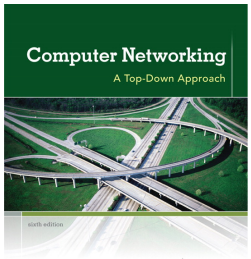
Chapter 1 Introduction



Computer Networking: A Top Down Approach
6th edition
Jim Kurose, Keith Ross
Addison-Wesley
March 2012

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Nota: Conteúdo atualizado, Uminho, PMC, 2018.

Chapter 1: introduction

our goal:

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

overview:

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

Chapter 1: roadmap

1.1 what *is* the Internet?

1.2 network edge

- end systems, access networks, links

1.3 network core

- packet switching, circuit switching, network structure

1.4 delay, loss, throughput in networks

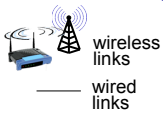
1.5 protocol layers, service models

1.6 networks under attack: security

1.7 history

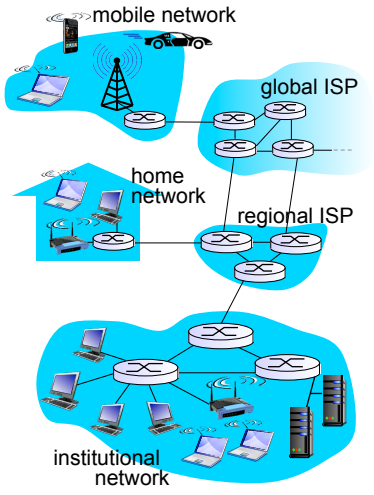
What's the Internet: "nuts and bolts" view

- millions of connected computing devices:
  - *hosts* = *end systems*
  - running *network apps*



- *communication links*
  - fiber, copper, radio, satellite
  - transmission rate: *bandwidth*

- *Packet switches:* forward packets (chunks of data)
  - *routers* and *switches*



"Fun" internet appliances

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

Web-enabled toaster +
weather forecaster

Tweet-a-watt:
monitor energy use

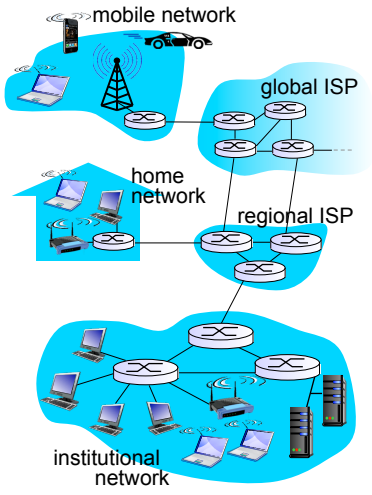
Internet
refrigerator

Slingbox: watch,
control cable TV remotely

Internet phones

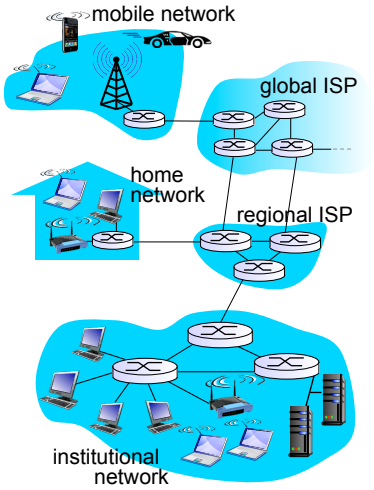
What's the Internet: "nuts and bolts" view

- *Internet:* "network of networks"
  - Interconnected ISPs
- *protocols* control sending, receiving of msgs
  - e.g., TCP, IP, HTTP, Skype, 802.11
- *Internet standards*
  - RFC: Request for comments
  - IETF: Internet Engineering Task Force



What's the Internet: a service view

- *Infrastructure that provides services to applications:*
  - Web, VoIP, email, games, e-commerce, social nets, …
- *provides programming interface to apps*
  - hooks that allow sending and receiving app programs to "connect" to Internet
  - provides service options, analogous to postal service



What's a protocol?

