Computer Networks

Lesson 1: Computer networks and Internet

Universidad de Sevilla

Departamento de Tecnología Electrónica

Lesson 1: Computer networks and Internet

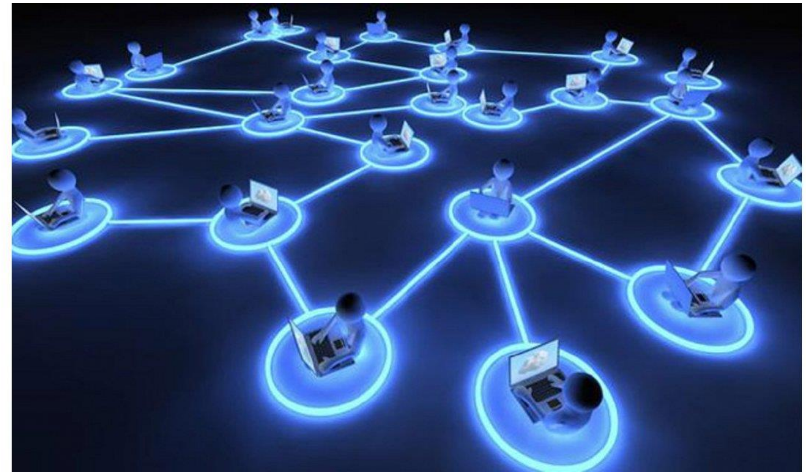
Objectives

- Contact and terminology
- Greater depth, details later in the course
- Focus: Use the Internet as an example

Content

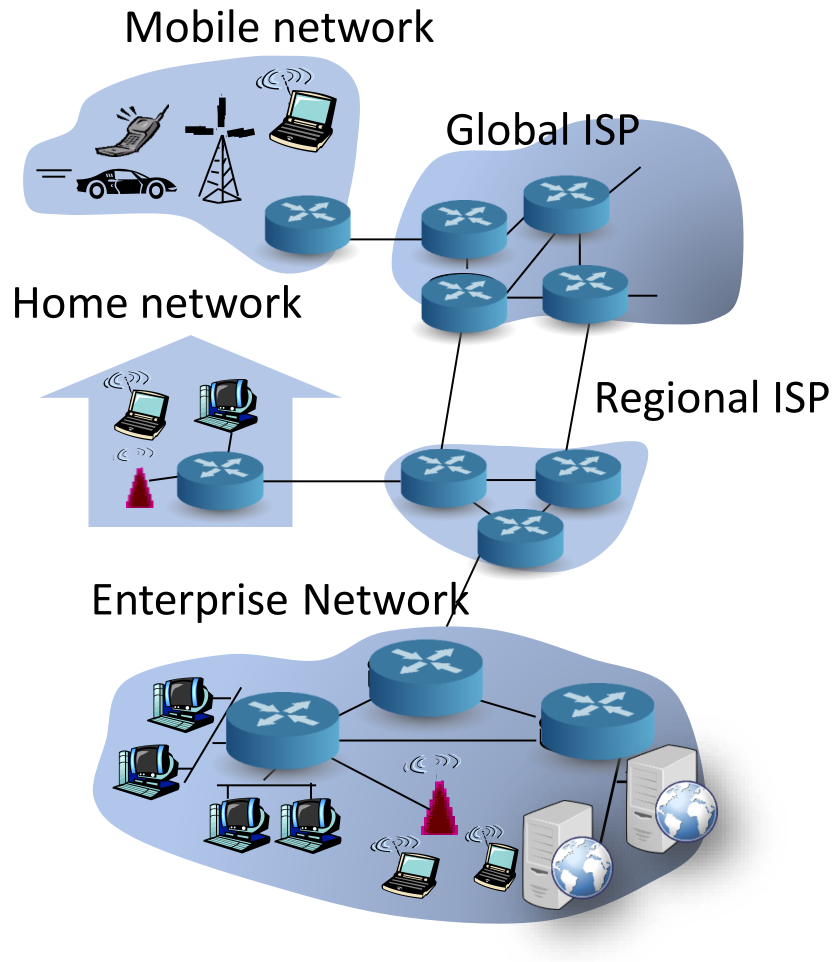
1. What is the Internet?
2. What is a protocol?
3. The network frontier: computers, access networks, physical media
4. The core of the network: packet/circuit switching, Internet architecture
5. Performance: losses, delays, transfer rate
6. Protocol layers, service models

What is the Internet?



What is the Internet?
Hardware and Software

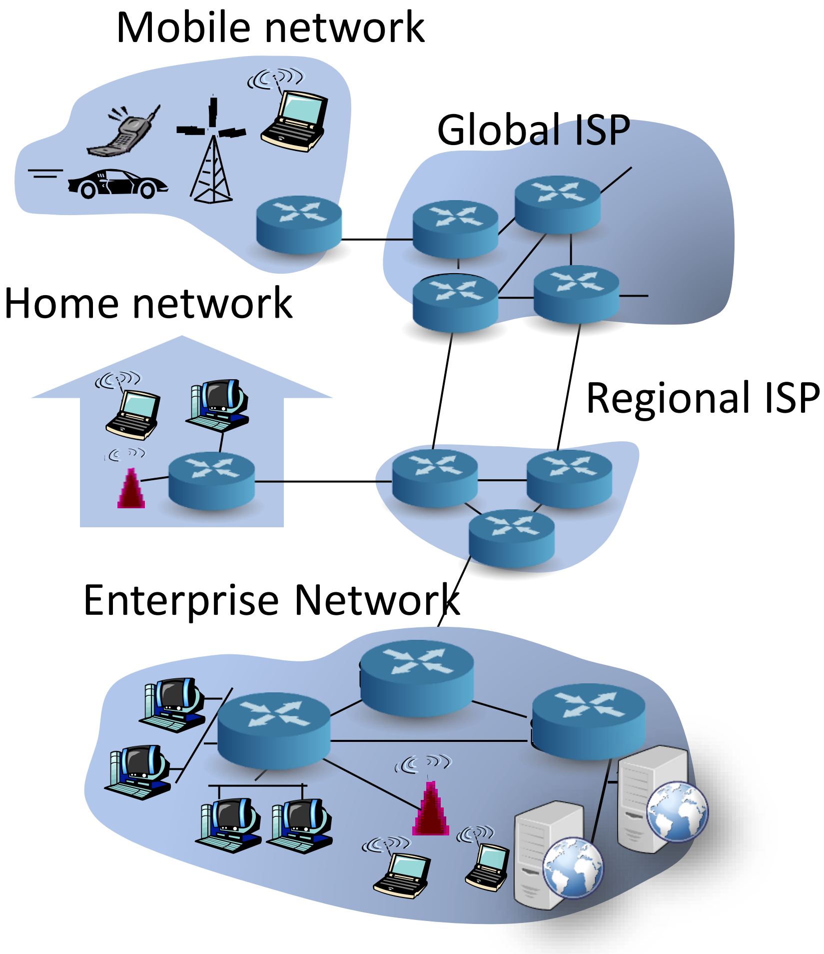
- Millions of connected computing devices: hosts, terminal systems
- Running network applications
- Network links



ISP = Internet Service Provider

What is the Internet?
Hardware and Software

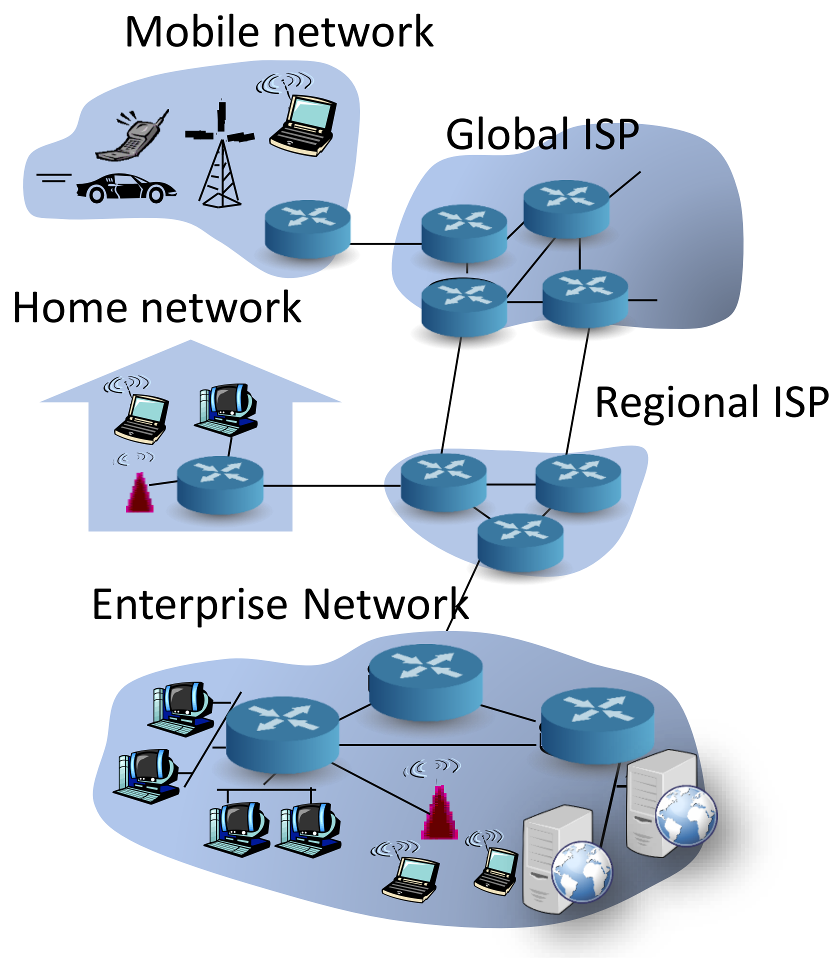
- Protocols control sending and receiving of information. Examples: TCP, IP, HTTP, Skype, Ethernet
- Internet: it is the "network of networks“
  - Not very hierarchical
  - Public Internet vs. Private Intranet
- Internet Standards
  - RFC: Request for comments
  - IETF: Internet Engineering Task Force



ISP = Internet Service Provider

What is the Internet? Services

- **Communication infrastructure** enables distributed applications:
- Web, VoIP, mail and e-commerce, games, file sharing, Facebook, Twitter, Spotify...
- **Communication services** provided to applications:
  - Reliable source-to-destination data delivery
  - "Best effort" (unreliable) data delivery



ISP = *Internet Service Provider*

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What is a protocol?

Human protocols

- Ask the current time
- Raise your hand
- Let out before entering
- ... specific messages are sent
- ... specific actions are taken when responses or other events are received

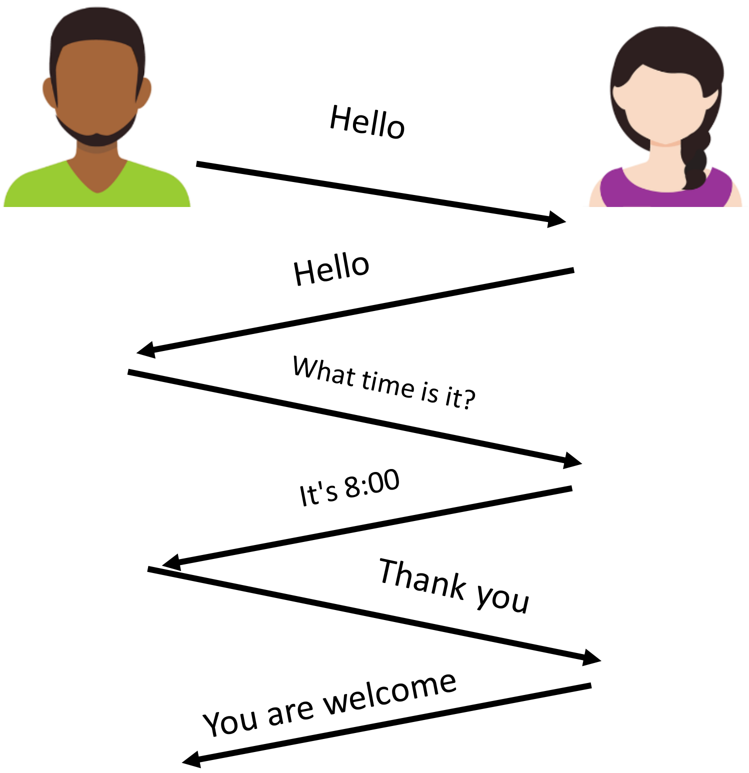
Network protocols

- Machines are involved instead of human beings
- All communication activity on the Internet is governed by protocols

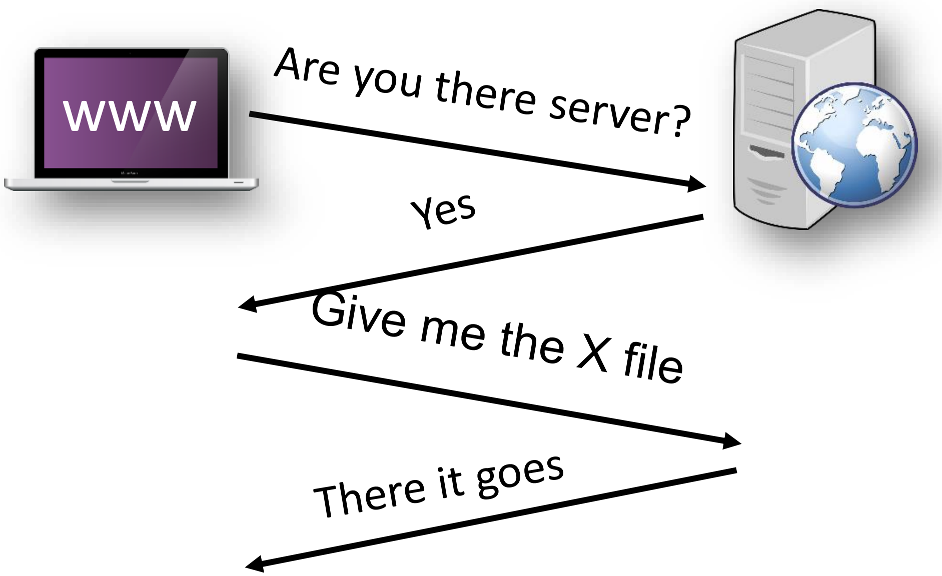
A protocol defines the format and order of messages sent and received between network entities, and the actions taken in transmitting and/or receiving a message or other event.

What is a protocol?

