

Reti di Elaboratori

Corso di Laurea in Informatica
Università degli Studi di Roma “La Sapienza”
Canale A-L
Prof.ssa Chiara Petrioli

Parte di queste slide sono state prese dal materiale associato al libro
Computer Networking: A Top Down Approach, 5th edition.

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Thanks also to Antonio Capone, Politecnico di Milano, Giuseppe Bianchi and
Francesco LoPresti, Un. di Roma Tor Vergata

Info Utili: I docenti

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Campo di ricerca del docente: reti, con focus su reti wireless, Internet of Things ma anche QoS per Internet, Content Delivery Networks,...

Pagina web del gruppo di ricerca (SENSES lab):
senseslab.di.uniroma1.it

Info Utili: I docenti

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Dipartimento di Informatica

E-mail:{caposese,divalerio}ATdi.uniroma1.it

Divisione del corso verticale (per argomenti –es. lezioni frontali fatte dal docente tranne lezioni su sicurezza informatica - Angelo Caposese; Esercitazioni su alcuni argomenti visti in classe: Valerio Di Valerio; Lab GENI: Caposese e Di Valerio)

Materiale Didattico

Libro consigliato: *Computer Networking: A Top Down Approach*, 5th edition (or more recent). Jim Kurose, Keith Ross, Addison-Wesley, April 2009.

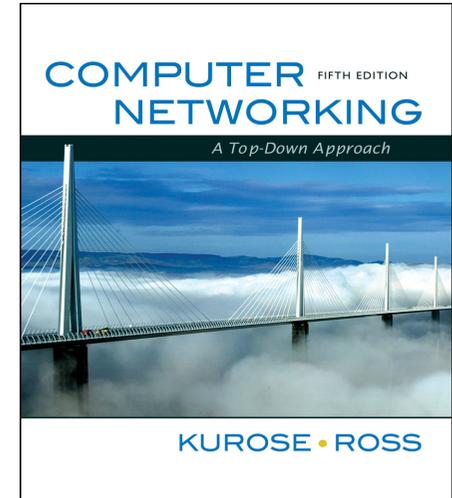
http://www.aw-bc.com/kurose_ross/

Versione italiana: Reti di calcolatori e internet. Un approccio top-down, James Kuros and Keith Ross, Pearson.

Altro materiale didattico (sul sito del corso): slide, articoli, RFC, riferimenti ad altri libri da usare per consultazione o per approfondire specifici argomenti.

Web page del corso: twiki.dsi.uniroma1.it → Reti degli elaboratori → Canale A-L

Orario di ricevimento: su appuntamento (per e-mail).



Modalità d'esame

- Scritto con domande aperte
 - Esonero nella settimana di interruzione dalla didattica (la data deve essere ancora comunicata dalla segreteria)
 - Si mantiene il voto per tutto l'anno accademico (e non oltre). Gli esonerati possono fare uno scritto solo sulla seconda parte del programma in tutti gli appelli di esame.
- Possibile orale per il 30/30 e lode con votazione maggiore o uguale a 28/30 allo scritto
 - o sul programma
 - o su approfondimenti concordati
- Consigliato seguire

Scopo del corso

INTERNET

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



Scopo del corso

Noi ci occuperemo:

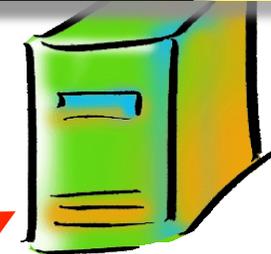
- ◆ **Dei protocolli usati per i colloqui a tutti i livelli**
- ◆ **Delle infrastrutture di rete necessarie al funzionamento di INTERNET**

ete
OS) e
a

usano una rete:
INTERNET



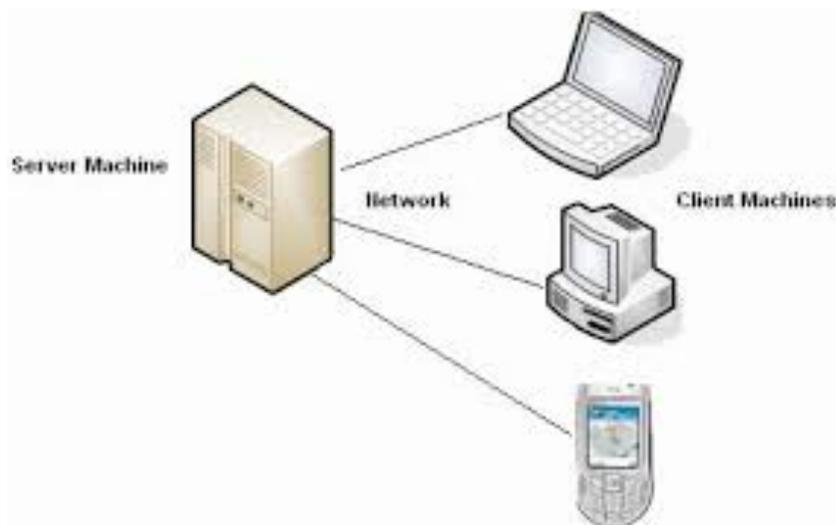
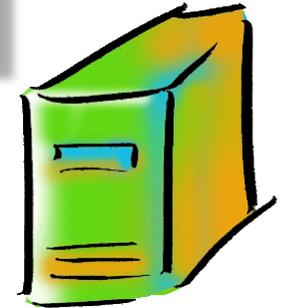
Molti software applicativi colloquiano con software remoti



I colloqui sono soggetti a regole (protocolli)

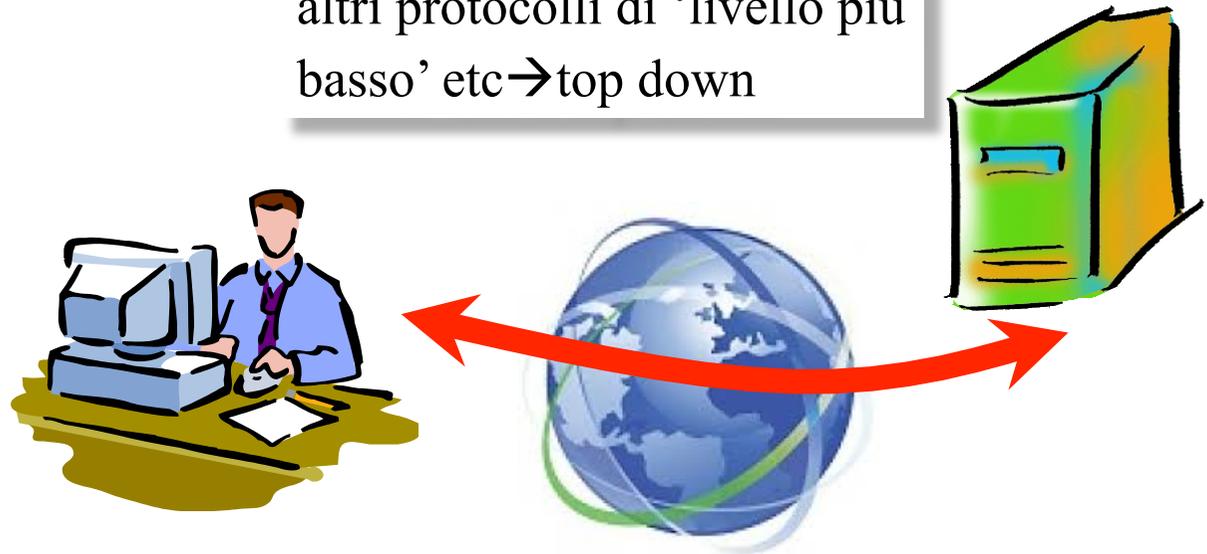
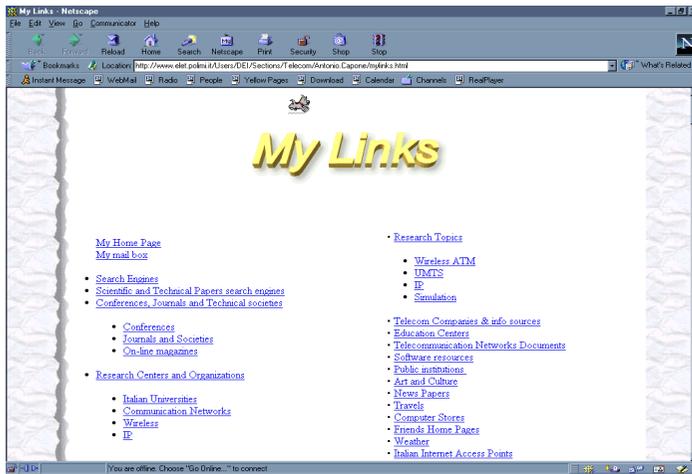
Perché top-down

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 capitoli del Kurose-Ross. Dalle applicazione alla trasmissione dei segnali sul canale fisico
- Simulazione di rete: una introduzione + Finestre su argomenti collegati (Mobile networks, Smart Cities, Cloud)
- Lab GENI per poter sperimentare sul campo il perché delle soluzioni attualmente in uso e le idee alla base della futura evoluzione di Internet
- Primo corso (sul quale è costruito un percorso formativo):
 - Pochissimo sul livello fisico
 - Descrizione dell'architettura TCP/IP classica → con alcune finestre su argomenti più avanzati o l'attuale evoluzione
 - Reti wireless, radio mobili e Sicurezza: solo alcune lezioni in questo corso. Sono aspetti estensivamente trattati in altri corsi (indirizzo Reti e Sicurezza), soprattutto alla specialistica.