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

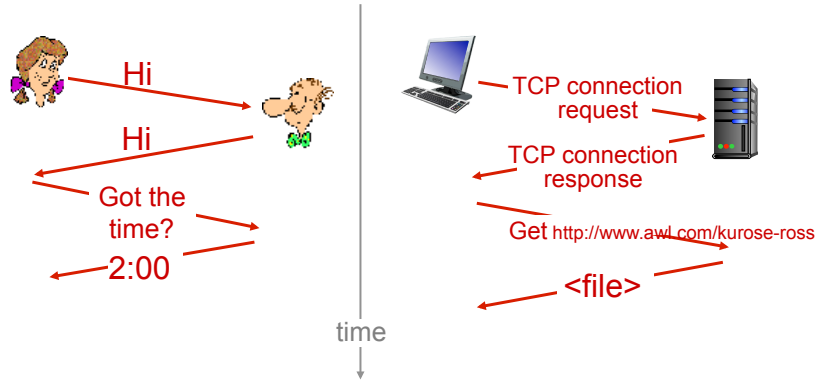
… specific msgs sent
… specific actions taken when msgs received, or other events

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

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

What's a protocol?

a human protocol and a computer network protocol:



Q: other human protocols?

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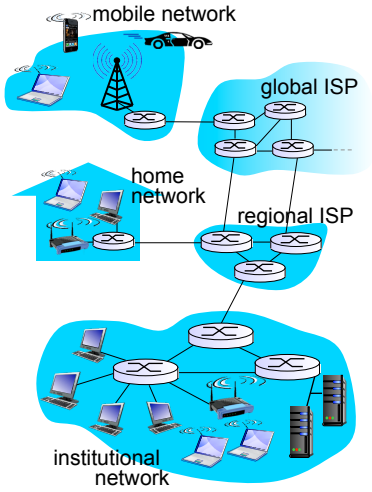
A closer look at network structure:

- *network edge:*
  - hosts: clients and servers
  - servers often in data centers
- *access networks, physical media:* wired, wireless communication links
- *network core:*
  - interconnected routers
  - network of networks



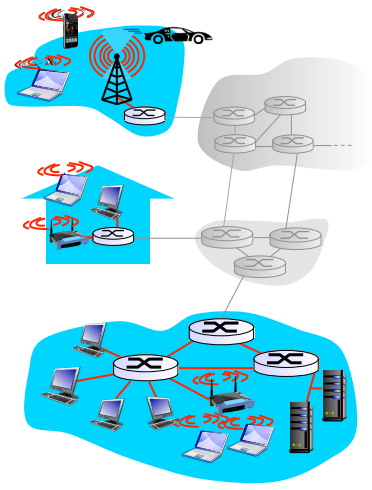
Access networks and physical media

Q: How to connect end systems to edge router?

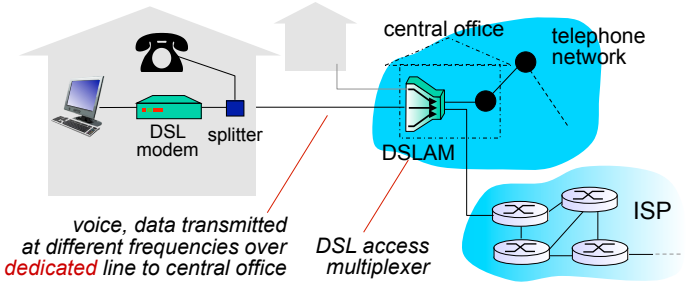
- residential access nets
- institutional access networks (school, company)
- mobile access networks

keep in mind:

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

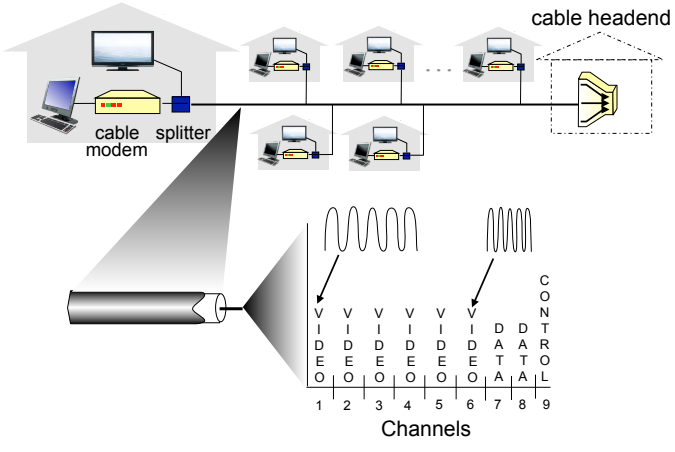


Access net: digital subscriber line (DSL)



