INP Grenoble
DÉPARTEMENT TÉLÉCOMMUNICATIONS

# Computer Networking

# Introduction

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## Course goals

- Understand TCP/IP and networking concepts
- Approach
  - bottom-up, descriptive, use Internet as an example
  - wrap up with the application layer seen during the 1st year course
- Organization
  - 27 h course
  - demos, exercises
  - slides are not exhaustive - you must take notes and ask questions!
  - bonus questions: 5 good answers get 1 point (limited to 5 per person)
- Exam
  - closed-book: no personal notes, textbook, etc., are allowed
  - we provide a summary of required factual knowledge
- Your team
  - Andrzej Duda (in English), Olivier Alphand (en français)

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## Networking lab

- Important part of the course (separate grade)
  - perform required operations, write lab reports, final exam
  - cannot be repeated
    - grade < 8, you repeat your year!
- Goals
  - acquire practical knowledge
  - plug cables, configure hosts and routers, monitor, measure, program network applications
- Rooms D200 and D201:
  - 80 PCs with multiple network interfaces
  - network equipement: hubs, switches, routers
  - isolated from the rest of the network
- Your team
  - Olivier Alphand, Sébastien Viardot, TAs

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## Contents

- Introduction
  - architecture, performance
- Data Link
  - PPP, LAN (Ethernet, 802.11)
- Network layer
  - IP, ATM
  - Routing
- Transport
  - reliable transfer protocols
  - TCP, UDP, sockets
  - congestion control

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## Course support

- Web site
  - **http://duda.imag.fr/2at**
- J. Kurose, K. Ross "Computer Networking", 4th edition, Addison Wesley, 2007
- J. Kurose, K. Ross, "Analyse structurée des réseaux. Des applications de l'internet aux infrastructures des télécommunications." Pearson Education France, 2003
- Others
  - L. Toutain "Réseaux locaux et Internet", 3me édition, Hermes, 2003
  - W. R. Stevens "TCP/IP illustrated, Volume I", Addison Wesley (Very detailed, experimental hands-on description of TCP/IP)

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## Overview

- Network architectures
  - recall on the Internet
  - protocol architectures
    - how entities cooperate?
  - interconnection structure
    - which entities are connected?
  - related protocols
    - how and where different functionalities are implemented?
- Performance
  - transmission
  - propagation
  - bandwidth-delay product
  - queueing delay

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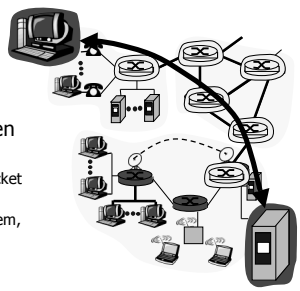
## Inside the Internet

- Between end systems
  - TCP protocol for reliable transmission
- Inside the network core
  - IP protocol: forwarding packets between routers
- Between routers or between end system and router
  - high speed link: ATM, POS (Packet over SONET), satellite links
  - access network: Ethernet, modem, xDSL, HFC



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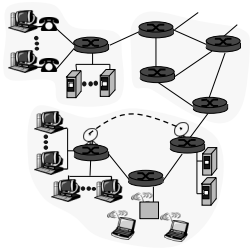
## Network structure

- network edge: applications and hosts
- network core:
  - routers
  - network of networks
- access networks, physical media: communication links



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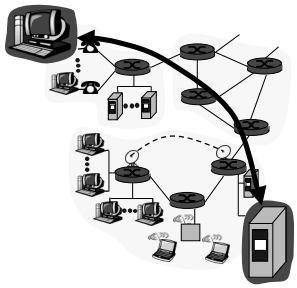
## The network edge:

- end systems (hosts):
  - run application programs
  - e.g., WWW, email
  - at "edge of network"
- client/server model
  - client host requests, receives service from server
  - e.g., WWW client (browser)/ server, email client/server
- peer-peer model:
  - symmetric host interaction
  - e.g. teleconferencing



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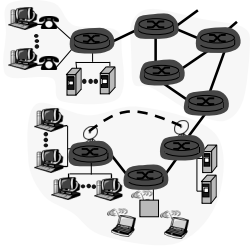
## The Network Core

- mesh of interconnected routers
- *the* fundamental question: how is data transferred through net?
  - circuit switching: dedicated circuit per call: telephone nets
  - packet-switching: data sent thru net in discrete "chunks" (IP)



