Computer Networks (part 1)

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UNIVERSITÉ JEAN MONNET SAINT-ÉTIENNE

Computer Networks: global overview

1. Introduction to computer networks
2. Networking application layer (HTTP, FTP, DNS, …)
3. Data transfer layer (UDP, TCP, …)
4. Network layer (routing, IP, ICMP, NAT, …)
5. Lower layers, wireless and mobile (Ethernet, ARP, …)
6. Security (SSL, …)

Part 1: General Introduction

- Goal
  - have a tour of the main concepts
  - that will be seen in details later
- Overview
  - what is internet
  - what is a protocol
  - the network edge
  - layers and encapsulation
  - security
  - some history
  - the network core
  - performance: latency, bandwidth, throughput, etc.

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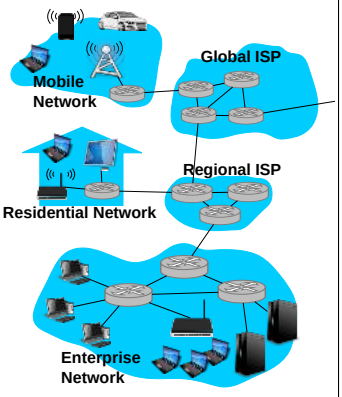
How do you use internet? (list your use cases)

What are the important properties of the network for each use case?

Internet

Internet: hardware aspects

- Millions or billions of interconnected hosts, executing applications
  - workstations, laptops, servers
  - phones, tablets, …
  - fridges, scales, toasters, …
  - host == machine == end system
- Communication links
  - wires, optical fibers, satellites, …
- Routing nodes
  - routers and switches



Internet: some hosts and appliances

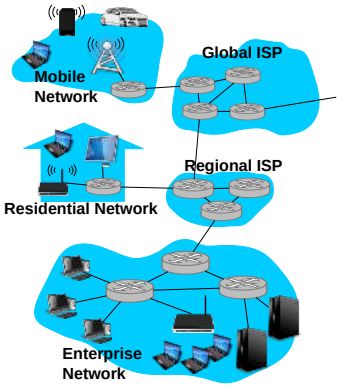
- Machines/Hosts






- Applications

Internet: fundamentals



- A network of networks
  - interconnection of networks
  - multi-level hierarchy
- A set of protocols
  - communication rules
  - ex: HTTP, FTP, TCP, IP, PPP
- A set of standards
  - « RFC » (Request For Comments)
  - « IETF » (Internet Engineering Task Force)

"The Internet"
youtube://iDbyYGrswtg
youtube://UTBsm0LzSP0

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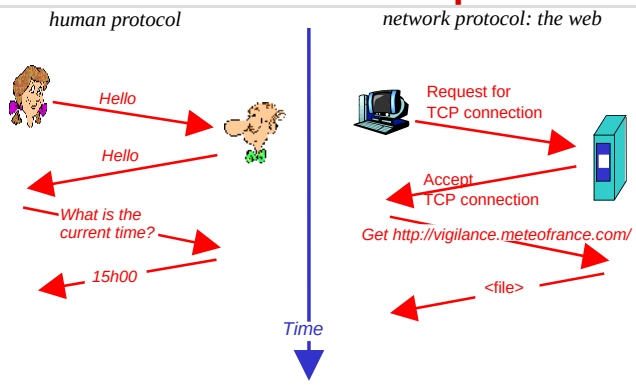
Meaning of the Word "Protocol"? Examples?

Protocol: Examples



Protocols

- Human examples
  - asking the current time
  - ask a question in class
  - introduce someone to someone else
  - …
- Elements of (human) protocols
  - etiquette, politeness, etc
  - communication rules
  - messages sent (content and sequence)
  - expected reactions
- Computer protocols
  - between machines
  - all communications on Internet follow some protocols
  - different levels (HTTP, TCP, ...)
- Definition of computer protocols
  - formats definition, and sequence (ordering)
  - … of all messages (sent and received)
  - … exchanged by connected hosts
  - + the actions taken after these messages