Human protocols

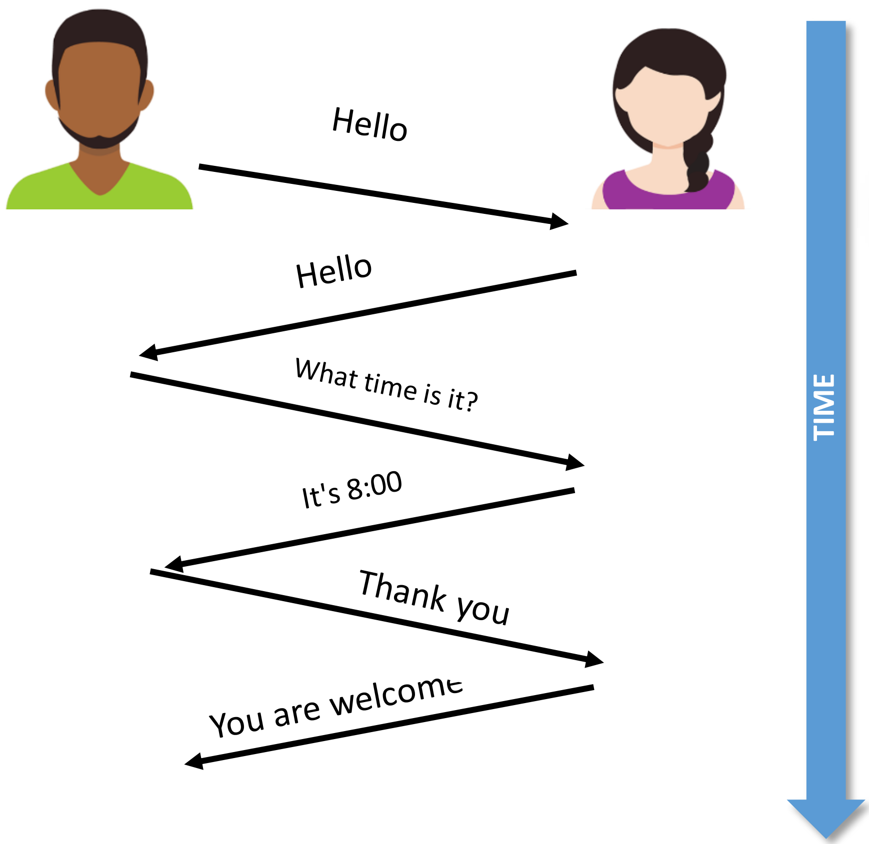


Network protocols

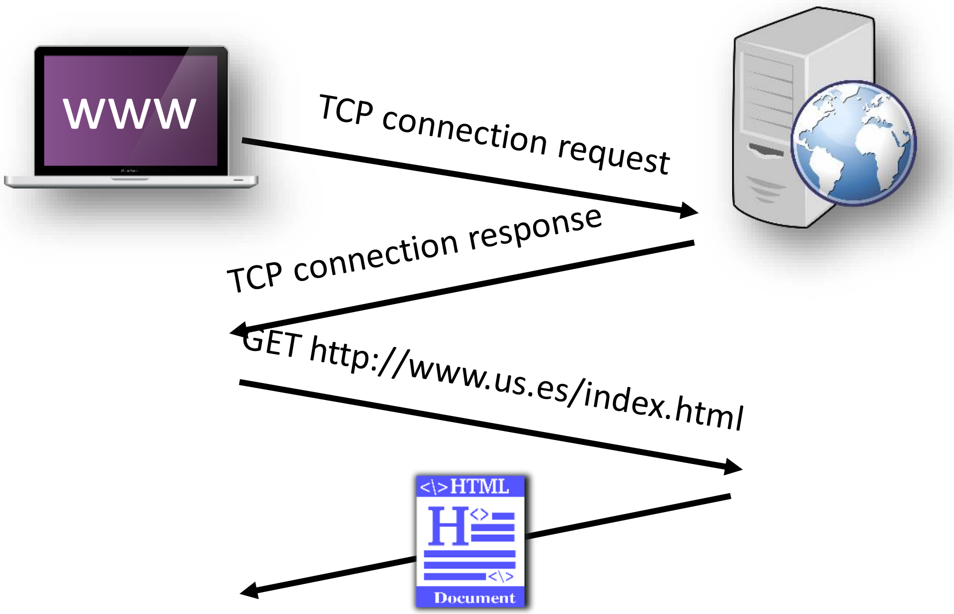


What is a protocol?

Human protocols



Network protocols



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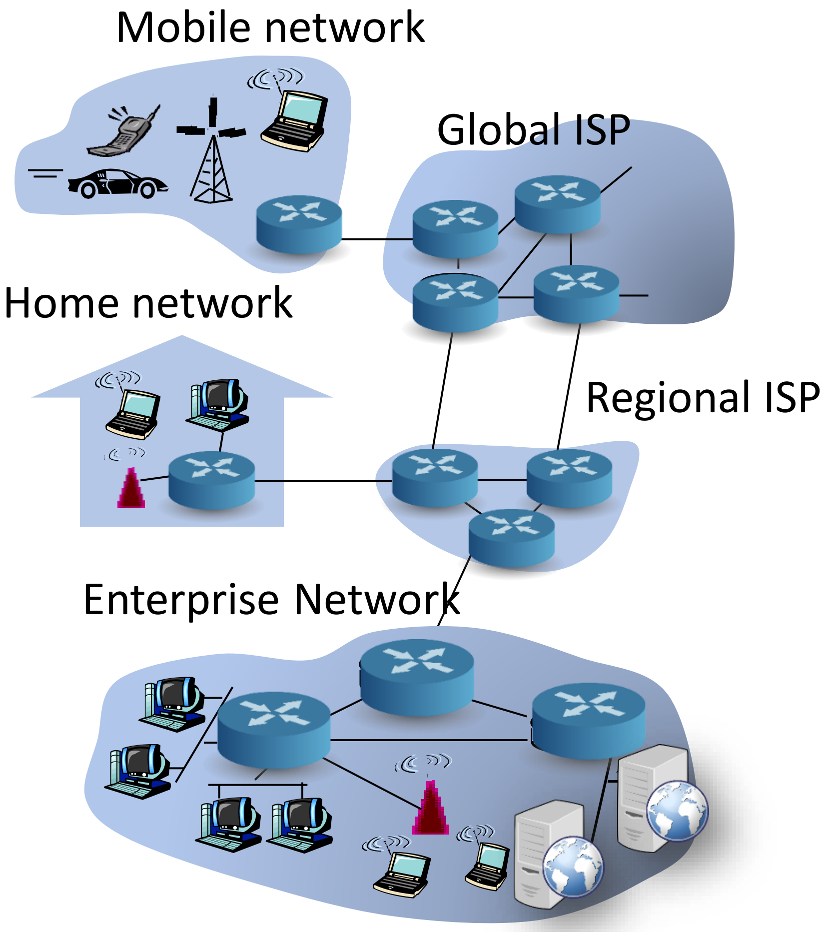
Detailed overview of the Network Structure

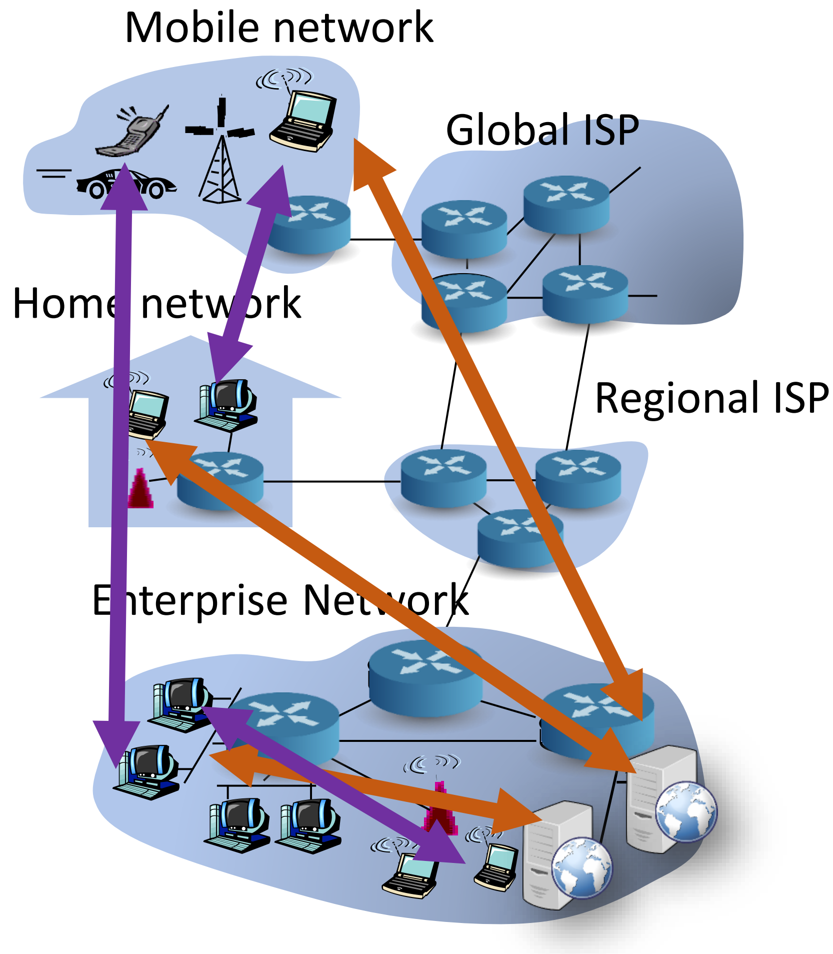
- **The frontier of the network:** applications and terminal systems.
- **Access networks, physical media:** wired and wireless communication links.
- **The core of the network:**
  - interconnected routers
  - network of networks



ISP = *Internet Service Provider*

Network structure: The frontier of the network

- **Terminal systems (hosts):**
  - Run application programs
  - E.g. Web, email...
  - On the “frontier of the network"
- **Client/server model**
  - Client terminal system requests and receives a service from a server
  - e.g. browser/web server...
- **Peer-peer model:**
  - Minimal (or no) use of dedicated servers
  - e.g. Skype, BitTorrent...



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Network Structure:
Access networks and physical media

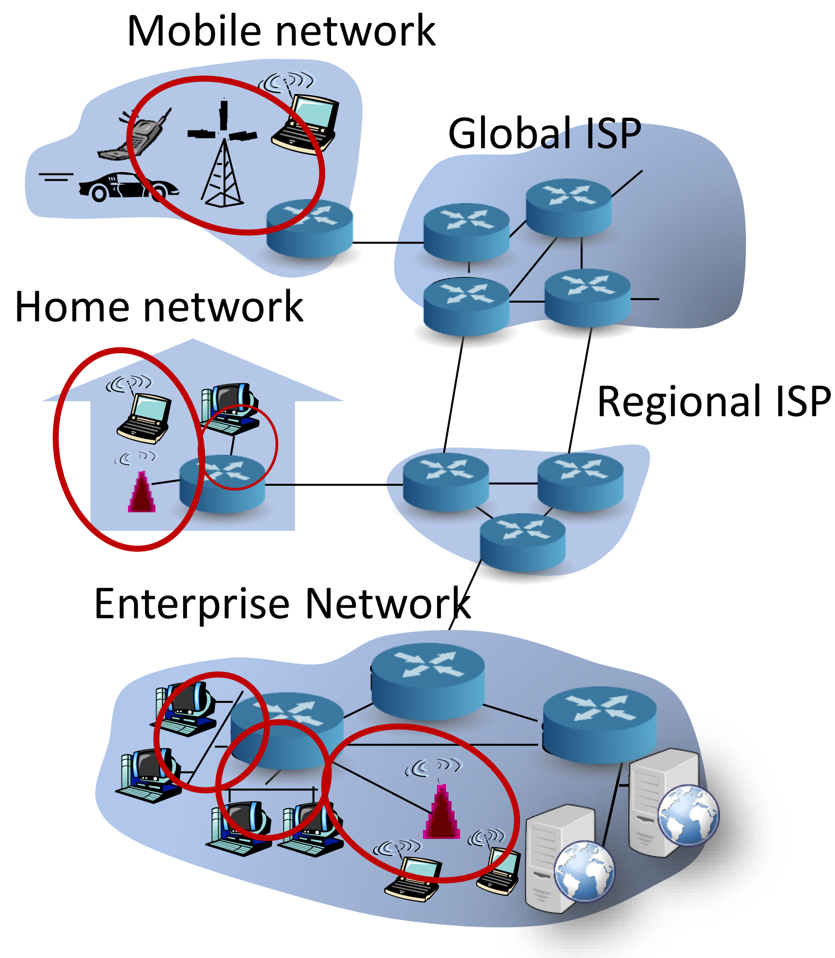
How to connect terminal systems to a border router?

Home access networks

- Institutional access networks (school, company)
- Mobile access networks

Please note:

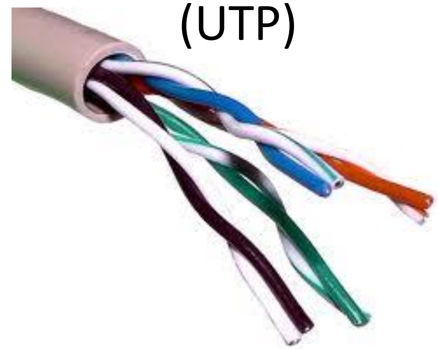
- Network access bandwidth (bits per second)
- Shared or dedicated
- Physical medium of transmission



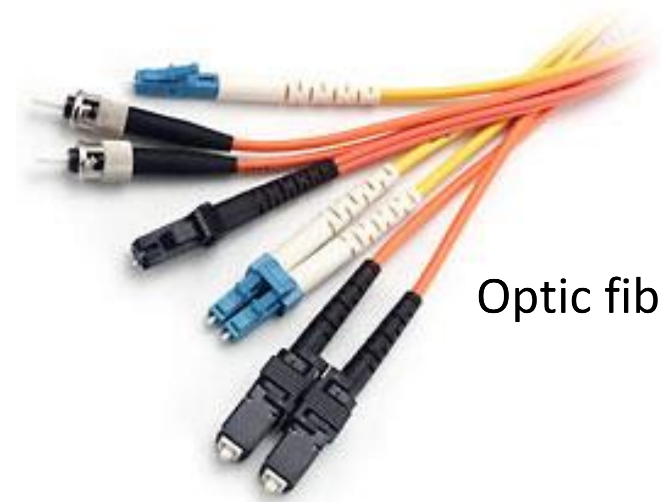
Network Structure: Physical media

- Bit: propagates between pairs of transmitters and receivers
- Physical link: the medium between the transmitter and the receiver
  - Guided: signals are transported by a solid medium: copper (twisted pair; coaxial), fiber
  - Unguided: Signals propagate through space: terrestrial microwaves, WLAN (WiFi), mobile (4G), satellite

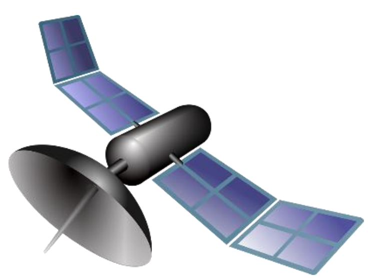
Twisted pair (UTP)



Coaxial



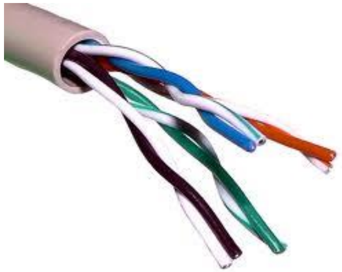
Optic fiber



Network Structure:
Guided physical media

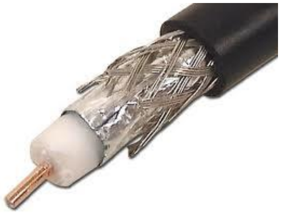
Twisted Pair (TP)

- two insulated copper cables
- Cable Category => Supported Speed



Coaxial cable:

- two concentric copper conductors
- bidirectional



Optic fiber cable:

- fiberglass driving pulses of light, each pulse represents one bit
- High operating speed:
  - high-speed point-to-point transmission (e.g., 10's-100's Gpbs)
- low error rate: low attenuation allows widely spaced repeaters; immune to electromagnetic interference

Network Structure:
Unguided physical media

- signals carried in the electromagnetic spectrum
- no physical "cable"
- Omnidirectional or directional.
- propagation environment effects:
  - reflection
  - object obstruction
  - interference

Types of radio channels:

- terrestrial microwave

  High directionality.