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

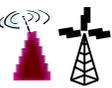
1.5 Internet structure and ISPs

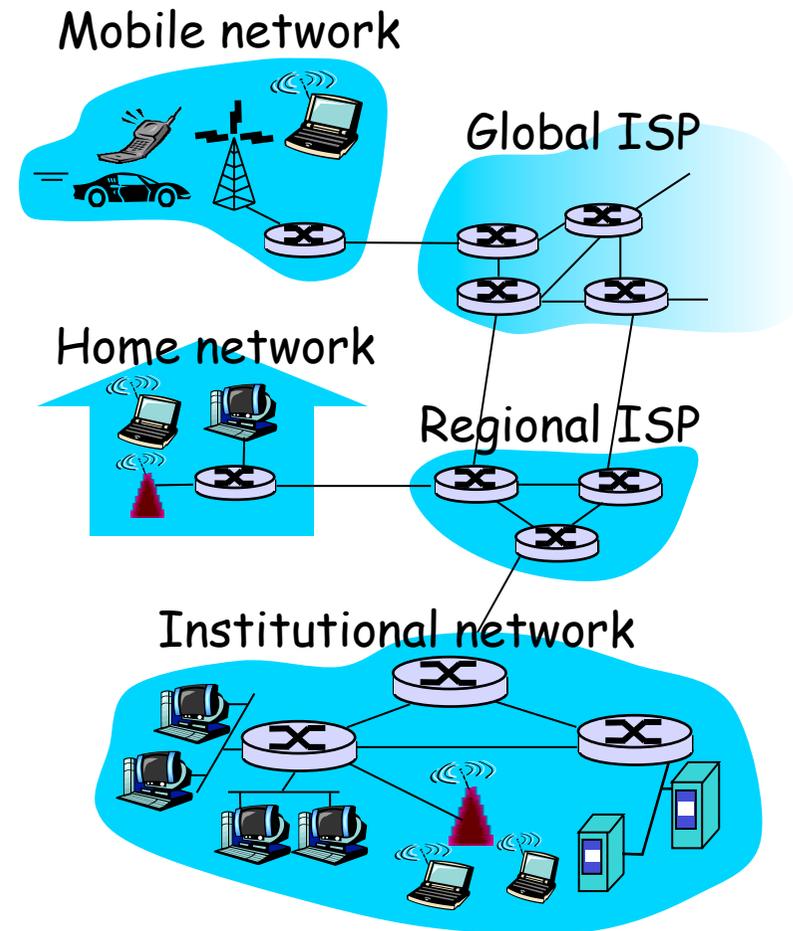
1.6 Delay & loss in packet-switched networks

1.7 Protocol layers, service models

1.8 History

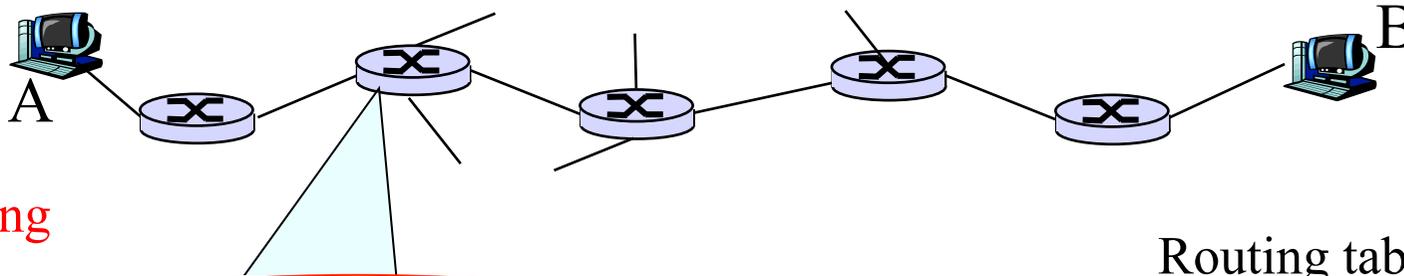
What's the Internet: "nuts and bolts" view

-  PC
 -  server
 -  wireless laptop
 -  cellular handheld
 -  access points
 -  wired links
 -  router
- 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)



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)



- 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

“Cool” internet appliances



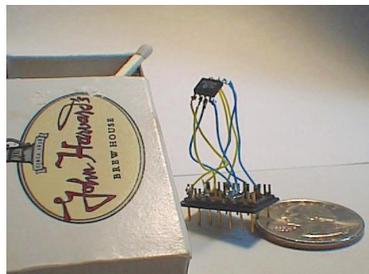
IP picture frame
<http://www.ceiva.com/>