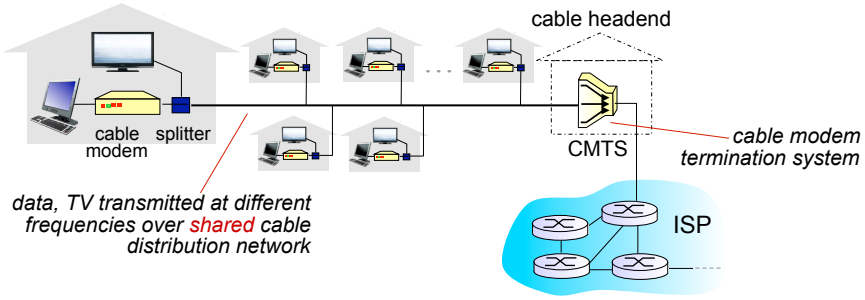
- use *existing* telephone line to central office DSLAM
  - data over DSL phone line goes to Internet
  - voice over DSL phone line goes to telephone net
- < 2.5 Mbps upstream transmission rate (typically < 1 Mbps)
- < 24 Mbps downstream transmission rate (typically < 10 Mbps)

Access net: cable network



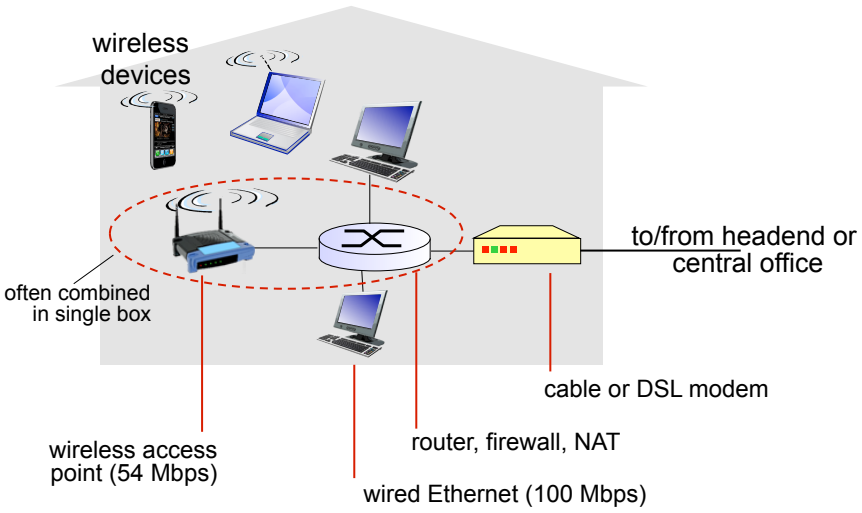
frequency division multiplexing: different channels transmitted in different frequency bands

Access net: cable network

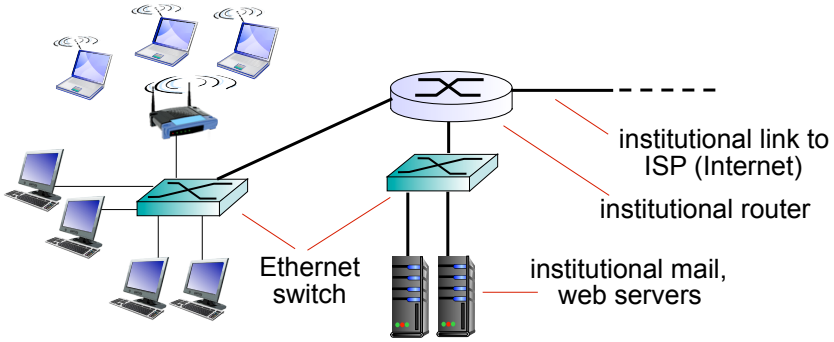


- HFC: hybrid fiber coax
  - asymmetric: up to 30Mbps downstream transmission rate, 2 Mbps upstream transmission rate (std. DOCSIS 1.0);
  - currently (DOCSIS 3.0): 400 Mbps / 100 Mbps
- network of cable, fiber attaches homes to ISP router
  - homes *share access network* to cable headend
  - unlike DSL, which has dedicated access to central office

Access net: home network



Enterprise access networks (Ethernet)



- typically used in companies, universities, etc
- 10 Mbps, 100Mbps, 1Gbps, 10Gbps transmission rates
- today, end systems typically connect into Ethernet switch

Wireless access networks

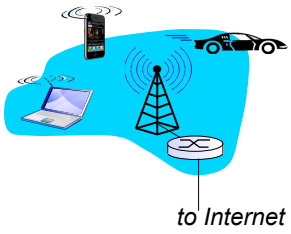
- shared *wireless* access network connects end system to router
  - via base station aka "access point"

wireless LANs:

