U.PORTO

Telecommunication Networks Introduction

Telemedicina e e-Saúde

2011/12

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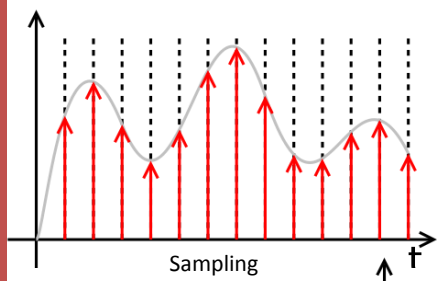
[dcc]

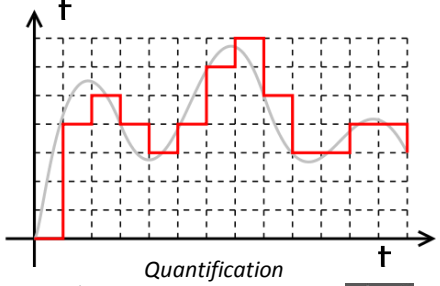
References

- These slides are the companions of "Computer Networking: A Top Down Approach 5th edition. Jim Kurose, Keith Ross Addison-Wesley, April 2009"

DIGITAL, ANALOGIC

Analogic → Digital





Images from Wikipedia

A few words on audio compression

- Audio signal sampling at a fixed rate:
  - telephone: 8,000 samples/sec
  - CD: 44,100 samples/sec
- Each sample is quantized, rounded:
  - Ex.:, 2^8=256 possible values
- Each quantized value is represented by bits
  - 8 bits for 256 values
- example: 8,000 samples/sec, 256 quantized values → 64,000 bps
- receiver converts bits back to analog signal:
  - some quality reduction

Example rates

- CD: 1.411 Mbps
- MP3: 96, 128, 160 kbps
- Internet telephony: 5.3 kbps and up

A few words on video compression

- video: sequence of images displayed at constant rate
  - e.g. 24 images/sec
- digital image: array of pixels
  - each pixel represented by bits
- redundancy
  - spatial (within image)
  - temporal (from one image to next)

Examples:

- MPEG 1 (CD-ROM) 1.5 Mbps
- MPEG2 (DVD) 3-6 Mbps
- MPEG4 (often used in Internet, < 1 Mbps)

Research:

- layered (scalable) video
  - adapt layers to available bandwidth

INTRODUCTION

Introduction

Our goal:

- get "feel" and terminology
- more depth, detail *later* in course
- approach:
  - use Internet as example

Overview:

- what's the Internet?
- what's a protocol?
- network edge; hosts, access net, physical media
- network core: packet/circuit switching, Internet structure
- performance: loss, delay, throughput
- protocol layers, service models

Summary

1.1 What *is* the Internet?

1.2 Network edge

- ❑ end systems, access networks, links

1.3 Network core

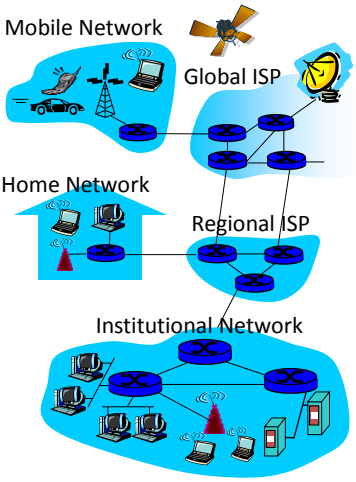
- ❑ circuit switching, packet switching, network structure

1.4 Delay, loss and throughput in packet-switched networks

1.5 Protocol layers, service models

What's the Internet: under the "hood"

- ❑ millions of connected computing devices: *hosts = end systems*
  - running *network apps*
- ❑ *communication links*
  - fiber, copper, radio, satellite
  - transmission rate = *bandwidth*
- ❑ *routers:* forward packets (chunks of data)



What's the Internet: under the "hood"

Network Equipment

Hub
(out-of-date)

LAN Switches

Access Point

Router

Router

What's the Internet: under the "hood"

Network Equipment

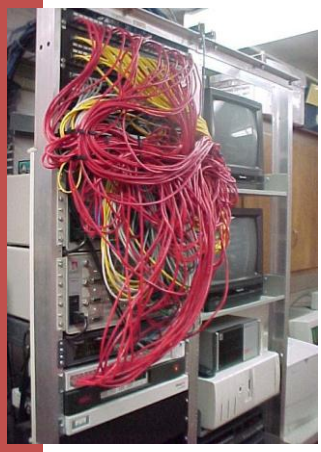
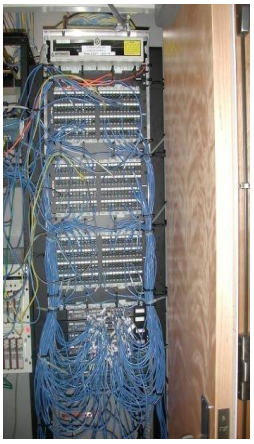
Firewall

Server

Modular server

What's the Internet: under the "hood"

Data centre

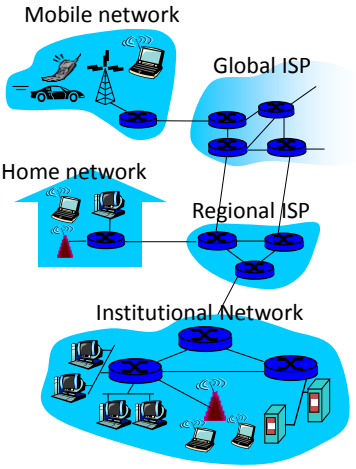

What's the Internet: under the "hood"