Web-enabled toaster +
weather forecaster



Internet TV



World's smallest web server



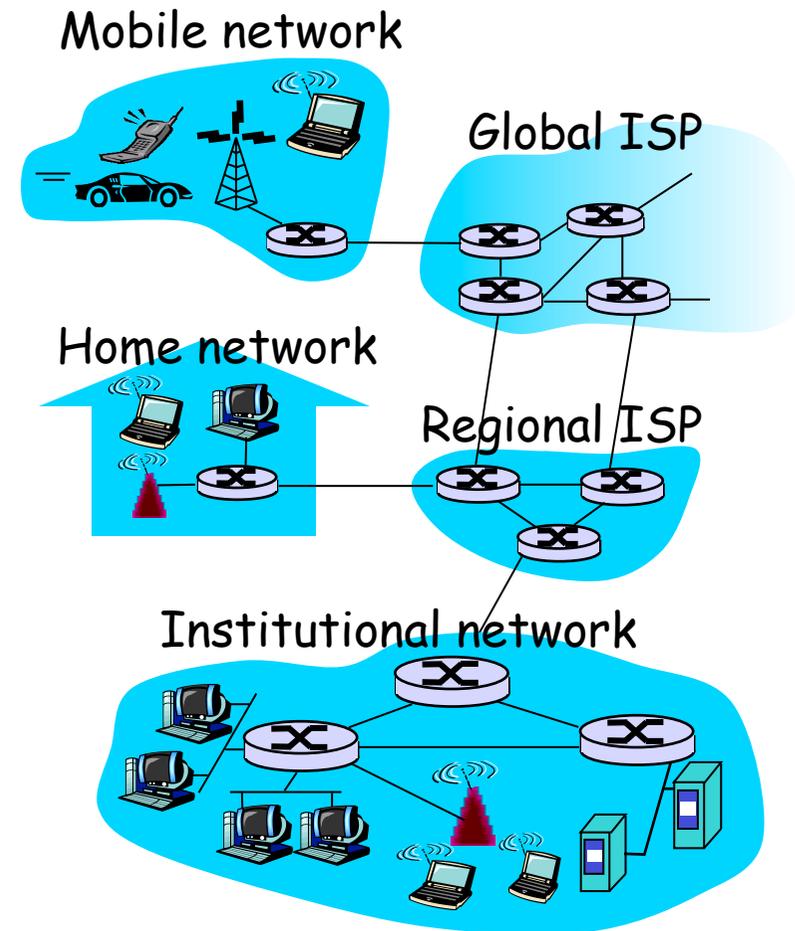
Internet of Things

Wearable computing

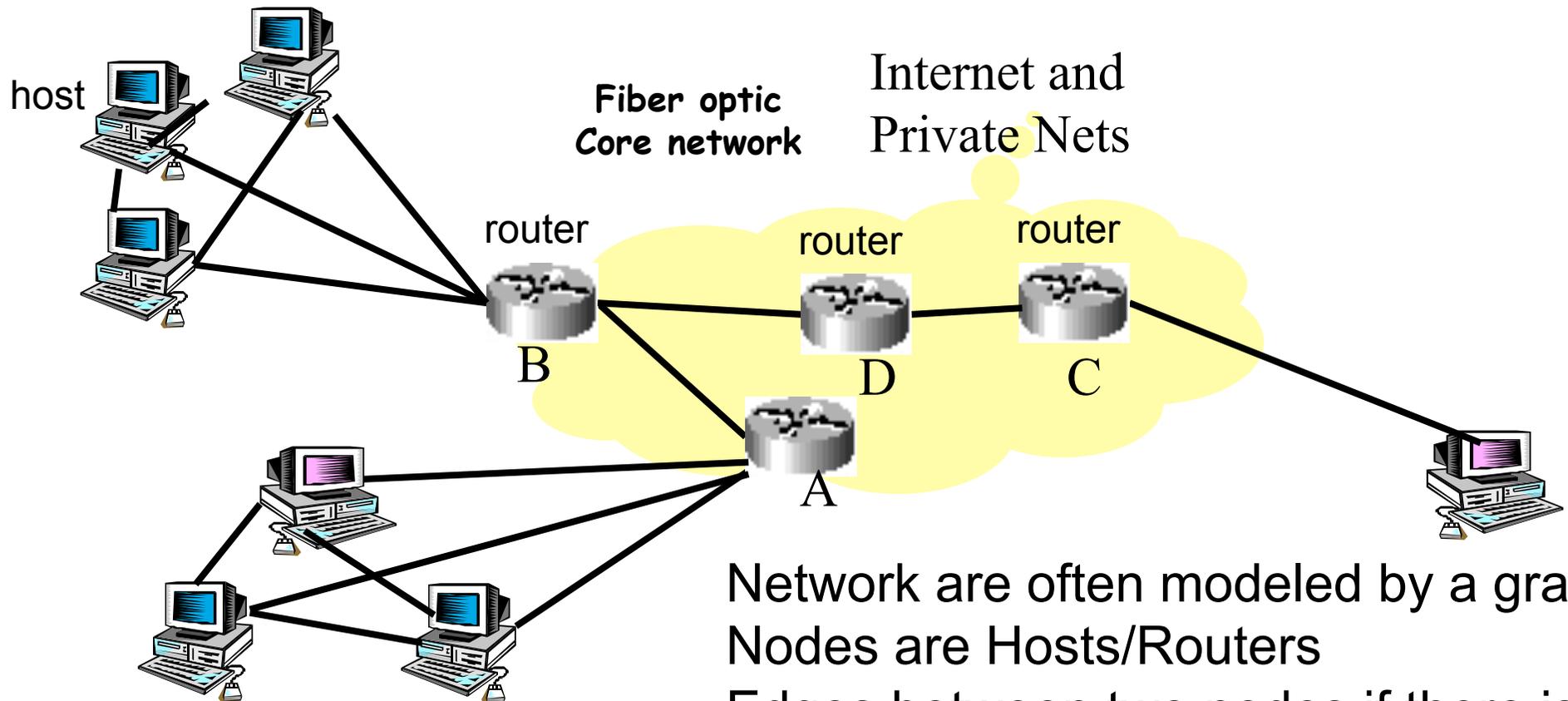


What's the Internet: "nuts and bolts" view

- *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



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



Host = 1 interface
Router = 2+ interfaces

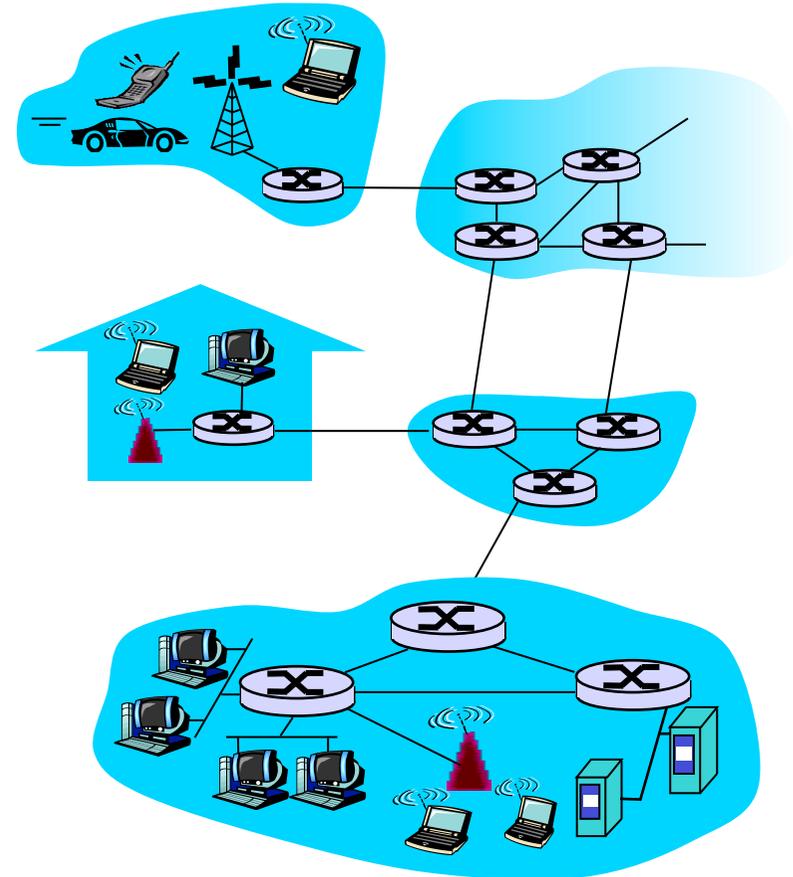
Network are often modeled by a graph
Nodes are Hosts/Routers
Edges between two nodes if there is a communication link between them
→ **Network Physical topology**

Rete logica e rete fisica

- ❑ Topologia fisica della rete
 - Un elemento di rete = un nodo
 - Esiste un arco tra due entità che sono collegate da un mezzo trasmissivo
- ❑ Topologia logica della rete
 - Un arco esprime un percorso diretto che l'informazione può seguire tra host ed un elemento di commutazione, o tra due elementi di commutazione
 - Nodo = elemento di commutazione, host

What's the Internet: a service view

- **communication *infrastructure***
enables distributed applications:
 - Web, VoIP, email, games, e-commerce, file sharing
- **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 msgs sent

... specific actions taken
when msgs received, or
other events

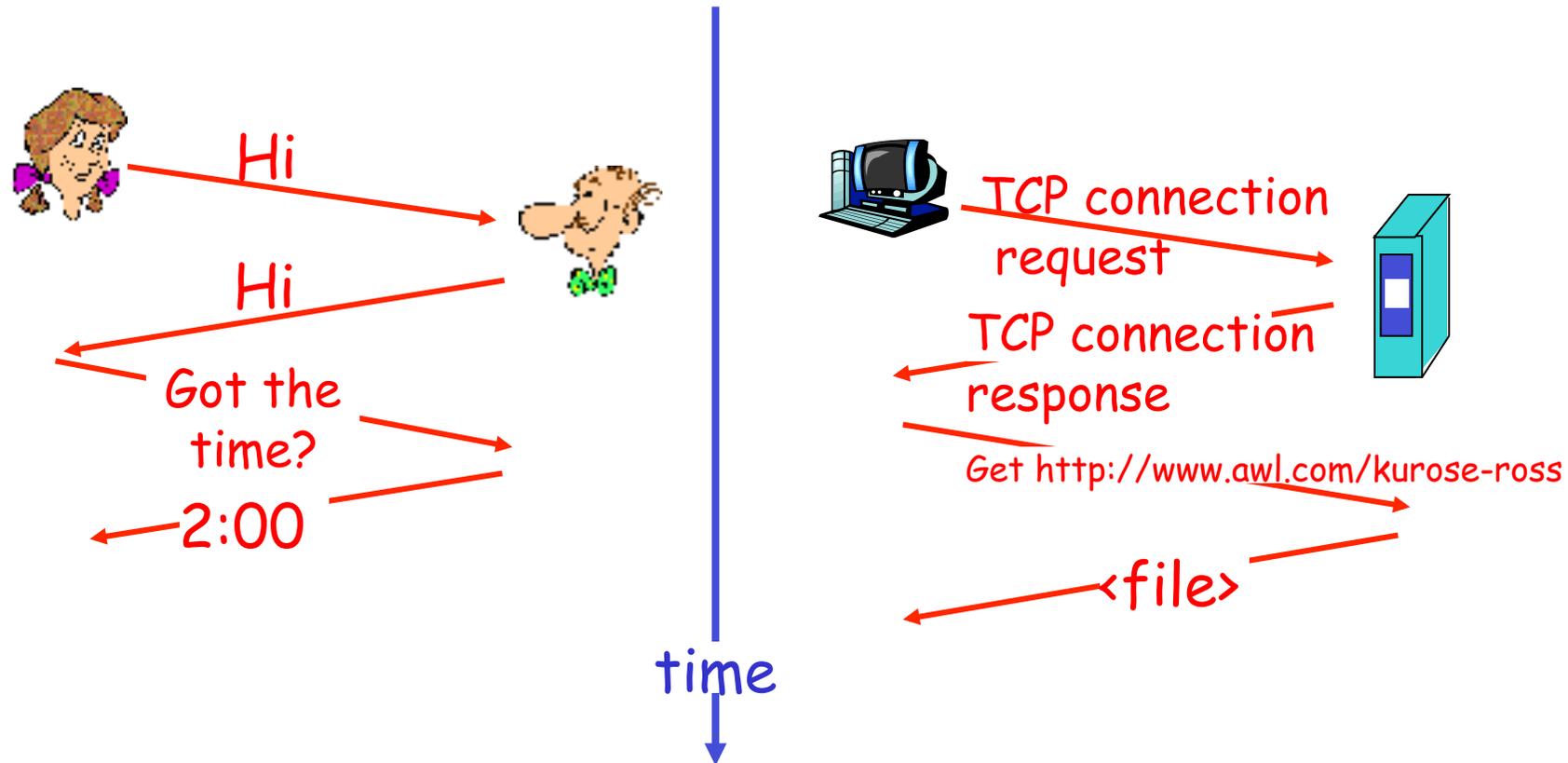
network protocols:

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

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

What's a protocol?