  - WLAN (e.g., WiFi)

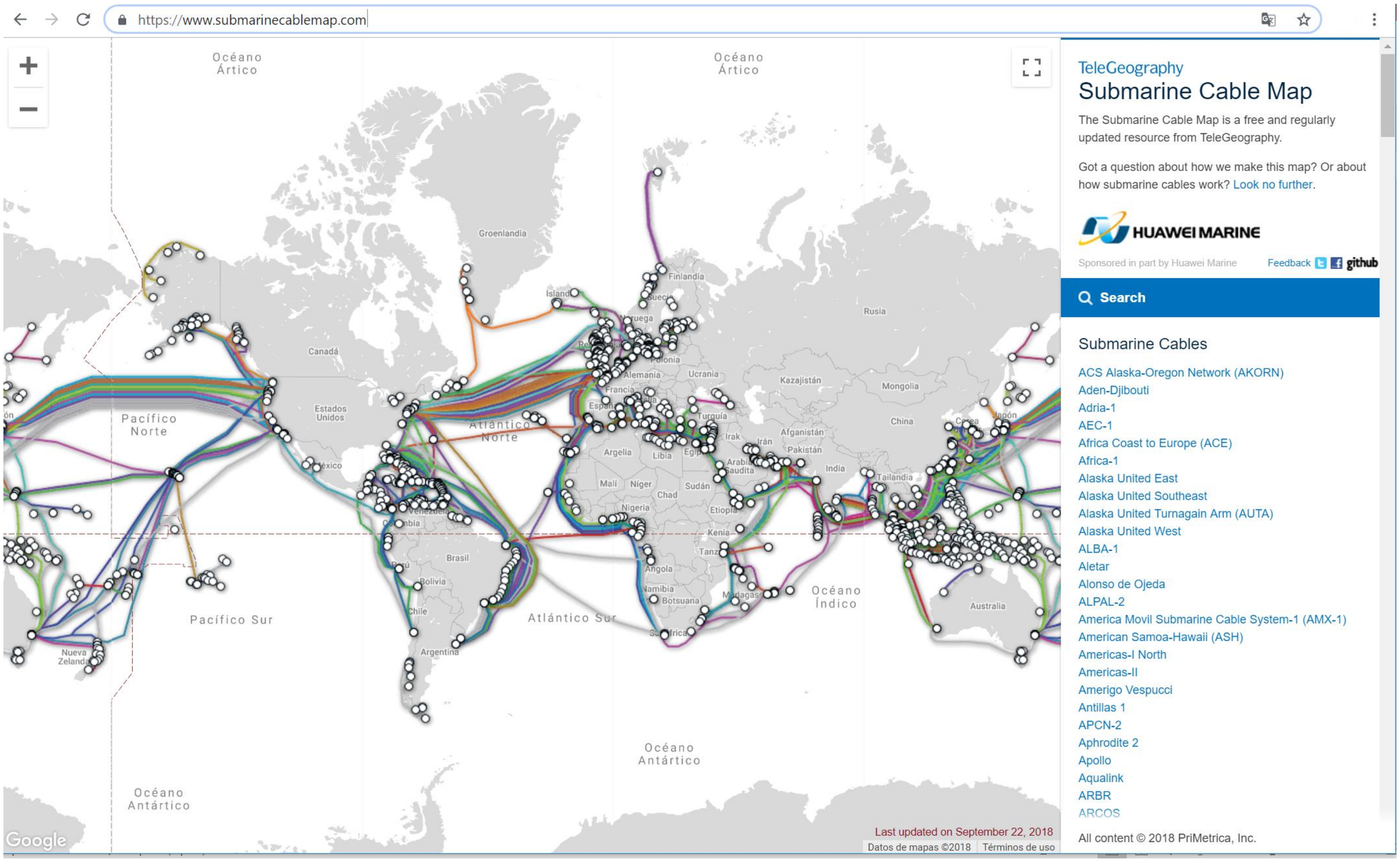
  Omnidirectional.
- area-wide (e.g., mobile)

  Mobile phones
- satellite

  End-to-end delay of 270ms => It's a problem!

  Satellite TV

  Internet: submarine cables preferred



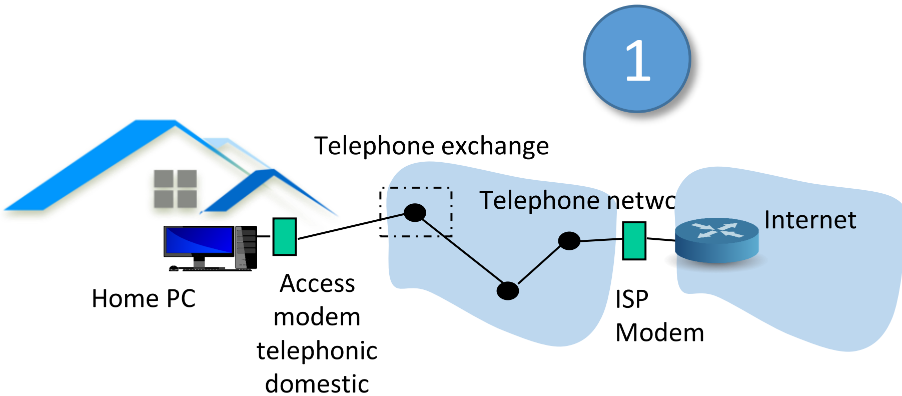
https://www.submarinecablemap.com/

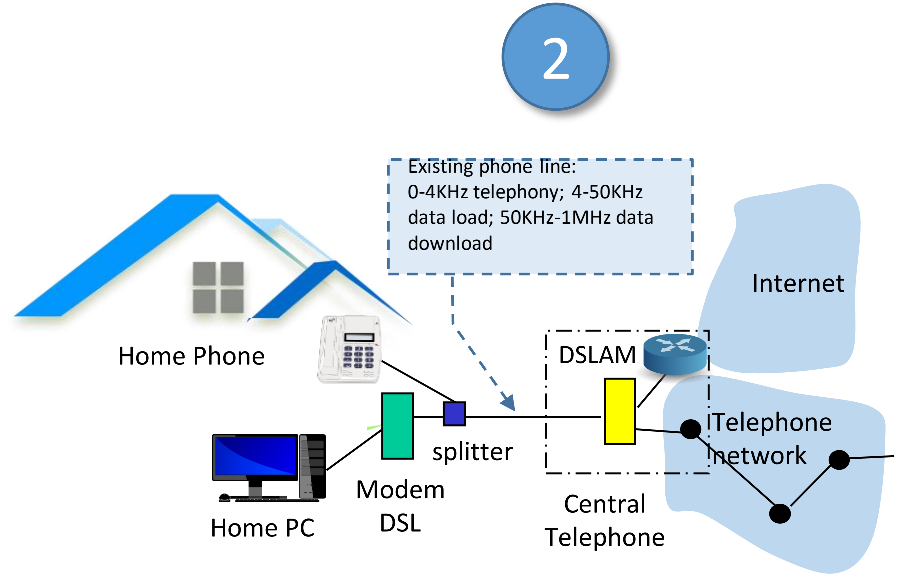
Network Structure:
Access Networks: Broadband Networks

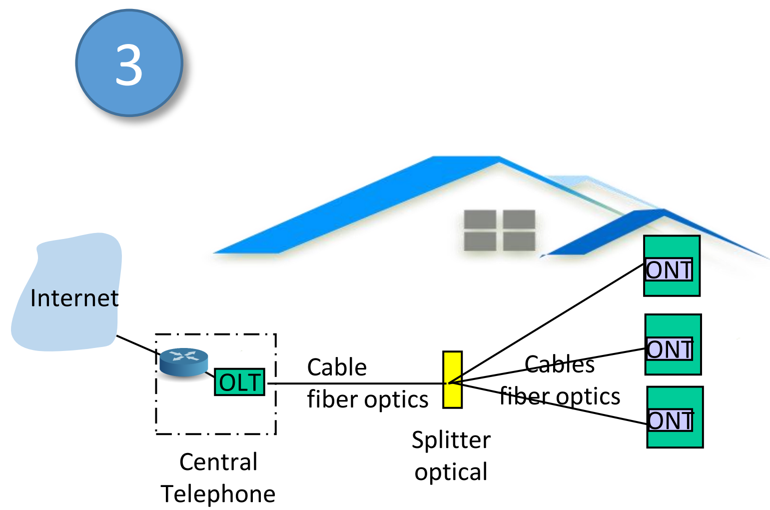
- Fixed access networks:
  - Digital subscriber lines over telephone copper pairs (ADSL and VDSL)
- Wired:
  - Hybrid Fiber and Coaxial (HFC) Solutions
  - Fiber Optics to the Home (FTTH)
- Wireless:
  - ≥ 2Mbps
  - ≥ 30Mpbs
- Mobile access networks:
  - 3.5G Networks (UMTS with HSPA)
  - 4G (LTE) networks
  - [5G Networks]

Note: Fast (≥ 30 Mbps) and ultra-fast (≥ 100 Mbps) broadband networks.

Network structure: Home access networks



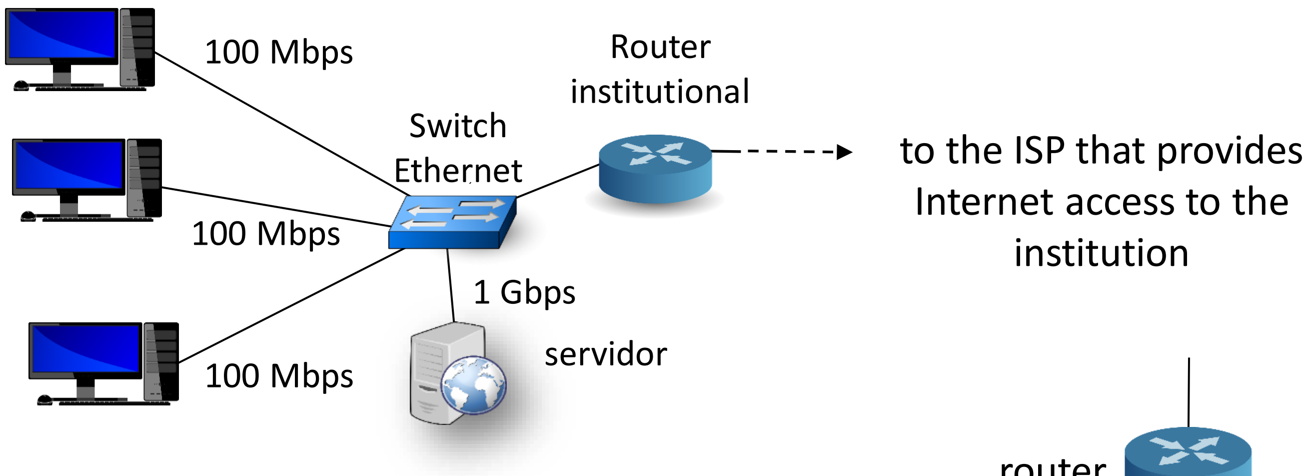




ONT: Optical Network Terminator
OLT: Optical Line Terminator

Network Structure:
Institutional access networks

4



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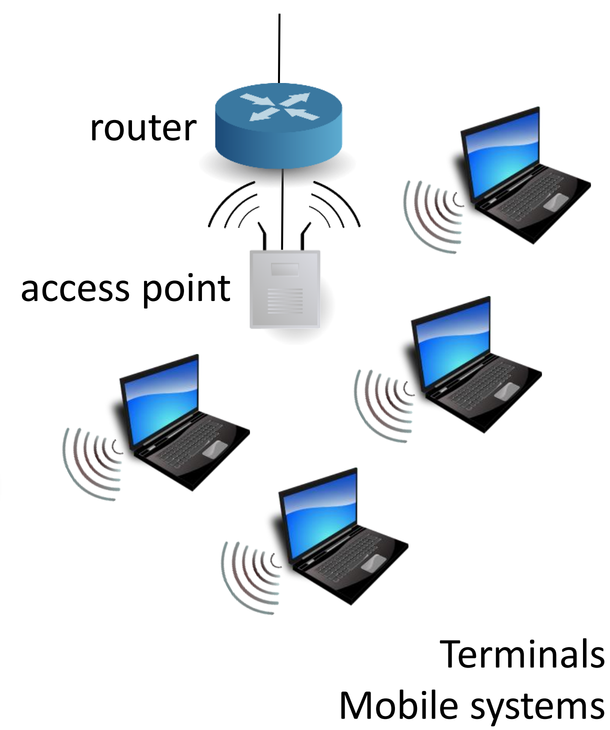
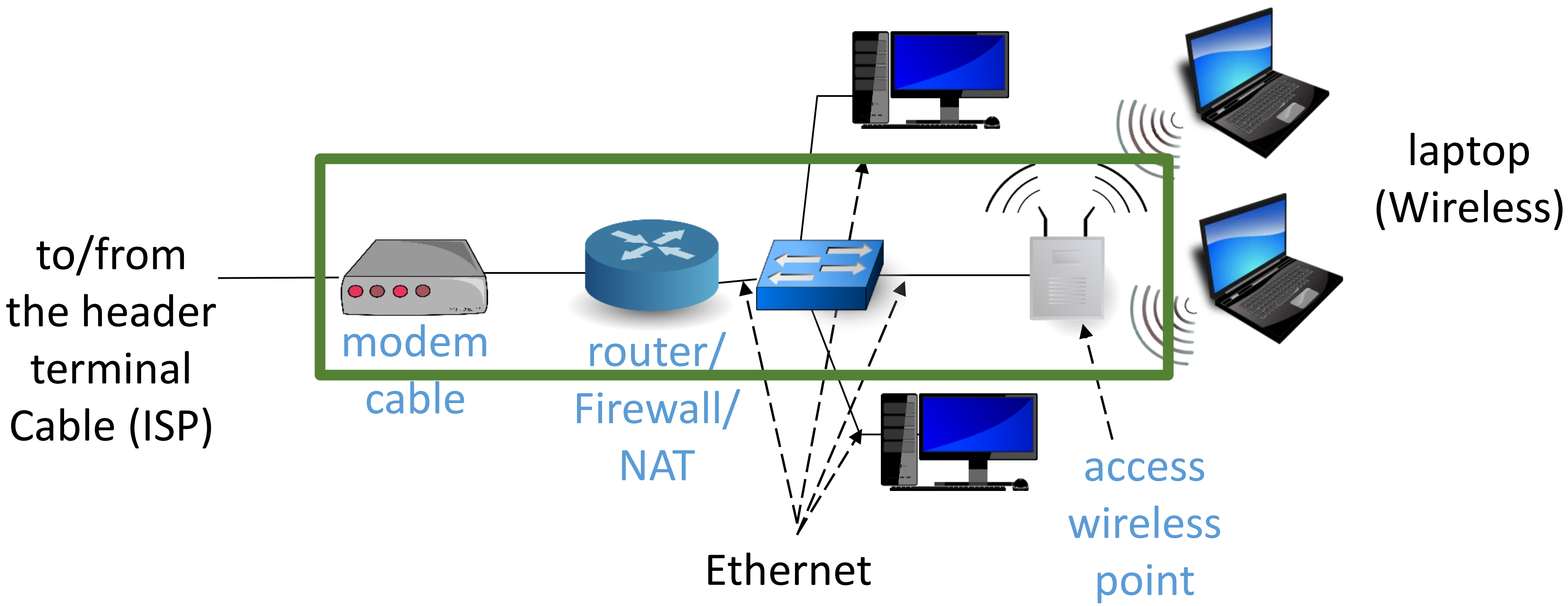


Network Structure:
Typical Components in a Home Access Network



SOHO (*Small Office, home Office*)

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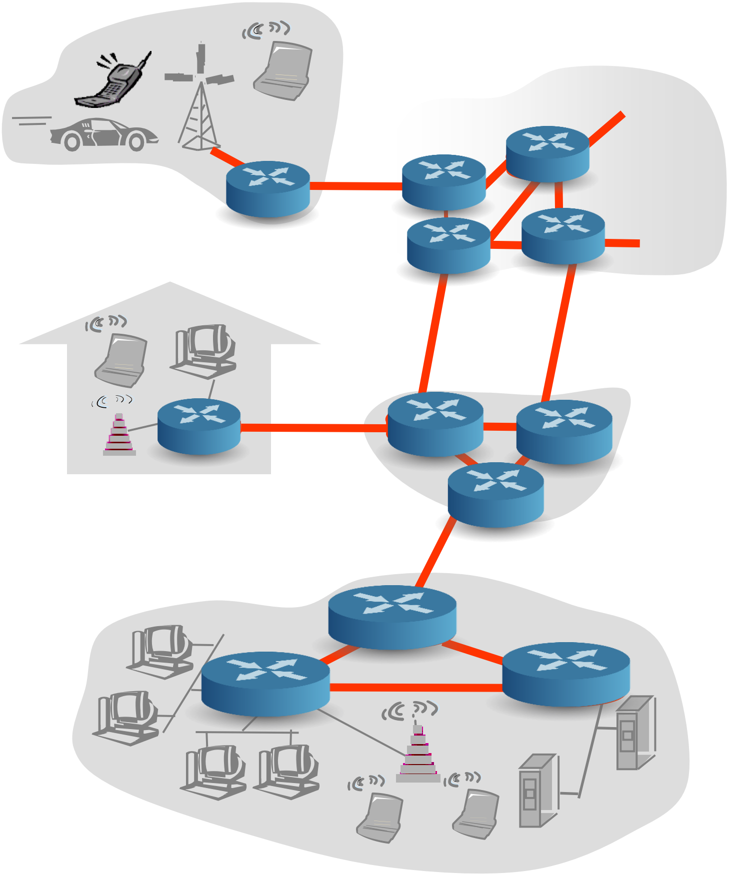
The core of the network

Mesh of interconnected routers.

How is data transferred over the network?