Data centre



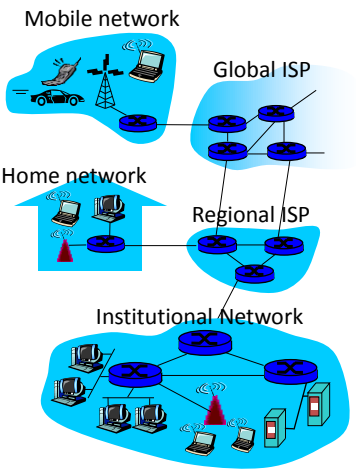
What's the Internet: under the "hood"

- *protocols* control sending, receiving of msgs
  - e.g., TCP, IP, HTTP, Skype, Ethernet
- *Internet:* "network of networks"
  - loosely hierarchical
  - public Internet versus private intranet
- Internet standards
  - RFC: Request for comments
  - IETF: Internet Engineering Task Force



What's the Internet: a service view

- communication *infrastructure* enables distributed applications:
  - Web, VoIP, email, games, e-commerce, file sharing, ***telemedicine***
- communication services provided to apps:
  - reliable data delivery from source to destination
  - "best effort" (unreliable) data delivery



What's a protocol?

human protocols:

- "what's the time?"
- "I have a question"
- introductions

… specific messages sent

… specific actions taken when messages received, or other events

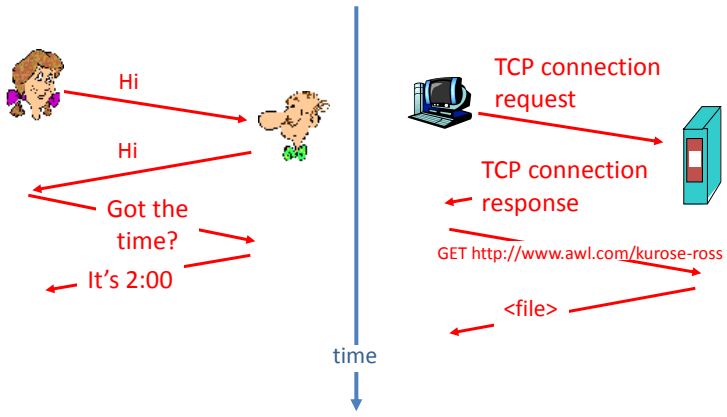
network protocols:

- machines rather than humans
- all communication activity in Internet governed by protocols

protocols define format, order of messages sent and received among network entities, and actions taken on messages transmission, receipt

What's a protocol?

a human protocol and a computer network protocol:



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1.2 Network edge
- ❑ end systems, access networks, links

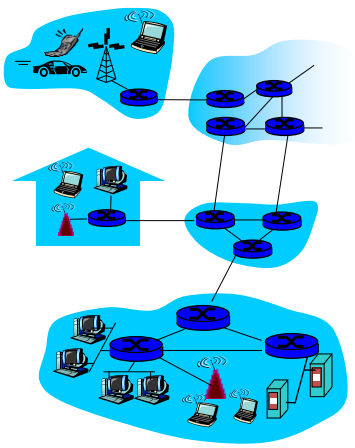
1.3 Network core
- ❑ circuit switching, packet switching, network structure

1.4 Delay, loss and throughput in packet-switched networks

1.5 Protocol layers, service models

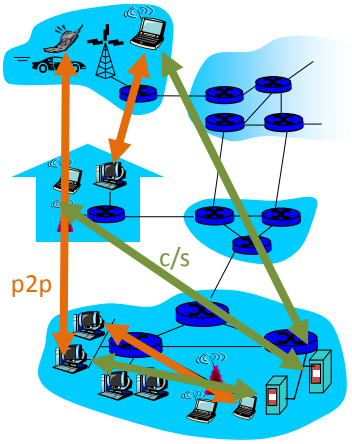
A closer look at network structure:

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



The network edge:

- end systems (hosts):
  - run application programs
  - e.g. Web, email
  - at "edge of network"
- client/server model
  - client host requests, receives service from always-on server
  - e.g. Web browser/server; email client/server
- peer-peer model:
  - minimal (or no) use of dedicated servers
  - e.g. Skype, BitTorrent



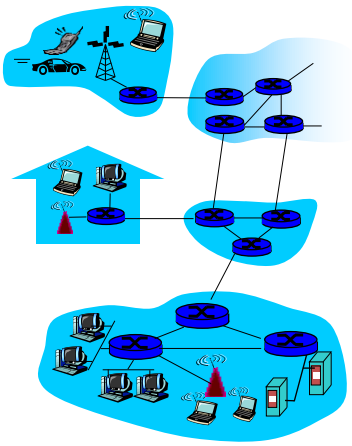
Access networks and physical media

Q: How to connect end systems to edge router?

