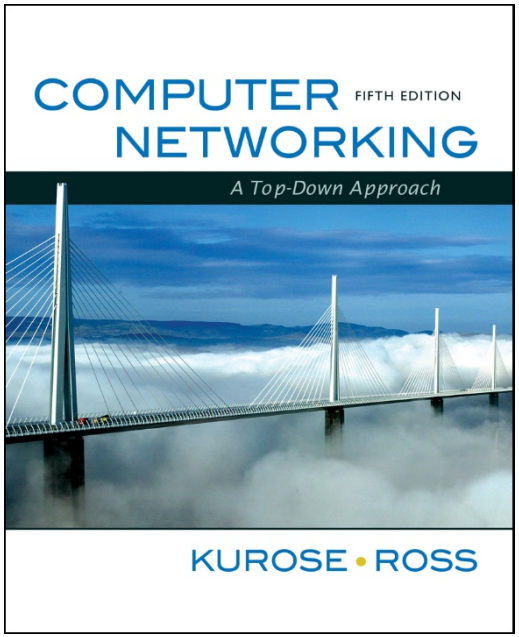
Chapter 1
Introduction



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Thanks and enjoy! JFK/KWR

Computer Networking: A Top Down Approach, 5th edition.
Jim Kurose, Keith Ross
Addison-Wesley, April 2009.

1. Gaia Sarrera

Helburua:

- Egituraketa eta terminologia ulertu
- Kurtsoan zehar gaiak era sakonagoan ikusiko dira
- Hurbilketa:
  - Internet, adibide bezala erabili

Gainbegirada:

- Zer da Internet?
- Zer da protokolo bat?
- Sarearen muturrak; hosts, atzipen sarea, physical media
- Sarearen nukleoa: pakete/zirkuituen konmutazioa, Internet estruktura
- Etekina: galerak, atzerapenak
- Segurtasuna
- Protokoloen geruzak, Zerbitzuen ereduak
- Historia

1. Gaia: eskema

1.1 Zer da Internet?

1.2 Sarearen muturrak

- end systems, access networks, links

1.3 Sarearen nukleoa

- circuit switching, packet switching, network structure

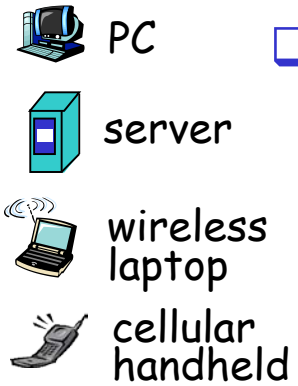
1.4 Atzerapenak, galerak eta etekina pakete-konmutatutako sareetan

1.5 Protokoloen geruzak, Zerbitzuen ereduak

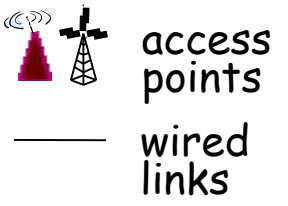
1.6 Segurtasuna

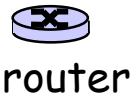
1.7 Historia

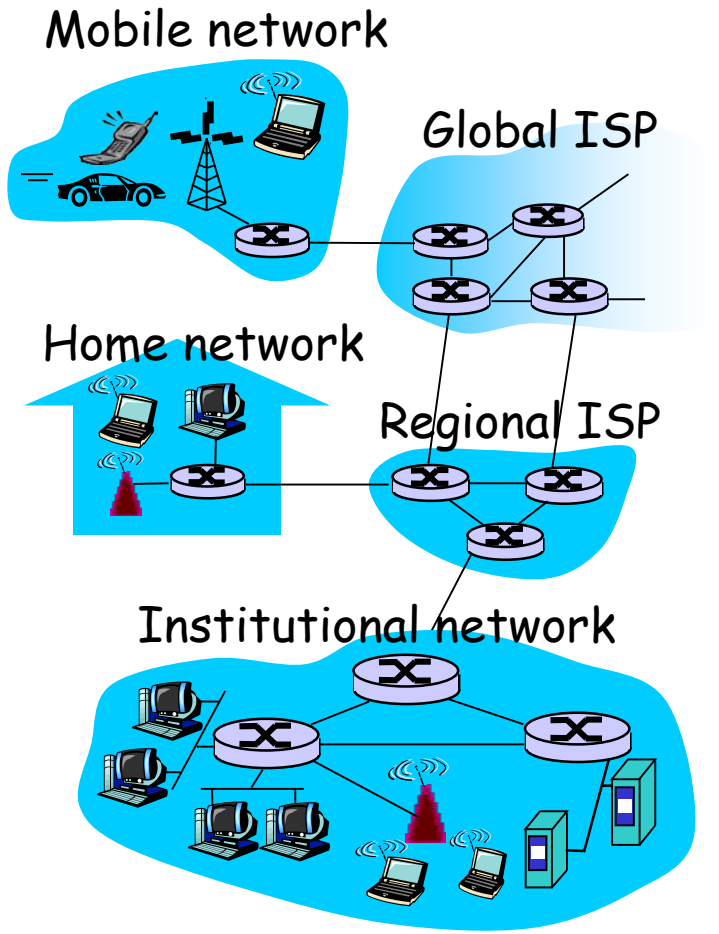
Zer da Internet



- Miloika konputagailu konektatuta: *hosts = end systems*
  - *Sareko aplikazio* exekutatzen
- *Komunikazioaren linkak*
  - Medio fisikoa
  - Transferentzia abiadura= banda zabalera *bandwidth*
- *routers:* informazio paketeak bidaltzeko



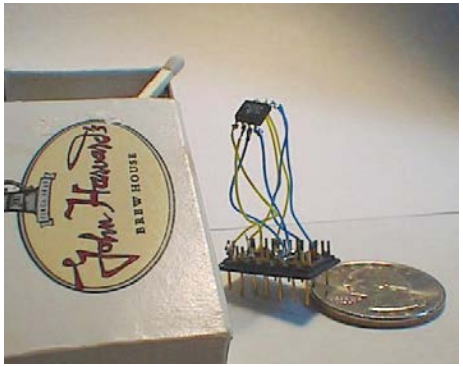




“Cool” internet appliances

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

Web-enabled toaster + weather forecaster

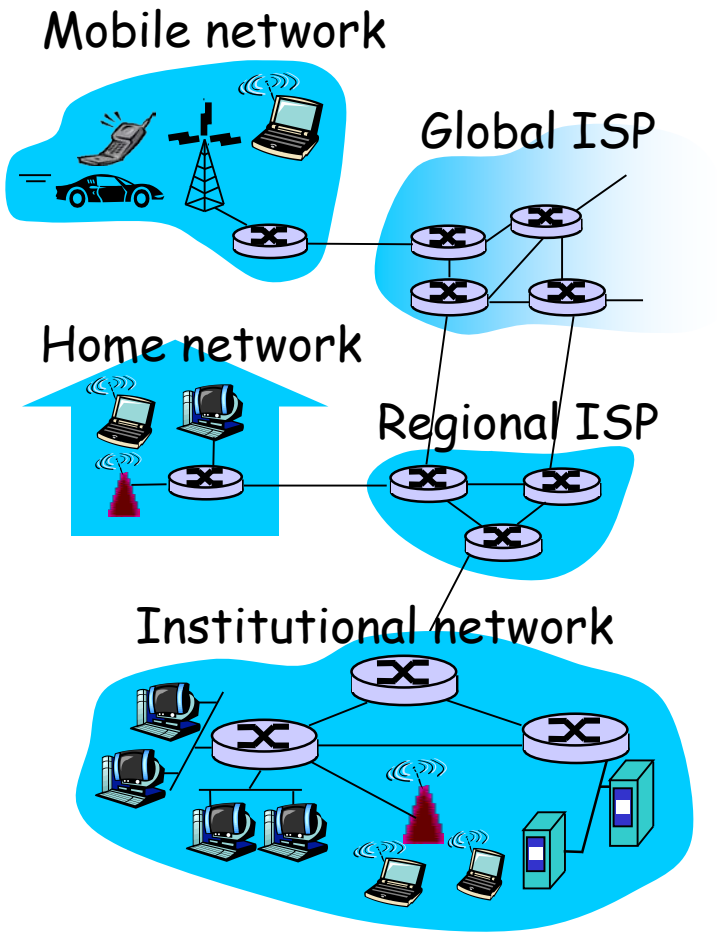


World’s smallest web server
http://www-ccs.cs.umass.edu/~shri/iPic.html

Internet phones

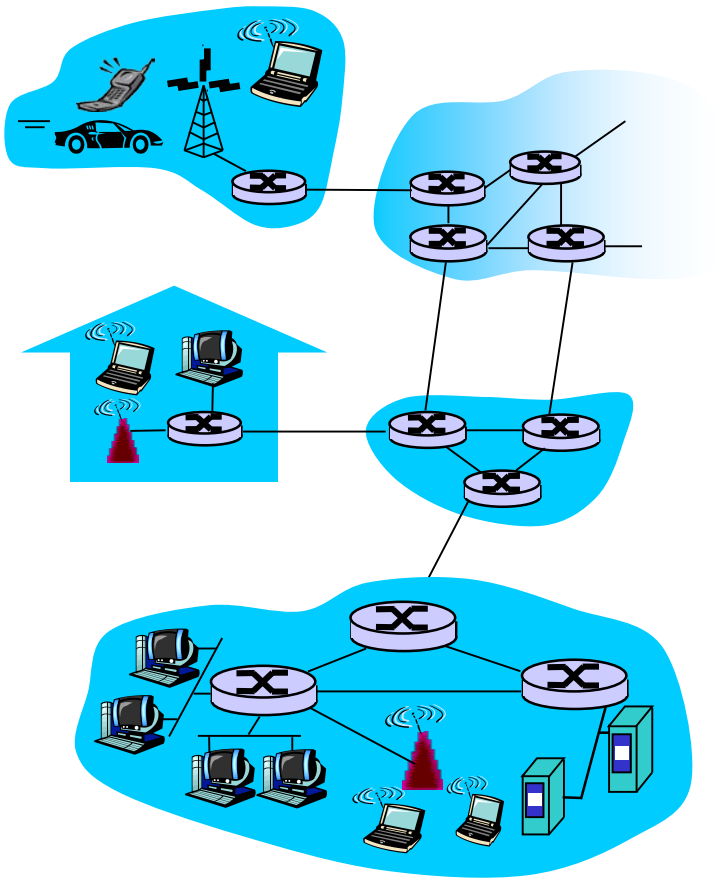
Zer da Internet?

- *Protocoloak* kontrol mezuen bidalketa eta jasoketa
  - e.g., TCP, IP, HTTP, Skype, Ethernet
- *Internet:* "sareen sarea"
  - Ez da oso ierarkikoa
  - Internet publikoa versus intranet pribatua
- Internetaren estandarrak
  - RFC: Request for comments
  - IETF: Internet Engineering Task Force



Zer da Internet: zerbitzuaren ikuspuntua

- Komunikaziorako infraestrukturek aplikazioen erabilera ahalbidetzen dute:
  - Web, VoIP, email, games, e-commerce, file sharing
- Aplikazioei komunikazio zerbitzuak ematen zaizkie:
  - Informazioaren bidalketa ziurtatua
  - “best effort” Informazioaren bidalketa EZ ziurtatua



Zer da protokolo bat?

Giza-protokoloak:

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

… mezuak bidali

… mezuak jasotzen direnean egin beharrekoak

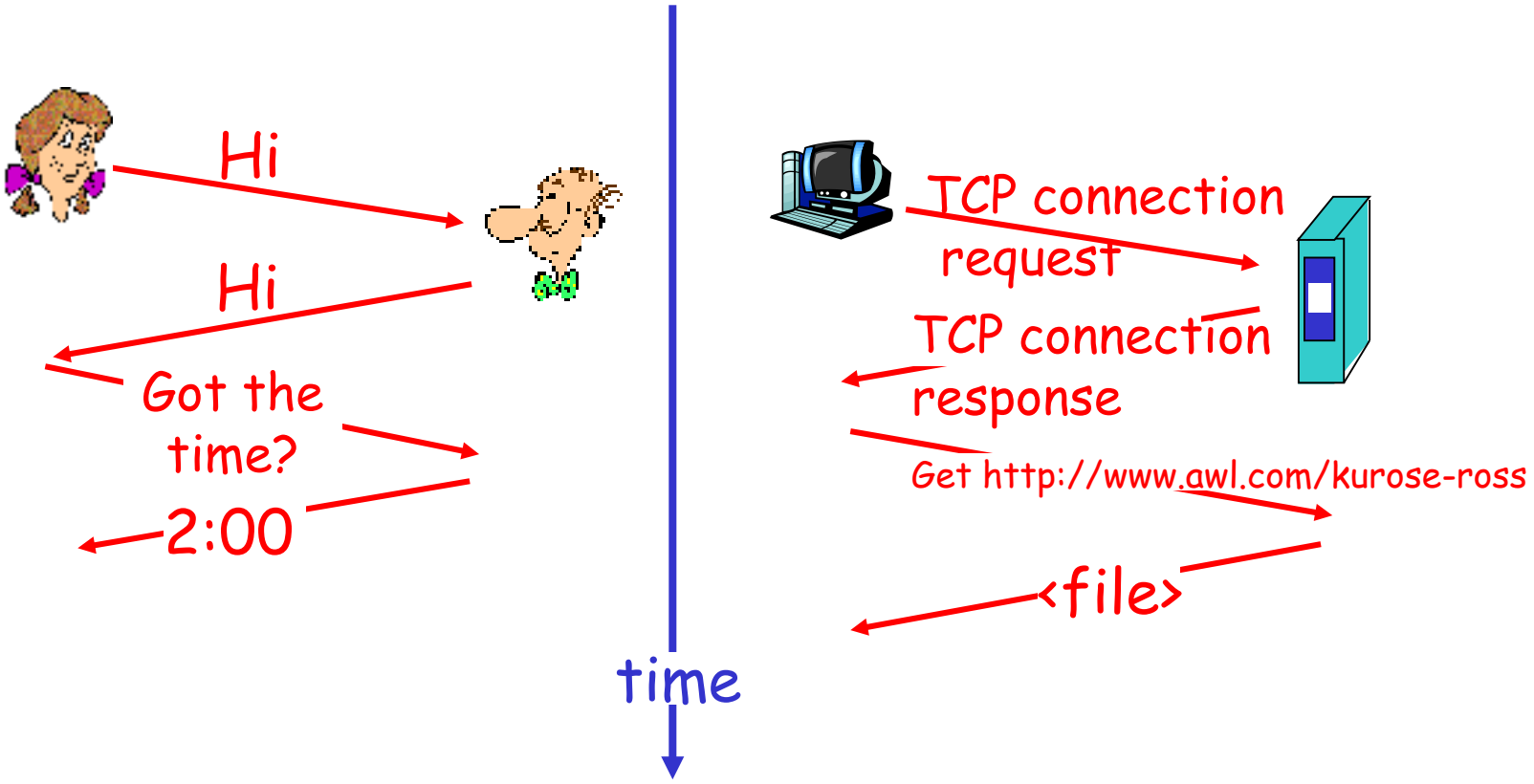
Sareen protokoloak:

- Makinak gizakien ordez
- Interneteko komunikazio guztia protokoloen menpe

Protokoloek, sarearen entitateen artean mezu bat zelan bidaltzen den definitzen dute; ain zuzen formatua, mezuen bidaltze- eta jasotze-ordena, baita mezuak bidaltzeko eta jasotzeko egitekoak

Zer da protokolo bat?

Giza protokoloa eta konputagailu sare baten protokoloa:



Q: Other human protocols?

1. Gaia: eskema

1.1 Zer da Internet?

1.2 Sarearen muturrak

- end systems, access networks, links

1.3 Sarearen nukleoa

- circuit switching, packet switching, network structure

1.4 Atzerapenak, galerak eta etekina pakete-konmutatutako sareetan

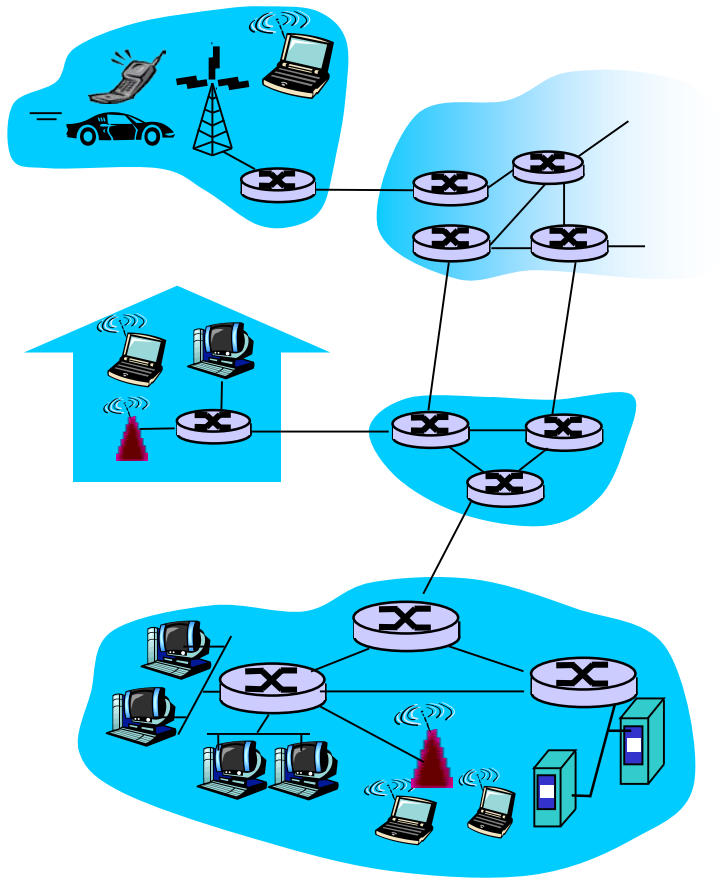
1.5 Protokoloen geruzak, Zerbitzuen ereduak

