

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

Docente responsabile del Corso:

Prof.ssa Chiara Petrioli

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E-mail:petrioli@di.uniroma1.it

Campo di ricerca del docente: networked systems, 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

Esercitatori: Gabriele Saturni, Christian Cardia, Georgia Koutsandria

Dipartimento di Informatica

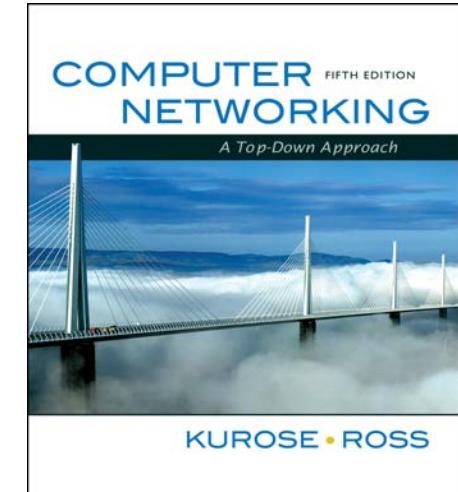
E-mail:{saturni,cardia,koutsandria}ATdi.uniroma1.it

Divisione del corso verticale (per argomenti –es. lezioni frontali fatte dal docente tranne alcune lezioni su specifici argomenti+esercitazioni,introduzione al C-Saturni,Cardia, Koutsandria)

Materiale Didattico

Libro consigliato: *Computer Networking: A Top Down Approach*, 7th edition 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 Kurose 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).

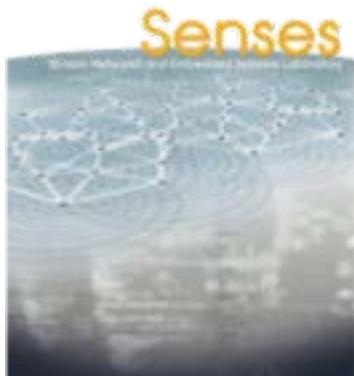
Modalità d'esame

- 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.
 - Domande sulle esercitazioni incluse nell'esame
- Consigliato seguire

Chiara Petrioli



POLITECNICO
DI MILANO



A purple banner for the NT100 initiative. It features the text "100 The 2016 NT100 is here! The world's most inspiring examples of tech for good We have unveiled 100 global social tech projects changing lives in 2016. Explore the 2016 NT100 on our interactive map." To the right, a person wearing a striped shirt is shown working on a device.

L'Università – il vostro momento





Caratteristica di (quasi) tutti i collaboratori/studenti che hanno lavorato con me in questi 15 anni e che si sono molto specializzati/hanno lavorato sui loro talenti:
Stanno facendo esattamente quello che desideravano nella vita (augurio per voi!)

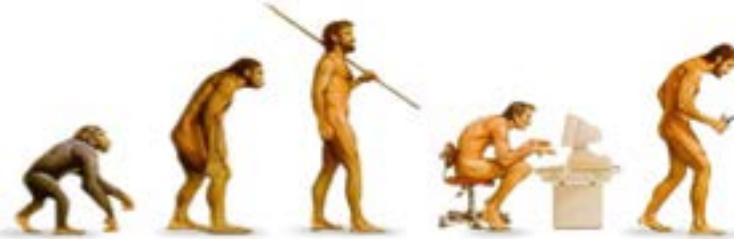


**Informatica
N.1 in Italia**

College experience



Facts on career development



Language Rank	Types	Spectrum Ranking
1. Python		100.0
2. C++		99.7
3. Java		97.5
4. C		96.7
5. C#		89.4
6. PHP		84.9
7. R		82.9
8. JavaScript		82.6
9. Go		76.4
10. Assembly		74.1

Perché proseguire (magistrale etc.)



Perché proseguire

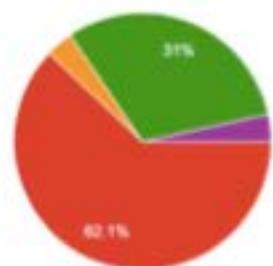


Perché proseguire

Our alumni are professors, researchers, senior engineers and managers in some of the most prestigious international academic Institutions, research centers and companies, including Google, Facebook, Microsoft, Amazon Lab, Digital Catapult, Telecom Paris Tech, NATO STO CMRE, Ericsson, INRIA, CNR, University of Padova, University of Rome La Sapienza, Università di Roma III, Missouri University of Science and Technology, Aalborg University, Cambridge University, UPC, IIT Bombay. Below the results of an anonymous questionnaire on job placement filled by our recent graduates (alumni graduated between two and eight years ago).

Job placement @PhD level– our alumni

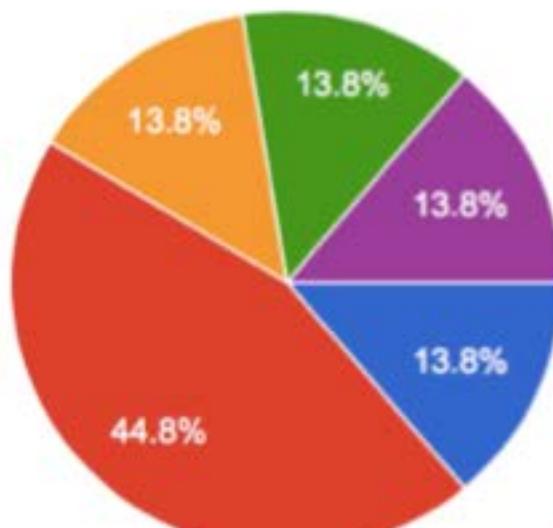
Current Work



- Self employed
- Employed by academia or research center
- Work in public administration
- Employed by a private company
- Entrepreneur
- Unemployed
- Other

Average time between end of the PhD and first job: two weeks

Monthly Net Salary



- <= 1500 €
- 1501 - 2500 €
- 2501 - 4000 €
- 4001 - 6000 €
- more than 6001 €

Data refer to students who got a PhD in CS @ our department in the last eight years

Perché proseguire



SENSES lab: IoT & Systems for Smarter City/Smarter Planet



Smart Cities



Smart Environment



Smart Water



Smart Metering



Security & Emergency



Retail



Logistics



Industrial Control



Smart Agriculture



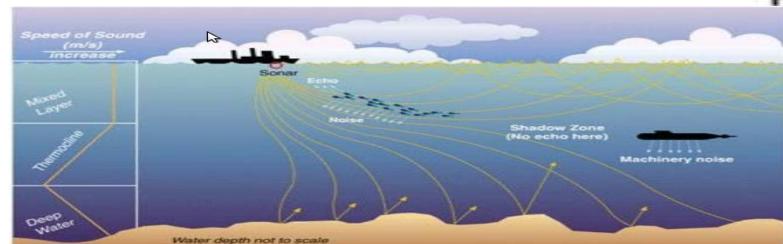
Smart Animal Farming



Domotic & Home Automation



eHealth



Underwater monitoring & control systems



Structural health monitoring

Cultural Heritage



College experience



+



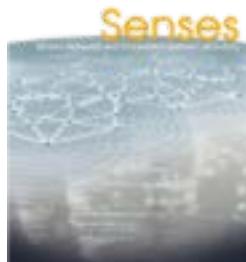
Collaborazione con lab scientifici
Seminari di esperti internazionali

Internship
Spinoff



Opportunità

<http://senseslab.di.uniroma1.it>



1. Internet&Networking seminars

2. Grant per iscrizioni per partecipare a conferenze



3. TIROCINI (Borse di studio per attività di ricerca durante la tesi alla magistrale)

www.wsense.it

4. Percorso di eccellenza

ANNO ACCADEMICO 2016-2017

- ▶ **Bando** per il corso di laurea in Informatica (Classe L-31).
▶ **Scadenza: 28 febbraio 2017**
- ▶ **Bando** per il corso di laurea magistrale in Informatica (Classe LM-18)
▶ **Scadenza: 28 febbraio 2017**

http://www.studiareinformatica.uniroma1.it/sites/default/files/L_31_Informatica.pdf

Opportunità



Association for
Computing Machinery

womENcourage 2019

ACM-W A small blue square icon with a white letter "P" inside.

HOME CALL FOR PARTICIPATION REGISTRATION PROGRAM VENUE INFORMATION SCHOLARSHIPS HACKATHON SUPPORTERS



[Home](#) > [Home](#)

womENcourage 2019 – “Diversity Drives Societal Change”

ACM Celebration of Women in Computing: womENcourage 2019
Rome, Italy, September 16 – 18, 2019