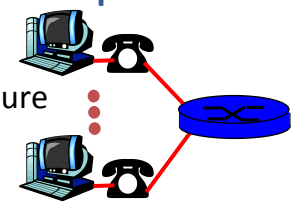
- residential access nets
- institutional access networks (school, company)
- mobile access networks

Keep in mind:

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



Residential access: point to point

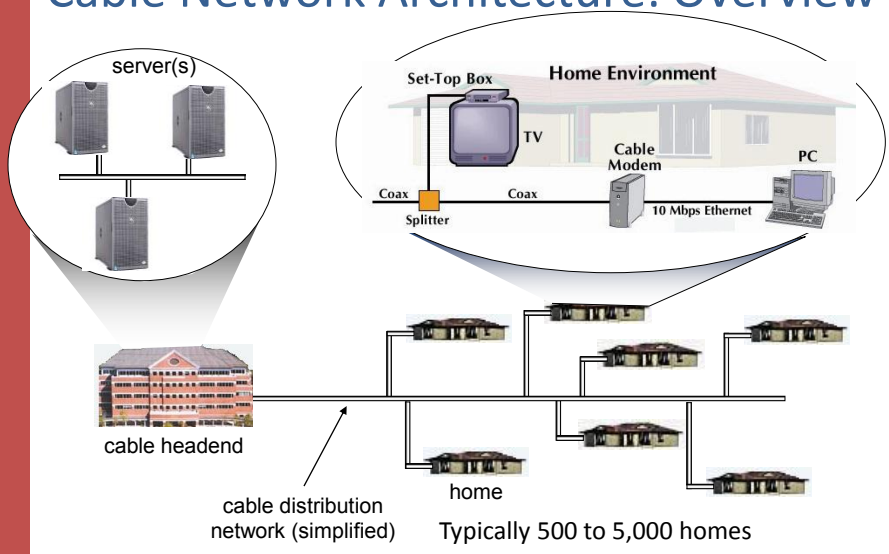


- Modem connection
  - Uses existing telephony infrastructure
    - Home is connected to central office
  - up to 56Kbps direct access to router (often less)
  - Can't surf and phone at same time: not "always on"
- DSL: Digital Subscriber Line
  - Also uses existing telephone infrastructure
  - up to 1 Mbps upstream (today typically < 256 kbps)
  - up to 8 Mbps downstream (today typically < 1 Mbps)
  - dedicated physical line to telephone central office

Residential access: cable modems

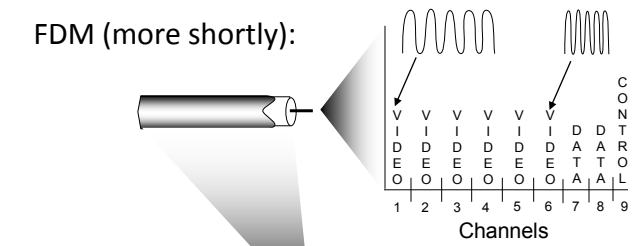
- HFC: hybrid fibre coaxial
  - asymmetric: up to 30Mbps downstream, 2 Mbps upstream
  - network of cable and fibre attaches homes to ISP router
  - homes share access to router
    - unlike DSL, which has dedicated access
  - Usually supplied by cable TV companies

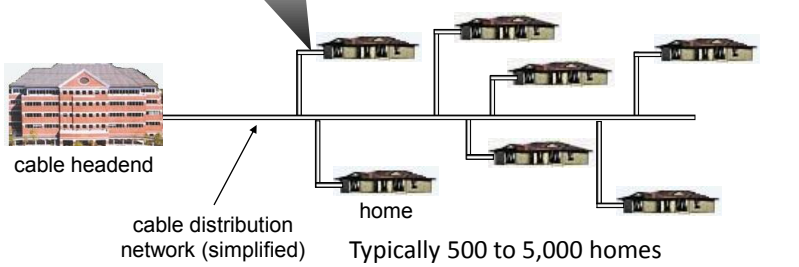
Cable Network Architecture: Overview



Cable Network Architecture: Overview

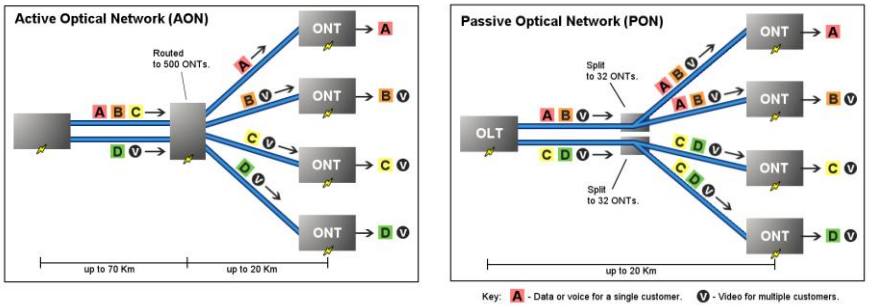
FDM (more shortly):





Cable Network Architecture: fibre optics

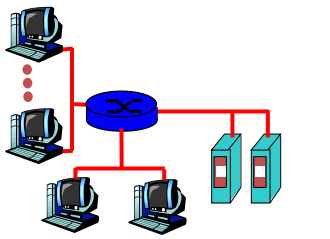
- Active (AON) or passive (PON)
- Commercial offers from tenths of Mbps up to 1Gbps