1.6 Segurtasuna

1.7 Historia

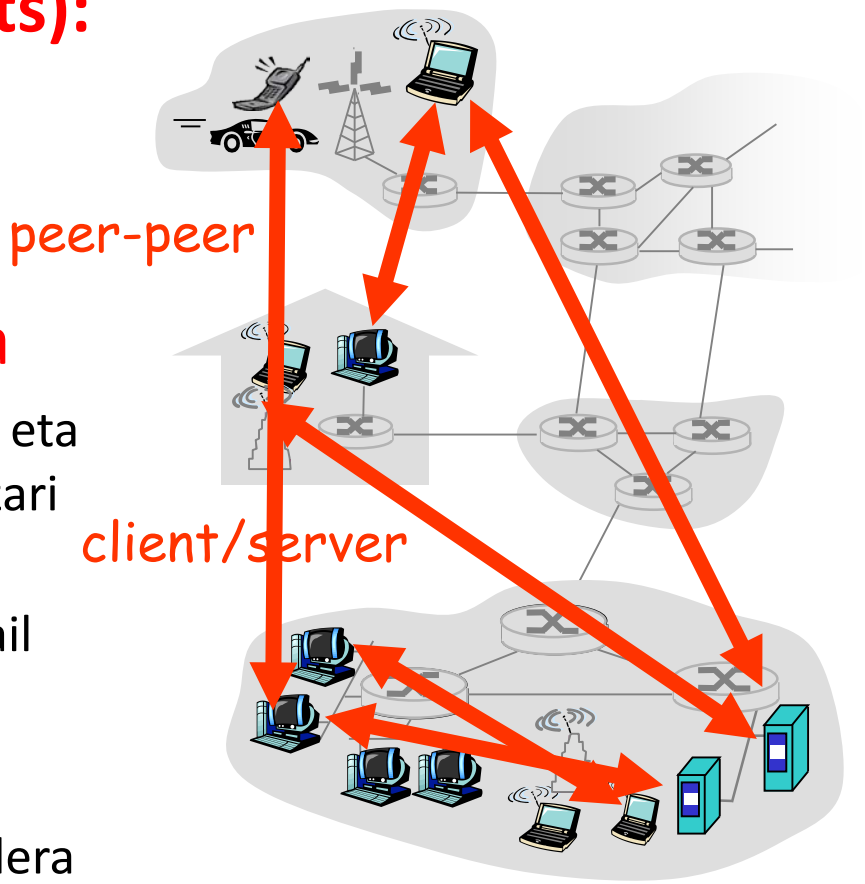
Hurbilagotik ikusita:

- Sarearen muturrak:
  aplikazio eta host-ak
- Atzipen sareak, medio fisikoa: wired, wireless communication links
- Sarearen nukleoa:
  - Elkar konektatutako routerrak
  - Sareen sarea



Sarearen muturra:

- **Bukaerako sistemak (hosts):**
  - Aplikazio programak
  - e.g. Web, email
  - at “edge of network”
- Bezero/zerbitzari eredua
  - Bezeroak eskaerak egiten ditu eta “beti” martxan dagoen zerbitzari baten zerbitzua jasotzen du
  - e.g. Web browser/server; email client/server
- peer-peer eredua:
  - Zerbitzari “dedikatuen” erabilera minimoa (edo eza)
  - e.g. Skype, BitTorrent



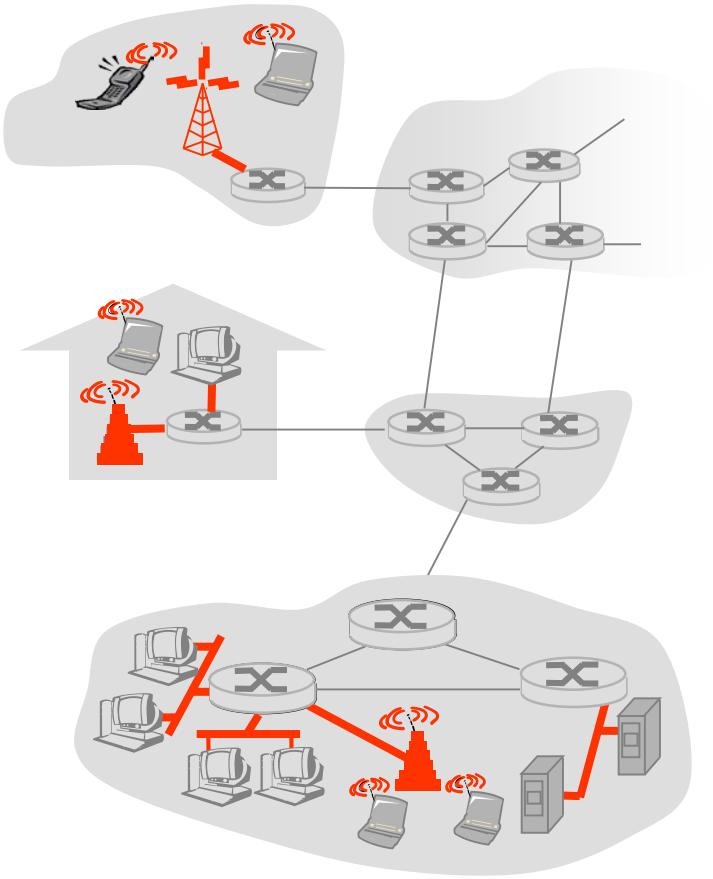
Atzipen sarea eta medio fisikoa

Q: Nola konektatzen dira terminalak routerretara?

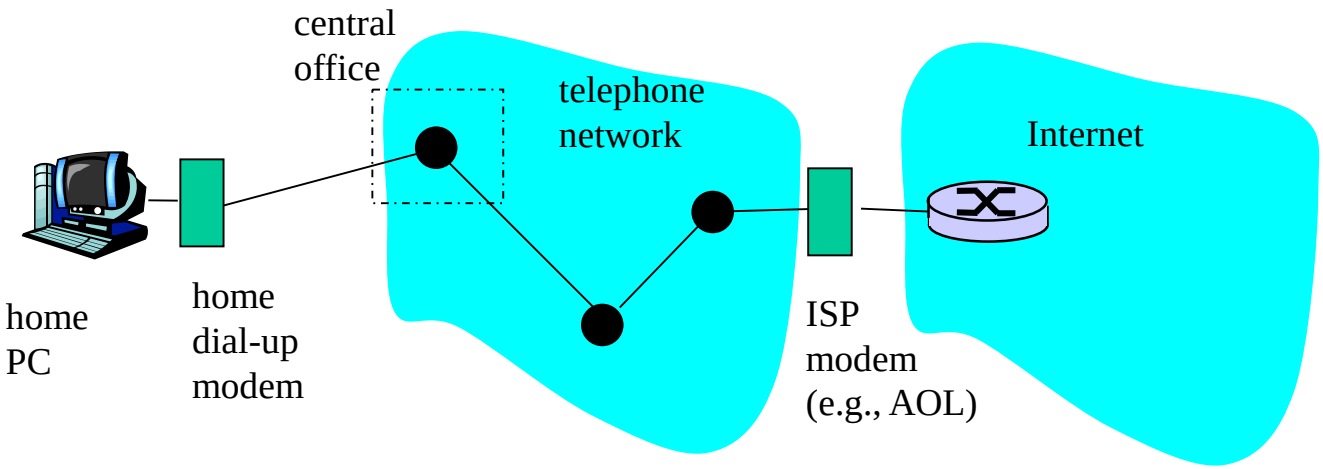
- residential access nets
- institutional access networks (school, company)
- mobile access networks

Ohar zaitez:

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

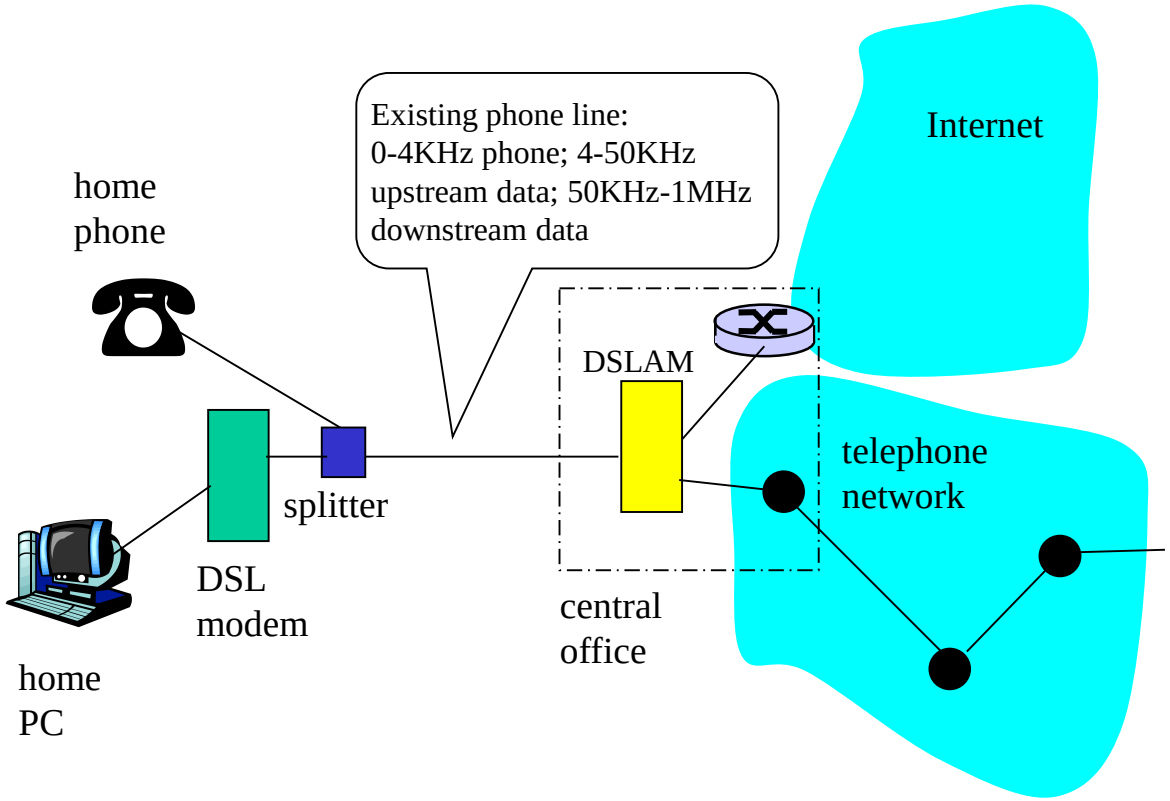


Dial-up Modem-a



- Telefoniaren infraestruktura erabiltzen du
  - Etxea zentralita batekin konektatuta
- 56Kbps-erainoko atzipen zuzena routerrera
- Ezin daiteke Internet eta telefonoa batera (ez dago beti piztuta)

Digital Subscriber Line (DSL)



- Existitzen den infraestruktura telefonikoa erabiltzen du
- up to 1 Mbps upstream (today typically < 256 kbps)
- up to 8 Mbps downstream (today typically < 1 Mbps)
- Lerro dedikatu bat erabiltzen du zentralitaraino

Residential access: cable modems

- EZ du erabiltzen telefoniako infraestruktura
  - Hari bidezko telebistako infraestruktura erabiltzen du
- HFC: hybrid fiber coax
  - asymmetric: up to 30Mbps downstream, 2 Mbps upstream
- Sarea, haria eta zuntzekoa da ISPren routerreraino

Residential access: cable modems

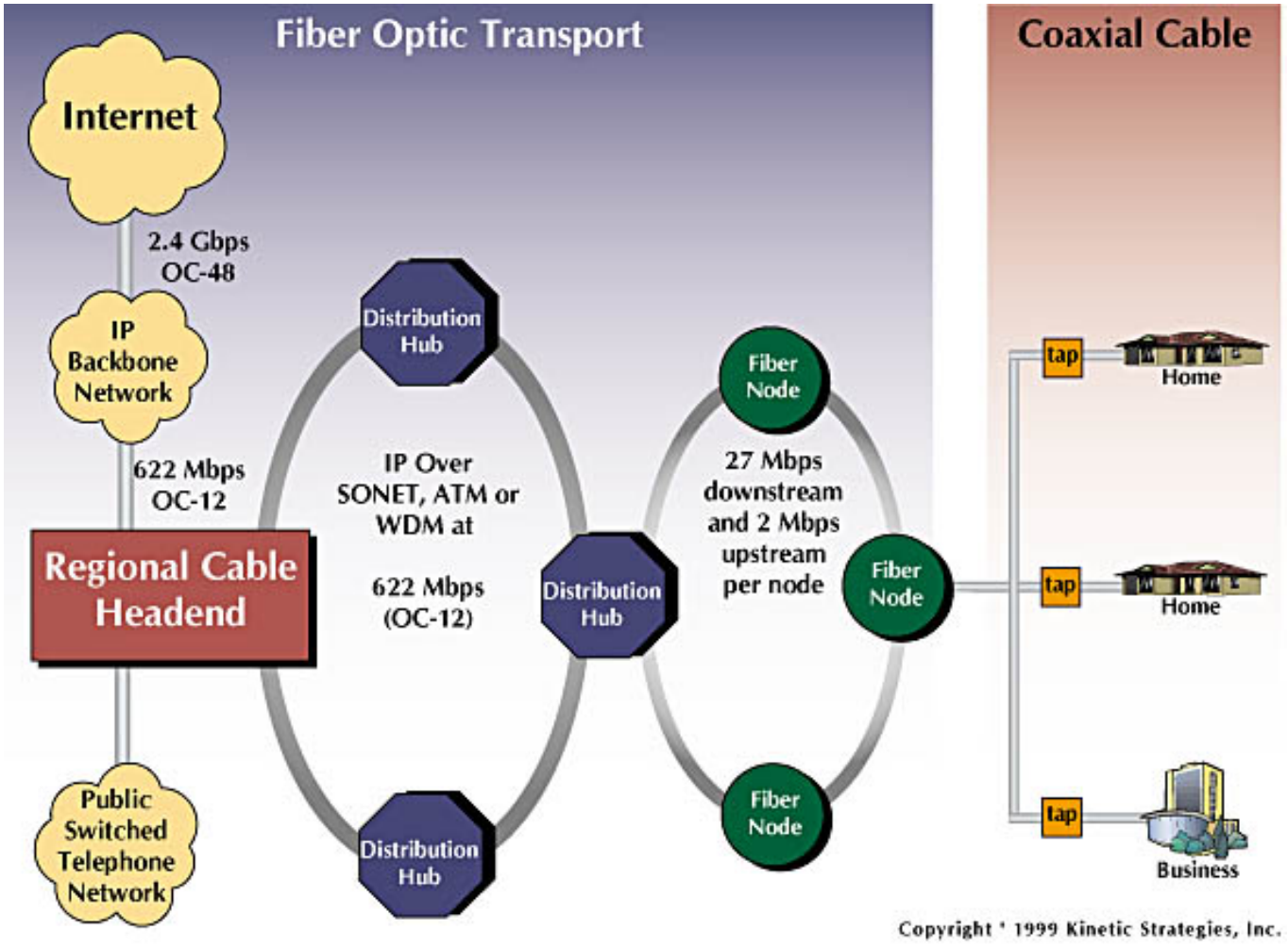
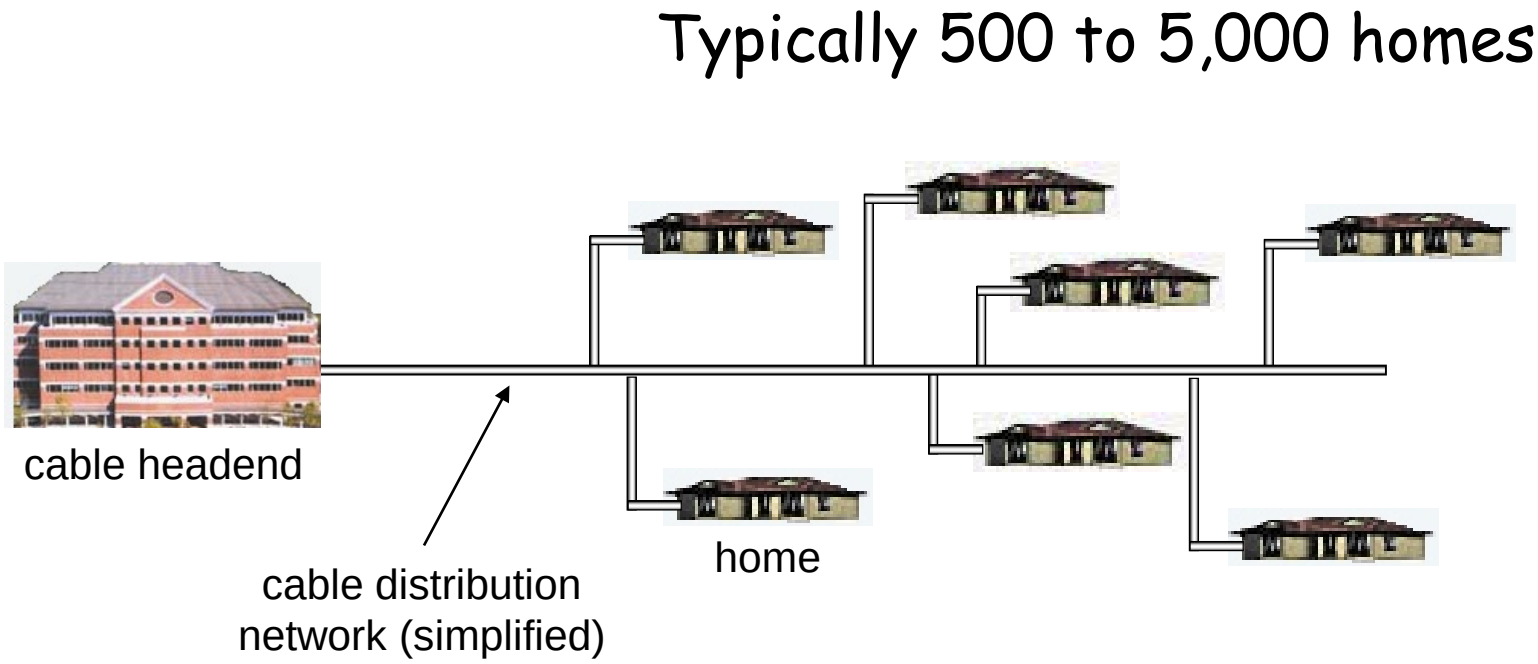
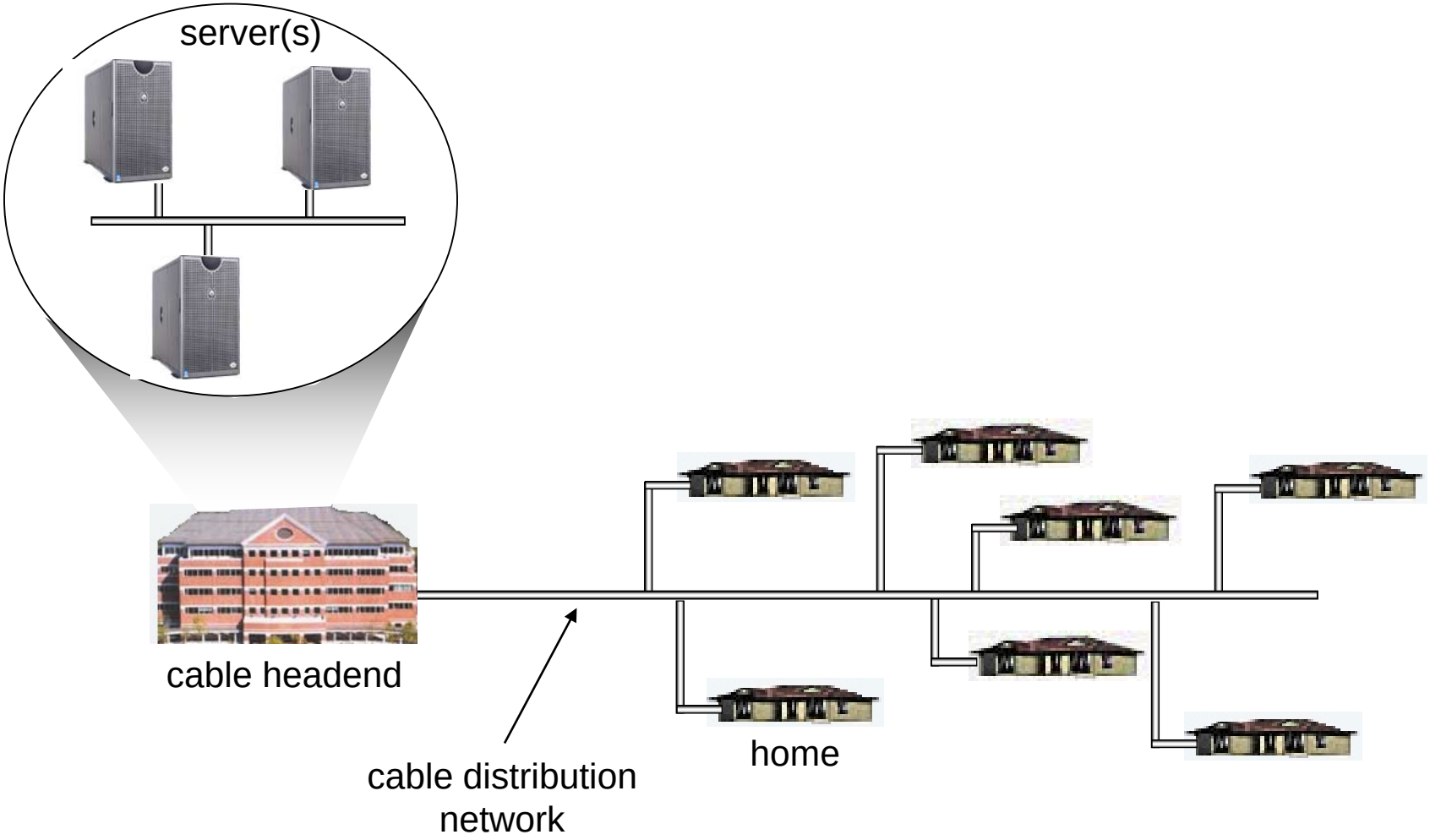


