Architettura di Internet

Corso di Laurea in Tecnologie Informatiche
Università degli Studi di Roma "La Sapienza"

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Info Utili: Il docente

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Usate questa e-mail per avere la garanzia che la vostra mail sarà letta e che le risposte avverranno in tempi rapidi)!!!

Web page del corso:twiki.dsi.uniroma1.it

Orario di ricevimento: Giovedì 11-13

Ricevimento fuori orario (in casi eccezionali) solo su appuntamento (mandate una mail!!!)

Materiale Didattico

Libro consigliato:

Jim Kurose, Keith Ross
Computer Networking: A Top Down Approach Featuring the Internet, 2nd edition. Addison-Wesley, luglio 2002.

Versione inglese fortemente consigliata (più accurata/divertente/terminologia corretta)

Nessun informatico di successo può prescindere dalla conoscenza dell'inglese: cominciate subito a usare testi in lingua originale!!!

Versione italiana: Jim Kurose, Keith Ross
Internet e Reti di Calcolatori. McGraw-Hill, settembre 2002.

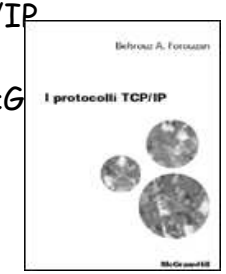
Altro Materiale Didattico

- Lucidi del corso (parte in inglese, parte in italiano)
- Altro materiale consigliato durante il corso (libri di approfondimento, standard, articoli, etc.) → verrà tutto inserito sul sito del corso
  - MUST read - parte del programma,
  - SHOULD read – fortemente consigliato
    (altrimenti argomenti del programma potrebbero non esservi sufficientemente chiari)
  - MAY read – approfondimenti
- Materiale addizionale disponibile sul sito associato al libro di Kurose e Ross

(http://www.aw.com/kurose-ross password richiesta)

Altri libri su TCP/IP

- Douglas E. Comer, Internetworking with TCP/IP volume 1, Prentice Hall, 1995.
- Behrouz A. Forouzan, *I protocolli TCP/IP*, McG Hill, Milano 2001



Prerequisiti culturali

- Conoscenza dei concetti basilari di probabilità

→ Per quelli di voi che intendono seguire l'indirizzo Reti l'esame di calcolo delle probabilità sarà probabilmente obbligatorio

Modalità d'esame

- Scritto di selezione(con domande aperte e/o a scelta multipla) + Scritto o Orale
- Solo gli studenti che superano lo scritto di selezione possono accedere alla seconda prova
- Il superamento della prova di selezione vale solo per un appello
- Non sono previsti esoneri
- Peso seconda prova vs. scritto selezione? Mini-progetto o tesina per incrementare il voto?? → decisione durante il corso. Aggiornamenti sulle modalità d'esame sul sito.
- Date d'esame (probabili—preliminari): primo appello 6 giugno, 23 giugno, 2 luglio. Un appello di recupero a settembre, uno a febbraio 2004.

Sto seguendo nel canale giusto??

- Studenti del secondo anno del corso di laurea in Tecnologie Informatiche ← SI
- Studenti del corso di laurea in Informatica ←NO
- Studenti del corso di laurea in Tecnologie Informatiche, anno >= terzo

Possono seguire il corso di Architettura di Internet per il corso di laurea in Informatica → In questo corso NON si adotteranno le dispense di Reti I. Dovete studiare il nuovo programma o cambiare canale.

Scopo del corso

- Come sono in relazione le conoscenze della tecnologia di Internet con quelle relative alla scrittura di software?

Scopo del corso

INTERNET

Anche la rete stessa usa software (OS) e colloqui tra macchine remote

Per colloquiare usano una rete: INTERNET

Molti software applicativi colloquiano con software remoti

I colloqui sono soggetti a regole (protocolli)

Scopo del corso

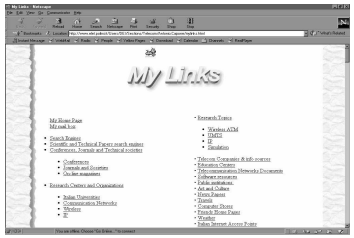
Noi ci occuperemo:

- Dei protocolli usati per i colloqui a tutti i livelli
- Delle infrastrutture di rete necessarie al funzionamento di INTERNET

Molti software applicativi colloquiano con software remoti

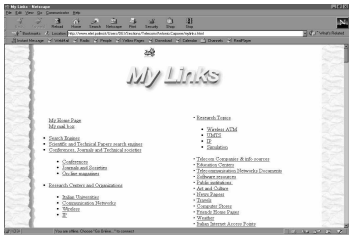
I colloqui sono soggetti a regole (protocolli)

Perché top-down



Chi di voi non ha mai navigato sul Web?
Ma chi di voi sa come tutto ciò sia possibile? MAGIC??

Perché top-down



Conoscere le applicazioni di rete aiuta a comprenderne il funzionamento, quindi i requisiti→ la necessità di altri protocolli di 'livello più basso' etc→top down

- OBIETTIVI DEL CORSO:
  - Comprendere come funziona Internet, perché i protocolli su cui si basa Internet funzionano efficacemente e quali problemi risolvono, le motivazioni alla base della loro introduzione e delle decisioni prese nella loro progettazione.
  - Sapere leggere gli standard e saper riconoscere le fonti da consultare quando vi si presenteranno problemi tecnici da risolvere.

Programma del corso

- Primi 5 capitoli del Kurose-Ross. Approccio top-down nella descrizione di come funziona Internet
  - -Dalle applicazioni alla trasmissione dei segnali sul canale fisico
- Possibilmente: 1)Simulazione di Rete: breve introduzione ad OPNET

  2) Seminari di professional del mondo delle telecomunicazioni)
- Limiti del corso:
  - pochissimo sul livello fisico
  - Descrizione dell'architettura TCP/IP classica → sviluppi in corso argomenti avanzati parzialmente trattati nel biennio
  - Reti mobili e Sicurezza: aspetti trattati in altri corsi (indirizzo Reti).

Chapter 1: Introduction

Computer Networks and the Internet

Our goal:

- get context, overview, "feel" of networking
- more depth, detail *later* in course
- approach:
  - descriptive
  - use Internet as example

Overview:

- what's the Internet
- what's a protocol?
- network edge
- network core
- access net, physical media
- Internet/ISP structure
- performance: loss, delay
- protocol layers, service models
- history
- Standardization activities

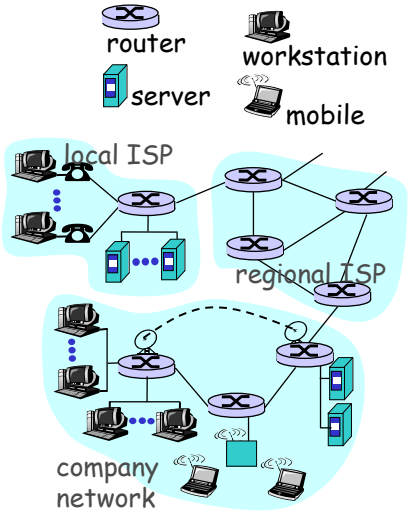
Chapter 1: roadmap

1.1 What *is* the Internet?
1.2 Network edge
1.3 Network core
1.4 Network access and physical media
1.5 Internet structure and ISPs
1.6 Delay & loss in packet-switched networks
1.7 Protocol layers, service models
1.8 History

What's the Internet: "nuts and bolts" view

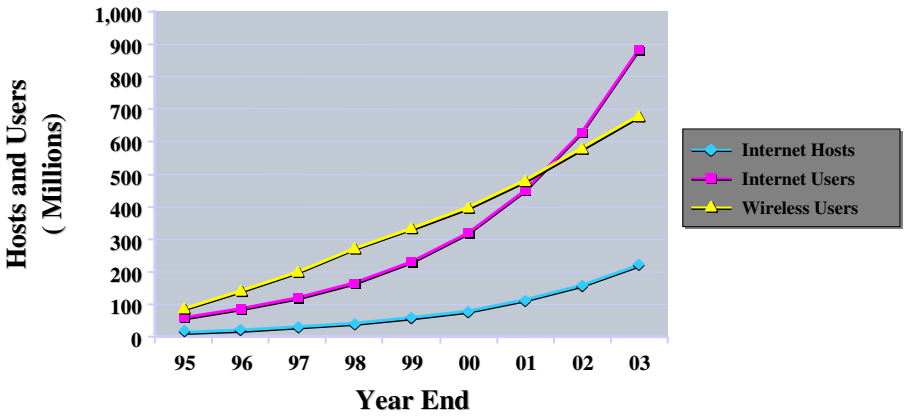
- millions of connected computing devices: *hosts, end-systems*
  - PCs workstations, servers
  - PDAs phones, toasters

  running *network apps*
- *communication links*
  - fiber, copper, radio, satellite
  - transmission rate = ***bandwidth***
- *routers:* forward packets (chunks of data)



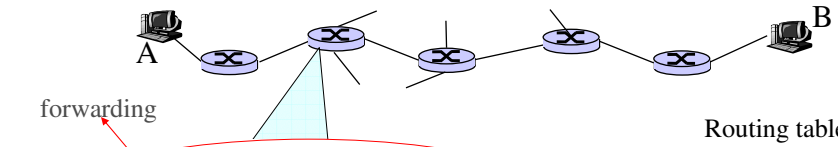
Wireless Users and Internet Hosts and Users Growth

World, 1998 projections



Router

- Forward a chunk of information (called *packet*) arriving on one of its communication links to one of its outgoing communications link (the *next hop* on the source-to-destination path)



forwarding

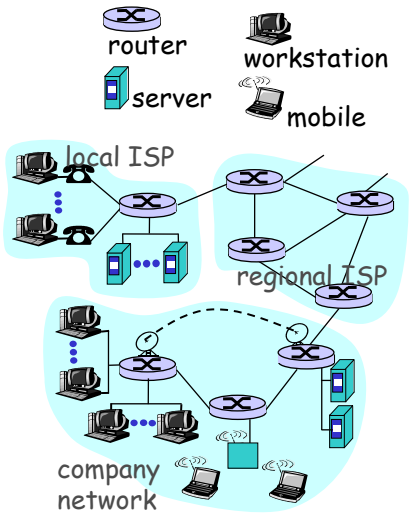
-Receives the packet
-Based on a routing table and the destination address, computes the 'next hop' to the destination
-Forwards the packet to the next hop
-The process of computing and maintaining the routing table is called Routing

Routing table

Dest. Address	Next Hop

What's the Internet: "nuts and bolts" view

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



What's a protocol?

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

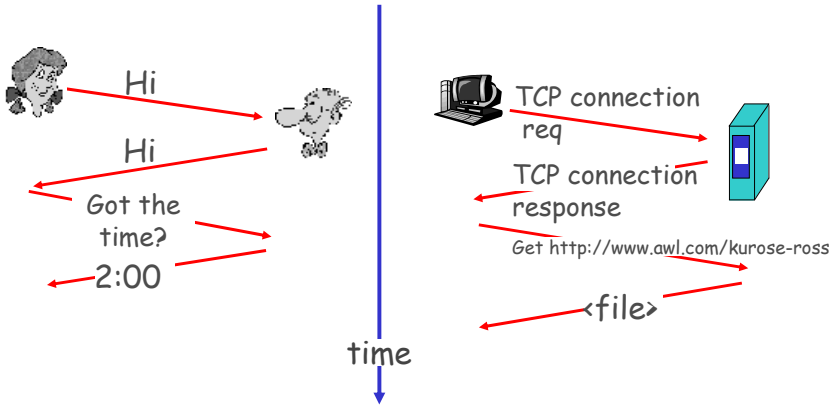
… specific msgs sent
… specific actions taken when msgs received, or other events

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

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

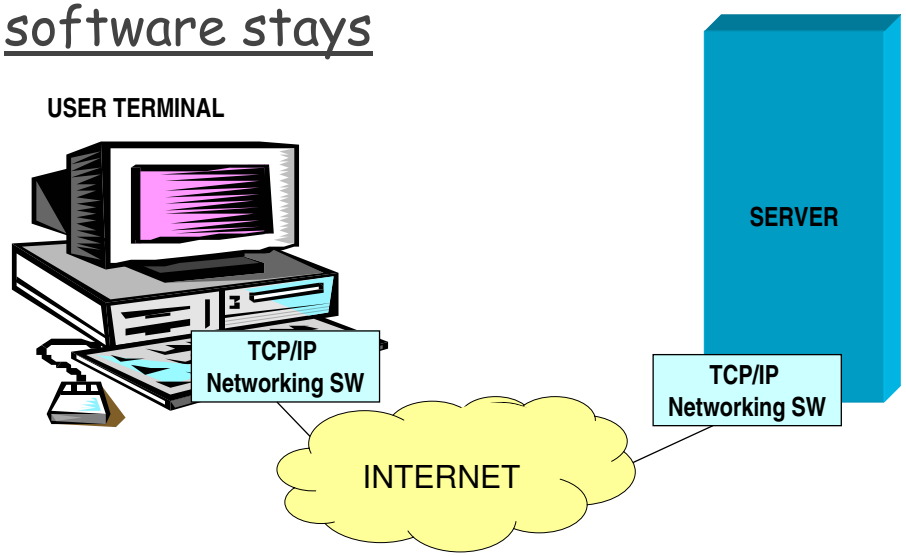
What's a protocol?

a human protocol and a computer network protocol:

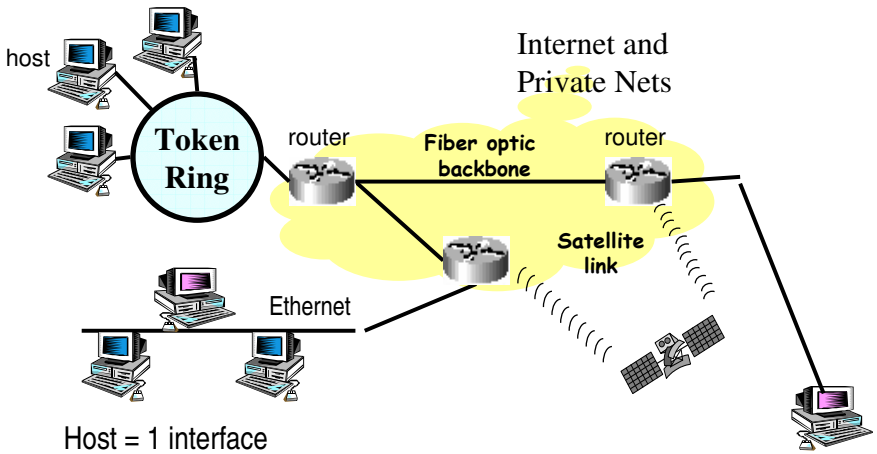


Q: Other human protocols?