Design and development of embedded systems for the Internet of Things

Altamente consigliato: Sfruttate le occasioni per fare laboratori e progetti

Fabio Angeletti
Michele Martinelli



SAPIENZA
UNIVERSITÀ DI ROMA



W • SENSE
INTEGRATED CABLELESS SOLUTIONS

From makers boards to IoT



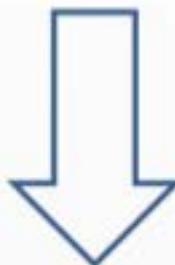
Arduino Duemilanove

- 16 MHz ATmega328 MCU
- 32KB flash, 2KB RAM



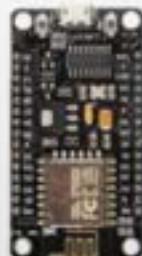
Nucleo-F401

- 84 MHz ARM 32-bit + FPU
- 512KB flash, 96KB RAM



ALEXA,
Turn ON/OFF the
light

ALEXA ECHO DOT



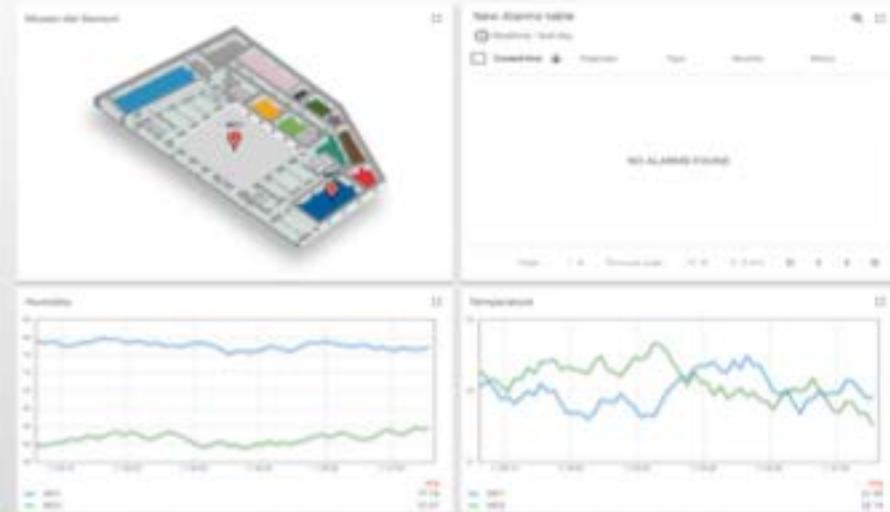
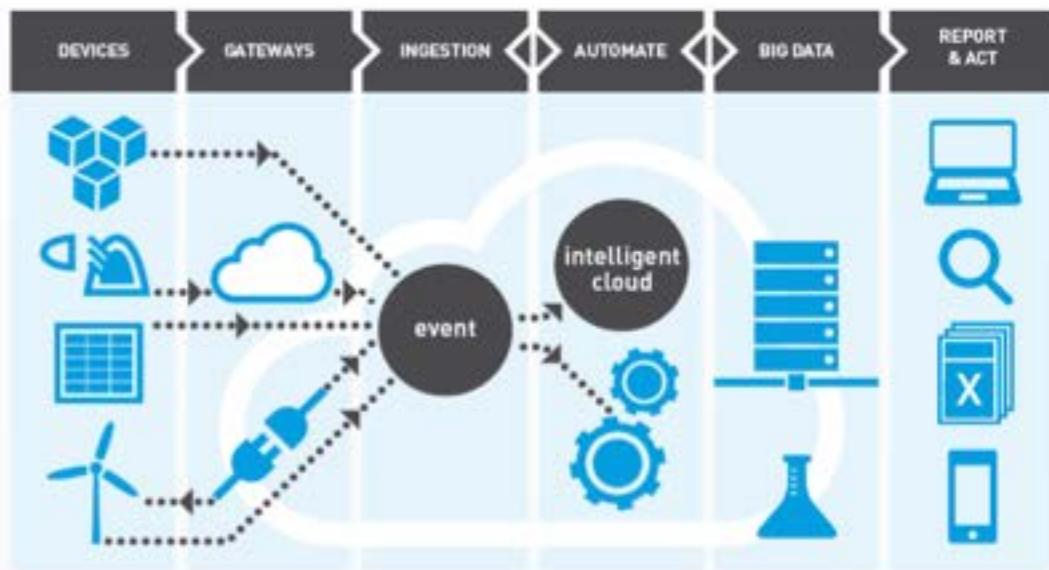
ESP32 / ESP8266

- Dual-core CPU
- Wi-Fi: 802.11 b/g/n
- Bluetooth: v4.2 BR/EDR and BLE



Data visualization and remote control

In cloud services allow the users to visualize and interact with the IoT ecosystems in a comfortable and effective way.



Scopo del corso



- 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

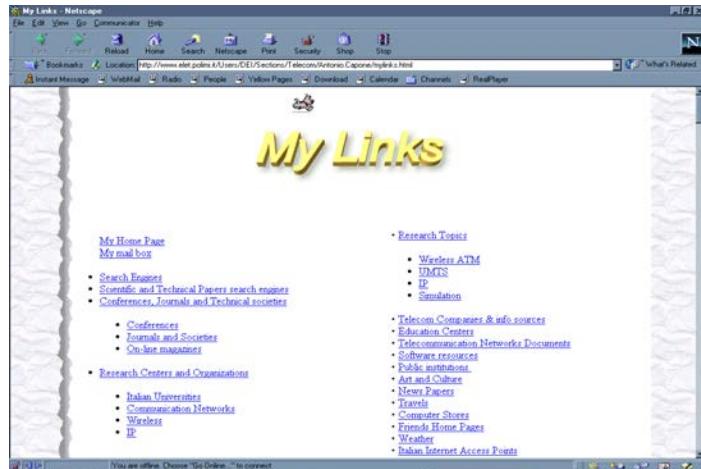
Molti software applicativi colloquiano con software remoti

usano una rete:
INTERNET

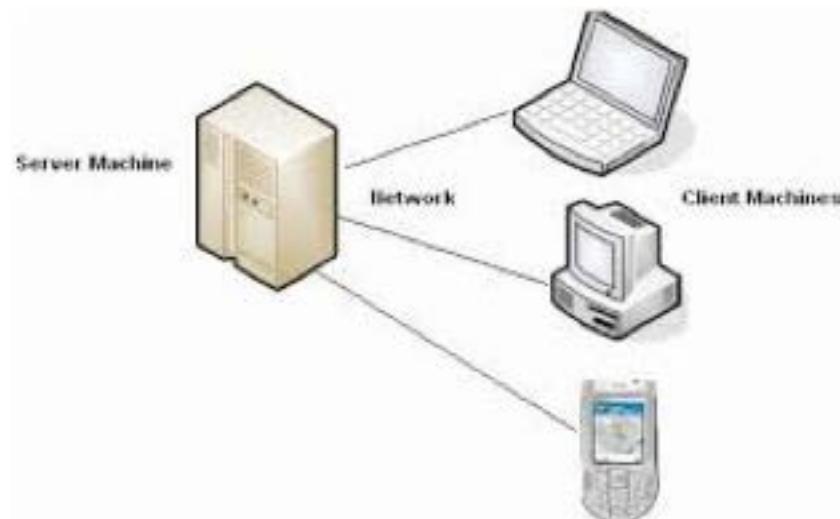
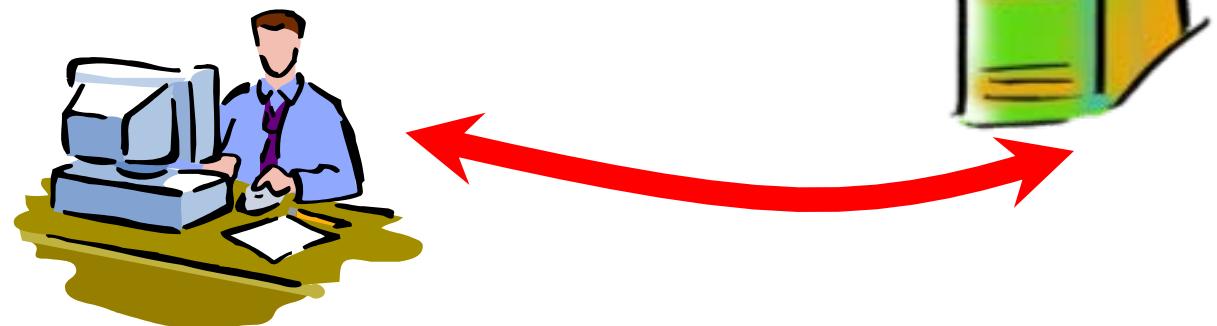


I colloqui sono soggetti a regole (protocolli)

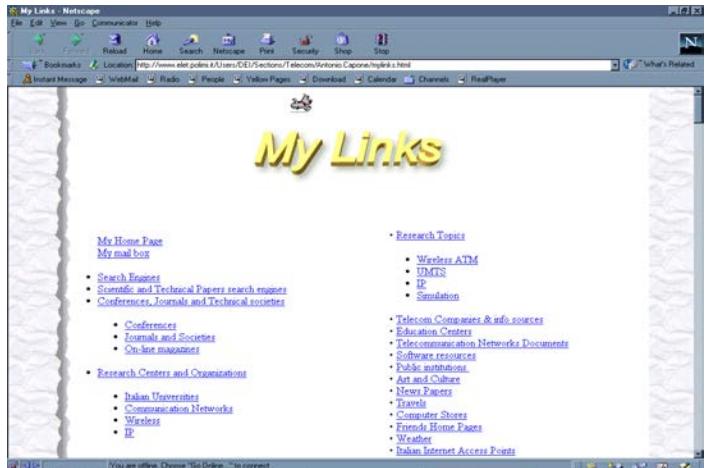
Perché top-down



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
- Programmazione C e Hands on Experience (esercitazioni)
- 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.
 - Pillole su How to Develop your career

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

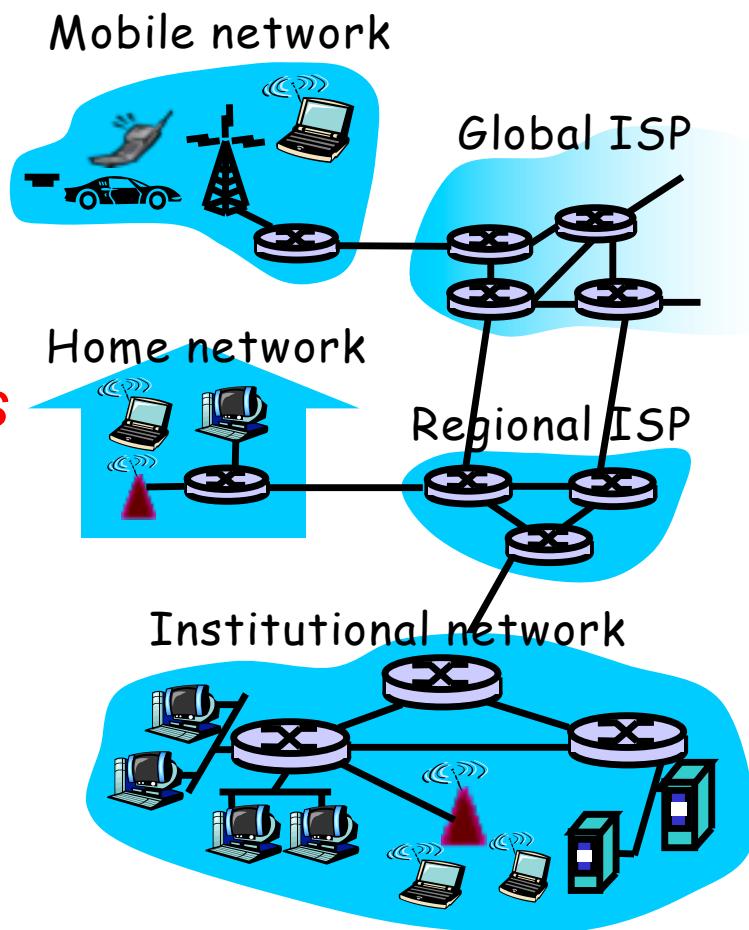
Chapter 1: roadmap

- 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

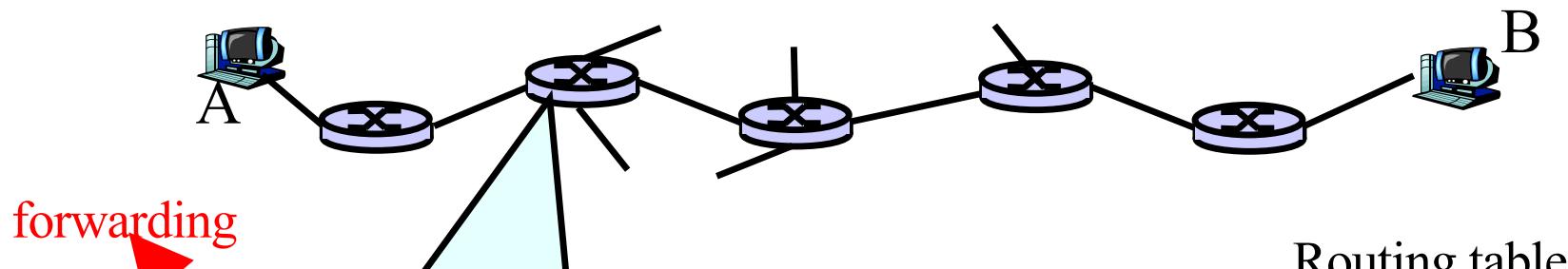


- Hundreds of millions/billions of connected computing devices: *hosts = end systems*
 - running *network apps*
- *communication links*
 - ❖ fiber, copper, radio, satellite
 - ❖ transmission rate, *bandwidth*
- *routers*: forward packets (chunks of data)