Diagram: http://www.cabledatacomnews.com/cmic/diagram.html

Cable Network Architecture: Overview



Cable Network Architecture: Overview



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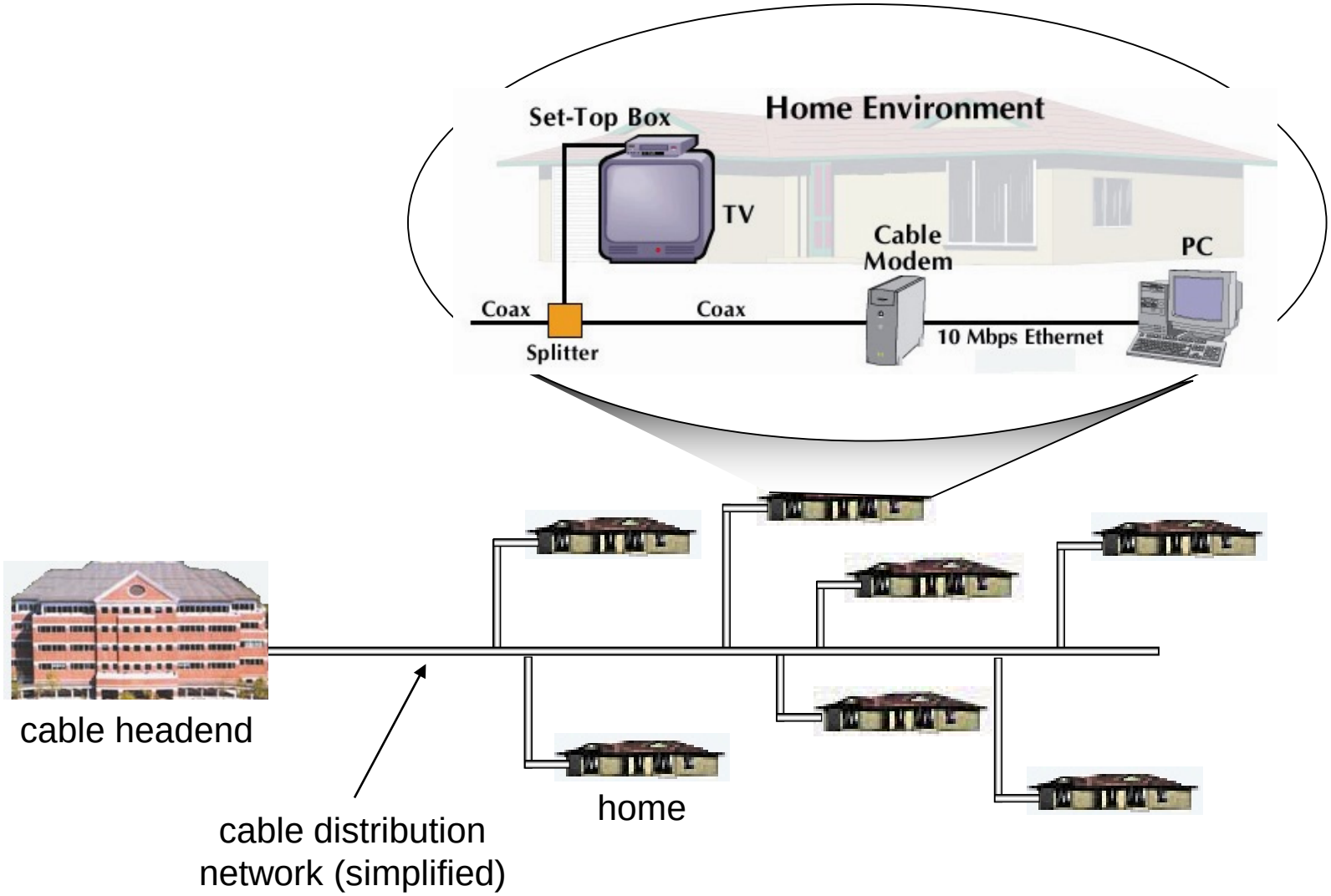
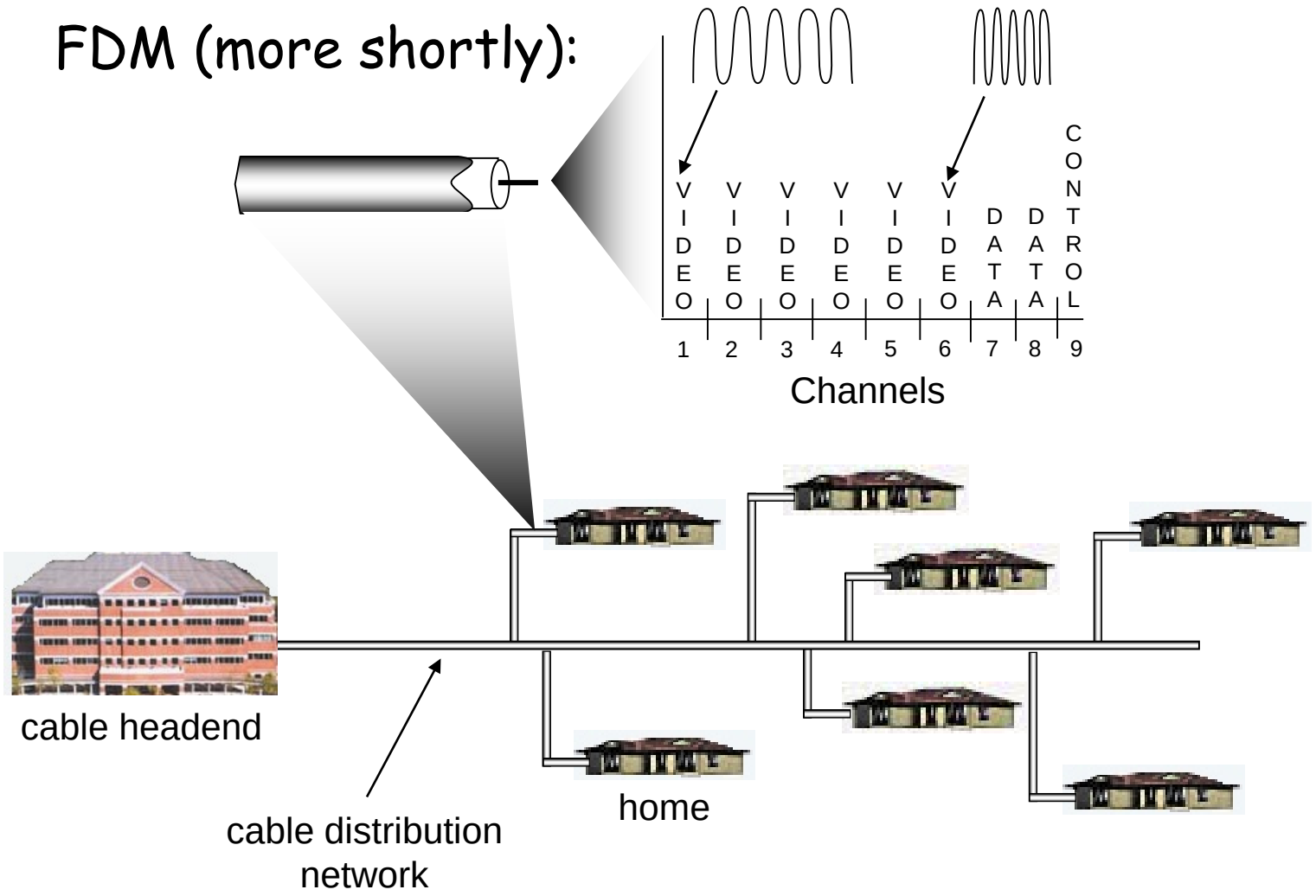
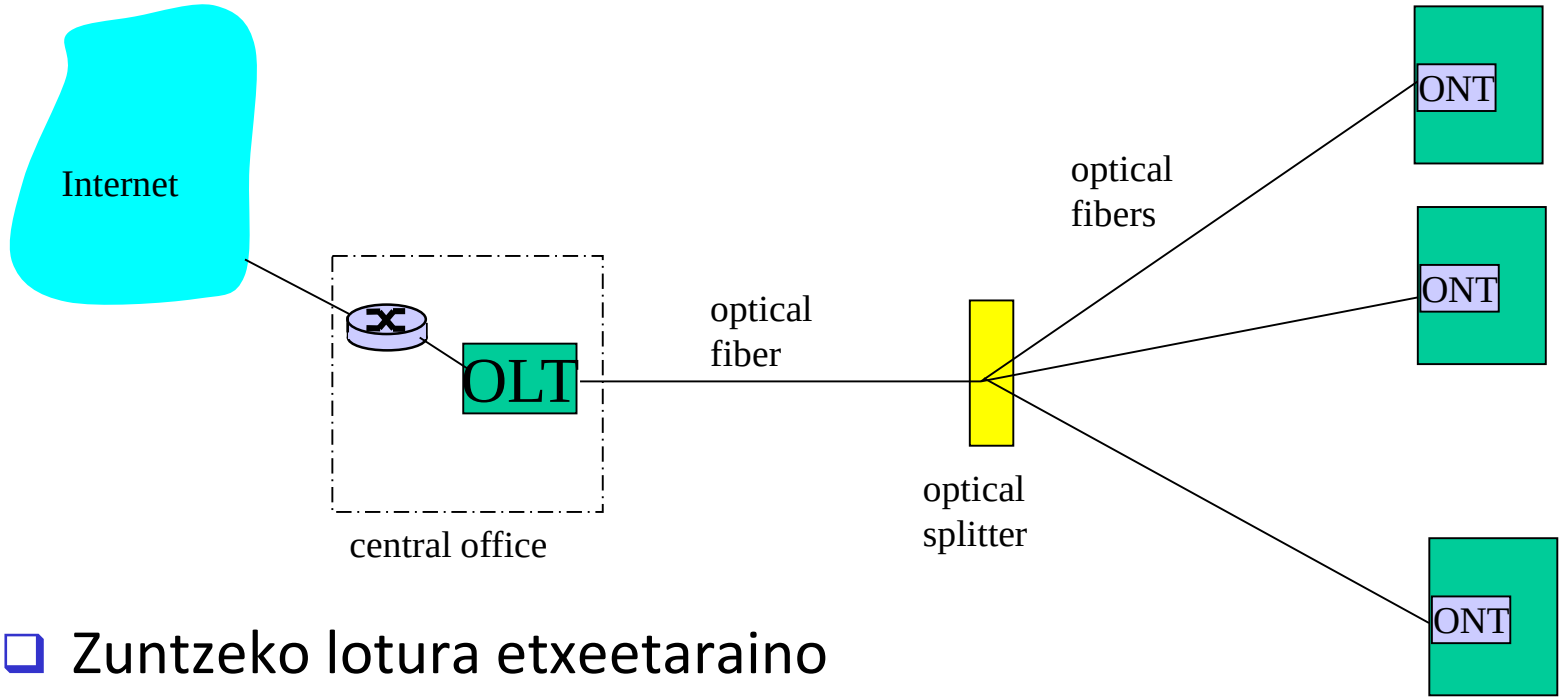


Cable Network Architecture: Overview

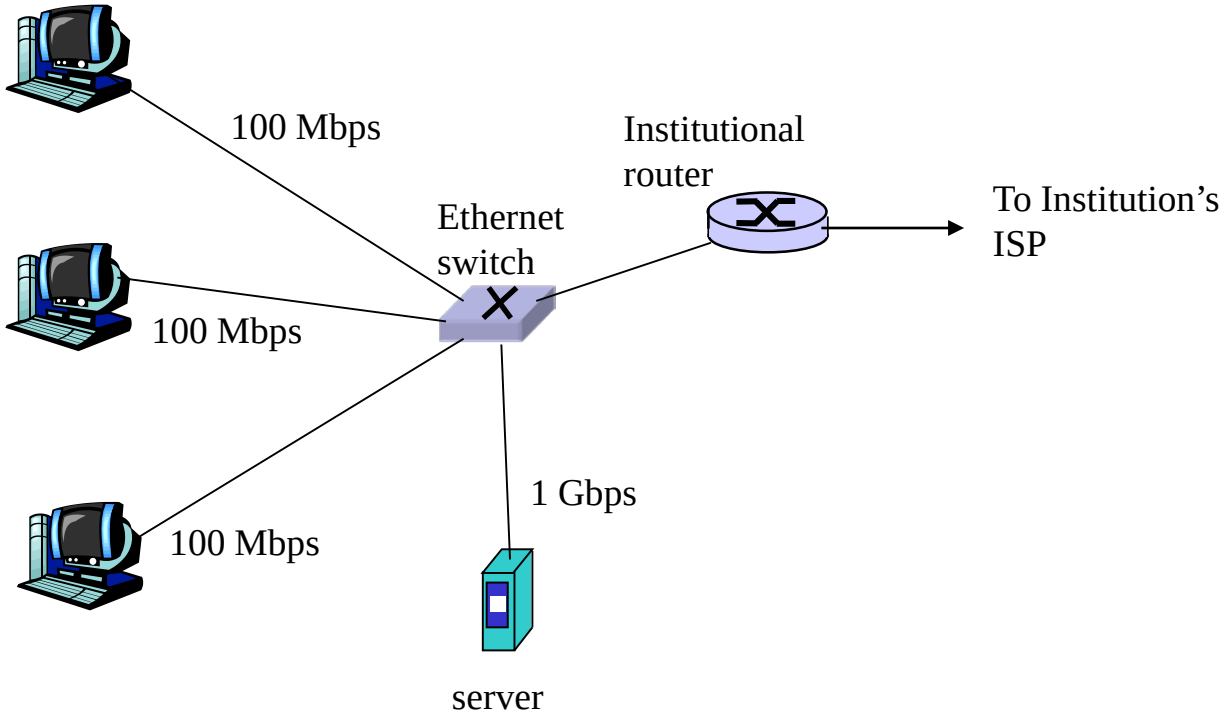


Fiber to the Home



- Zuntzeko lotura etxeetaraino
- Bi teknologia:
  - Passive Optical network (PON)
  - Active Optical Network (PAN)
- Abiadura handiagoak; zuntzak, telebista eta telefonoa ere eramaten du
- Kostu handiago