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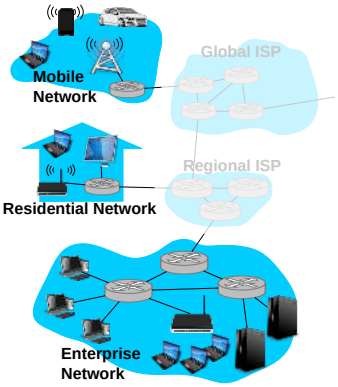
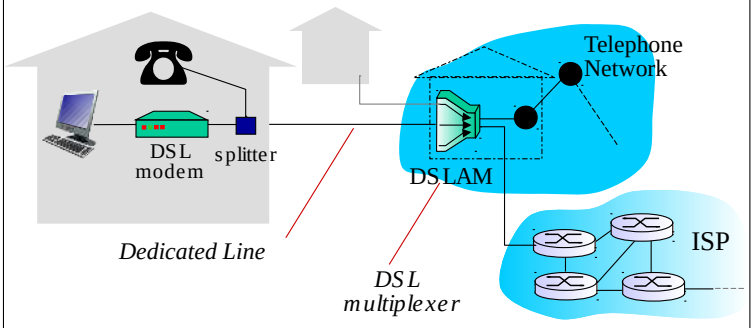
The Network Edge – Internet access

Internet Network Structure

- Network core
  - interconnections of routers
  - network of networks
- Physical links
  - wires, cables
  - wireless transmissions
- Network edge, network border
  - hosts (clients, servers)
  - access points (routers)

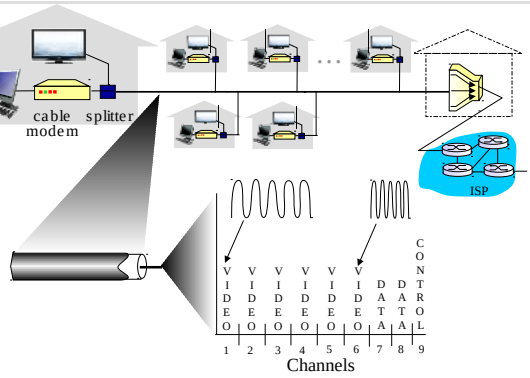


Access Network: ADSL Asymmetric Digital Subscriber Line



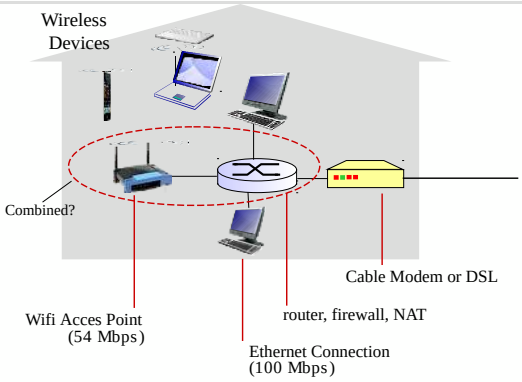
- Using existing phone telephone lines
- Asymmetric: download (<25Mbps) vs upload (<2.5Mbps)

Access Network: Cable (and fiber)

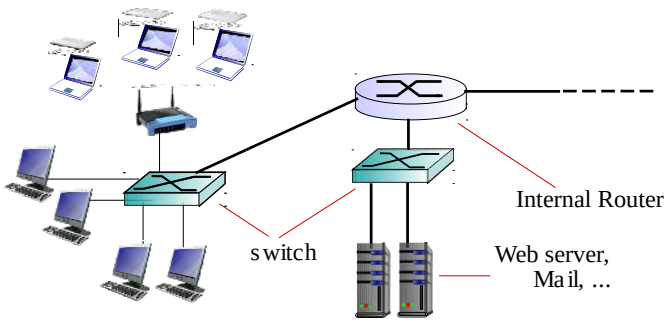


- Using television network, shared line
- Frequency channels
- Original cable: download (<30Mbps), upload (<2Mbps)

Residential Network



Institutional Networks: companies, university, ...



- Dedicated routers and switches
- Mostly wired connections at 10Gbps

Wireless Access

- Wifi
  - residential
  - institutional
  - public spaces
  - limited range
  - bandwidth: 802.11n norm, <300Mbps
- Mobile networks: 2G, 3G, 4G, ...
  - mobile phone antennas
  - long range
  - bandwidth: 4G, 100Mbps

Sending Information from Host to Host

- Application level abstraction
  - messages can be big
  - ex: an audio or video file
- Work to be done by the host
  - splitting the message in "packets"
  - sending each packet on the network
  - sending data via a network link
- Network link properties
  - a given "binary bitrate" (or rate), e.g., 1Gbps
  - time/delay for transferring a packet of size as a function of the bandwidth

Types of Physical Links

- Cables etc
  - coaxial cables: multiple frequency channel
  - RJ45 cables (twisted pair), 10Gbps
  - optical fiber
    - glass fiber, light pulses
    - low error rates, 100Gbps
- Radio waves, etc
  - electromagnetic waves, multiple frequency channels
  - interference, occlusions, …
  - different technologies
    - wifi: 54Mbps
    - 3G: 0.3 à 2Mbps
    - satellites: 45Mbps, latency (250ms)

Given a 5MB message (e.g., image).

when sent from host to host what happens ?