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

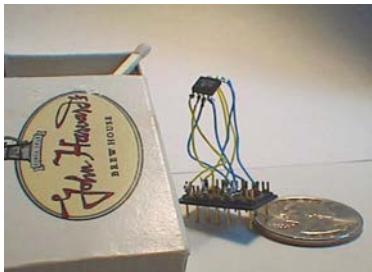
“Cool” internet appliances



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



Web-enabled toaster +
weather forecaster



World's smallest web server



Internet TV



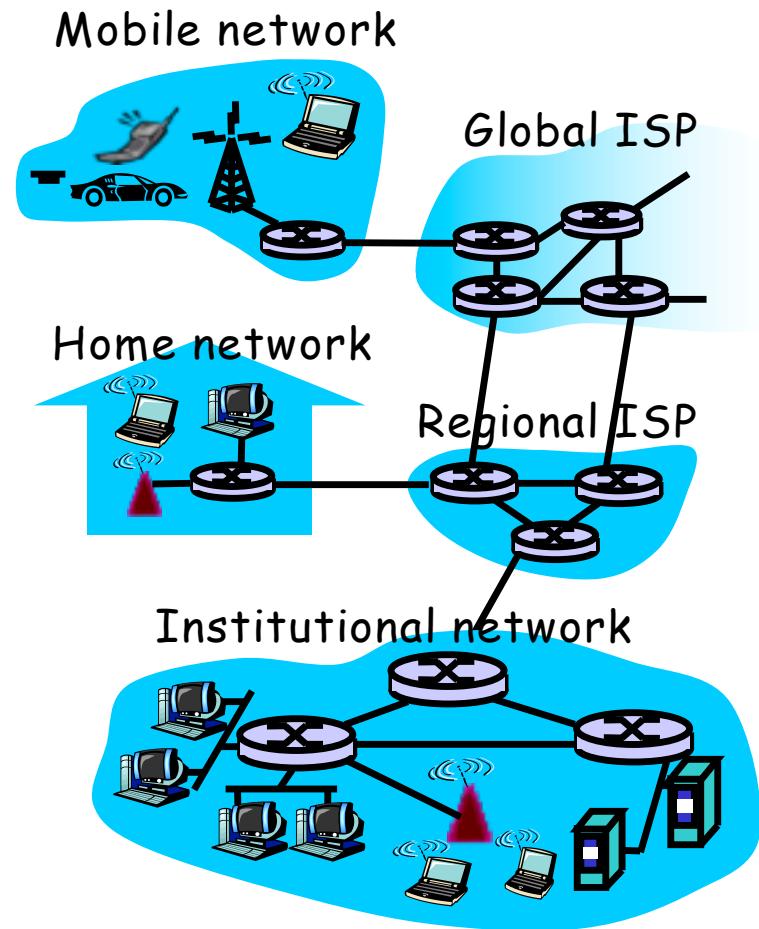
Internet of Things



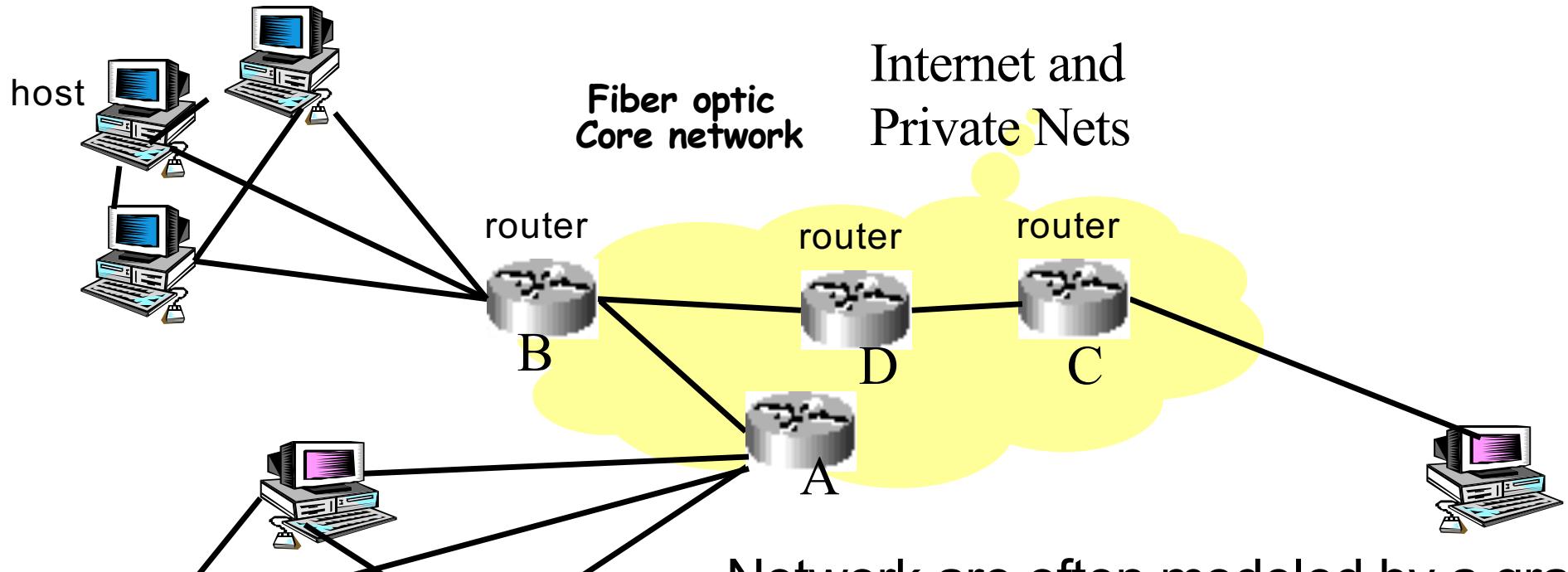
Wearable computing

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



Host = 1 interface
Router = 2+ interfaces

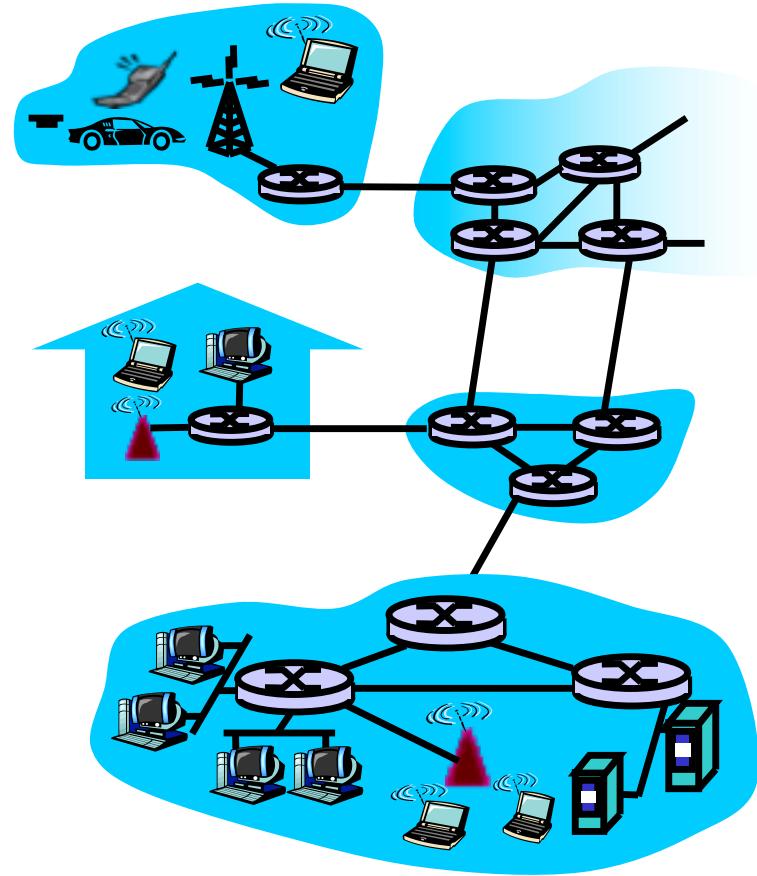
Network are often modeled by a graph
Nodes are Hosts/Routers
Edges between two nodes if there is a communication link between them
→ **Network Physical topology**