- **Circuit switching:** dedicated circuit by call (telephone network)
- **Packet switching:** data is sent over the network in smaller chunks (packets)



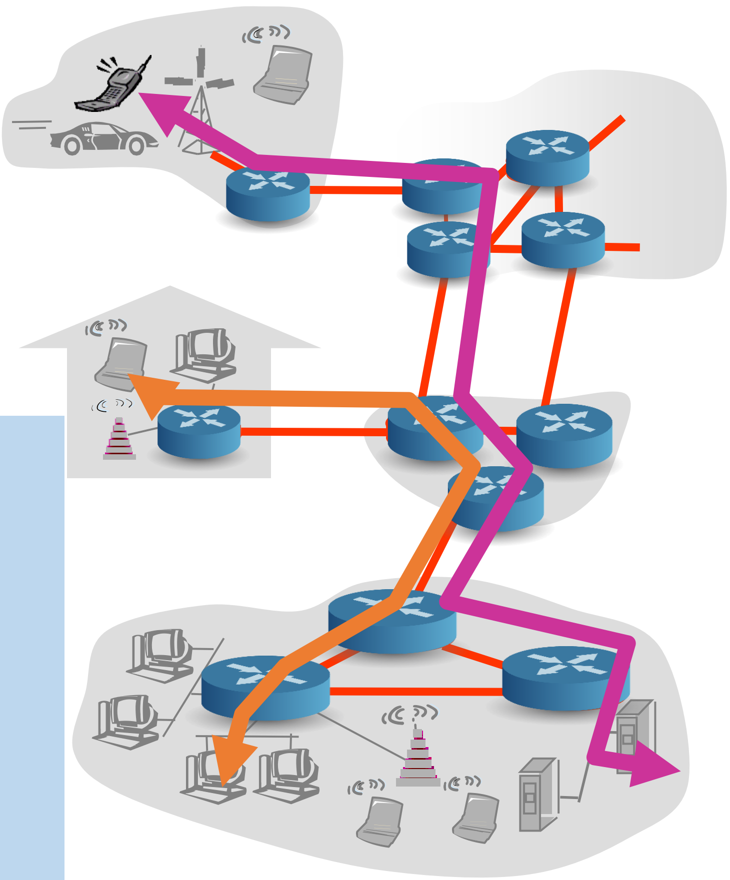
The core of the network

Mesh of interconnected routers.

How is data transferred over the network?

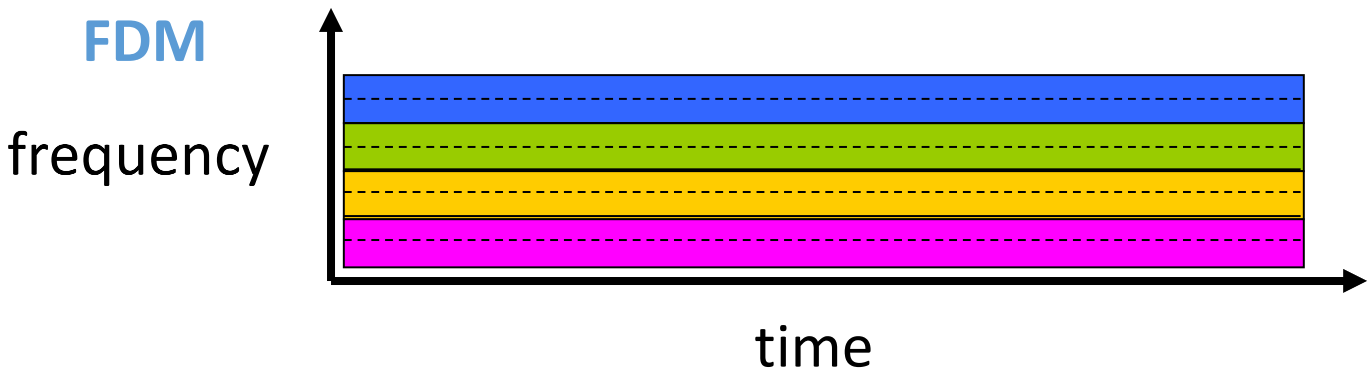
Circuit switching: dedicated circuit by call (telephone network)

- End-to-end resources reserved by "call"
- Link bandwidth, router capacity
- Dedicated resources: not shared
- Guaranteed performance
- Required connection establishment
- Network resources (e.g., bandwidth) divided into "parts“
    - Parts assigned to calls
    - Part of the resource unused if it is not used by the caller (not shared)
- Dividing link bandwidth into "parts“
    - Frequency division
    - Time division



The core of the network
Circuit Switching: Examples of Media Access

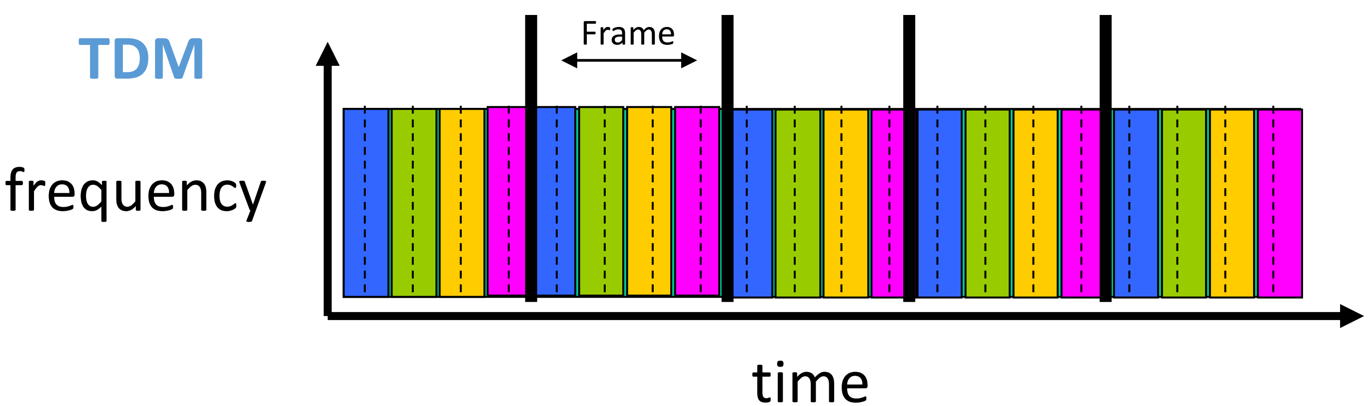
FDM



Division of the link **into the frequency**

Example with 4 users:

TDM



Division of the link **in time**

Core of the network

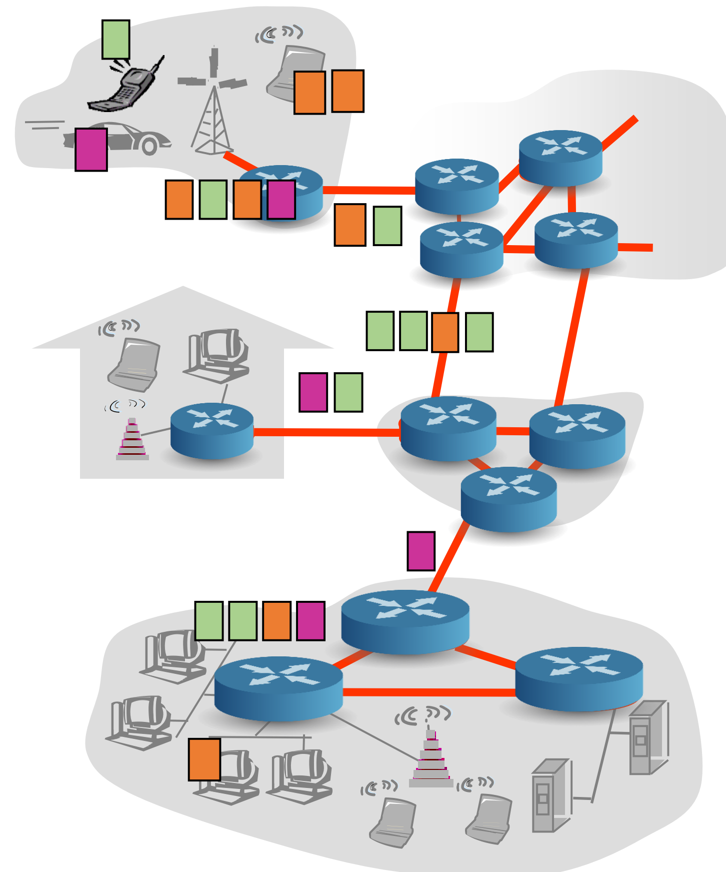
Each end-to-end data stream is divided into packets:

- packets from different users share network resources
- Each packet uses the bandwidth of the full link
- Resources are used as needed, there is no reserve of resources

Contest for resources:

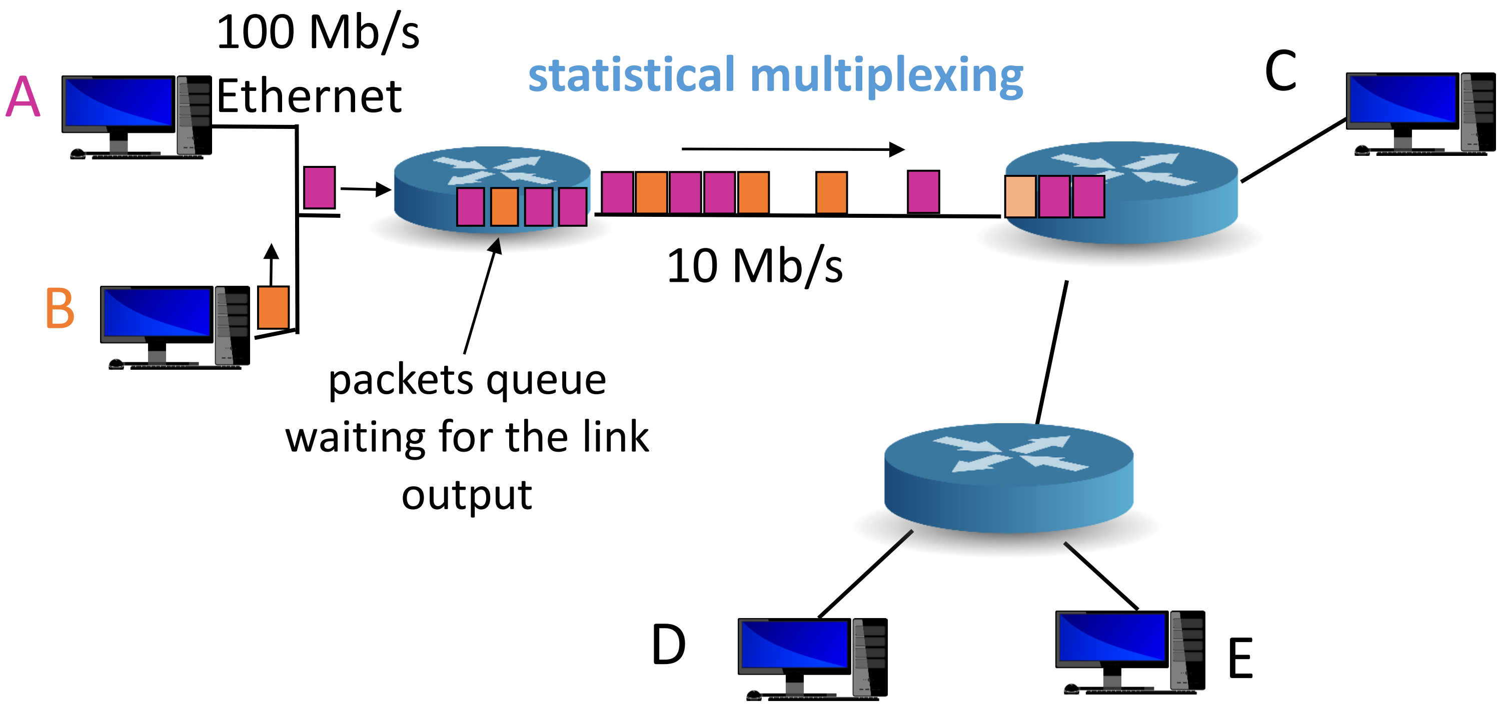
- The resource demand of the set may exceed the amount available -> congestion (waiting for link use -> packet queues)
- Propagation via store and forward: packets advance one step at a time and the node fully receives the packet before forwarding

- **Packet switching:** data is sent over the network in smaller chunks (packets)



The core of the network

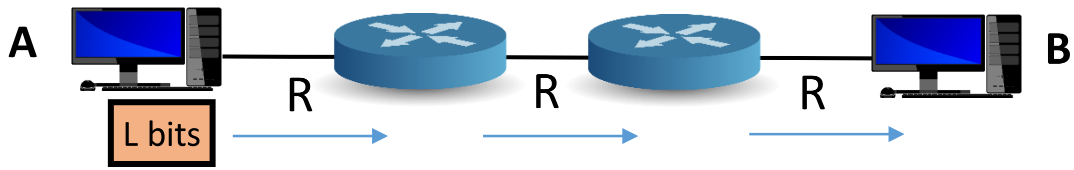
Packet Switching: Example of Media Access



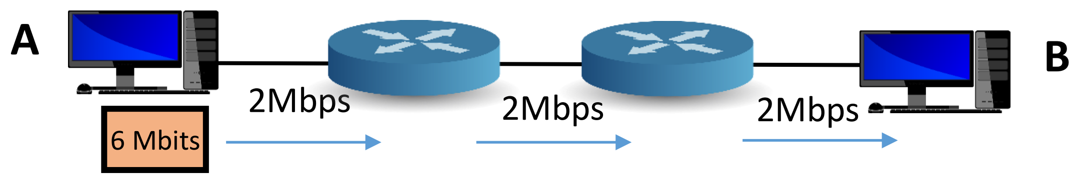
- the packet sequence of a and b has no fixed time pattern
    - Bandwidth is shared on demand: statistical multiplexing

The core of the network

Packet Switching: Store-and-Forward Propagation



- It takes L/R seconds to transmit L-bit packets over an R bps link
- Store and forward: the entire package must reach the router before being transmitted to the following link
- Delay from node A to node B is 3L/R (assuming zero propagation delay)

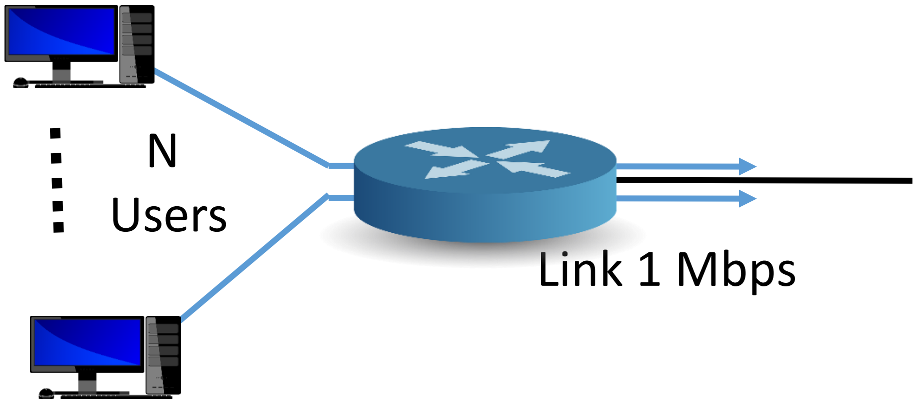


The core of the network
Packet vs. circuit switching

Packet switching allows more users to use the network.

Example:

- 1Mbps link
- Each user:
  - 100Kbps when "active“
  - Active 10% of the time
- Circuit switching:
  - 10 users
- Packet switching:
  - with 35 users, probability > 10 active in the same time is less than 0.0004



Q: What happens if > 35 users?