How long does it take?

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Layered Architecture

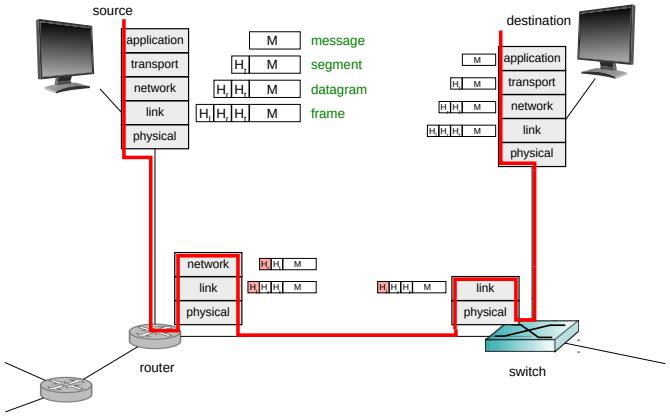
- Complexity of the network architecture
  - hosts, routers, links (cables, …)
  - applications, protocols
  - mixing hardware and software
- Layered architectures general advantages
  - advantages for complex systems
    - specification of services/roles of each layer
    - isolation of abstraction levels
    - easier maintenance
  - drawbacks?

The Network Stack: the 5 layer model

- 5-layer model
  - application
    - ex: HTTP, FTP, SMTP (mails), DNS
  - transport
    - ex: TCP, UDP
  - network
    - ex: IP, ICMP
  - link
    - ex: Ethernet, 802.11 (wifi)
  - physical
    - ex: telephone, ADSL, satellite
- Other well known model: OSI (7 layers)

application
transport
network
link
physical

Encapsulation and Routing



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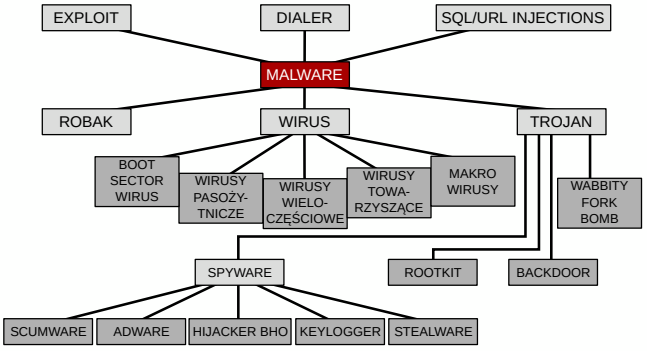
Network Security

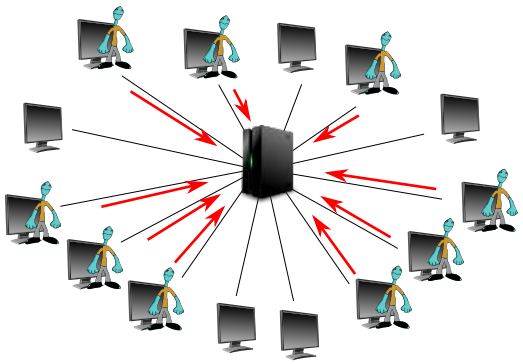
- Security area
  - identify possible means of attack
  - find ways to protect from these
  - conceive architectures that are immune to attacks
- Internet
  - original vision
    - a network of trusted users
    - transparent communications
  - need to add security at every layer

Malware: malicious software

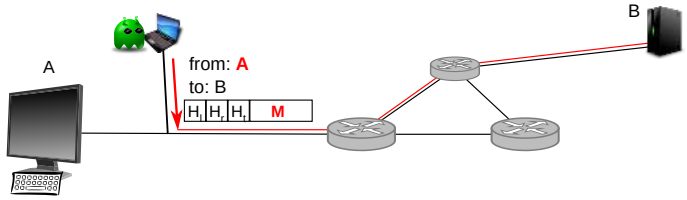


- propagated via users over the internet
- remote control of machines
- spying on user (keyboard, etc)