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

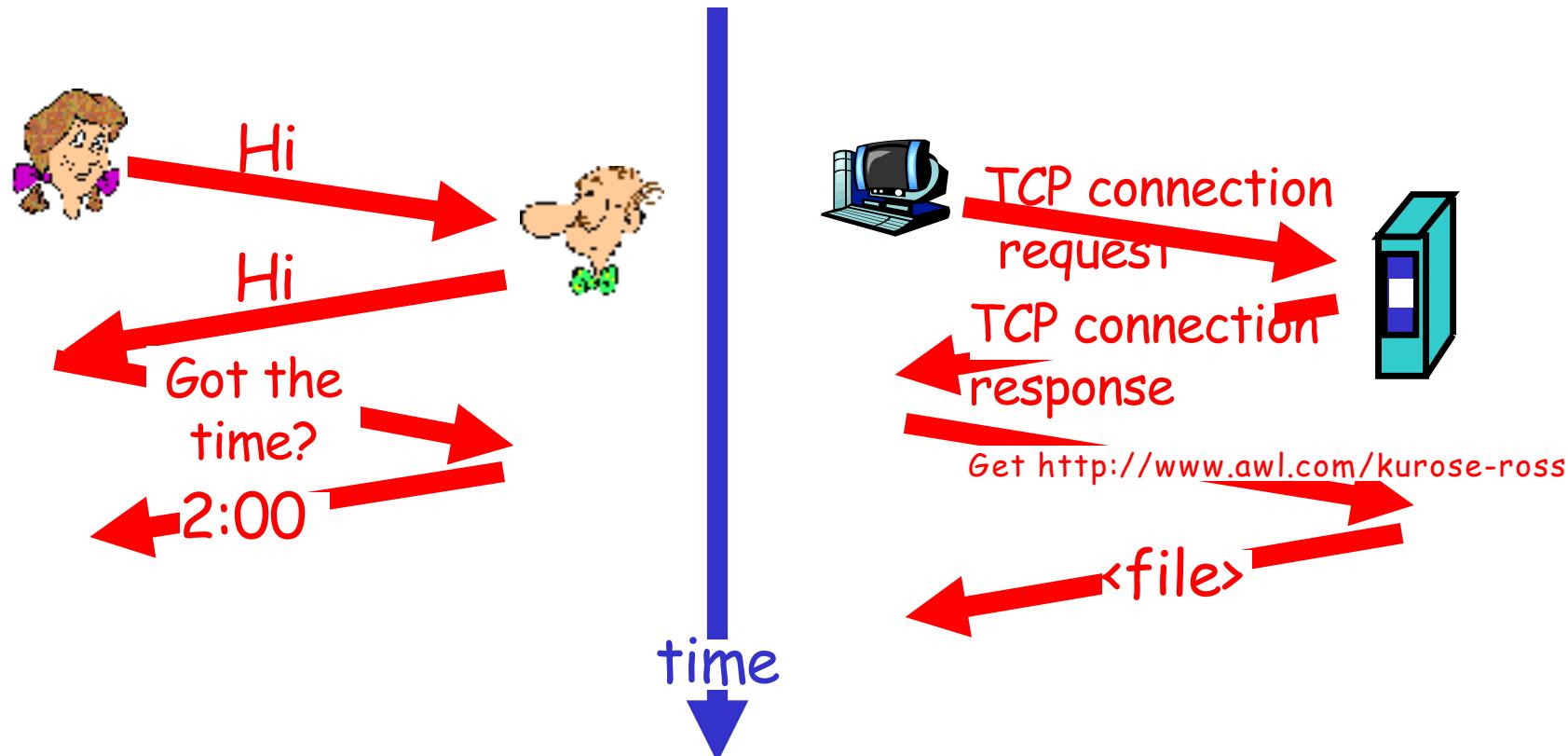
network protocols:

- 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?

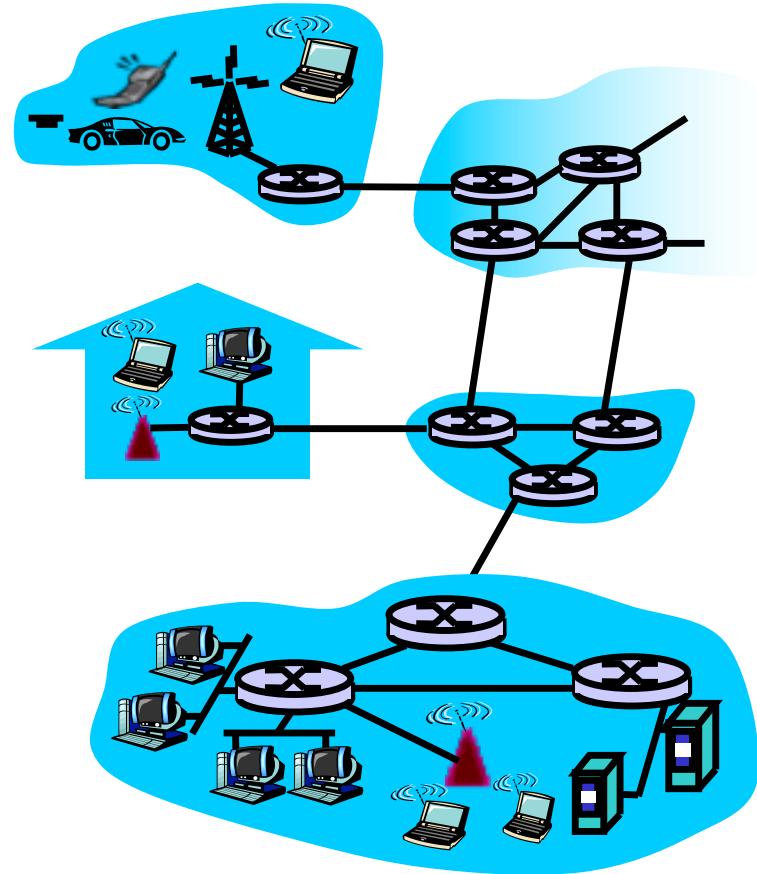
a human protocol and a computer network protocol:



Q: Other human protocols?

What's the Internet: a service view

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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

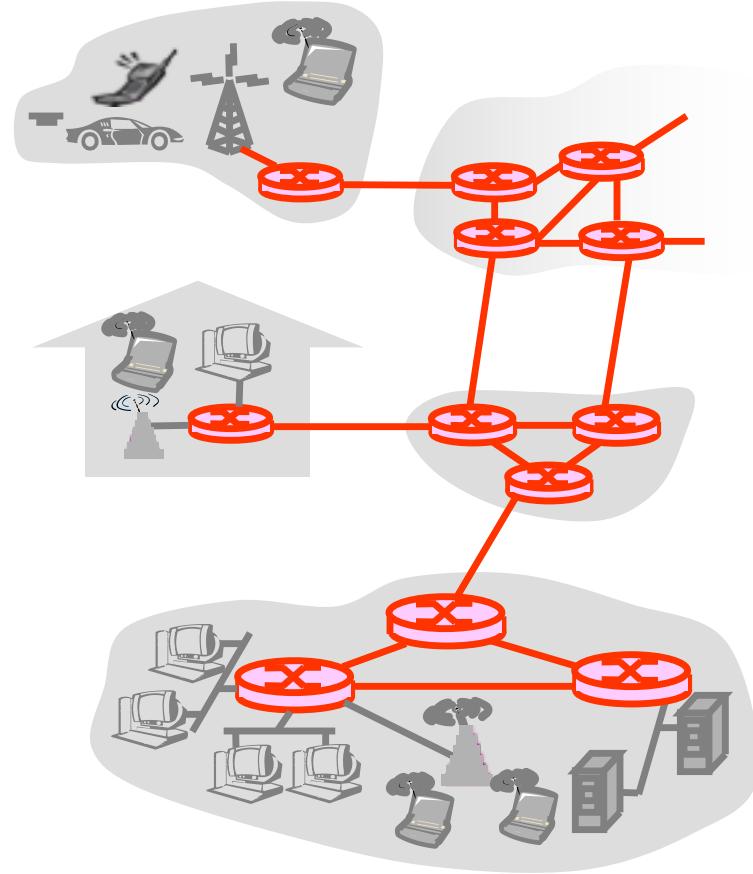
1.5 Protocol layers, service models

1.6 Networks under attack: security

1.7 History

The Network Core

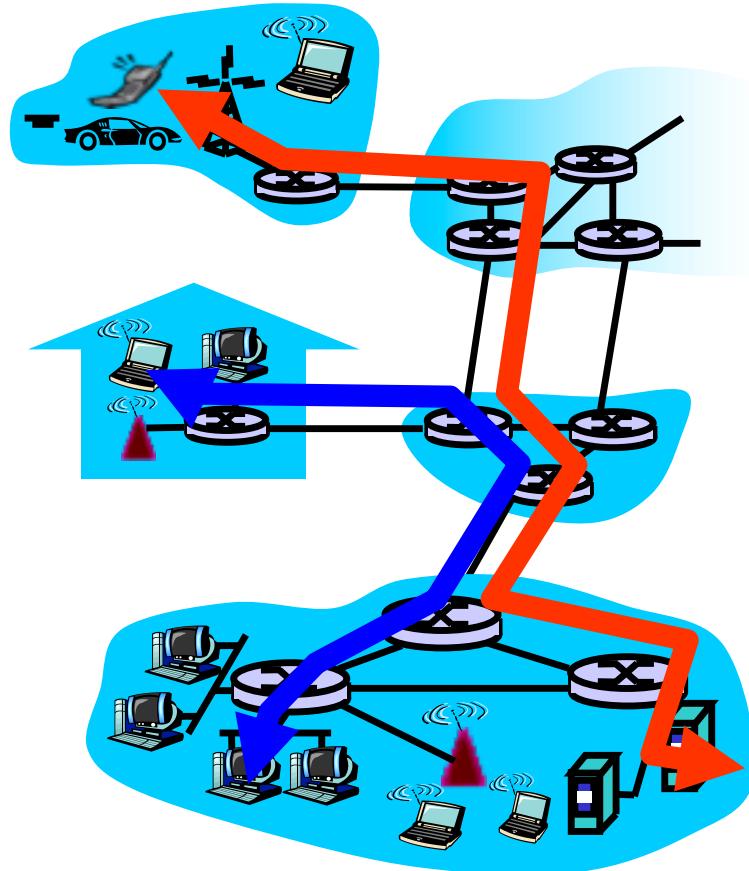
- mesh of interconnected routers
- ***the fundamental question:***
how is data transferred
through net?
 - **circuit switching:**
dedicated circuit per call:
telephone net
 - **packet-switching:** data
sent thru net in discrete
“chunks”