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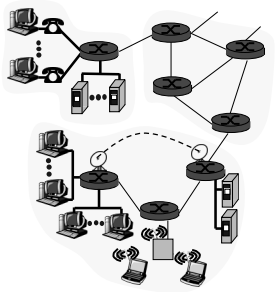
## Access networks and physical media

*How to connect end systems to edge router?*

- residential access nets
- institutional access networks (school, company)
- mobile access networks

*Characteristics:*

- bandwidth (bits per second) of access network
- shared or dedicated



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## Internet design principles

- Cerf and Kahn's internetworking principles:
  - minimalism, autonomy - no internal changes required to interconnect networks
  - best effort service model
  - stateless routers
  - decentralized control
- Small number of layers
  - compromise between performance and flexibility
    - thin layers encourage flexibility, but increases overhead
- Define today's Internet architecture

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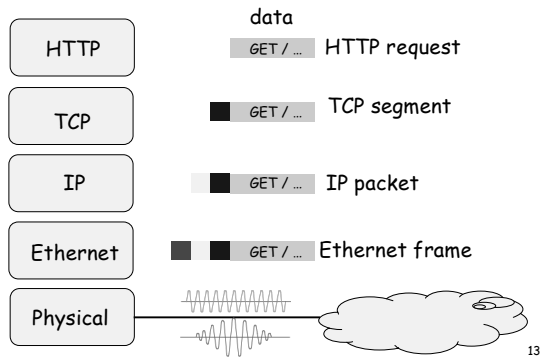
## TCP/IP Architecture

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## Application Layer

- Application layer supports network application
  - applications that are distributed over the network
  - applications that communicates through the network
- Many known protocols
  - FTP: file transfer
  - SMTP: email protocol
  - HTTP:web protocol
- An application uses UDP or TCP, it is a designer's choice
- Interface with the transport layer
  - use for example the **socket** API: a library of C functions
  - **socket** also means (IP address, port number)

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## Transport Layer

- Why a transport layer ?
  - **transport layer** = makes network service available to programs
  - is end-to-end only, not in routers
- In TCP/IP there are two transport protocols
  - UDP (user datagram protocol)
    - unreliable
    - offers a datagram service to the application (unit of information is a message)
  - TCP (transmisssion control protocol)
    - reliable
    - offers a stream service (unit of information is a byte)

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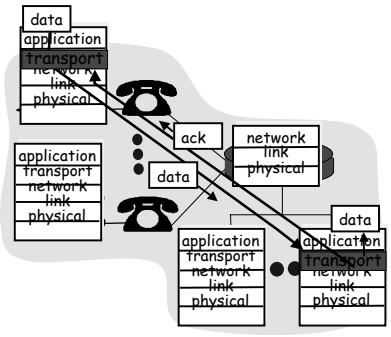
## Layering: *logical* communication

- E.g.: transport
- take data from app
- add addressing, reliability check info to form "datagram"
- send datagram to peer
- wait for peer to ack receipt
- analogy: post office

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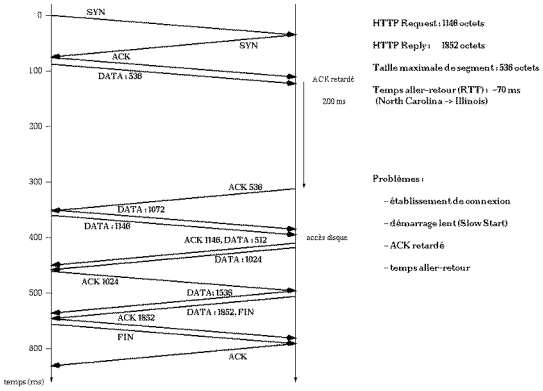
## TCP

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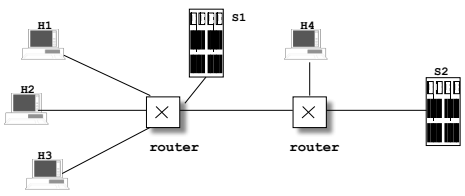
## Network Layer

- Set of functions required to transfer packets end-to-end (from host to host)
  - hosts are not directly connected - need for intermediate systems
  - examples: IP, Appletalk, IPX
- Intermediate systems
  - routers: forward packets to the final destination
  - interconnection devices