- within building (100 ft)
- 802.11b/g/n (WiFi): 11, 54, 54-600 Mbps transmission rate
- 802.11ac (5GHz): 400Mbps-2.5G

wide-area wireless access

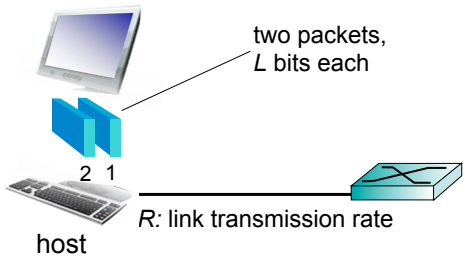
- provided by telco (cellular) operator, 10's km
- 3G between 1 and 10 Mbps;
- 4G LTE, 50 /150 Mbps
- 5G, 10-200Mbps/up to 1.4Gbps



Host: sends *packets* of data

host sending function:

- takes application message
- breaks into smaller chunks, known as *packets*, of length *L* bits
- transmits packet into access network at *transmission rate R*
  - link transmission rate, aka link *capacity, aka link bandwidth*



$$\text{packet transmission delay} = \text{time needed to transmit } L\text{-bit packet into link} = \frac{L \text{ (bits)}}{R \text{ (bits/sec)}}$$

Physical media

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

twisted pair (TP)

- two insulated copper wires
  - Category 5: 100 Mbps, 1 Gpbs Ethernet
  - Category 6: 10Gbps

Physical media: coax, fiber

coaxial cable:

- two concentric copper conductors
- bidirectional
- broadband:
  - multiple channels on cable
  - HFC

fiber optic cable:

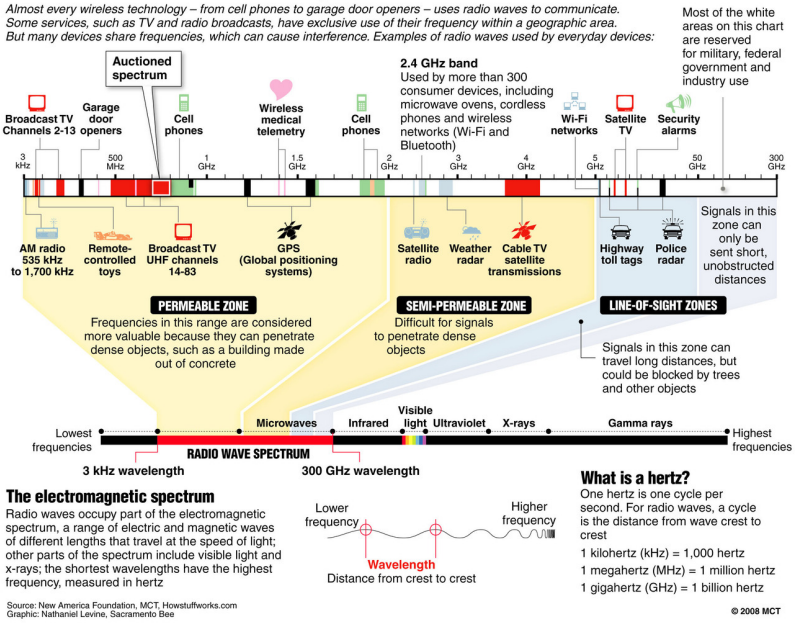
- glass fiber carrying light pulses, each pulse a bit
- high-speed operation:
  - high-speed point-to-point transmission (e.g., 10's-100's Gpbs transmission rate)
- low error rate:
  - repeaters spaced far apart
  - immune to electromagnetic noise

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)
  - e.g. 11Mbps, 54 Mbps, 600Mbps
- wide-area (e.g., cellular)
  - 3G cellular: ~ few Mbps
- Satellite
  - kbps to 45Mbps channel (or multiple smaller channels)
  - 270 msec end-end delay
  - geosynchronous versus low altitude



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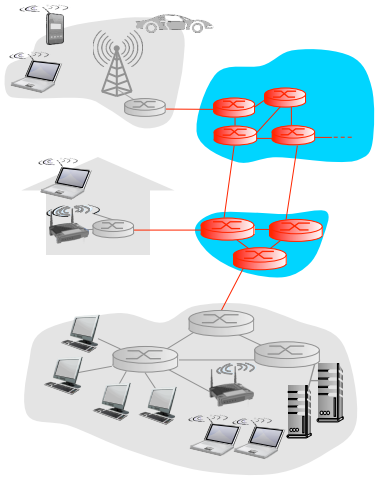
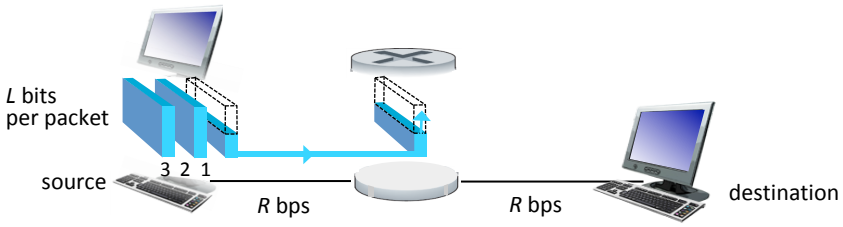
The network core

