protocols

A network is the infrastructure and the set of mechanisms that allow multiple correspondents to communicate with the best possible performance :

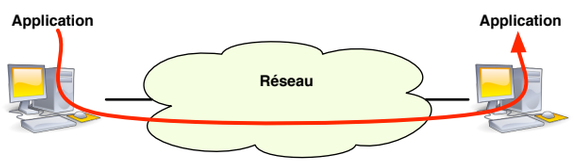
- Quality (speed, stability, ...)
- Robustness (availability, information loss, ...)
- Security (confidentiality, ...)
- Efficiency (do not waste resources)
- etc.

# Network examples




- Public Switched Telephone Network (PSTN)
  - Built for a single service
  - Network evolutions : modems ; ISDN ; xDSL

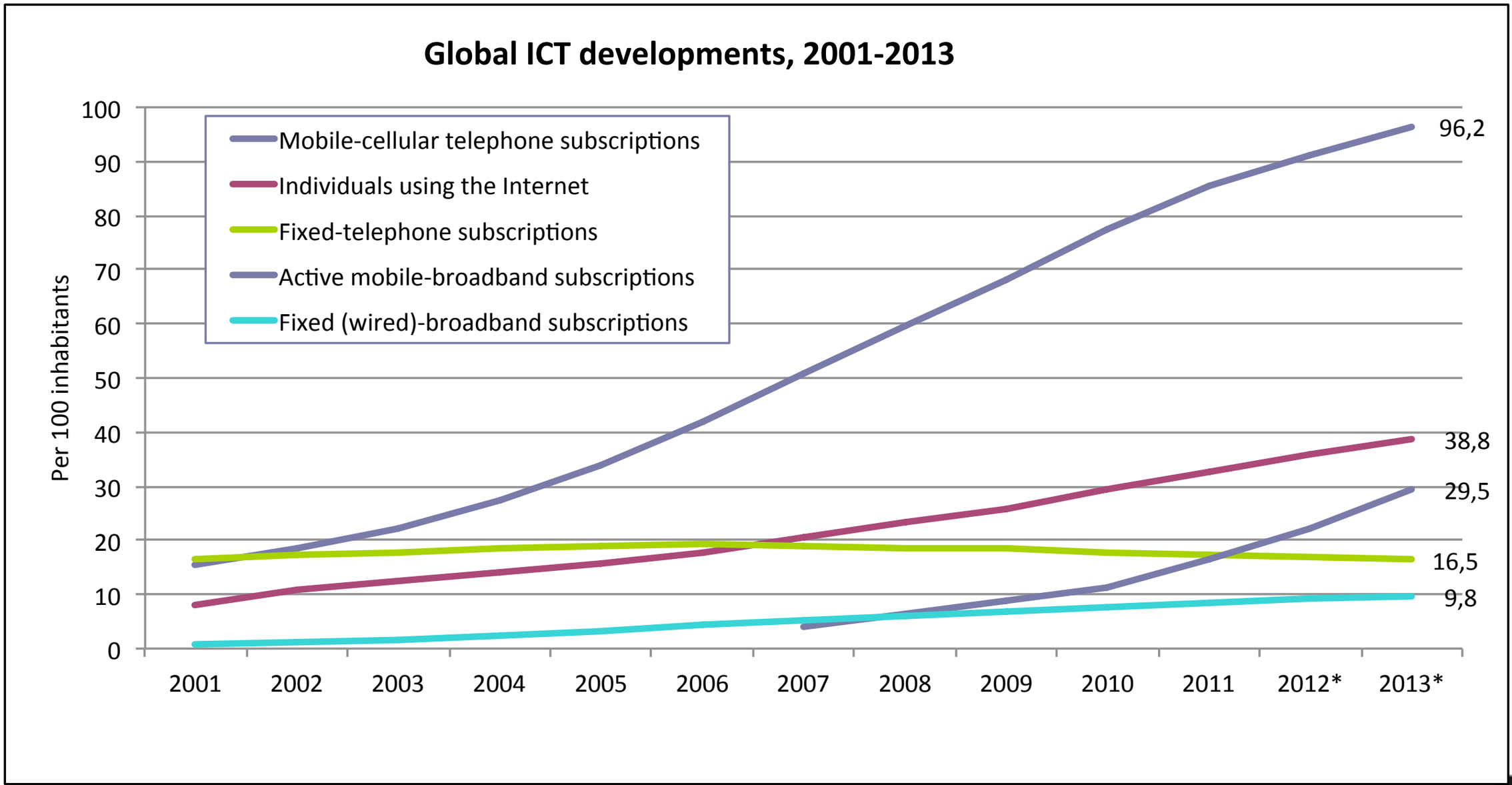
- Cellular Networks (GSM)
  - Built for a single service, evolved to a multi services network
  - Interconnection with PSTN
  - Network evolutions : GPRS, EDGE, UMTS (3G)



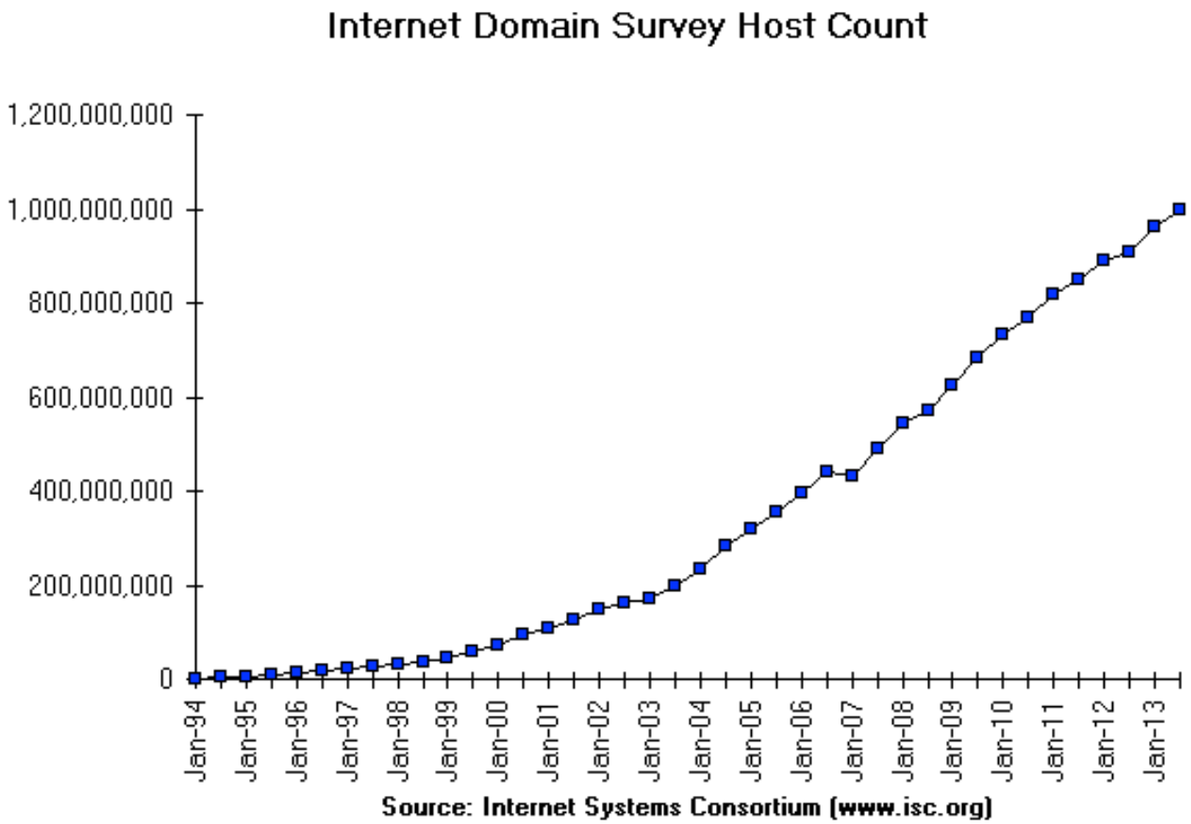

- Local Area Networks (LAN)
  - Typical Size : a few dozens of terminals
  - Interconnection to form a network of networks (Internet)
  - Dedicated to a ***best effort*** data transmission service
  - Typical technologies: Ethernet, Wi-Fi
  - ***Applications*** evolutions : ToIP, streaming, ...

# Networks today

- Source : International Telecommunications Union (ITU)
  - http://www.itu.int/ITU-D/ict/statistics/



# What is the size of the Internet?



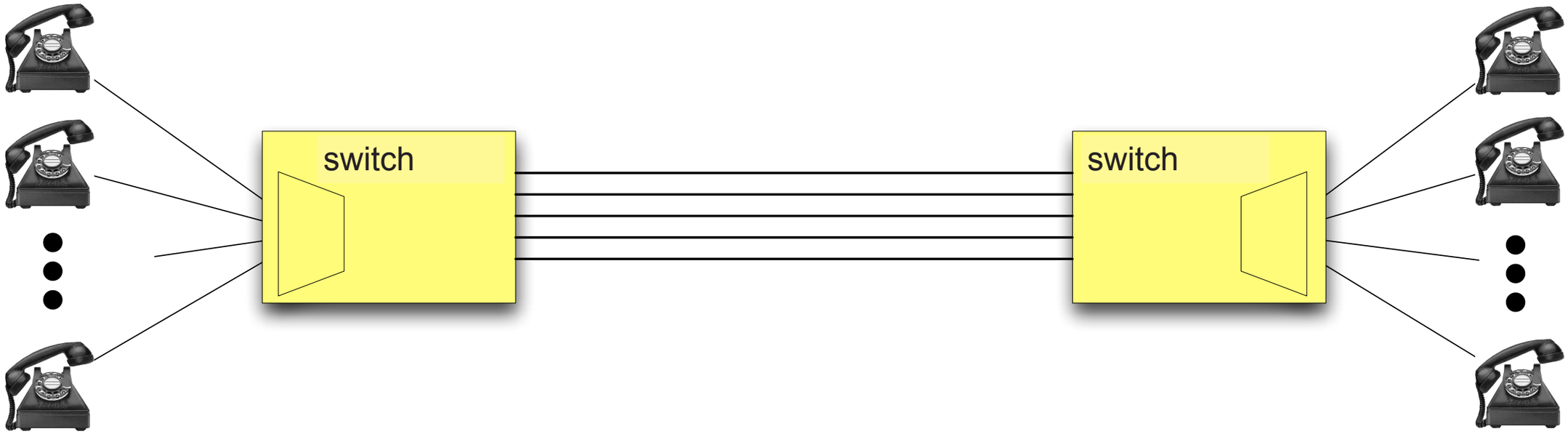

**Evolution of the number of connected machines (estimation)**

*Source : Internet Systems Consortium*

- Main problem: scalability.
  - How to identify the terminals and servers ?
  - How to localize terminals and convey data to them?
  - How to react to the failures and changes in the topology?

# Public Switched Telephone Network

# Telephony Service (PSTN)



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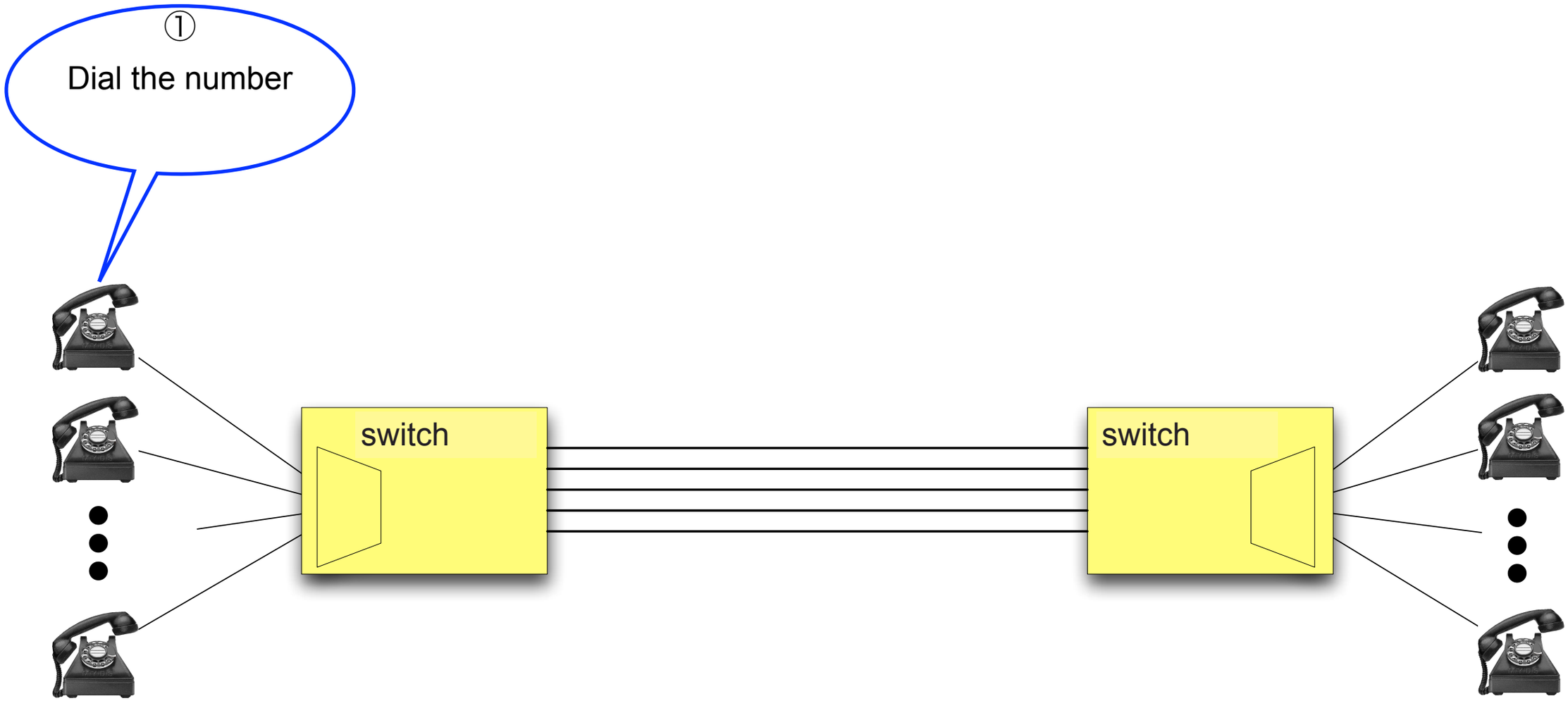

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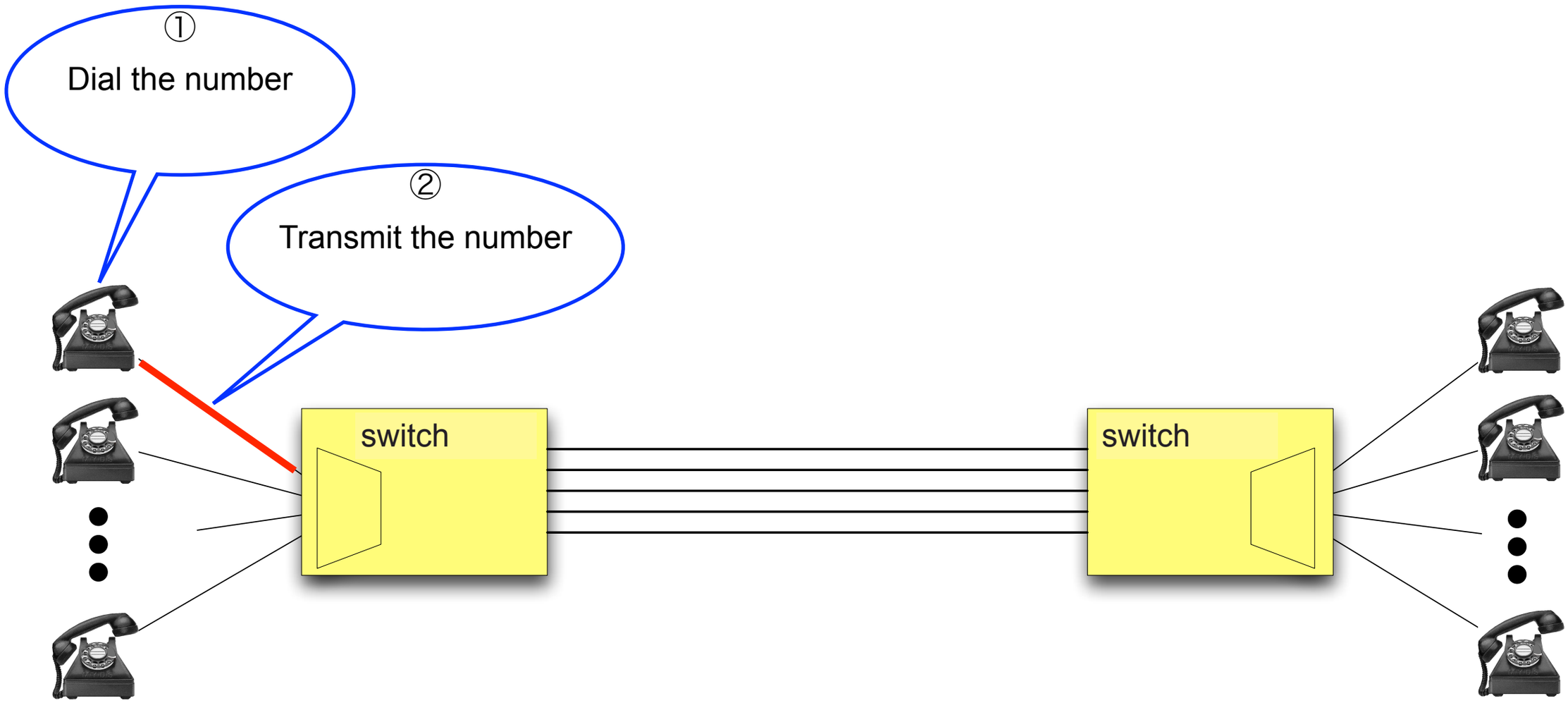

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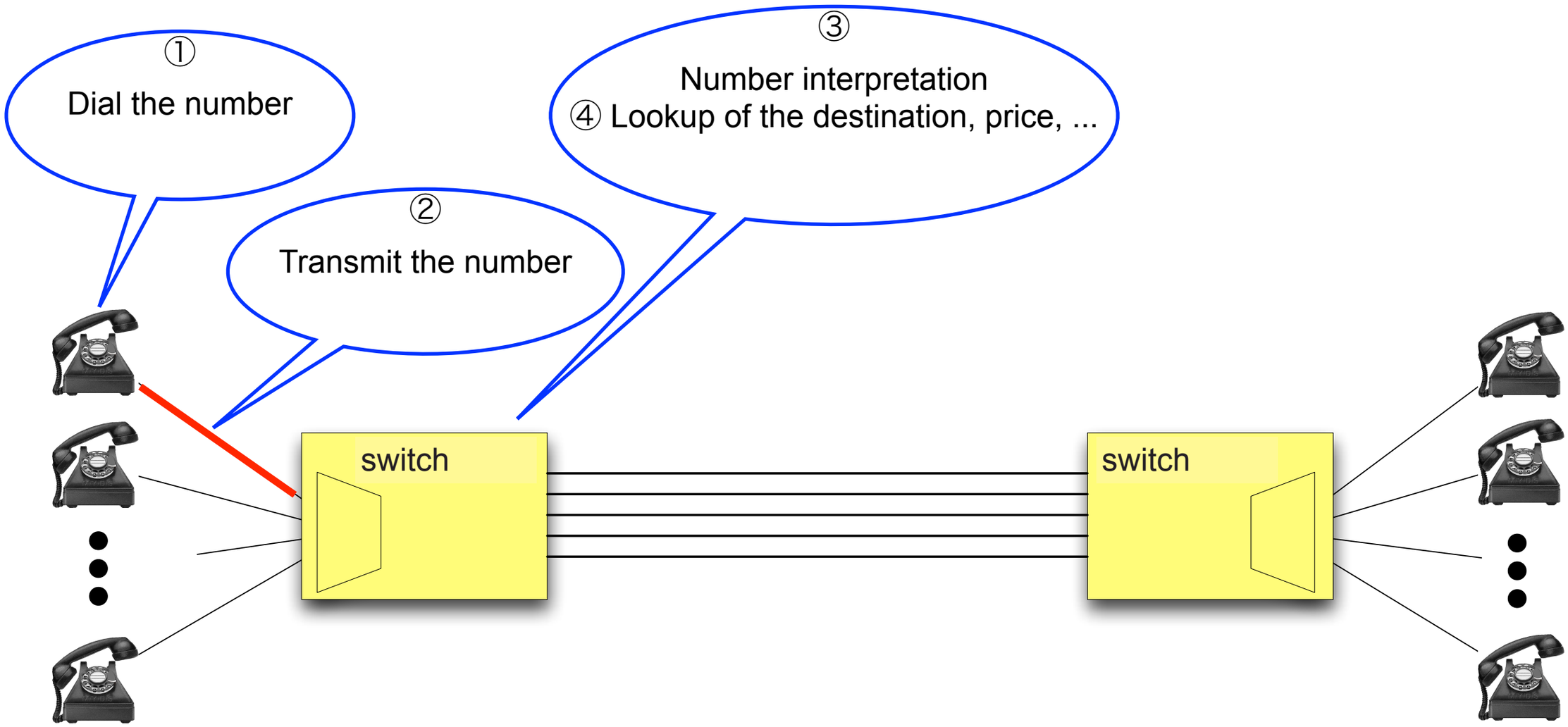