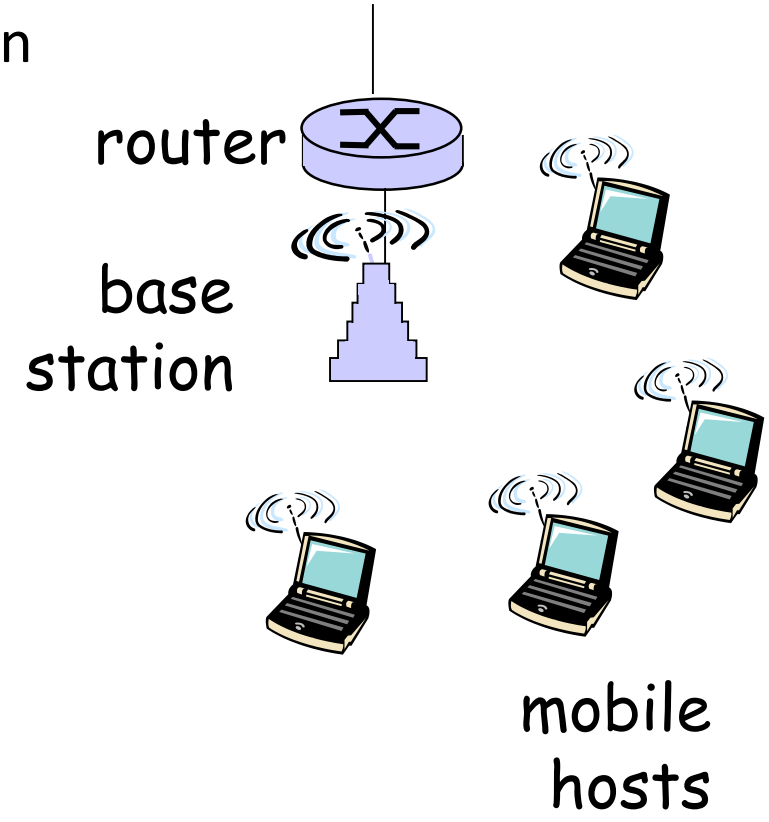
Ethernet Internet access



- Enpresa, unibertsitateetan… erabiltzen da normalean
- 10 Mbs, 100Mbps, 1Gbps, 10Gbps Ethernet
- Gaur egun, terminalak switch-en bidez konektatzen dira

Wireless access networks

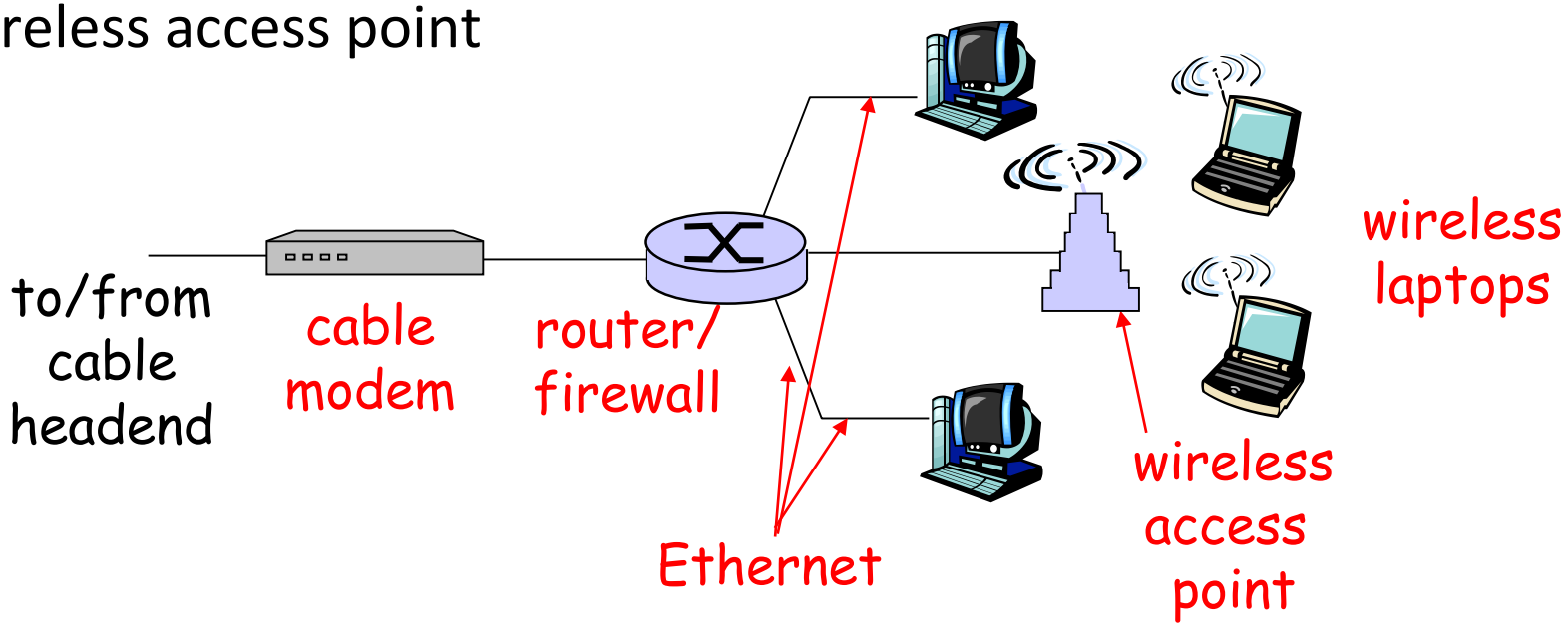
- *Sarerako wireless* bidezko atzipen puntuak terminal eta router artean
  - via “access point”
- wireless LANs:
  - 802.11ay (WiFi): 20 Gbps
- wider-area wireless access
  - Telekomunikazio enpresen bidez
  - 3G, 4G, 5G…



Etxeetako sareak

Etxeetako sareen oinarrizko elementuak:

- DSL edo cable modem
- router/firewall/NAT
- Ethernet
- wireless access point



Physical Media

- Bit: terminalen artean hedatzen da
- physical link: emisore eta hartzailearen artean dagoena
- guided media:
  - Seinalea, medio solido batean hedatzen da: copper, fiber, coax
- unguided media:
  - Seinaleak aske hedatzen dira, e.g., radio

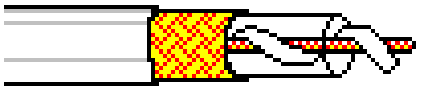
Twisted Pair (TP)

- Isolatutako kuprezko bi hari
  - Category 3: traditional phone wires, 10 Mbps Ethernet
  - Category 5: 100Mbps Ethernet
  - Cat 6: 10GBASE-T Ethernet
  - Cat 8.2: 40GBASE-T Ethernet

Physical Media: coax, fiber

Coaxial cable:

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



Fiber optic cable:

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

Physical media: radio

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

Radio link types:

- terrestrial microwave
  - e.g. up to 45 Mbps channels
- LAN (e.g., Wifi)
  - 11Mbps, 54 Mbps
- wide-area (e.g., cellular)
  - 3G cellular: ~ 1 Mbps
  - 5G cellular: ~ 10 Gbps
- satellite
  - Kbps to 45Mbps channel (or multiple smaller channels)
  - 270 msec end-end delay
  - geosynchronous versus low altitude

➢ Maiztasun bandaren banaketa

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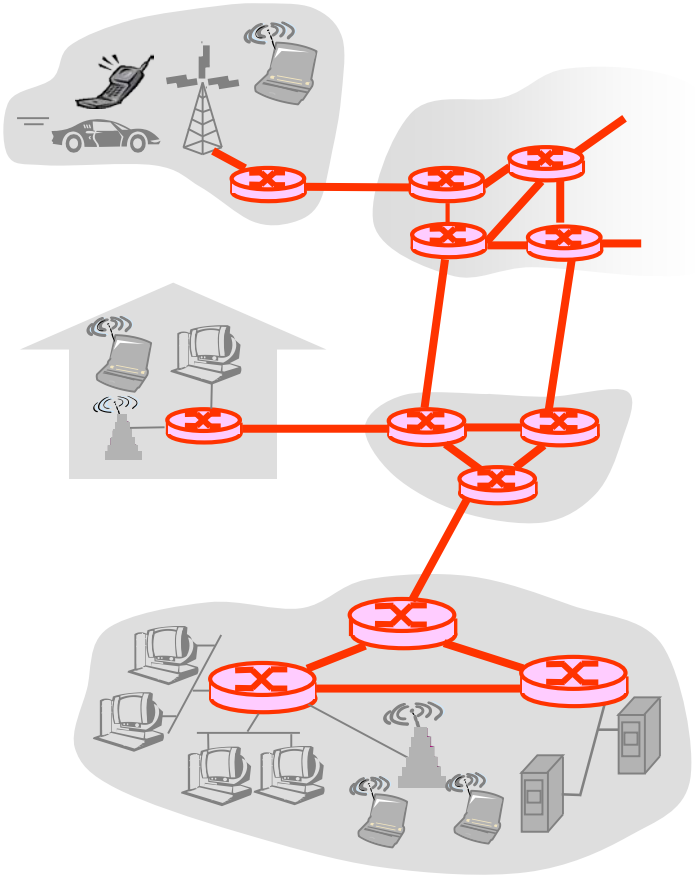
1.5 Protokoloen geruzak, Zerbitzuen ereduak

1.6 Segurtasuna

1.7 Historia

Sarearen nukleoa

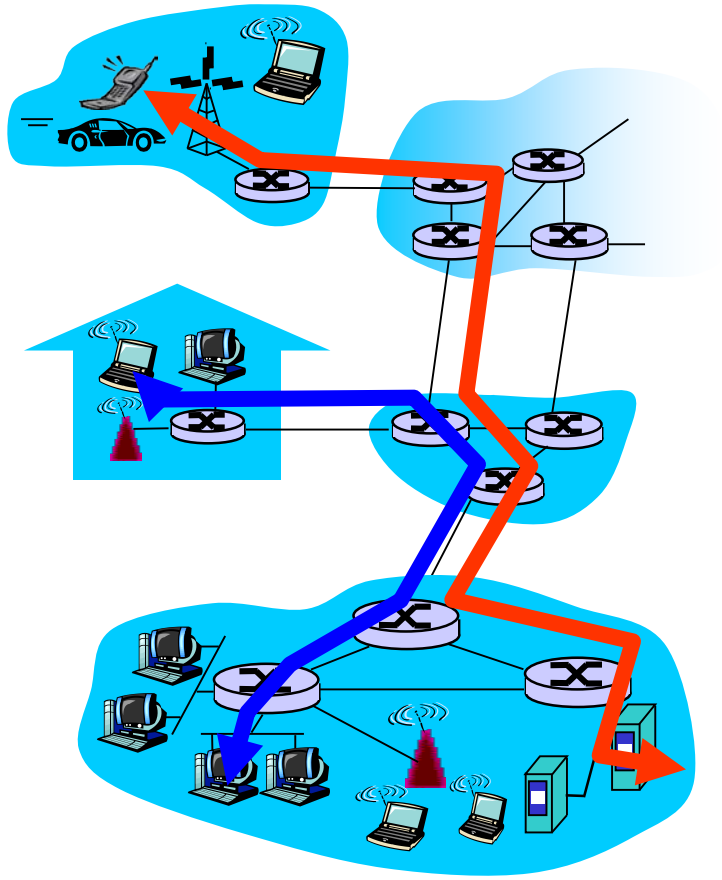
- Elkar konektatutako routerren banaketa
- *Oinarrizko galdera*: Nola bideratzen da informazioa sarean?
  - circuit switching: zirkuitu dedikatu baten bidez: sare telefonikoa
  - packet-switching: informazioa pakete diskretuetan bidaltzen da sarean zehar



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)*

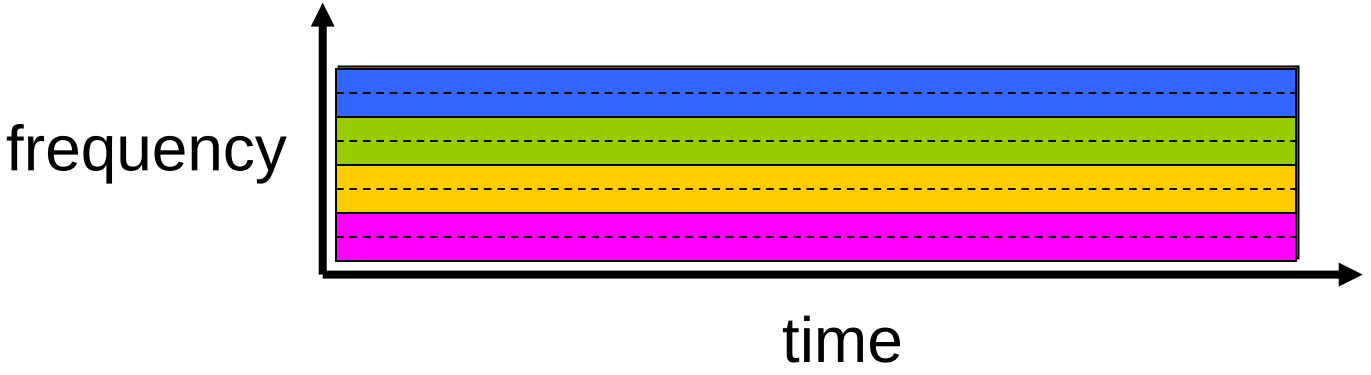
- dividing link bandwidth into "pieces"
  - frequency division
  - time division

Circuit Switching: FDM and TDM

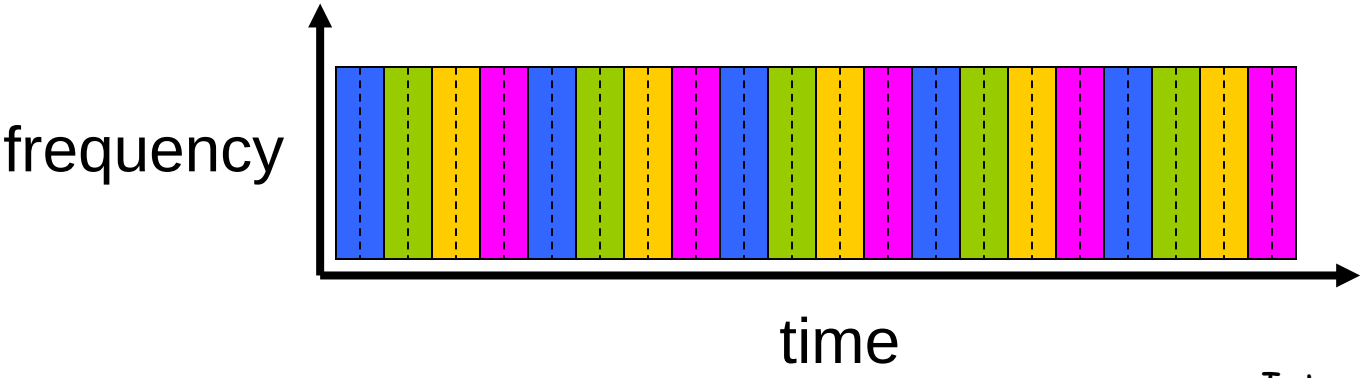
Example:

4 users

FDM



TDM



Numerical example

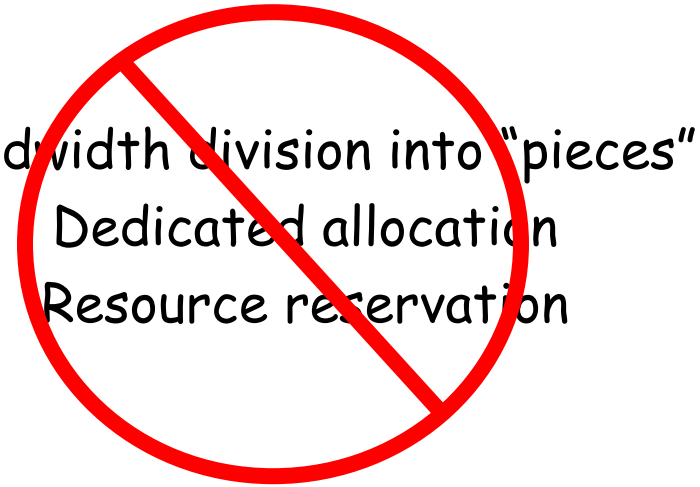
- How long does it take to send a file of 640,000 bits from host A to host B over a circuit-switched network?
  - All links are 1.536 Mbps
  - Each link uses TDM with 24 slots/sec
  - 500 msec to establish end-to-end circuit

Let's work it out!