- mesh of interconnected routers
- packet-switching: hosts break application-layer messages into *packets*
  - forward packets from one router to the next, across links on path from source to destination
  - each packet transmitted at full link capacity



Packet-switching: store-and-forward



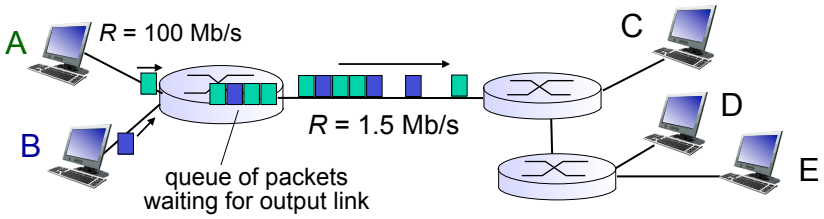
- takes *L*/*R* seconds to transmit (push out) *L*-bit packet into link at *R* bps
- *store and forward:* entire packet must arrive at router before it can be transmitted on next link
- end-end delay = 2*L*/*R* (assuming zero propagation delay)

one-hop numerical example:

- *L* = 7.5 Mbits
- *R* = 1.5 Mbps
- one-hop transmission delay = 5 sec

more on delay shortly …

Packet Switching: queueing delay, loss



queuing and loss:

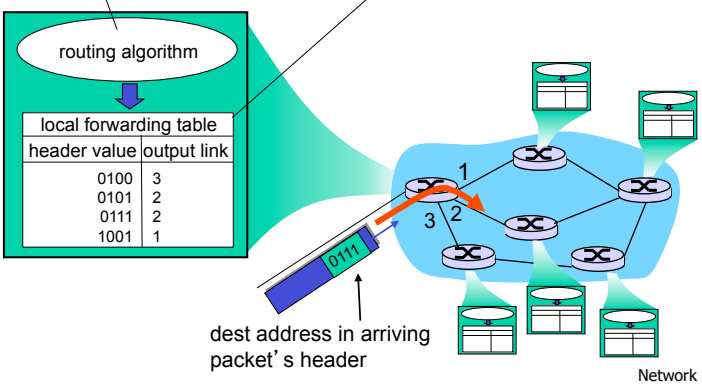
- If arrival rate (in bits) to link exceeds transmission rate of link for a period of time:
  - packets will queue, wait to be transmitted on link
  - packets can be dropped (lost) if memory (buffer) fills up

Two key network-core functions

routing: determines source-destination route taken by packets

- *routing algorithms*

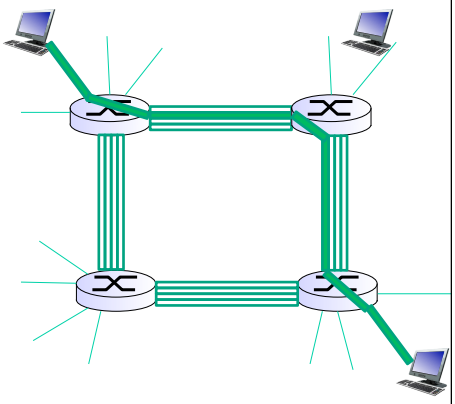
forwarding: move packets from router's input to appropriate router output



Alternative core: circuit switching

end-end resources allocated to, reserved for "call" between source & dest:

- In diagram, each link has four circuits.
  - call gets 2nd circuit in top link and 1st circuit in right link.
- dedicated resources: no sharing
  - circuit-like (guaranteed) performance
- circuit segment idle if not used by call *(no sharing)*
- Commonly used in traditional telephone networks



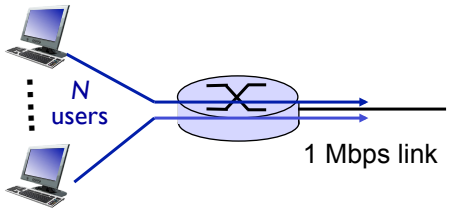
packet switching vs. circuit switching

Função	Rede de Datagramas	Rede de Circuitos Virtuais (VC)
Estabelecimento prévio da conexão (ou circuito)	Não é necessário	É necessário
Endereçamento	Endereço de origem e destino em cada PDU	PDUs contêm o identificador do circuito
Routing / Forwarding	PDUs são encaminhados de forma independente entre si	A rota é estabelecida inicialmente e todos os PDUs utilizam essa rota
Informação de estado	não é necessária	necessária por VC
Falha de um elemento de rede	não é normalmente problemática	todos os VC são terminados
Controlo de tráfego e Controlo de congestão	difícil	fácil, se os recursos atribuídos são suficientes

Packet switching versus circuit switching

packet switching allows more users to use network!

example:
- 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: what happens if > 35 users ?