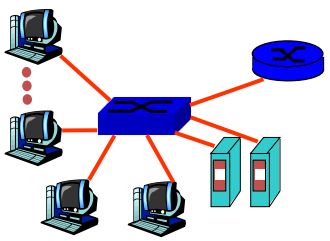


Source: Images from Wikipedia

Local Area Networks

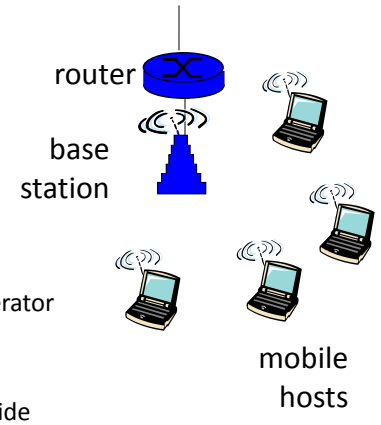
- local area network (LAN) connects terminals to routers
- Ex.: Ethernet:
  - 10 Mbs, 100Mbps, 1Gbps, 10Gbps
  - Usual configuration: terminals connect to Ethernet switch





Wireless access networks

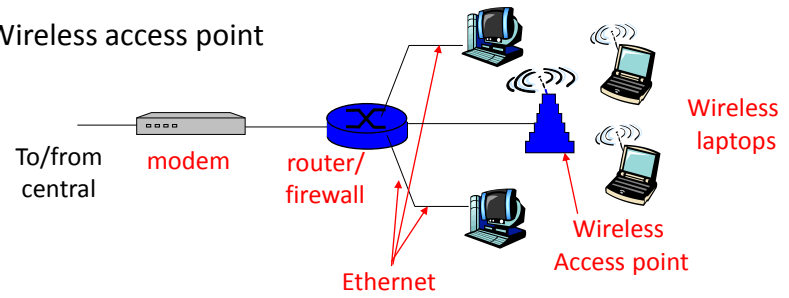
- shared *wireless* access network connects end system to router
  - via base station aka "access point"
- wireless LANs:
  - 802.11b/g (WiFi): 11 or 54 Mbps
  - 802.11n: upto 600 Mbps
- wider-area wireless access
  - provided by telecommunication operator
  - ~1Mbps over cellular system (EVDO, HSDPA)
  - next up: WiMAX (10's Mbps) over wide area



Home Networks

Typical home network components:

- DSL or cable modem
- router/firewall/NAT
- Ethernet
- Wireless access point



Physical Media

- Bit: propagates between transmitter/rcvr pairs
- physical link: what lies between transmitter & receiver
- guided media:
  - signals propagate in solid media: copper, fiber, coax
- unguided media:
  - signals propagate freely, e.g., radio

Twisted Pair (TP)

- two insulated copper wires
  - Category 3: traditional phone wires, 10 Mbps Ethernet
  - Category 5: 100Mbps Ethernet

Physical Media: coax, fiber

Coaxial cable:

- two concentric copper conductors
- bidirectional
- baseband:
  - single channel on cable
  - legacy Ethernet
- broadband:
  - multiple channels on cable
  - HFC

Fiber optic cable:

- glass fiber carrying light pulses, each pulse a bit
- high-speed operation:
  - high-speed point-to-point transmission (e.g., 10's-100's Gps)
- low error rate: repeaters spaced far apart ; immune to electromagnetic noise

Physical media: radio

- signal carried in electromagnetic spectrum
- no physical "wire"
- bidirectional
- propagation environment effects:
  - reflection
  - obstruction by objects
  - interference

Radio link types:

- terrestrial microwave
  - e.g. up to 45 Mbps channels
- LAN (e.g., Wifi)
  - 11Mbps, 54 Mbps
- wide-area (e.g., cellular)
  - 3G cellular: ~ 1 Mbps
- Satellite
  - Kbps to 45Mbps channel (or multiple smaller channels)
  - 270 msec end-end delay
  - geosynchronous versus low altitude

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- circuit switching, packet switching, network structure

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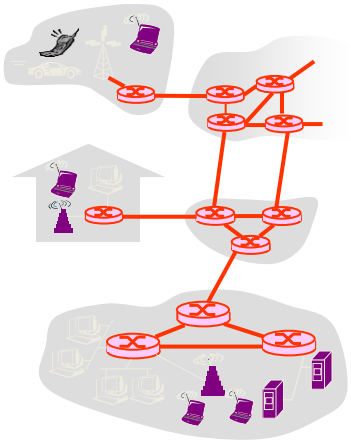
1.5 Protocol layers, service models

The Network Core

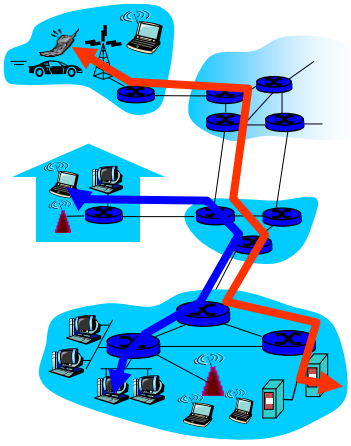
- mesh of interconnected routers
- *the* fundamental question: how is data transferred through net?
  - circuit switching: dedicated circuit per call: telephone net
  - packet-switching: data sent thru net in discrete "chunks"



Network Core: Circuit Switching

End-end resources reserved for "call"