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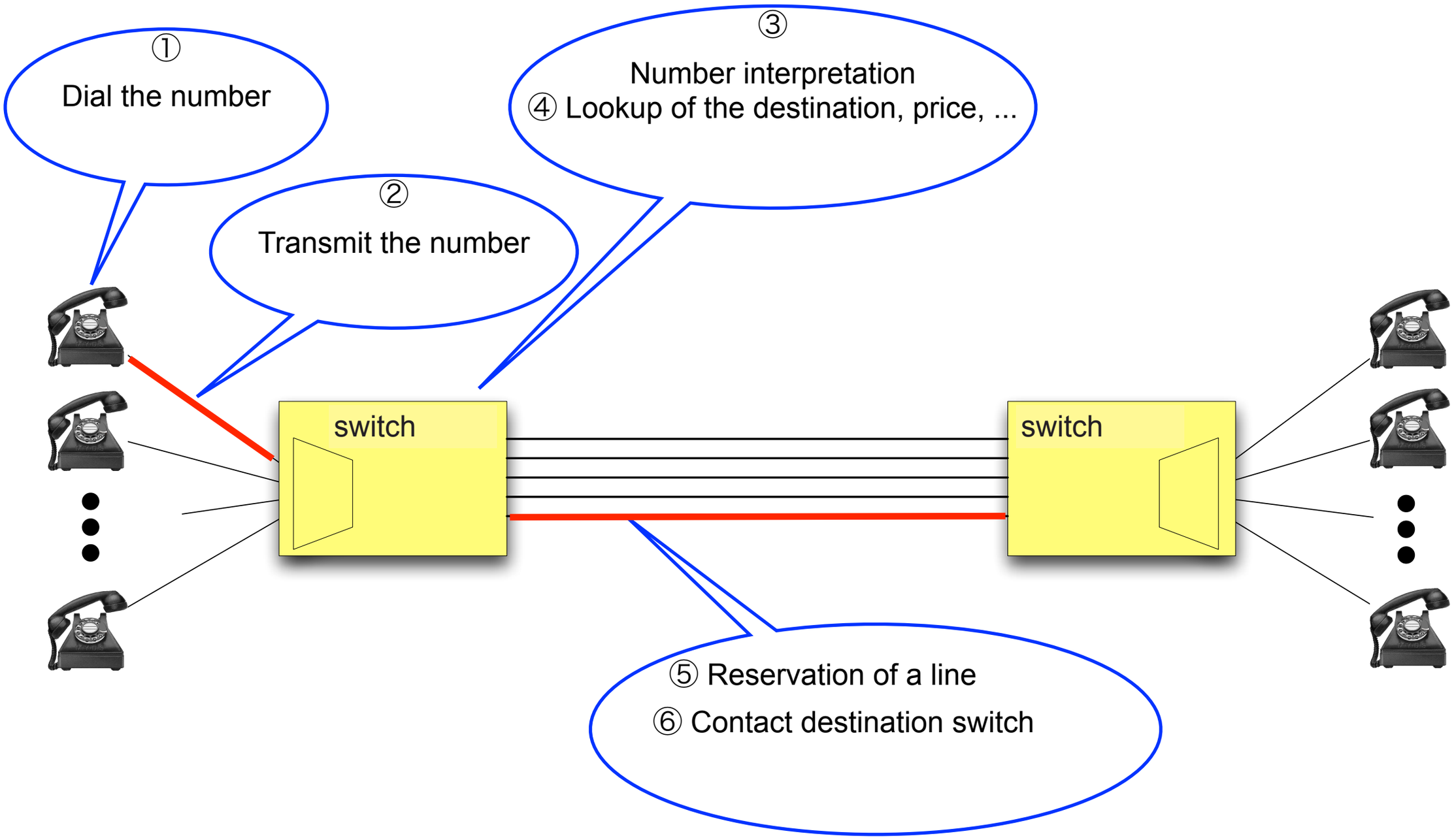

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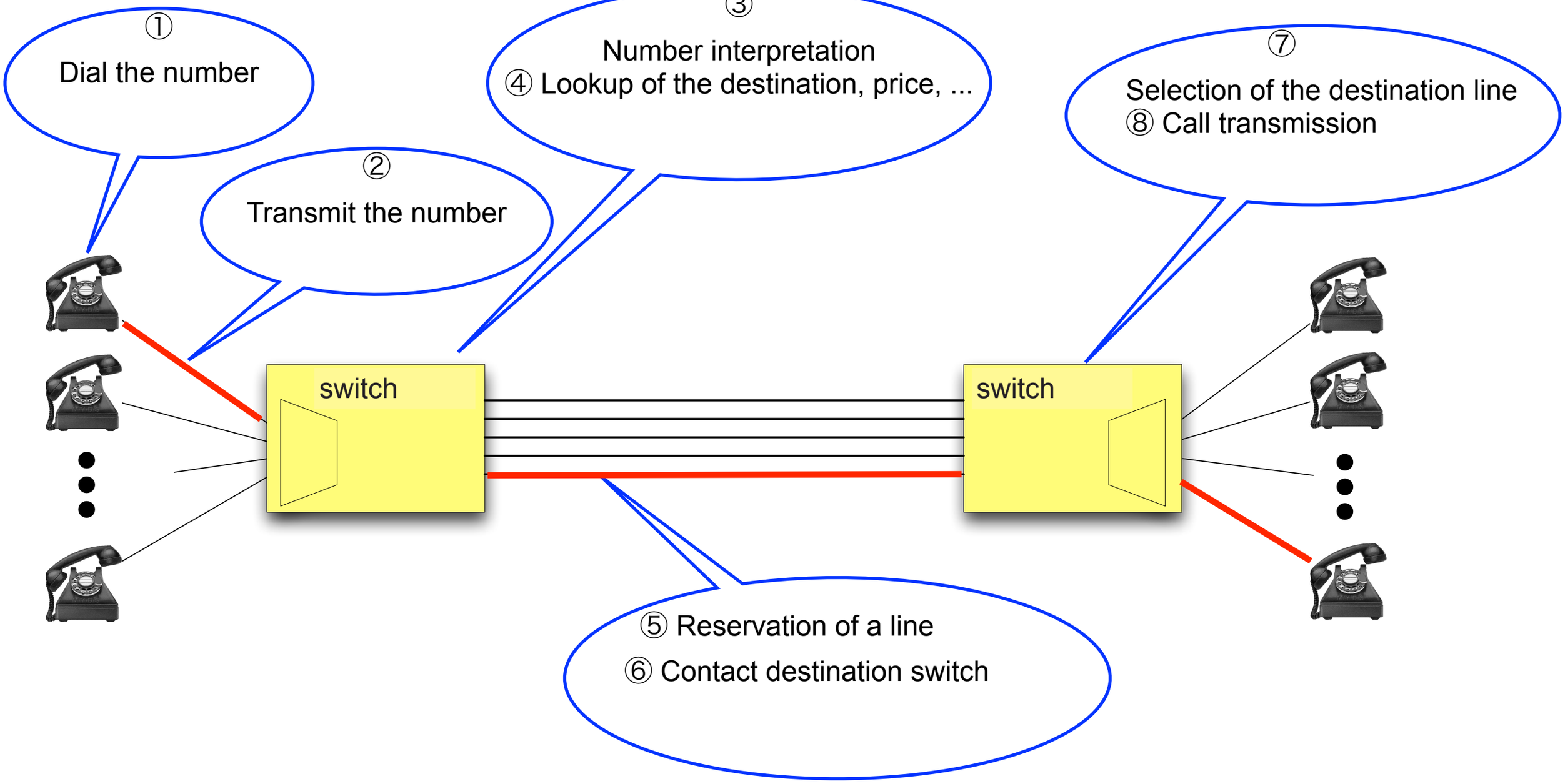

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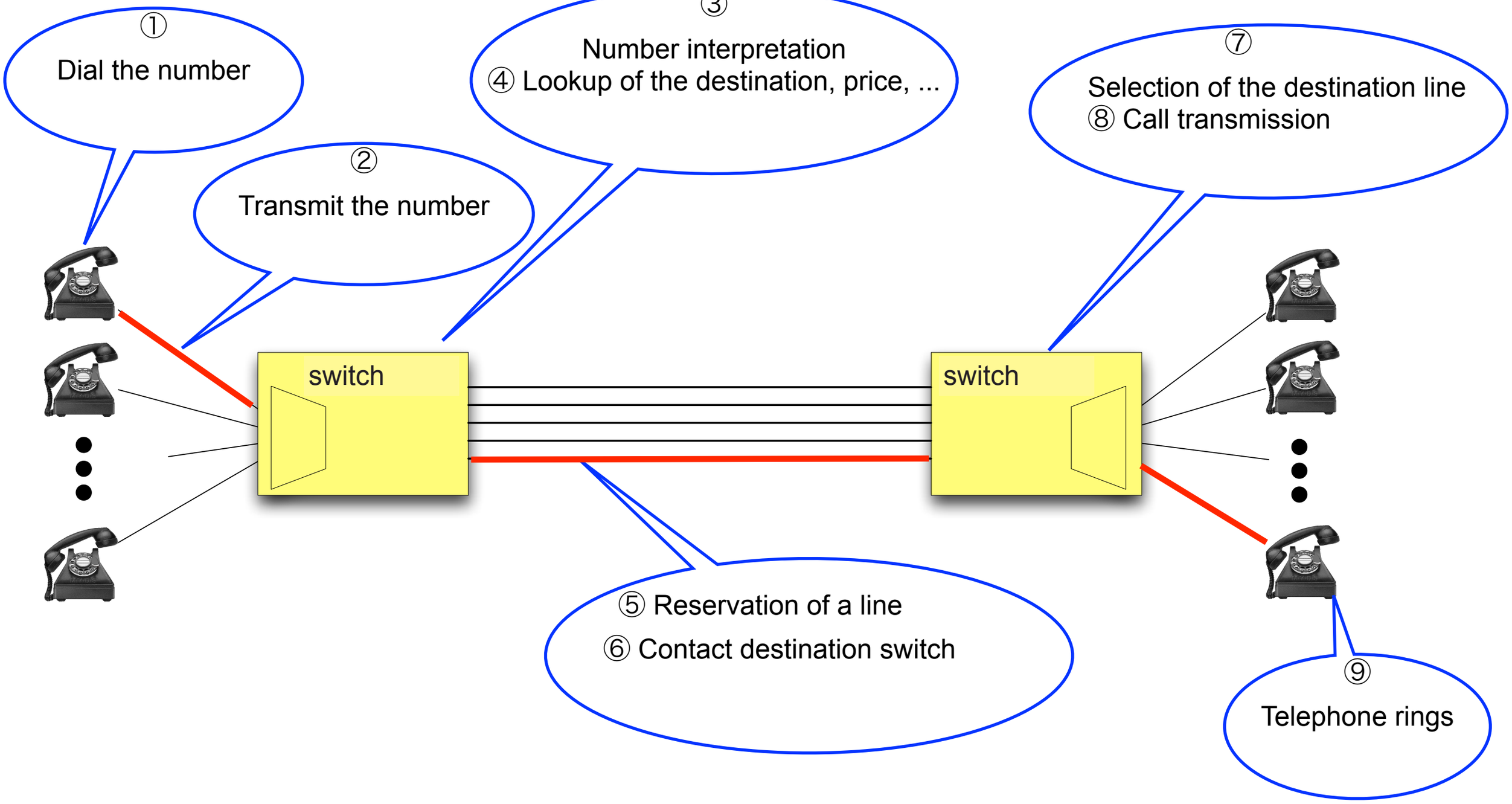


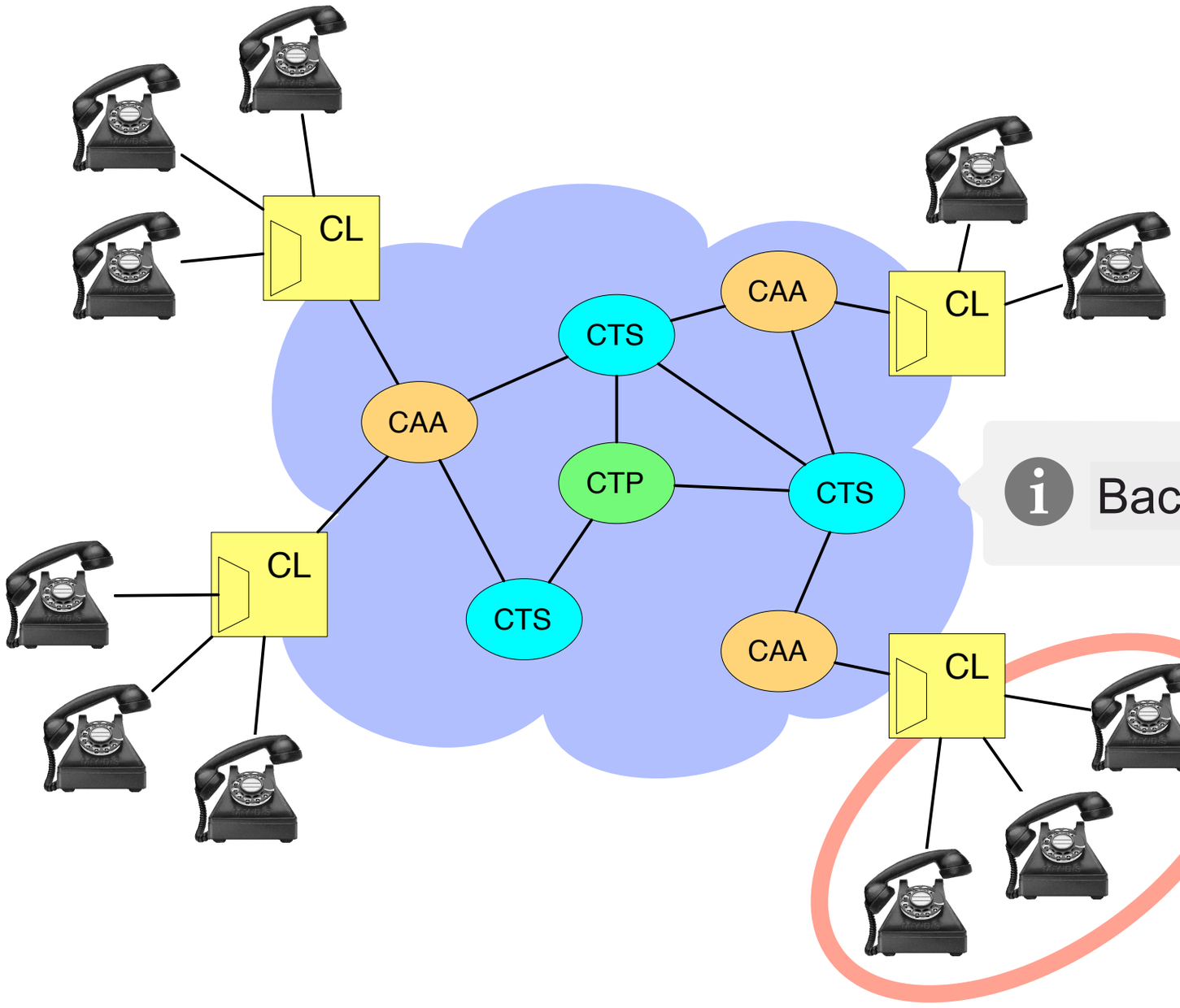
# PSTN — architecture

CTP = Regional Center

CTS = Sectional Center

CAA = Toll Center

CL = End Office

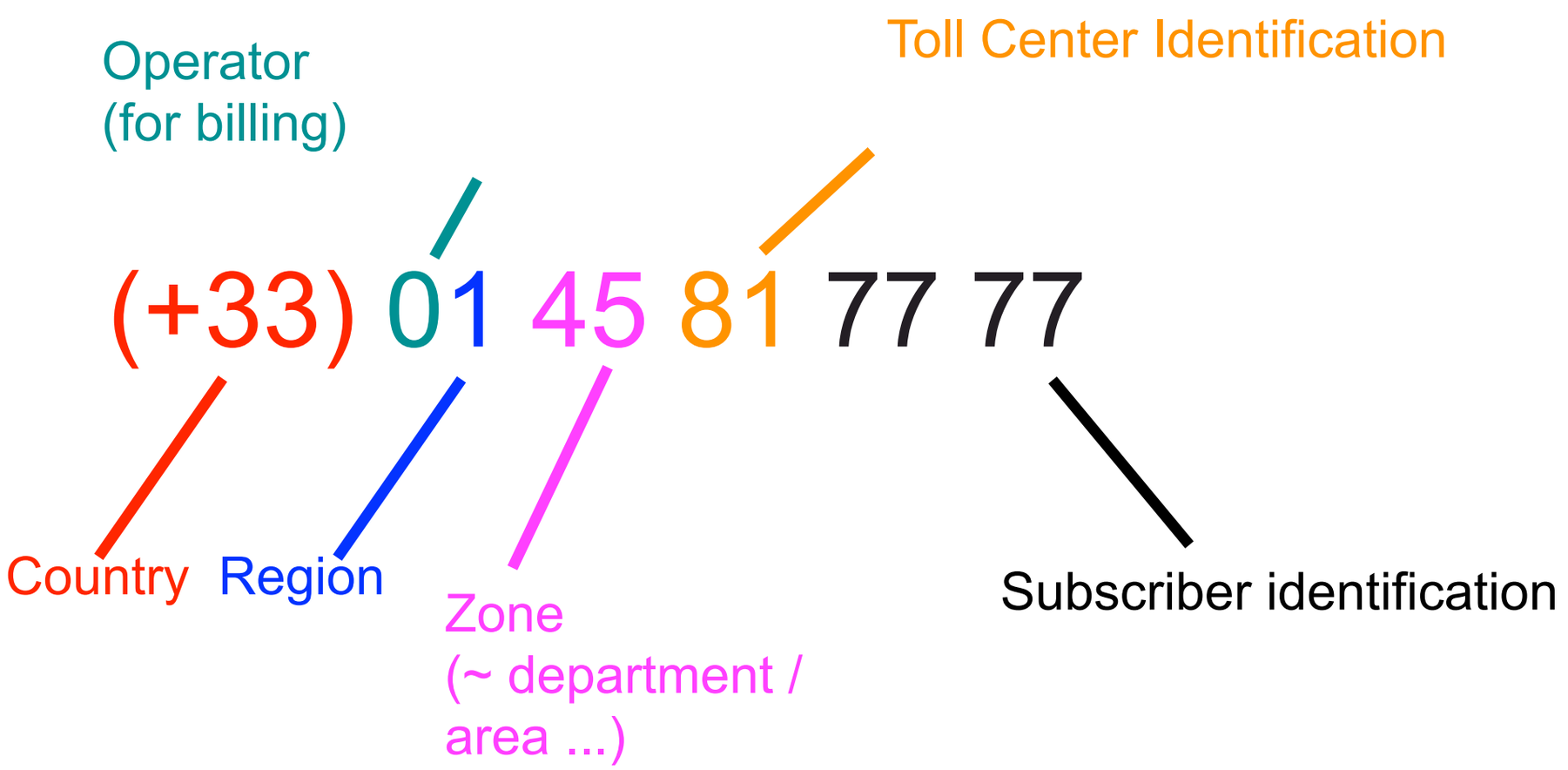



Backbone

Local dispatch

# Identification of the callees and routing

- The selection of the different lines (next switch, callee line, etc.) si based on the phone number
- There is a numbers plan that identifies the subscribers and the routes with databases
  - In France, the plan is defined by the ARCEP (http://www.arcep.fr/)



# Using the network to transfer data: from modems to ADSL

- PSTN offers a noisy communication channel between subscribers
  - Any type of data can be transferred
    - E.g. : dictate a text that somebody writes down
- Successive enhancements of the last mile transmission (connecting the subscriber to the network)
  - Analog modems
    - Modulation and demodulation : conversion analog (audio) ↔ digital
    - Typical throughput : 56 kbit/s (V.92 recommendation)
  - ISDN
    - Multiple telephone lines, some dedicated to data transfer
    - Throughput up to 2 Mb/s
  - xDSL (ADSL, SDSL, VDSL, ADSL2+, ...)
    - Use an unused frequency on PSTN to transfer data (advanced modulation techniques)
    - Throughput up to 100Mb/s (VDSL2)
    - No guarantee on the transmission quality

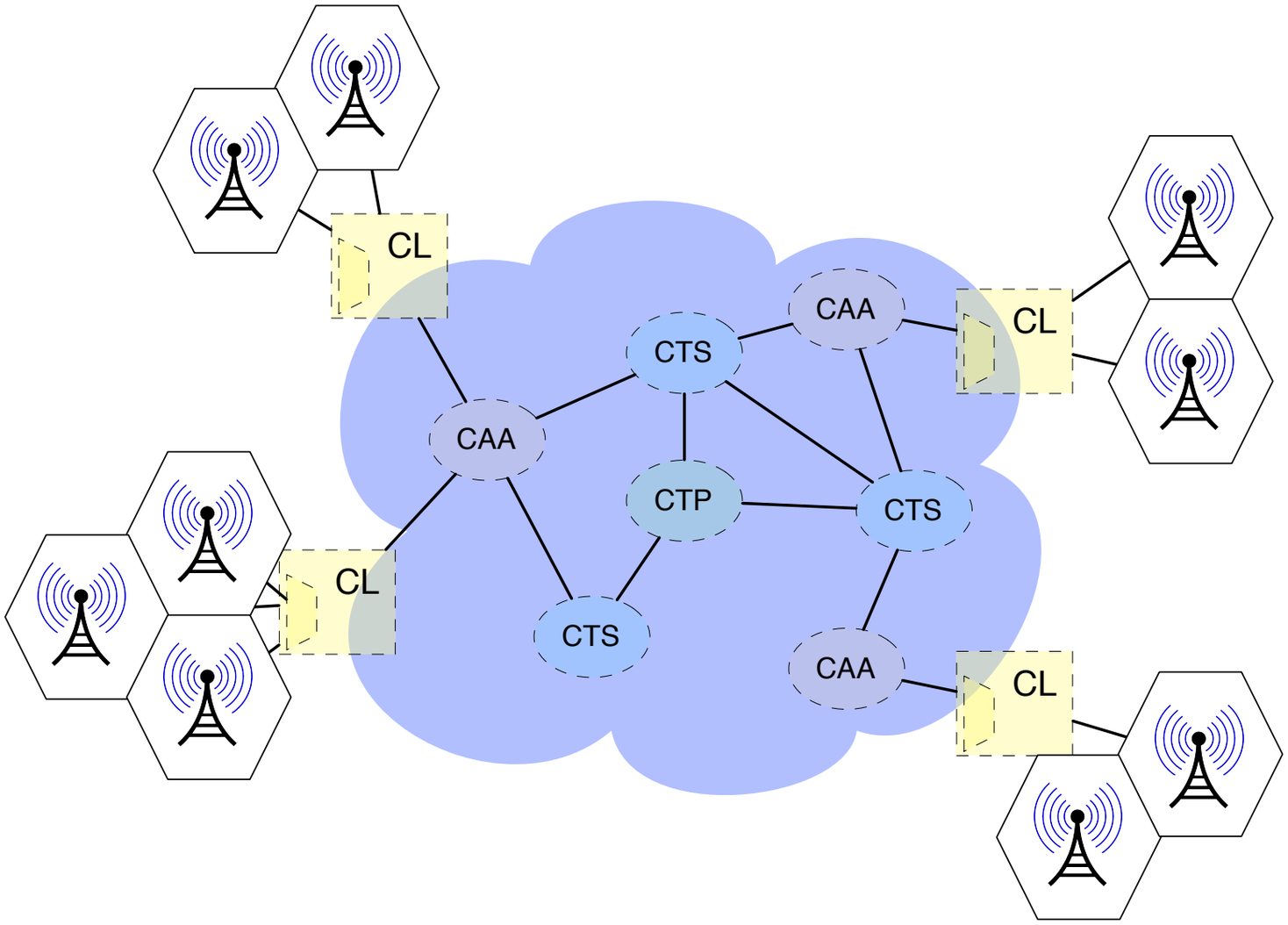
# Cellular (mobile) telephony

# Mobile telephony (GSM)

- Main difference with PSTN: the last interconnection link is wireless (radio frequencies)