Network Core: Packet Switching

Terminalen arteko informazio fluxua *paketetan* banatzen da

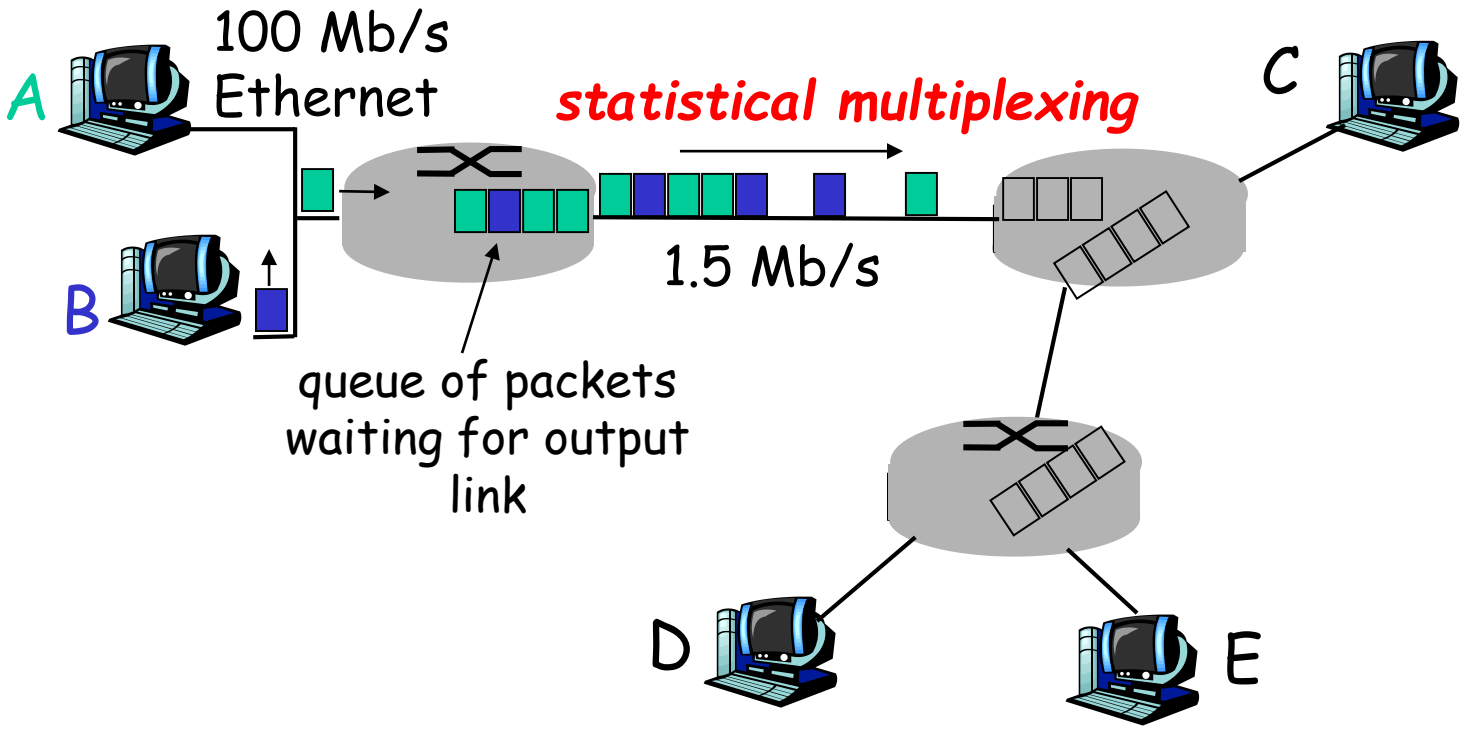
- Erabiltzaileek sarearen baliabideak partekatzen dituzte
- *Pakete* bakoitzak banda zabalera osoa erabiltzen du
- Errekurtsoak, behar direnean erabiltzen dira



Baliabideen falta:

- Eskatzen den baliabideen erabilera, posiblea baino handiago izan daiteke
- Kongestioa: paketeak pilatzen dira, bideraketaren zain (buffer)
- store and forward: paketeek jauzi bat egiten dute bakoitzean
  - Nodoak pakete osoa jasotzen du bidali aurretik

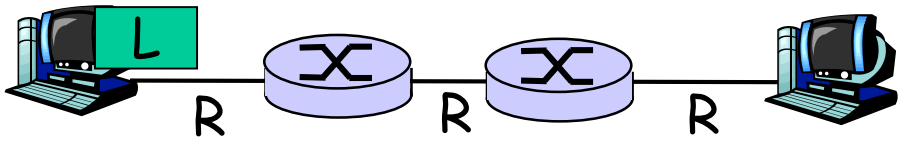
Packet Switching: Statistical Multiplexing



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

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

Packet-switching: store-and-forward



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

Example:

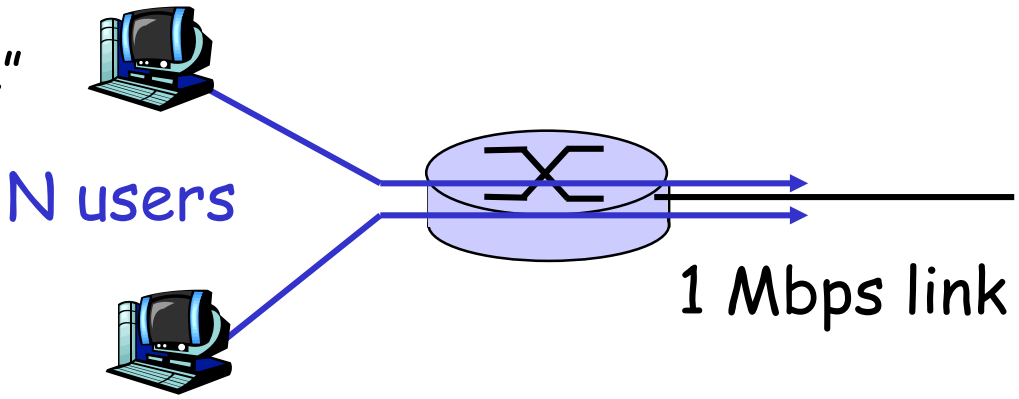
- L = 7.5 Mbits
- R = 1.5 Mbps
- transmission delay = 15 sec

more on delay shortly …

Packet switching versus circuit switching

Packet switching ahalbidetzen du sarea erabiltzaile gehiagok erabiltzea!

- 1 Mb/s link
- each user:
  - 100 kb/s when "active"
  - active 10% of time
- *circuit-switching:*
  - 10 users
- *packet switching:*
  - with 35 users, probability > 10 active at same time is less than .0004



Q: how did we get value 0.0004?

Packet switching versus circuit switching

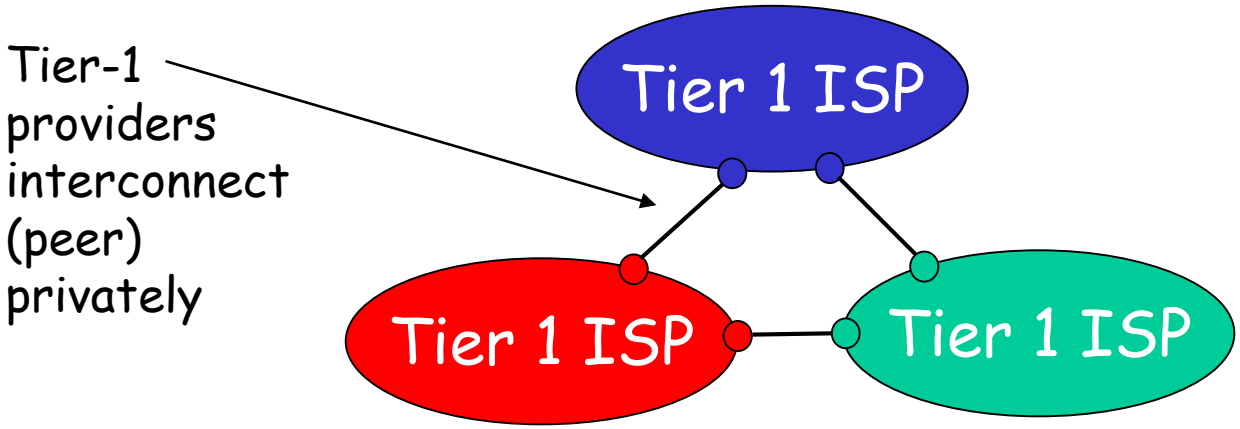
Paketen trukaketa irabazlea da?

- Egokia data fluxu ez jarraiarentzat
  - Baliabideak banatzen dira
  - errazago, ez dago deiaren ezarpena
- Kongestio gehiegi: paketeen galera eta atzerapenak
  - Protokoloak behar dira bideraketa egokia gauzatzeko, kongestio eta atzerapenak ekiditzeko
- Q: Nola ziurtatu zirkuitu moduko jokaera?
  - Banda zabalera ziurtatu behar da streming aplikazioetan

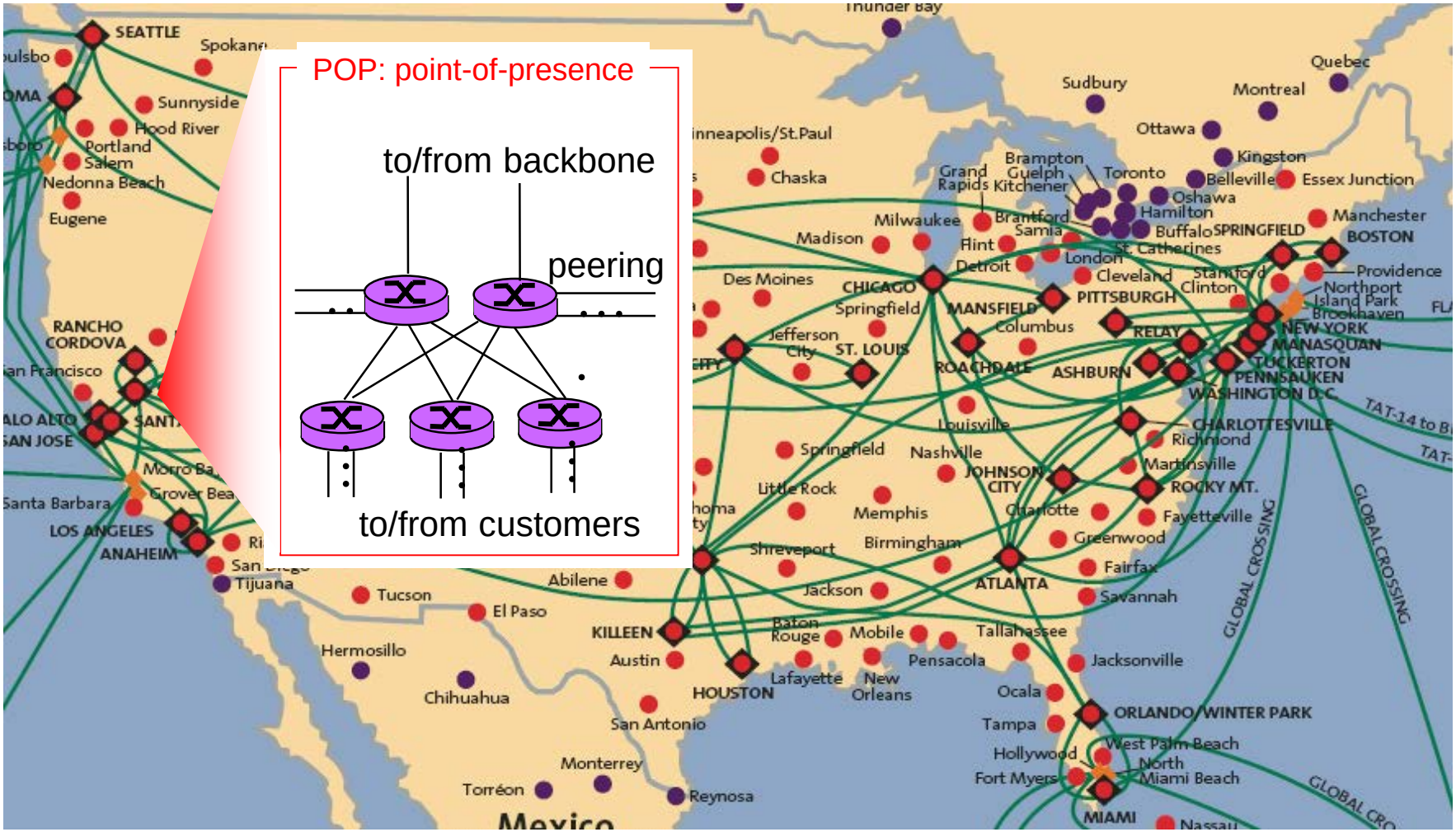
Q: human analogies of reserved resources (circuit switching) versus on-demand allocation (packet-switching)?

Internetaren egitura: sareen sarea

- Estruktura ez erabat ierarkikoa
- at center: “tier-1” ISPs (e.g., Verizon, Sprint, AT&T, Cable and Wireless), national/international coverage
  - Berdinen arteko tratamendua