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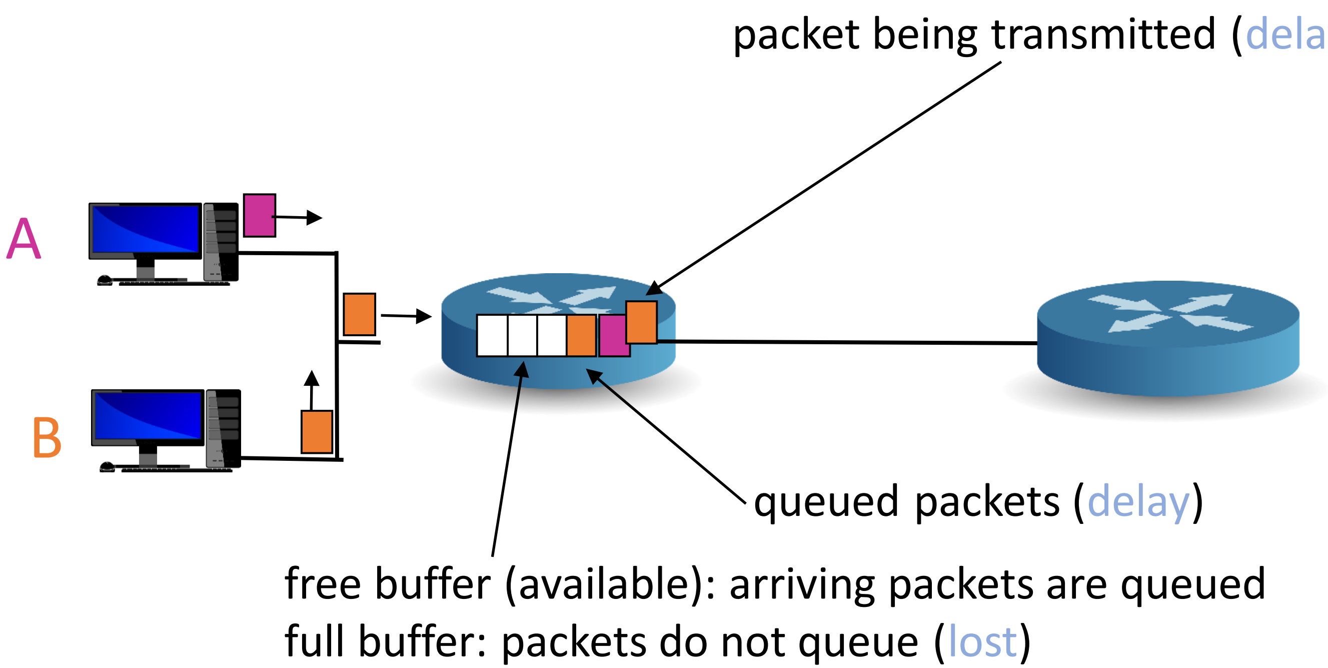
Performance

How do losses and delays occur?

Packets are **queued** into the router's buffer.

If the rate of arrival of packets to the link exceeds the output capacity of the link, the packets are queued, waiting for their turn.

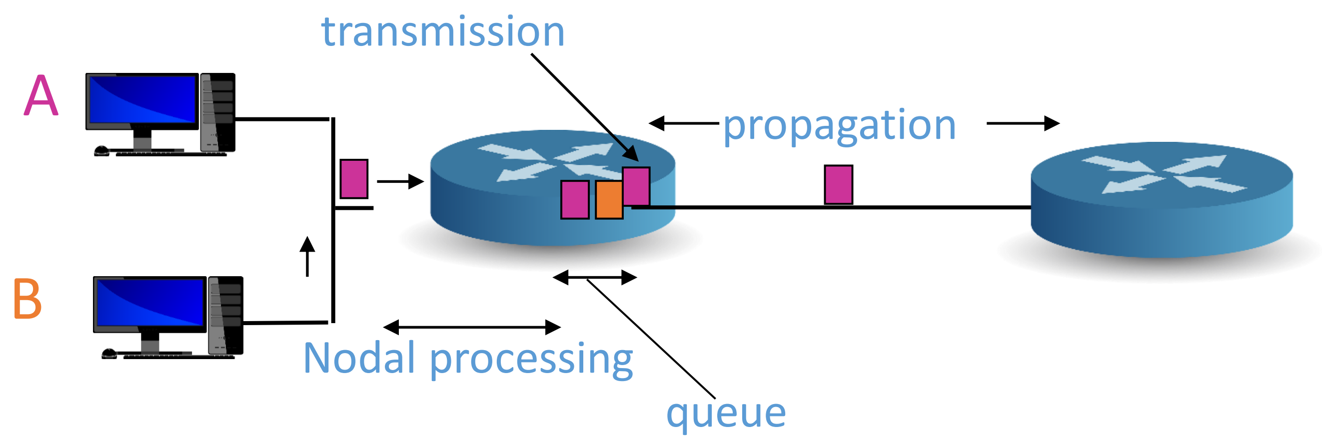


Note

As we will see later in the subject in addition to routers there are other devices that introduce delays.

Performance

Four sources of delays



$$d_{nodal} = d_{proc} + d_{queue} + d_{trans} + d_{prop}$$

d_{proc}: nodal processing

Check for bit-level errors

- Determine the output link
- Typically < µs

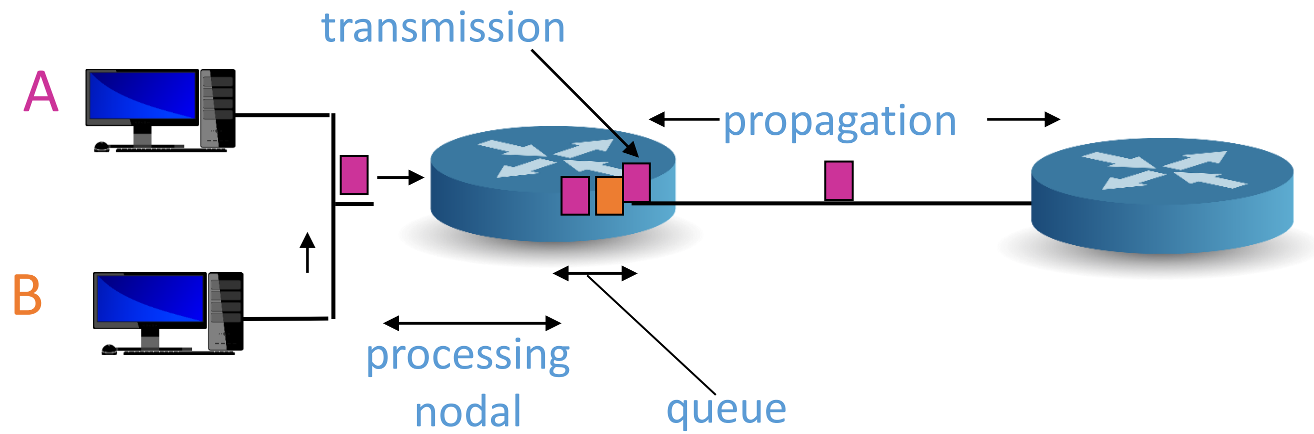
d_{queue}: queue delay

Timeout before being transmitted by the output link

- Depends on the level of <u>congestion</u> of the router
- Typically µs or ms

Performance

Four sources of delays



$$d_{nodal} = d_{proc} + d_{queue} + d_{trans} + d_{prop}$$

d_{trans}: transmission delay

L: packet length (bits)

R: link bandwidth (bps)

d_{trans} = L/R (µs o ms)

d_{trans} y d_{prop}

Very different

d_{prop}: propagation delay

d: physical link length

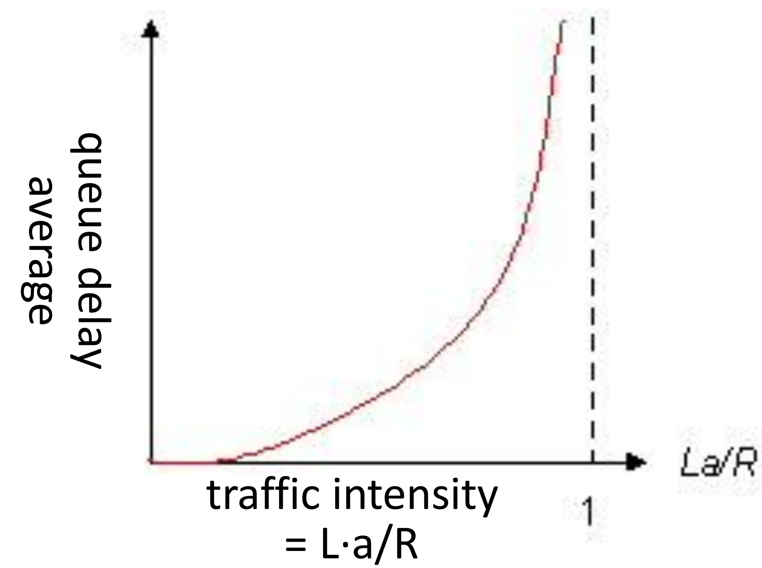
- s: media propagation speed ($\sim 2 \times 10^8$ m/s)

d_{prop} = d/s

Performance

Queue delay

- A: Link bandwidth (bps)
- L: Packet length (bits)
- a: average package arrival rate (packets per second)



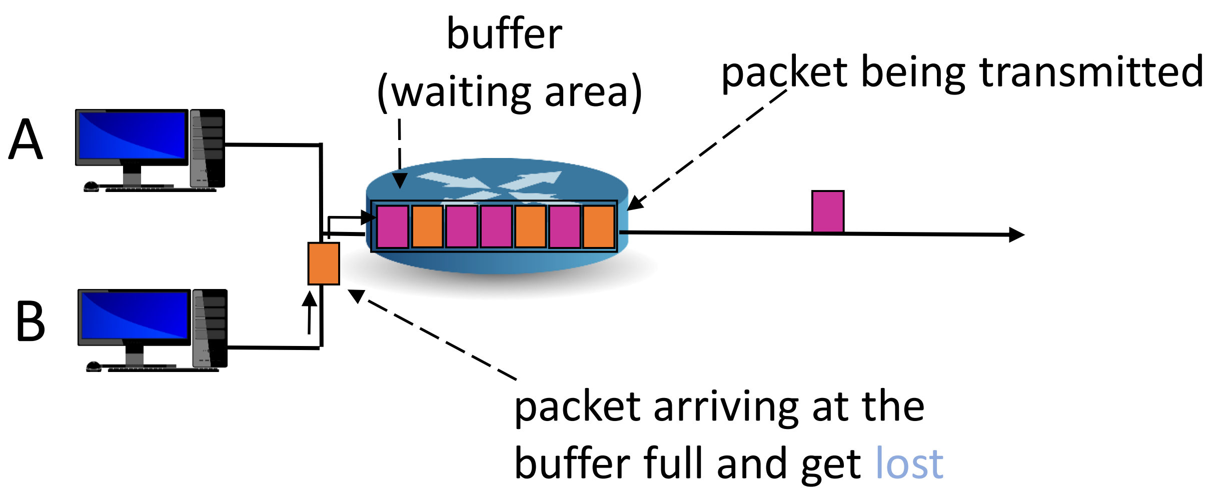
- L·a/R~0: Small average queue delay
- L·a/R < 1: large average queue delay
- L·a/R > 1: more packets arrive than can be served, infinite queue delay!

L·a/R ~ 0

L·a/R → 1

Performance
Packect loss

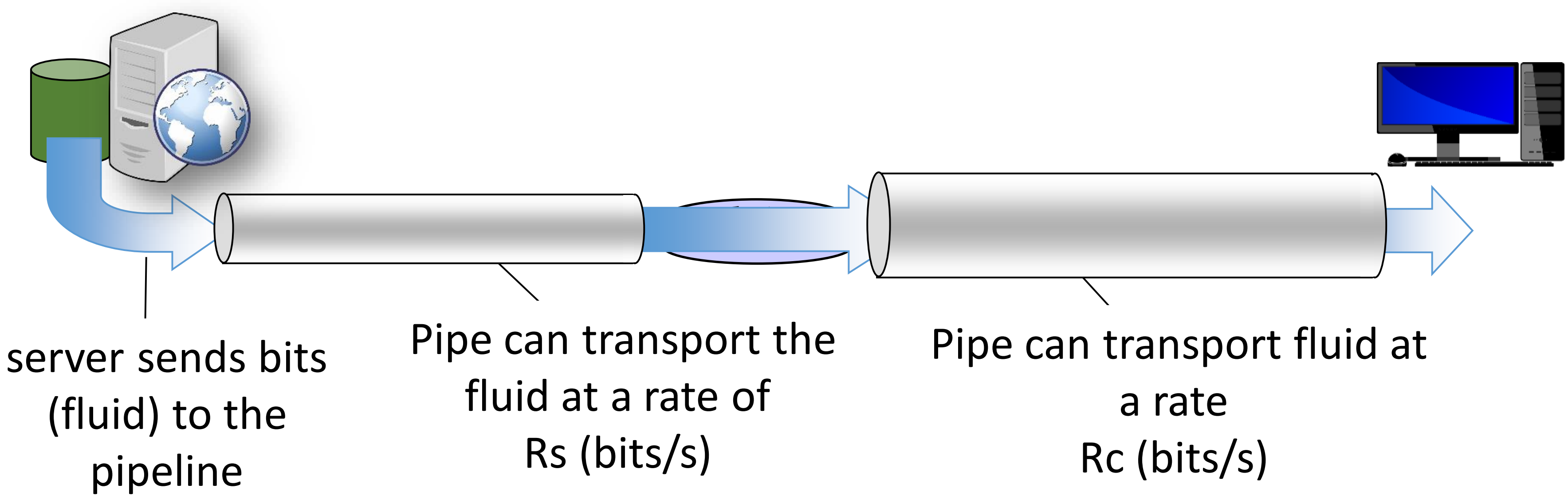
- The buffer associated with a link has a finite capacity
- Packages that arrive in a full queue are dropped (lost)
- Discarded packets can be retransmitted by the source terminal system, by the previous node or by no one



Performance
Transfer rate (end-to-end)

Throughput: rate (bits/unit of time) at which bits are transferred between client and server

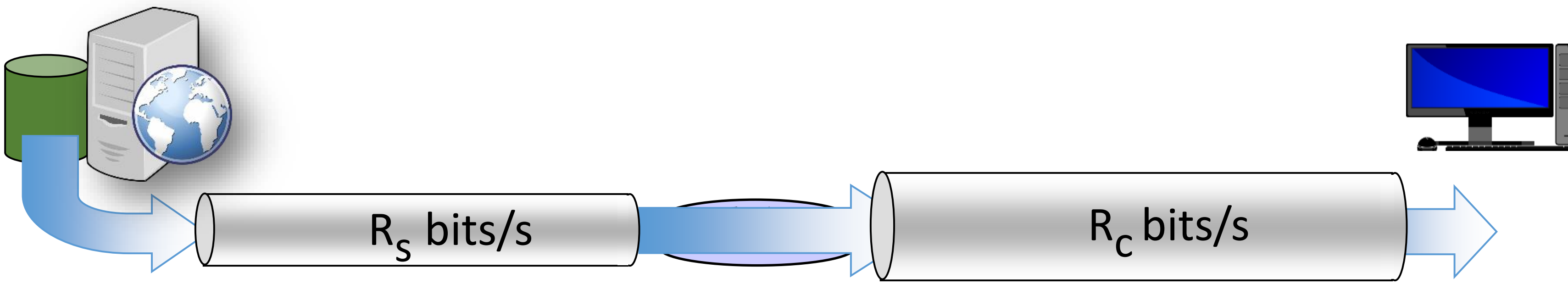
- Instantaneous: rate in a given instant of time
- Average: rate measured over a period of time



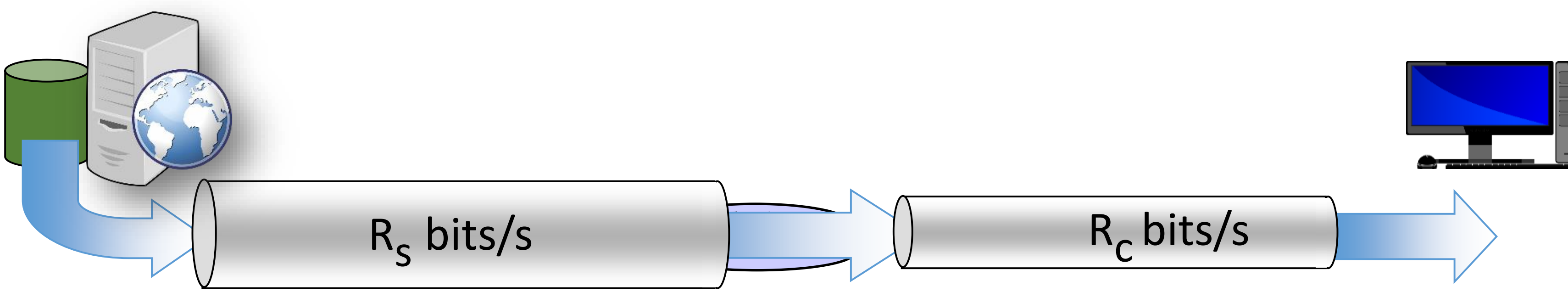
Performance

Transfer rate (end-to-end)

If Rs < Rc, average terminal-to-terminal transfer rate?