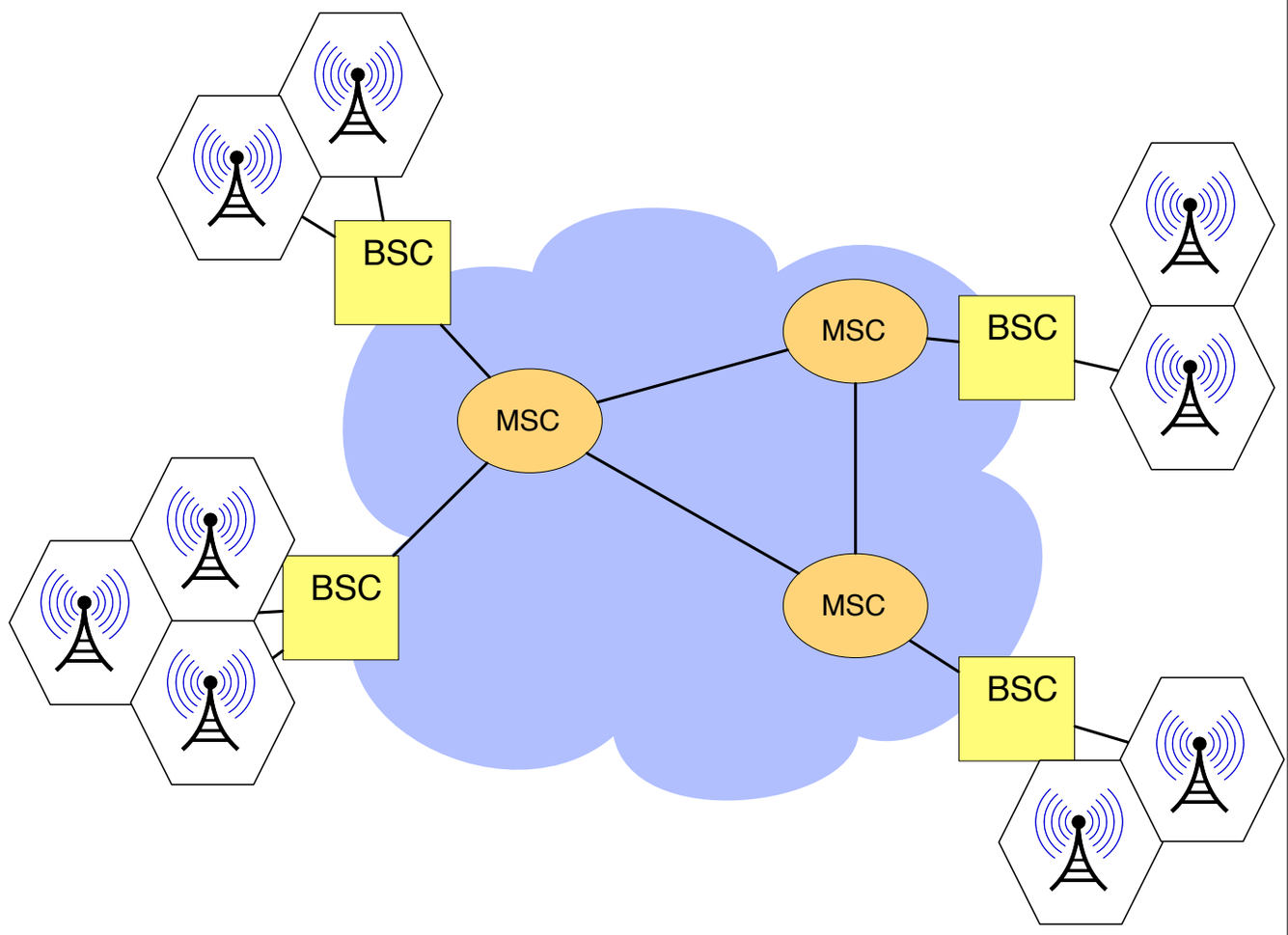
- New problems:
  - Spectrum sharing
    - Between operators
    - Between a single operator's antennas

- Users mobility



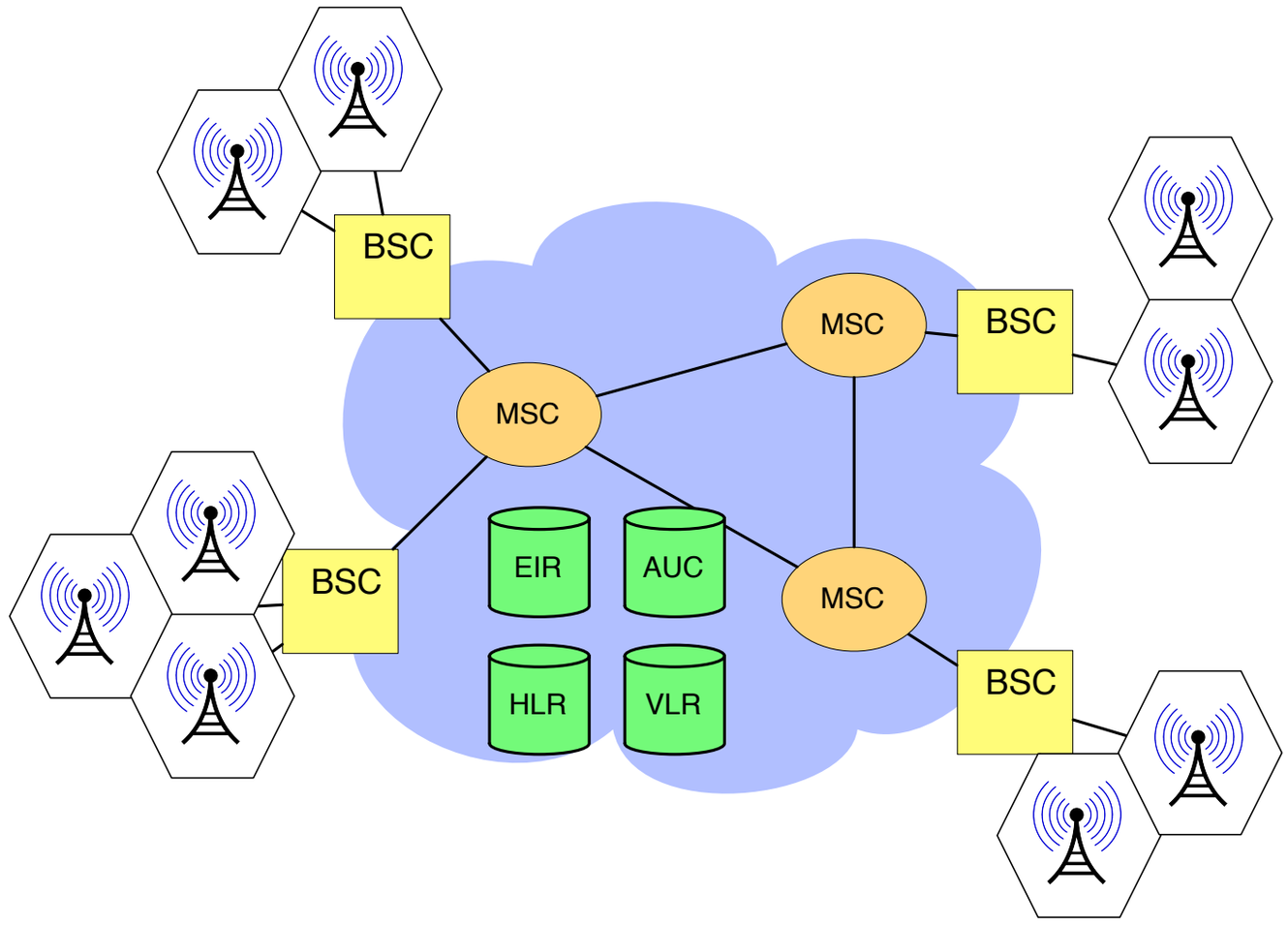
# Mobile telephony (GSM)

- Logical simplification of the backbone architecture:
  - BSC (Base Station Controller)
    - Spectrum management (channels allocation)
    - Local mobility management (handovers)
  - MSC (Mobile service Switching Center)

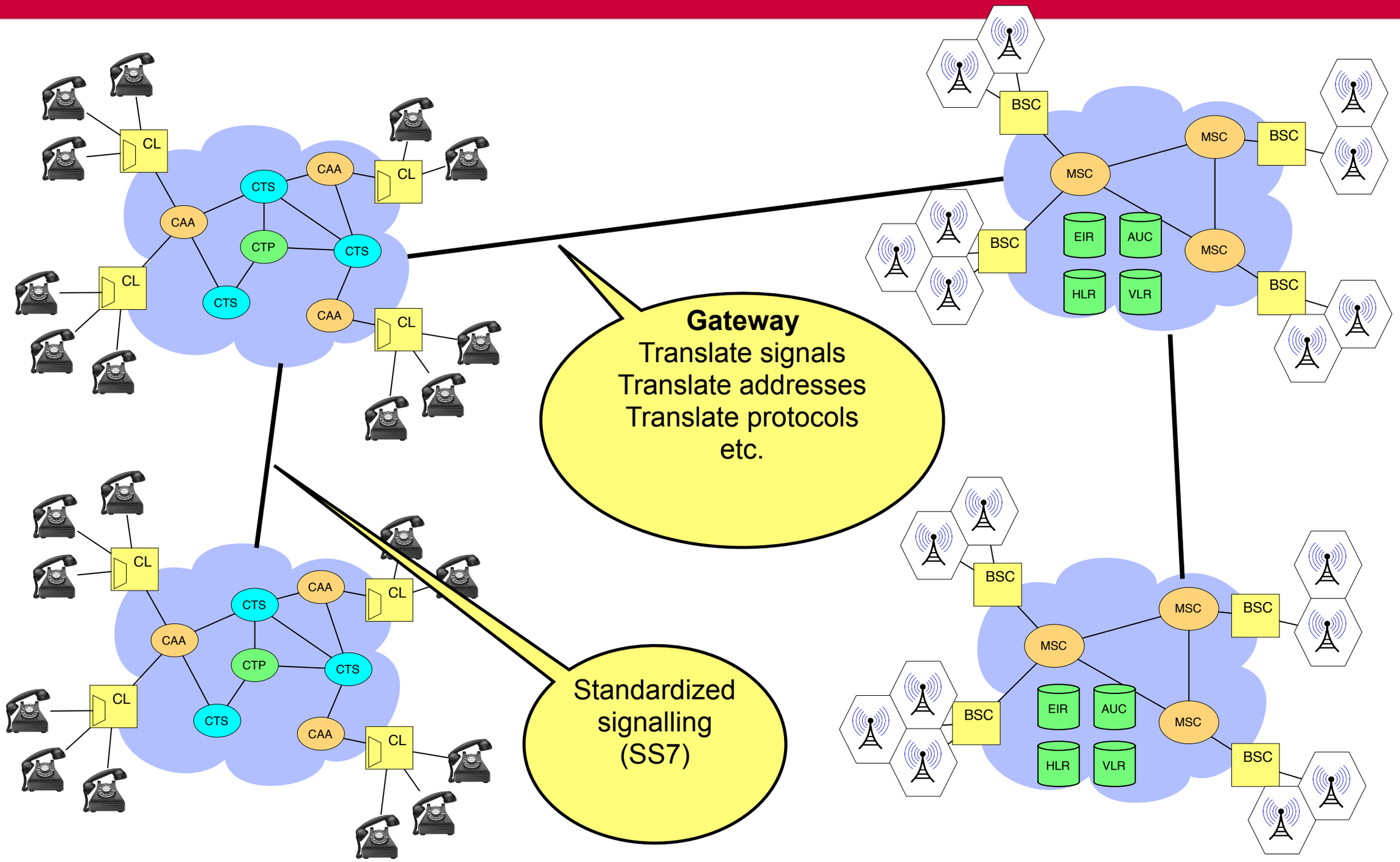


# Mobile telephony (GSM)

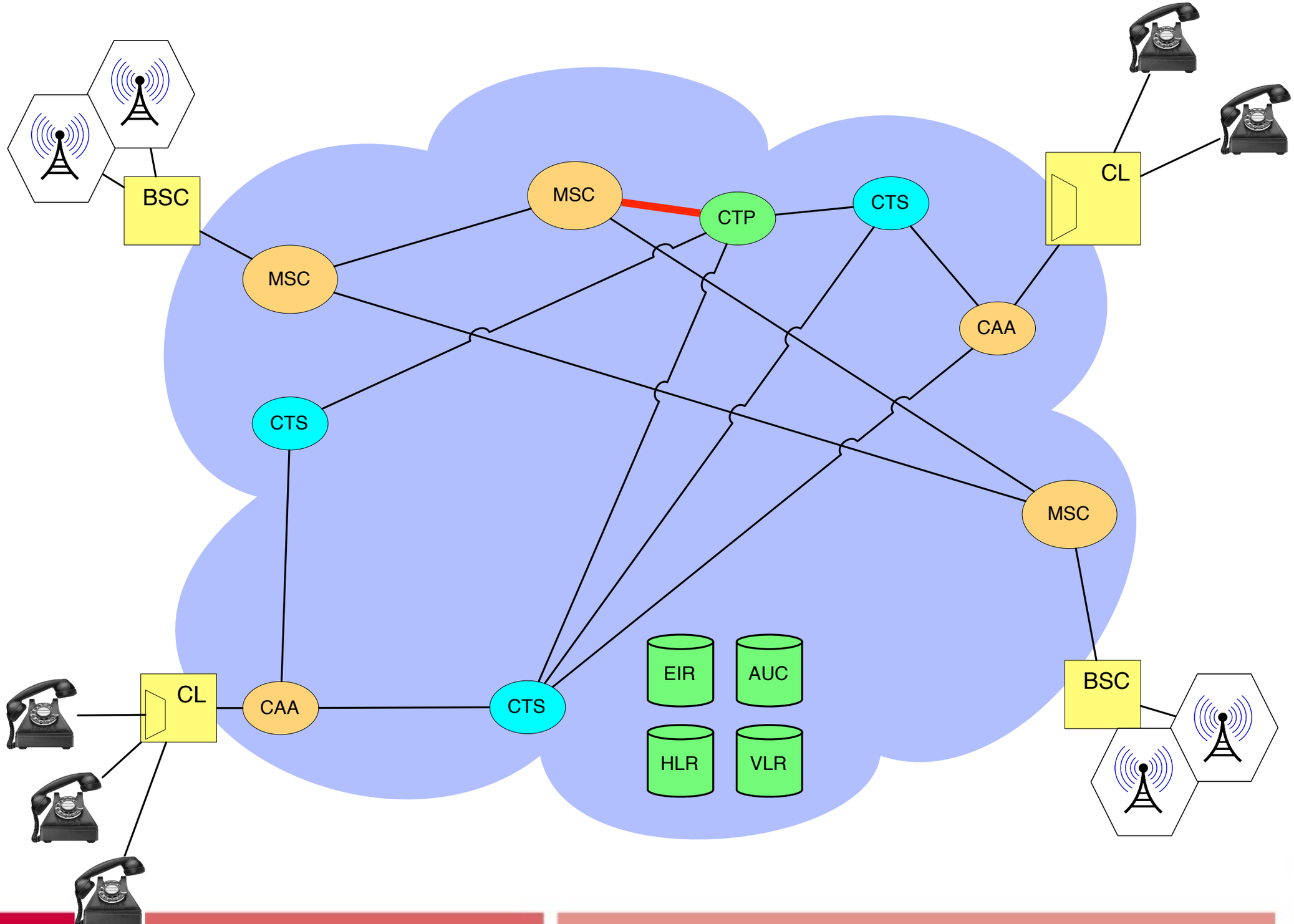
- Databases in the network:
  - Billing
  - Subscribers localization (HLR)
  - Visitors management (VLR)
  - Devices management (EIR)



# Telephone Networks Interconnection



# Backbones interconnection



# Data transfer over cellular telephony

- GSM (2G)
  - Throughput : 9.6 kb/s
- GPRS (2,5G)
  - Explicit “data” mode (packet switching) added to GSM
  - Maximum throughput ~ 50kbit/s
- EDGE (2,75G ; enhanced GPRS)
  - Coding and modulation techniques evolution
  - Maximum throughput 384 kbit/s
- UMTS (3G)
  - Change of frequency range
  - Throughput up to 2Mbit/s (fixed) or 384 kb/s (moving)
- HSDPA (3,5G ; 3G+)
  - Enhanced error correction
  - Throughput up to 7 Mb/s on downlink
- LTE, LTE advanced (4G)
  - Theoretical throughput: 300Mb/s

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Successive enhancements that concern :

the frequency band
coding, modulation
compression, error correction

# Data Networks

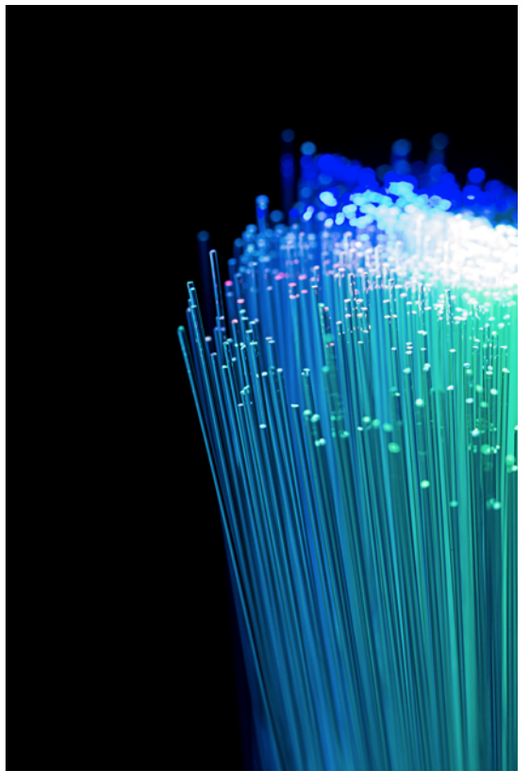
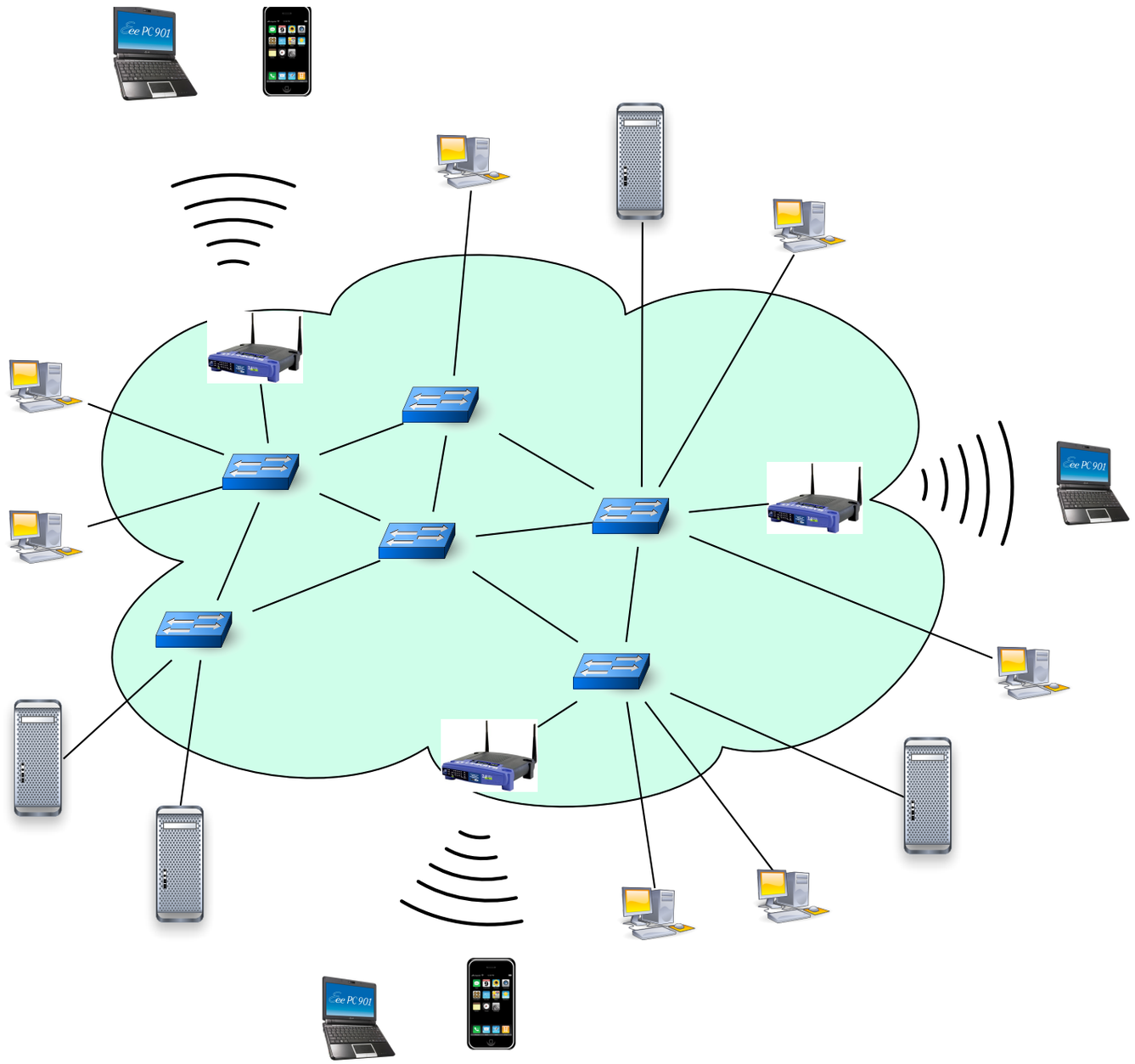


Illustration : Ben Felten

# Local Area Network (LAN)

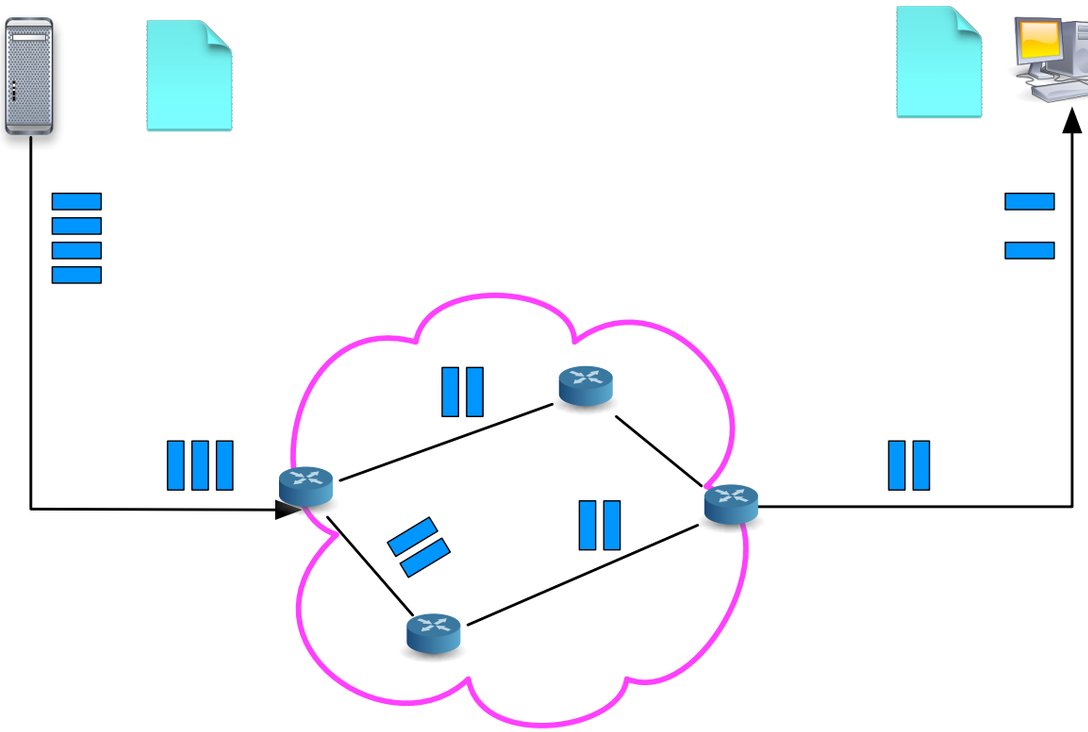
- Physical infrastructure
  - Switches (Ethernet)
  - Wireless Access Points (Wi-Fi)