Where the networking software stays

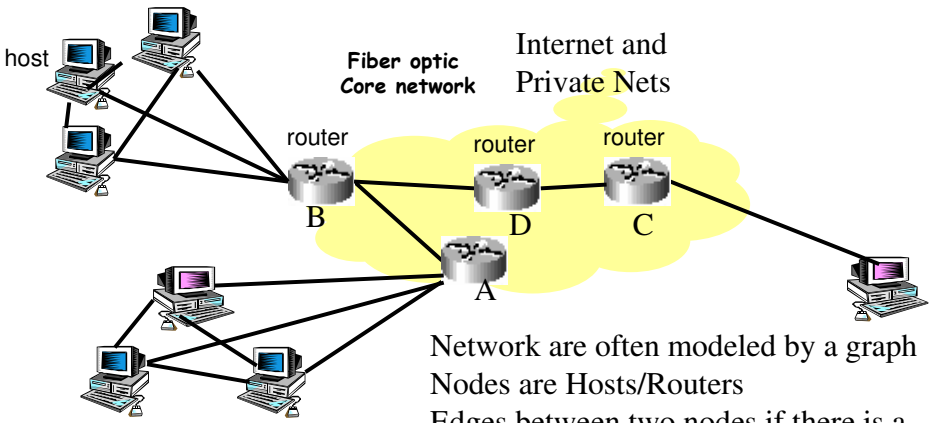


What Internet is: a network of heterogeneous networks



Host = 1 interface
Router = 2+ interfaces

Network Modeling: Network Physical Topology (a link to what you know)



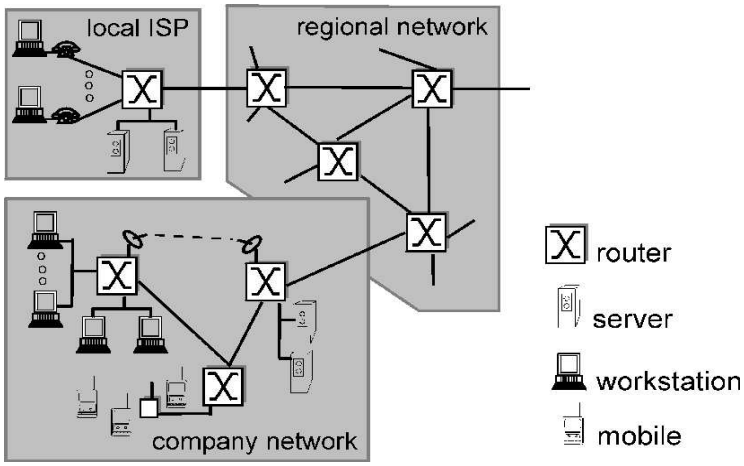
Host = 1 interface
Router = 2+ interfaces

Network are often modeled by a graph
Nodes are Hosts/Routers
Edges between two nodes if there is a communication link between them
→ Network Physical topology

What Internet attempts to be

(but only loosely is):

a hierarchical network…



The core: Digital Transmission Hierarchy Levels

STM-N : Synchronous Digital Hierarchy, level N
OC-N : Synchronous Optical Network, level N

STM-1/ OC-3	155.52	Mbit/s
STM -4/ OC-12	622.08	Mbit/s
STM-16/ OC-48	2,488.32	Mbit/s
STM-64/ OC-192	9,953.28	Mbit/s
STM-256/ OC-768	39,813.12	Mbit/s
STM-1024/ OC-3072	159,252.48	Mbit/s

HD-WDM -High Density-Wavelength Division Multiplexing

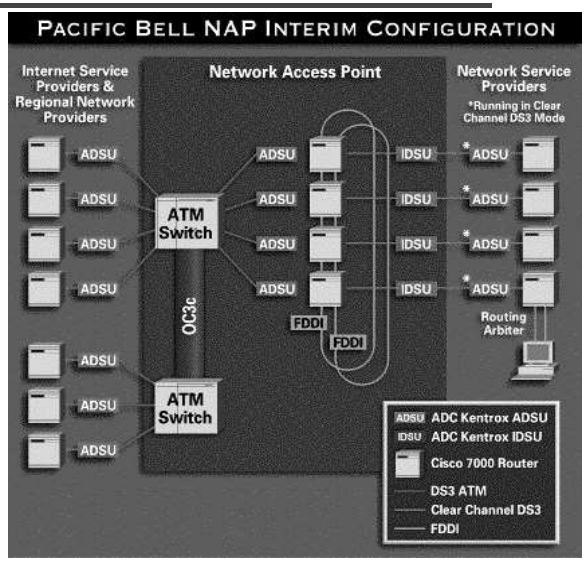
End 2001:
Commercial: 128 wavelengths @ STM-64
Experimental: 1024 wavelengths @ STM-64

Architecture Hierarchy - USA

- Local ISPs
- Regional ISPs
- National & International Backbone Providers (NBPs)
  - AT&T, MCIWorldcom, Sprint, Cable and Wireless, KPNQWest, …
  - interconnected via **big** switching centers called Neutral Access Points (NAPs)

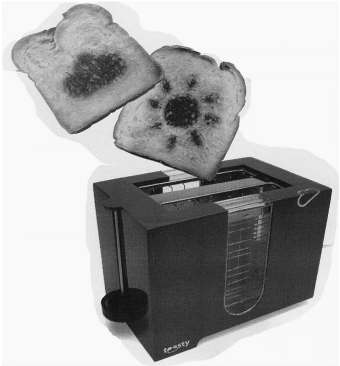
A NAP: just another router…?

Pacific Bell S. Francisco NAP

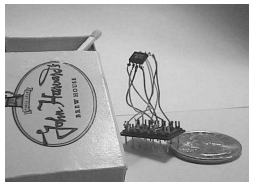


"Cool" internet appliances

IP picture frame
http://www.ceiva.com/



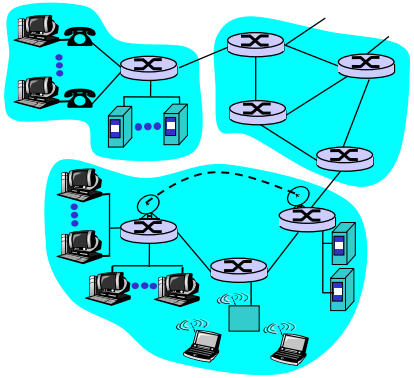
Web-enabled toaster+weather forecaster



World's smallest web server
http://www-ccs.cs.umass.edu/~shri/iPic.html

What's the Internet: a service view

- communication *infrastructure* enables distributed applications:
  - Web, email, games, e-commerce, database access, file (MP3) sharing
- communication services provided to apps:
  - connectionless
  - connection-oriented



Network Applications

(the User perception/exploitation of the Internet) –not exhaustive

- Access to remote information:
  - Web surfing
  - Access via web to bank account info
  - E-commerce and M-commerce (Mobile e-commerce)
- Person to person communications:
  - E-mail
  - Video-conferencing
  - Discussion forum (mailing lists)
  - VoIP
  - Instant messaging
- Entertainment
  - Video on demand
  - Interactive games (e.g. Quake)
  - Peer to peer (P2P) e.g. MP3 file sharing via Kazaa

Chapter 1: roadmap

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1.2 Network edge
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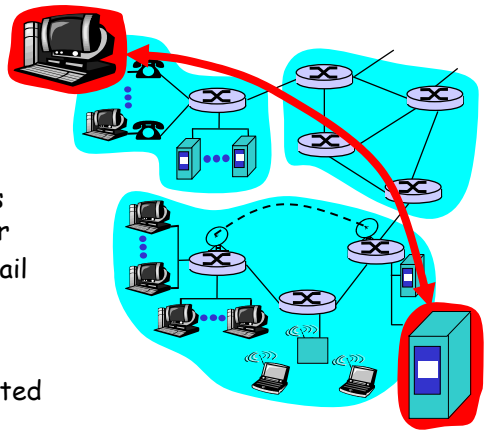
The network edge:

- 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. Gnutella, KaZaA



Network edge: connection-oriented service

Goal: data transfer between end systems

- *handshaking:* setup (prepare for) data transfer ahead of time
  - Hello, hello back human protocol
  - *set up "state"* in two communicating hosts
- TCP - Transmission Control Protocol
  - Internet's connection-oriented service

TCP service [RFC 793]

- *reliable, in-order* byte-stream data transfer
  - loss: acknowledgements and retransmissions
- *flow control:*
  - sender won't overwhelm receiver
- *congestion control:*
  - senders "slow down sending rate" when network congested

Network edge: connectionless service

Goal: data transfer between end systems

- same as before!

- UDP - User Datagram Protocol [RFC 768]: Internet's connectionless service
  - unreliable data transfer
  - no flow control
  - no congestion control

App's using TCP:

- HTTP (Web), FTP (file transfer), Telnet (remote login), SMTP (email)

App's using UDP:

- streaming media, teleconferencing, DNS, Internet telephony

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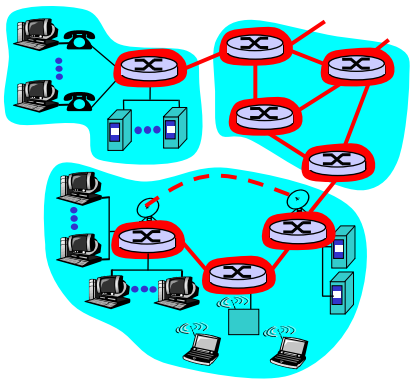
The Network Core

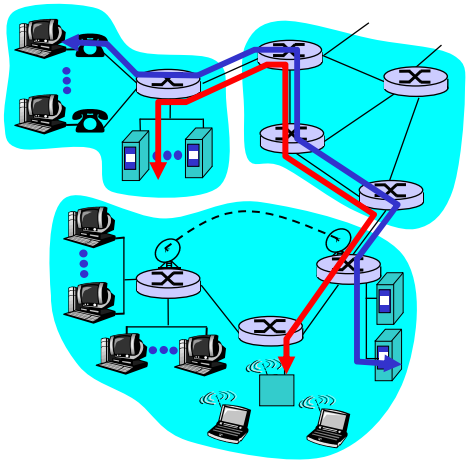
- mesh of interconnected routers
- *the* fundamental question: how is data transferred through net?
  - circuit switching: dedicated circuit per call: telephone net
  - packet-switching: data sent thru net in discrete "chunks"



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

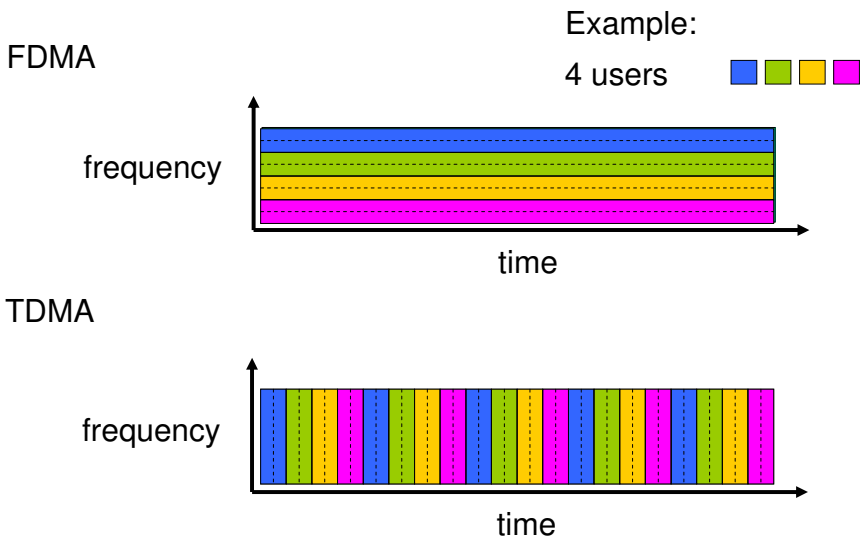


Network Core: Circuit Switching

network resources (e.g., bandwidth) divided into "pieces"

- pieces allocated to calls
- resource piece *idle* if not used by owning call *(no sharing)*
- dividing link bandwidth into "pieces"
  - frequency division
  - time division

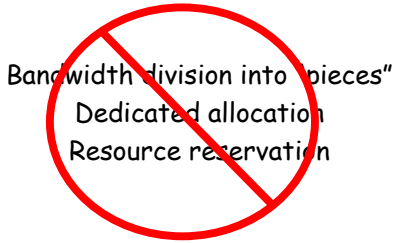
Circuit Switching: TDMA and TDMA



Network Core: Packet Switching

each end-end data stream divided into *packets*

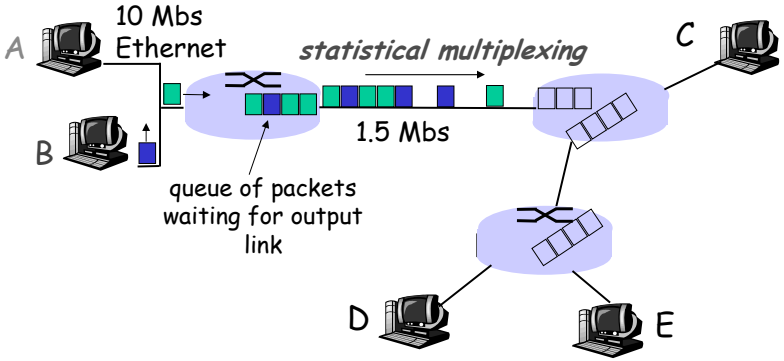
- user A, B packets *share* network resources
- each packet uses full link bandwidth
- resources used *as needed*



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
  - transmit over link
  - wait turn at next link

Packet Switching: Statistical Multiplexing



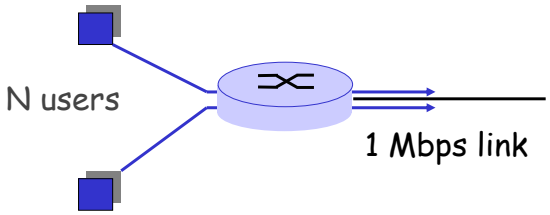
Sequence of A & B packets does not have fixed pattern ➔ ***statistical multiplexing***.

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

Packet switching versus circuit switching

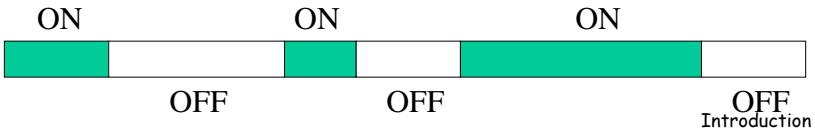
Packet switching allows more users to use network!