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



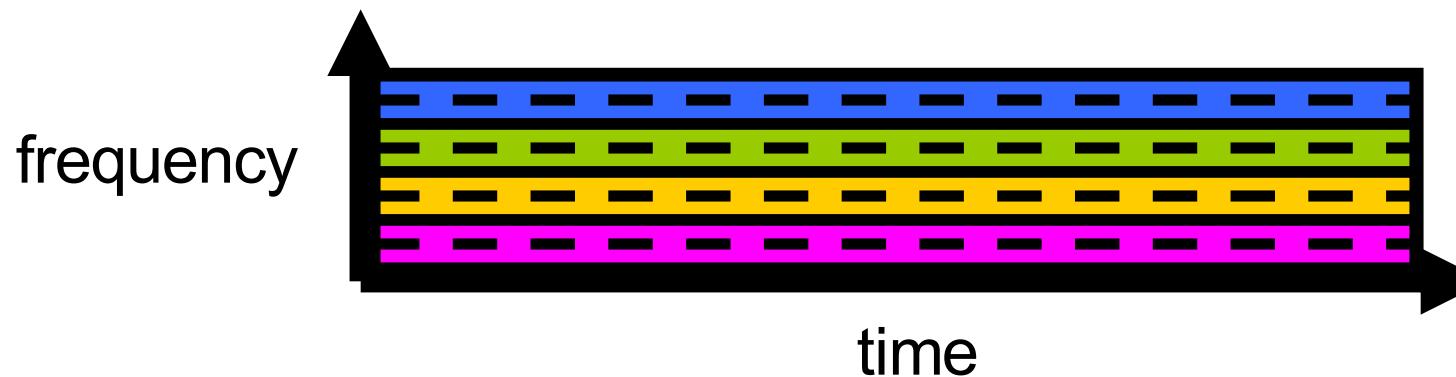
Network Core: Circuit Switching

network resources (e.g., bandwidth) **divided into “pieces”**

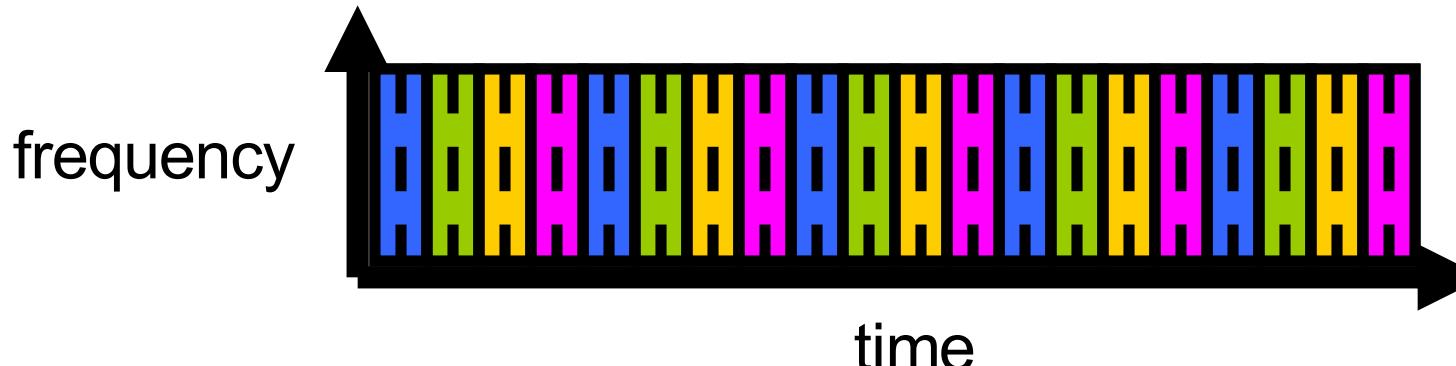
- ❑ pieces allocated to calls
- ❑ resource piece *idle* if not used by owning call (*no sharing*)
- ❑ dividing link bandwidth into “pieces”
 - ❖ frequency division
 - ❖ time division

Circuit Switching: FDM and TDM

FDM



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*

resource contention:

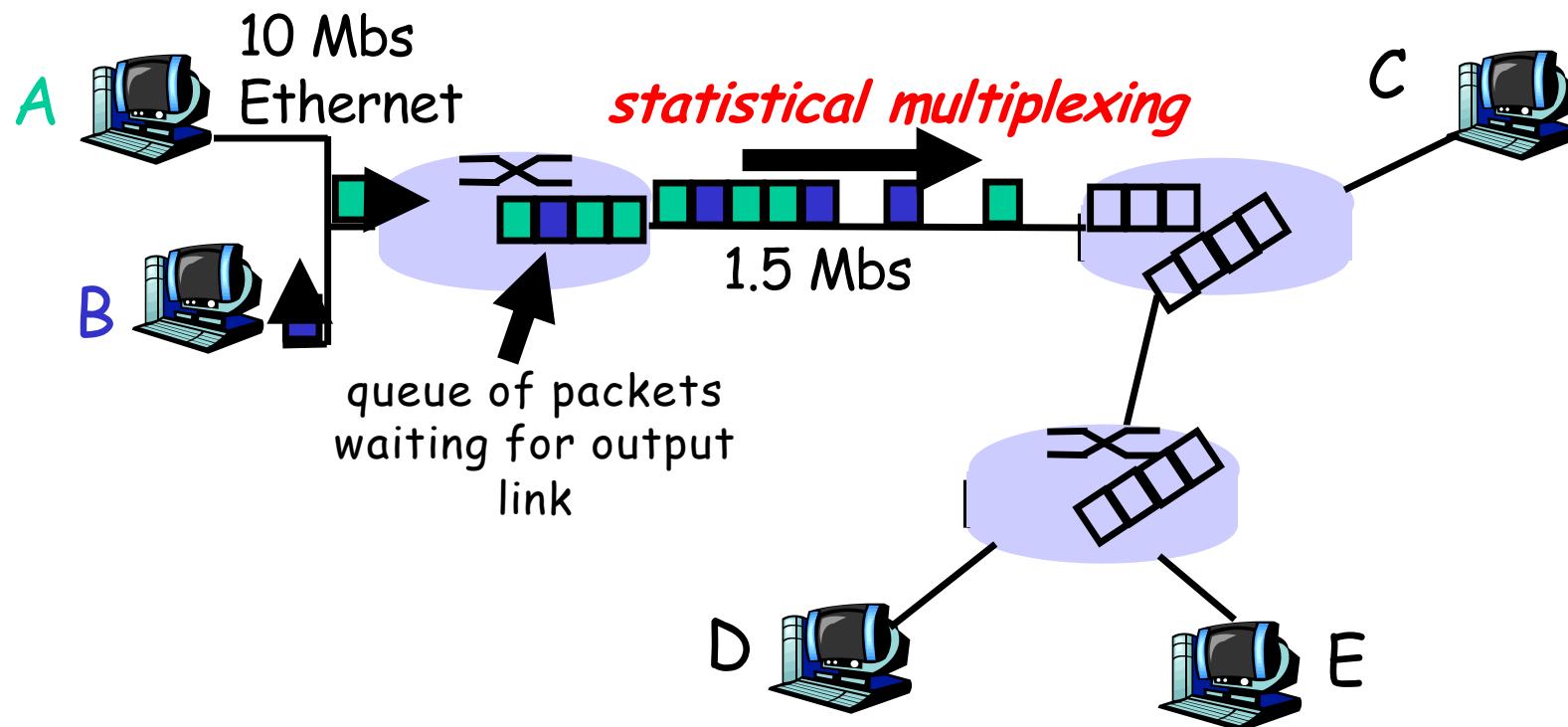
- aggregate resource demand can exceed amount available
- congestion: packets queue, wait for link use
- store and forward: packets move one hop at a time

Node receives complete packet before forwarding

Bandwidth division into “pieces”
Dedicated allocation
Resource reservation



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
- resources used as *needed*

Bandwidth division into “pieces”
Dedicated allocation
Resource reservation



resource contention:

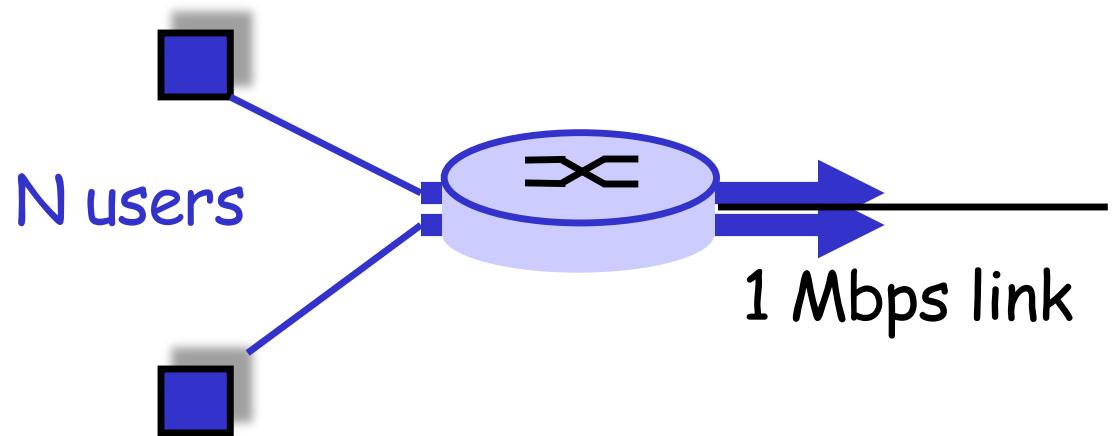
- aggregate resource demand can exceed amount available
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Packet switching versus circuit switching

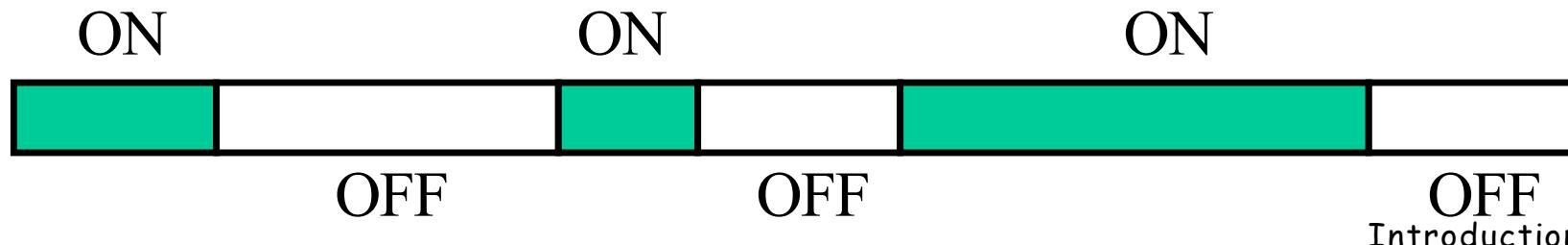
Packet switching allows more users to use network!

- ❑ 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

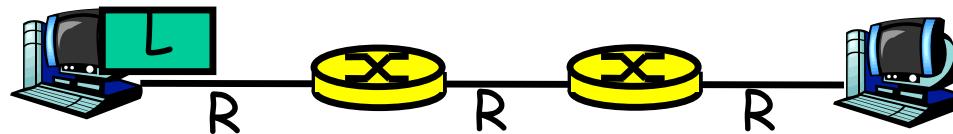
Is packet switching a “slam dunk winner?”