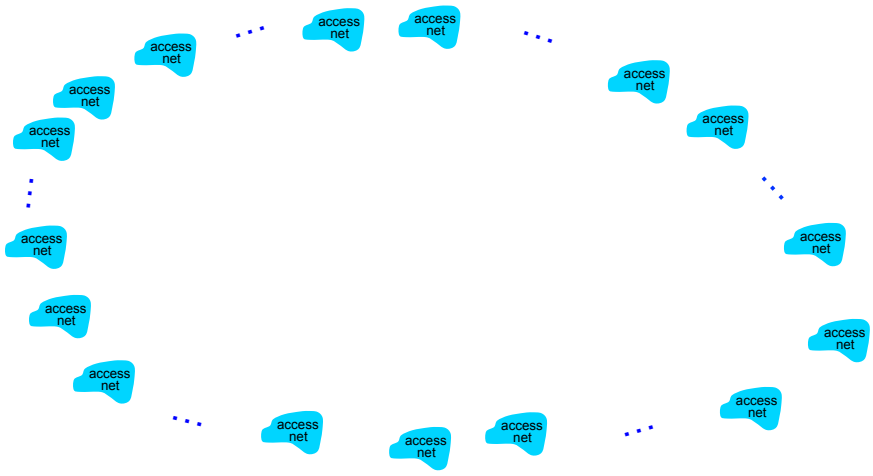
* Check out the online interactive exercises for more examples

Internet structure: network of networks

- End systems connect to Internet via access ISPs (Internet Service Providers)
  - Residential, company and university ISPs
- Access ISPs in turn must be interconnected.
  - So that any two hosts can send packets to each other
- Resulting network of networks is very complex
  - Evolution was driven by economics and national policies
- Let's take a stepwise approach to describe current Internet structure

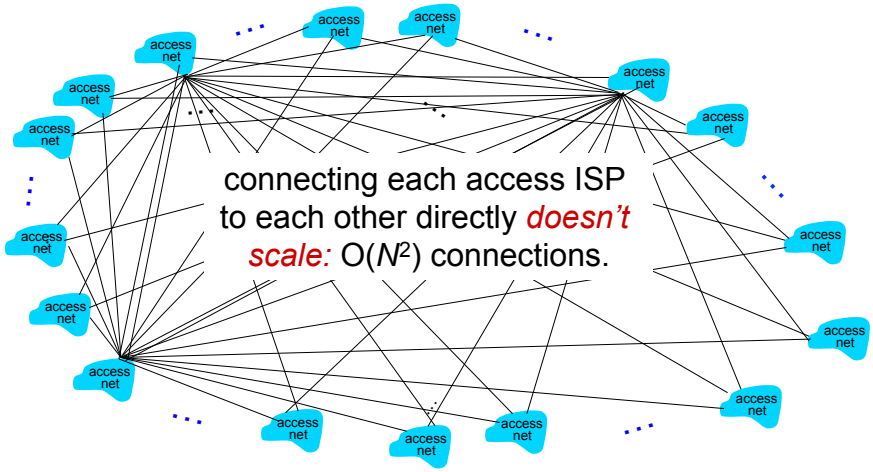
Internet structure: network of networks

Question: given *millions* of access ISPs, how to connect them together?



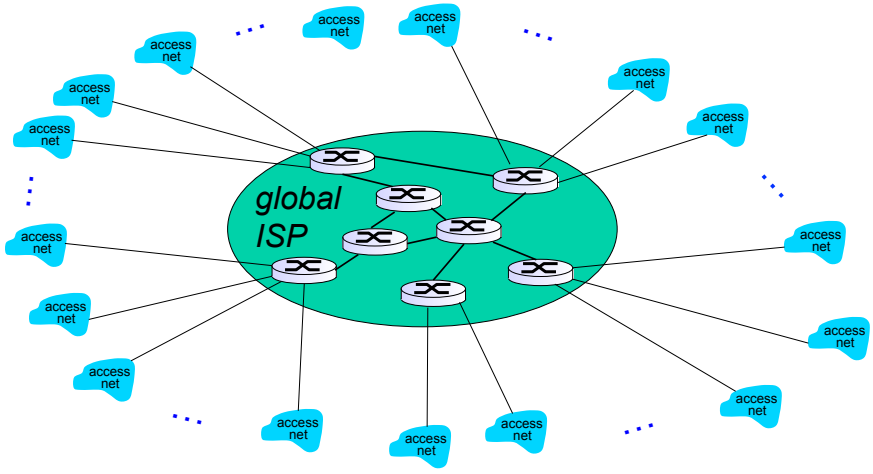
Internet structure: network of networks

Option: connect each access ISP to every other access ISP?