- 1 Mbit link
- each user:
  - 100 kbps when "active"
  - active 10% of time
- circuit-switching:
  - 10 users
- packet switching:
  - with 35 users, probability > 10 active less than .0004



Source types

- Constant Bit Rate (e.g. encoded voice without silence suppression→ voice packets have fixed size and are trasmitted periodically. Required bit rate: 64Kbps)
- Variable Bit Rate (e.g. Video encoding, voice with silence suppression, file downloading etc.)
  - The bit rate varies with time
  - Source behavior characterized by min/max transmission rate, and average bit rate. Source burstiness = max bit rate/ average bit rate.
  - Example: CBR ON/OFF



Packet switching versus circuit switching

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, object of current research

Packet-switching: store-and-forward

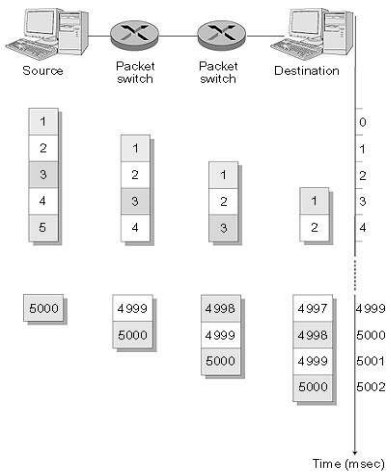
- Takes L/R seconds to transmit (push out) packet of L bits on to link or R bps
- Entire packet must arrive at router before it can be transmitted on next link: *store and forward*
- delay = 3L/R

Example:

- L = 7.5 Mbit
- R = 1.5 Mbps
- delay = 15 sec

(only transmission delay considered here)

Packet Switching: Message Segmenting



Now break up the message into 5000 packets

- Each packet 1,500 bits
- 1 msec to transmit packet on one link
- *pipelining:* each link works in parallel
- Delay reduced from 15 sec to 5.002 sec

See packet-switching vs. message switching (no segmentation) and the effect of queueing delay through the Java applets on the Kurose-Ross website.

Effect of packet sizes

Packet format

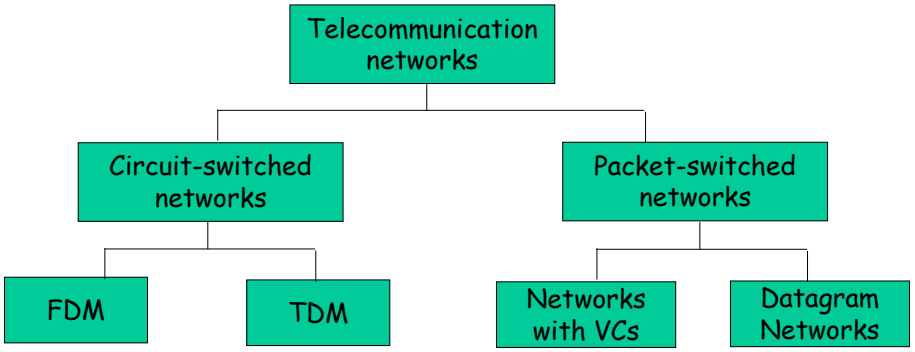
- A longer packet (more data transmitted in a single packet) leads to a lower overhead
- Longer packets result in a higher chance to be corrupted (critical especially for wireless transmission)
- When a packet is corrupted all the data are lost and need to be retransmitted

Packet-switched networks: forwarding

- *Goal:* move packets through routers from source to destination
  - we'll study several path selection (i.e. routing)algorithms (chapter 4)
- datagram network:
  - *destination address* in packet determines next hop
  - routes may change during session
  - analogy: driving, asking directions
- virtual circuit network:
  - each packet carries tag (virtual circuit ID), tag determines next hop
  - fixed path determined at *call setup time*, remains fixed thru call; VC share network resources
  - *routers maintain per-call state (the link on which a packet with a VC tag arriving to a given inbound link has to be forwarded and its VC tag on the next hop)*

Internet

Network Taxonomy



• Datagram network is *not* either connection-oriented or connectionless.
• Internet provides both connection-oriented (TCP) and connectionless services (UDP) to apps.

Chapter 1: roadmap

1.1 What *is* the Internet?
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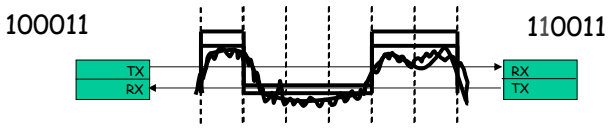
1.7 Protocol layers, service models
1.8 History

Transmission across a physical link

- Bits: propagate between transmitter and receiver
- 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

Transmission across a physical link

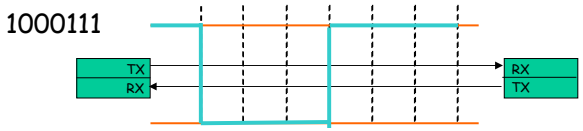


- Bit sequence modulates a suitable waveform which is sent across the link
  - How and which depends on the medium
- As the signal travels it experiences
  - Attenuation (absorption)
  - Distortion (limited bandwidth (frequency))
  - Noise (interference, thermal noise)
  - Influenced by medium, bit rate and distance
- Received sequence may be incorrect!!!

Codifica NRZ

- Codifica NRZ (Non Return to Zero)

Ogni bit ha associato un valore stabile per la sua intera durata (1: High; 0: Low)

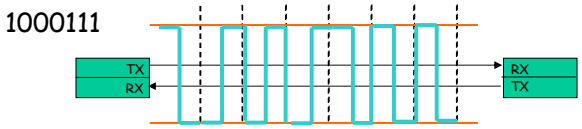


Problemi di sincronizzazione del ricevitore (nessuna transizione nel caso di sequenze di zeri o di uni)→ NRZ 5B6B o 4B5B

Codifica Manchester

- Codifica Manchester

Una transizione basso-alto (codifica dello zero) o alto-basso (codifica del valore uno) in corrispondenza di ogni bit



Usato in Ethernet 10Mbps e Token Ring

Physical Media: coax, fiber

- Twisted Pair (TP)
- two insulated copper wires
  - Category 3: traditional phone wires, 10 Mbps Ethernet
  - Category 5 TP: 100Mbps Ethernet

Coaxial cable:

- two concentric copper conductors
- Bidirectional
- Used: legacy Ethernet, HFC

Fiber optic cable:

- glass fiber carrying light pulses, each pulse a bit
- high-speed operation:
  - high-speed point-to-point transmission (e.g., 5 Gps)
- low error rate: repeaters spaced far apart ; immune to electromagnetic noise

Physical media: radio

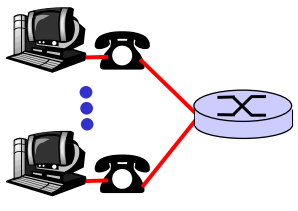
- signal carried in electromagnetic spectrum
- no physical "wire"
- bidirectional
- propagation environment effects:
  - reflection
  - obstruction by objects
  - attenuation
  - multipath
  - interference

Radio link types:

- LAN (e.g., WaveLAN)
  - 2Mbps, 11Mbps
- wide-area (e.g., cellular)
  - e.g. 3G: hundreds of kbps
- satellite
  - up to 50Mbps channel (or multiple smaller channels)
  - 270 msec end-end delay
  - geosynchronous versus LEOS

Residential access: point to point access

- Dialup via modem
  - up to 56Kbps direct access to router (often less)
  - Can't surf and phone at same time: can't be "always on"



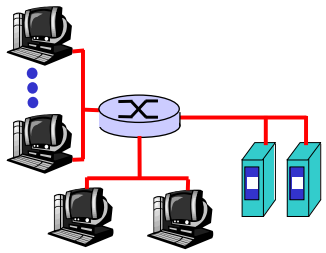
- ADSL: asymmetric digital subscriber line
  - up to 1 Mbps upstream (today typically < 256 kbps)
  - up to 8 Mbps downstream (today typically < 1 Mbps)
  - FDM: 50 kHz - 1 MHz for downstream
    4 kHz - 50 kHz for upstream
    0 kHz - 4 kHz for ordinary telephone

Residential access: cable modems

- HFC: hybrid fiber coax
  - asymmetric: up to 10Mbps upstream, 1 Mbps downstream
- network of cable and fiber attaches homes to ISP router
  - shared access to router among home
  - issues: congestion, dimensioning
- deployment: available via cable companies, e.g., MediaOne

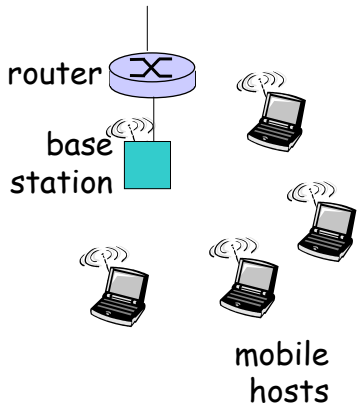
Company access: local area networks

- company/univ local area network (LAN) connects end system to edge router
- Ethernet:
  - shared or dedicated link connects end system and router
  - 10 Mbs, 100Mbps, Gigabit Ethernet
- deployment: institutions, home LANs happening now
- LANs: chapter 5

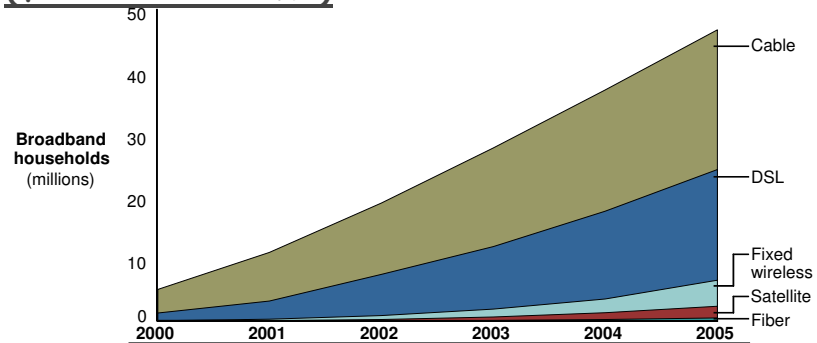


Wireless access networks

- shared *wireless* access network connects end system to router
  - via base station aka "access point"
- wireless LANs:
  - 802.11b (WiFi): 11 Mbps
- wider-area wireless access
  - provided by telco operator
  - 3G ~ 384 kbps
    - Will it happen??
  - WAP/GPRS in Europe



Broadband access, USA (fixed networks)



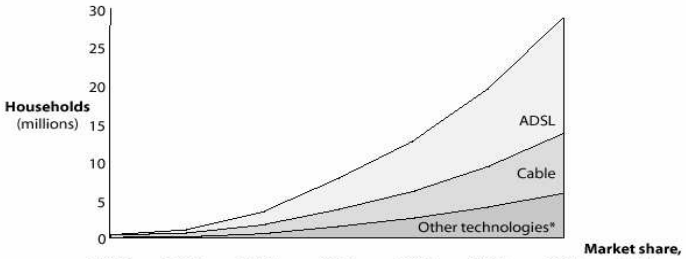
	2000	2001	2002	2003	2004	2005
Cable	3.74	7.76	11.42	15.81	19.43	22.42
DSL	1.25	2.96	6.61	10.07	14.06	17.75
Fixed wireless	0.02	0.25	0.66	1.25	2.22	4.20
Satellite	0.00	0.00	0.19	0.55	1.11	1.87
Fiber	0.00	0.00	0.01	0.06	0.19	0.47
Total (millions)	**5.00**	**10.97**	**18.89**	**27.73**	**37.01**	**46.72**

(numbers may not total due to rounding)

Source: Forrester Research, 2000

Broadband access, Europe (fixed networks)

Figure 5 European Residential Broadband Projections By Technology



	1999	2000	2001	2002	2003	2004	2005	Market share, 2005
ADSL	36	421	1,645	4,019	6,556	10,159	15,117	53%
Cable	308	490	1,138	2,190	3,473	5,298	7,804	27%
Other*	18	100	492	1,430	2,519	3,961	5,783	20%
Total	**362**	**1,011**	**3,274**	**7,639**	**12,548**	**19,417**	**28,705**	

* Includes fixed wireless, satellite, and fiber (Figures may not total due to rounding)

Source: Forrester Research, Inc.

Source: Forrester Research, 2000

Broadband Access in Italy

	2000	2001	2002	2003	2004	2005	2006	2007
fibra	0,0	0,1	0,2	0,2	0,4	0,5	0,8	1,0
satellite	0,0	0,1	0,1	0,2	0,4	0,7	1,0	1,2
wireless loops	0,0	0,0	0,2	0,4	0,7	1,0	1,2	1,4
dsl	0,1	0,3	0,8	1,8	2,7	3,8	4,5	5,0
totale fisso lb	0,1	0,5	1,3	2,6	4,2	6,0	7,5	8,6
mobile lb umts	0,0	0,0	0,3	1,5	3,0	6,0	10,0	15,0

(Millions of units)

UPDATED: march 2001

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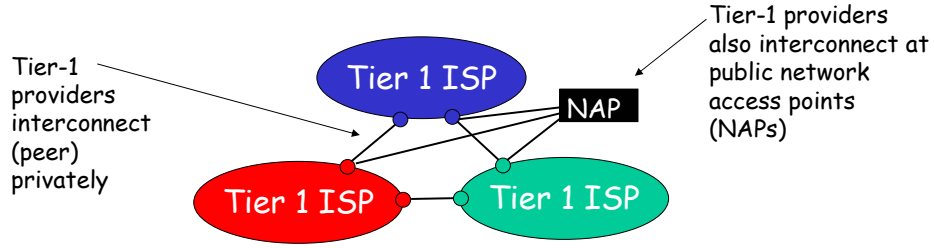
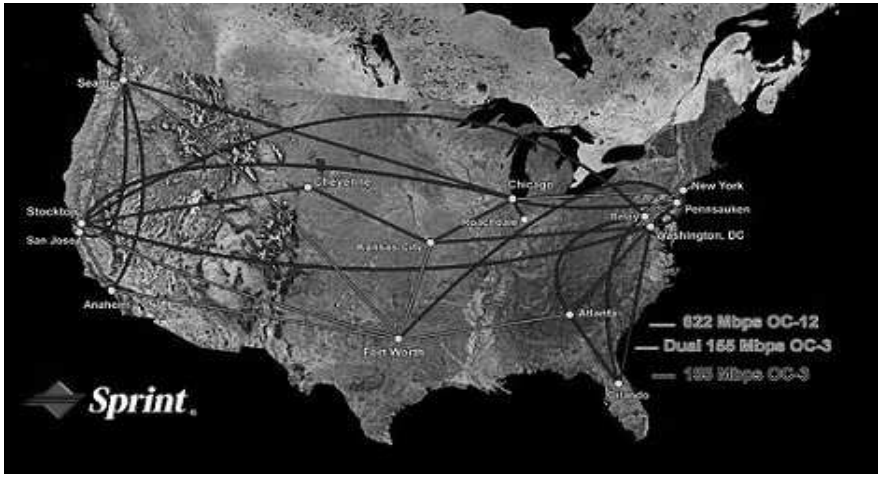
Internet structure: network of networks