- 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

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

Packet-switching: store-and-forward

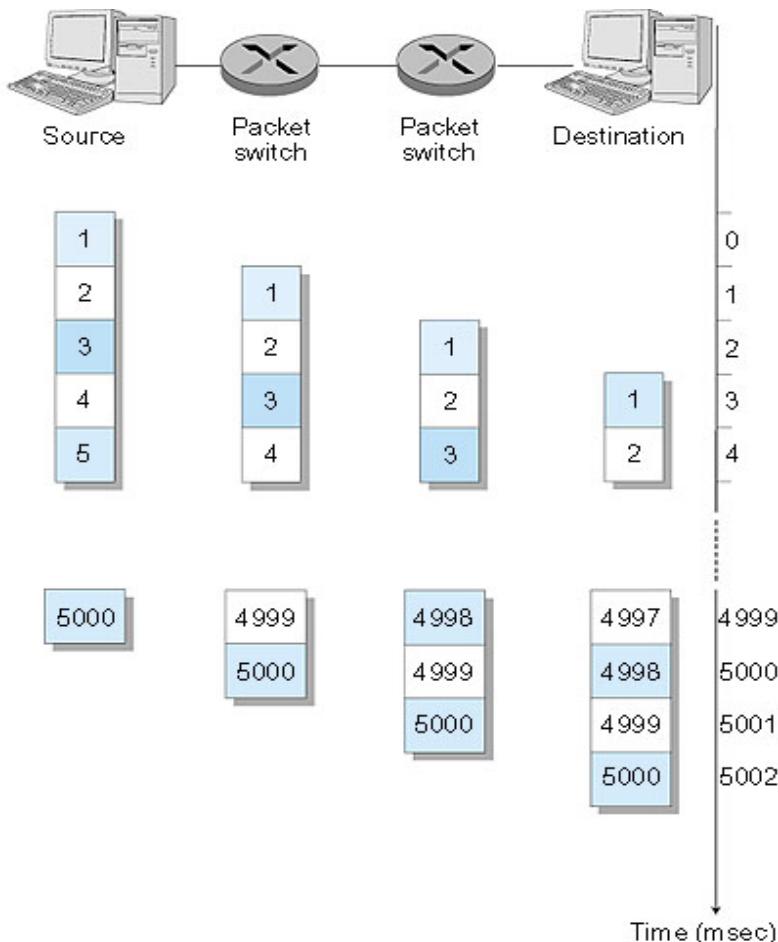


- Takes L/R seconds to transmit (push out) packet of L bits on to link or R bps
- Entire packet must arrive at router before it can be transmitted on next link:
store and forward
- delay = $3L/R$

Example:

- $L = 7.5 \text{ Mbit}$
- $R = 1.5 \text{ Mbps}$
- 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 pacchetti= dim. 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.

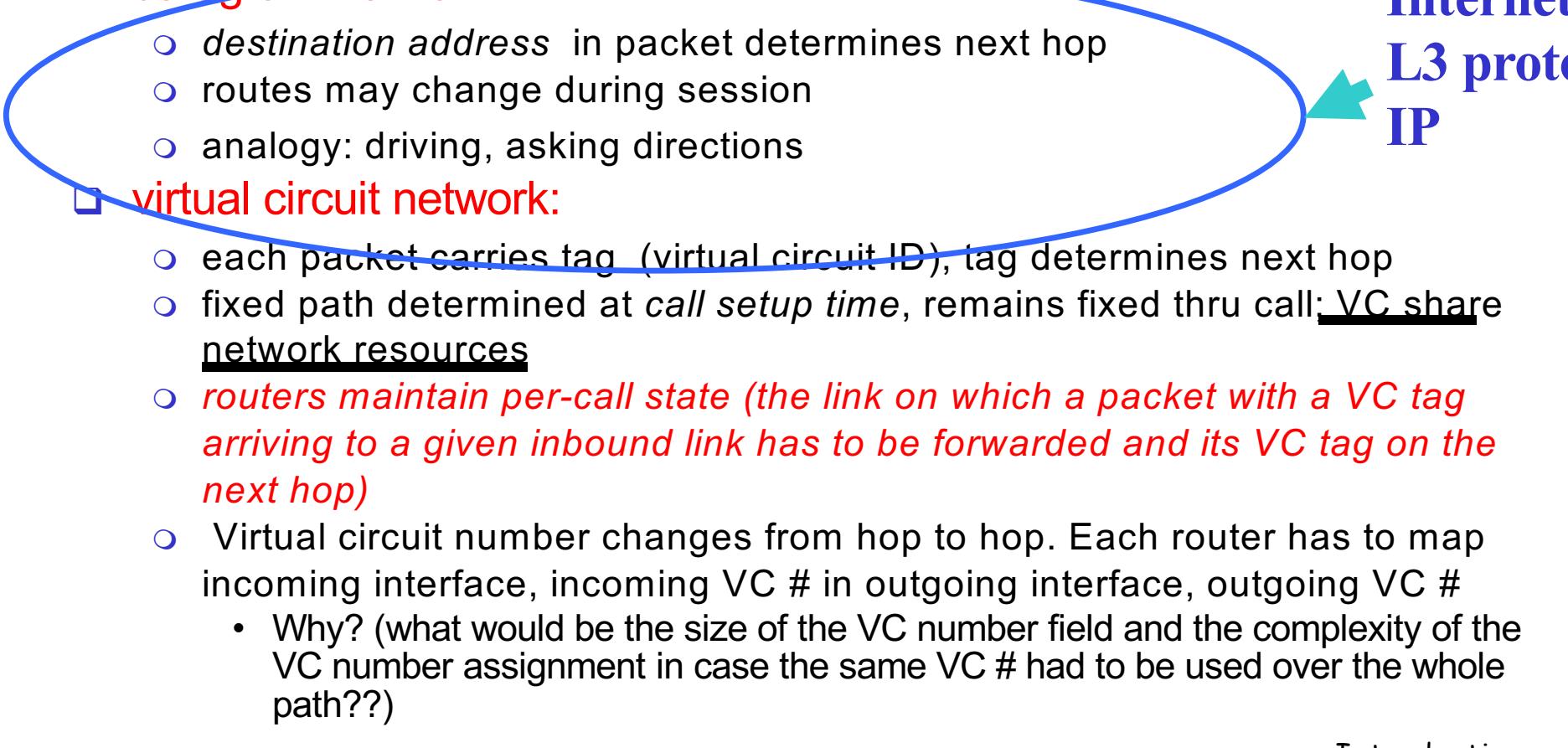
Effect of packet sizes

Packet format

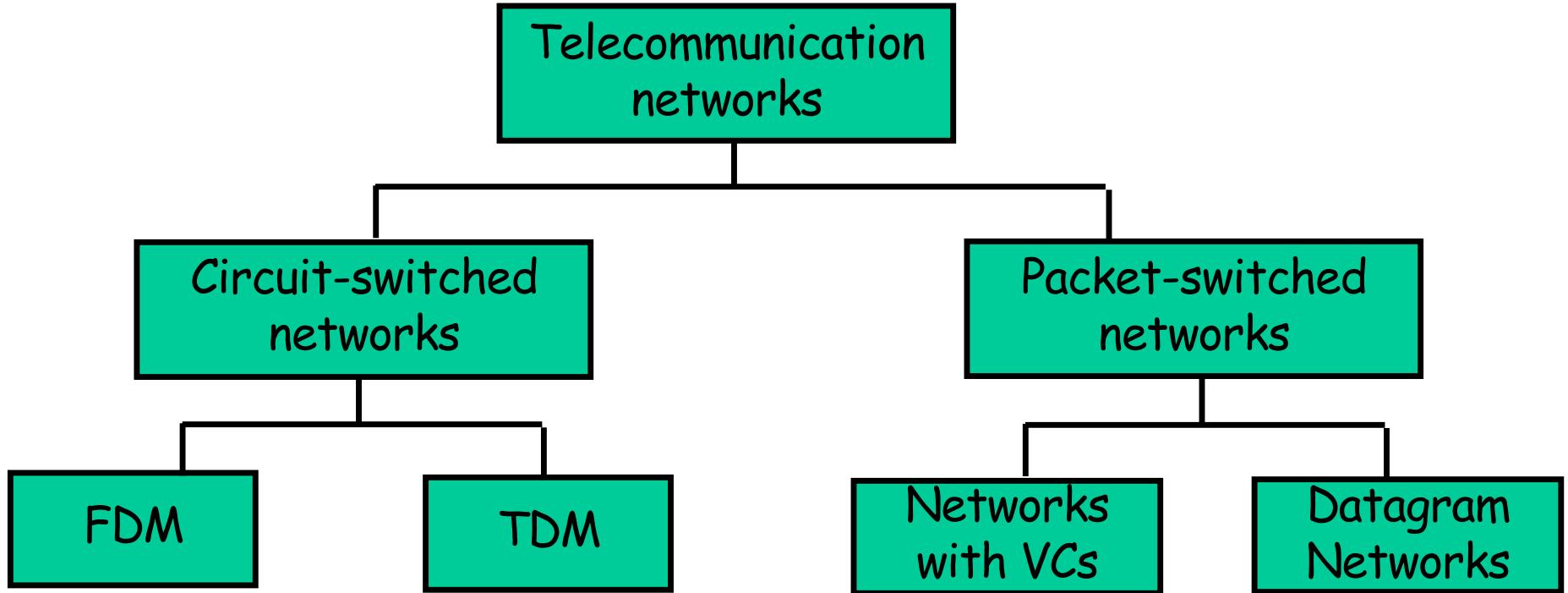


- A longer packet (more data transmitted in a single packet) leads to a lower overhead
- Longer packets result in a higher chance to be corrupted (critical especially for wireless transmission)
- When a packet is corrupted all the data are lost and need to be retransmitted
- Longer packets might decrease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