Denial of Service (DoS)



Packet Sniffing and Spoofing



- Sniffing
  - spying of transmitted packets
  - sensitive data, passwords, ...
- Spoofing
  - sending new packets
  - falsifying the packet source
  - pass for someone else

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Internet: a few key dates

- 1961: packet switching (Kleinrock)
- 1967: conception of ARPAnet
- 1969: ARPAnet is operational
- 1972
  - public demonstration of ARPAnet
  - 15 nodes
  - first emails
- 1976: Ethernet at Xerox
- 1979: ARPAnet has 200 nodes
- 1970's: many other networks than ARPAnet

Internet: a few key dates

- 1969: ARPAnet is operational
- 1982: SMTP
- 1983: TCP/IP, DNS
- 1985: FTP
- 1988: congestion control for TCP
- 1980's: even more networks
  - including the Minitel
  - 100k hosts

Internet: last decades

- early 1990's: public internet, web, HTTP, HTML
- late 1990's
  - instant messaging, peer to peer file sharing
  - importance of security
  - 50M hosts
  - network core uses Gbps links
- 2000+
  - high-speed internet: democratization of internet access
  - ubiquity: mobile access on smart-phones, tablets
  - more and more online services (google, facebook, ...)
  - dedicated network in parallel to internet
    - created by content providers (Google, Microsoft, ...)
  - online education
  - Iaas, PaaS, SaaS, BaaS
    - many companies externalize their services
    - in the "cloud"

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Given a 5MB message (e.g., image).

when sent from host → host what happens ?

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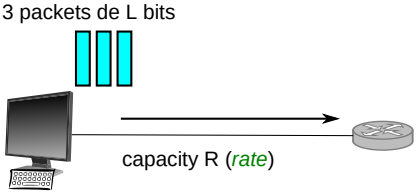
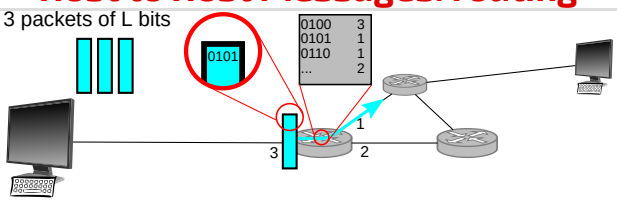
Sending Messages from Host to Host

- Applications
  - splitting of the message in « packets », sent on the network
- Network link capacity
  - capacity == binary rate == bitrate == rate (language shortcut) == bandwidth
  - transmission delay (1 packet): $t = \frac{\text{packet size}}{\text{bitrate}} = \frac{L}{R}$

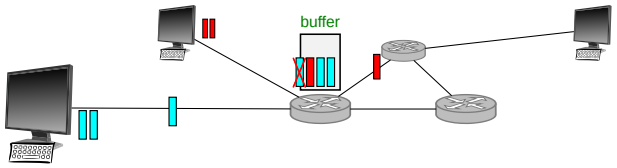


Host to Host Messages: routing



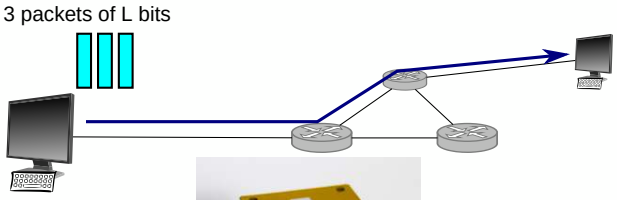
- Router: transfers/routes packets
  - forwarding table (routing table)
- Router: stores and forward packets
  - unit of transfer: packet
  - receives a **whole packet**
  - **then** forwards it
- Delay for 1 packet: sum of delays

Routing: buffers and packet loss



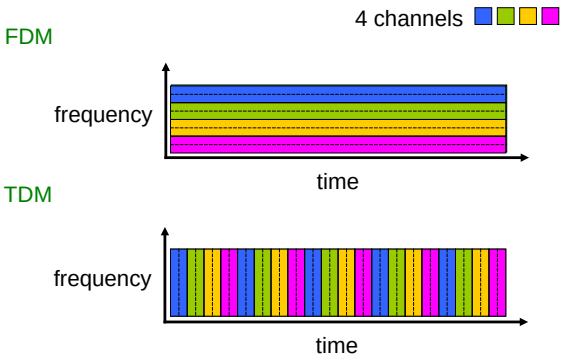
- Buffering of packets
  - too many received packets
  - not enough output capacity
  - queuing/buffering
- Packet loss
  - memory full / buffer overflow
  - cannot store, packets are dropped

Host to host communication? Case with 3 packets: rate? delay?