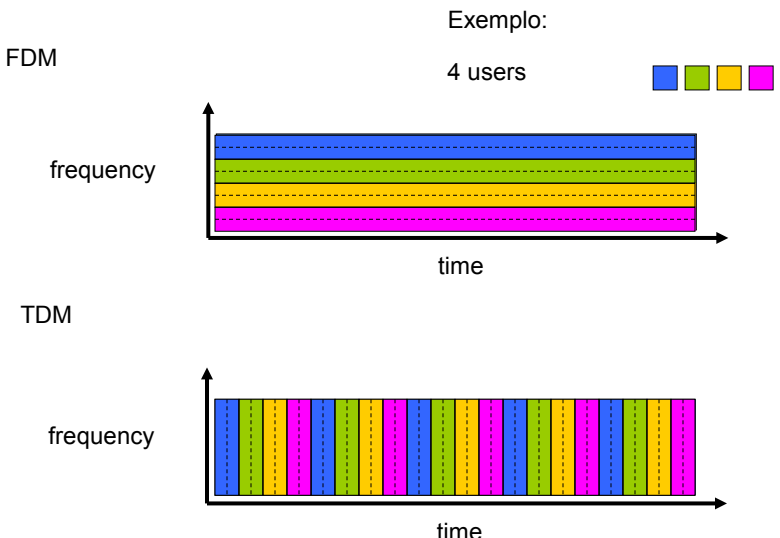
- link bandwidth, switch capacity
- dedicated resources: no sharing
- circuit-like (guaranteed) performance
- call setup required
  - Establishing connection
  - Data transfer
  - disconnecting



Network Core: Circuit Switching

- Developed to transmit voice
- "Intelligence" resides on the network
- Dedicated resources per call
  - No sharing (capacity wasted)
  - Guaranteed performance
- Good resource usage for voice calls
  - Someone is always talking most of the time…
- For data
  - Inactive line most of the time
- Dividing link bandwidth into "pieces"
  - Frequency division (FDM)
  - Time division (TDM)

Circuit Switching: FDM and TDM



Numerical example

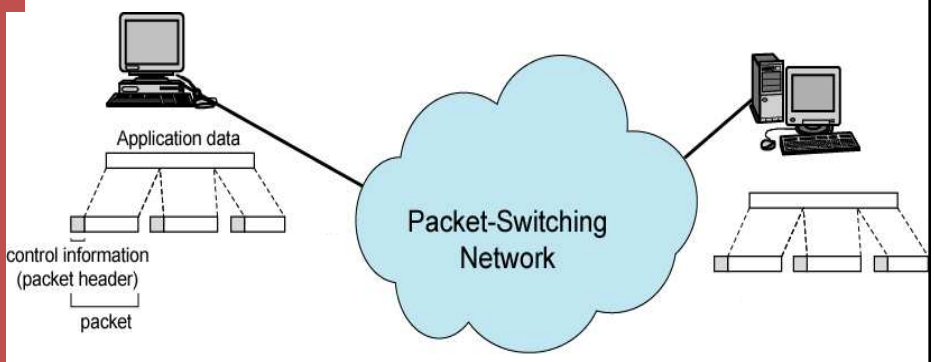
- How long does it take to send a file of 640,000 bits from host A to host B over a circuit-switched network?
  - All links are 1,536 Mbps
  - Each link uses TDM with 24 slots/s
  - 500 ms to establish end-to-end circuit

$$\frac{1536Mbps}{24} = 64kbps \qquad \frac{640000bits}{64kbps} = 10s$$

10s + 500ms = **10,5s**

* In practice we need to add propagation delay… More on that later

Network core: packet switching



Network Core: Packet Switching

idea: divide end-to-end data flow de in small pieces (packets)

- Packets o different users share network resources
- each packet uses full link bandwidth
- resources used *as needed*

resource contention:

- aggregate resource demand can exceed amount available
- congestion: packets queue, wait for link use
- store and forward: packets move one hop at a time
  - Node receives complete packet before forwarding

Bandwidth division into "pieces"
Dedicated allocation
Resource reservation

Network core: packet switching

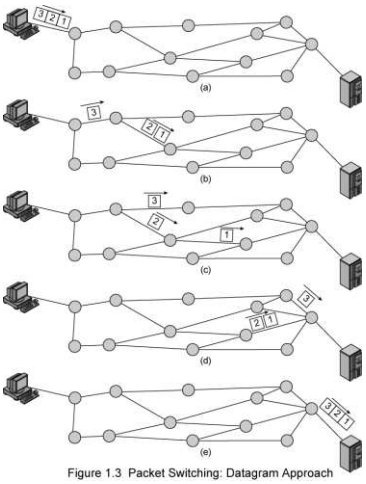
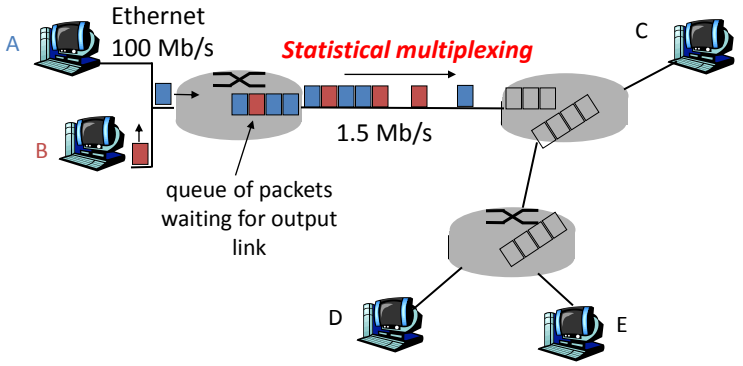


Figure 1.3 Packet Switching: Datagram Approach

Each packet is dealt with independently:

- No relation with preceding packets
- Each node chooses next hop per packet
- Packets for the same destination do not necessarily follow the same route (although they usually do)
- Packets may arrive out of order
  - Destination re-orders them
- Packets may be dropped or corrupted in transit
- Source and destination are responsible for dealing with losses and corruption

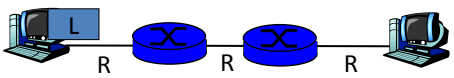
Packet Switching: Statistical Multiplexing



Sequence of A & B packets does not have fixed pattern, bandwidth shared on demand ➔ ***statistical multiplexing***.