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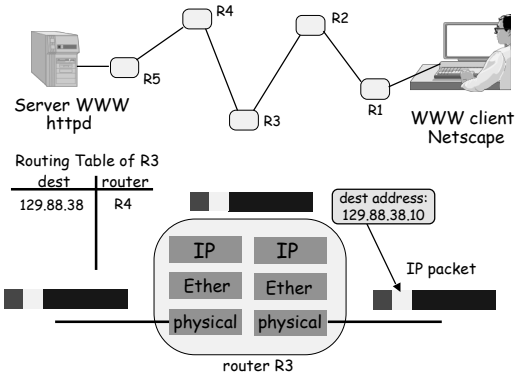
## IP

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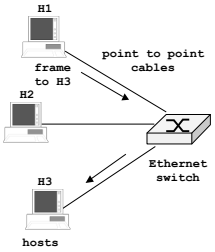
## Physical Layer
## Data Link Layer




- Physical transmission = **Physical** function
  - bits <-> electrical / optical signals
  - transmit individual bits over the cable: modulation, encoding
- Frame transmission = **Data Link** function
  - bits <-> frames
  - bit error detection
  - packet boundaries
  - in some cases: error correction by retransmission (802.11)
- Modems, xDSL, LANs

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## Protocol architectures

- Protocol entity
  - provides a set of services, eg.
    - *connect, send*
  - data multiplexing/demultiplexing
  - construction/analysis of PDUs
  - execution of procedures
- Protocol unit (PDU)
  - header: control functions
  - opaque data
- Procedures
  - actions to perform protocol functions: e.g. lost packet retransmission

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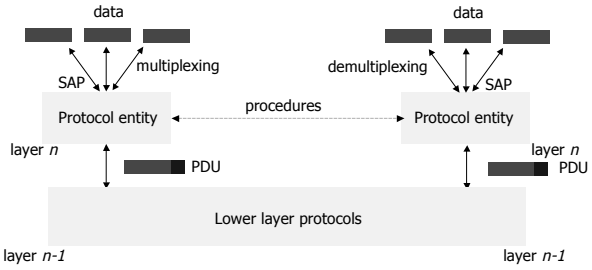
## Protocol architecture

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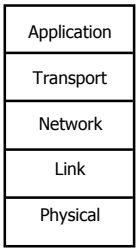
## Internet protocol stack

- **Application**: supporting network applications
  - FTP, SMTP, HTTP, OSPF, RIP
- **Transport**: host-host data transfer
  - TCP, UDP
- **Network**: routing of datagrams from source to destination
  - IP
- **Link**: data transfer between neighboring network elements
  - PPP, Ethernet
- **Physical**: bits "on the wire"

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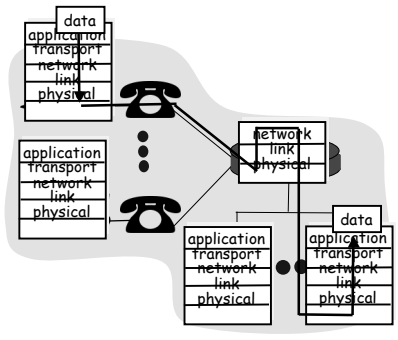
## Layering: physical communication

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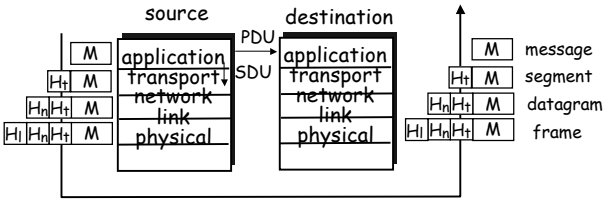
## Protocol layering and data

Each layer takes data from above
- adds header information to create new data unit
- passes new data unit to layer below

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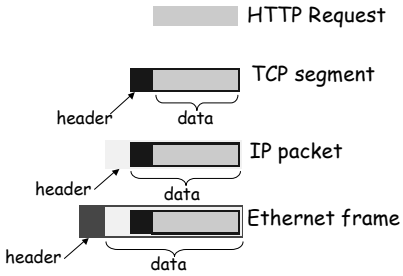
## Encapsulation

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## OSI ISO Model

| | |
|---|---|
| Application | Common functions |
| Presentation | Interchangable formats |
| Session | Organizing dialog |
| Transport | Reliable transmission |
| Network | Forwarding in the network |
| Data link | Transmission between two nodes |
| Physical | Signal transmission |

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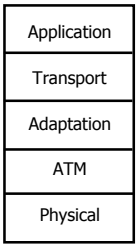
## ATM protocol stack