- Main principles :
  - No reservation (resources, path, ...) for a communication
  - Transmission of small information units (frames)

# Packet Switching

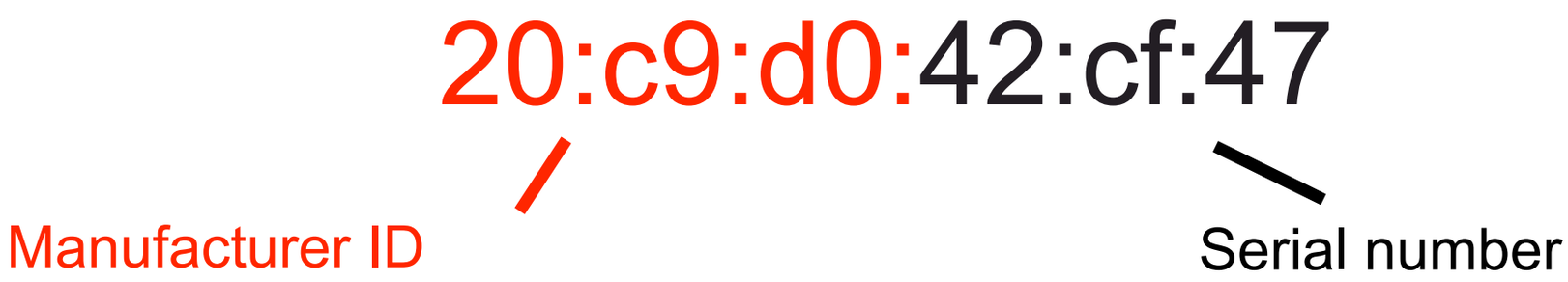
- Main idea : divide information is small units (datagrams, packets, ...) that are transmitted independently
  - Better reaction to losses in the network
  - Better sharing of communication links (especially when traffic is irregular)



- Main foundation of today's Internet
  - Cyclades Project (Louis Pouzin, 1971)
  - TCP/IP (Vint Cerf, Bob Kahn, 1974)

# Identification des correspondants : adressage MAC

- Frames are transmitted from link to link based on the next device's MAC address
  - MAC address are associated to a network card
    - A Wi-Fi and an Ethernet cards on the same computer have different addresses
  - MAC addresses are allocated when the network card is manufactured



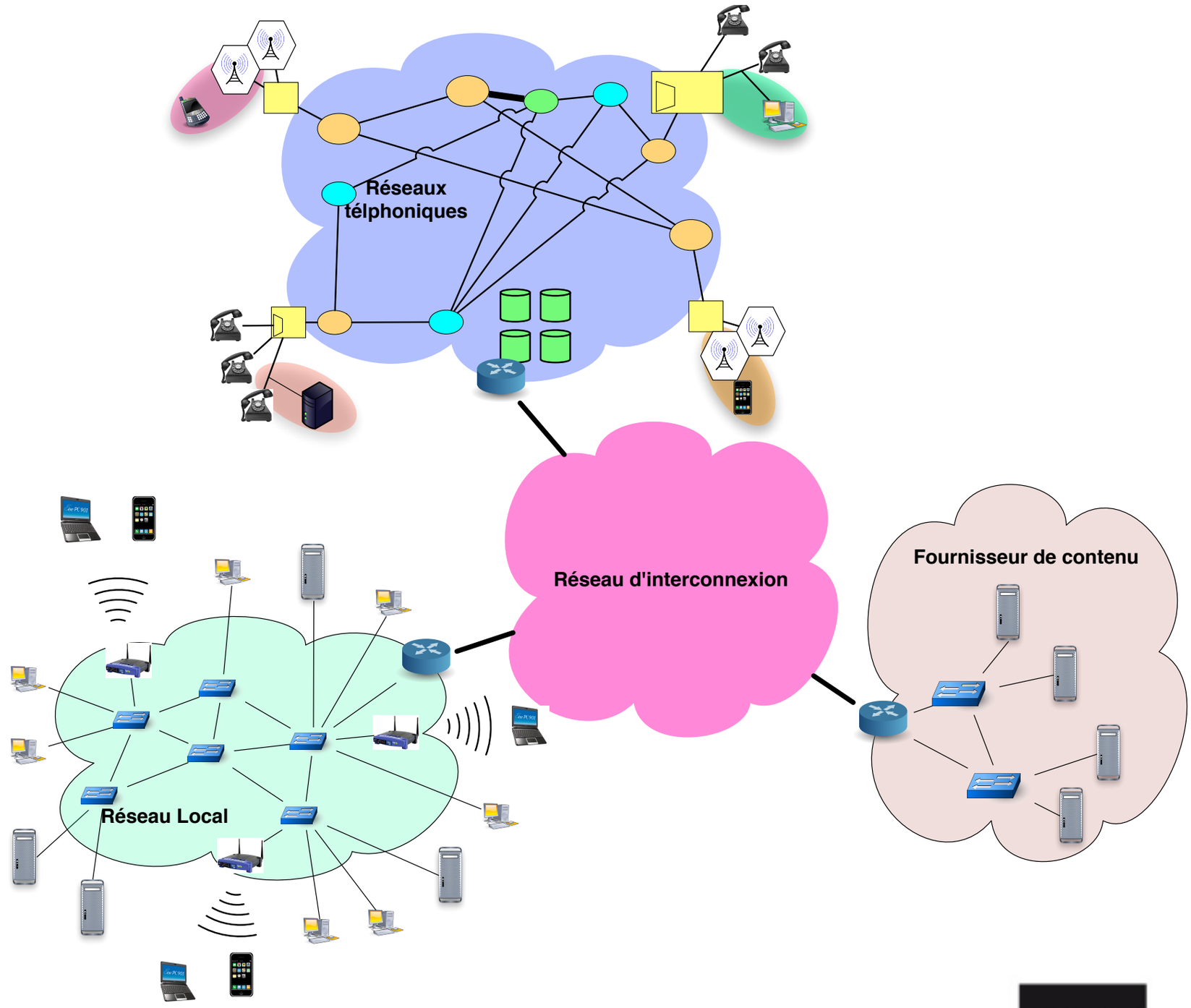

- *De facto*, no organization of the numbering
  - The address does not contain no information on how to reach the destination
- No central database: devices that need to use MAC address (i.e. switches) learn them on the fly
  - Local database, one per switch

# Internet

Illustration : OCDE

# Internet as the interconnection of data services

- PSTN, cellular wireless part and LANs are **access networks**
  - Users
  - Contents and application suppliers
- Internet adds a **backbone network**
  - dedicated to interconnection
  - no or few traffic source or destination
  - Multiple operators, different from access



# Standards for interconnection

- Each network has its own internal management / behavior. The interface to the global network is standardized.

- Internet is a packet switched network
  - Problem for services that require a circuit switching.
  - Internet offers a best effort service (no guarantee) => late arrival of ToIP

- IP addressing everywhere
  - Individual devices addressing (e.g MAC addressing) could be different
  - No embedded localization information in MAC addresses
  - No guarantee on MAC addresses unicity in the global network

# IP addressing

- IPv4 address : 32 bits (4 numbers between 0 et 255)
- Composed of two parts :
  - Prefix : Network identifier, attributed by a central organization (IANA)
  - Interface identifier : one per network interface
    - Allocation : left to the network manager


- Adaptable format
  - **Prefix length is variable** (depends on the network size)
  - Defined at the bit level
- Dynamic addressing
  - Address can change at each connection
  - **The IP address indicates a location, not an identity**

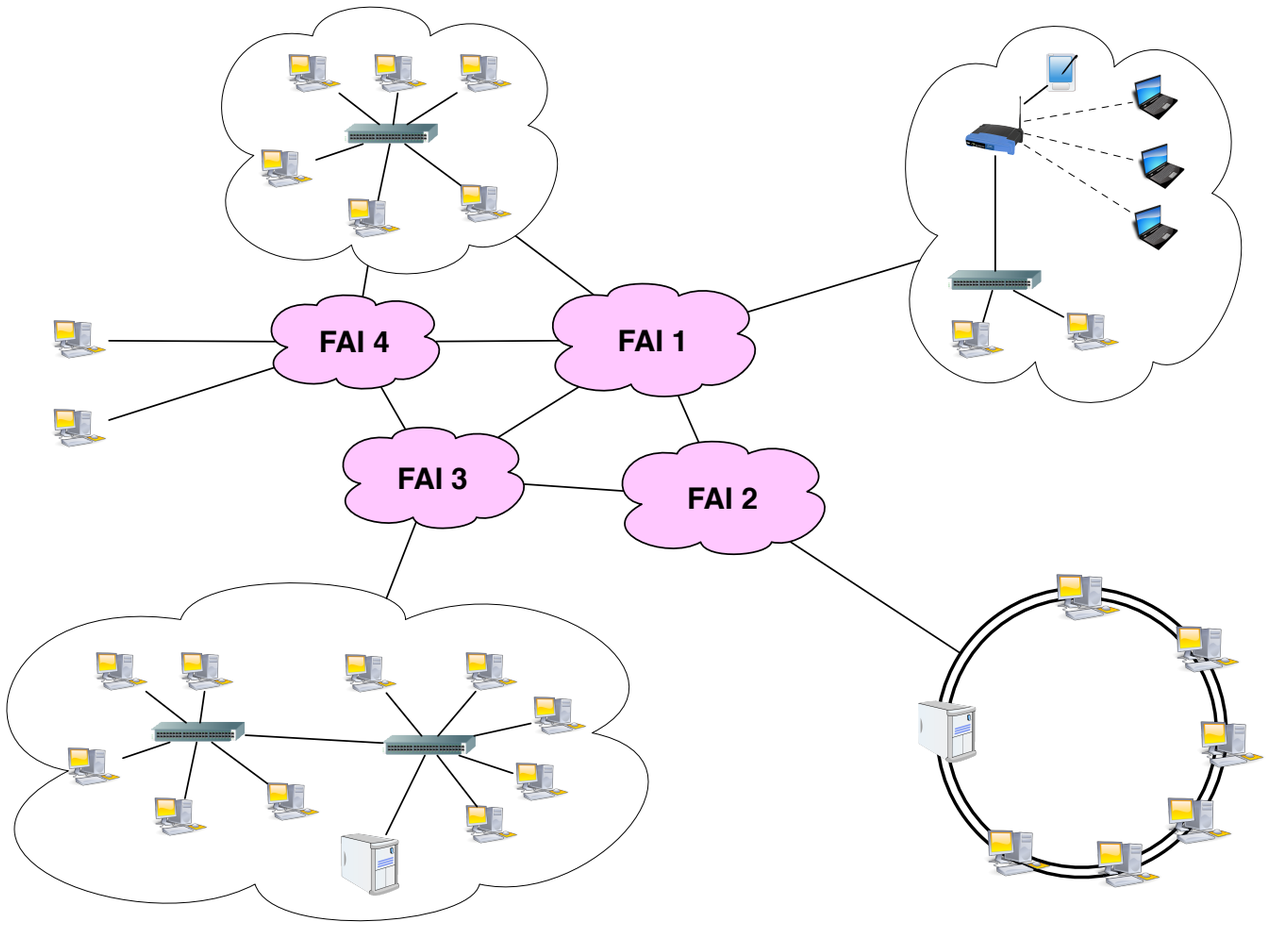
# Internet Architecture

# Internet Organization

- Internet is more than a simple LANs interconnection
  - It is different to want to interconnect and to make interconnection
  - There are companies / organizations that make this interconnection possible

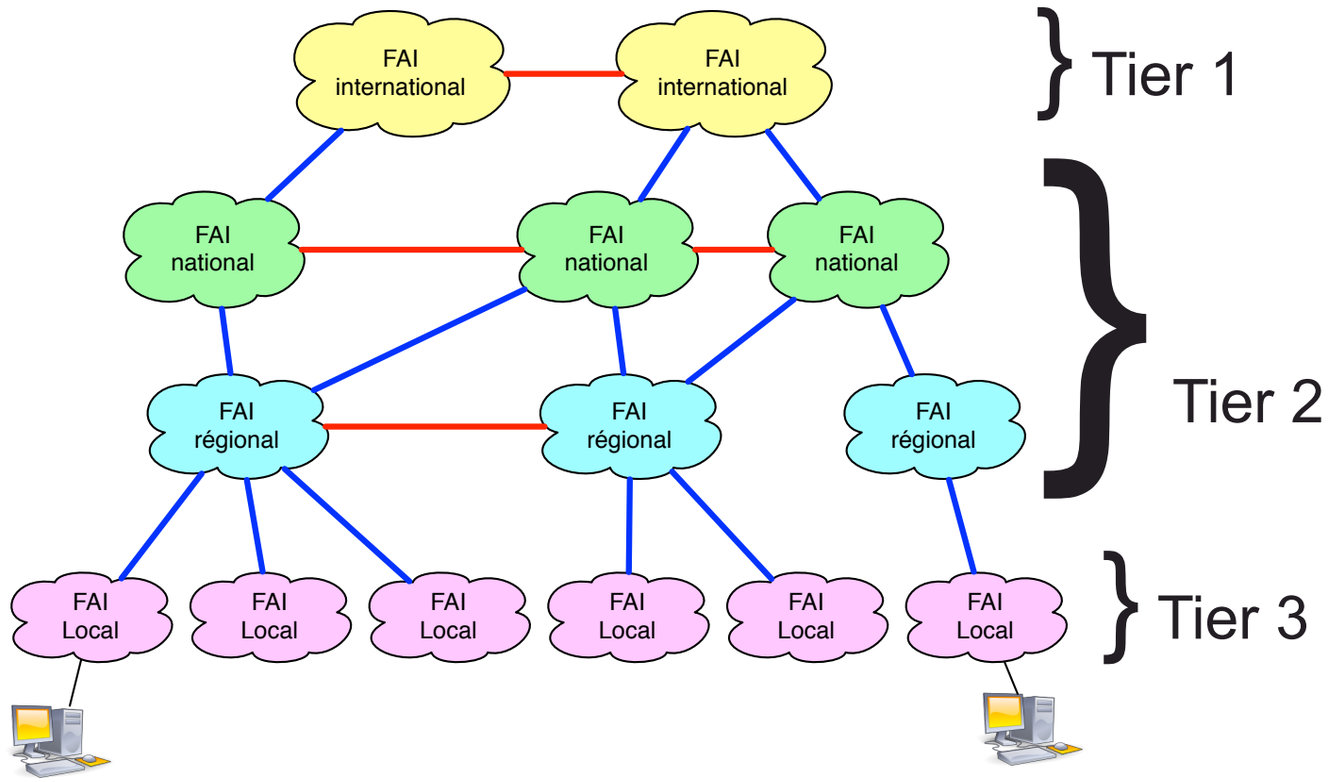
- These companies are called Internet Service Providers (ISP)

- Every ISP is autonomous
  - Freedom to choose internal management policy
  - Only interfaces are standardized



# ISPs agreements and hierarchy

- There are different ISP levels
  - Some connect end users, some are only serve other ISPs
  - Policy is often related to the geographic span
  - Called Tier {1,2,3} (unclear definition)




- Agreements between ISPs
  - Specify the authorized data amount that can be transferred in each direction
  - Transit agreements (—) between different levels ISPs
    - Usually paid service, a transit ISP generally does not connect end users
  - *Peering* agreements (—) between same level ISPs
    - Often free and bi-directionnal

# Economical model of the Internet

- Electronic communication providers
  - Local ISPs sell Internet Access to their subscribers
    - All-in-one “Best Effort” subscriptions
    - Leased lines with guarantees
  - ISPs sell transit bue peering is free
    - Peering with contents providers to sends less traffic on transit links
  - Investment in the network: new technologies, larger interconnection links, radio licenses, etc.

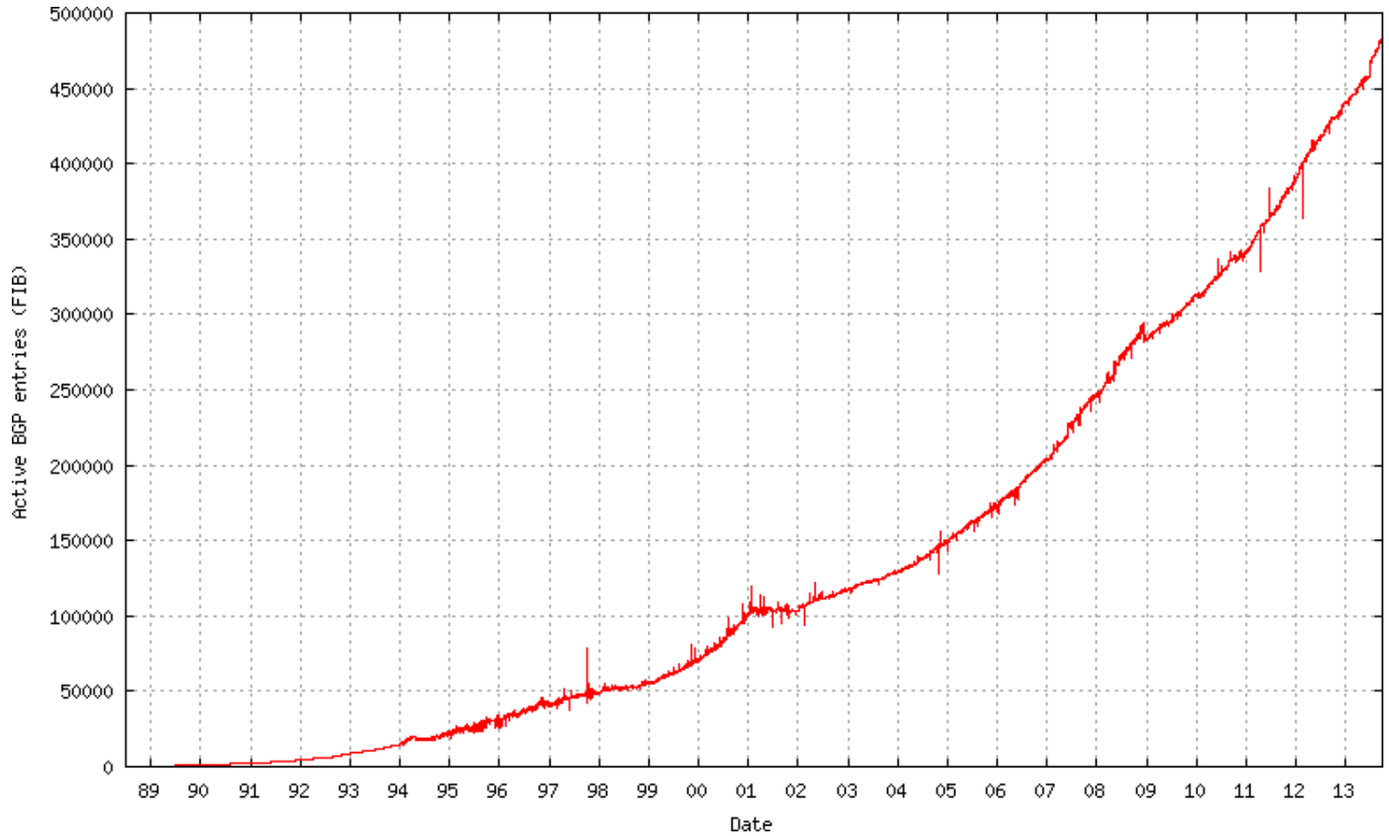
- Content providers
  - e-shoping
  - Advertising and related activities (users profiling for targeted advertisement)
    - Few really important players

# Network Neutrality

- Key issue: should the ISPs be able to control (block, slow down, ...) the traffic that passes their network?
- ISPs' point of view
  - Continuous increase in exchanged data volume (video, download, ...)
  - Most investments concern access networks: Fiber (FTTx), 4G (LTE)
  - There is no income sharing from contents providers (free peering)
- Content provider's point of view
  - Today's situation is fine: they pay for network access
  - Taxing contents providers: additional income would be too low to fund new access networks
  - Contents providers should decide alone of the featured contents
- Users point of view
  - Quality decrease based on commercial criteria (partnerships)
  - Censorship (control of the ISPs by states)

# Internet - interconnexion de réseaux

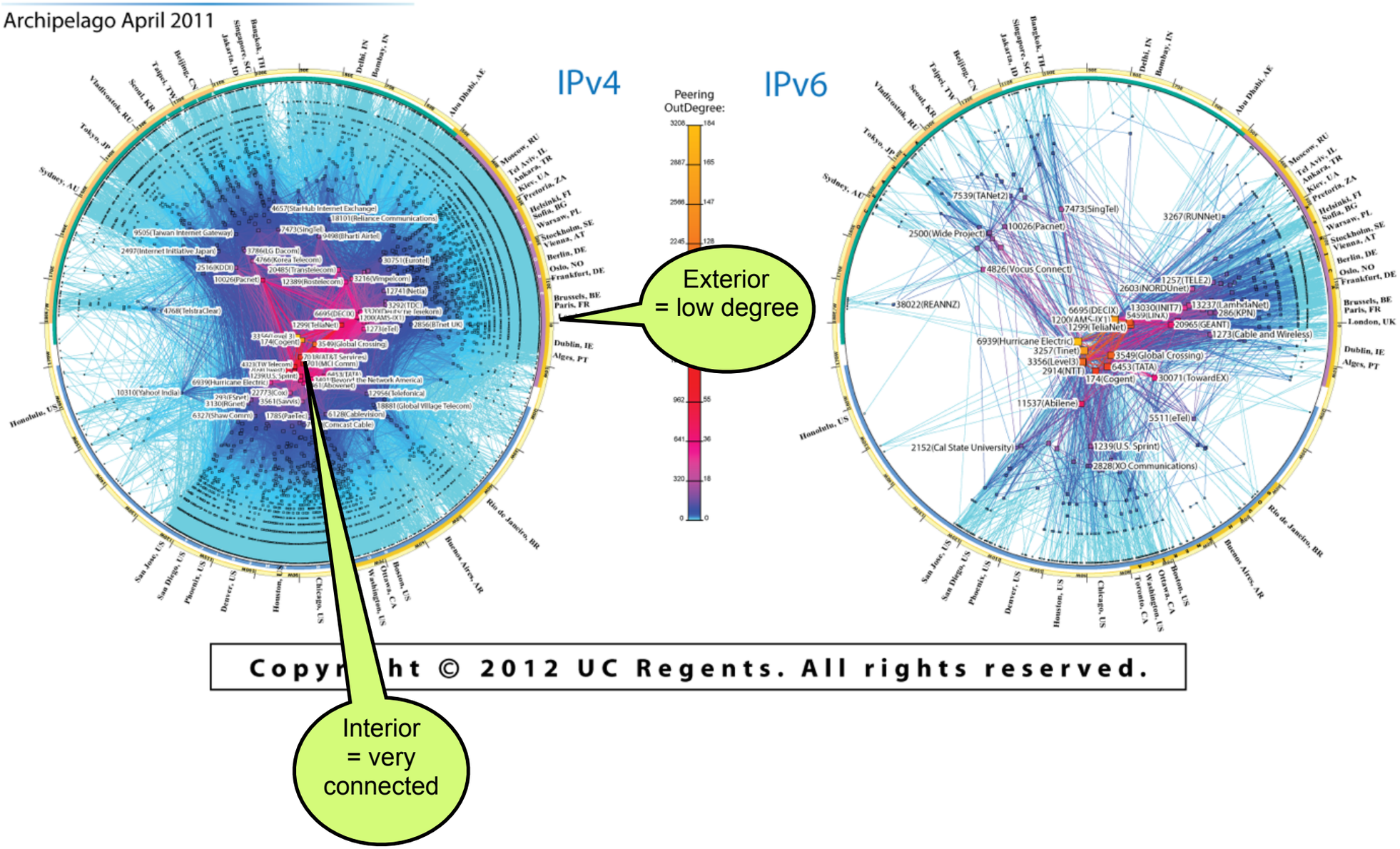
- Today, Internet is composed of about 50000 *Autonomous systems*
  - Access networks
  - Contents providers
  - ISPs networks
  - Company networks
  - etc.