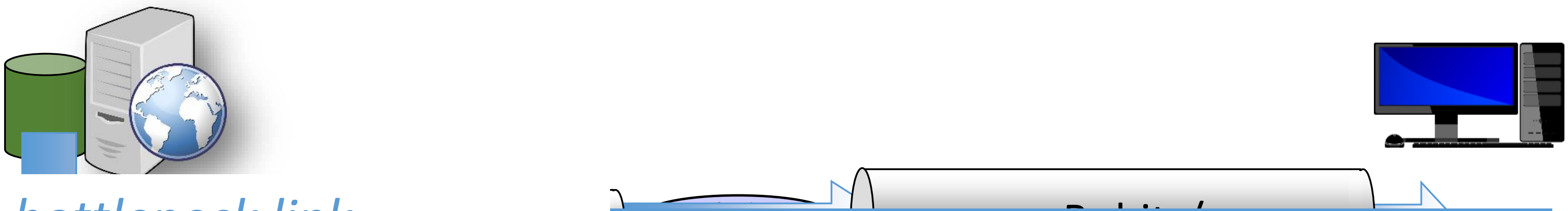


If Rs > Rc, average terminal-to-terminal transfer rate?



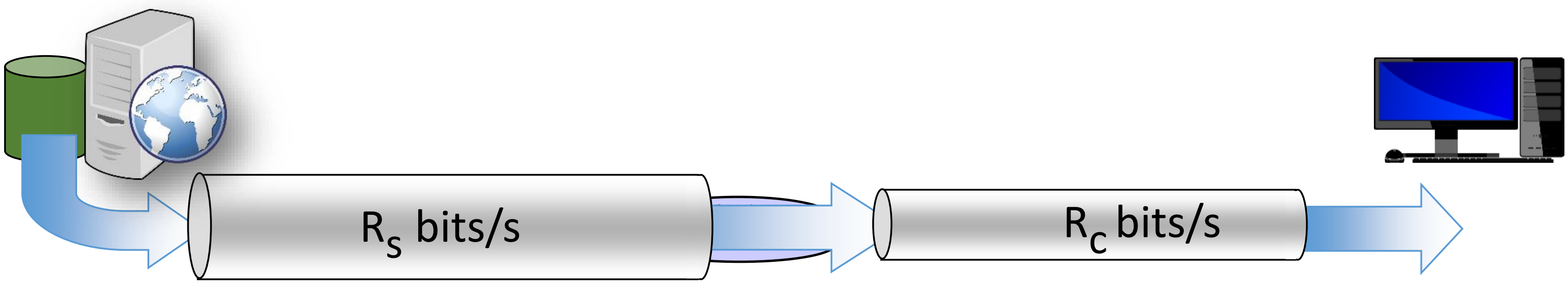
Performance
Transfer rate (end-to-end)

If Rs < Rc, average terminal-to-terminal transfer rate?



bottleneck link

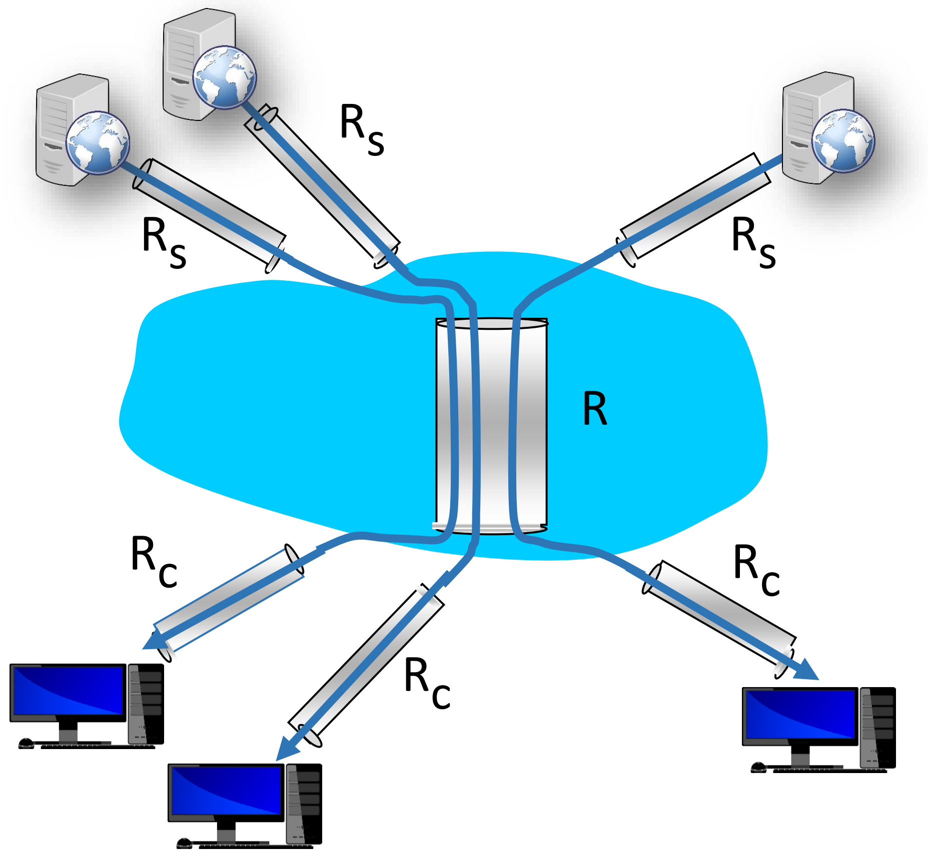
It is the link in the end-to-end path that limits the end-to-end transfer rate.



Performance
Transfer Rate: Internet Scenario

- Terminal-to-terminal transfer rate per connection: min(Rc,Rs,R/10)
- In practice: Rc or Rs is often the bottleneck

The transfer rate depends not only on the transmission speeds of the links but also on the existing traffic. Even if the transmission speed of the link is high, it can be the bottleneck if there is a lot of data flow going through that link.



10 connections share the common link (in equal parts) with R bit/s rate

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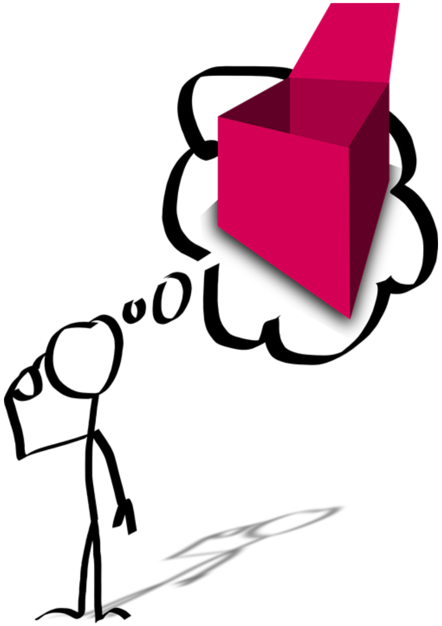
Protocol layers, service models

Networks are complex, with many "pieces":

- Terminal systems
- Routers
- Multi-media links
- Applications
- Protocols
- Software
- Hardware



Do we have any hope of being able to organize a network architecture?

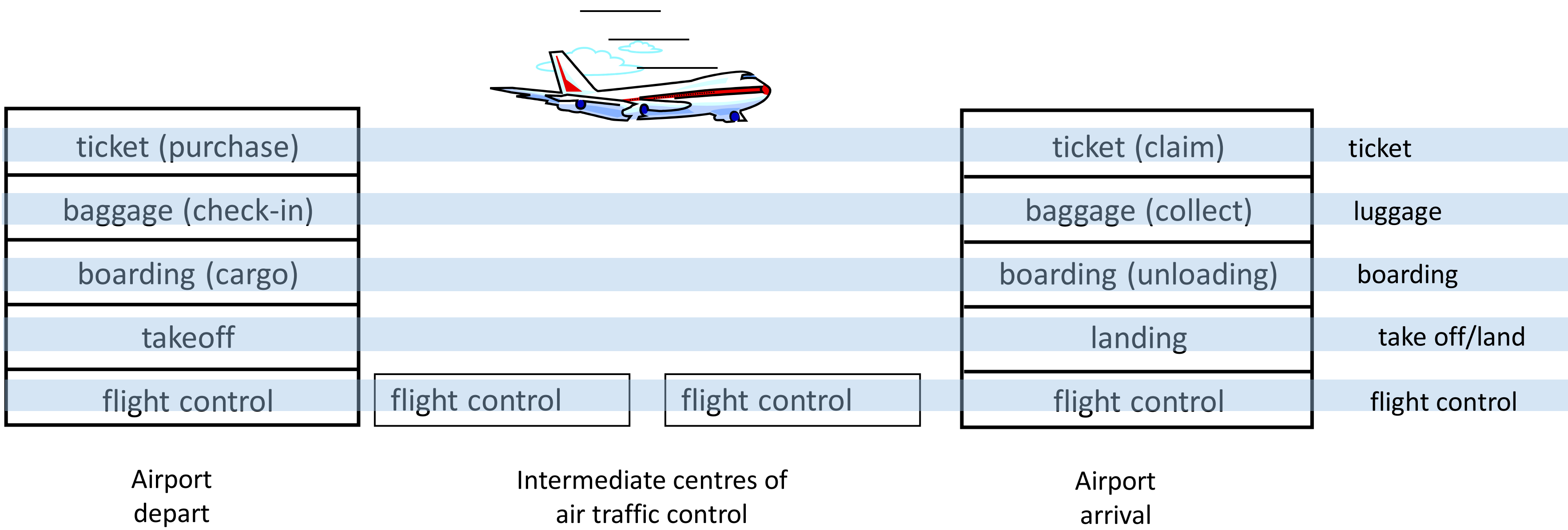
Protocol layers, service models
Simile with the organization of a plane trip

ticket (purchase)	ticket (claim)
baggage (check-in)	baggage (collect)
embarkation (cargo)	boarding (unloading)
takeoff	landing
flight control	flight control

flight control

A set of steps...

Protocol layers, service models
Simile with the organization of a plane trip



Layers or levels: each layer implements a service...

- performing certain actions within that layer
- using the services provided by the layer you have directly below it

Protocol layers, service models
Why a layered architecture?

Systems are complex:

- A specific structure makes it possible to identify and relate the complex parts of the system
- A **layered reference** model for analysis and discussion
- Modularization simplifies system maintenance and upgrade
- Modifying the service implementation of a layer is transparent to the rest of the system
- E.g., change in boarding procedure does not affect the rest of the system

Protocol layers, service models

How do you organize a layered architecture?

- At each end there must be an instance of a certain level, known as an **entity**.
- Each level performs a set of tasks, known as **functions**
- Not all functions are performed at each end of the communication.
- E.g., in the baggage layer there is the check-in function and the collect function.
- Each level offers a set of features (provider) at the top level (user), known as **services**
- E.g., the check-in service.
- Access to services at a certain level is done through an interface known as SAP (Service Access Point).

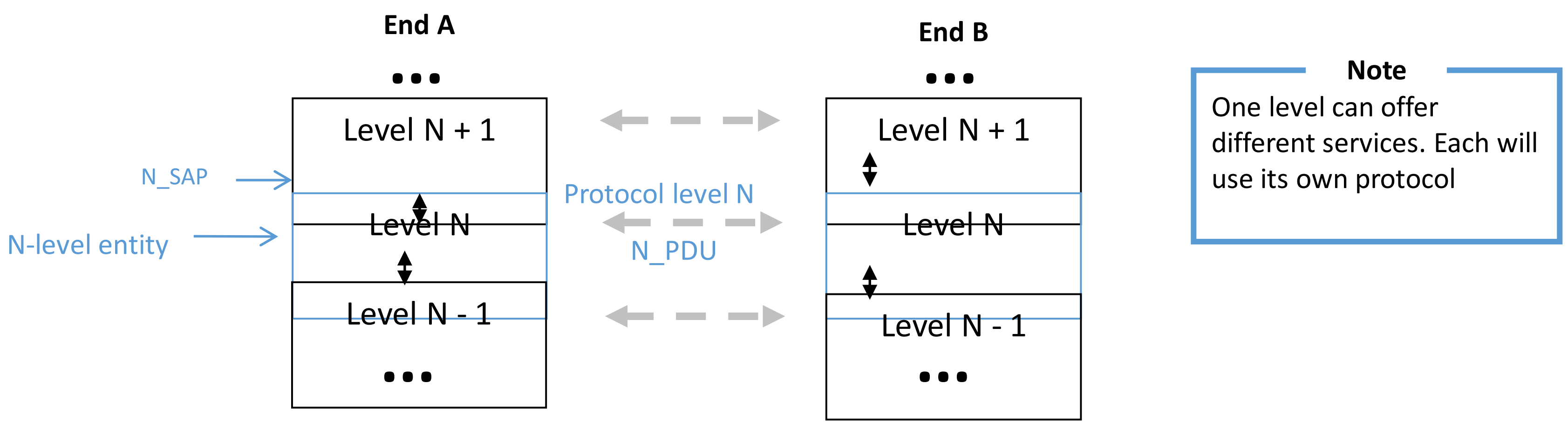
Protocol layers, service models

How do you organize a layered architecture?

- At each level, a certain protocol is used to communicate with another entity of the same level, offer services to its higher level and perform the functions entrusted to it.
  - Use the services offered by the lower level.

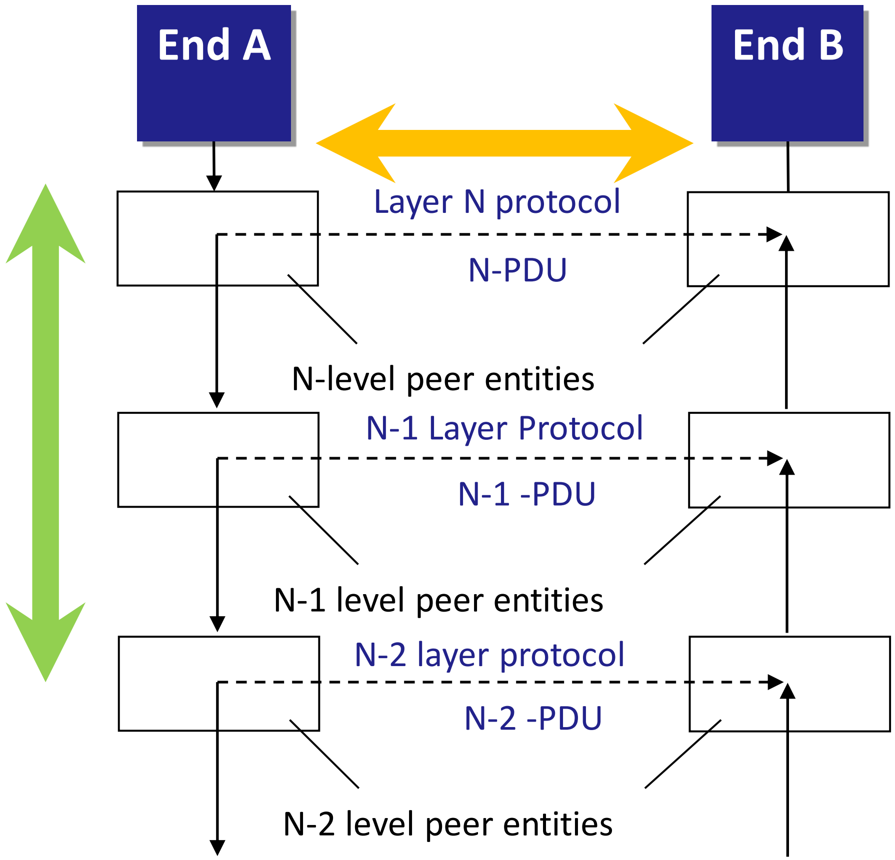
  The protocol describes:
  - the format of the messages to be exchanged PDU (Protocol Data Unit)
  - message exchange rules

  Example



Protocol layers, service models

Layered architecture



What is the flow of information?