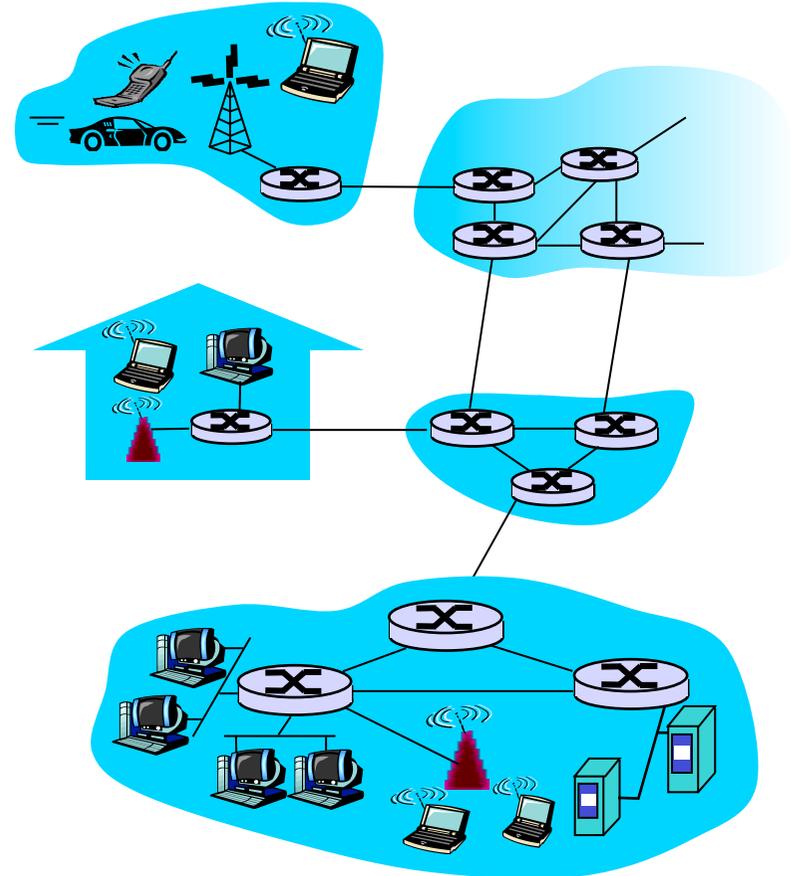
a human protocol and a computer network protocol:



Q: Other human protocols?

What's the Internet: a service view

- **communication *infrastructure***
enables distributed applications:
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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
(not in the network!!)
- ❑ 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

Chapter 1: roadmap

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

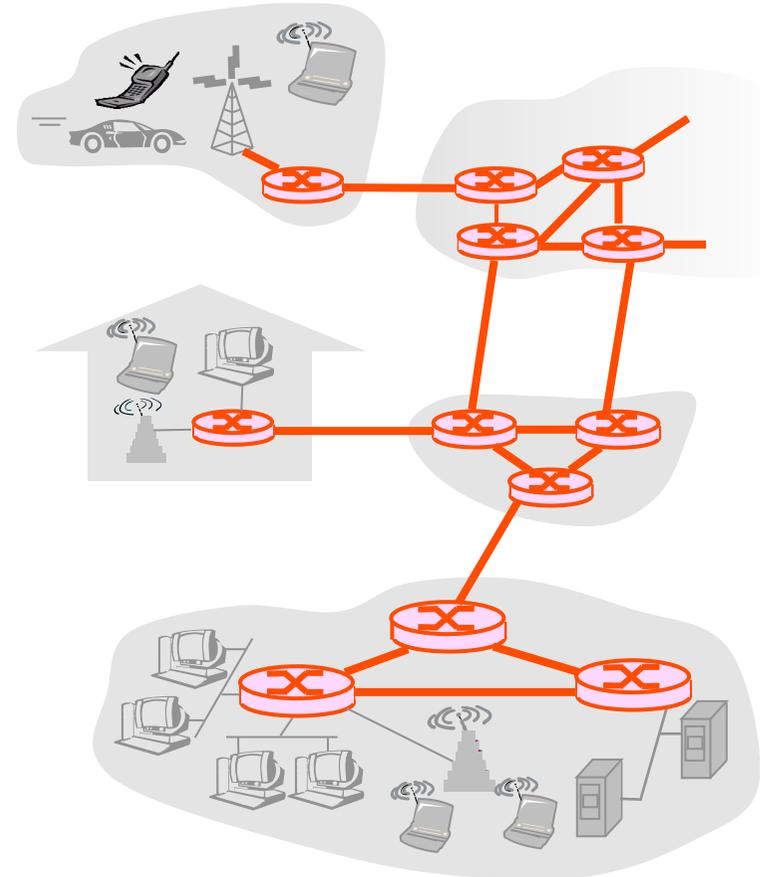
1.5 Protocol layers, service models

1.6 Networks under attack: security

1.7 History

The Network Core

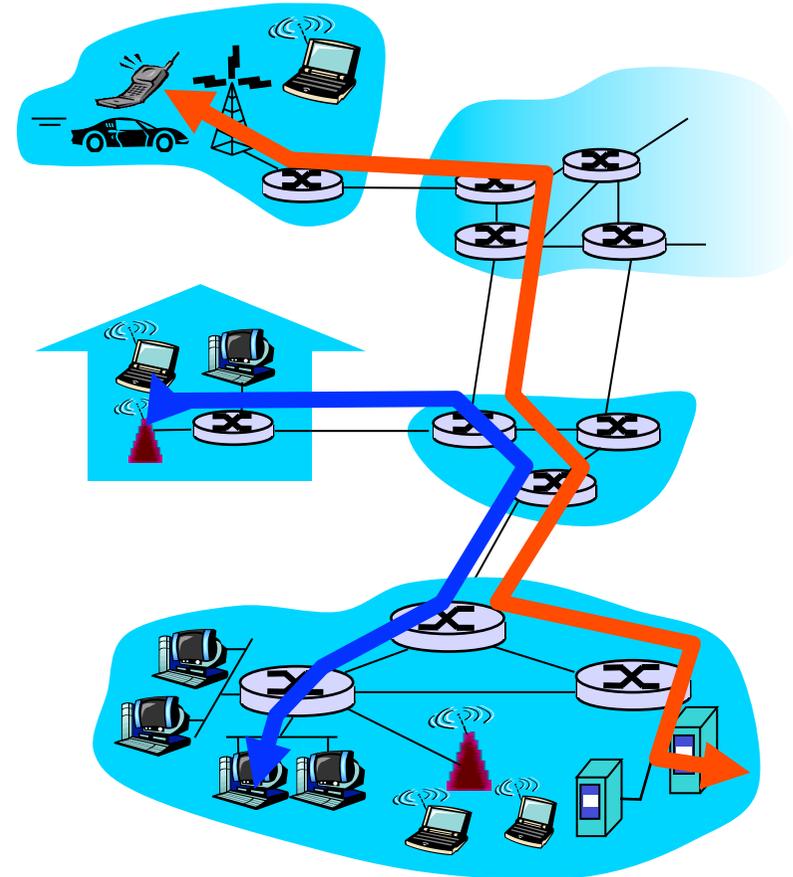
- ❑ mesh of interconnected routers
- ❑ ***the* fundamental question:** how is data transferred through net?
 - **circuit switching:** dedicated circuit per call: telephone net
 - **packet-switching:** data sent thru net in discrete “chunks”



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*)