**Evolution of the number of autonomous systems in the Internet**

*Source : http://bgp.potaroo.net/as1221/bgp-active.html*

# Graphically



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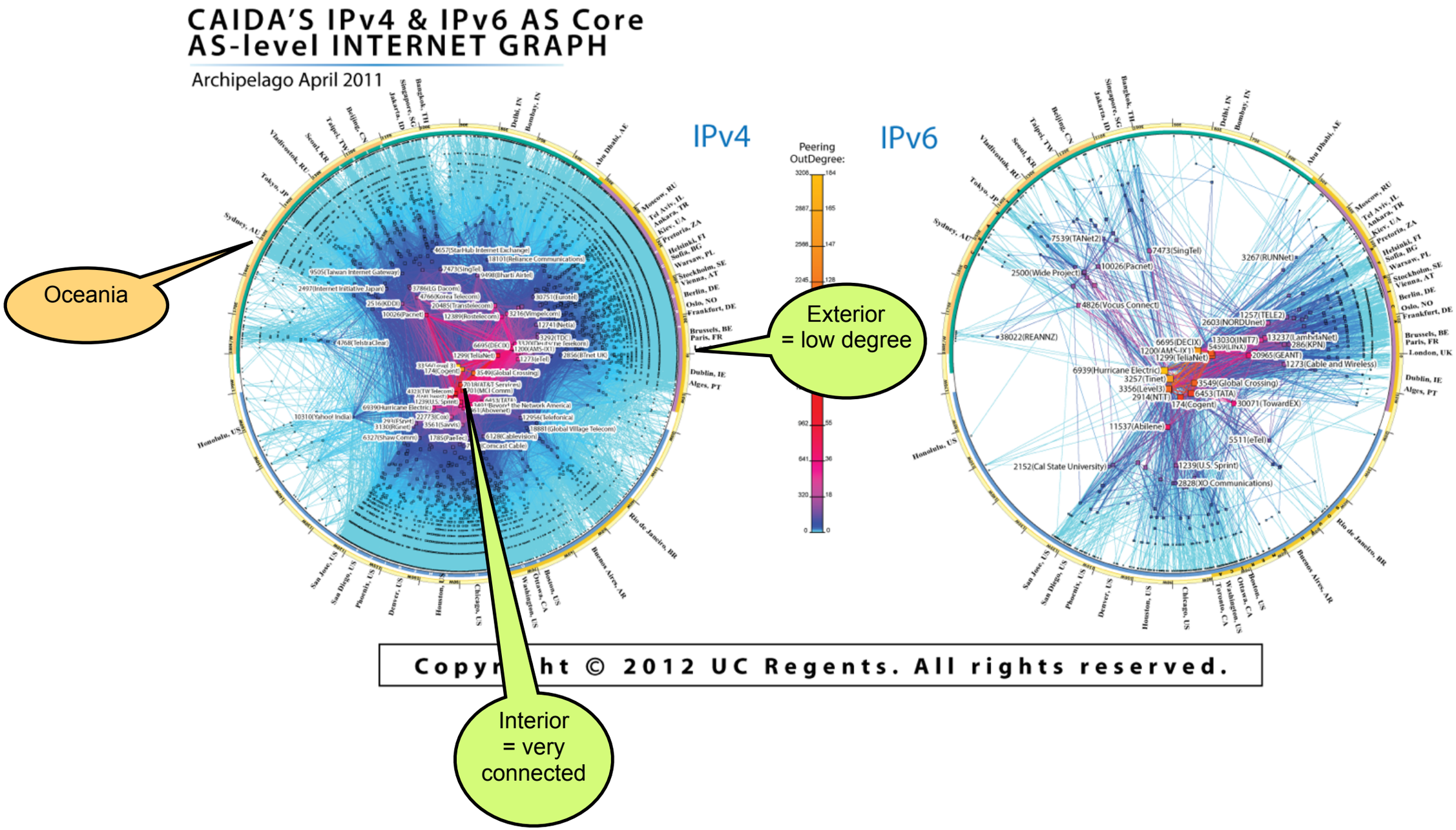

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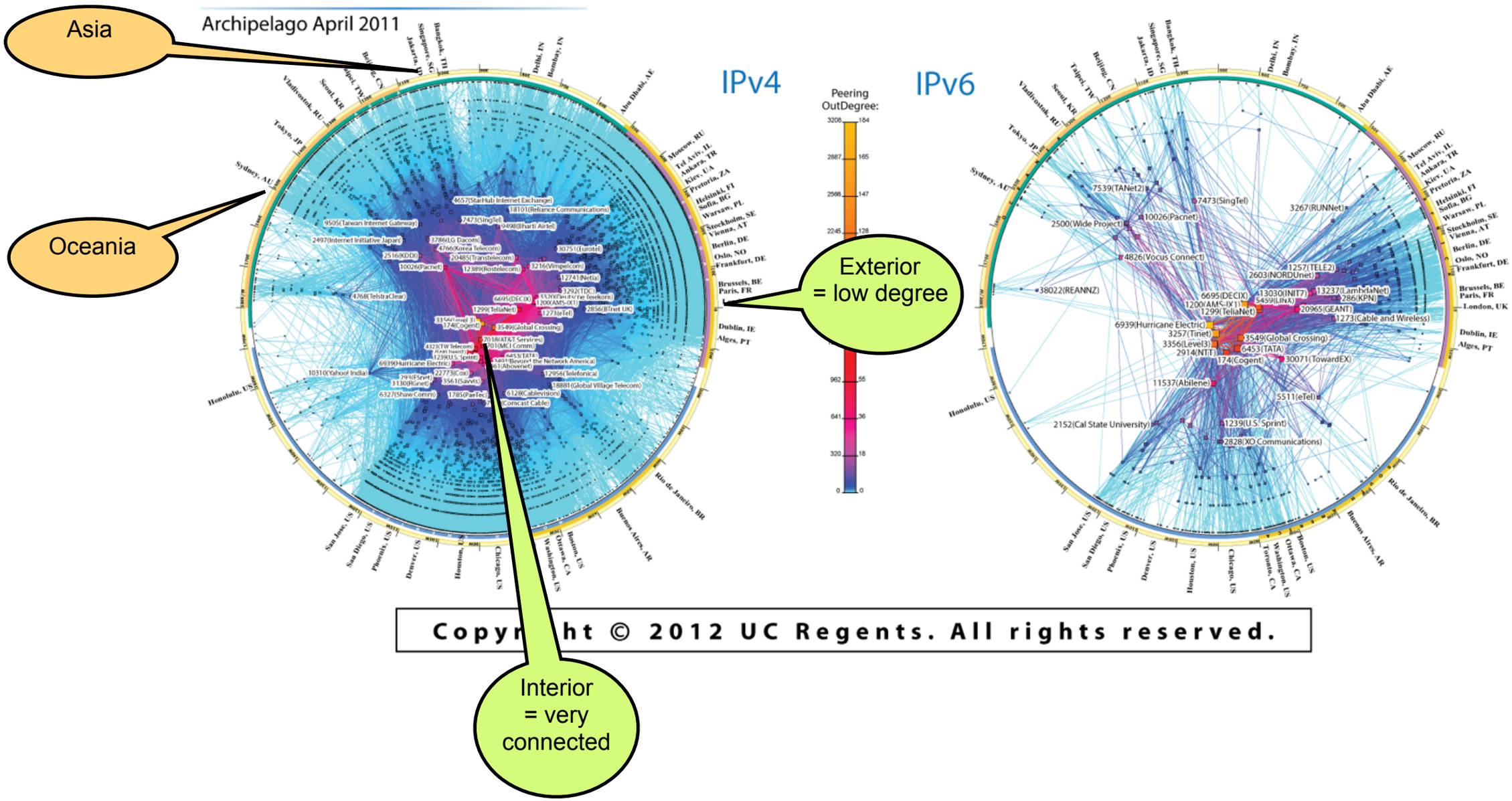

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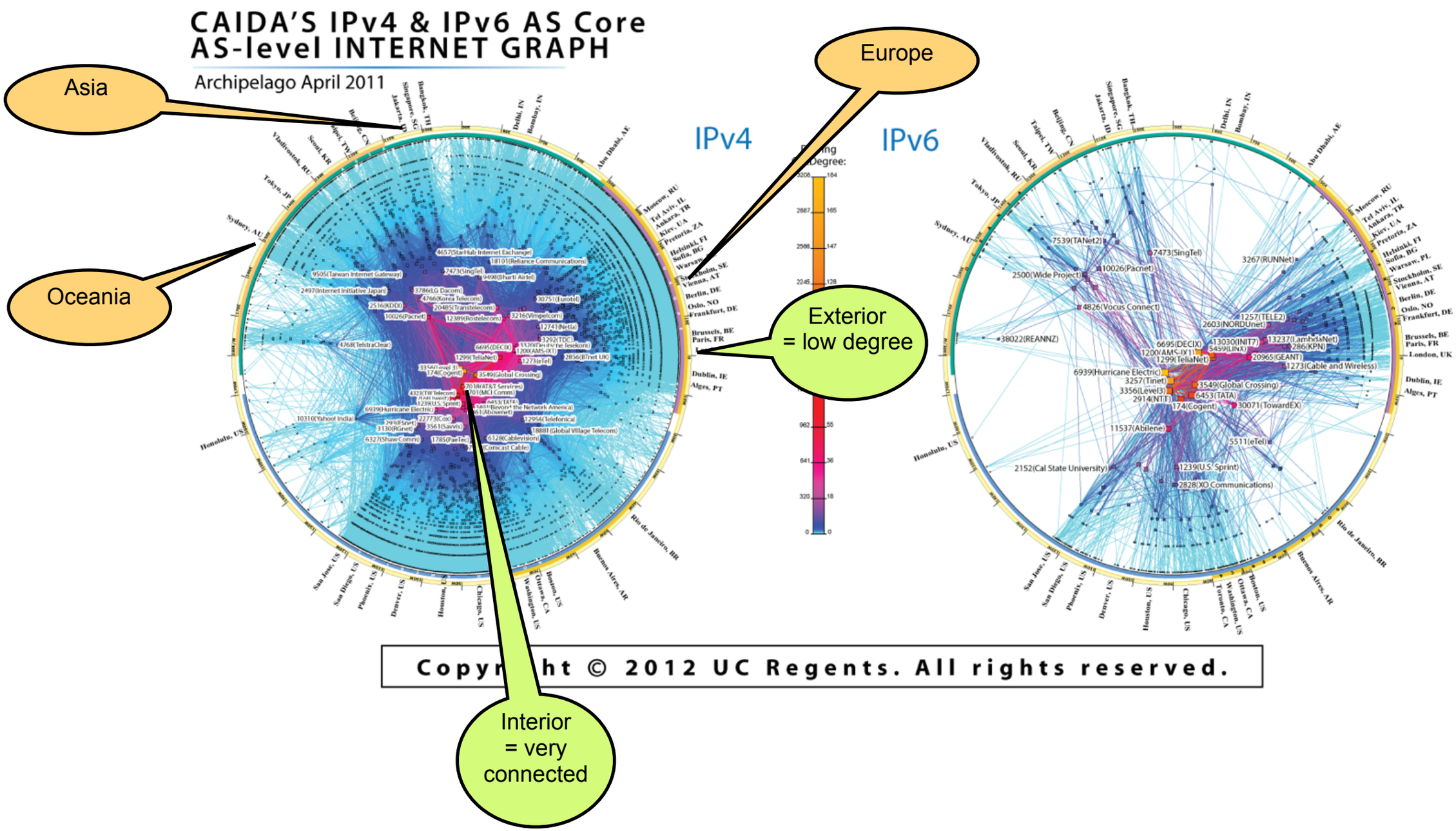

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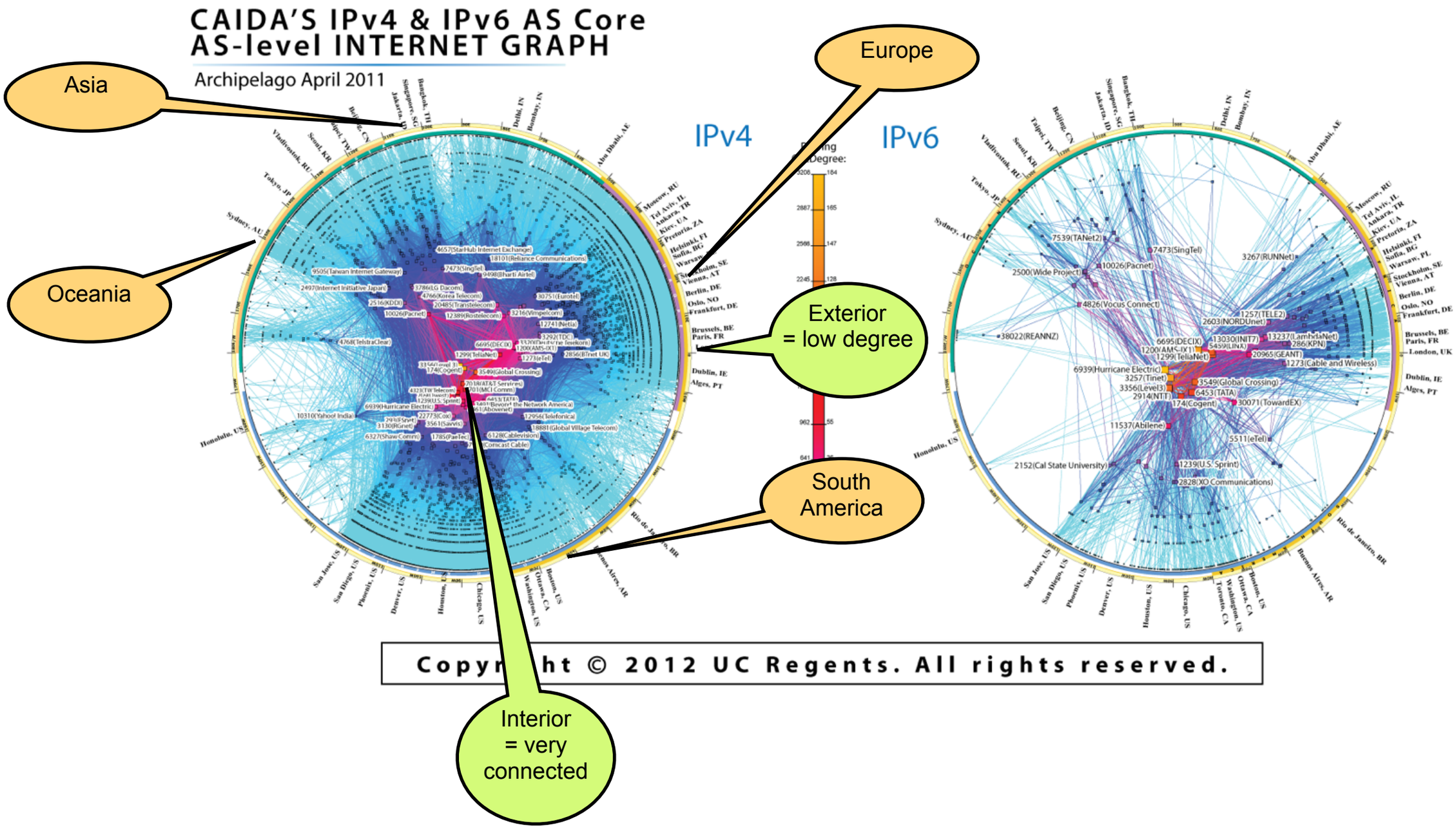

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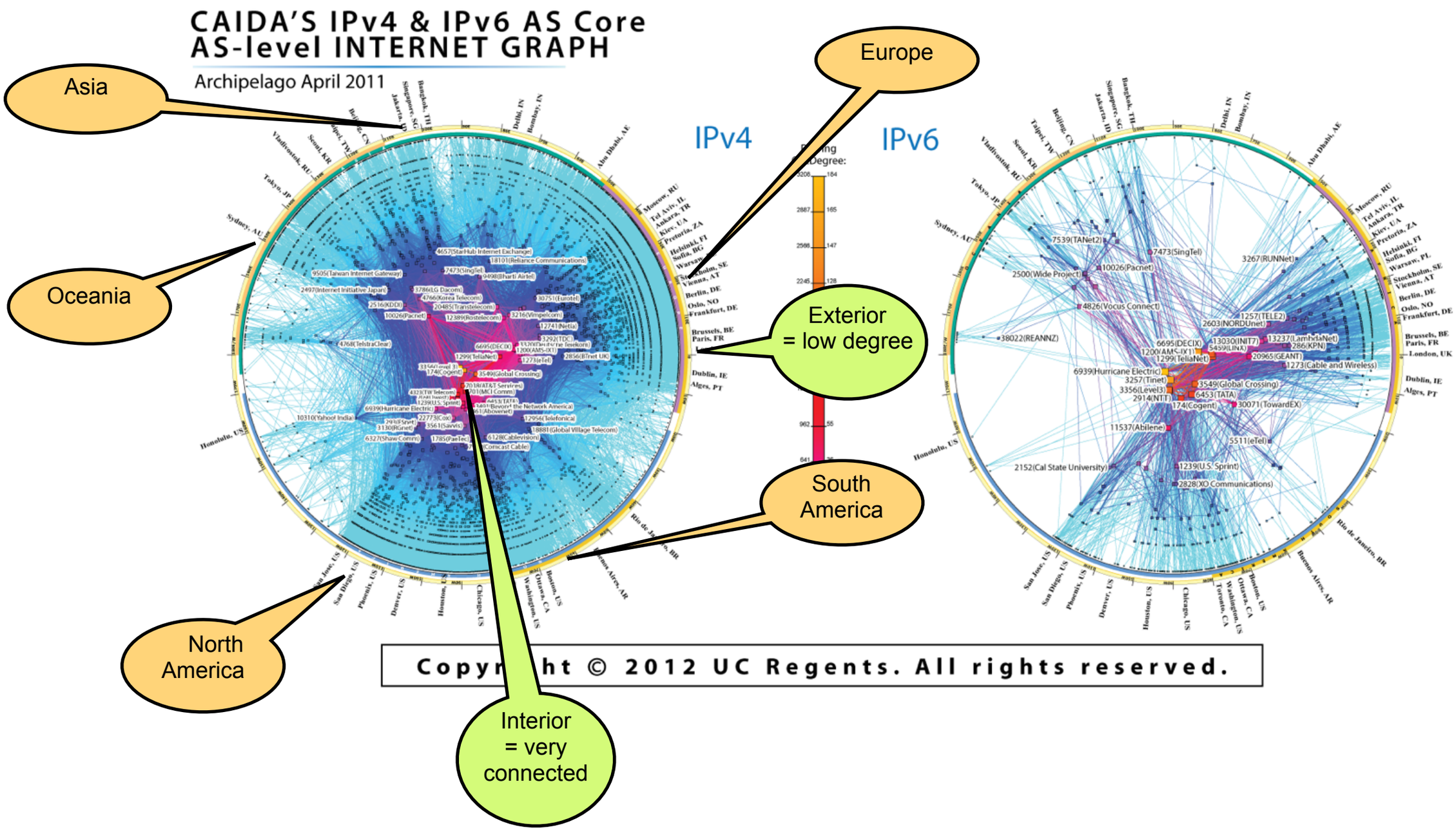
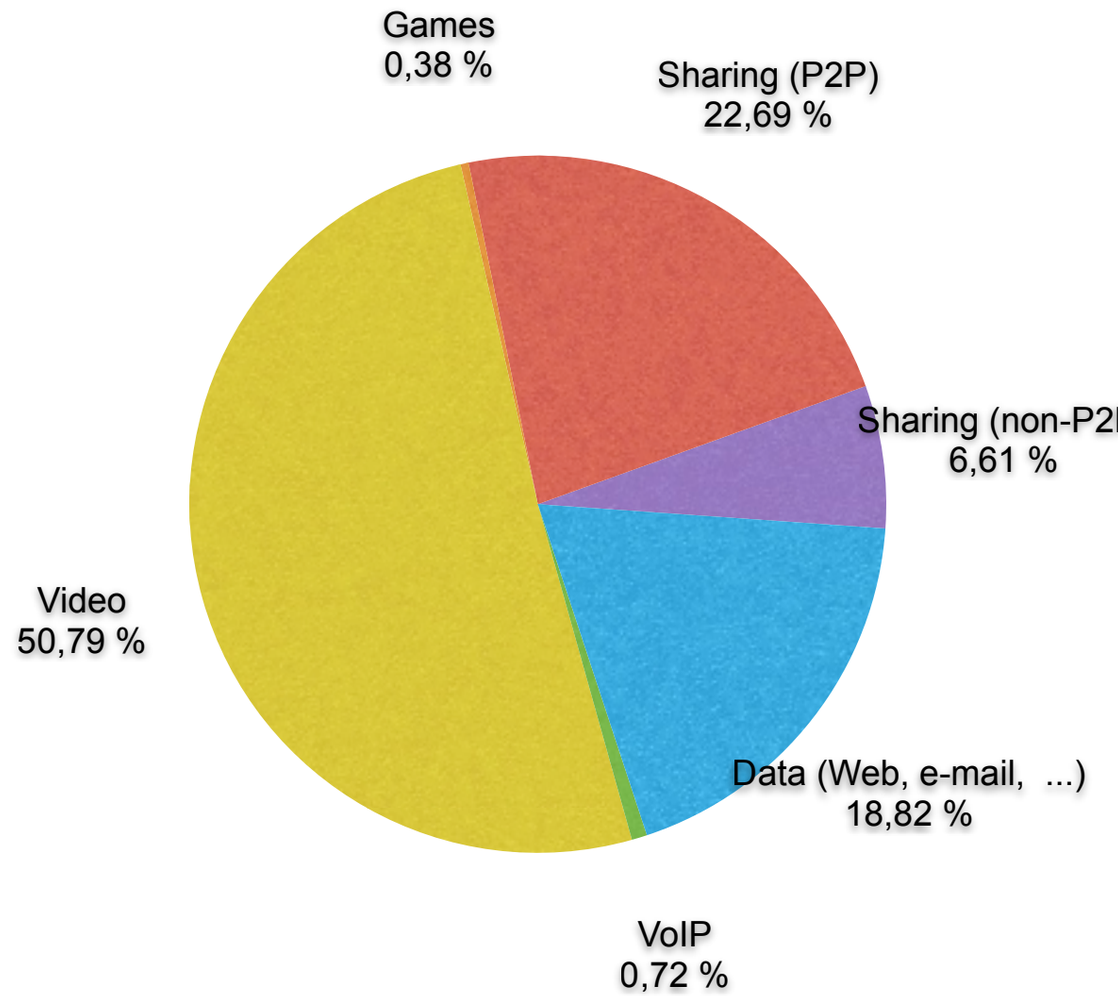


# Applications

# Multiservices Networks

- Internet, unlike PSTN, is not dedicated to a single service
  - Web (Google, Yahoo, Facebook, Wikipedia)
  - Downloads (FTP, P2P, storage, ...)
  - Messaging (instantaneous, e-mail, twitter, ...)
  - Video (Streaming (youtube), broadcast (TV), VoD, ...)
  - Telephony (ToIP, Skype, ...)
  - Online Gaming
  - “Cloud Computing” (Google Docs, iCloud, Salesforce, Amazon, ...)
  - etc.