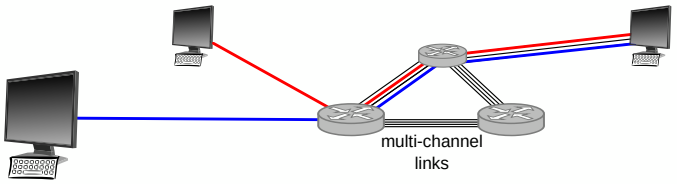
Principle of Multiplexing

- Multiple channels on a single link
  - in the frequency domain, FDM: frequency-division multiplexing
  - in the time domain, TDM: time-division multiplexing



Alternative to packet switching

- Idea: dedicated virtual lines using multiplexing
- Circuit switching
  - dedicated connection through the whole interaction
  - guaranteed performances (throughput, latency)
  - used for telephone communications

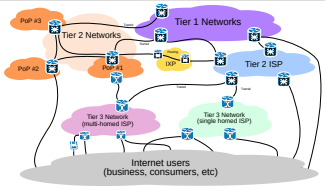


Why doesn't internet use circuit switching? (no loss, guaranteed throughput and latency)

Why Doesn't Internet Use Circuit Switch.?

- Packet switching allows for more simultaneous users
- Example
  - a link at 1Mbps
  - a typical user behavior
    - active only 10% of the time
    - using 100kbps when active
- Circuit switching
  - max 10 users
- Packet switching
  - how often do we queue?
  - probability of congestion
  - ex: 10 users (or less)
    - $p(n_{\text{active}} > 10) = 0$
- Packet switching
  - ex: 11 users
    - $p(n_{\text{actifs}} > 10) = 10^{-11}$
  - ex: 35 users
    - $p(n_{\text{active}} > 10) < 0.0004$
  - ex: 50 users
    - $p(n_{\text{active}} > 10) \approx 0.01$

Internet Structure: a network of networks



- Tiers
  - Tier1 (~12)
    - the network core
    - free data exchange
  - Tier2 (numerous)
    - buys bandwidth to Tier1 actors
    - sells bandwidth
  - Tier3 (numerous)
    - buy only
- Interconnections and agreements
  - PoP: Point of Presence
  - IXP: Internet Exchange Point
  - peering agreements

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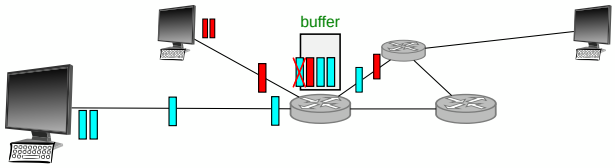
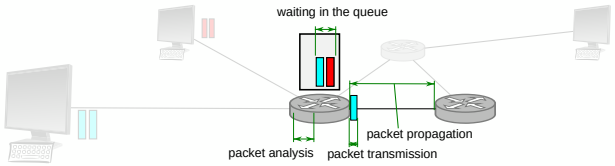
Buffering/Queuing and Packet Loss



- Cause
  - input bitrates are greater than the capacity of the output link
  - a temporary situation
  - but long enough to fill the buffer ⇒ need to drop packets
- Effects
  - delay due to the queuing
  - necessity to handle (at higher levels) the loss

Four Sources of Delay



- Sources of delay/latency
  - d_{proc} : < 1ms
  - d_{queue}: depending on router congestion
  - $d_{trans} = \frac{L}{R} = \frac{\text{size}}{\text{capacity}}$
  - $d_{prop} = \frac{d}{s} = \frac{\text{distance}}{\text{speed}}$

Exercise

- Total delay d_{total} includes $d_{proc} + d_{queue} + d_{trans} + d_{prop}$
- How much time does it take to transfer
  - a single 125 kB packet
  - over a 100 Mbps link
  - supposing there is no congestion

1. To a computer in the classroom next-door?
2. To a computer in San Francisco? (~ 9000 km)

Capacity, Bitrate, Throughput, Bandwidth

- Precise terminology
  - for a link: bandwidth == capacity == rate
  - from a device to another
    - transfer rate == throughput
    - the actual throughput is upper bounded by the link capacity
    - instantaneous throughput, average throughput
- Data transfer rates in a network
  - analogy with fluids in some pipes