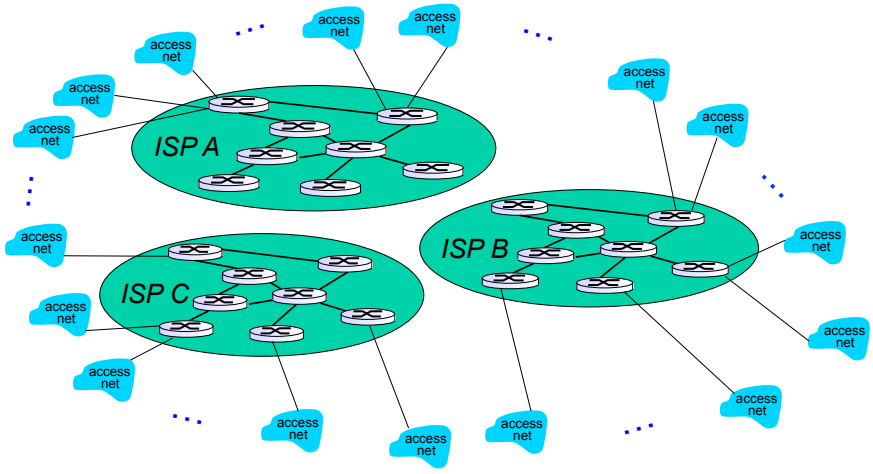
Internet structure: network of networks

Option: connect each access ISP to a global transit ISP? Customer and provider ISPs have economic agreement.



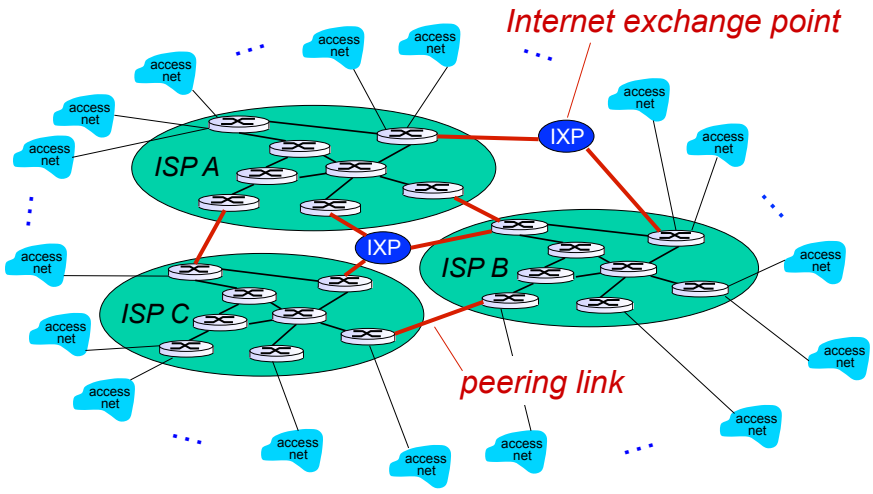
Internet structure: network of networks

But if one global ISP is viable business, there will be competitors ….



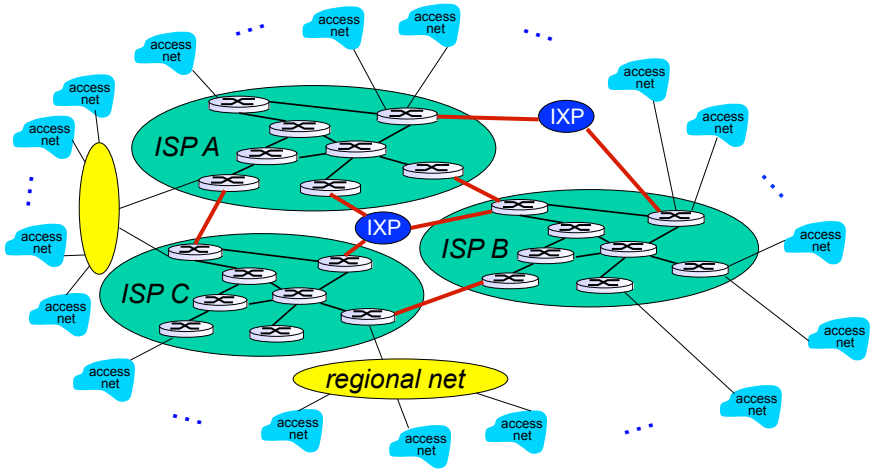
Internet structure: network of networks

But if one global ISP is viable business, there will be competitors …. which must be interconnected