- roughly hierarchical
- at center: "tier-1" ISPs (e.g., UUNet, BBN/Genuity, Sprint, AT&T), national/international coverage
  - treat each other as equals



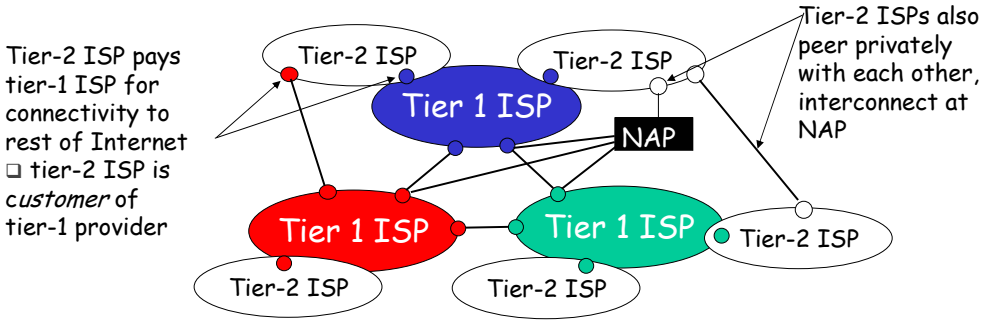
Tier-1 ISP: e.g., Sprint

Sprint US backbone network



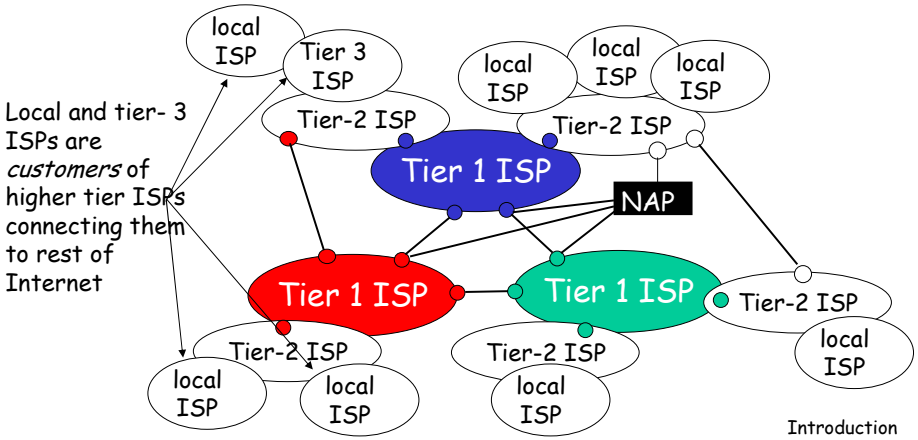
Internet structure: network of networks

- "Tier-2" ISPs: smaller (often regional) ISPs
  - Connect to one or more tier-1 ISPs, possibly other tier-2 ISPs



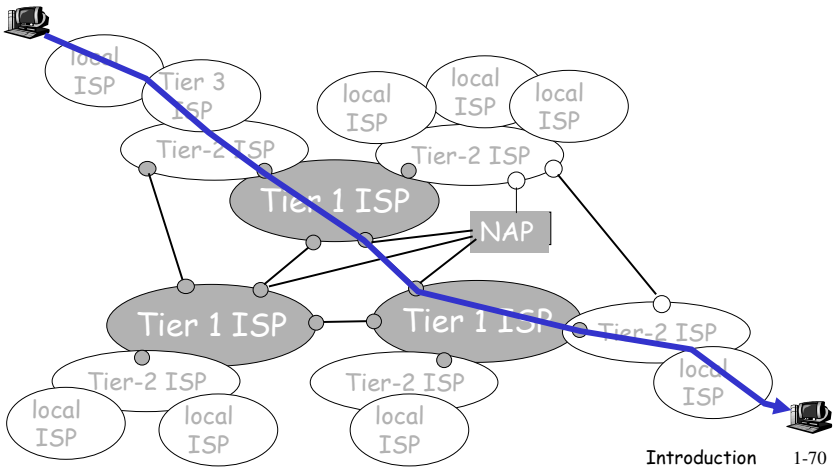
Internet structure: network of networks

- "Tier-3" ISPs and local ISPs
  - last hop ("access") network (closest to end systems)



Internet structure: network of networks

- a packet passes through many networks!



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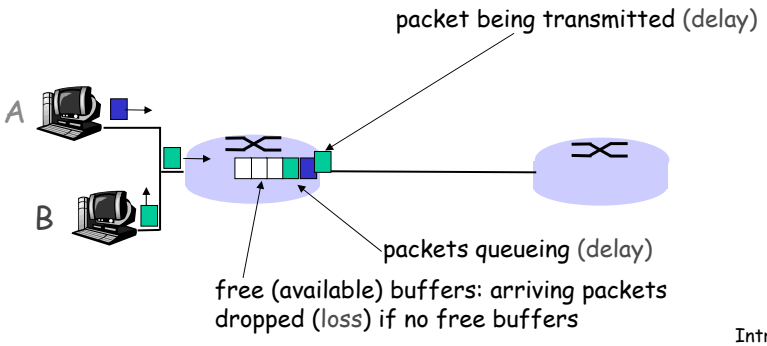
How do loss and delay occur?

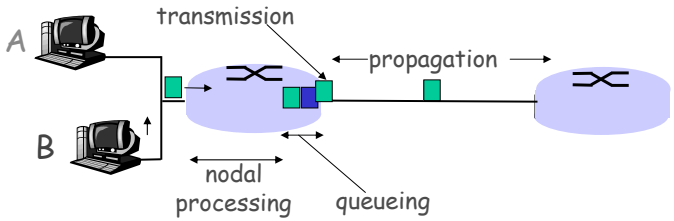
packets *queue* in router buffers

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



Four sources of packet delay

- 1. nodal processing:
  - check bit errors
  - determine output link
- 2. queueing
  - time waiting at output link for transmission
  - depends on congestion level of router

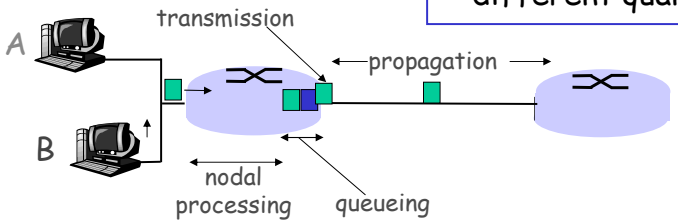


Delay in packet-switched networks

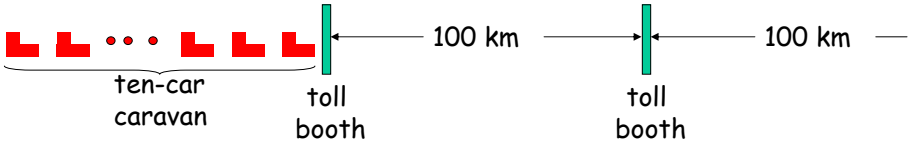
3. Transmission delay:
- R=link bandwidth (bps)
- L=packet length (bits)
- time to send bits into link = L/R

4. Propagation delay:
- d = length of physical link
- s = propagation speed in medium (~2×10^8 m/sec)
- propagation delay = d/s

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

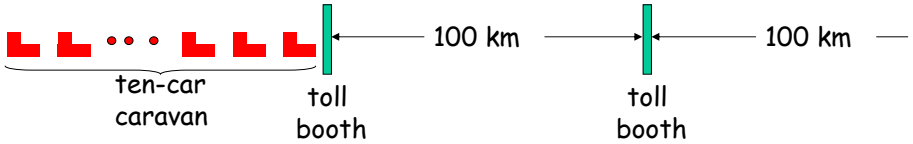


Caravan analogy



- Cars "propagate" at 100 km/hr
- Toll booth takes 12 sec to service a 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

Caravan analogy (more)



- Cars now "propagate" at 1000 km/hr
- Toll booth now takes 1 min to service a car
- Q: Will cars arrive to 2nd booth before all cars serviced at 1st booth?
- Yes! After 7 min, 1st car at 2nd booth and 3 cars still at 1st booth.
- 1st bit of packet can arrive at 2nd router before packet is fully transmitted at 1st router!
  - See Ethernet applet at AWL Web site

Nodal delay

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

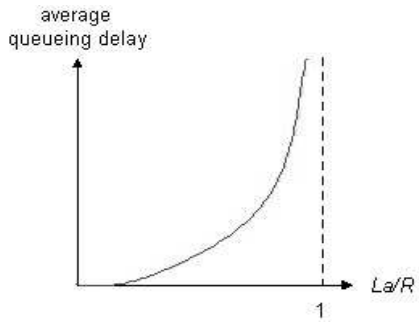
- d_{proc} = processing delay
  - typically a few microsecs or less
- d_{queue} = queuing delay
  - depends on congestion
- d_{trans} = transmission delay
  - = L/R, significant for low-speed links
- d_{prop} = propagation delay
  - a few microsecs to hundreds of msecs

Delay for each hop!!!

Queueing delay (revisited)

- R=link bandwidth (bps)
- L=packet length (bits)
- a=average packet arrival rate

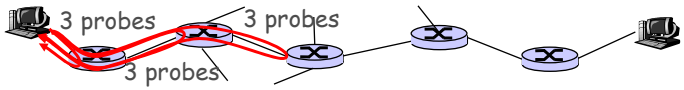
traffic intensity = La/R



- La/R ~ 0: average queueing delay small
- La/R -> 1: delays become large
- La/R > 1: more "work" arriving than can be serviced, average delay infinite!

"Real" Internet delays and routes

- What do "real" Internet delay & loss look like?
- Traceroute program: provides delay measurement from source to router along end-end Internet path towards destination. For all *i*:
  - sends three packets that will reach router *i* on path towards destination
  - router *i* will return packets to sender
  - sender times interval between transmission and reply.



"Real" Internet delays and routes

traceroute: gaia.cs.umass.edu to www.eurecom.fr

Three delay measements from gaia.cs.umass.edu to cs-gw.cs.umass.edu

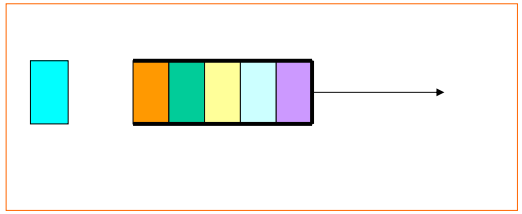
```
1  cs-gw (128.119.240.254)  1 ms  1 ms  2 ms
2  border1-rt-fa5-1-0.gw.umass.edu (128.119.3.145)  1 ms  1 ms  2 ms
3  cht-vbns.gw.umass.edu (128.119.3.130)  6 ms 5 ms 5 ms
4  jn1-at1-0-0-19.wor.vbns.net (204.147.132.129)  16 ms 11 ms 13 ms
5  jn1-so7-0-0-0.wae.vbns.net (204.147.136.136)  21 ms 18 ms 18 ms
6  abilene-vbns.abilene.ucaid.edu (198.32.11.9)  22 ms  18 ms  22 ms
7  nycm-wash.abilene.ucaid.edu (198.32.8.46)  22 ms  22 ms  22 ms
8  62.40.103.253 (62.40.103.253)  104 ms 109 ms 106 ms
9  de2-1.de1.de.geant.net (62.40.96.129)  109 ms 102 ms 104 ms
10  de.fr1.fr.geant.net (62.40.96.50)  113 ms 121 ms 114 ms
11  renater-gw.fr1.fr.geant.net (62.40.103.54)  112 ms  114 ms  112 ms
12  nio-n2.cssi.renater.fr (193.51.206.13)  111 ms  114 ms  116 ms
13  nice.cssi.renater.fr (195.220.98.102)  123 ms  125 ms  124 ms
14  r3t2-nice.cssi.renater.fr (195.220.98.110)  126 ms  126 ms  124 ms
15  eurecom-valbonne.r3t2.ft.net (193.48.50.54)  135 ms  128 ms  133 ms
16  194.214.211.25 (194.214.211.25)  126 ms  128 ms  126 ms
17  * * *
18  * * *
19  fantasia.eurecom.fr (193.55.113.142)  132 ms  128 ms  136 ms
```

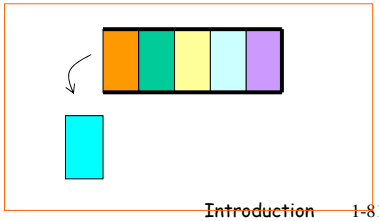
trans-oceanic link

* means no reponse (probe lost, router not replying)

Packet loss

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





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Protocol "Layers"

Networks are complex!

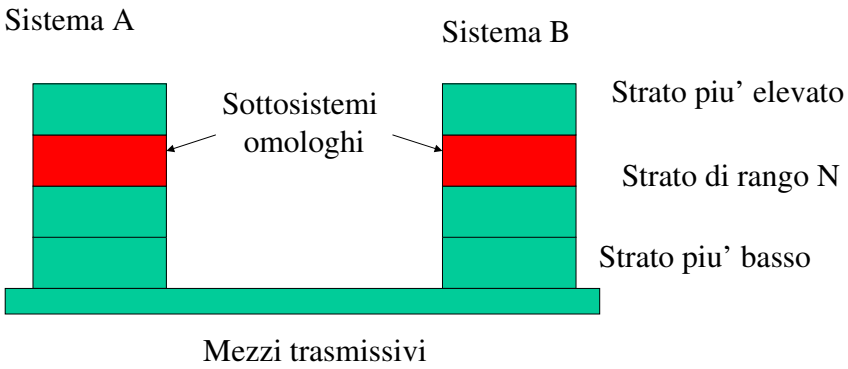
- many "pieces":
  - hosts
  - routers
  - links of various media
  - applications
  - protocols
  - hardware, software

Question:

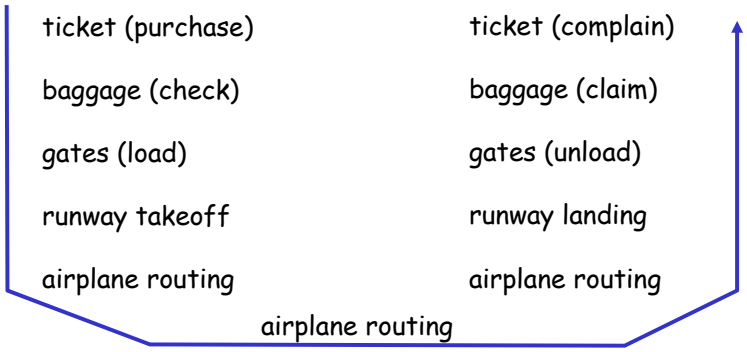
Is there any hope of *organizing* structure of network?