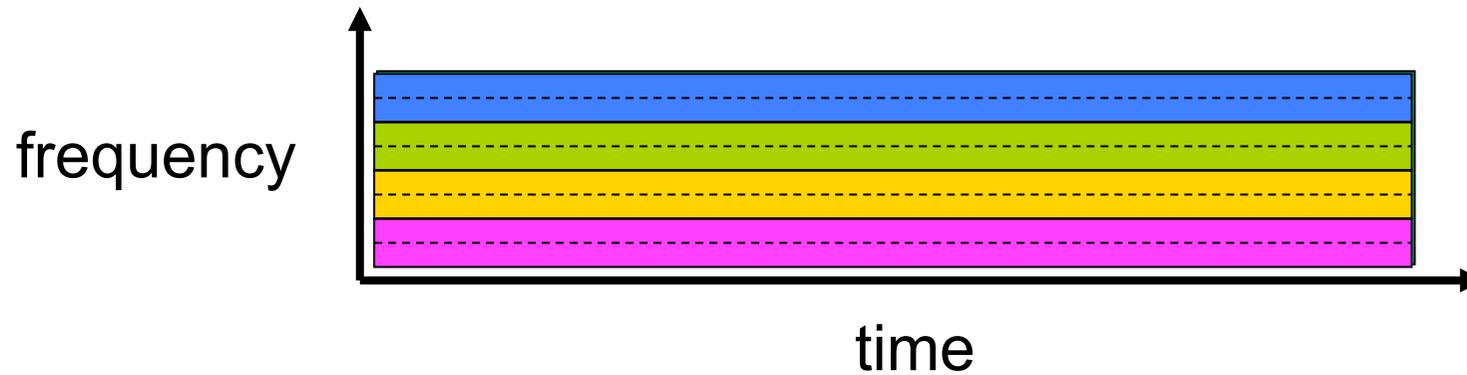
- dividing link bandwidth into “pieces”
 - ❖ frequency division
 - ❖ time division

Circuit Switching: FDM and TDM

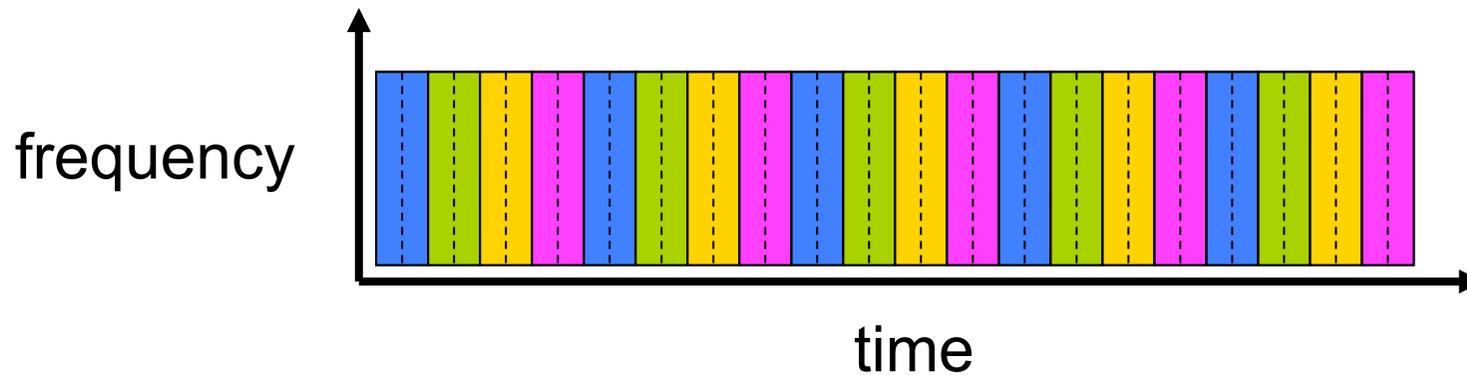
FDM

Example:

4 users



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/sec
 - 500 msec to establish end-to-end circuit

Let's work it out!

..Numerical example

- ❑ Each circuit has a transmission rate of $(1,536\text{Mbps})/24=64\text{Kbps}$
- ❑ $640000/64000=10\text{s}$
- ❑ Plus the circuit establishment $\rightarrow 10,5\text{s}$

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*

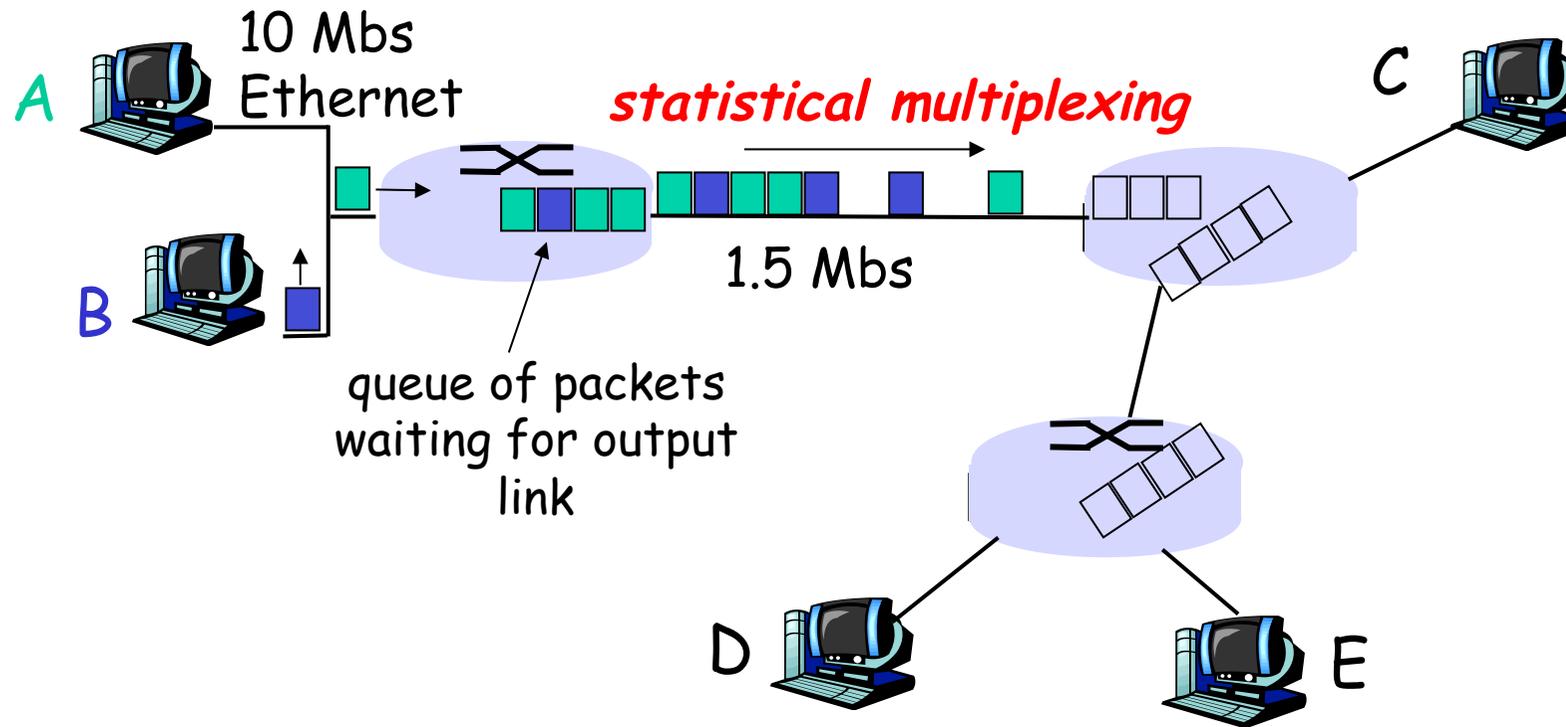
Bandwidth division into “pieces”
Dedicated allocation
Resource reservation



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

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.