In TDM: each host gets same slot in revolving TDM frame.

Packet-switching: store-and-forward



- takes L/R seconds to transmit (push out) packet of L bits on to link at R bps
- *store and forward:* entire packet must arrive at router before it can be transmitted on next link
- delay = 3L/R (assuming zero propagation delay)

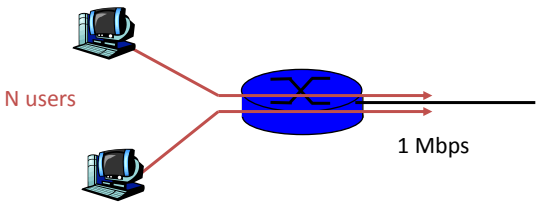
Example:

- L = 7.5 Mbits
- R = 1.5 Mbps
- Transmission delay = 15 sec

Packet switching versus circuit switching

Packet switching allows more users to use network!

- 1 Mb/s link
- Each user:
  - 100 kb/s when "active"
  - active 10% of time
- *circuit switching:*
  - 10 users
- *packet switching :*
  - With 35 users, probability > 10 active at same time is less than 0.0004



Packets vs. Circuits

Is packet switching a "slam dunk winner?"

- Great for bursty data
  - resource sharing
  - simpler, no call setup
- excessive congestion: packet delay and loss
  - protocols needed for reliable data transfer, congestion control

Q: How to provide circuit-like behavior?

- bandwidth guarantees needed for audio/video apps
- still an unsolved problem

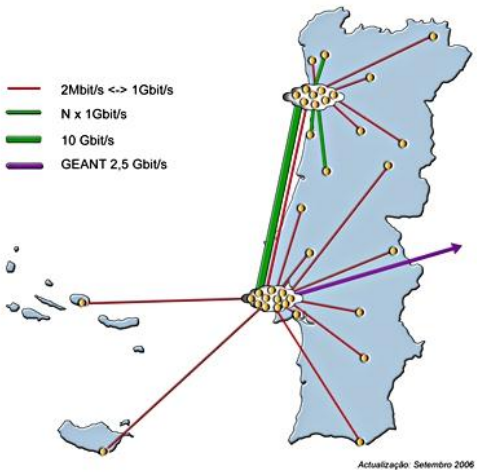
Internet: network of networks

Internet is composed of

- *Backbones:* infrastructures to interlink networks, like NSFNET, in the USA, GÉANT in Europe, as well as commercial operators *backbones* like PT
- Regional networks, connecting for example universities and research institutes, e.g. FCCN
- Commercial networks, e.g. internal usage or for supplying services to customers, like internet connections, e.g. PT, CLIX, ZON, VODAFONE…
- Local networks

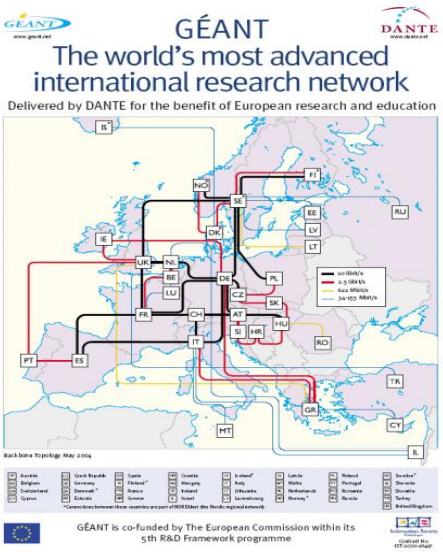
RCTS (Rede Ciência, Tecnologia e Sociedade)

- Education and research national network
- Communication platform to provide researchers, professors and students the specific network resources needed



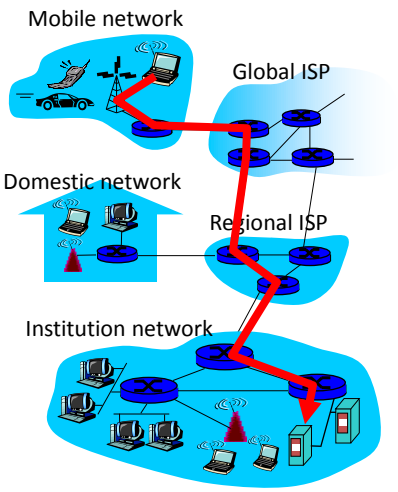
GÉANT

- Pan-European network of research and education
- Interconnects RCTS and its 30 European counterparts
- Core at 10Gbps, connections starting at 155Mbps



Internet: network of networks

- A packet flow crosses several networks



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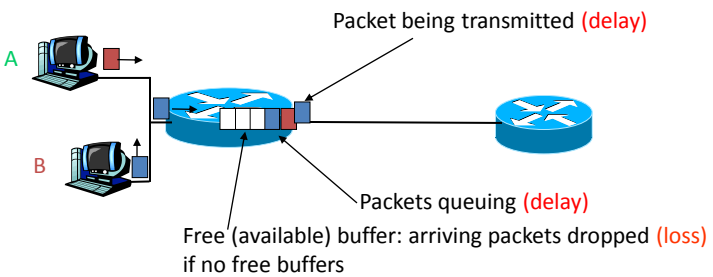
How do losses and delays occur?