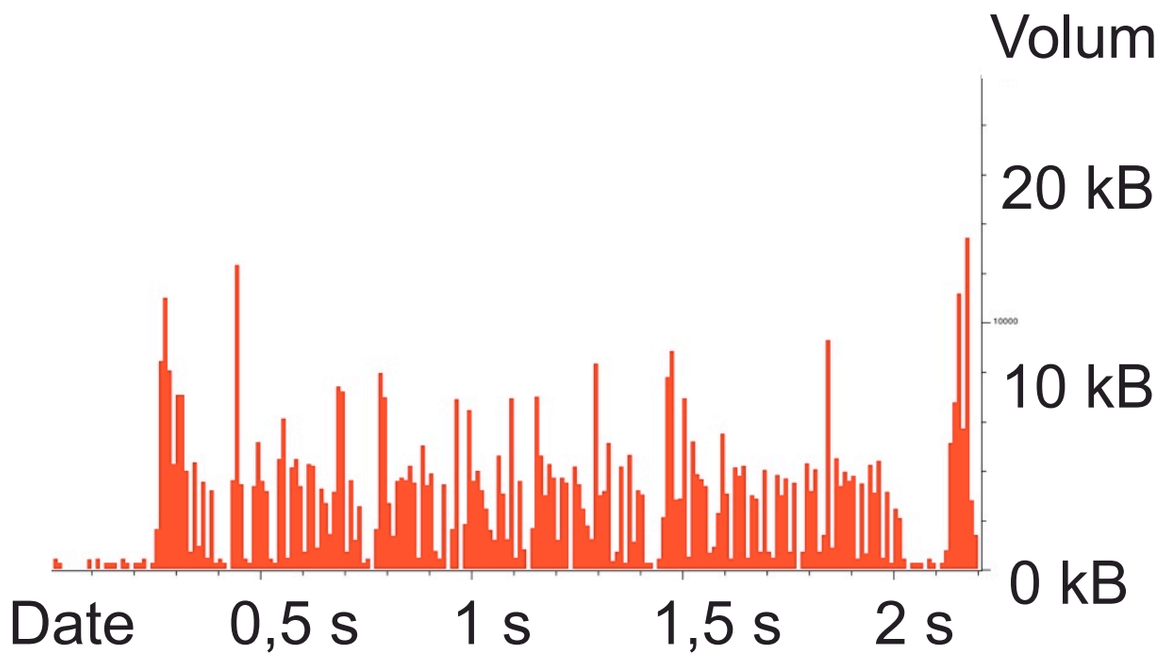



**Sources repartition on hi-speed links**

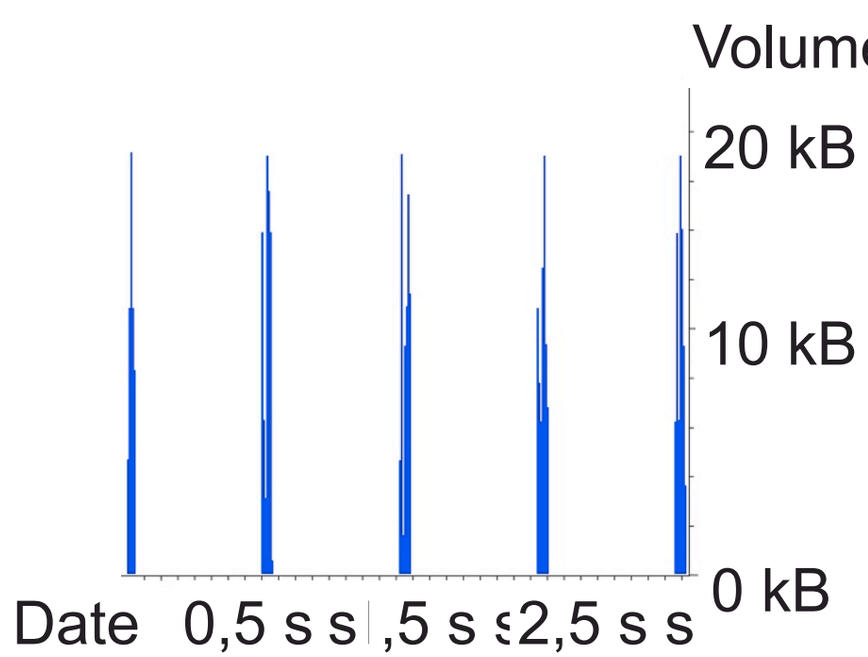
*Source : Cisco Visual Networking Index, 2012*

# Applications vs. network performance

- Inserting a probe (hardware or software) between the source and destination of a flow, it is possible to measure data flows characteristics




http://www.fi.enst.fr/df/cgi-bin/trombino.cgi



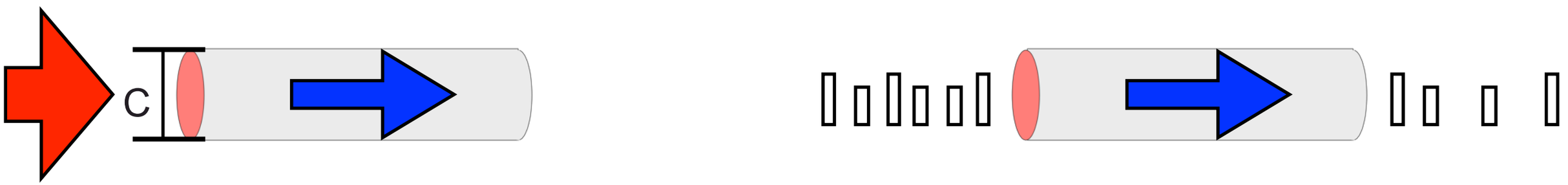

http://www.youtube.fr

- Video : average duration 270s at 300 kb/s throughput (bitrate)
  - http://www.websiteoptimization.com/bw/1108/
- Average web page size : 1585 kB
  - http://www.httparchive.org/interesting.php

# Data throughput vs. network capacity

- A flow's throughput is the amount of data emitter per unit of time
  - Note: averaged notion, be careful to the observation interval
- A network's capacity is the amount of information that can be tranferred per unit of time.
  - Influenced by : medium bandwidth (Hz) ; coding ; channel noise ; ...

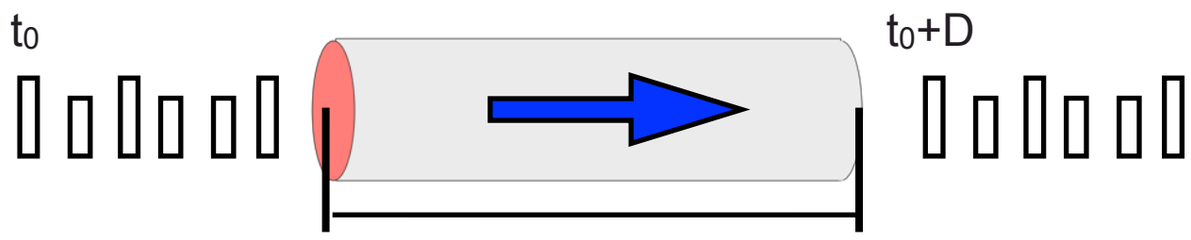
- Effect on data flows:
  - Slow-down (X bit are sent $T_1$ s ; transmitted in $T_2$ s.)
  - Information loss (can be compensated by retransmission)



# Delay

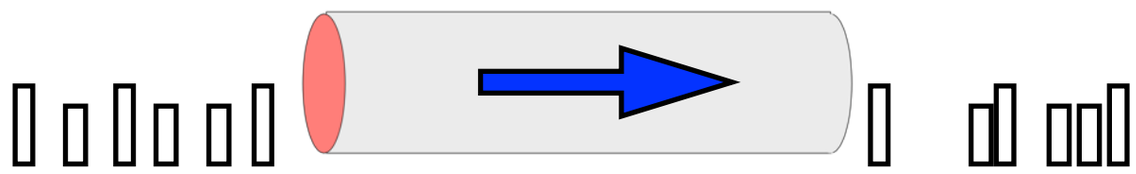
- The latency is the propagation time of a single data unit (one symbol, one bit) between an emitter and a receiver
  - The *transmission delay* is the same notion for a frame
  - Influenced by : distance, propagation speed, interconnection devices load, ...

- Effect on data flows :
  - shift in the time scale (the first bit of information is emitted and received at different times)



# Jitter

- The jitter is the variation of the delay
  - Influenced by: medium load, interconnection devices load
- Effect of data flows:
  - loss of rhythm
- The usual counter-measure consists, when it is possible, to insert buffers on the receiver's side
  - Increase in connection delay for initial buffering and for buffer dimensioning



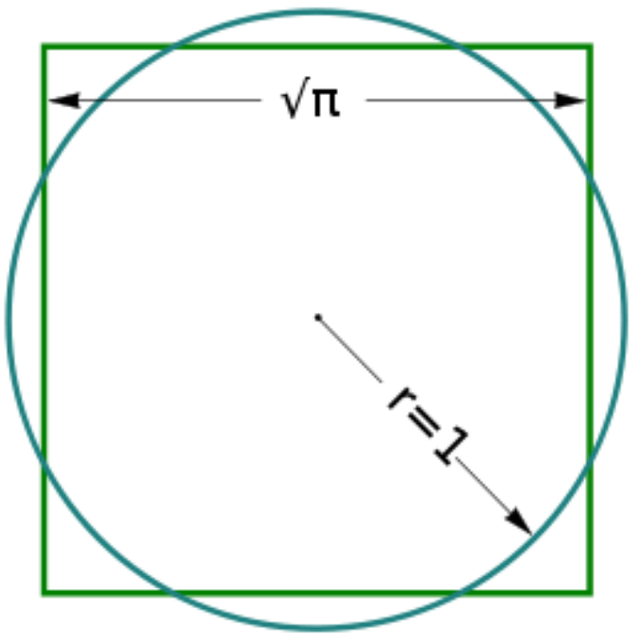
# Applications classification

- **Elastic** applications are not much sensitive to network performance
  - Examples: file transfer, web pages download, e-mail
  - Reasonable performance appreciated
- **Conversational** applications are delay-sensitive
  - Examples: telephone, videoconferencing, online gaming
  - Past a certain limit, a real-time conversation is not possible anymore
- **Streaming** applications are jitter-sensitive
  - Examples: on-demand video, broadcast video/audio
  - A bad buffer dimensioning causes pauses while playing
- Some applications are throughput-sensitive
  - Example: video (on-demand or broadcast)
  - Below a certain throughput, the network cannot meet application's requirements

# Relative importance of performance criteria

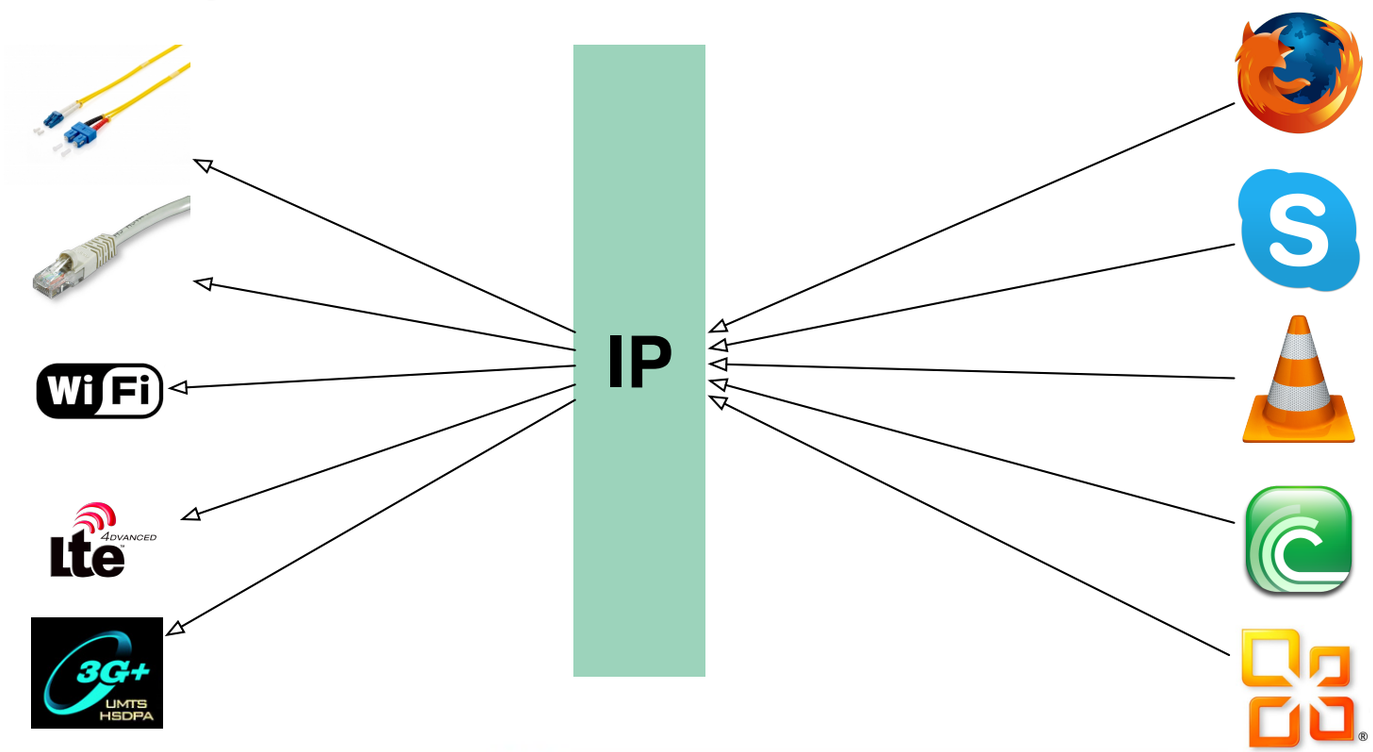
| | Typical Throughput | Tolerated loss rage | Delay | Jitter |
|---|---|---|---|---|
| **File tranfer** | As fast as possible | As low as possible (retransmissions) | n/a | n/a |
| **Conversational (voice) - ToIP** | 6,4 kb/s — 64 kb/s | 0,1% (strong compression) à 15% | 150 ms à 300 ms mouth to ear | 0 à 50 ms |
| **Conversational (video)** | 128 kbit/s (mobile) to 768 kbit/s | Depends on compression | 150 ms à 300 ms | 0 à 50 ms |
| **Broadcast (voice)** | 128 kb/s — 900 kb/s | 15% acceptable (no compression) | few seconds | low |
| **Diffusion (H.264 video)** | 64 kbit/s (Mobile) to 20 Mbit/s (HDTV) | Depends on compression | few seconds | low |
| **Interactive (Web, ...)** | n/a | as low as possible (retransmissions) | 600 ms | n/a |
| **Asynchronous (e-mail, ...)** | n/a | n/a | n/a | n/a |

# Multiple applications over an heterogeneous network

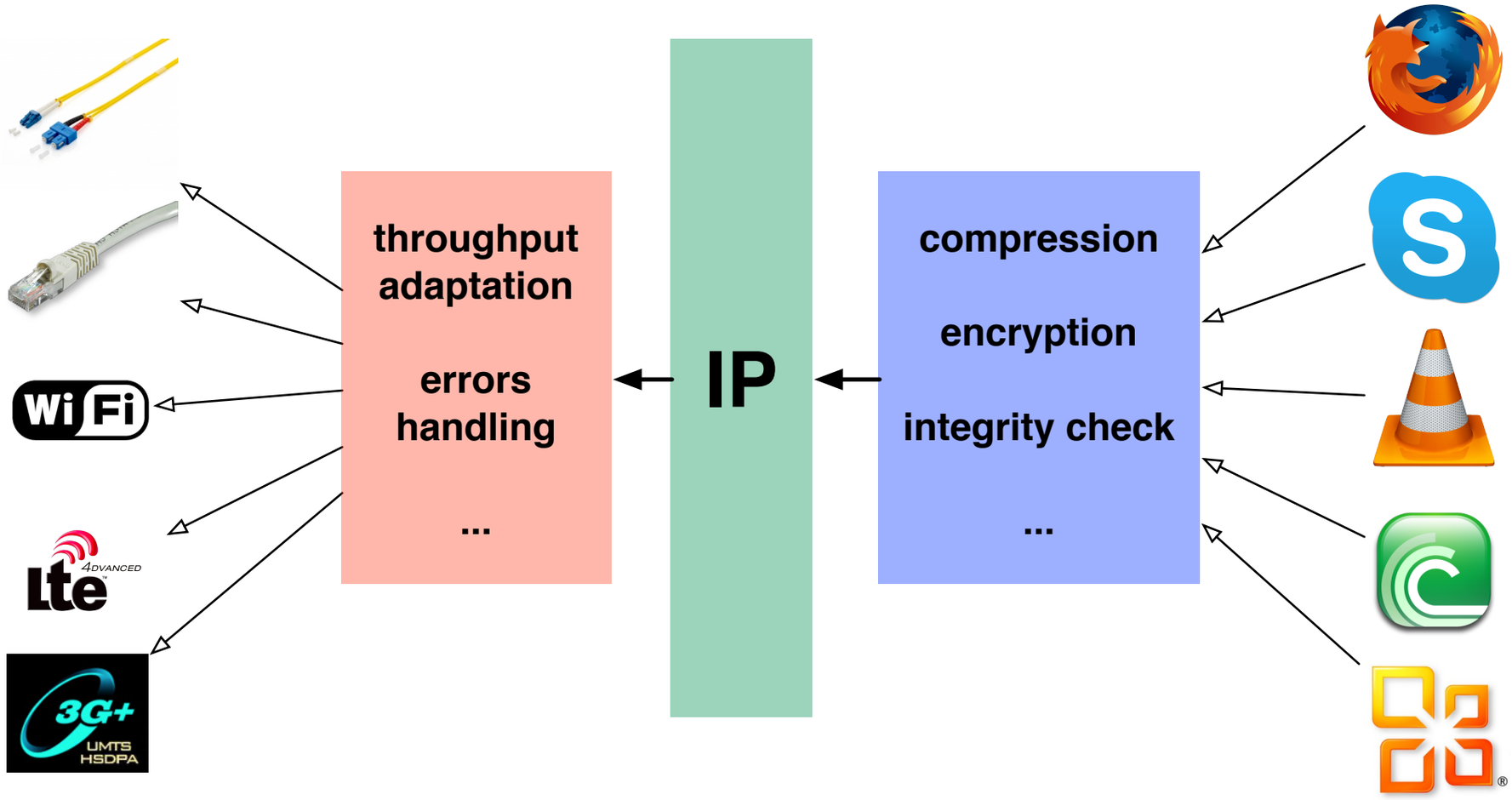


# How to handle multiple services ?

- Network and applications should be independent
  - The network needs to be blind to what if carries
    - It only knows it is data
  - Applications need to ignore the network technology and shape
    - IP abstracts the network: similar behavior on Ethernet, Wi-Fi, ADSL, 3G, ...
    - Packet switching
    - Only performance can change



# Aggregation of common tasks

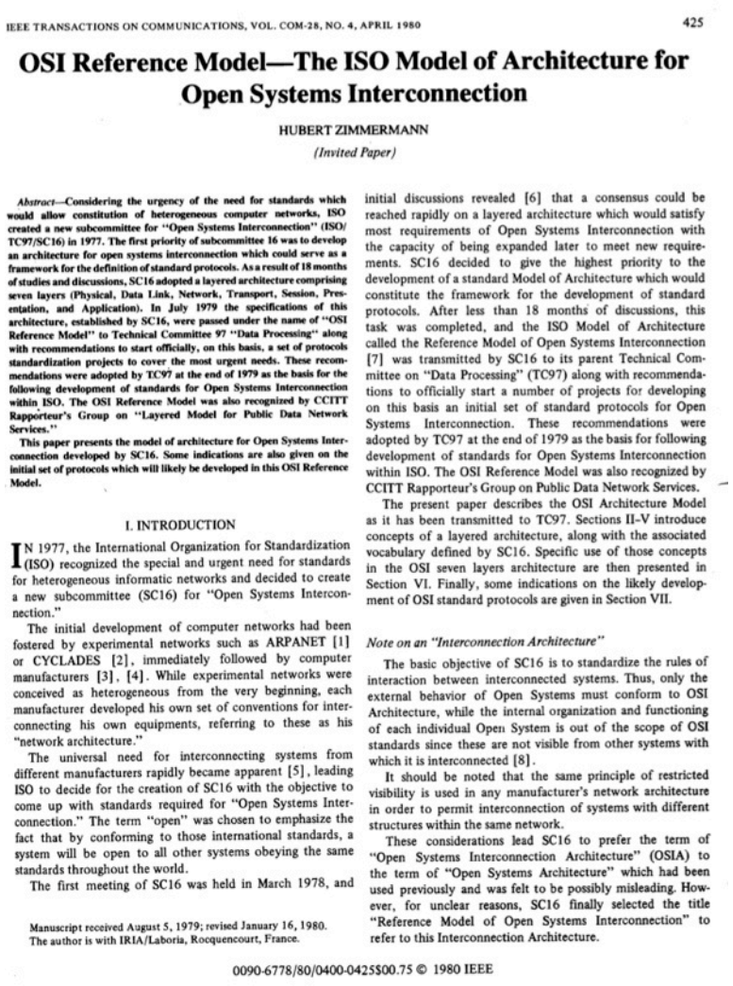


# Who does what ?

- **To transmit a data flow (file, conversation, ...)**
- Source and destination *applications* and/or *operating systems*
  - Cut the file in small units (packets) and reassemble it
- The *network* (from LANs to ISPs)
  - Find an efficient path (sequence of ISPs, of devices, ...) from source to destination
- Each network *device* or *communication link*
  - Takes care of the transmission to the next designated checkpoint

# The OSI (Open Systems Interconnection) model

- Generic model of the organization of the tasks a network has to perform
  - Conception: end 1970's
- Purposes:
  - Facilitate independence between network and applications
  - Allow heterogeneous networks to interconnect
  - Avoid useless or duplicated operations
  - Push intelligence (i.e. most time-consuming algorithms) to the network edges, where traffic is the lowest



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**OSI Reference Model—The ISO Model of Architecture for Open Systems Interconnection**

HUBERT ZIMMERMANN
*(Invited Paper)*

*Abstract*—**Considering the urgency of the need for standards which would allow constitution of heterogeneous computer networks, ISO created a new subcommittee for "Open Systems Interconnection" (ISO/TC97/SC16) in 1977. The first priority of subcommittee 16 was to develop an architecture for open systems interconnection which could serve as a framework for the definition of standard protocols. As a result of 18 months of studies and discussions, SC16 adopted a layered architecture comprising seven layers (Physical, Data Link, Network, Transport, Session, Presentation, and Application). In July 1979 the specifications of this architecture, established by SC16, were passed under the name of "OSI Reference Model" to Technical Committee 97 "Data Processing" along with recommendations to start officially, on this basis, a set of protocols standardization projects to cover the most urgent needs. These recommendations were adopted by TC97 at the end of 1979 as the basis for the following development of standards for Open Systems Interconnection within ISO. The OSI Reference Model was also recognized by CCITT Rapporteur's Group on "Layered Model for Public Data Network Services."**

**This paper presents the model of architecture for Open Systems Interconnection developed by SC16. Some indications are also given on the initial set of protocols which will likely be developed in this OSI Reference Model.**

I. INTRODUCTION

IN 1977, the International Organization for Standardization (ISO) recognized the special and urgent need for standards for heterogeneous informatic networks and decided to create a new subcommittee (SC16) for "Open Systems Interconnection."