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
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Bandwidth division into “pieces”

Dedicated allocation
Resource reservation



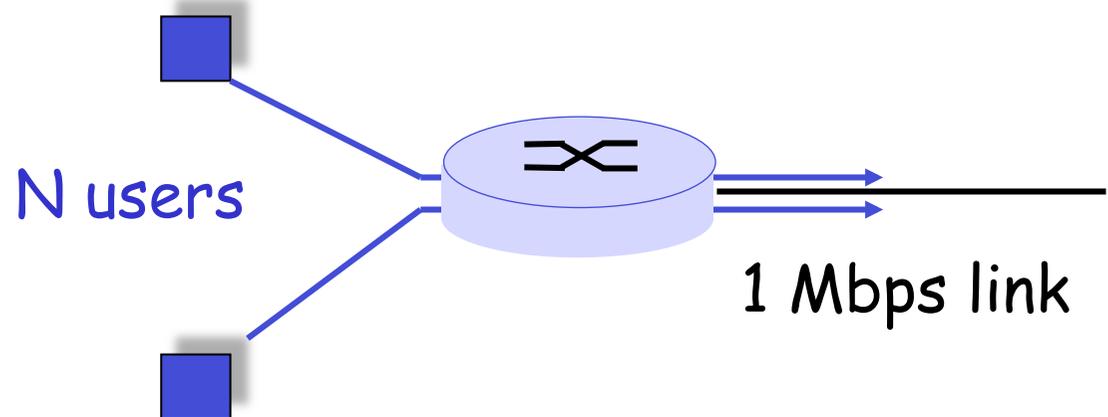
resource contention:

- ❑ aggregate resource demand can exceed amount available
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Packet switching versus circuit switching

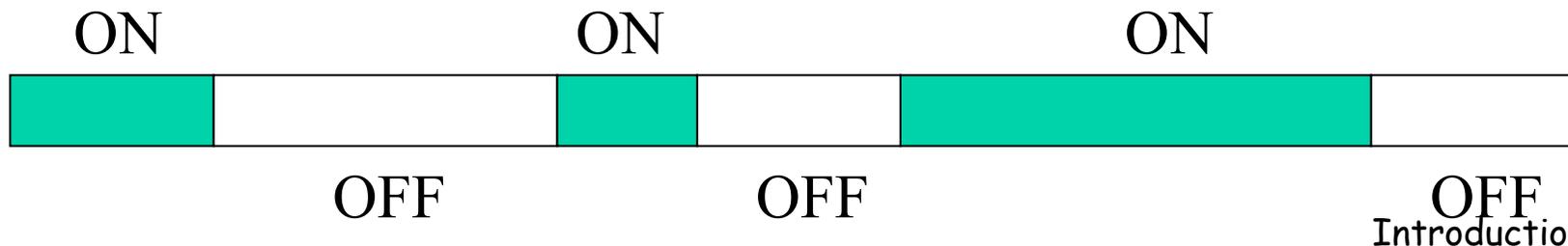
Packet switching allows more users to use network!

- ❑ 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 transmitted 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

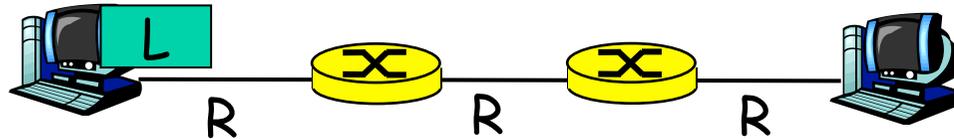
Is packet switching a “slam dunk winner?”

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

Packet switching

- ❑ Perché dividere i messaggi trasmessi dall'applicazione in pacchetti di dimensione limitata.
 - Nelle prossime slides pro e contro....

Packet-switching: store-and-forward

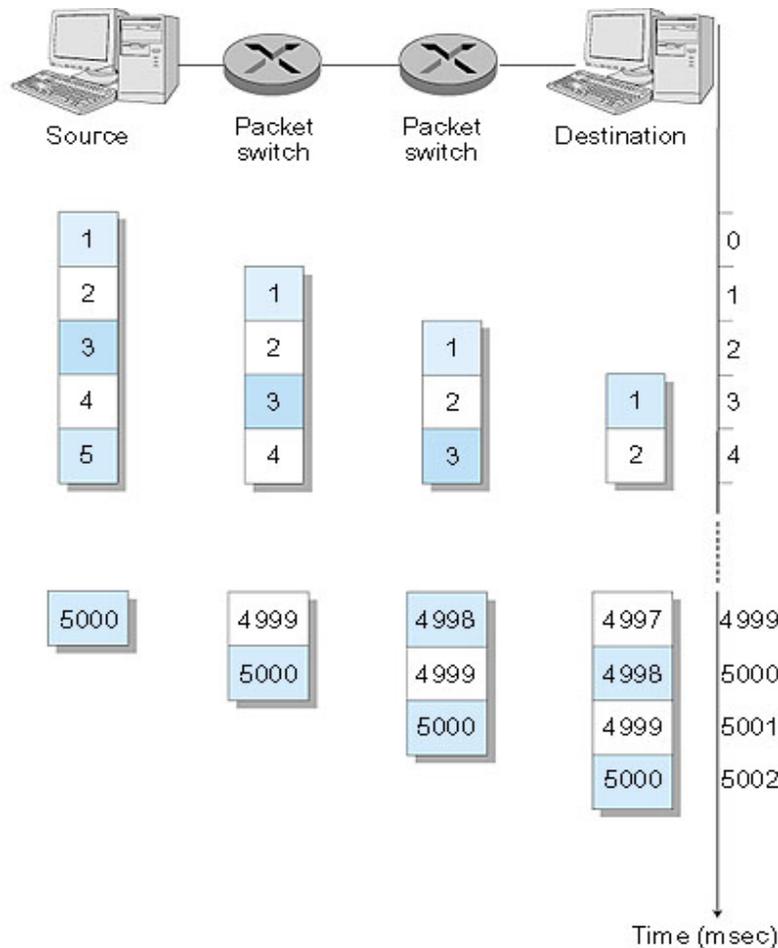


- ❑ Takes L/R seconds to transmit (push out) packet of L bits on to link or R bps
- ❑ Entire packet must arrive at router before it can be transmitted on next link:
store and forward
- ❑ delay = $3L/R$

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 5.003 sec

Message switching iff $\dim \text{pacchetti} = \dim. \text{messaggio originale applicativo}$

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
- ❑ Longer packets might decrease the parallelism of transmission

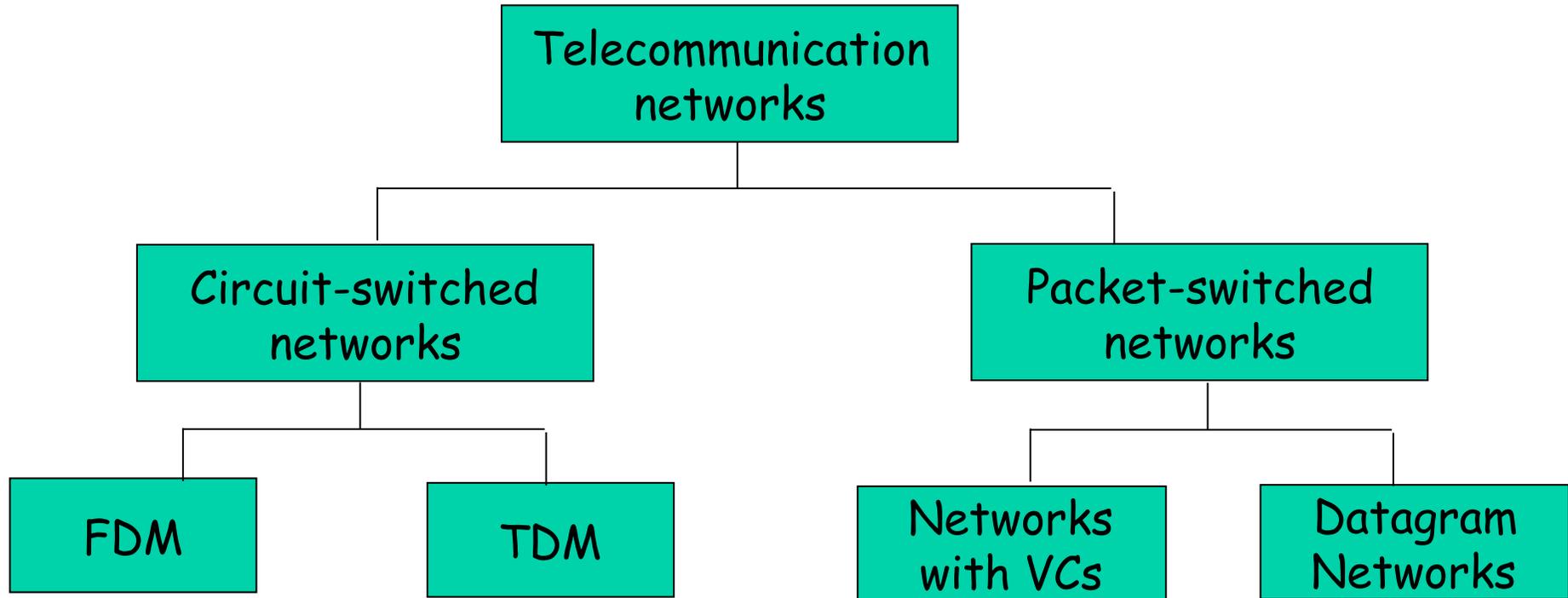
Packet-switched networks: forwarding

- ❑ **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)*
 - Virtual circuit number changes from hop to hop. Each router has to map incoming interface, incoming VC # in outgoing interface, outgoing VC #
 - Why? (what would be the size of the VC number field and the complexity of the VC number assignment in case the same VC # had to be used over the whole path??)