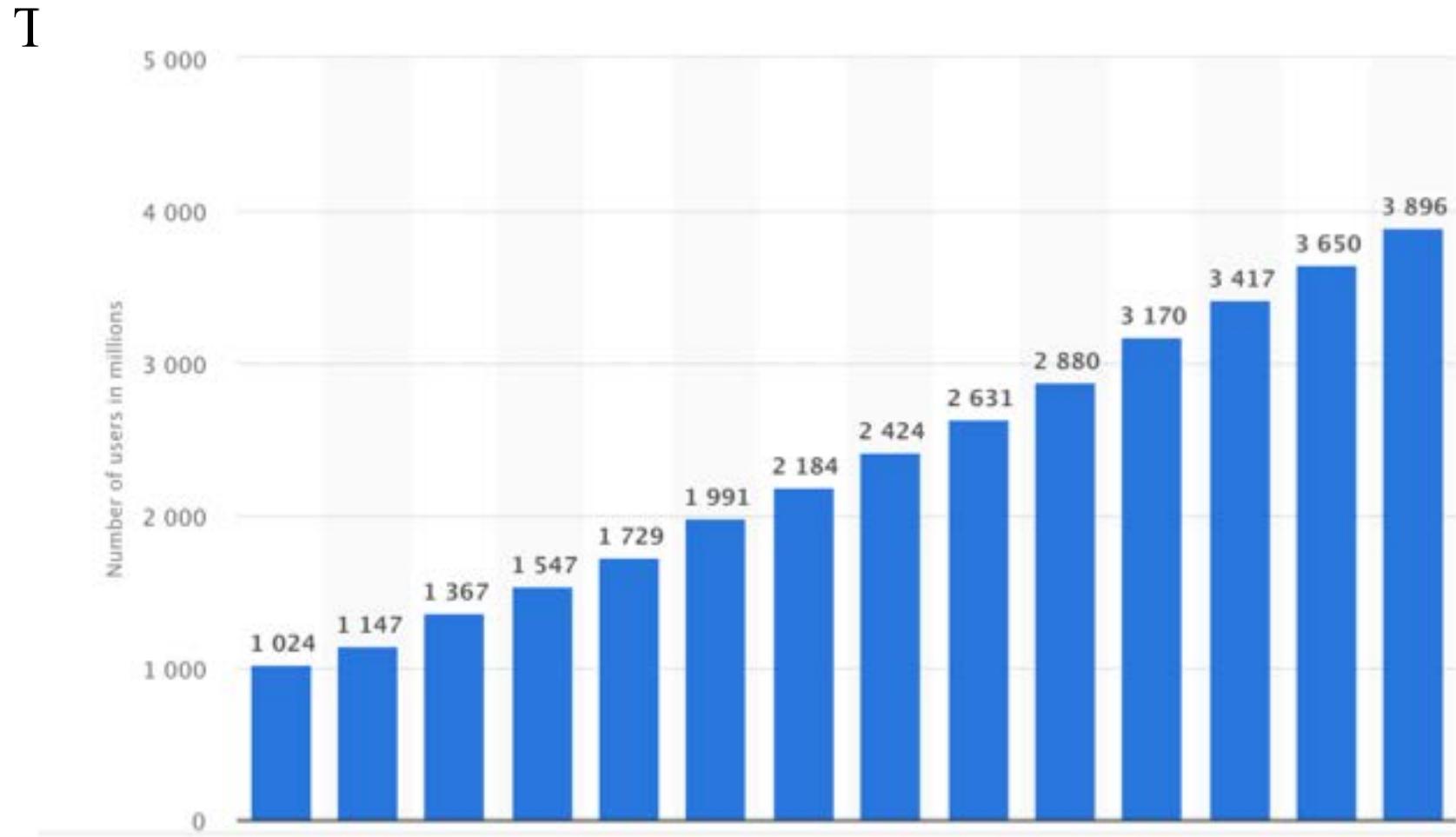
Packet-switched networks: forwarding

- ***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

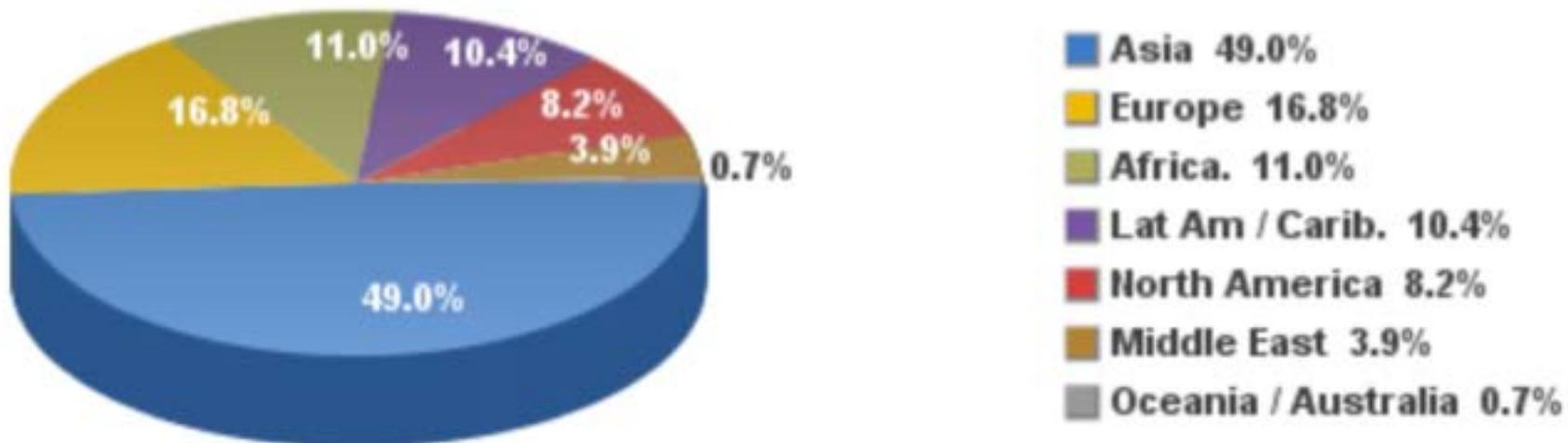
Network Taxonomy



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



Internet Users in the World by Regions - June 30, 2018



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

Basis: 4,208,571,287 Internet users in June 30, 2018

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Figure 1. Cisco VNI forecasts 396 EB per month of IP traffic by 2022

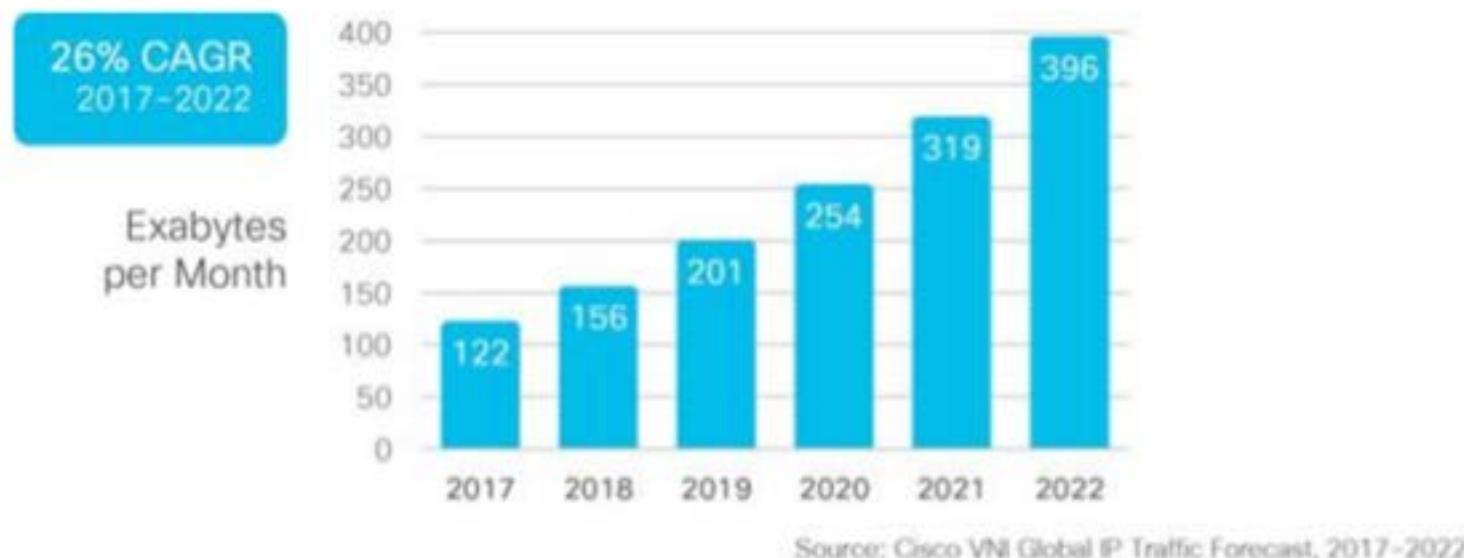
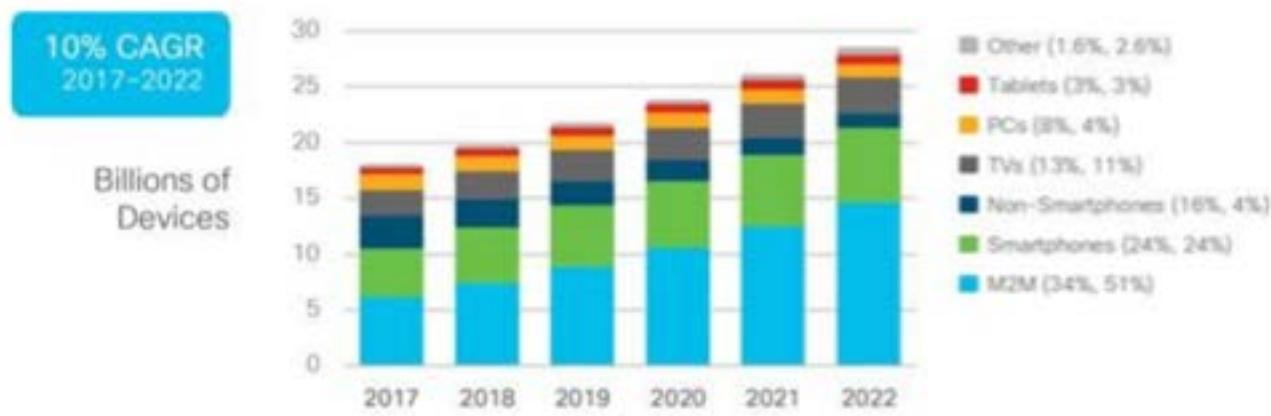