- **Application**: native applications, other protocols
  - LAN Emulation, IP, Signaling
- **Transport**: host-host data transfer
  - SSCOP
- **Adaptation**: adapt the ATM layer to different types of applications
  - circuit emulation, real-time data
  - AAL5 suitable for IP traffic
- **ATM**: cell switching over virtual circuits
- **Physical**: bits "on the wire", usually fiber

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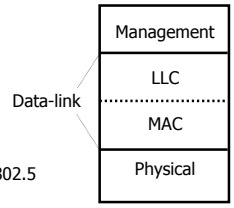
## LAN stack

- **Management**: e.g. construct forwarding tables
  - SNAP: Spanning Tree protocol
- **LLC**: multiplex different protocols
  - IP, IPX, SNAP
- **MAC**: medium access
  - 802.3 (Ethernet), 802.4 (Token Ring), 802.5 (Token Bus), 802.11 (Wi-Fi)
- **Physical**: bits "on the wire"

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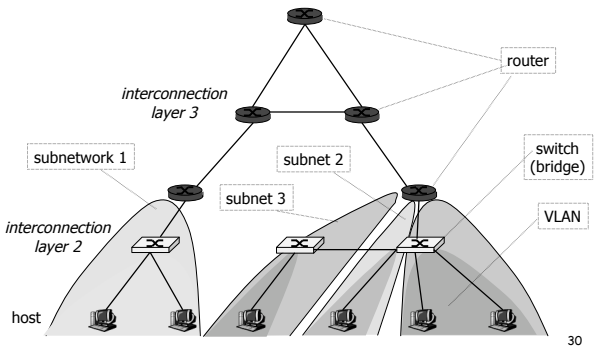
## Interconnection structure - layer 3

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## Interconnection at layer 2

- Switches (bridges)
  - interconnect hosts
  - logically separate groups of hosts (VLANs)
  - managed by one entity
- Type of the network
  - broadcast
- Forwarding based on MAC address
  - flat address space
  - forwarding tables: one entry per host
  - works if no loops
    - careful management
    - Spanning Tree protocol
  - not scalable

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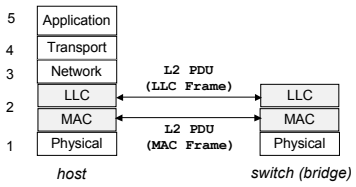
## Protocol architecture




- Switches are layer 2 intermediate systems
- Transparent forwarding
- Management protocols (Spanning Tree, VLAN)

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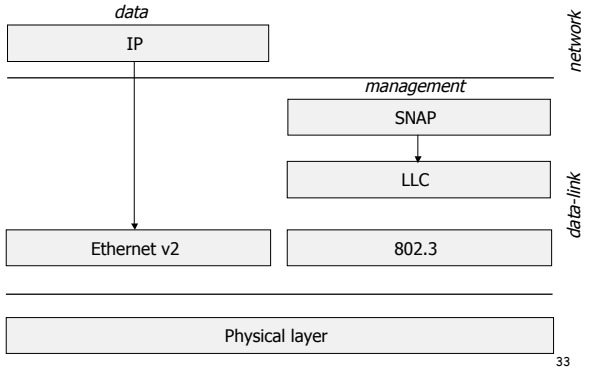
## Protocols

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## Interconnection at layer 3

- Routers
  - interconnect subnetworks
  - logically separate groups of hosts
  - managed by one entity
- Forwarding based on IP address
  - structured address space
  - routing tables: aggregation of entries
  - works if no loops - routing protocols (IGP - Internal Routing Protocols)
  - scalable inside one administrative domain

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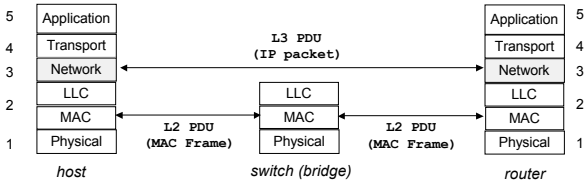
## Protocol architecture




- Routers are layer 3 intermediate systems
- Explicit forwarding
  - host has to know the address of the first router
- Management protocols (control, routing, configuration)