Or at least our discussion of networks?

Layering

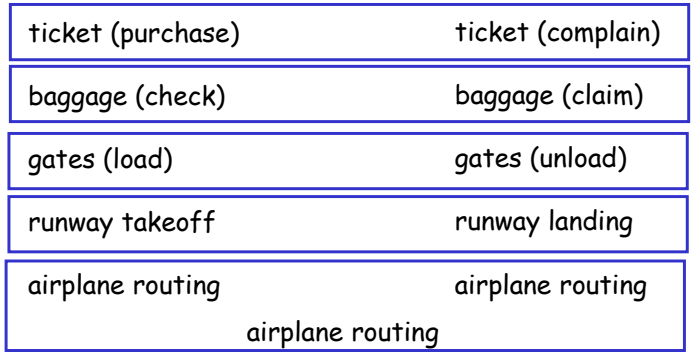


Organization of air travel



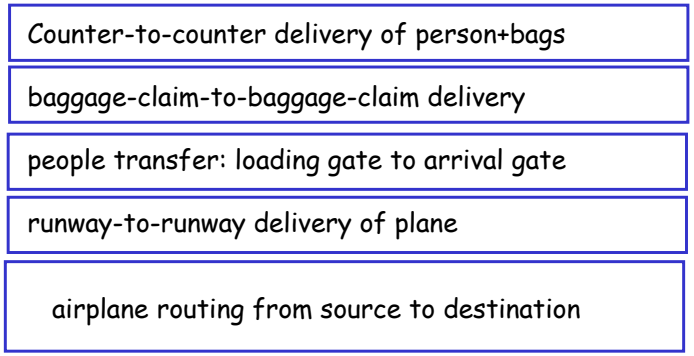
- a series of steps

Organization of air travel: a different view

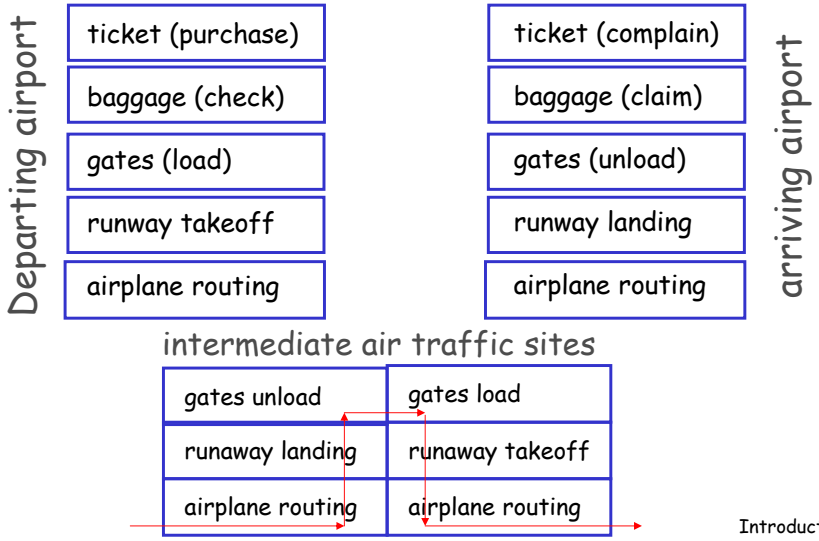


Layers: each layer implements a service
- via its own internal-layer actions
- relying on services provided by layer below

Layered air travel: services



Distributed implementation of layer functionality



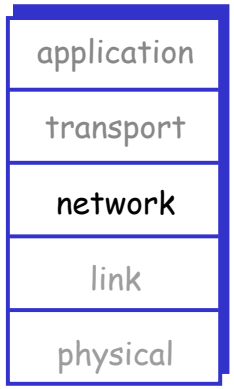
Why layering?

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
- layering considered harmful?

Internet protocol stack

- application: supporting network applications
  - FTP, SMTP, HTTP
- transport: host-host data transfer
  - TCP, UDP
- network: routing of datagrams from source to destination
  - IP, routing protocols
- link: data transfer between neighboring network elements
  - PPP, Ethernet
- physical: bits "on the wire"

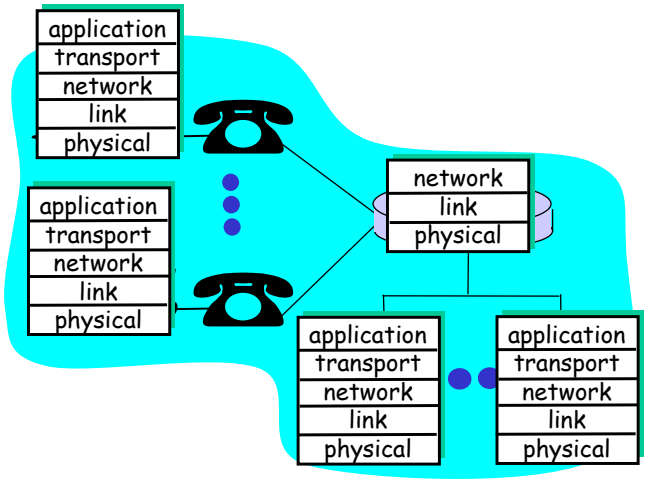


Typically in HW
Typically SW

Layering: logical communication

Each layer:

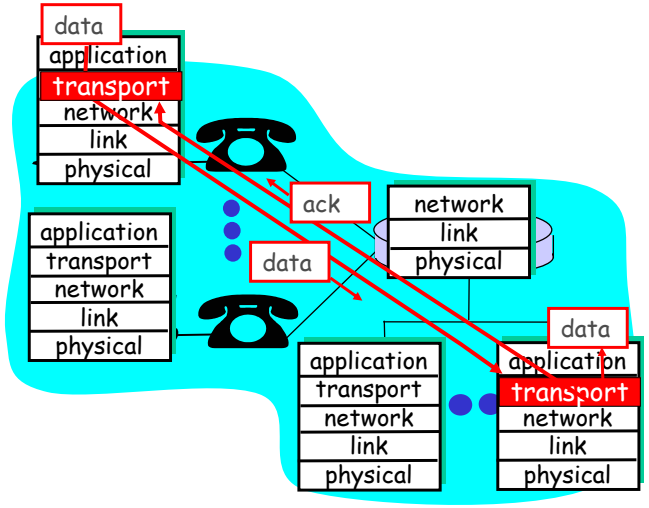
- distributed
- "entities" implement layer functions at each node
- entities perform actions, exchange messages with peers



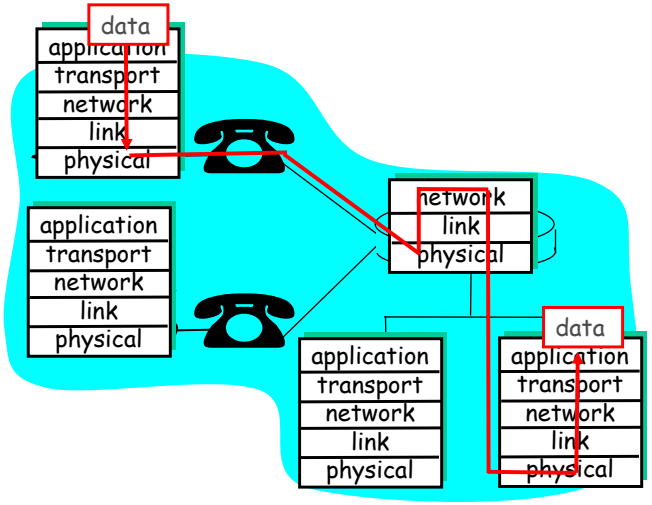
Layering: *logical* communication

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

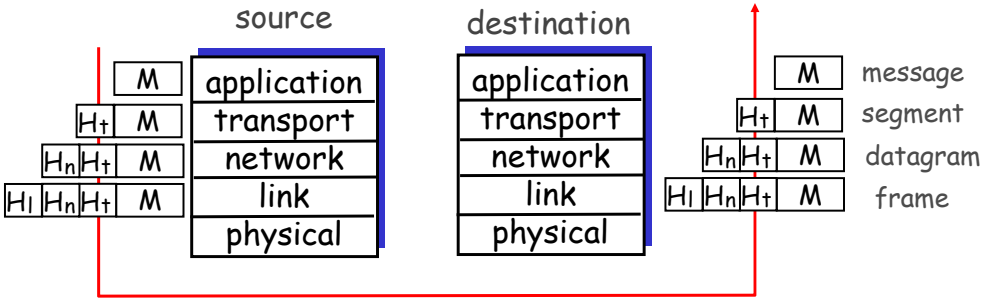


Layering: physical communication



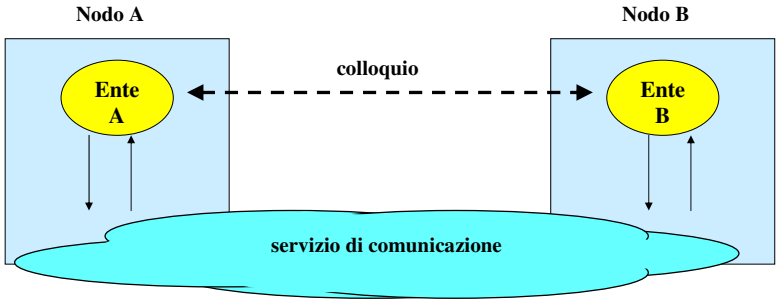
Protocol layering and data

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



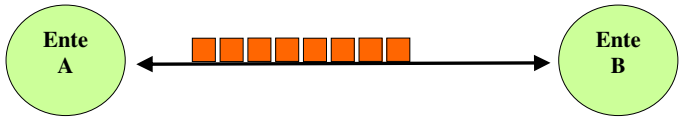
Il servizio di comunicazione

- Modelli funzionali
- Date due o più entità remote
- Possiamo descrivere il sistema di comunicazione per scambio di messaggi come un
  "fornitore del servizio di trasporto dell'informazione"



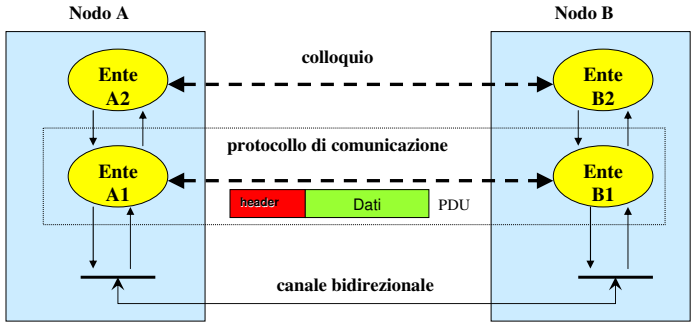
Il servizio di comunicazione

- **E' basato sul servizio di trasporto, ossia il meccanismo di scambio di informazione fra due "entità"**
- **E' in generale un servizio di trasferimento di unità informative**
  - **bit**
  - **gruppi di bit (trame o pacchetti)**
  - **files**
  - **flussi multimediali**



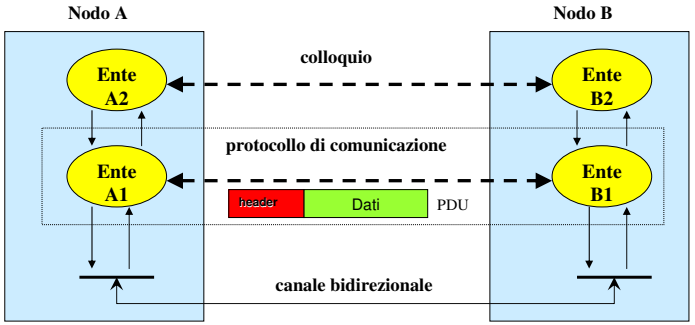
Livelli

- le entità che colloquiano in un servizio di telecomunicazione possono anche offrire un servizio di comunicazione a entità terze, dette di livello superiore



Livelli

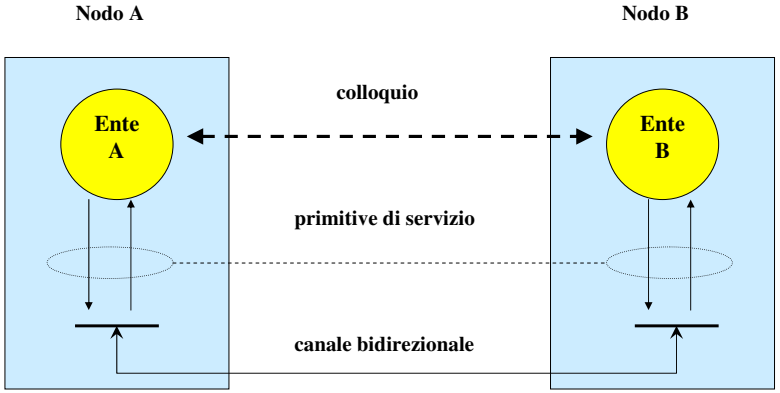
- A che serve?
  - il servizio offerto alle entità di livello superiore può essere diverso da quello base



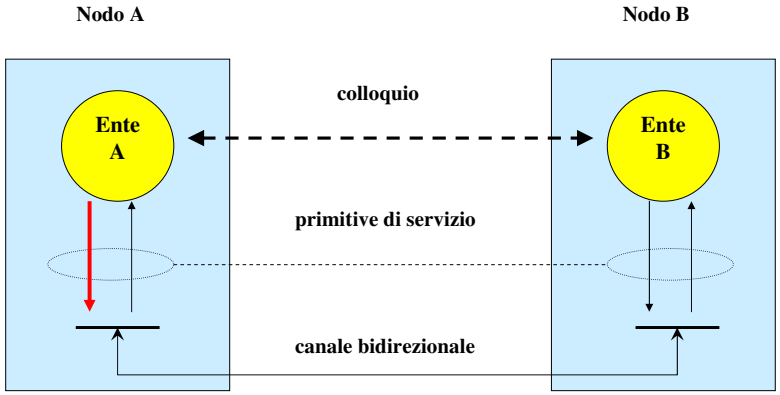
Il servizio di comunicazione

- il servizio di comunicazione può essere descritto mediante delle *chiamate di servizio* dette *primitive di servizio*
- le primitive di servizio servono a descrivere il servizio, a richiederlo e a ricevere informazioni sul servizio dal fornitore
- le primitive di servizio sono caratterizzate da parametri tra cui:
  - informazione da trasferire
  - indicazione del destinatario
  - caratteristiche del servizio richiesto
  - ecc.