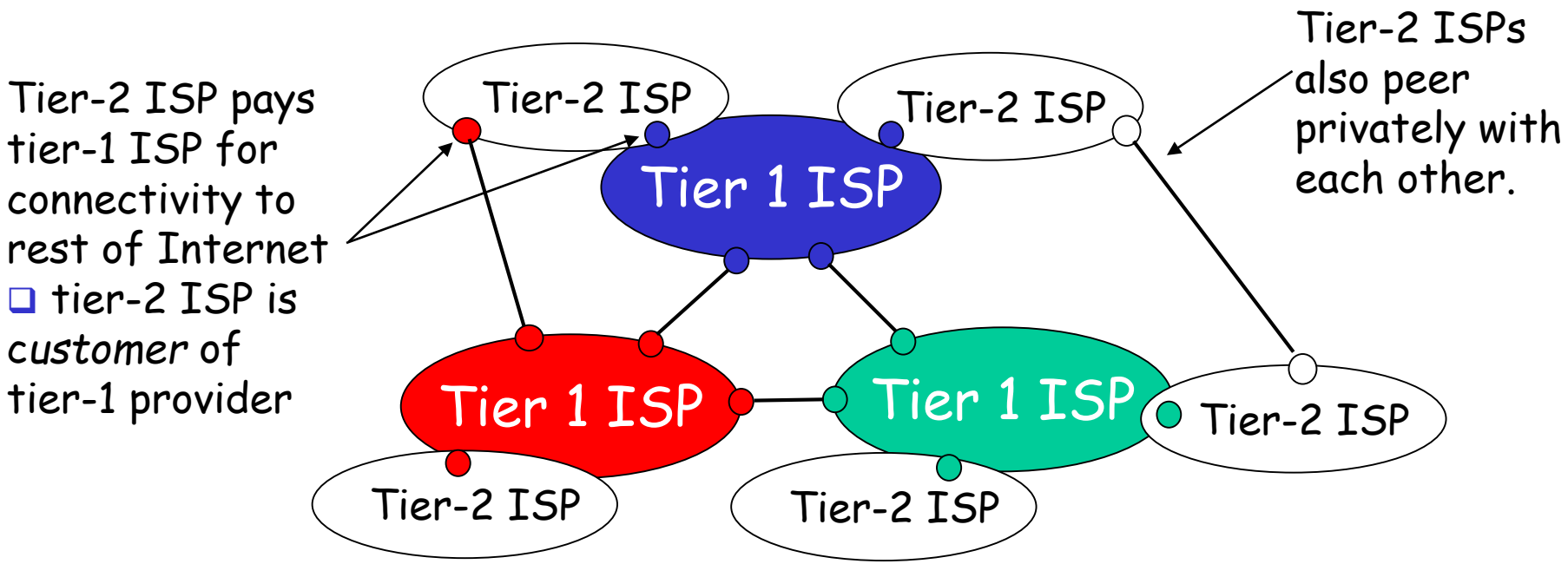


Tier-1 ISP: e.g., Sprint



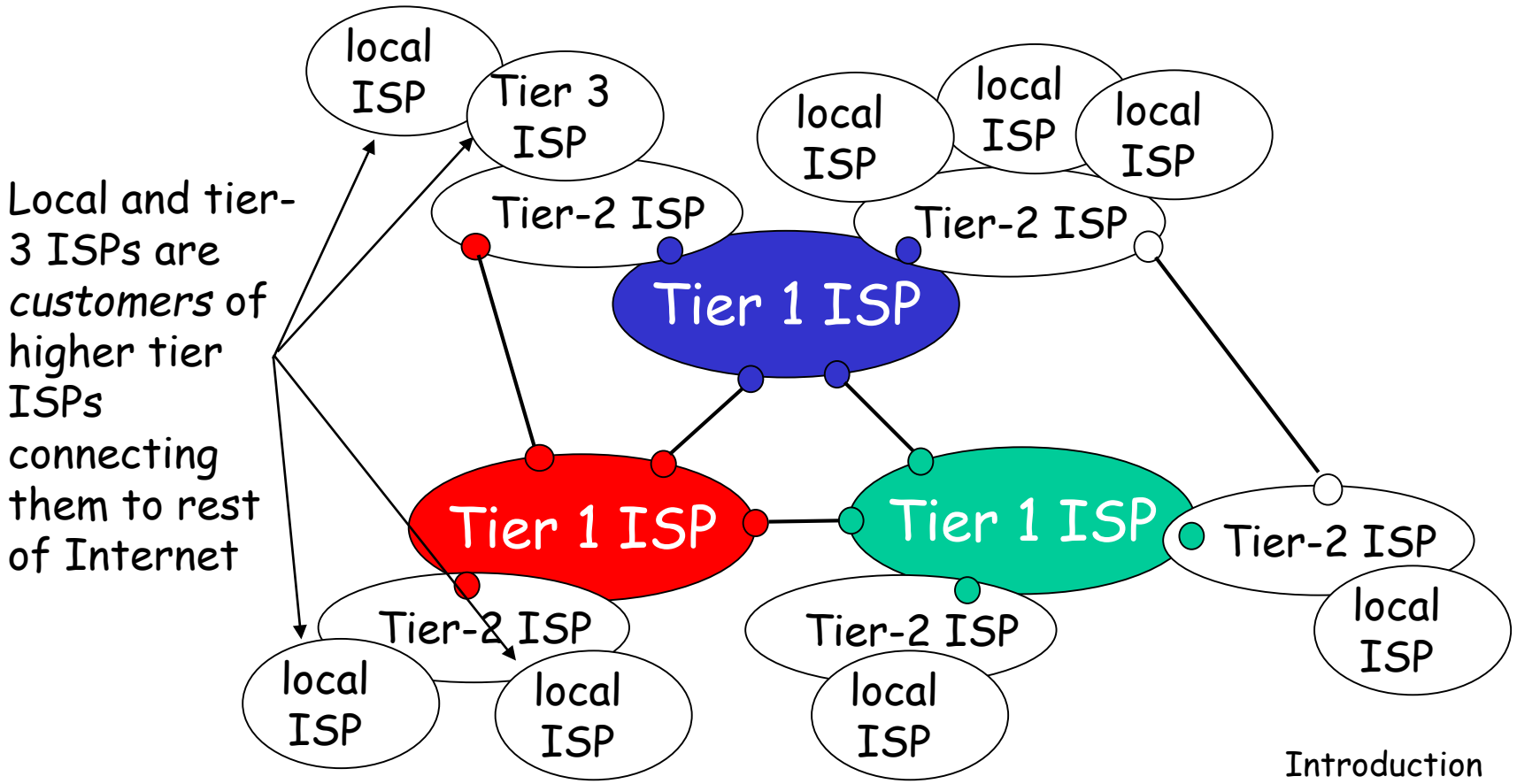
Internetaren egitura: sareen sarea

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



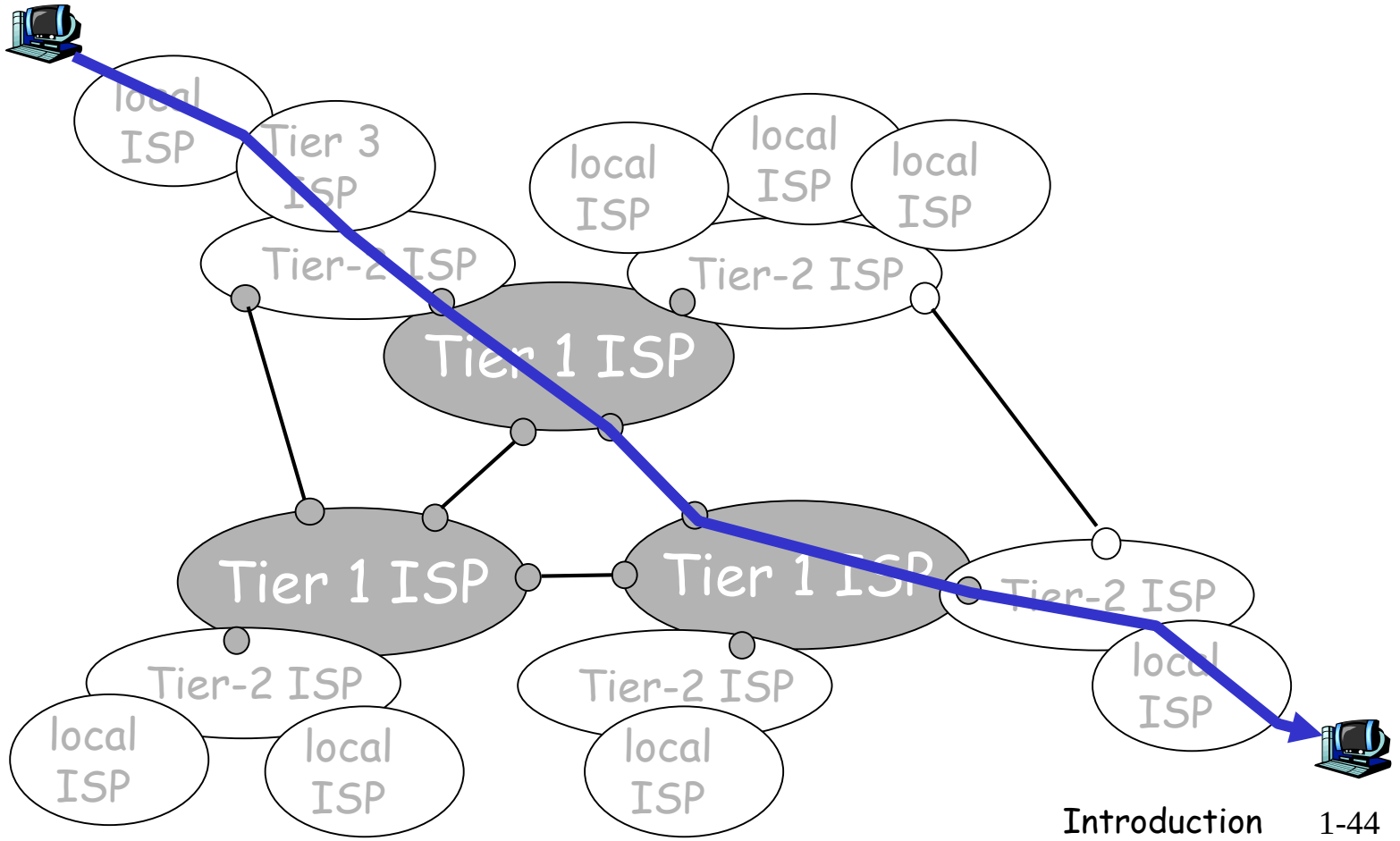
Internetaren egitura: sareen sarea

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



Internetaren egitura: sareen sarea

- Pakete bat sare ugaritik pasa daiteke!



1. Gaia: eskema

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1.3 Sarearen nukleoa

- circuit switching, packet switching, network structure

1.4 Atzerapenak, galerak eta etekina pakete-konmutatutako sareetan

1.5 Protokoloen geruzak, Zerbitzuen ereduak

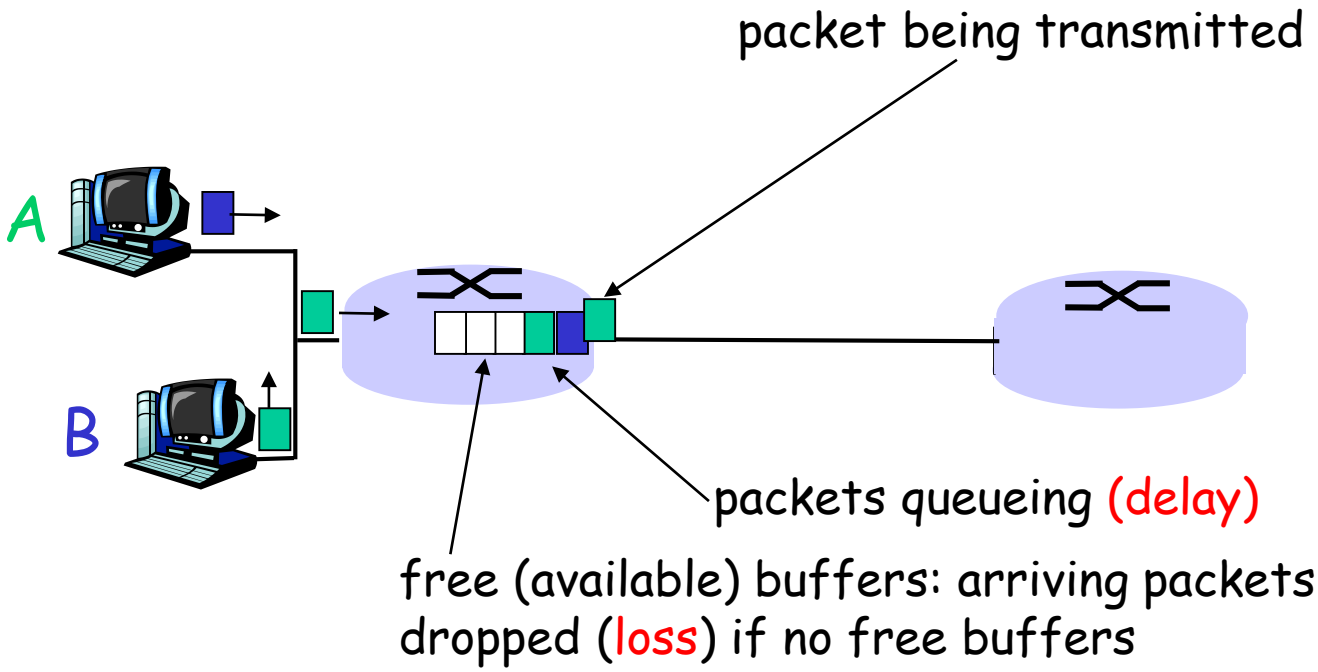
1.6 Segurtasuna

1.7 Historia

Nola gertatzen dira galerak eta atzerapenak?

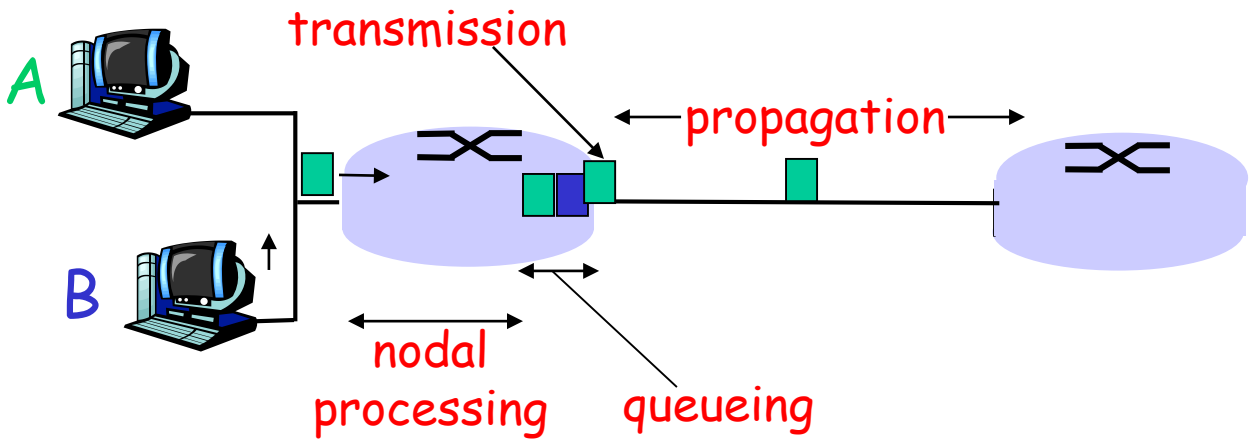
Paketeak, routerren bufferetan *pilatzen* dira

- Paketeen heltze abiadura bideraketarena baino handiagoa da
- Lerrokatutako paketeek haien txanda itxaron behar dute



Atzerapenen lau iturri

- 1. nodal processing:
  - Bit akatsen kudeaketa
  - Irteera nodoaren ebazpena
- 2. queueing
  - Itzaropen denbora bideraketa aurretik
  - Routerraren kongestio mailaren menpe



Delay in packet-switched networks

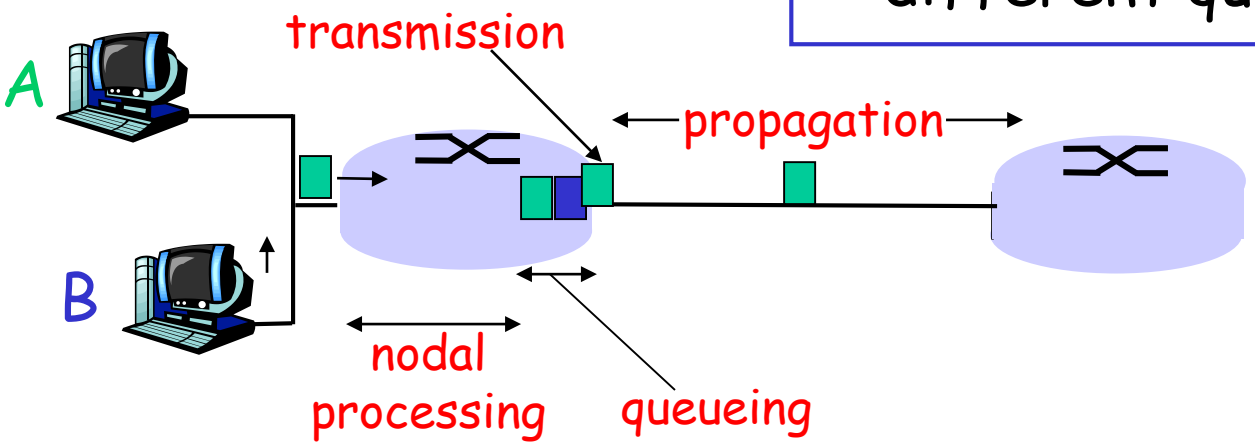
3. Transmission delay:

- R=link bandwidth (bps)
- L=packet length (bits)
- time to send bits into link = L/R

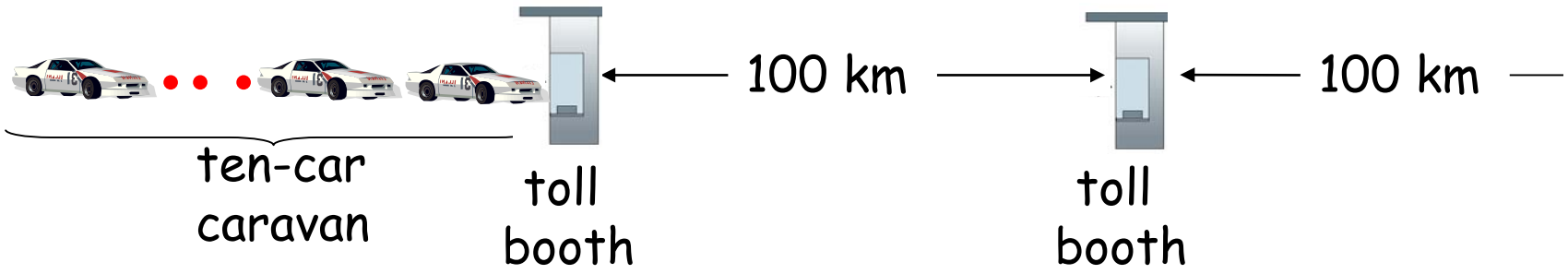
4. Propagation delay:

- 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!



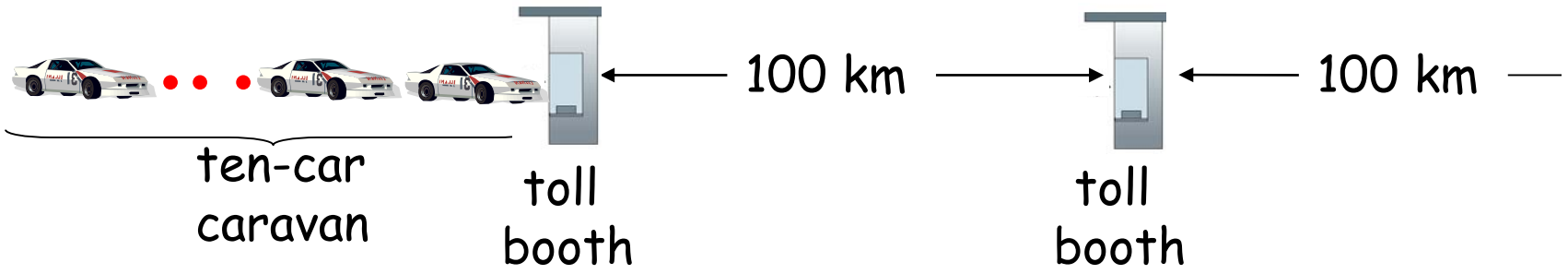
Caravan analogy



- cars "propagate" at 100 km/hr
- toll booth takes 12 sec to service 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

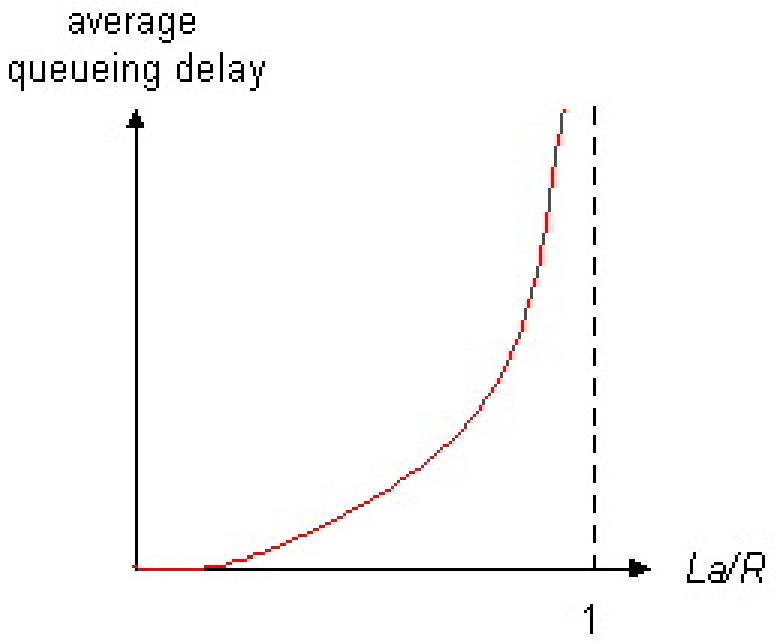
$$d_{\text{nodal}} = d_{\text{proc}} + d_{\text{queue}} + d_{\text{trans}} + d_{\text{prop}}$$

- 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

Queueing delay (revisited)

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

traffic intensity = La/R

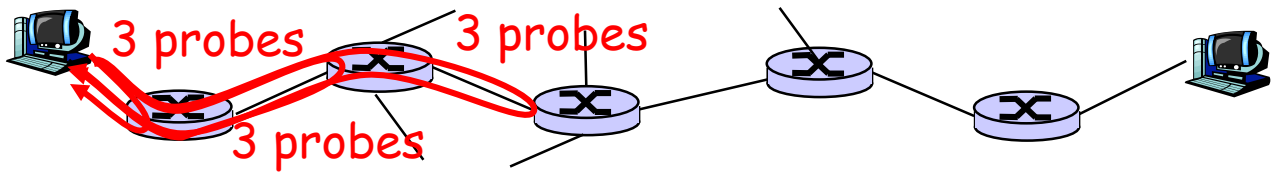


- La/R ~ 0: average queueing delay small
- La/R -> 1: delays become large
- La/R > 1: more "work" arriving than can be serviced, average delay infinite!