Internet
L3 protocol:
IP

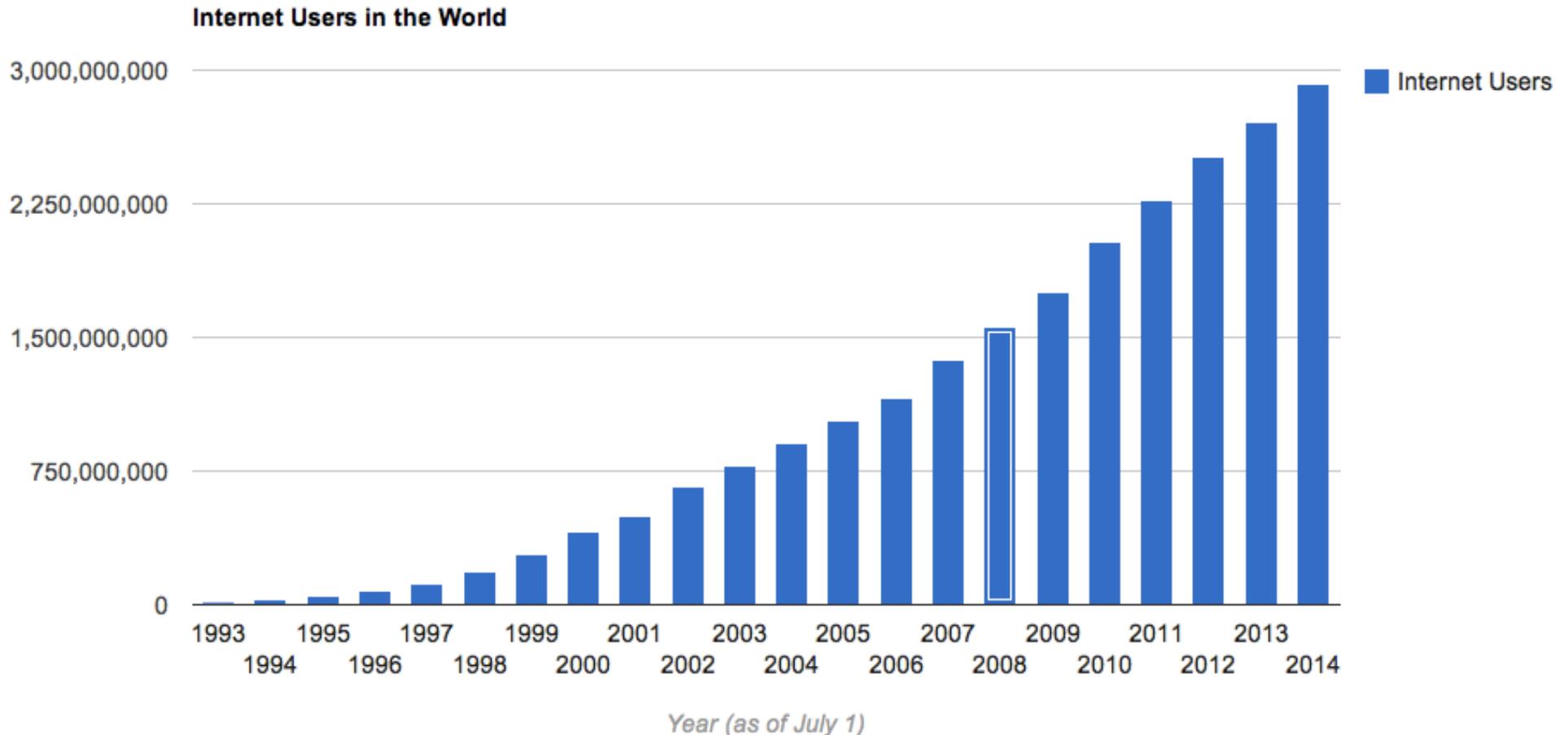
MPLS

Network Taxonomy

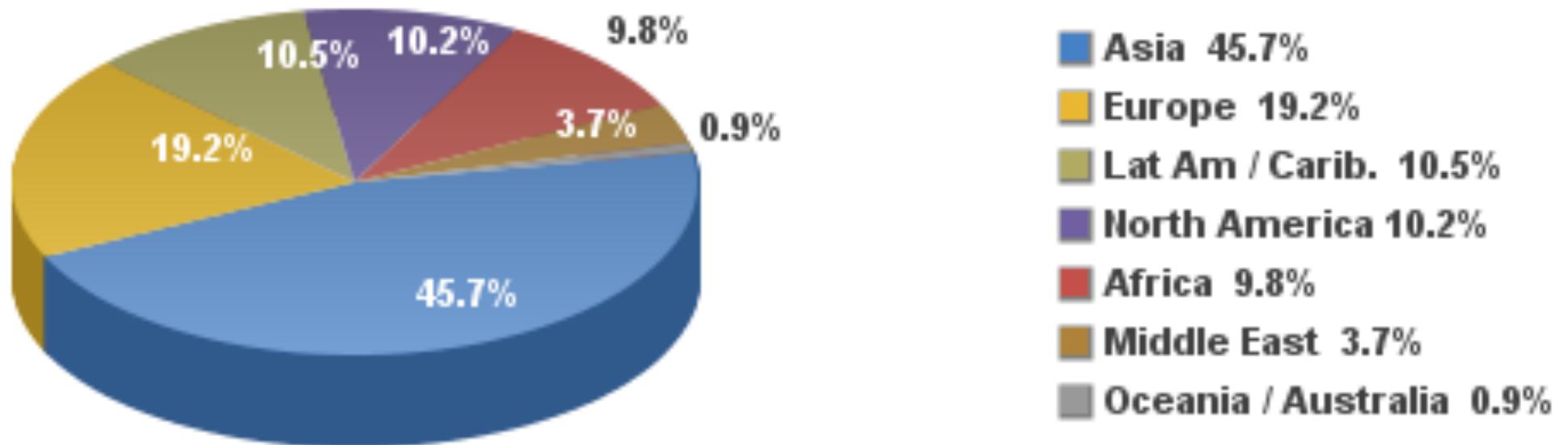


To conclude general introduction: Why is Internet So Important-- Some Statistics

Today: over 3 billions



Internet Users in the World Distribution by World Regions - 2014 Q2



Source: Internet World Stats - www.internetworldstats.com/stats.htm

Basis: 3,035,749,340 Internet users on June 30, 2014

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To conclude general introduction: Why is Internet So Important-- Some Statistics

List of Countries by Internet Usage (2014)

Show entries

Search:

Rank [▲]	Country	Internet Users	1 Year Growth %	1 Year User Growth	Total Country Population	1 Yr Population Change (%)	Penetration (% of Pop. with Internet)	Country's share of World Population	Country's share of World Internet Users
1	China	641,601,070	4%	24,021,070	1,393,783,836	0.59%	46.03%	19.24%	21.97%
2	United States	279,834,232	7%	17,754,869	322,583,006	0.79%	86.75%	4.45%	9.58%
3	India	243,198,922	14%	29,859,598	1,267,401,849	1.22%	19.19%	17.50%	8.33%
4	Japan	109,252,912	8%	7,668,535	126,999,808	-0.11%	86.03%	1.75%	3.74%
5	Brazil	107,822,831	7%	6,884,333	202,033,670	0.83%	53.37%	2.79%	3.69%
6	Russia	84,437,793	10%	7,494,536	142,467,651	-0.26%	59.27%	1.97%	2.89%
7	Germany	71,727,551	2%	1,525,829	82,652,256	-0.09%	86.78%	1.14%	2.46%
8	Nigeria	67,101,452	16%	9,365,590	178,516,904	2.82%	37.59%	2.46%	2.30%
9	United Kingdom	57,075,826	3%	1,574,653	63,489,234	0.56%	89.90%	0.88%	1.95%
10	France	55,429,382	3%	1,521,369	64,641,279	0.54%	85.75%	0.89%	1.90%

Showing 1 to 10 of 198 entries

Previous 2 3 4 5 ... 20 Next

To conclude general introduction: Why is Internet So Important-- Some Statistics

List of Countries by Internet Usage (2014)

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Rank	Country	Internet Users	1 Year Growth %	1 Year User Growth	Total Country Population	1 Yr Population Change (%)	Penetration (% of Pop. with Internet)	Country's share of World Population	Country's share of World Internet Users
11	Mexico	50,923,060	7%	3,423,153	123,799,215	1.20%	41.13%	1.71%	1.74%
12	South Korea	45,314,248	8%	3,440,213	49,512,026	0.51%	91.52%	0.68%	1.55%
13	Indonesia	42,258,824	9%	3,468,057	252,812,245	1.18%	16.72%	3.49%	1.45%
14	Egypt	40,311,562	10%	3,748,271	83,386,739	1.62%	48.34%	1.15%	1.38%
15	Viet Nam	39,772,424	9%	3,180,007	92,547,959	0.95%	42.97%	1.28%	1.36%
16	Philippines	39,470,845	10%	3,435,654	100,096,496	1.73%	39.43%	1.38%	1.35%
17	Italy	36,593,969	2%	857,489	61,070,224	0.13%	59.92%	0.84%	1.25%
18	Turkey	35,358,888	3%	1,195,610	75,837,020	1.21%	46.62%	1.05%	1.21%
19	Spain	35,010,273	3%	876,986	47,066,402	0.30%	74.38%	0.65%	1.20%
20	Canada	33,000,381	7%	2,150,061	35,524,732	0.98%	92.89%	0.49%	1.13%