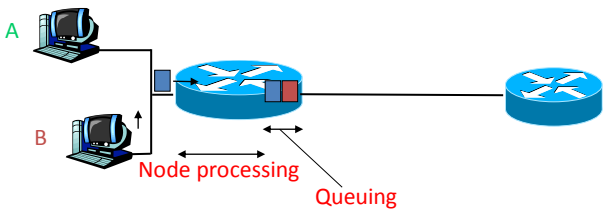
Packets queue in router buffers

- packet arrival rate to link exceeds output link capacity
- packets queue, wait for turn



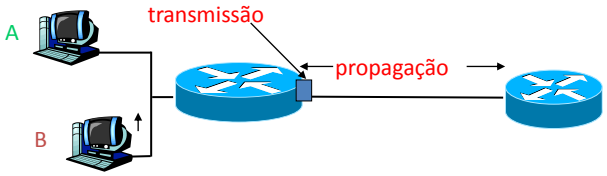
Four sources of packet delay

1. Node processing :
   - Check bit errors
   - Determine output link
2. Queuing
   - time waiting at output link for transmission
   - depends on congestion level of router



Four sources of packet delay

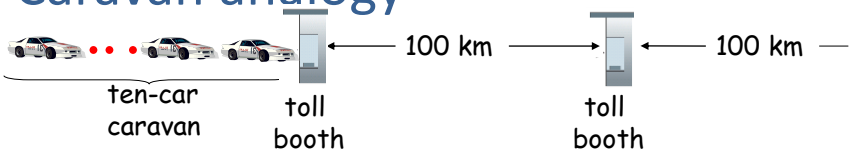
3. Transmission delay
   - R= link bandwidth (bps) (*rate*)
   - L= packet length (bits)
   - Time to send bits into link = L/R
4. Propagation delay
   - d = length of physical link (distance)
   - s = propagation speed in medium (~$2x10^8$ m/s)
   - Propagation delay = d/s



Note: s and R are ***very*** different quantities!

Example

Caravan analogy



- cars "propagate" at 100 km/hr
- toll booth takes 12 sec to service car (transmission time)
- car~bit; caravan ~ packet
- Q: How long until caravan is lined up before 2nd toll booth?

- Time to "push" entire caravan through toll booth onto highway = 12*10 = 120 sec
- Time for last car to propagate from 1st to 2nd toll both: 100km/(100km/hr)= 1 hr
- A: 62 minutes

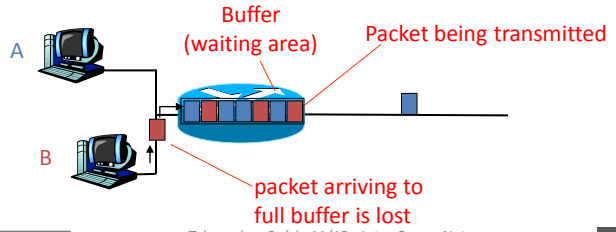
Nodal delay

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

- d_{proc} = processing delay
  - Typically a few microseconds or less
- d_{queue} = queuing delay
  - depends on congestion
- d_{trans} = transmission delay
  - = L/R, significant for low speed links
- d_{prop} = propagation delay
  - A few microseconds to hundreds of milliseconds

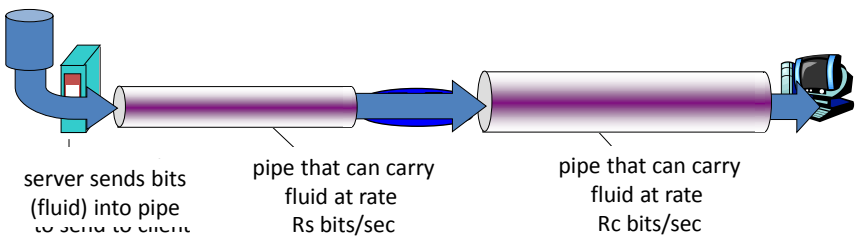
Packet loss

- queue (buffer) preceding link in buffer has finite capacity
- packet arriving to full queue dropped (lost)
- lost packet may be retransmitted by previous node, by source end system, or not at all



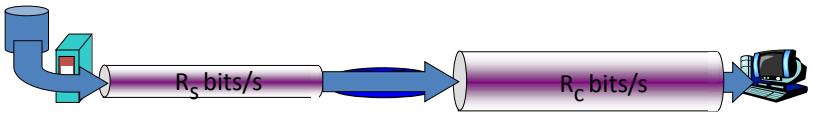
Throughput

- Throughput: rate (bits/time unit) at which bits transferred between sender/receiver
  - *instantaneous:* rate at given point in time
  - *average:* rate over longer period of time

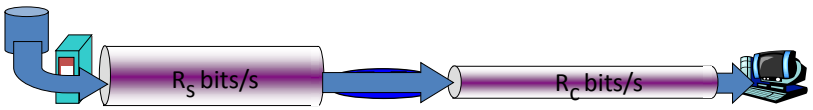


Throughput

- $R_s < R_c$ What is average end-end throughput?



- $R_s > R_c$ What is average end-end throughput?