“Real” Internet delays and routes

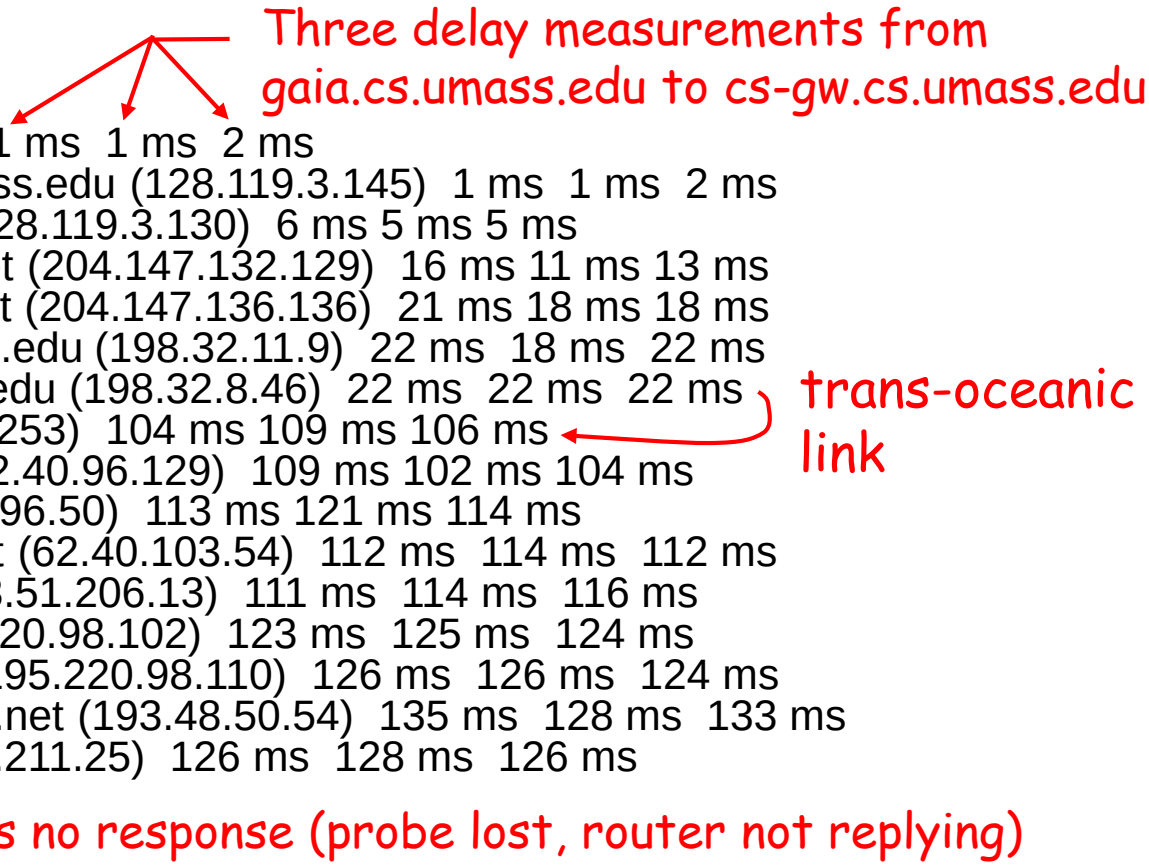
- Nolakoak dira “benetako” Internetaren atzerapenak eta galerake?
- **`Traceroute`** program: bi terminalen arteko paketeen bidea erakusten du, baita tarteko nodoetan gauzatutako atzerapena:
  - sends three packets that will reach router *i* on path towards destination
  - router *i* will return packets to sender
  - sender times interval between transmission and reply.

```
C:\>Tracert www.google.com
```



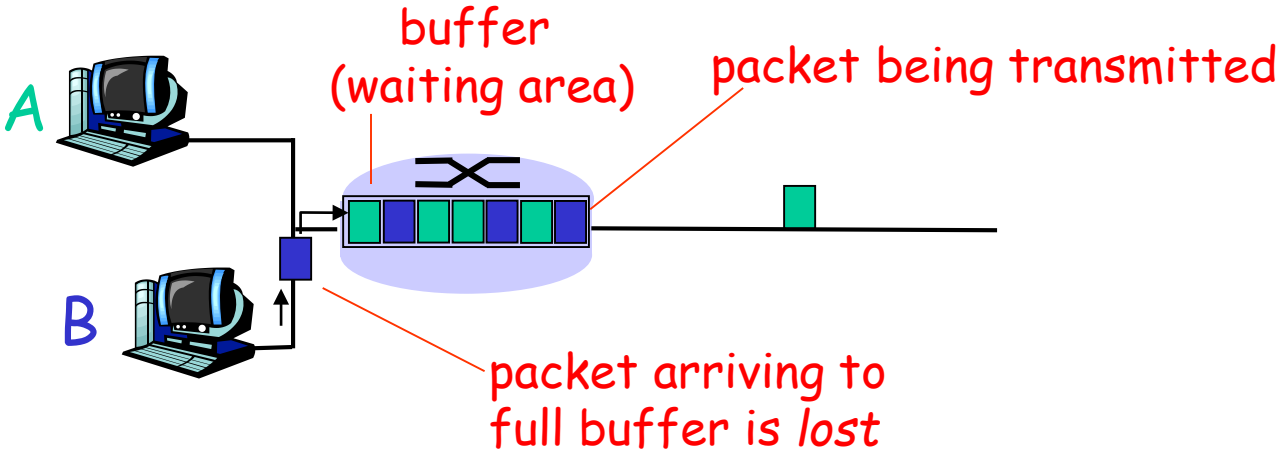
"Real" Internet delays and routes

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



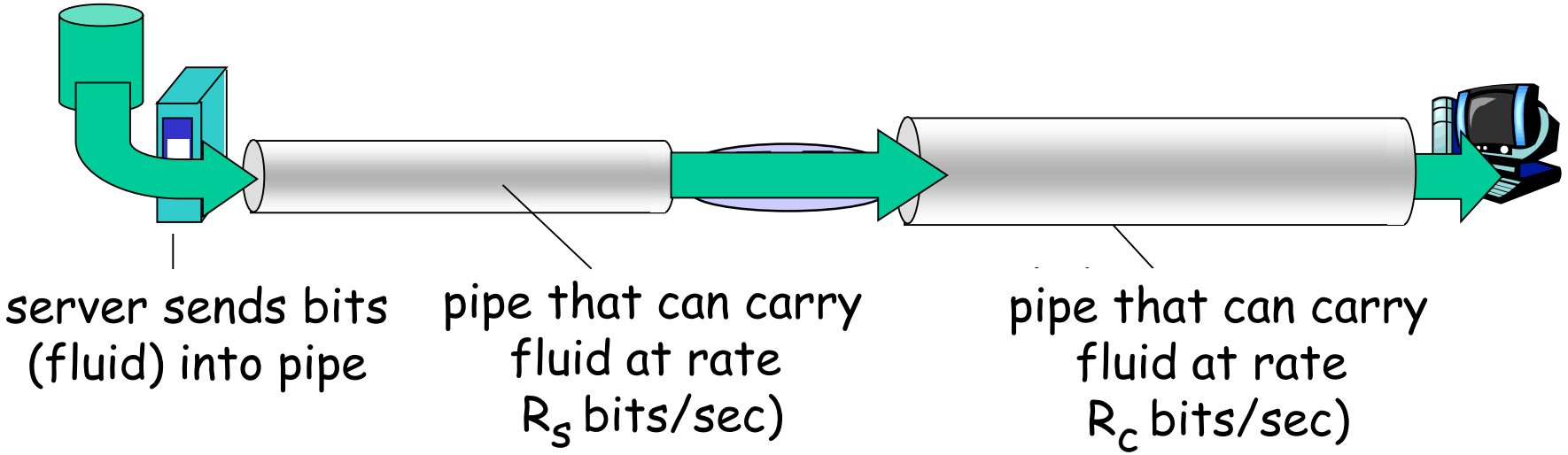
Paketen galerak

- Switch-ek edukiera mugatua da (buffer)
- Beteriko buffer-etara heltzen diren paketeak galtzen dira (lost)
- Aurreko nodoak edo Iturriak galdutako paketeak berbidal ditzakete (edo ez)



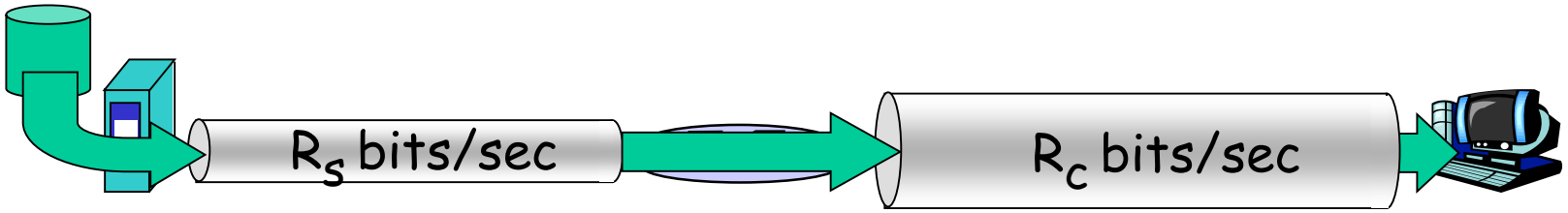
Throughput (etekina)

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

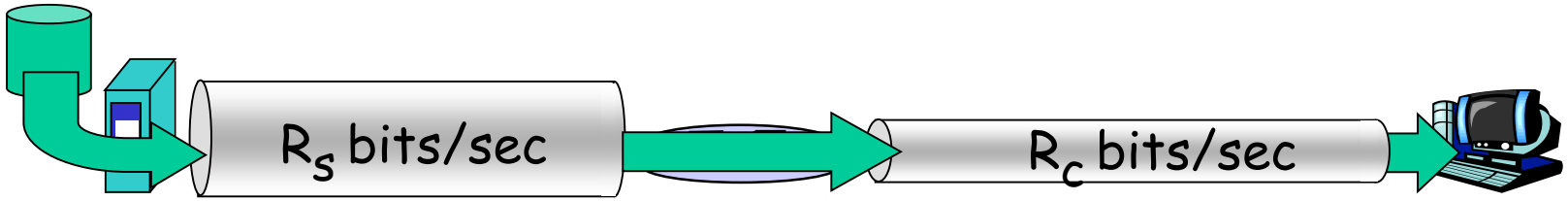


Throughput (more)

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



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

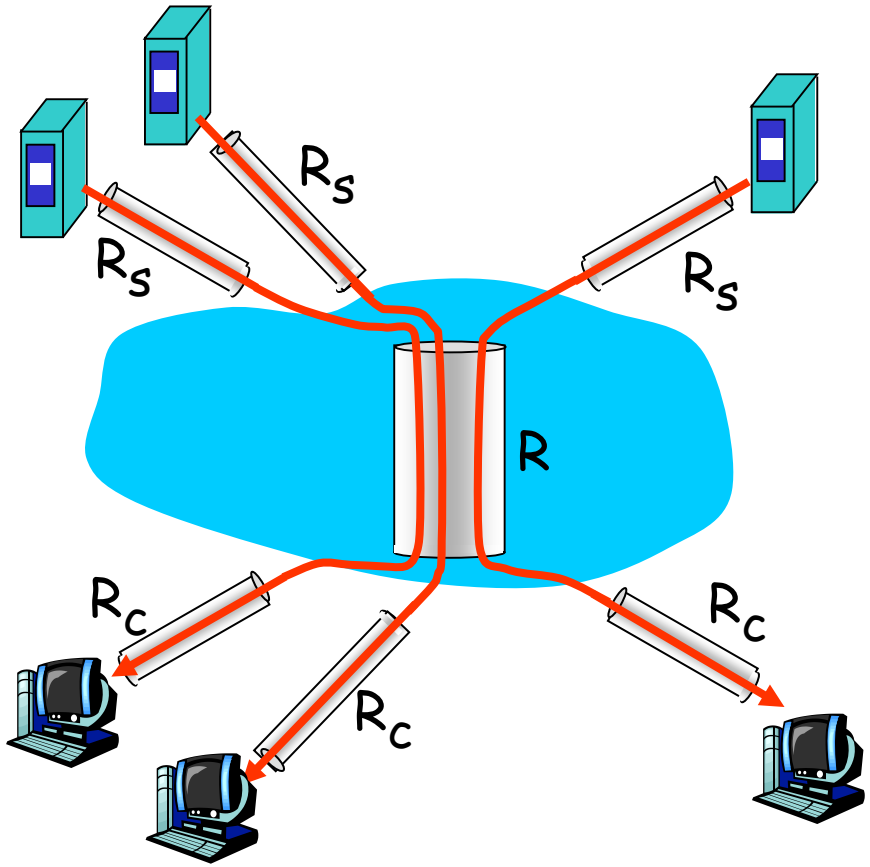


bottleneck link

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

Etekina: Internet-a

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



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

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1.4 Atzerapenak, galerak eta etekina pakete-konmutatutako sareetan

1.5 Protokoloen geruzak, Zerbitzuen ereduak

1.6 Segurtasuna

1.7 Historia

Protokoloen “geruzak”

Sareak konplexuak dira!

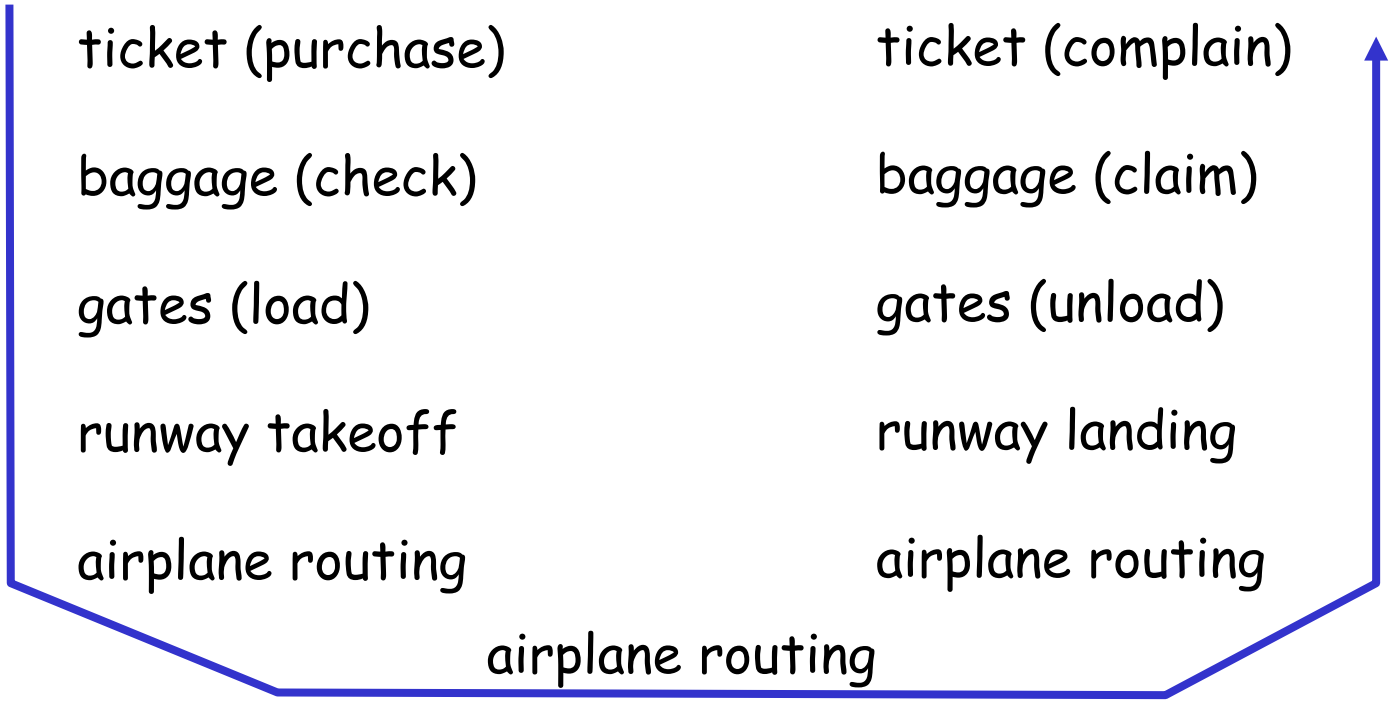
- “Elementu” ugari:
  - hosts
  - routers
  - links of various media
  - applications
  - protocols
  - hardware, software

Galdera:

Sarearen estruktura antolatzeko asmorik al da?

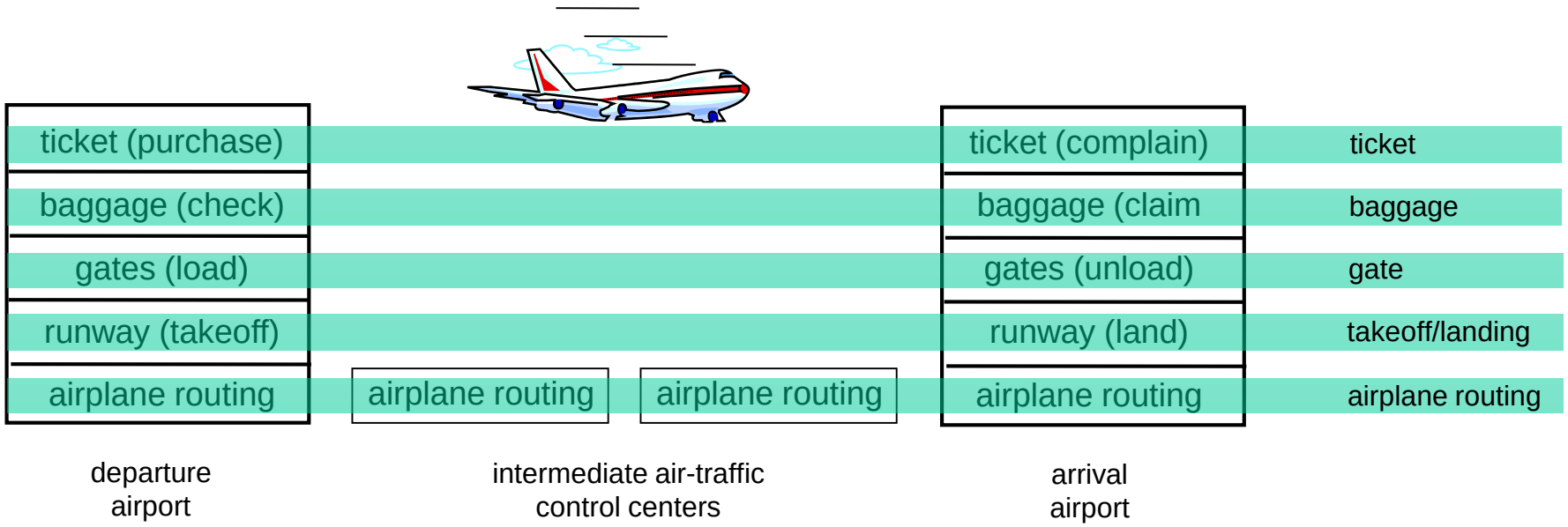
Or at least our discussion of networks?

Hegazkin bidezko bidaiaren antolaketa



- Pausu desberdinak

Layering of airline functionality



Geruzak: Geruza bakoitzak serbitzu bat betetzen du

- Bere geruzaren betebeharrak betetzen
- Beheko geruzak egin behar duen lana ondo egin duela suposatuz

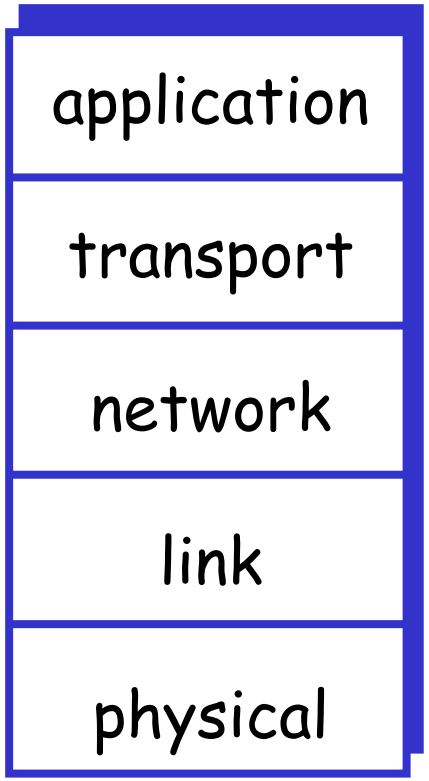
Zergatik geruzak?