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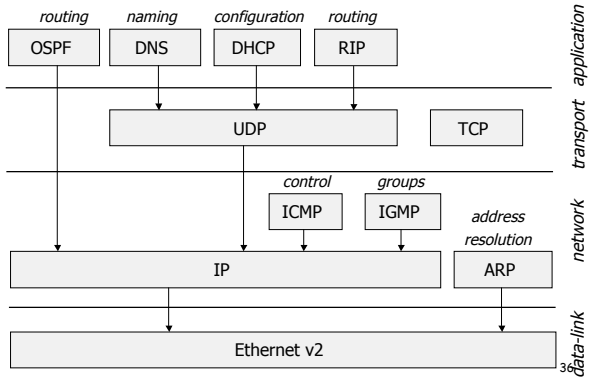
## Protocols

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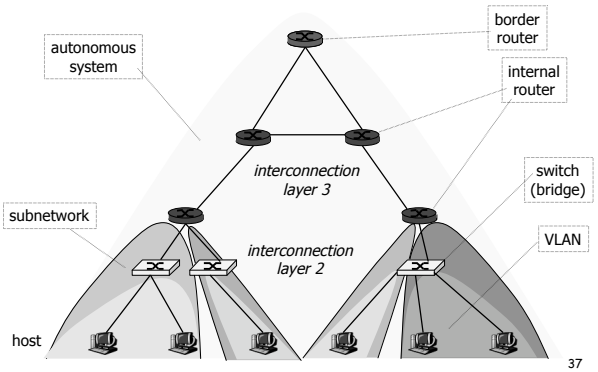
## Autonomous systems

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## Overlaid stacks? Long-haul links

- Fiber at physical layer (SONET/SDH)
  - Dense Wave Division Multiplexing (DWDM)
    - one color of the light λ
- Different technologies
  - ATM
  - Frame Relay
  - POS (Packet over SONET/SDH)
- Type of the network
  - NBMA (Non Broadcast Multiple Access) or point-to-point
- Complex protocol hierarchies
  - IP over ATM

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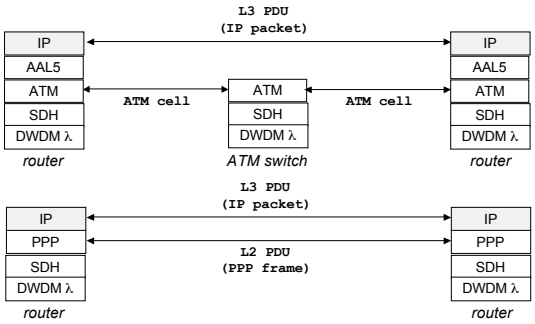
## Protocol architecture

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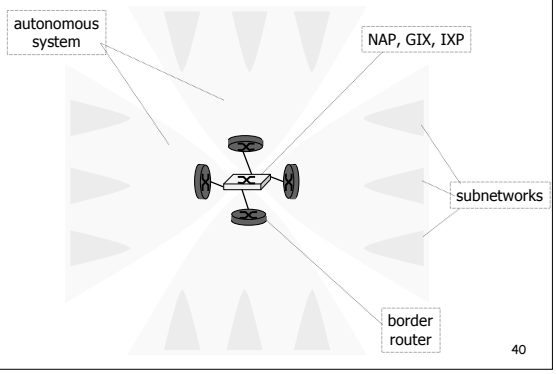
## Internet

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## Interconnection of AS

- Border routers
  - interconnect AS
- NAP or GIX, or IXP
  - exchange of traffic - peering
- Route construction
  - based on the path through a series of AS
  - based on administrative policies
  - routing tables: aggregation of entries
  - works if no loops and at least one route - routing protocols (EGP - External Routing Protocols)

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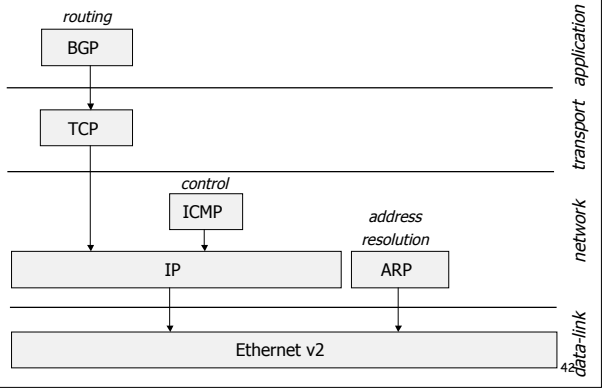
## Protocols