Real:

- Between adjacent levels.
- Through SAP.
- Vertical communication.
- PDUs have to be encapsulated and deencapsulated.
- On the same computer.

Logic:

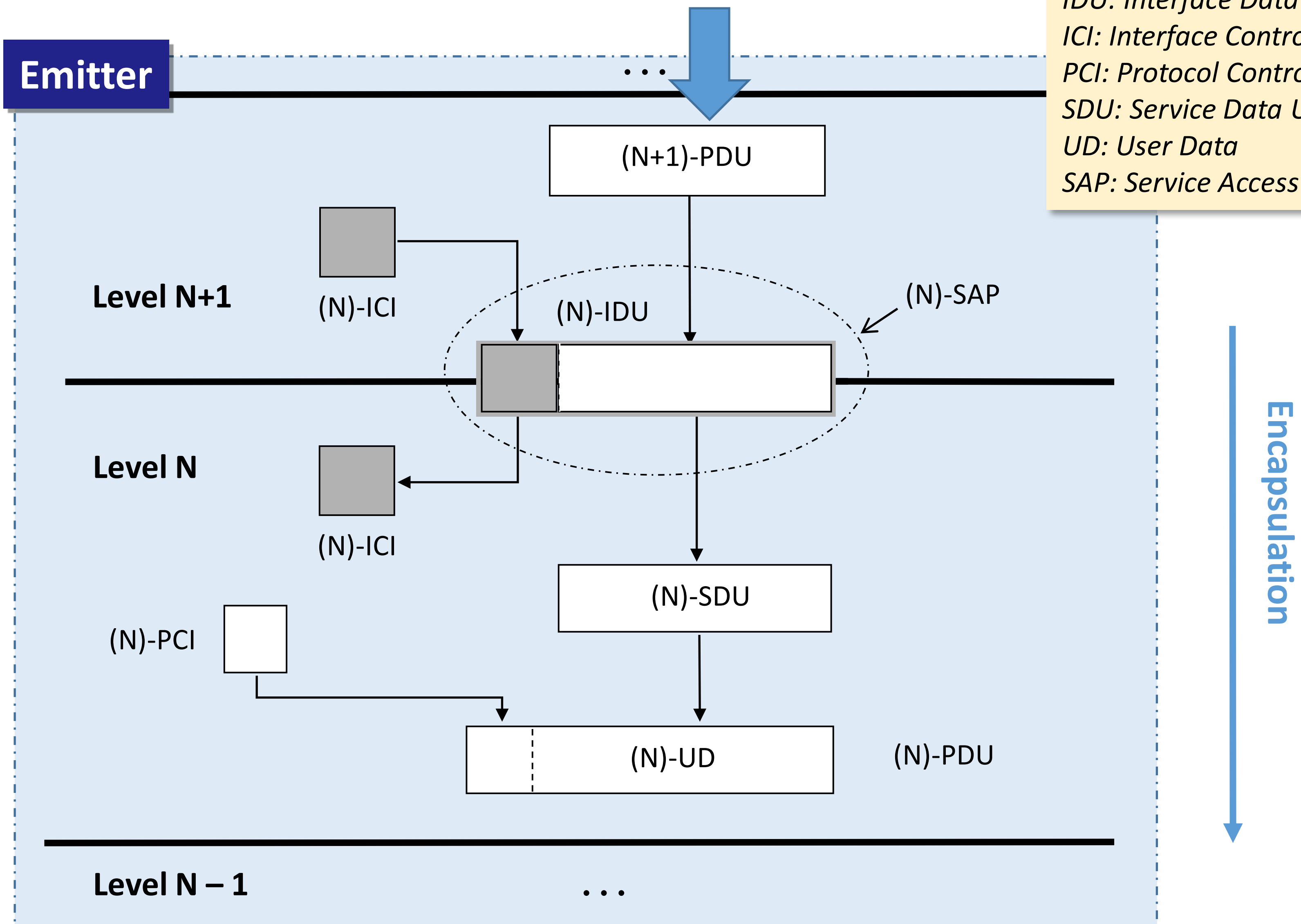
- Between peer entities.
- Horizontal communication
- Between different teams.
- PDUs are exchanged.

Note

Entities at the same level are known as peer entities

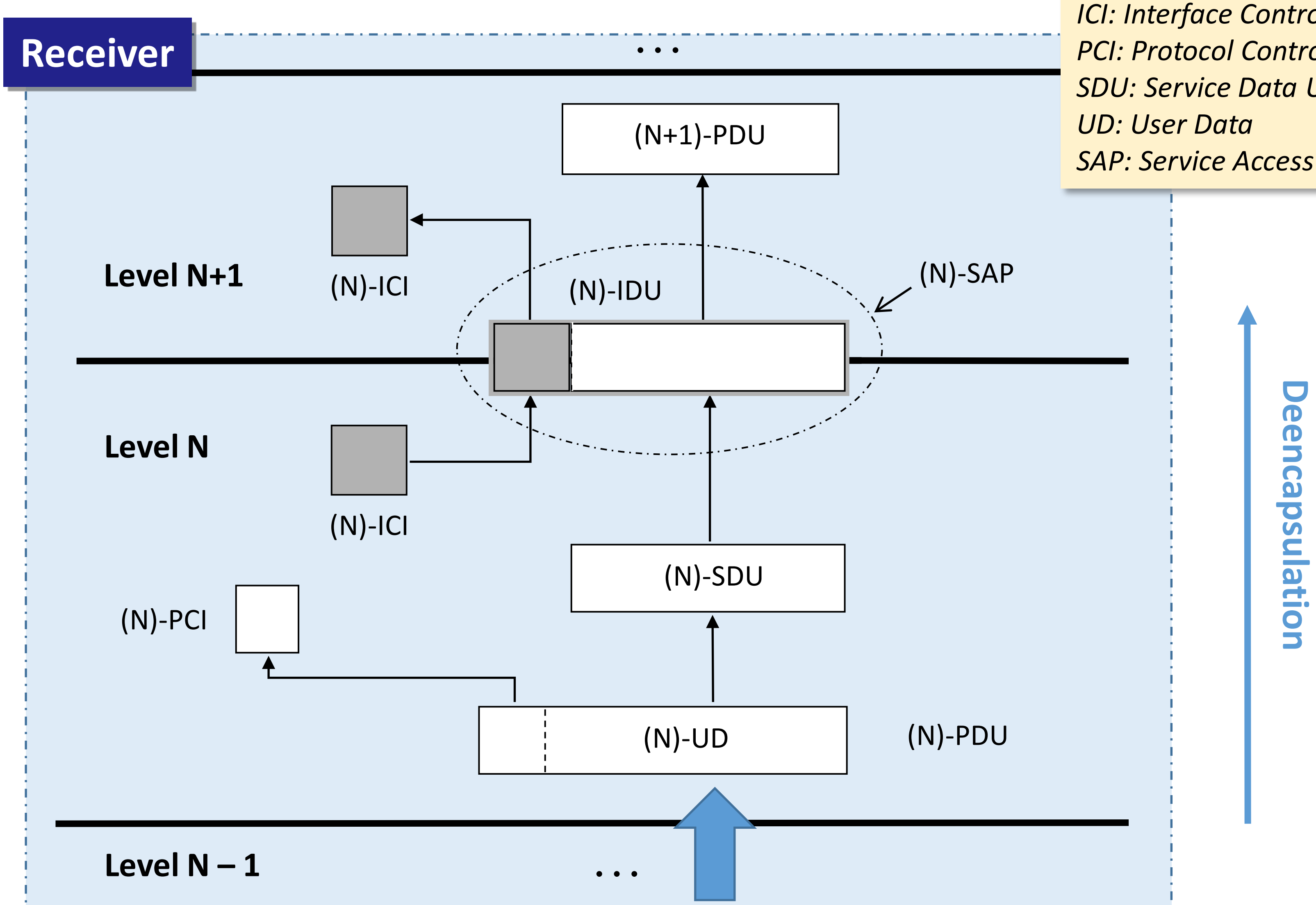
Protocol layers, service models
Encapsulation

IDU: Interface Data Unit
ICI: Interface Control Information
PCI: Protocol Control Information
SDU: Service Data Unit
UD: User Data
SAP: Service Access Point



Protocol layers, service models
Deencapsulation

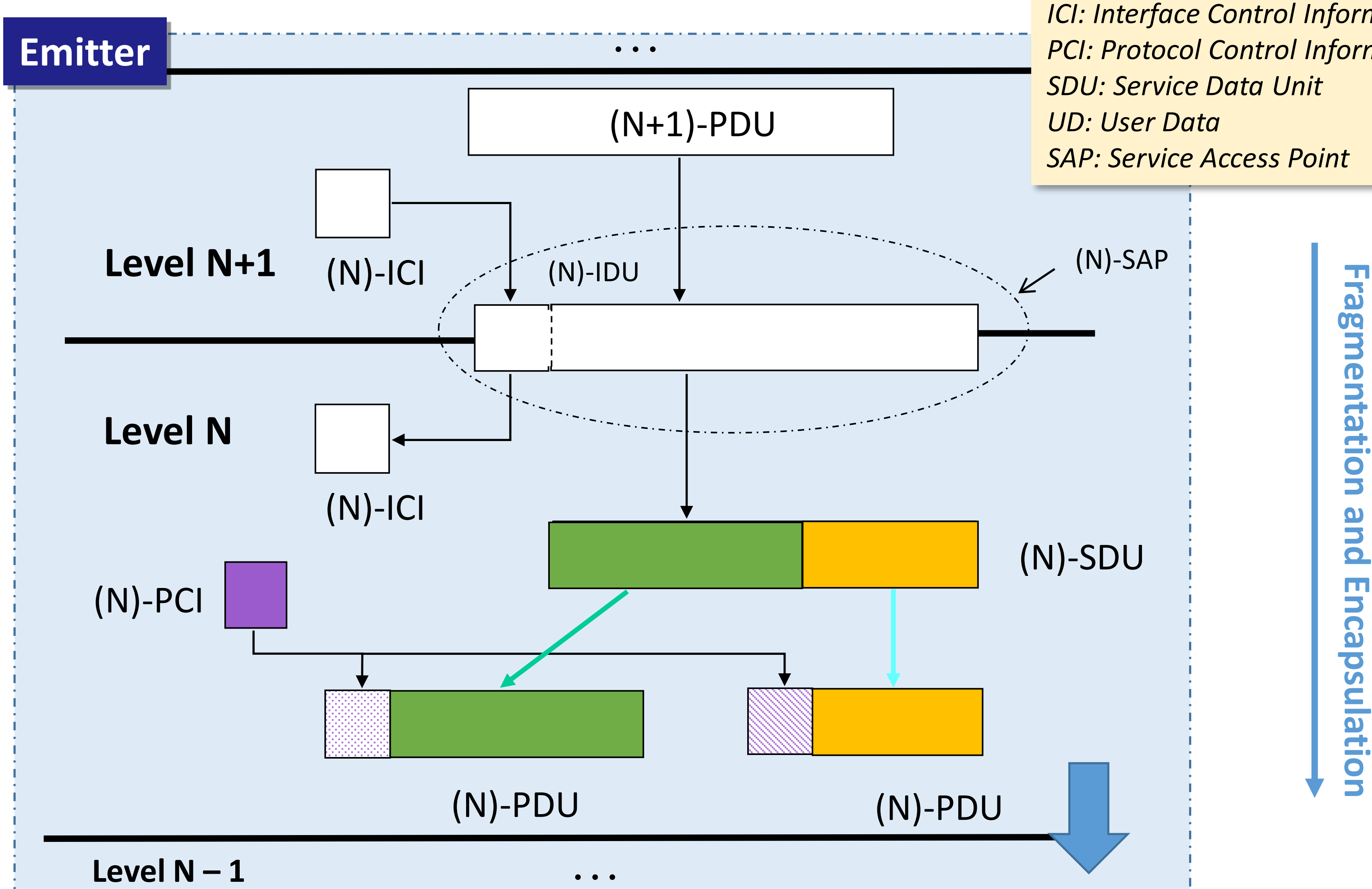
IDU: Interface Data Unit
ICI: Interface Control Information
PCI: Protocol Control Information
SDU: Service Data Unit
UD: User Data
SAP: Service Access Point



Protocol layers, service models

Fragmentation

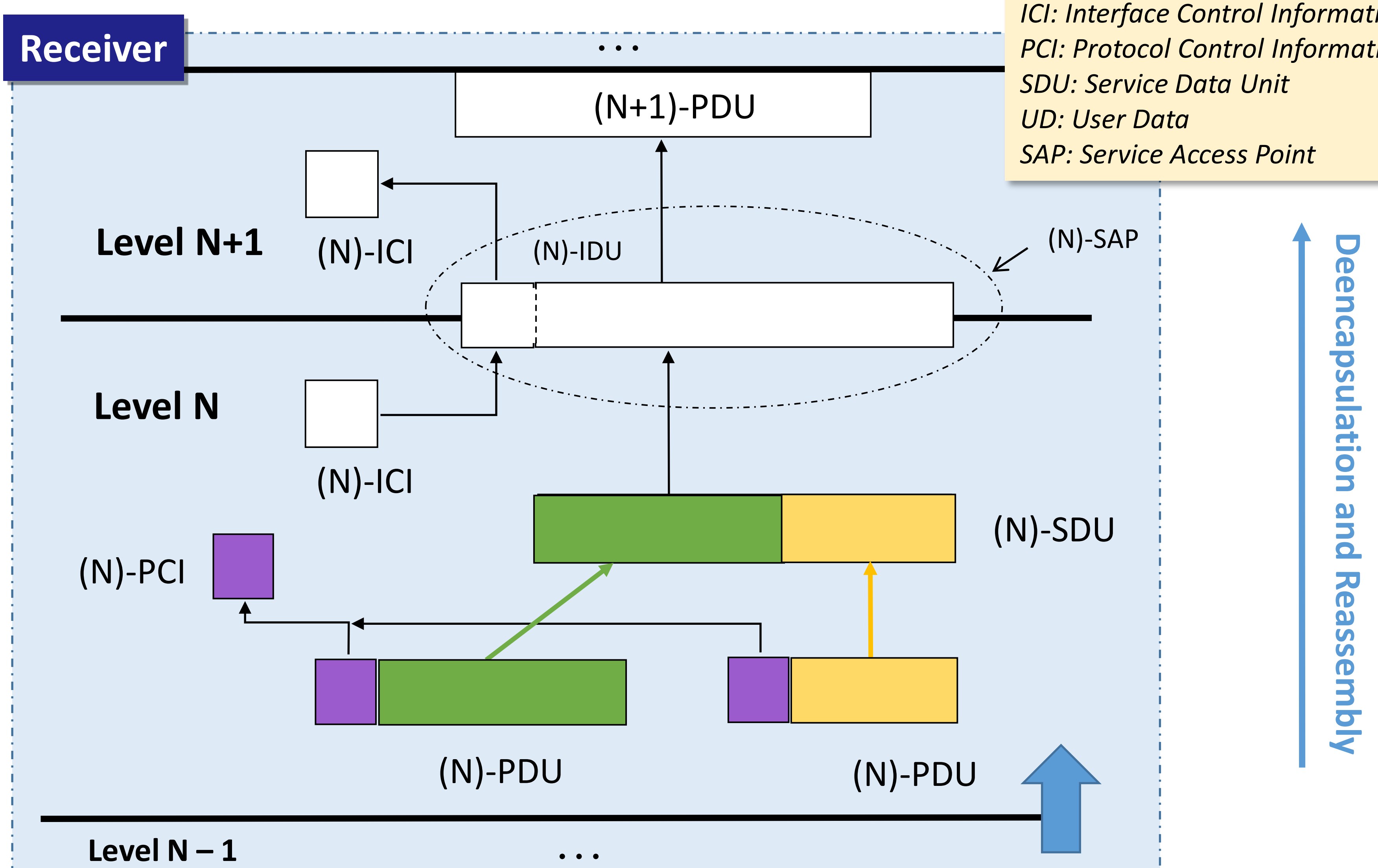
IDU: Interface Data Unit
ICI: Interface Control Information
PCI: Protocol Control Information
SDU: Service Data Unit
UD: User Data
SAP: Service Access Point



Protocol layers, service models

Reassembly

IDU: Interface Data Unit
ICI: Interface Control Information
PCI: Protocol Control Information
SDU: Service Data Unit
UD: User Data
SAP: Service Access Point

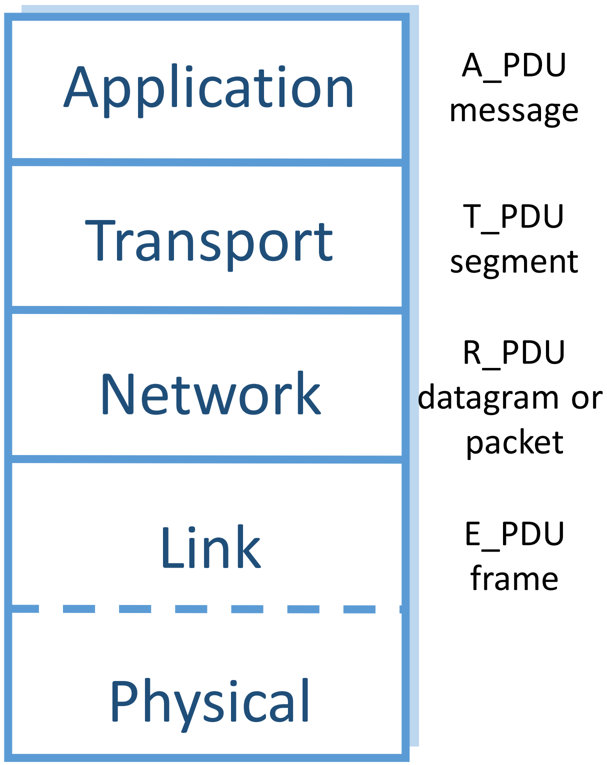


Protocol layers, service models
How many layers are needed?