Sistema konplexuak dira:

- Estruktura esplizitu batek sistema konplexuen piezen identifikazio eta erlazioen definizioa ahalbidetzen du
  - Ereduak
- Modularizazioak sistemaren eguneraketa eta mantentze lanak errazten ditu
  - Geruza batean gertatzen diren aldaketak gardenak dira besteentzat

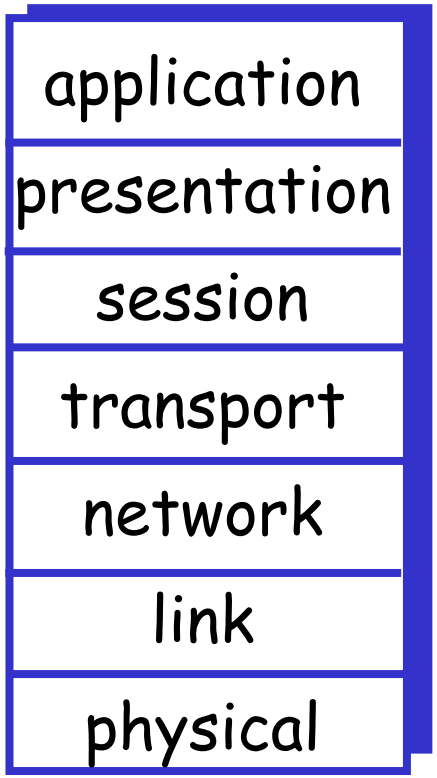
Internet protokoloak

- Aplikazioa: Sareko aplikazioen soportea
  - FTP, SMTP, HTTP
- Garraioa: prozesuen arteko data bidalketa
  - TCP, UDP
- Sarea: datagramen bideraketa iturri eta helmuga artean
  - IP, routing protocols
- Lotura: paketeen transferentzia elkarren-ondoko nodoen artean
  - PPP, Ethernet
- Fisikoa: bits “on the wire”

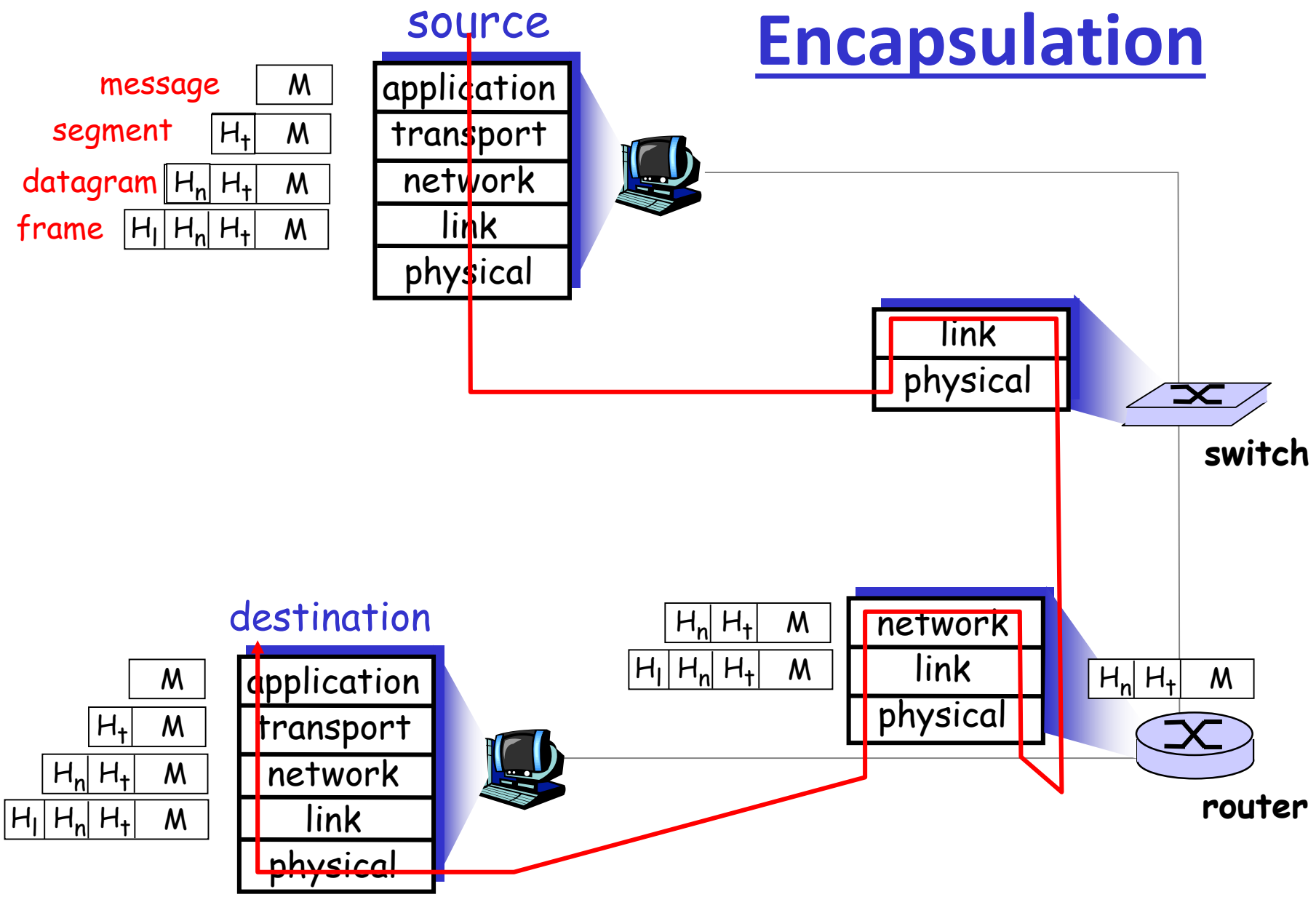


ISO/OSI Erreferentzia eredua

- presentation: allow applications to interpret meaning of data, e.g., encryption, compression, machine-specific conventions
- *session:* synchronization, checkpointing, recovery of data exchange
- Internet stack "missing" these layers!
  - these services, *if needed,* must be implemented in application
  - needed?



Encapsulation



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1.7 Historia

Sarearen segurtasuna

- The field of network security is about:
  - how bad guys can attack computer networks
  - how we can defend networks against attacks
  - how to design architectures that are immune to attacks
- Internet not originally designed with (much) security in mind
  - *original vision:* "a group of mutually trusting users attached to a transparent network" ☺
  - Internet protocol designers playing "catch-up"
  - Security considerations in all layers!

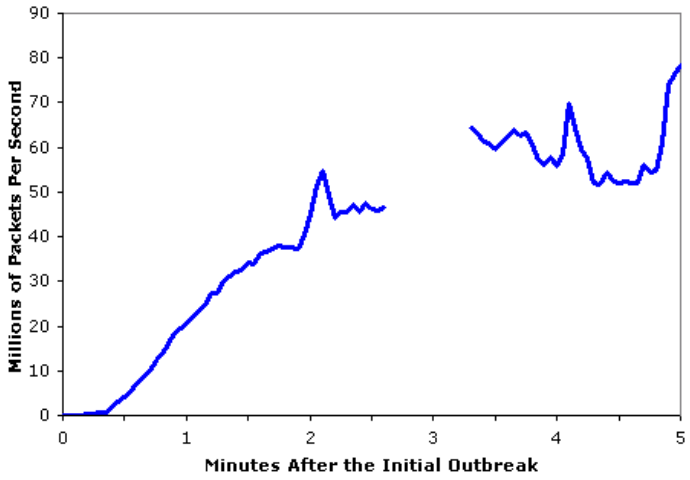
Bad guys can put malware into hosts via Internet

- Malware sar daiteke host batean birus, worm, edo trojan horse moduan.
- Spyware malware, sakatutako teklak, bisitatutako web orriak… lor ditzake, informazio hori “bad guys”ei pasatuz
- Kutsatutako host bat, botnet batean sar dezakete eta erabili spam eta DDoS erasoentzako.
- Malware auto-erreplikagarria da sarritan, beste host batzuk kutsatuz

Bad guys can put malware into hosts via Internet

- Trojan horse
  - Hidden part of some otherwise useful software
  - Today often on a Web page (Active-X, plugin)
- Virus
  - infection by receiving object (e.g., e-mail attachment), actively executing
  - self-replicating: propagate itself to other hosts, users
- Worm:
  - infection by passively receiving object that gets itself executed
  - self- replicating: propagates to other hosts, users

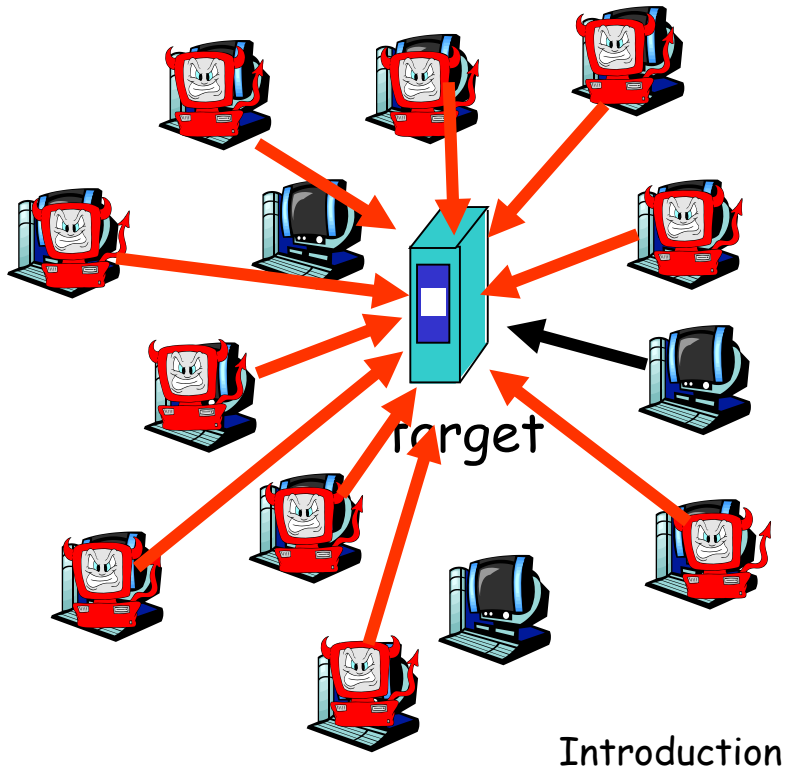
Sapphire Worm: aggregate scans/sec
in first 5 minutes of outbreak (CAIDA, UWisc data)



Bad guys can attack servers and network infrastructure

- Denial of service (DoS): Erasotzaileek, bidezko trafikoari errekurtsoak (server, bandwidth) kentzen dizkiote, bidezkoa ez den trafiko bidez gainkargatzen

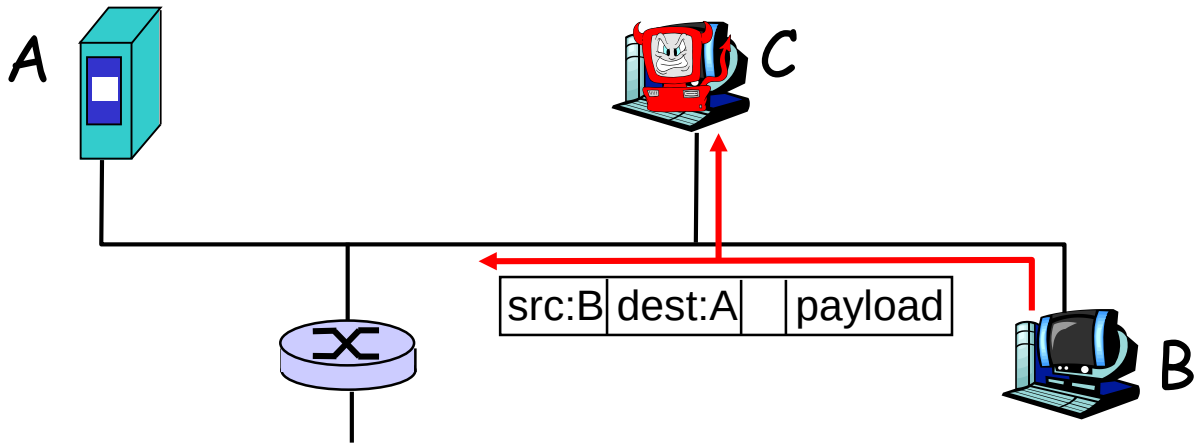
1. Helburua aukeratu
2. Botneteko hostetan "sartu"
3. Botnet-eko hostetatik trafikoa bidali helburuari



The bad guys can sniff packets

Packet sniffing:

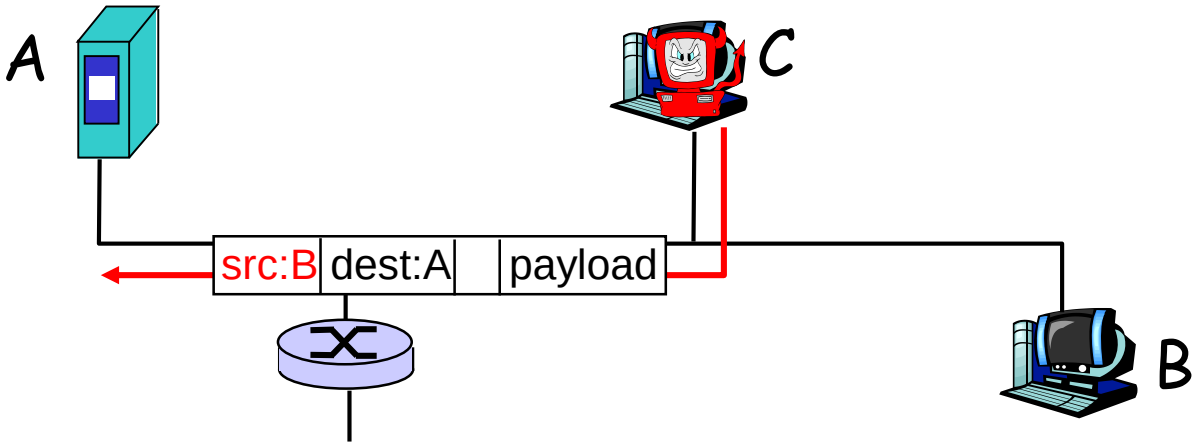
- broadcast media (shared Ethernet, wireless)
- promiscuous network interface reads/records all packets (e.g., including passwords!) passing by



- Wireshark software used for end-of-chapter labs is a (free) packet-sniffer

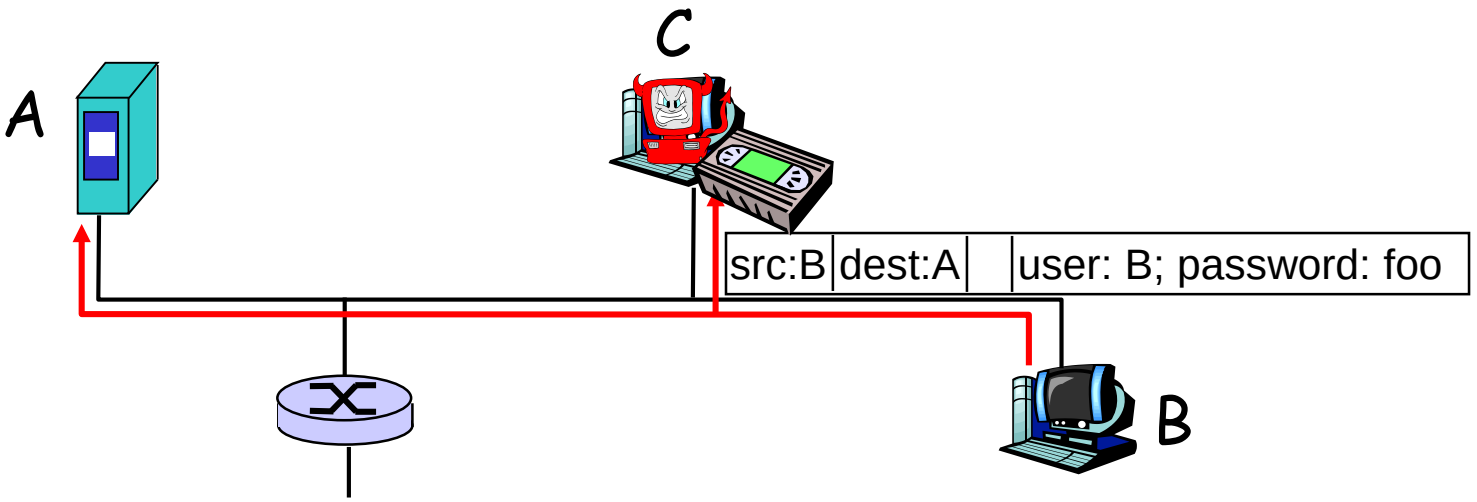
The bad guys can use false source addresses

- *IP spoofing:* send packet with false source address



The bad guys can record and playback

- *record-and-playback*: sniff sensitive info (e.g., password), and use later
  - password holder *is* that user from system point of view



Network Security

- more throughout this course
- chapter 8: focus on security
- crypographic techniques: obvious uses and not so obvious uses

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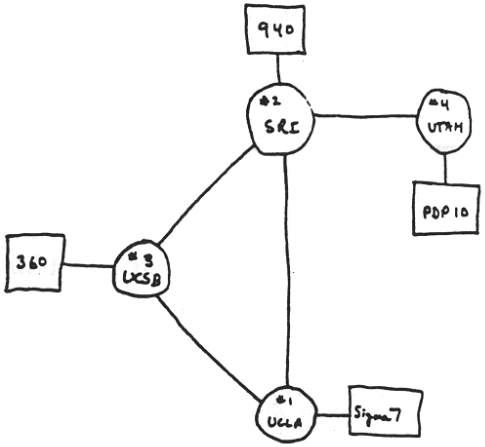
1.7 Historia

Internetaren Historioa

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 public demonstration
  - NCP (Network Control Protocol) first host-host protocol
  - first e-mail program
  - ARPAnet has 15 nodes



THE ARPA NETWORK

Internetaren Historioa

1972-1980: Internetworking, new and proprietary nets

- 1970: ALOHAnet satellite network in Hawaii
- 1974: Cerf and Kahn - architecture for interconnecting networks
- 1976: Ethernet at Xerox PARC
- ate70'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

Internetaren Historioa

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

Internetaren Historioa

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, P2P file sharing
- network security to forefront
- est. 50 million host, 100 million+ users
- backbone links running at Gbps

Internetaren Historioa

2007:

- ~500 million hosts
- Voice, Video over IP
- P2P applications: BitTorrent (file sharing) Skype (VoIP), PPLive (video)
- more applications: YouTube, gaming
- wireless, mobility

Introduction: Summary

Covered a "ton" of material!

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

You now have:

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