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## Performance

- Bit Rate (débit binaire) of a transmission system
  - bandwidth, throughput
  - number of bits transmitted per time unit
  - units: b/s or bps, kb/s = 1000 b/s, Mb/s = 10e+06 b/s, Gb/s=10e+09 b/s
  - OC3/STM1 - 155 Mb/s, OC12/STM4 - 622 Mb/s, and OC48/STM-16 - 2.5 Gb/s, OC192/STM-48 10 Gb/s
- Latency or Delay
  - time interval between the beginning of a transmission and the end of the reception
  - RTT - Round-Trip Time

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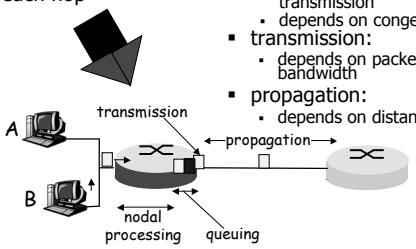
## Delay in packet-switched networks

packets experience delay on end-to-end path

- four sources of delay at each hop
  - nodal processing:
    - check bit errors
    - determine output link
  - queuing
    - time waiting at output link for transmission
    - depends on congestion level of node
  - transmission:
    - depends on packet length and link bandwidth
  - propagation:
    - depends on distance between nodes

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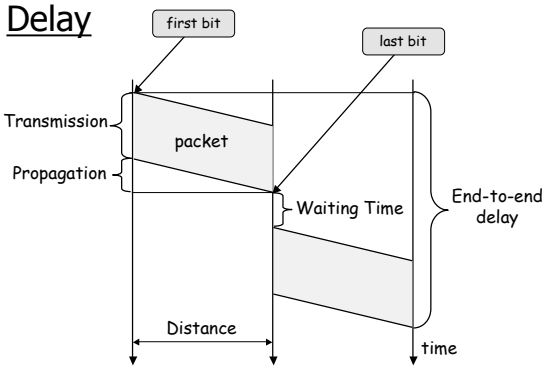
## Delay

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## Performance

- Latency
  - Latency = Propagation + Transmission + Wait
  - Propagation = Distance / Speed
    - copper : Speed = $2.3 \times 10^8$ m/s
    - glass : Speed = $2 \times 10^8$ m/s
    - Transmission = Size / BitRate
- 5 μs/km
- New York - Los Angeles in 24 ms
  - request - 1 byte, response - 1 byte: 48 ms
  - 25 MB file on 10 Mb/s: 20 s
- World tour in 0.2 s

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## Example

- At time 0, computer A sends a packet of size 1000 bytes to B; at what time is the packet received by B (speed = 2e+08 m/s)?

| | | | | |
|---|---|---|---|---|
| *distance* | 20 km | 20000 km | 2 km | 20 m |
| *bit rate* | 10kb/s | 1 Mb/s | 10 Mb/s | 1 Gb/s |
| *propagation* | 0.1ms | 100 ms | 0.01 ms | 0.1μs |
| *transmission* | 800 ms | 8 ms | 0.8 ms | 8 μs |
| *latency* | ? | ? | ? | ? |
| | *modem* | *satellite* | *LAN* | *Hippi* |

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## Example

- At time 0, computer A sends a packet of size 1000 bytes to B; at what time is the packet received by B (speed = 2e+08 m/s)?

| | | | | |
|---|---|---|---|---|
| *distance* | 20 km | 20000 km | 2 km | 20 m |
| *bit rate* | 10kb/s | 1 Mb/s | 10 Mb/s | 1 Gb/s |
| *propagation* | 0.1ms | 100 ms | 0.01 ms | 0.1μs |
| *transmission* | 800 ms | 8 ms | 0.8 ms | 8 μs |
| *latency* | 800.1 ms | 108 ms | 0.81 ms | 8.1 μs |
| | *modem* | *satellite* | *LAN* | *Hippi* |

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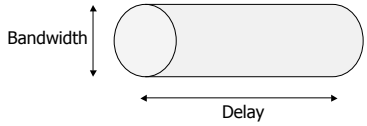
## Bandwidth-Delay Product




- Bandwidth-Delay product
  - how many bits should we send before the arrival of the first bit?
  - good utilization - keep the pipe filled!