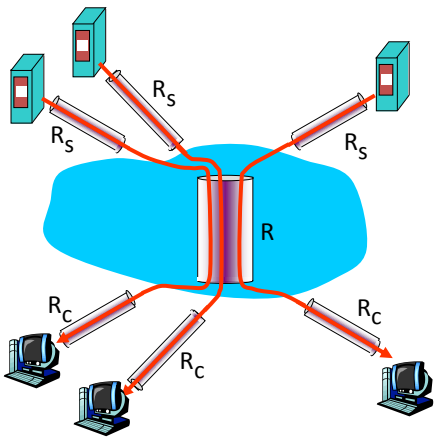


bottleneck link

link on end-end path that constrains end-end throughput

Throughput: Internet scenario

- Q: throughput per connection?
  - min(R_c,R_s,R/10)
- in practice: R_c or R_s is often bottleneck



10 connections (fairly) share backbone bottleneck link R bits/sec

Summary

1.1 What *is* the Internet?

1.2 Network edge

- ❑ end systems, access networks, links

1.3 Network core

- ❑ circuit switching, packet switching, network structure

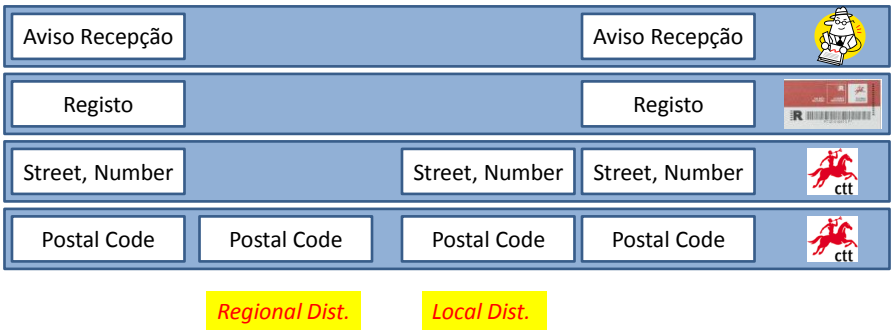
1.4 Delay, loss and throughput in packet-switched networks

1.5 Protocol layers, service models

Protocol layers

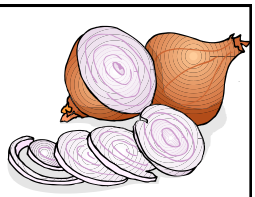
- ❑ Networks are complex!!!!
- ❑ Many "*pieces*":
  - hosts
  - routers
  - Links of various types
  - applications
  - protocols
  - hardware, software

Sending "*snail*" mail



- Each layer uses the lower adding something:
  - Address "precision"
  - Extra services (reliability, receipt acknowledgement)

Why layering?

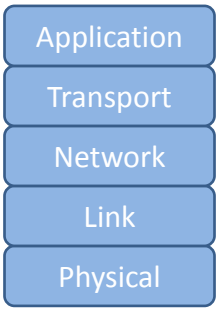


Dealing with complex systems:

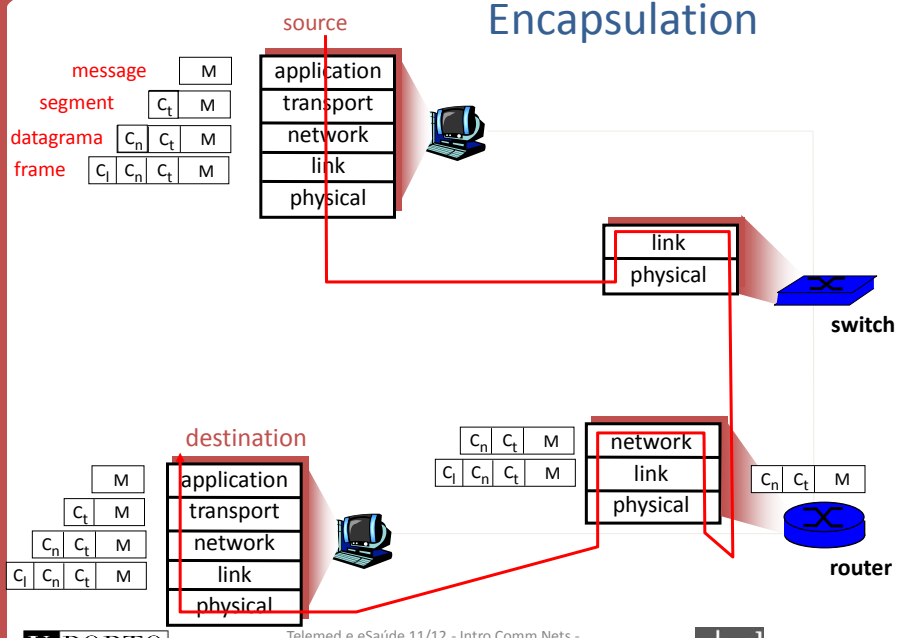
- explicit structure allows identification, relationship of complex system's pieces
  - layered reference model for discussion
- modularization eases maintenance, updating of system
  - change of implementation of layer's service transparent to rest of system
  - e.g., change in gate procedure doesn't affect rest of system

Internet protocol stack

- Application : network applications
  - FTP, SMTP, HTTP
- transport: transferring data between processes
  - TCP, UDP
- Network : routing of datagrams between source and destination
  - IP, routing protocols
- link: data transfer between neighbouring network elements
  - PPP, Ethernet
- Physical: bits “on the wire”



Encapsulation



END INTRODUCTION TO COMMUNICATION NETWORKS