Showing 11 to 20 of 198 entries

Previous 1 **2** 3 4 5 ... 20 Next

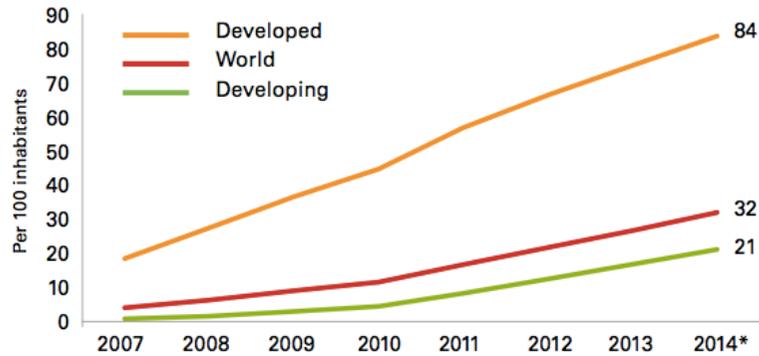
Some Statistics

WORLD INTERNET USAGE AND POPULATION STATISTICS JUNE 30, 2014 - Mid-Year Update						
World Regions	Population (2014 Est.)	Internet Users Dec. 31, 2000	Internet Users Latest Data	Penetration (% Population)	Growth 2000-2014	Users % of Table
<u>Africa</u>	1,125,721,038	4,514,400	297,885,898	26.5 %	6,498.6 %	9.8 %
<u>Asia</u>	3,996,408,007	114,304,000	1,386,188,112	34.7 %	1,112.7 %	45.7 %
<u>Europe</u>	825,824,883	105,096,093	582,441,059	70.5 %	454.2 %	19.2 %
<u>Middle East</u>	231,588,580	3,284,800	111,809,510	48.3 %	3,303.8 %	3.7 %
<u>North America</u>	353,860,227	108,096,800	310,322,257	87.7 %	187.1 %	10.2 %
<u>Latin America / Caribbean</u>	612,279,181	18,068,919	320,312,562	52.3 %	1,672.7 %	10.5 %
<u>Oceania / Australia</u>	36,724,649	7,620,480	26,789,942	72.9 %	251.6 %	0.9 %
<u>WORLD TOTAL</u>	7,182,406,565	360,985,492	3,035,749,340	42.3 %	741.0 %	100.0 %

NOTES: (1) Internet Usage and World Population Statistics are for June 30, 2014. (2) CLICK on each world region name for detailed regional usage information. (3) Demographic (Population) numbers are based on data from the [US Census Bureau](#) and local census agencies. (4) Internet usage information comes from data published by [Nielsen Online](#), by the [International Telecommunications Union](#), by [GfK](#), local ICT Regulators and other reliable sources. (5) For definitions, disclaimers, navigation help and methodology, please refer to the [Site Surfing Guide](#). (6) Information in this site may be cited, giving the due credit to [www.internetworldstats.com](#). Copyright © 2001 - 2014, Miniwatts Marketing Group. All rights reserved worldwide.

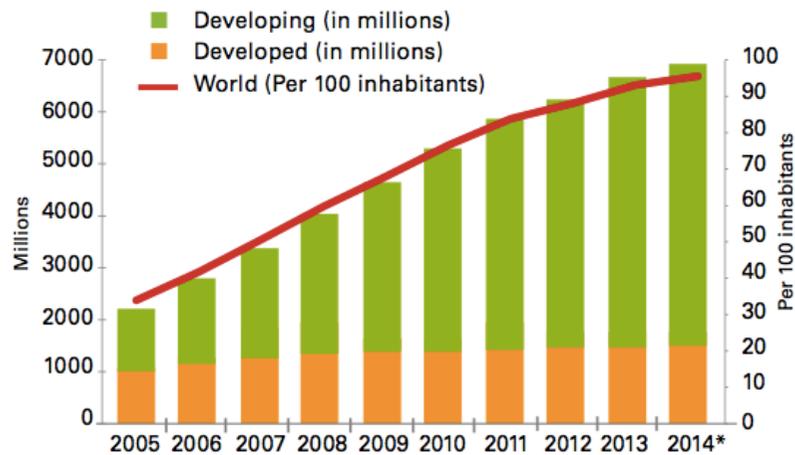
A changing Internet...

Active mobile broadband subscription



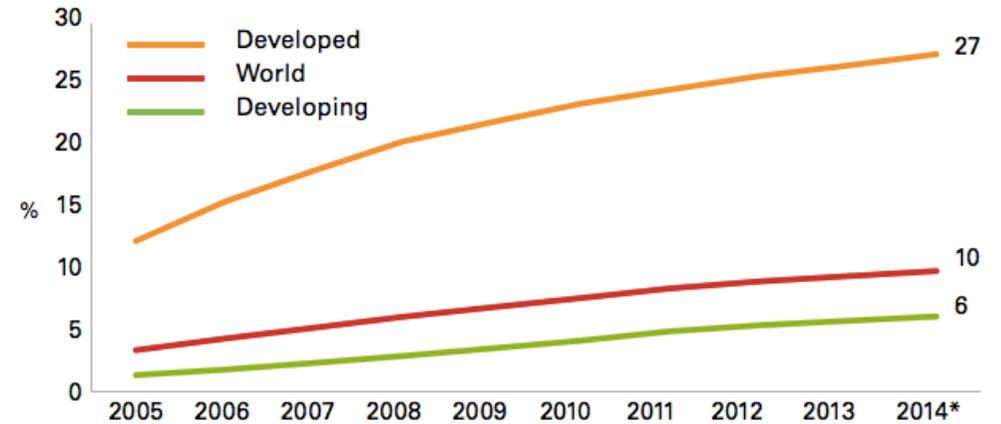
Note: * Estimate
Source: ITU World Telecommunication/ICT Indicators database

Mobile cellular subscription



Note: * Estimate
Source: ITU World Telecommunication/ICT Indicators database

Wired broadband subscription (for 100 users)



Note: * Estimate
Source: ITU World Telecommunication/ICT Indicators database

A changing Internet...

CISCO forecasting

IP Traffic, 2013–2018							
	2013	2014	2015	2016	2017	2018	CAGR 2013–2018
By Type (Petabytes [PB] per Month)							
Fixed Internet	34,952	42,119	50,504	60,540	72,557	86,409	20%
Managed IP	14,736	17,774	20,898	23,738	26,361	29,305	15%
Mobile data	1,480	2,582	4,337	6,981	10,788	15,838	61%
By Segment (PB per Month)							
Consumer	40,905	50,375	61,439	74,361	89,689	107,958	21%
Business	10,263	12,100	14,300	16,899	20,016	23,595	18%
By Geography (PB per Month)							
Asia Pacific	17,950	22,119	26,869	32,383	39,086	47,273	21%
North America	16,607	20,293	24,599	29,377	34,552	40,545	20%
Western Europe	8,396	9,739	11,336	13,443	16,051	19,257	18%
Central and Eastern Europe	3,654	4,416	5,443	6,666	8,332	10,223	23%
Latin America	3,488	4,361	5,318	6,363	7,576	8,931	21%
Middle East and Africa	1,074	1,546	2,174	3,027	4,108	5,324	38%
Total (PB per Month)							
Total IP traffic	51,168	62,476	75,739	91,260	109,705	131,553	21%

Source: Cisco VNI, 2014

A changing Internet...

CISCO forecasting

Table 10. Global Consumer Internet Traffic, 2013–2018

Consumer Internet Traffic, 2013–2018							
	2013	2014	2015	2016	2017	2018	CAGR 2013–2018
By Network (PB per Month)							
Fixed	27,882	33,782	40,640	48,861	58,703	70,070	20%
Mobile	1,189	2,102	3,563	5,774	8,968	13,228	62%
By Subsegment (PB per Month)							
Internet video	17,455	22,600	29,210	37,783	48,900	62,972	29%
Web, email, and data	5,505	6,706	8,150	9,913	11,827	13,430	20%
File sharing	6,085	6,548	6,803	6,875	6,856	6,784	2%
Online gaming	26	30	41	64	88	113	34%

Changes in trends:
Multimedia support
Network devices reconfigurability and virtualization
Cloud vs. Edge computing