Entità colloquianti tramite primitive

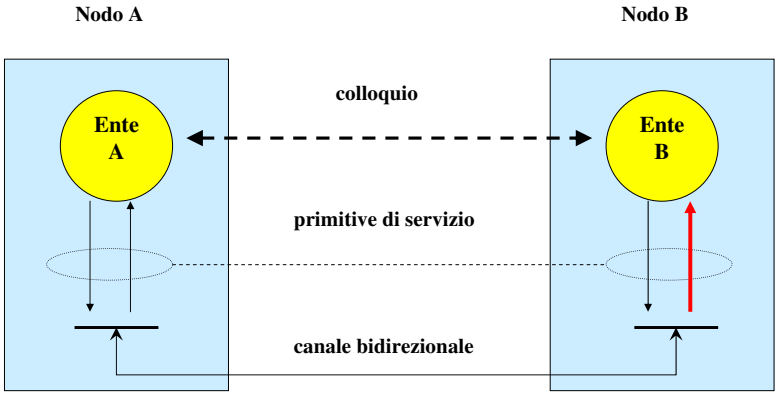


Primitive



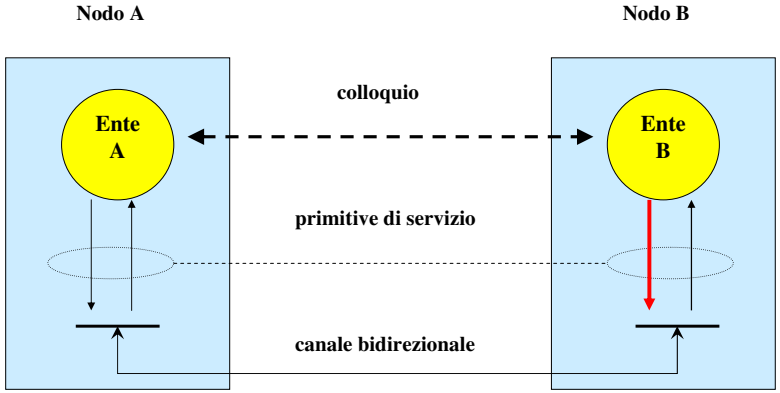
Richiesta di A

Primitive



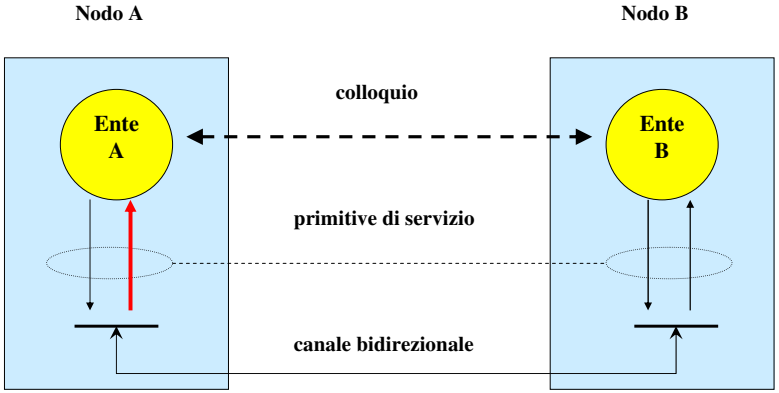
Indicazione verso B

Primitive



Risposta di B

Primitive



Conferma verso A

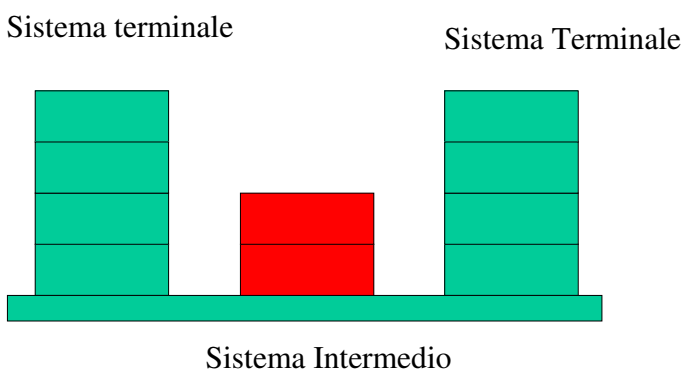
Primitive

- Riassumendo:
  - servono a chiedere il servizio e essere informati dell'esito della richiesta
  - hanno significato locale tra fornitore e cliente del servizio
  - non sono legate direttamente al modo con il quale il fornitore effettua il servizio
  - devono contenere tutte le informazioni necessarie al fornitore

Protocolli di comunicazione

- le entità di un livello collaborano per fornire il servizio di comunicazione al livello superiore e si scambiano messaggi mediante il servizio offerto dal livello inferiore
- Protocollo:
  - Insieme delle regole che sovrintendono al colloquio tra entità dello stesso livello
    - formato dei messaggi
    - informazioni di servizio
    - algoritmi di trasferimento
    - ecc.

Sottosistemi di comunicazione



Packet Data Units (PDU)

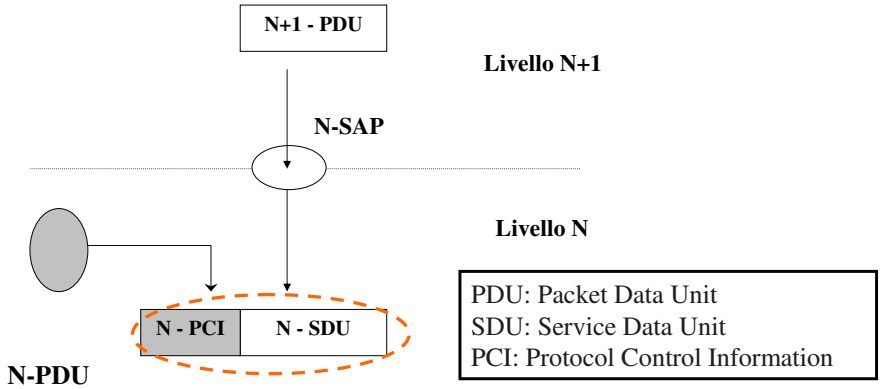
- un protocollo utilizza per il colloquio tra entità dello stesso livello delle unità di trasferimento dati dette PDU o anche trame del protocollo
- Le PDU possono contenere:
  - **informazione di servizio necessaria al coordinamento tra le entità**
  - **informazione vera e propria ricevuta dai livelli superiori**

Architettura a strati

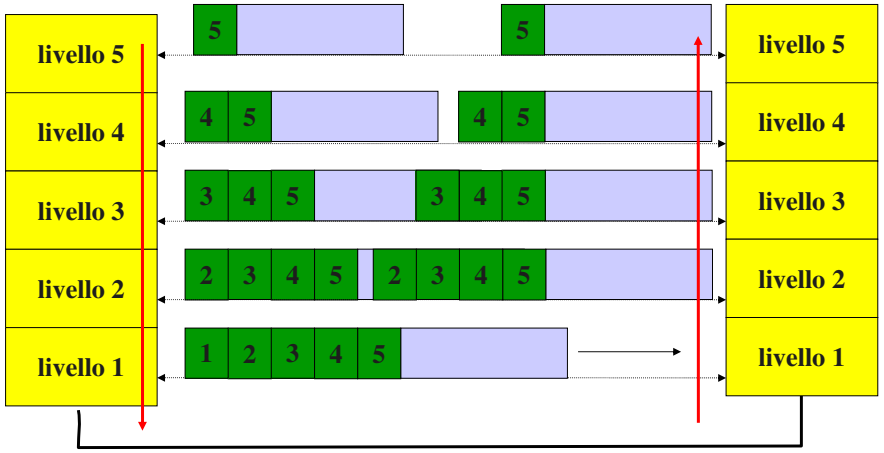
- I servizi di comunicazione complessi possono essere articolati a strati
  - da un livello che garantisce solo il trasporto dei bit
  - a un livello dove sono definite complessi servizi caratterizzati da molti parametri e funzionalità

Relazioni tra i livelli

- Il servizio offerto da uno strato è rappresentato da un Service Access Point (SAP)

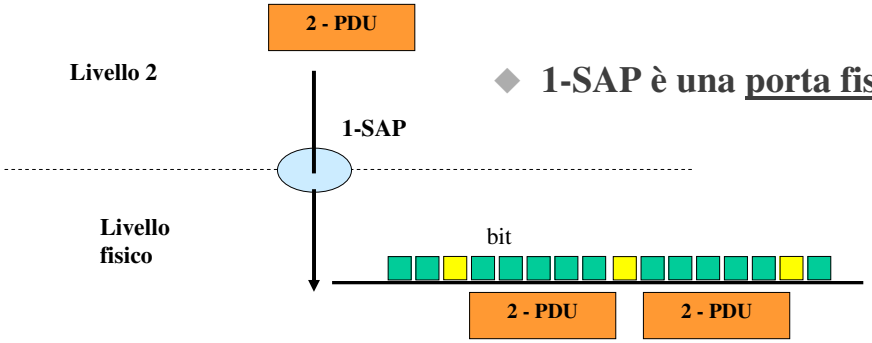


Architettura completa



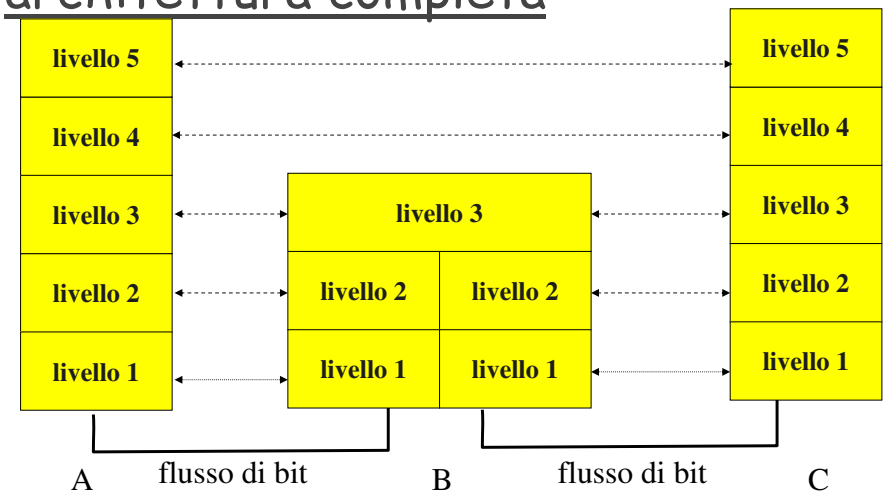
Livello fisico

- **Al livello più basso che è il livello fisico, le PDU sono i flussi di bit**



- **1-SAP è una porta fisica**
- **I livelli superiori arricchiscono questo servizio di comunicazione base con funzionalità anche complesse**

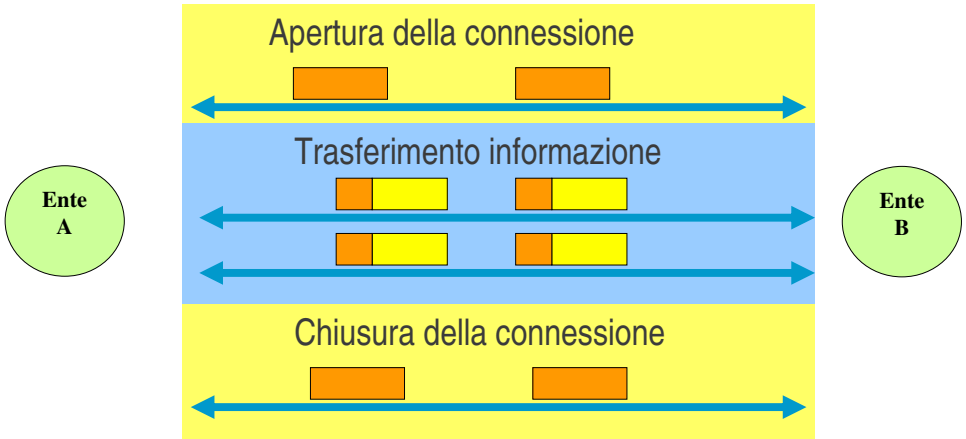
Esempio di funzionalità di una architettura completa



Modalità di comunicazione

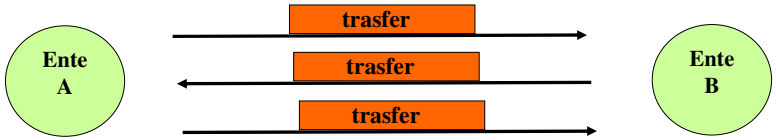
- modalità a connessione
  - instaurazione della connessione
  - trasferimento dell'informazione
  - rilascio delle connessione
- modalità senza connessione
  - una sola fase

Servizio a connessione



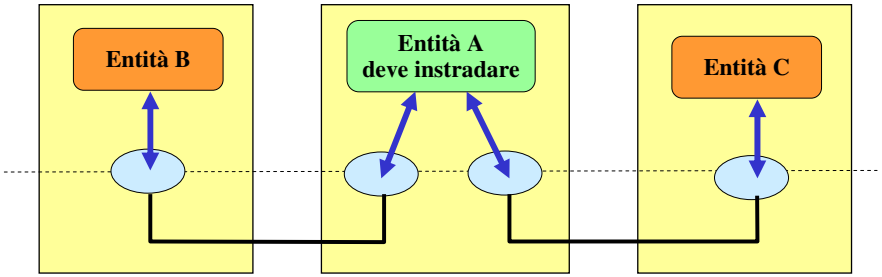
Servizio senza connessione

- Il trasferimento dati avviene in modo autonomo, senza preventivo accordo
- non lega fra loro i diversi trasferimenti effettuati fra gli stessi utenti
- non consente i servizi tipici del trasferimento a connessione



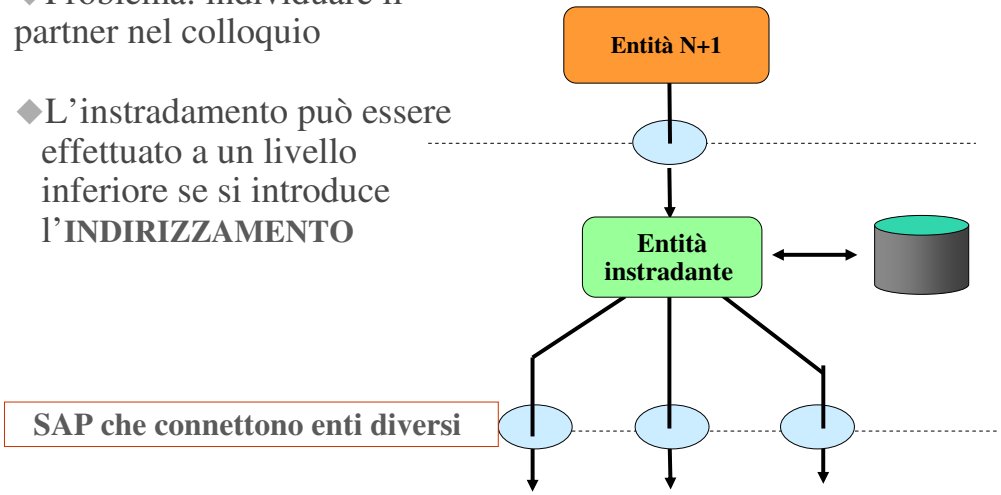
Funzione di rete

- **Si parla di funzioni di rete implementata in un livello quando è possibile il colloquio tra più di due entità dello stesso livello**
- **Viene introdotta la funzione di <u>INSTRADAMENTO</u> (scelta del SAP)**