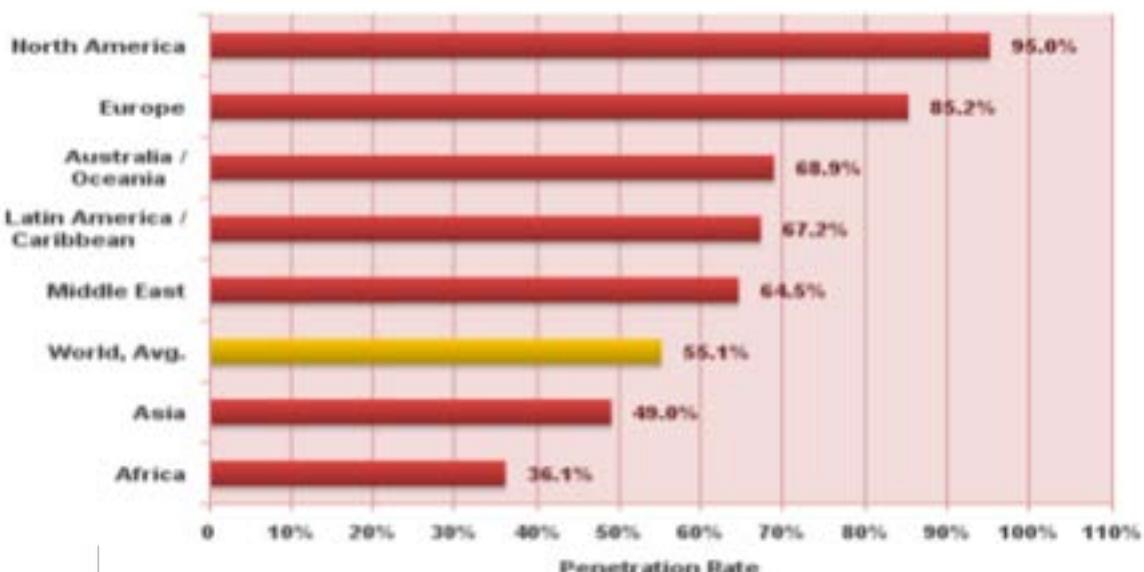
Figure 3. Global devices and connections growth



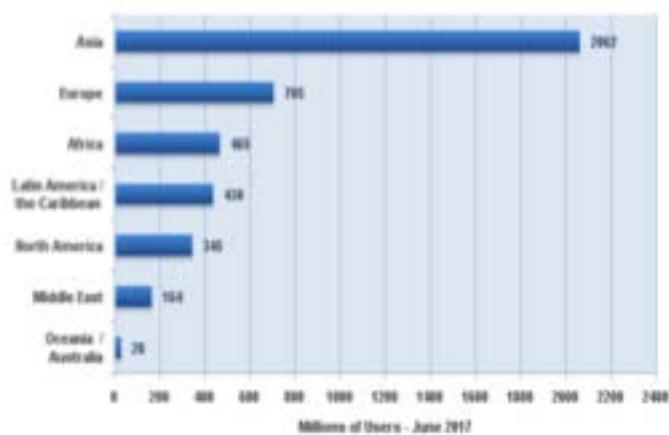
* Figures (n) refer to 2017, 2022 device share

Source: Cisco VNI Global IP Traffic Forecast, 2017-2022

Internet World Penetration Rates by Geographic Regions - June 30, 2018



Internet Users in the World by Geographic Regions - June 30, 2018



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

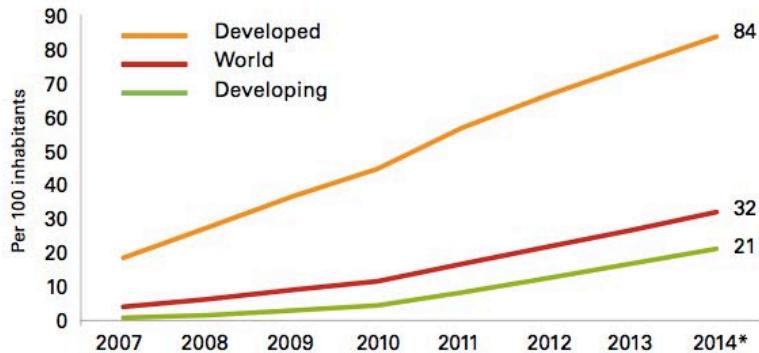
Basic: 4,209,571,287 Internet users estimated in June 30, 2018

Copyright © 2018, Miniwatts Marketing Group

Internet World Stats - www.internetworldstats.com/stats.htm
Penetration Rates are based on a world population of 7,634,758,428
08,571,287 estimated Internet users in June 30, 2018.
ht © 2018, Miniwatts Marketing Group

A changing Internet...

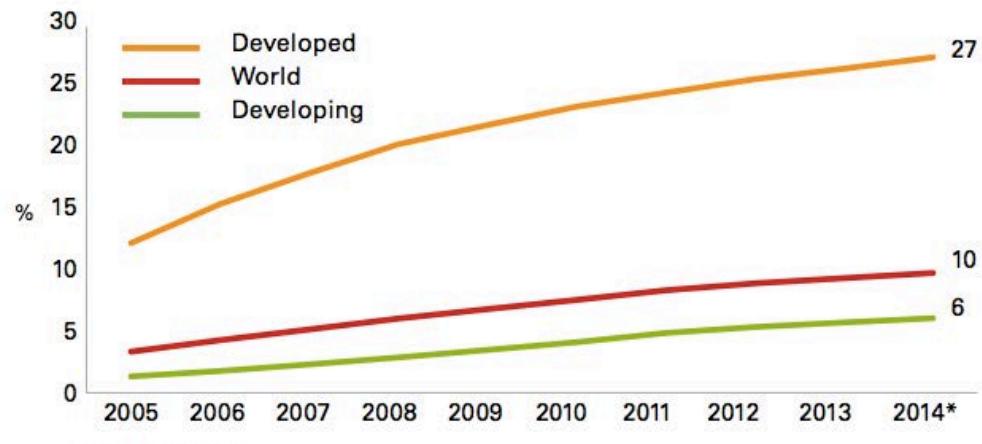
Active mobile broadband subscription



Note: * Estimate

Source: ITU World Telecommunication/ICT Indicators database

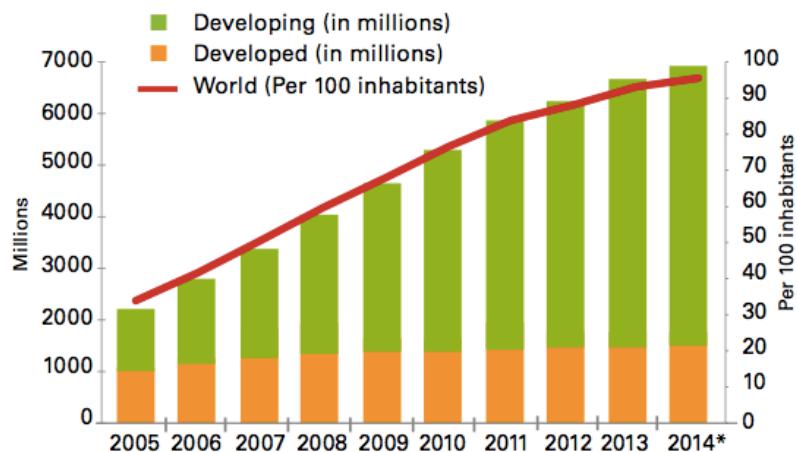
Wired broadband subscription (for 100 users)



Note: * Estimate

Source: ITU World Telecommunication/ICT Indicators database

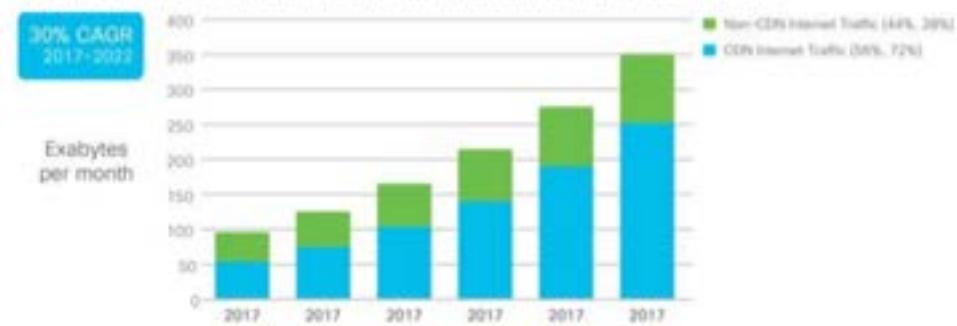
Mobile cellular subscription



Note: * Estimate

Source: ITU World Telecommunication/ICT Indicators database

Figure 24. Global content delivery network Internet traffic, 2017 and 2022



* Figures [n] refer to 2017, 2022 traffic share

Source: Cisco VM Global IP Traffic Forecast, 2017–2022

A changing Internet...

CISCO forecasting

Consumer Internet Traffic, 2017-2022	2017	2018	2019	2020	2021	2022	CAGR 2017-2022
By Network (EB per Month)							
Fixed	67	86	111	141	179	225	27%
Mobile	10	16	25	36	50	68	47%
By Subsegment (EB per Month)							
Internet video	56	77	105	140	184	240	34%
Web, email, and data	12	15	19	23	27	31	22%
Online gaming	1	3	4	7	11	15	59%
File sharing	8	7	7	7	7	7	-3%

A changing Internet...

CISCO forecasting

Consumer Internet Traffic, 2017-2022	2017	2018	2019	2020	2021	2022	CAGR 2017-2022
By Network (EB per Month)							
Fixed	67	86	111	141	179	225	27%
Mobile	10	16	25	36	50	68	47%

Changes in trends:

IoT

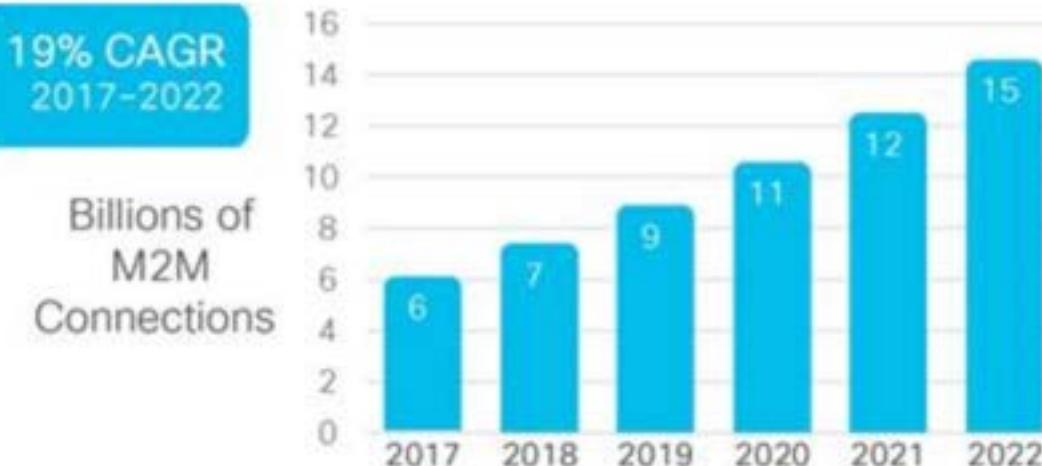
Multimedia support

Network devices reconfigurability and virtualization

Cloud vs. Edge computing

240	34%
31	22%
15	59%
7	-3%

Figure 10. Global M2M connection growth



Source: Cisco VNI Global IP Traffic Forecast, 2017-2022

Figure 11. Global M2M connection growth by industries