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## Bandwidth-Delay Product

- File transfer: 1 Mbit, 100 ms delay
  - 1 Mb/s link, D×b = 0.1 Mbit
    - 10 transmissions, 10% each time
  - 1 Gbit/s link, D×b = 100 Mbit
    - 1 transmission, pipe not filled

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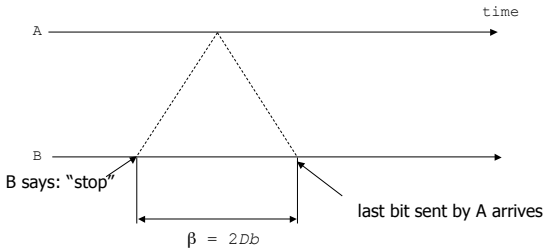
## Bandwidth-Delay Product

- Consider the scenario :




- β = maximum number of bits B can receive after saying stop
- large β means: delayed feedback
- amount of data "in the pipe"

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## A Simple Protocol: Stop and Go

- Packets may be lost during transmission: bit errors due to channel imperfections, various noises.
- Computer A sends packets to B; B returns an acknowledgement packet immediately to confirm that B has received the packet;

  A waits for acknowledgement before sending a new packet; if no acknowledgement comes after a delay *T1*, then A retransmits

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## A Simple Protocol: Stop and Go

- **Question**: What is the maximum throughput assuming that there are no losses?

  *notation:*
  - packet length = *L*, constant (in bits);
  - acknowledgement length = *l*, constant
  - channel bit rate = *b*;
  - propagation = *D*
  - processing time = 0

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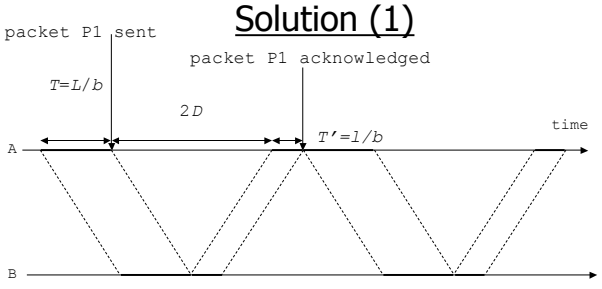
## Solution (1)




cycle time = $T + 2D + T'$

useful bits per cycle time = L

throughput = $Lb / (L + l + 2Db) = b / (\omega + \beta/L)$

with $\omega = (L+l)/L$=overhead and $\beta = 2Db$=**bandwidth-delay product**

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## Solution (2)

| | | | | |
|---|---|---|---|---|
| distance | 20 km | 20000 km | 2 km | 20 m |
| bit rate | 10kb/s | 1 Mb/s | 10 Mb/s | 1 Gb/s |
| propagation | 0.1ms | 100 ms | 0.01 ms | 0.1µs |
| transmission | 800 ms | 8 ms | 0.8 ms | 8 µs |
| reception time | 800.1 ms | 108 ms | 0.81 ms | 8.1 µs |
| | *modem* | *satellite* | *LAN* | *Hippi* |
| $\beta=2Db$ | 2 bits | 200 000 bits | 200 bits | 200 bits |
| throughput = $b$ ×99.98% | | 3.8% | 97.56% | 97.56% |

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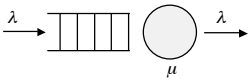
## Waiting time

- Queueing system M/M/1
  - interarrival times ~ exponentially distributed
  - service times ~ exponentially distributed
  - arrival rate λ, service rate μ, utilization ρ= λ/μ
  - number of packets N, waiting time T

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## Waiting time

- Average packet length 1500 bytes
  - link with 1 Mb/s bit rate (propagation = 0)
    - transmission time 12 ms
    - service rate 83 packet/s

| | | | | | |
|---|---|---|---|---|---|
| $\lambda$ | [p/s] | 10 | 40 | 60 | 70 |
| $1/\lambda$ | [ms] | 100 | 25 | 16 | 14 |
| $T$ | [ms] | 13 | 23 | 43 | 76 |

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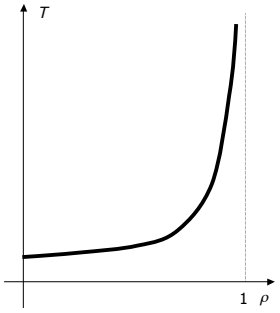
## Waiting time

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## Summary

- Network architectures
  - protocol architectures
    - different protocol stacks, overlaid stacks
  - interconnection structure
    - switches, routers
  - related protocols
    - complex protocol families
- Performance
  - transmission
  - propagation
  - bandwidth-delay product
  - queueing delay

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