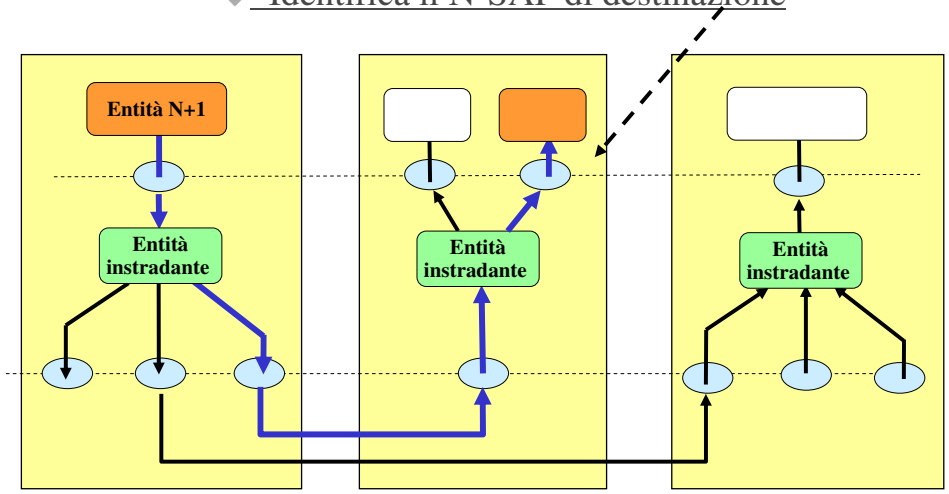
Instradamento

- Problema: individuare il partner nel colloquio
- L'instradamento può essere effettuato a un livello inferiore se si introduce l'**INDIRIZZAMENTO**



Indirizzamento

- <u>Identifica il N-SAP di destinazione</u>

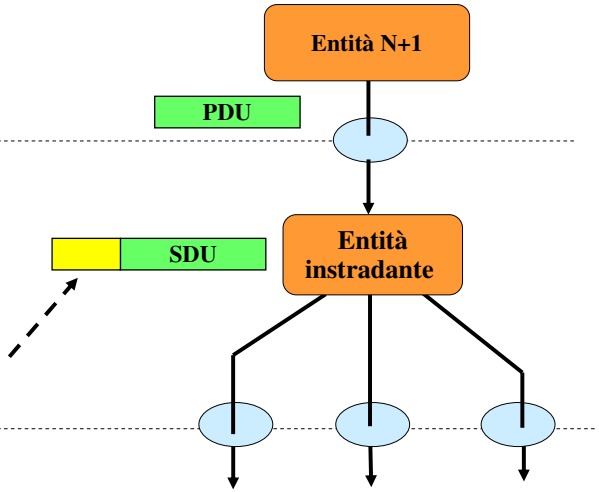


Indirizzamento & Instradamento

La PDU viene passata col parametro **INDIRIZZO**

L' **INDIRIZZO** viene usato per **instradare (scegliere il SAP di uscita)**

e viene incapsulato perché possa essere instradato da altri nodi



Indirizzamento

- Indirizzo: identificativo del SAP da cui raggiungere l'entità, univoco fra tutti i SAP delle stesso livello
- Tipologie di indirizzamento
  - unicast: singolo SAP
  - multicast: gruppi di SAP
  - broadcast: tutti i SAP

Forwarding o commutazione

- **E' il servizio di inoltro che un'entità fornisce ad altre entità allo stesso livello**
- **Il SAP è già scelto occorre ora effettuare il passaggio**

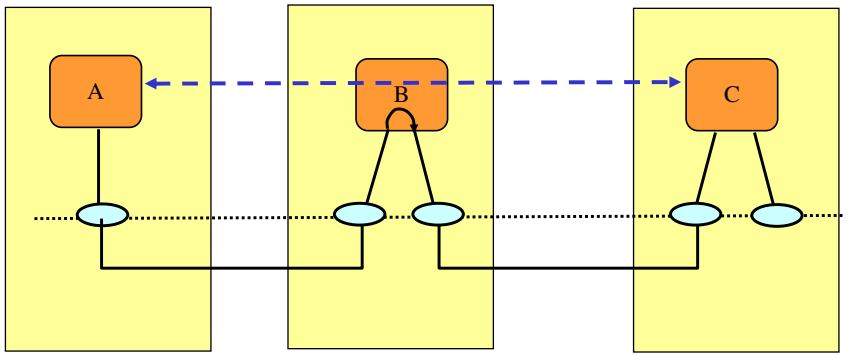


Tabelle di Instradamento

- scelta del SAP di uscita sulla base delle informazioni memorizzate

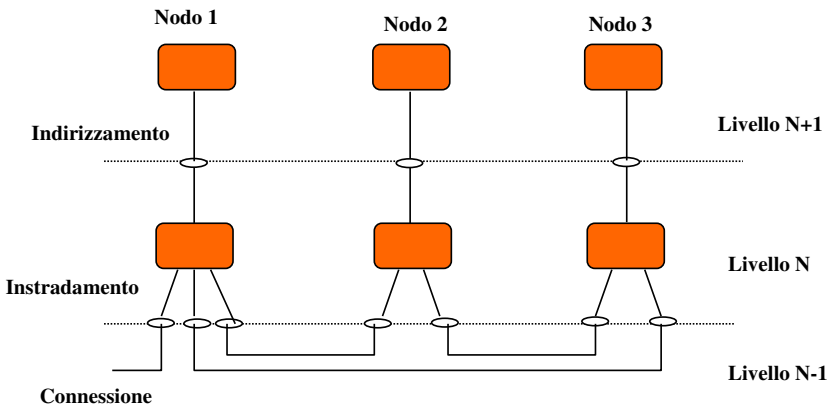
tabella di instradamento	
destinaz.	SAP uscita

- raccolta delle informazioni mediante scambio di dati con gli altri nodi
  - protocolli di instradamento

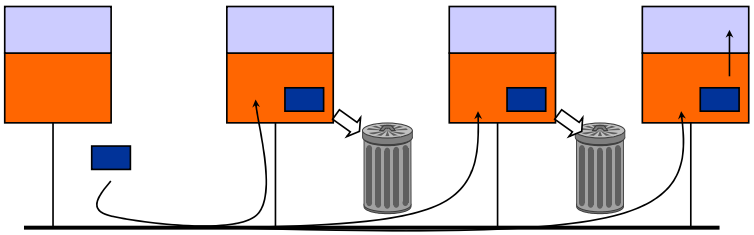
La via verso la destinazione

- è possibile attraversare molti nodi prima di giungere a destinazione
- alcuni nodi possono svolgere solo la funzione di relay

Funzioni di rete sopra un servizio di collegamenti punto-punto



Servizio di rete sopra un collegamento broadcast



Chapter 1: roadmap

1.1 What *is* the Internet?
1.2 Network edge
1.3 Network core
1.4 Network access and physical media
1.5 ISPs and Internet backbones
1.6 Delay & loss in packet-switched networks
1.7 Internet structure and ISPs
1.8 History

Internet History

1961-1972: Early packet-switching principles

- 1961: Kleinrock - queueing theory shows effectiveness of packet-switching
- 1964: Baran - packet-switching in military nets
- 1967: ARPAnet conceived by Advanced Research Projects Agency
- 1969: first ARPAnet node operational
- 1972:
  - ARPAnet demonstrated publicly
  - NCP (Network Control Protocol) first host-host protocol
  - first e-mail program
  - ARPAnet has 15 nodes

Internet History

1972-1980: Internetworking, new and proprietary nets

- 1970: ALOHAnet satellite network in Hawaii
- 1973: Metcalfe's PhD thesis proposes Ethernet
- 1974: Cerf and Kahn - architecture for interconnecting networks
- late70's: proprietary architectures: DECnet, SNA, XNA
- late 70's: switching fixed length packets (ATM precursor)
- 1979: ARPAnet has 200 nodes

Cerf and Kahn's internetworking principles:
- minimalism, autonomy - no internal changes required to interconnect networks
- best effort service model
- stateless routers
- decentralized control

define today's Internet architecture

Internet History

1980-1990: new protocols, a proliferation of networks

- 1983: deployment of TCP/IP
- 1982: SMTP e-mail protocol defined
- 1983: DNS defined for name-to-IP-address translation
- 1985: FTP protocol defined
- 1988: TCP congestion control
- new national networks: Csnet, BITnet, NSFnet, Minitel
- 100,000 hosts connected to confederation of networks

Internet History

1990, 2000's: commercialization, the Web, new apps

- Early 1990's: ARPAnet decommissioned
- 1991: NSF lifts restrictions on commercial use of NSFnet (decommissioned, 1995)
- early 1990s: Web
  - hypertext [Bush 1945, Nelson 1960's]
  - HTML, HTTP: Berners-Lee
  - 1994: Mosaic, later Netscape
  - late 1990's: commercialization of the Web

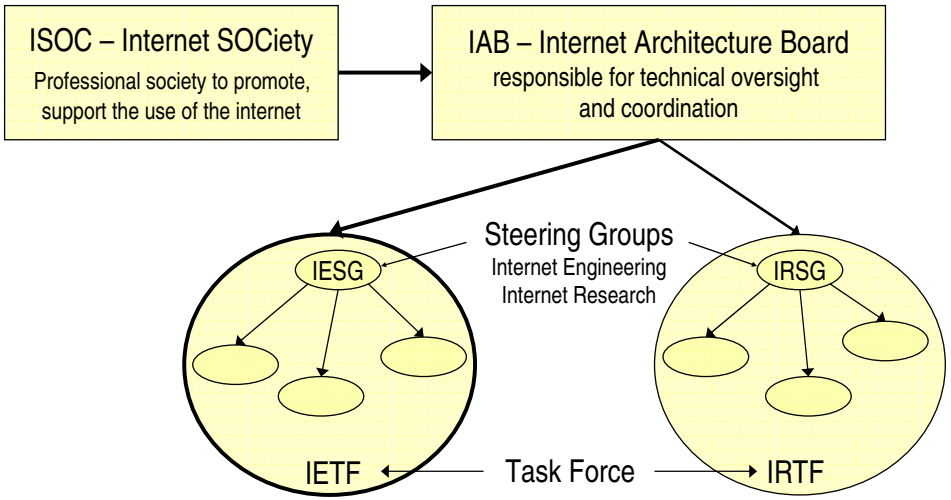
Late 1990's – 2000's:
- more killer apps: instant messaging, peer2peer file sharing (e.g., Naptser)
- network security to forefront
- est. 50 million host, 100 million+ users
- backbone links running at Gbps

A short digression:

where is Internet standardized? Who controls the Internet?

- No single administrative organization
- IETF - Internet Engineering Task Force
  - Developement of current protocols and specifications for standardization.
    - International community, open to everyone
    - Most of the work via mailing lists
    - Meets three times/year
  - organized in areas and working groups
    - Dynamically activated & deactivated on need
    - group coordination: IESG (Internet Engineering Steering Group). Area directors are members of the IESG. Responsible for the the actions associated with entry into and movement along the Internet "standards track," including final approval of specifications as Internet Standards.
- Industry also preemptively determine standards

Technical Bodies Structure

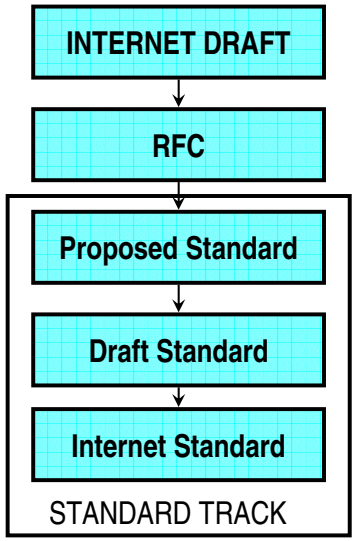


IETF credo

We reject kings, presidents and voting.
We believe in rough consensus
and running code

David Clark (MIT), 1992

Internet Standard Process



Draft version for information review and comments. 6 months lifetime

Official Internet publication: never expires

Entry level - protocol specification should be stable technically

At least 2 independent & interoperable implementations testing all spec. fcts

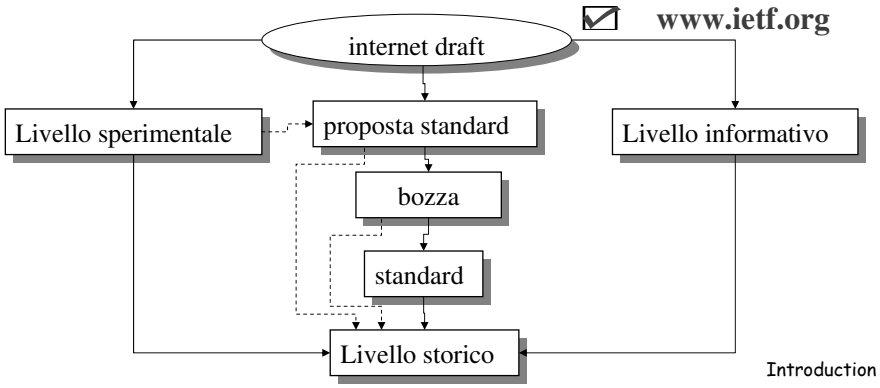
Have had significant field use and clear community interest in production use

Non-Standard Track
(the most common track!!)

- Specifications may not be intended to be an Internet standard
- Three labels
  - Informational
  - Experimental
  - Historic
- Informational status: entry status for any proposal...