The initial development of computer networks had been fostered by experimental networks such as ARPANET [1] or CYCLADES [2], immediately followed by computer manufacturers [3], [4]. While experimental networks were conceived as heterogeneous from the very beginning, each manufacturer developed his own set of conventions for interconnecting his own equipments, referring to these as his "network architecture."

The universal need for interconnecting systems from different manufacturers rapidly became apparent [5], leading ISO to decide for the creation of SC16 with the objective to come up with standards required for "Open Systems Interconnection." The term "open" was chosen to emphasize the fact that by conforming to those international standards, a system will be open to all other systems obeying the same standards throughout the world.

The first meeting of SC16 was held in March 1978, and initial discussions revealed [6] that a consensus could be reached rapidly on a layered architecture which would satisfy most requirements of Open Systems Interconnection with the capacity of being expanded later to meet new requirements. SC16 decided to give the highest priority to the development of a standard Model of Architecture which would constitute the framework for the development of standard protocols. After less than 18 months of discussions, this task was completed, and the ISO Model of Architecture called the Reference Model of Open Systems Interconnection [7] was transmitted by SC16 to its parent Technical Committee on "Data Processing" (TC97) along with recommendations to officially start a number of projects for developing on this basis an initial set of standard protocols for Open Systems Interconnection. These recommendations were adopted by TC97 at the end of 1979 as the basis for following development of standards for Open Systems Interconnection within ISO. The OSI Reference Model was also recognized by CCITT Rapporteur's Group on Public Data Network Services.

The present paper describes the OSI Architecture Model as it has been transmitted to TC97. Sections II-V introduce concepts of a layered architecture, along with the associated vocabulary defined by SC16. Specific use of those concepts in the OSI seven layers architecture are then presented in Section VI. Finally, some indications on the likely development of OSI standard protocols are given in Section VII.

*Note on an "Interconnection Architecture"*

The basic objective of SC16 is to standardize the rules of interaction between interconnected systems. Thus, only the external behavior of Open Systems must conform to OSI Architecture, while the internal organization and functioning of each individual Open System is out of the scope of OSI standards since these are not visible from other systems with which it is interconnected [8].

It should be noted that the same principle of restricted visibility is used in any manufacturer's network architecture in order to permit interconnection of systems with different structures within the same network.

These considerations lead SC16 to prefer the term of "Open Systems Interconnection Architecture" (OSIA) to the term of "Open Systems Architecture" which had been used previously and was felt to be possibly misleading. However, for unclear reasons, SC16 finally selected the title "Reference Model of Open Systems Interconnection" to refer to this Interconnection Architecture.

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Hubert Zimmermann
***OSI Reference Model — The ISO Model of Architecture for Open Systems Interconnection***
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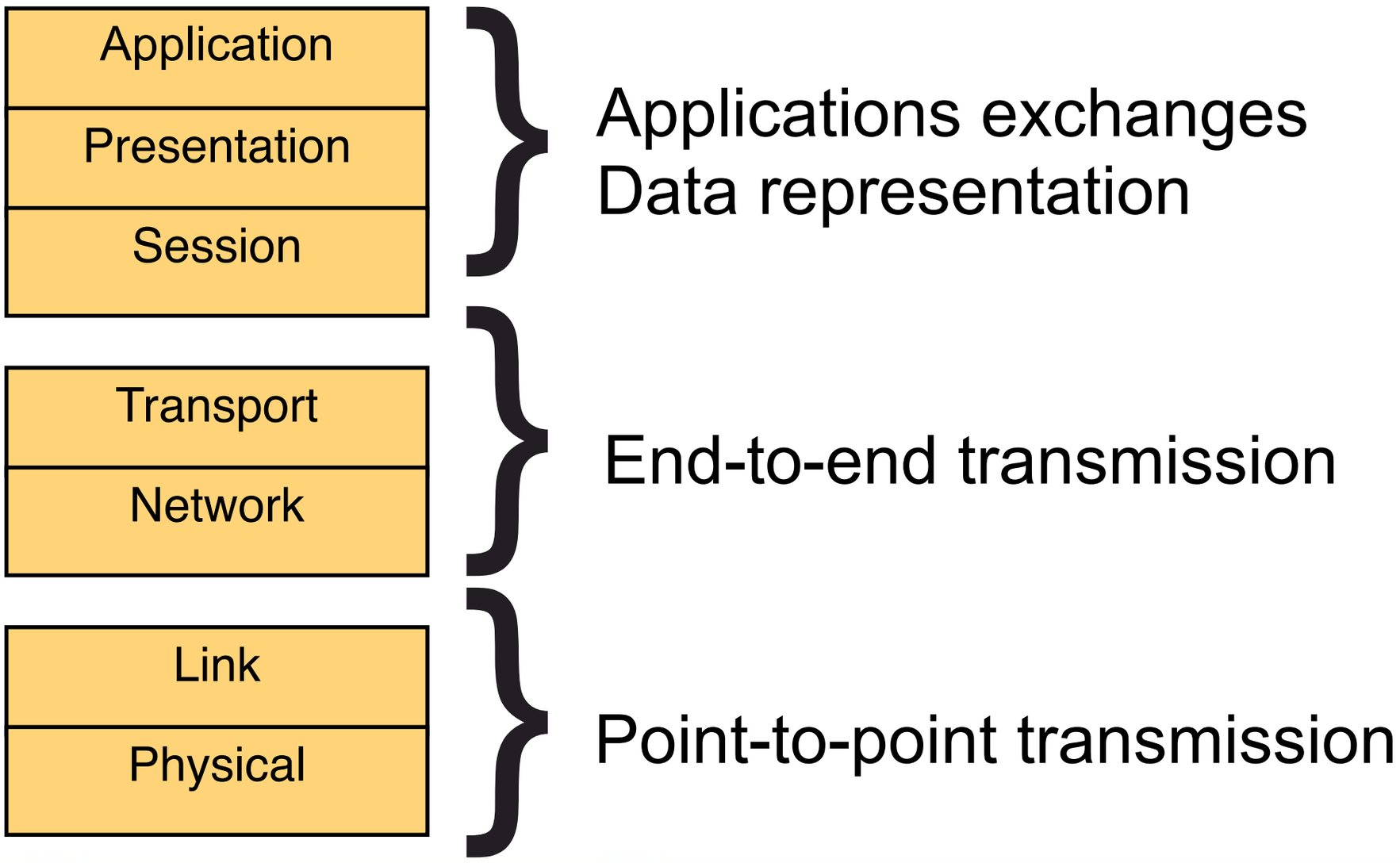
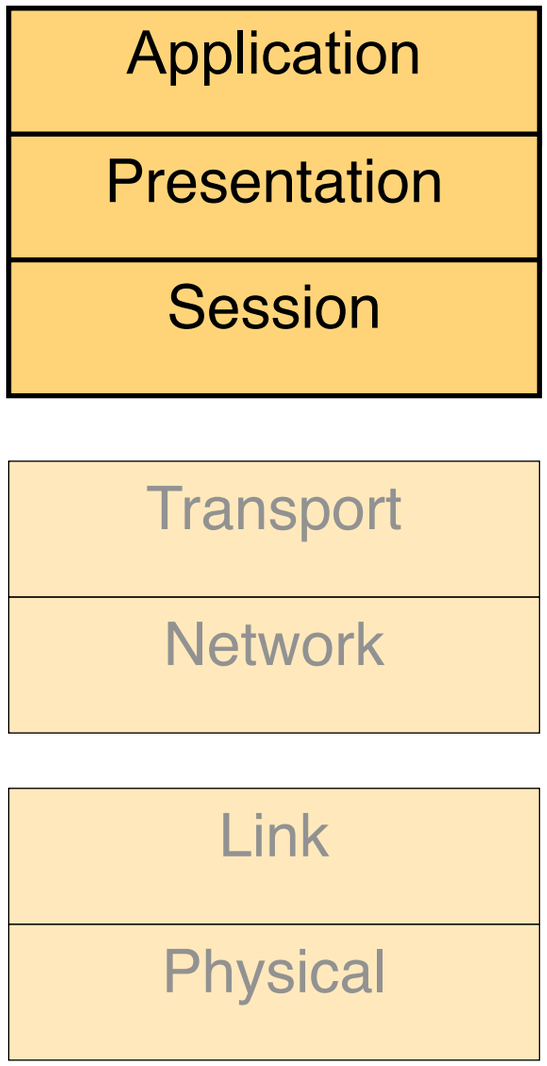
Avril 1980

# 7 layers model

- The model decomposes the communication in 7 steps
  - Information traverses 7 successive layers from application to transmission
  - Layer n only uses the services offered by layer n-1

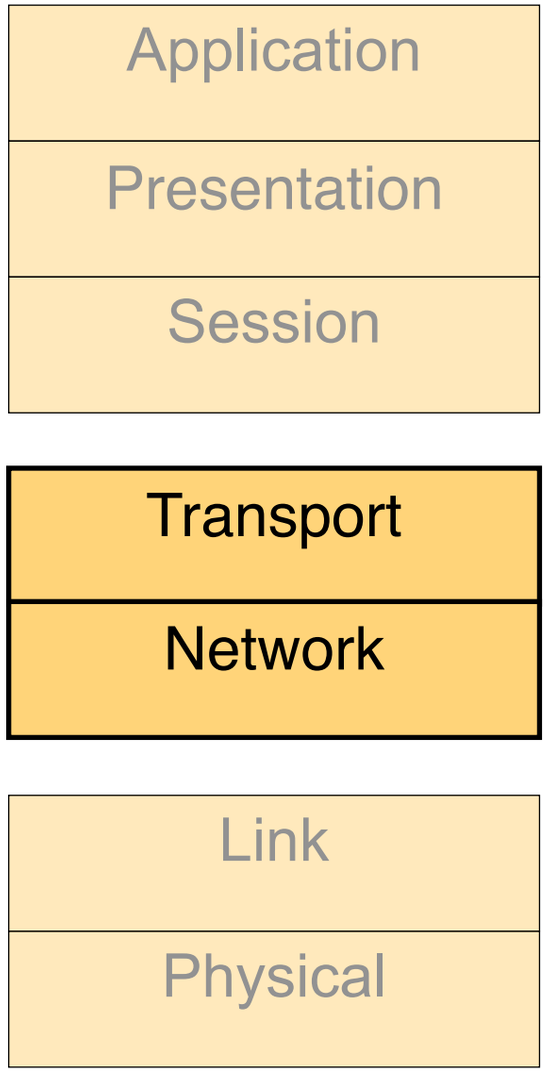


# "Applicative" layers



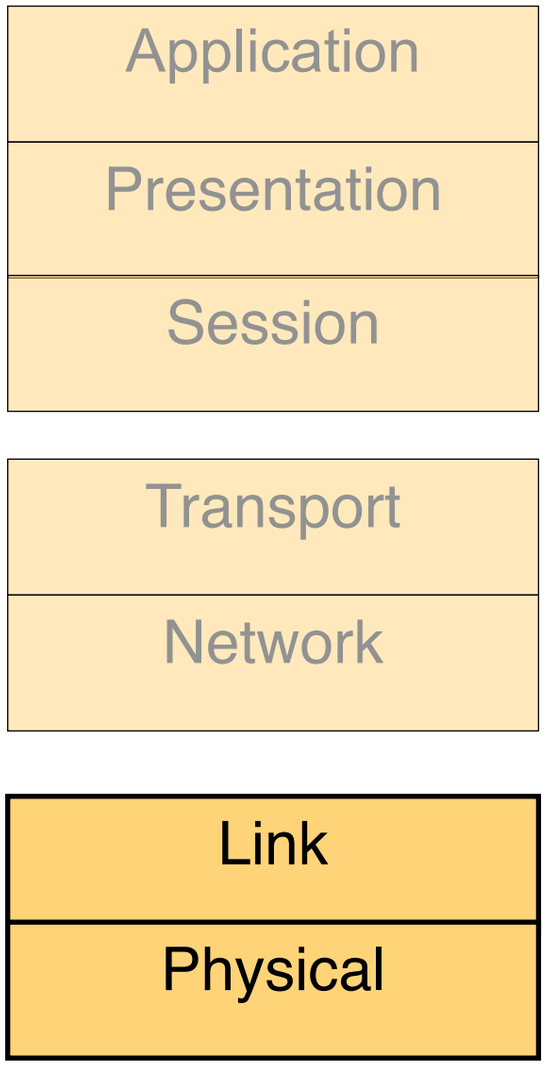

- Application layers
  - Protocol (language) between two applications
  - Example: ask for a web page, stream MPEG video, audio flow transmission, ...
- Presentation layer
  - Data structure
  - Representation (XML), encryption, compression
- Session layer
  - Applications synchronization
  - Maintain a global shared state
  - Errors recovery

# "End-to-end" layers




- Transport layer
  - End-to-end reliability
  - Throughput control (avoid saturation)
  - Multiplexing / demultiplexing between applications
- Network layer
  - Routing (find good paths in the network)
  - Global addressing (organization, definition of the addressing space)

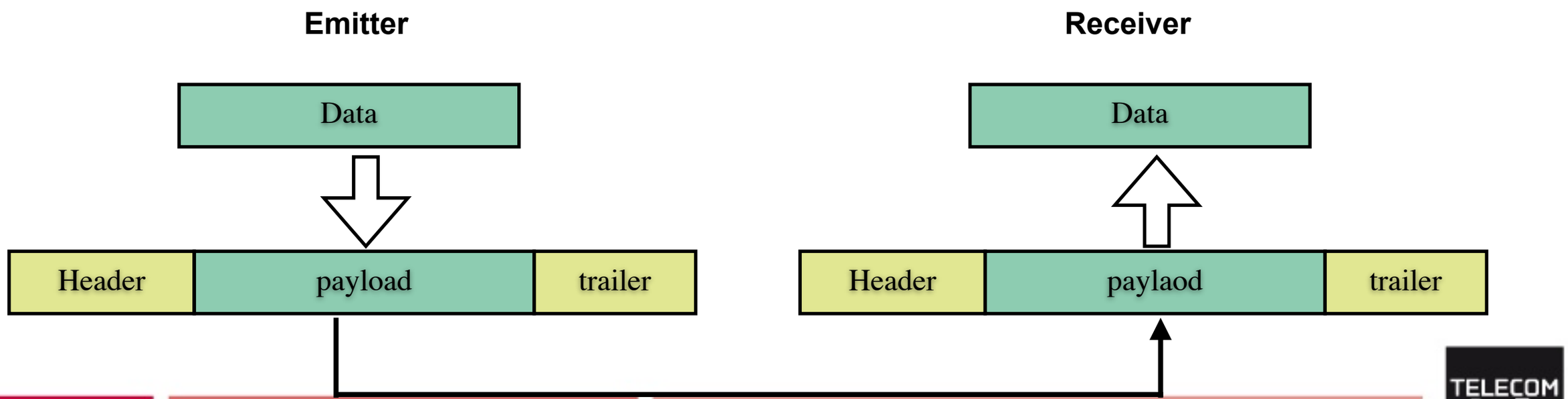
# "Point-to-point" layers




- Link layer
  - Multiple concurrent access to a link
  - Frames beginning and end
  - Detection, correction and handling of transmission errors
- Physical layer
  - Coding from bits to signals
  - Bits transmission

# In practice: encapsulation

- A message created by an application is passed to the presentation layer
- Presentation layer does not care about the message contents
- It adds its own information (header) to the data before transmitting it to the session layer
- etc.
  - For layer *n*, the part containing the real data is called **payload**
  - Layer n payload corresponds to layer n+1 payload and headers



# Example: HTTP

- RFC 2616 defines the exchanges between a web browser and a server
  - Example: display main page of http://www.telecom-paristech.fr
  - 1) The client (browser) sends :

command

parameters

```
GET / HTTP/1.1
Host:www.telecom-paristech.fr
```

protocol version

  - 2) The server receives this message, interprets it and sends back:

Return code 200 = OK

Server identification

Contents characteristics

HTML code of the homepage

```
HTTP/1.1 200 OK
Date: Mon, 23 Jan 2012 14:54:13 GMT
Server: Apache
X-Powered-By: PHP/5.3.3-7+squeeze3
Set-Cookie: fe_typo_user=cd1c6aa97a8a65b1ee671c8871463075; path=/
Vary: Accept-Encoding
Transfer-Encoding: chunked
Content-Type: text/html; charset=utf-8

131b8
<!DOCTYPE html
     PUBLIC "-//W3C//DTD XHTML 1.1//EN"
     "http://www.w3.org/TR/xhtml11/DTD/xhtml11.dtd">
<html xmlns="http://www.w3.org/1999/xhtml" xml:lang="fr">
<head>
...
```

# Encaspulation in practice: what is transferred over a network link

| Ethernet | IP | TCP | HTTP |
|---|---|---|---|

```
|00|04|80|84|56|00|00|1f|f3|8b|7b|45|08|00|45|00|03|ae|39|a0|40|00|40|06|11|14|89|c2|a5|09
|89|c2|34|08|e5|01|00|50|74|96|94|35|44|0c|c4|2e|80|18|20|2b|88|62|00|00|01|01|08|0a|32|ee
|75|26|70|36|59|19|47|45|54|20|2f|20|48|54|54|50|2f|31|2e|31|0d|0a|48|6f|73|74|3a|20|77|77
|77|2e|74|65|6c|65|63|6f|6d|2d|70|61|72|69|73|74|65|63|68|2e|66|72|0d|0a|43|6f|6e|6e|65|63
|74|69|6f|6e|3a|20|6b|65|65|70|2d|61|6c|69|76|65|0d|0a|43|61|63|68|65|2d|43|6f|6e|74|72|6f
|6c|3a|20|6d|61|78|2d|61|67|65|3d|30|0d|0a|41|63|63|65|70|74|3a|20|74|65|78|74|2f|68|74|6d
|6c|2c|61|70|70|6c|69|63|61|74|69|6f|6e|2f|78|68|74|6d|6c|2b|78|6d|6c|2c|61|70|70|6c|69|63
|61|74|69|6f|6e|2f|78|6d|6c|3b|71|3d|30|2e|39|2c|2a|2f|2a|3b|71|3d|30|2e|38|0d|0a|55|73|65
|72|2d|41|67|65|6e|74|3a|20|4d|6f|7a|69|6c|6c|61|2f|35|2e|30|20|28|4d|61|63|69|6e|74|6f|73
|68|3b|20|49|6e|74|65|6c|20|4d|61|63|20|4f|53|20|58|20|31|30|5f|38|5f|32|29|20|41|70|70|6c
|65|57|65|62|4b|69|74|2f|35|33|37|2e|31|37|20|28|4b|48|54|4d|4c|2c|20|6c|69|6b|65|20|47|65
|63|6b|6f|29|20|43|68|72|6f|6d|65|2f|32|34|2e|30|2e|31|33|31|32|2e|35|36|20|53|61|66|61|72
|69|2f|35|33|37|2e|31|37|0d|0a|44|4e|54|3a|20|31|0d|0a|41|63|63|65|70|74|2d|45|6e|63|6f|64
|69|6e|67|3a|20|67|7a|69|70|2c|64|65|66|6c|61|74|65|2c|73|64|63|68|0d|0a|41|63|63|65|70|74
|2d|4c|61|6e|67|75|61|67|65|3a|20|65|6e|2d|55|53|2c|65|6e|3b|71|3d|30|2e|38|0d|0a|41|63|63
|65|70|74|2d|43|68|61|72|73|65|74|3a|20|49|53|4f|2d|38|38|35|39|2d|31|2c|75|74|66|2d|38|3b
|71|3d|30|2e|37|2c|2a|3b|71|3d|30|2e|33|0d|0a|43|6f|6f|6b|69|65|3a|20|5f|72|65|64|69|72|65
|63|74|5f|75|73|65|72|5f|69|64|70|3d|68|74|74|70|73|25|33|41|25|32|46|25|32|46|69|64|70|2e
|74|65|6c|65|63|6f|6d|2d|70|61|72|69|73|74|65|63|68|2e|66|72|25|32|46|69|64|70|25|32|46|73
|68|69|62|62|6f|6c|65|74|68|3b|20|5f|73|61|6d|6c|5f|69|64|70|3d|61|48|52|30|63|48|4d|36|4c
|79|39|70|5a|48|41|75|64|47|56|73|5a|57|4e|76|62|53|31|77|59|58|4a|70|63|33|52|6c|59|32|67
|75|5a|6e|49|76|61|57|52|77|4c|33|4e|6f|61|57|4a|69|62|32|78|6c|64|47|67|25|33|44|3b|20|5f
|73|61|6d|6c|5f|73|70|3d|61|48|52|30|63|48|4d|36|4c|79|39|6c|62|32|78|6c|4c|6e|52|6c|62|47
|56|6a|62|32|30|74|63|47|46|79|61|58|4e|30|5a|57|4e|6f|4c|6d|5a|79|3b|20|66|65|5f|74|79|70
|6f|5f|75|73|65|72|3d|32|62|62|35|31|34|36|35|39|39|64|63|38|36|39|63|61|34|66|37|61|61|62
|63|31|39|65|61|64|63|34|65|3b|20|5f|5f|75|74|6d|61|3d|32|35|39|30|35|32|34|33|31|2e|32|31
|35|31|32|31|34|34|2e|31|33|35|34|31|38|34|34|32|36|2e|31|33|35|34|31|38|34|34|32|36|2e|31
|33|35|39|33|37|36|36|39|35|2e|32|3b|20|5f|5f|75|74|6d|62|3d|32|35|39|30|35|32|34|33|31|2e
|31|2e|31|30|2e|31|33|35|39|33|37|36|36|39|35|3b|20|5f|5f|75|74|6d|63|3d|32|35|39|30|35|32
|34|33|31|3b|20|5f|5f|75|74|6d|7a|3d|32|35|39|30|35|32|34|33|31|2e|31|33|35|34|31|38|34|34
|32|36|2e|31|2e|31|2e|75|74|6d|63|73|72|3d|28|64|69|72|65|63|74|29|7c|75|74|6d|63|63|6e|3d
|28|64|69|72|65|63|74|29|7c|75|74|6d|63|6d|64|3d|28|6e|6f|6e|65|29|0d|0a|0d|0a|
```