- Depends on the set of functions that you want your network architecture to have.
- Two network architectures:
- **TCP/IP**
  - It is the one used on the Internet.
  - It consists of five layers.
  - Describes functions, services, and protocols
- **Reference model OSI (Open System Interconnection).**
  - It consists of seven layers.
  - ISO (International Organization for Standardization) standard.
  - Describes roles and services.

Protocol layers, service models
Internet Protocol Stack

- **Application:** Supports network applications. Serves as an interface with the end user
  - FTP, SMTP, HTTP, DNS
- **Transport:** end-to-end data transfer between processes
  - TCP, UDP
- **Internet or Network:** addressing and routing datagrams from source to destination
  - IP, protocolos de rutado
- **Link:** Data transfer among "nearby" network elements
  - Ethernet, 802.11 (WiFi), PPP
- **Physical:** bits "on the wire“
  - Ethernet (conectores y cables)

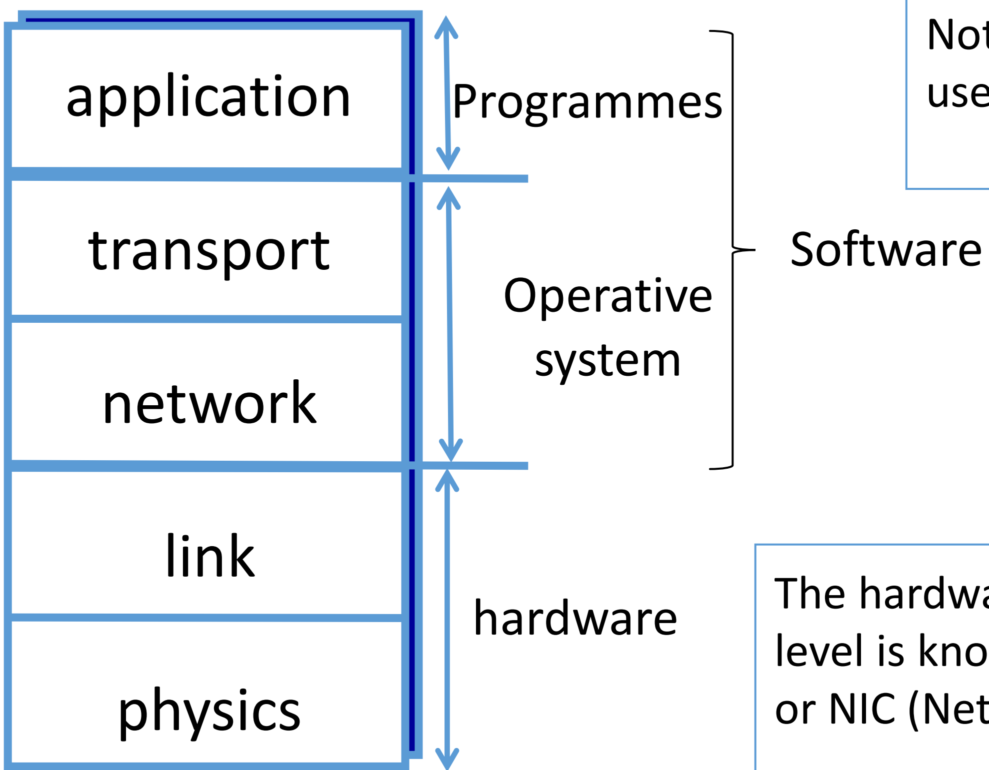


Protocol layers, service models

Reference model ISO/OSI

- **Presentation**: allows applications to interpret the meaning of data, e.g. encryption, compression, encodes data in standard mode
- **Session**: synchronization, checkpoints, data exchange recovery
- The Internet stack "skips" these layers...
  - If these services are necessary, they must be implemented in application
  - Are they necessary?

Protocol layers, service models
How are layers implemented?



Note

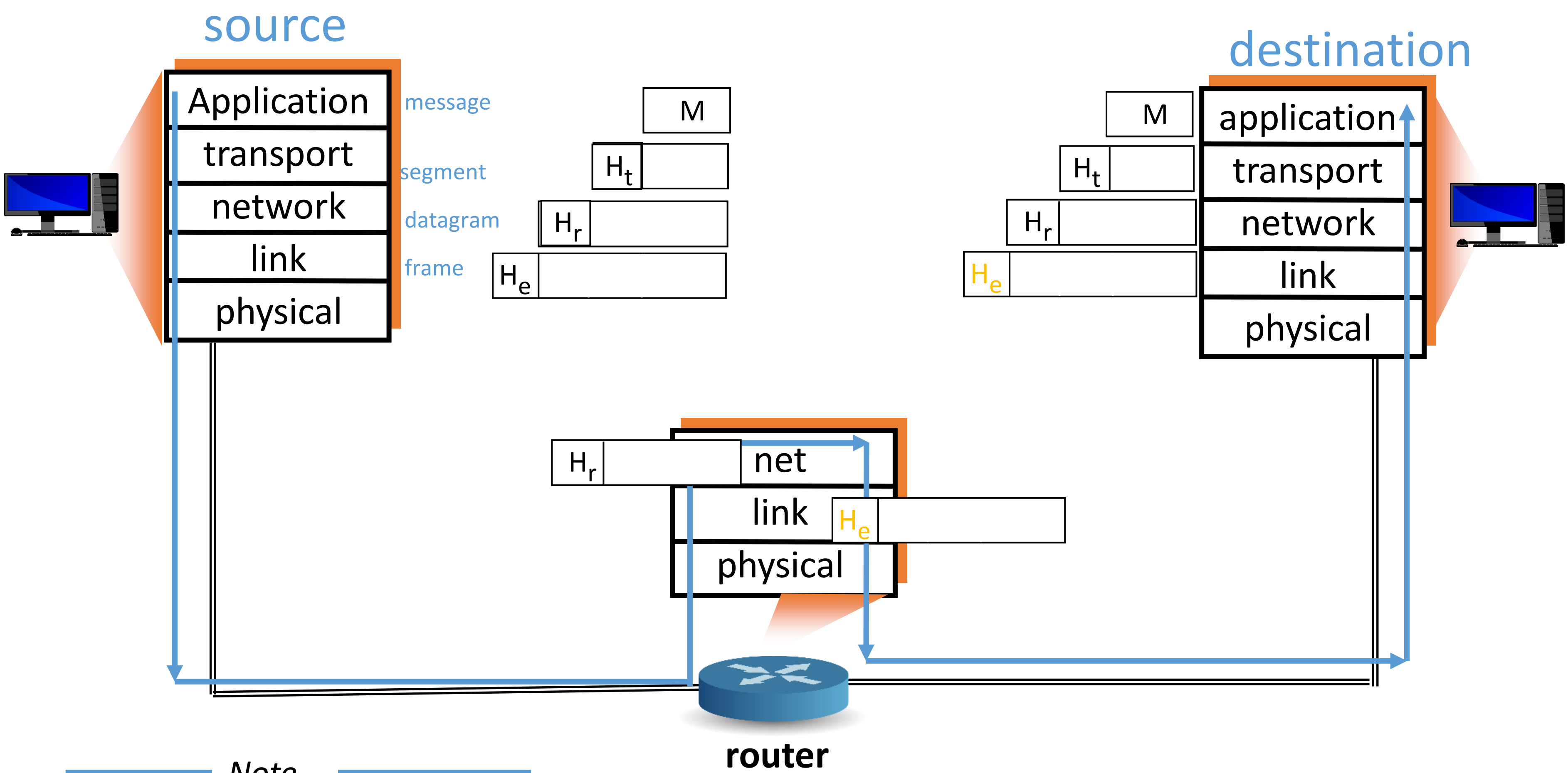
Not all levels are on all devices that are used on the Internet.

Note

The hardware that implements the link and physical level is known as a network interface, network card or NIC (Network Interface Card).

Protocol layers, service models

Example of two end systems interconnected by a router



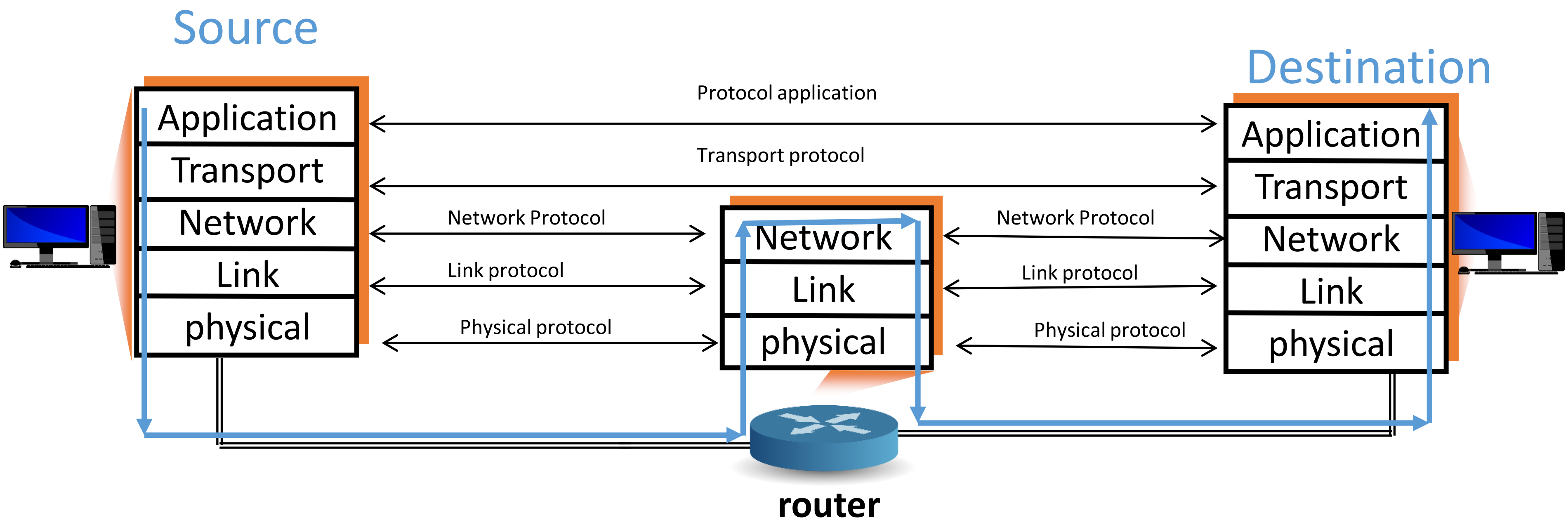
Note

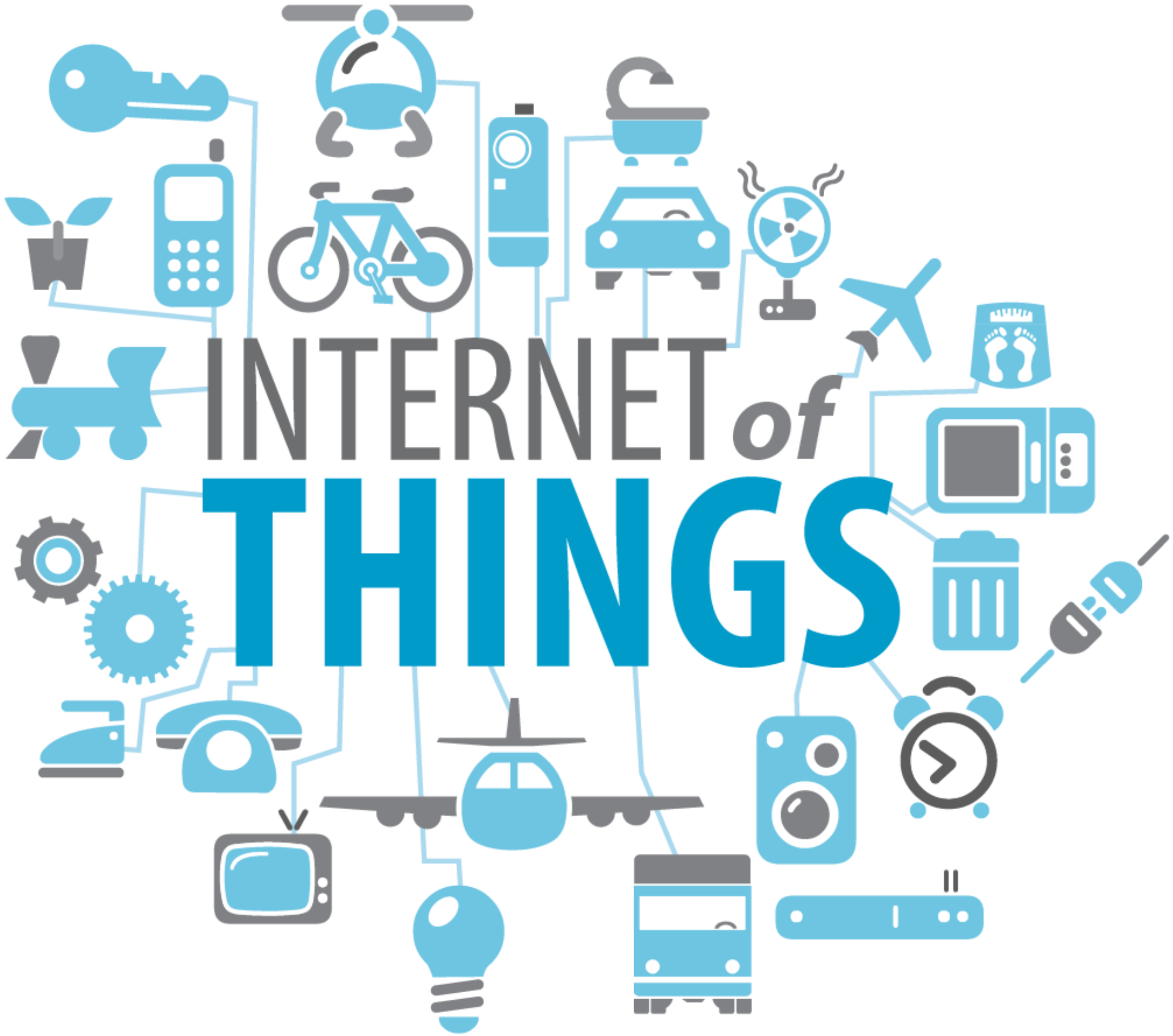
Hx = X_PCI
M = A_PCI(Ha) + User Data (UD)
UD Example:
Subject/body of a e_mail
Text of a WhatsApp message

Physical media

Protocol layers, service models

Example of two end systems interconnected by a router

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7
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