Gli standard di Internet

- Gli standard di Internet sono documenti pubblici denominati RFC (Request For Comments)
- L'organismo che coordina la stesura degli RFC è l'IETF (Internet Engineering Task Force)



Internet Documents

- RFC - Request For Comments
  - RFC3000 in Nov 2000
  - Updated RFCs published with new numbers
  - Not all describe protocols
  - Not all used!
- BCP - Best Current Practice
- FYI - For Your Information
  - RFC subseries: FYI = no protocol specs (es. RFC1718: the Tao of the Internet)
- STD - STanDard
  - official Internet Standard

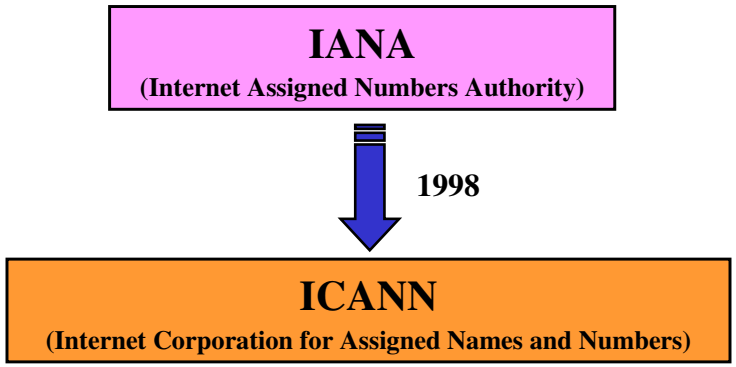
Important Documents

all RFCs from ftp://ds.internic.net/rfc
RFCs + IDs + WG: http://www.ietf.org

- RFC2300 (STD0001): Internet Official Protocol Standards
- RFC1340 (STD0002): Assigned Numbers
- RFC1122 + RFC1123 (STD0003) Requirement for Internet hosts - communication layer (1122), Application and support (1123)

Indirizzi e nomi

- Gli indirizzi IP sono assegnati su base globale
- Internet fa uso anche di nomi simbolici che sono anch'essi assegnati su base globale



What was the Internet
(for the mass-media, a couple of years ago)

- Internet synonimous of WWW (**W**orld **W**ide **W**eb) sites & pages:
  - millions of documents
  - Spreaded worldwide
  - mostly written in **HTML** language (*HyperText Markup Language*)
  - mostly accessible via the **HTTP** protocol (*HyperText Transfer Protocol*)

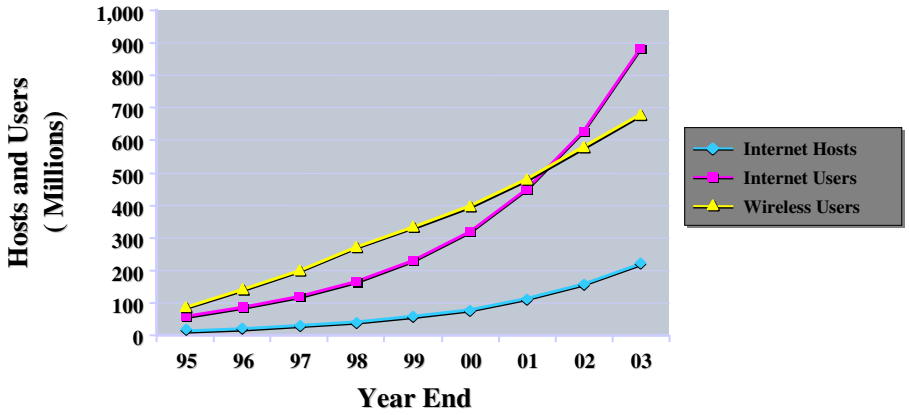
What was the Internet
(for the scientist in the 80s)

- Internet synonimous of FTP (**F**ile **T**ransfer **P**rotocol) and e-mail:
  - Scientists were the only ones having a presence on the Internet (unix logins)
    - contacts via email, talk program
  - Research documents archived in FTP sites
    - accessible via FTP, gopher
  - Scientific (and cultural) forums: Usenet news

What is the internet
(for the mass media, today)

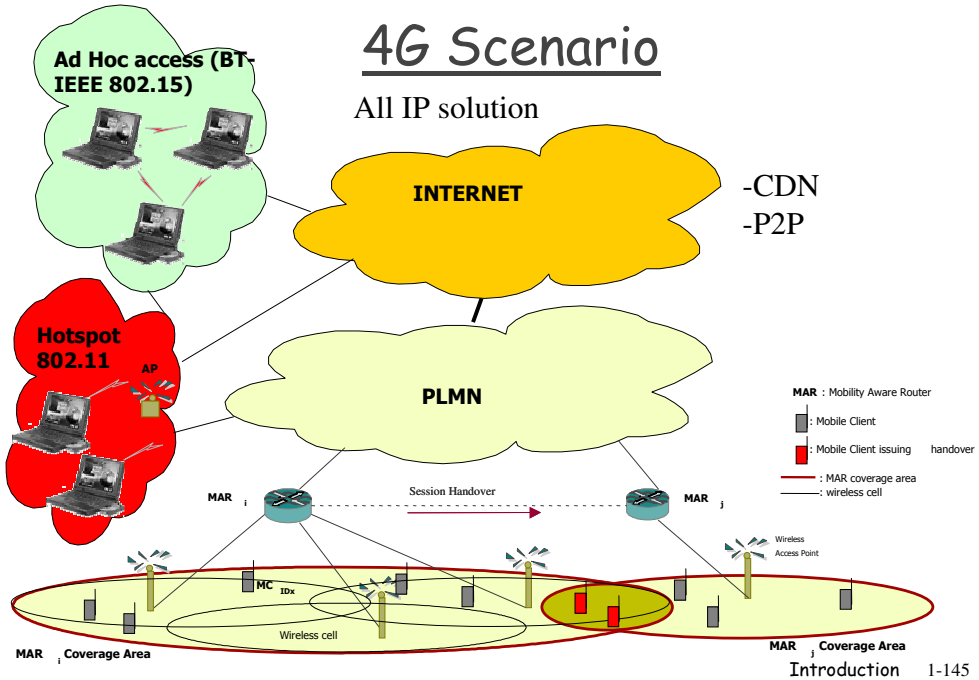
- Huge marketplace for e-business
  - B2B and B2C portals with full-fledged transaction capabilities
- Virtual communities
  - Chat & messaging
  - Peer to peer applications
- Communication network
  - IP Telephony / Multimedia commun.

Wireless Users and Internet Hosts and Users Growth
World, 1998 projections



4G Scenario

All IP solution



What is the Internet (For networking experts: We!)

1. A worldwide computer network
   - Connecting end-systems (host, servers)
   - Each uniquely identified by a numeric address (IP address)
2. the world wide group of networks combined with TCP/IP
   - TCP/IP synonimous of the entire suite of networking protocols.
     - The name comes from the two most important:
       - TCP = Transmission Control Protocol
       - IP = Internet Protocol
3. A packet switching network

Internet and Intranets

- Internet is an interconnection of public networks based on the TCP/IP technology
  - everyone establishing a connection with an Internet Service Provider can access it
- The TCP/IP technology is used more and more often as the technology to build private networks (Intranets)
  - access controlled and restricted
  - may not have any Internet access
  - since nodes of the Intranets cannot be accessed from the outside world local addresses are used (and the same address can be re-used in different Intranets)

Introduction: Summary

Covered a "ton" of material!

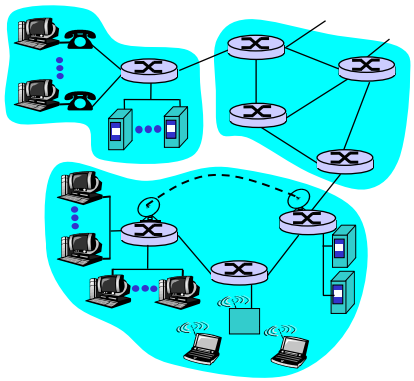
- Internet overview
- what's a protocol?
- network edge, core, access network
  - packet-switching versus circuit-switching
- Internet/ISP structure
- performance: loss, delay
- layering and service models
- history

You now have:

- context, overview, "feel" of networking
- more depth, detail *to follow!*

A closer look at network structure:

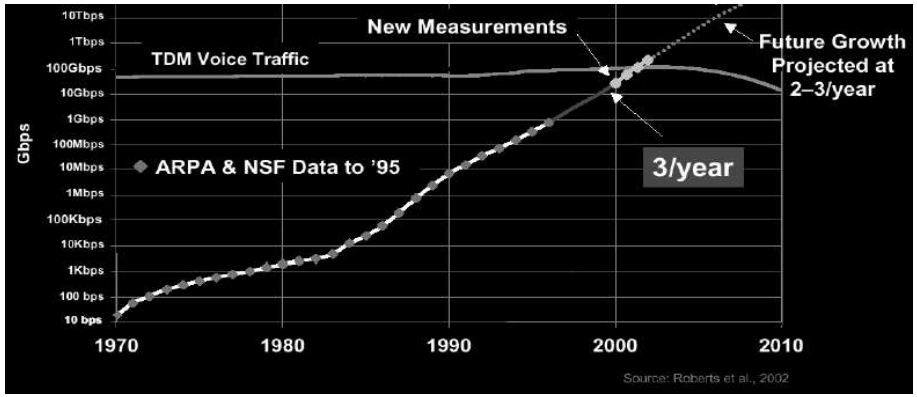
- network edge:
  applications and hosts
- network core:
  - routers
  - network of networks
- access networks, physical media:
  communication links



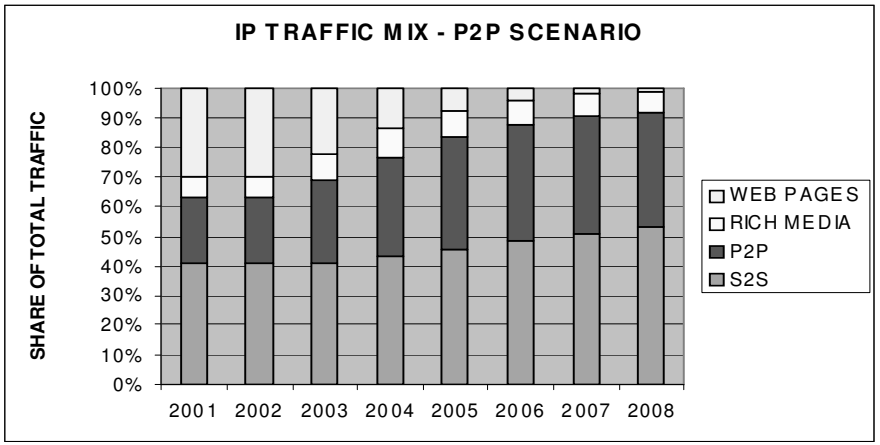
Internet Administration

- DDN (USA Defense Data Network): government organization with overall responsibility of administrating the Internet:
  - DDN NIC (Network Information Center):
    - assigns unique names & addresses
    - collects & distributes information about TCP/IP protocols
  - IANA (Internet Assigned Numbers Authority):
    - assigns value for network parameters, name of services, identifiers
  - NOC (Network Operation Center)
    - manages communication links

Recent traffic growth measurements

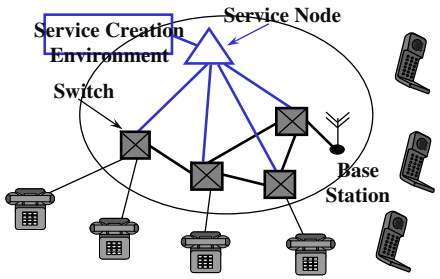


Traffic share - projections



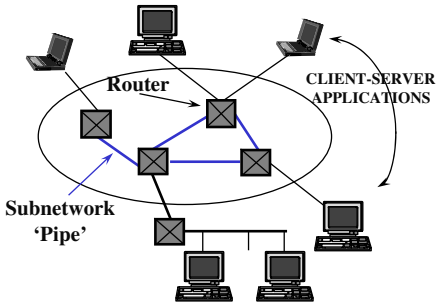
Telecom vs Internet Intelligence

A major motivation for Internet success



Telephony Service Control Architecture

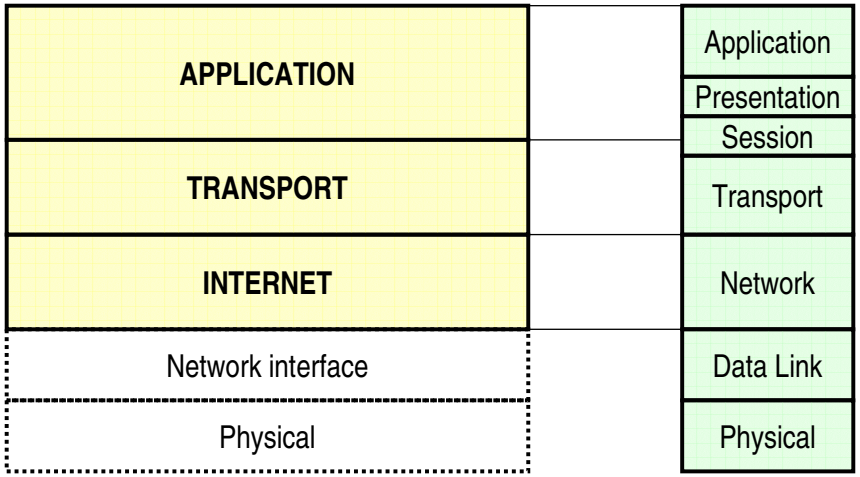
Network provides Intelligence
Proprietary API



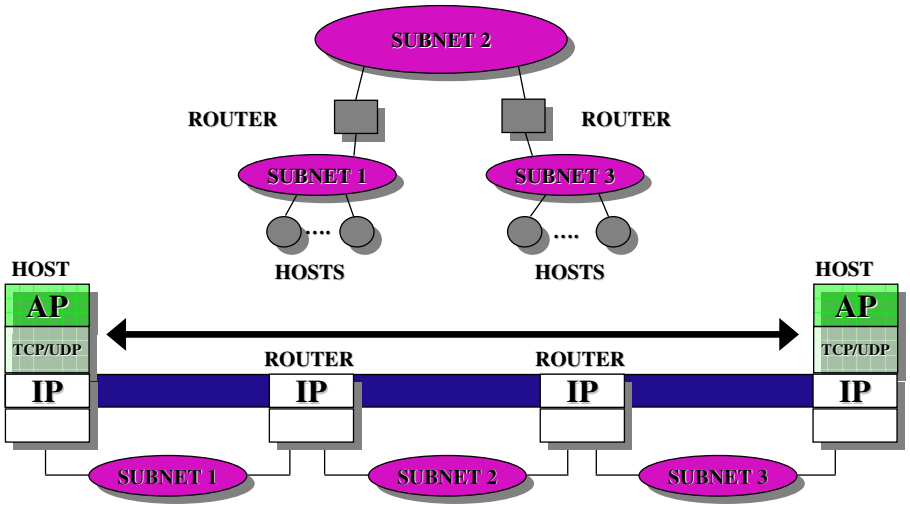
Internet Network Architecture

Intelligence at the Edge:
Network only provides "bearer services"
Open API

TCP/IP protocol layers
and relationship with OSI



Architecture and layers



TCP/IP basic protocol stack