# On the network (decoding)

Ethernet: 00 04 80 84 56 00 00 1f f3 8b 7b 45 08 00 45 00

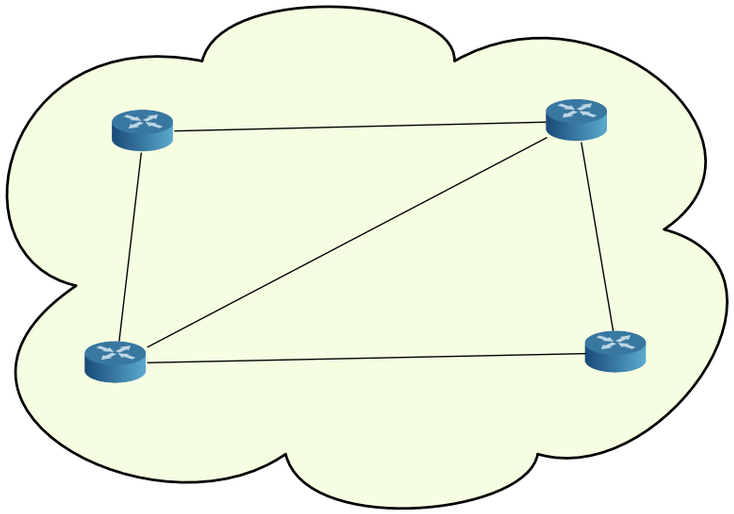
```
Ethernet II
  Destination: 00:04:80:84:56:00
  Source: 00:1f:f3:8b:7b:45
  Type: IP (0x0800)
```

```
Internet Protocol Version 4
  Version: 4
  Header length: 20 bytes
  Differentiated Services Field: 0x00)
  Total Length: 942
  Identification: 0x39a0 (14752)
  Flags: 0x02 (Don't Fragment)
  Fragment offset: 0
  Time to live: 64
  Protocol: TCP (6)
  Header checksum: 0x1114 [correct]
  Source: 137.194.165.9
  Destination: 137.194.52.8
```

```
Transmission Control Protocol
  Source port: 58625
  Destination port: http (80)
  Sequence number: 1
  [Next sequence number: 891]
  Acknowledgment number: 1
  Header length: 32 bytes
  Flags: 0x018 (PSH, ACK)
  Window size value: 8235
  Checksum: 0x8862
```

```
Hypertext Transfer Protocol
  GET / HTTP/1.1\r\n
  Host: www.telecom-paristech.fr\r\n
  Connection: keep-alive\r\n
  User-Agent: Mozilla/5.0 (Macintosh;
Intel Mac OS X 10_8_2) AppleWebKit/537.17
(KHTML, like Gecko) Chrome/24.0.13
  12.56 Safari/537.17\r\n
  Accept-Encoding: gzip,deflate,sdch\r\n
  Accept-Language: en-US,en;q=0.8\r\n
  Accept-Charset:
ISO-8859-1,utf-8;q=0.7,*;q=0.3\r\n
```

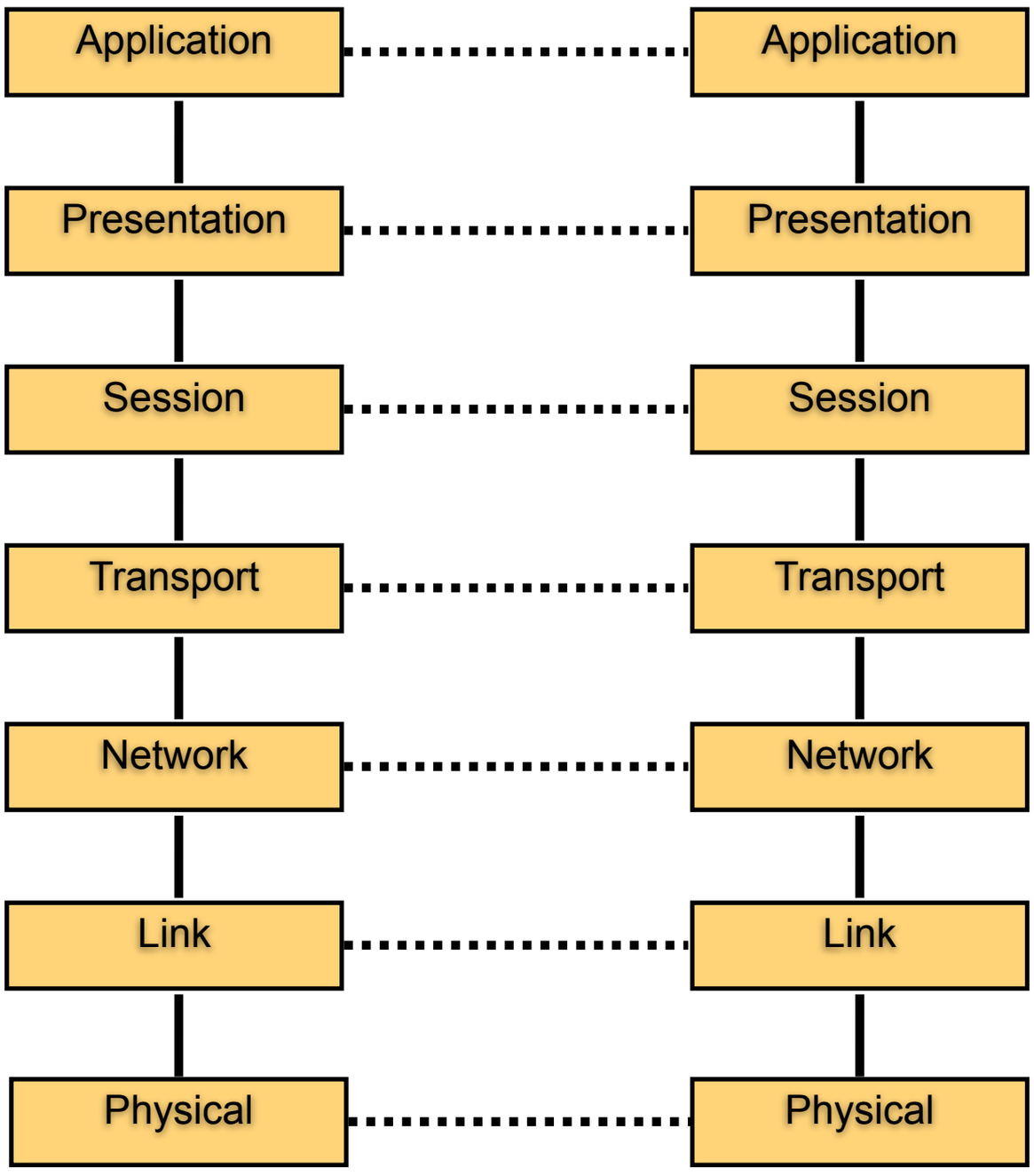
# Avoiding redundant tasks



| Application | | | Application |
|---|---|---|---|
| Presentation | | | Presentation |
| Session | | | Session |
| Transport | | | Transport |
| Network | Network | Network | Network |
| Link | Link | Link | Link |
| Physical | Physical | Physical | Physical |

- Along a path, the devices only implement the necessary protocol.
  - In-network elements do not examine application or transport layer headers
- **Complex algorithms are implemented where the traffic is the lightest (i.e. on end points)**

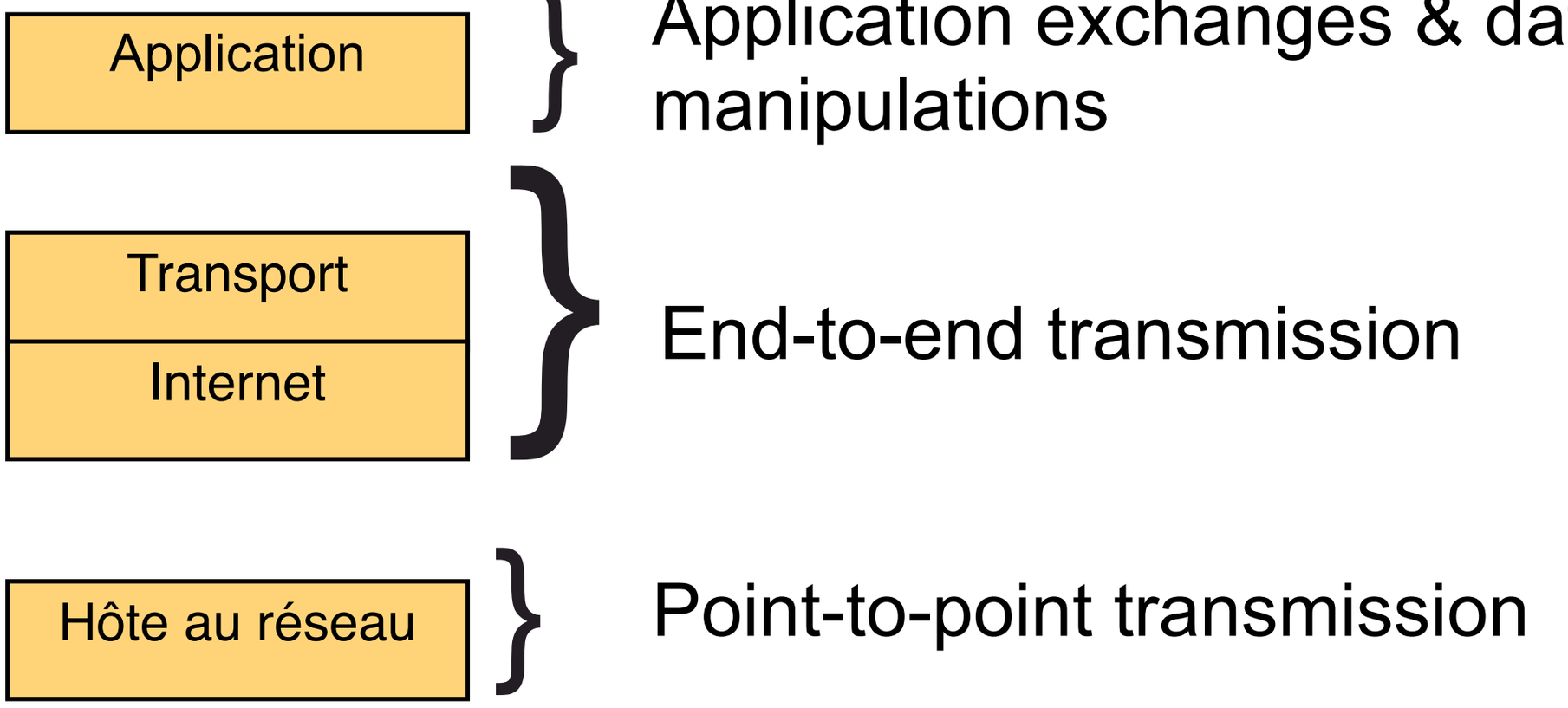
# Définitions : Primitives & Protocols




- A layer only communicates with:
  - The immediately upper layer and the immediately lower layer (Primitives)
  - The same level layers on other devices (Protocol)

# TCP/IP model

- Simplified, more pragmatic, 4-layers model
  - Presentation and session layers are the application's job
  - Physical and link layers are aggregated



# Standards



TELECOM ParisTech

# Standards

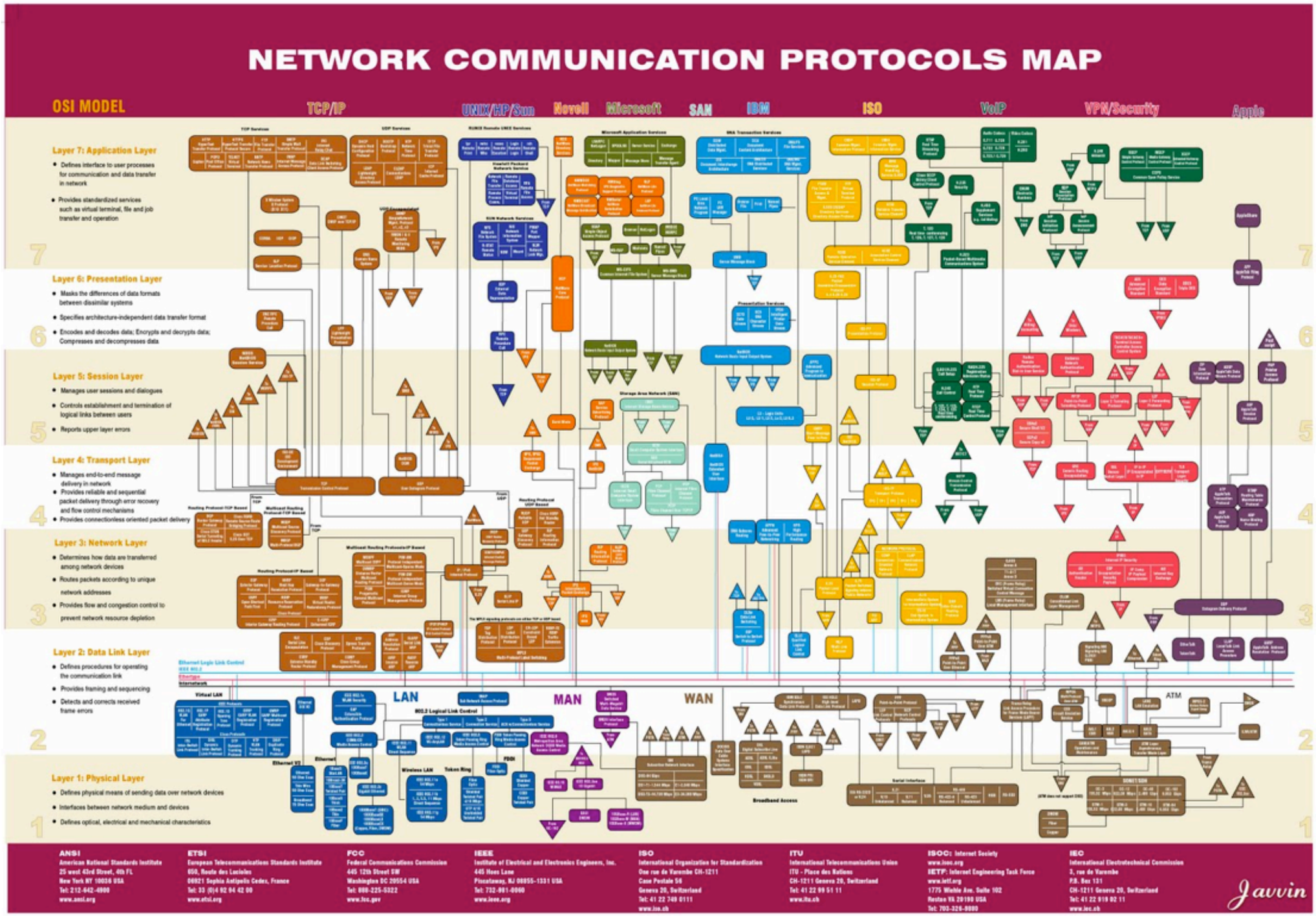
- There are two levels of standards that define exchanges
- Technical specifications, complete and usable. Usually require licensing, it is validated by an international/national organization. It bring royalties:
  - ISO
  - UIT (ITU)
  - AFNOR
  - IEEE Standards Association
  - ...
- Agreement documents, published and endorsed by an organization, which are adopted by a large community. Sometimes incomplete:
  - IETF (RFC)
  - W3C
  - Software editors (.doc ; PDF ; ...)

# Are standards important?

- In the telecommunications world, most of the protocols are defined in standards
  - Telecommunications (PSTN, mobile telephony) : UIT-T
  - Internet protocols : IETF — RFC
  - Transmission technologies (LAN, MAN) : IEEE 802

- Lots of documents are available online :
  - RFC : http://www.ietf.org/rfc
  - IEEE 802 : http://standards.ieee.org/getieee802/
    - Freely available 12 months after initial publication for study (i.e. non-commercial use)

# Internet protocols




**Javvin Protocol Map**

*Source : http://www.javvin.com/*

# Memento - what is expected?

- There are different network types (telephone, data, ...)
  - Be able to distinguish networks (PSTN, LAN, ...) and their operation mode
  - Be able to give orders of magnitude (size, throughputs, ...)
- Commutation modes (circuits vs. packets)
  - Understand the difference between the two paradigms
- Internet architecture
  - Be able to differentiate actors, understand the autonomous system concept.
  - Be able to explain the difference between peering and transit links
  - Understand IP's central position
- Applications
  - Be able to define performance criteria
  - Be able to classify applications
- Models (OSI, TCP/IP)
  - Understand what each layer does
  - Understand encapsulation

# Typical networking engineers jobs

- Opérations/Installation/Maintenance
  - Install, operate networks and make them evolve
- Marketing
  - Imagine tomorrow's requirement and stay alert
- Innovation / development
  - Build, equipments, technologies, services
- Commercial
  - Promote and sell technologies
- Normalisation
  - Define standards that are used in networks
- Research
  - Performance evaluation, algorithms design, ...
- More information in French: référentiel de l'APEC
  - http://presse.apec.fr/resource/mediatec/domain1/media27/17903-46hwggx3m39.pdf
  - Using Google: "APEC référentiel Métiers Télécoms"

# Coming next

- Courses and lab sessions

- Go down the OSI model
  - Application layer through DNS
  - Transport layer (TCP, UDP) mechanisms
  - Addressing and routing at the network layer
  - Interconnection management (fault tolerance, ...)
  - Multiple access management
  - Link layer logical operation

- Performance evaluation examples

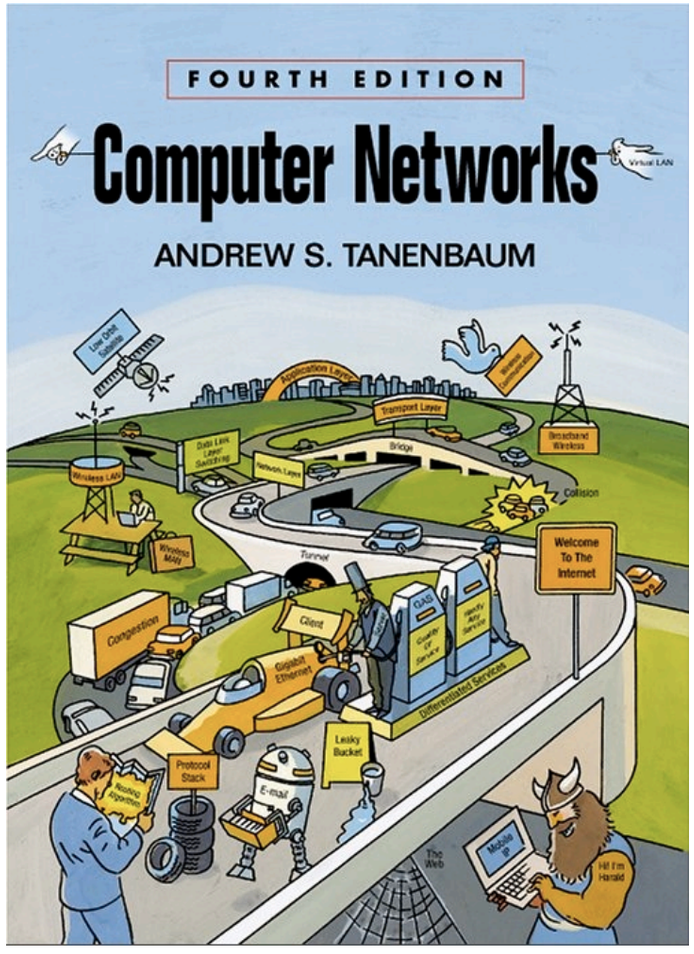
- Security

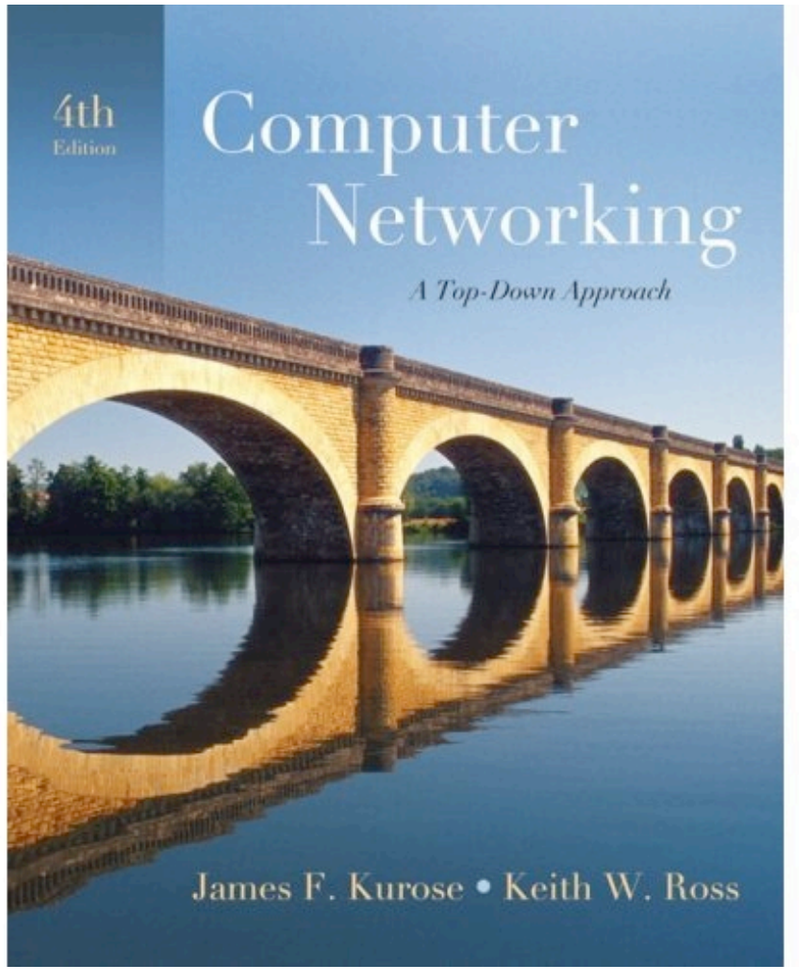
# Advice

- Do not rely only on slides copies
  - **You have to take notes**
- You can practice at home
  - Lab material can be installed on your computers
- Explore the web
  - Basic networking course => everything is available online (wikipedia, online classes, MOOCs, ...)
- e-mail support (chaudet@enst.fr), or appointments (bureau I451 ; ave. d'Italie)
  - **Do not wait until the week before the exam**

# Useful bibliography

- Books following the course outline
  - A. Tannenbaum — Computer Networks
  - J. Kurose, K. Ross — Computer networking - A top-down approach



# INFRES 821 - Practical projects

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