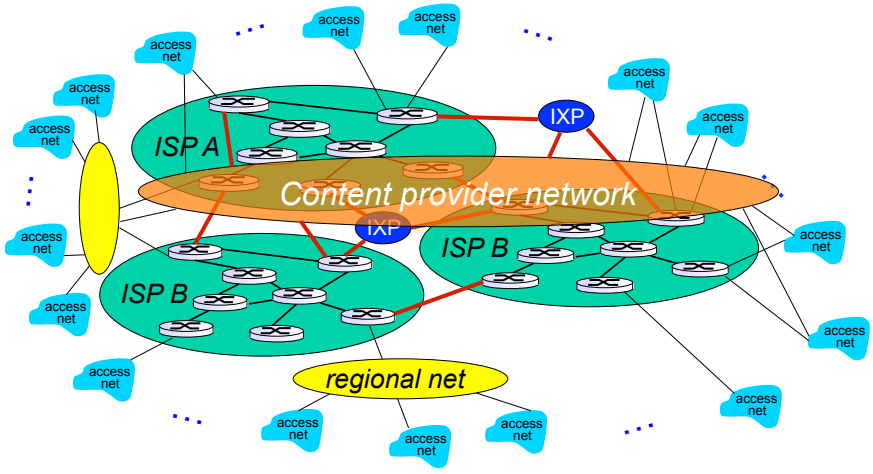
Internet structure: network of networks

… and regional networks may arise to connect access nets to ISPS

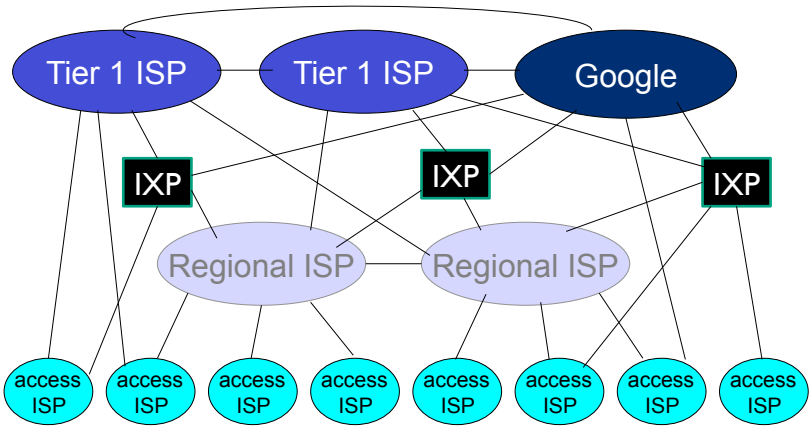


Internet structure: network of networks

… and content provider networks (e.g., Google, Microsoft, Akamai) may run their own network, to bring services, content close to end users



Internet structure: network of networks



- at center: small # of well-connected large networks
  - "tier-1" commercial ISPs (e.g., Level 3, Sprint, AT&T, NTT), national & international coverage
  - content provider network (e.g, Google): private network that connects it data centers to Internet, often bypassing tier-1, regional ISPs

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Protocol "layers"

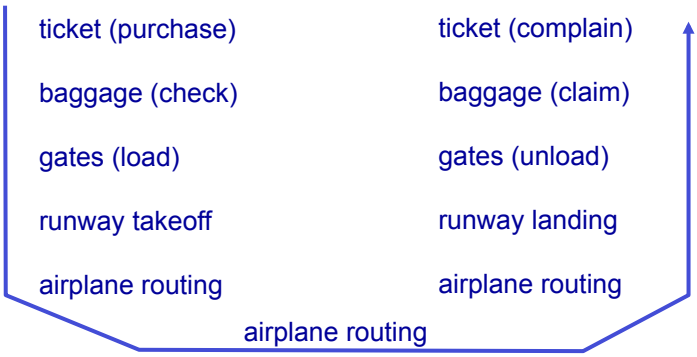
Networks are complex, with many "pieces":
- hosts
- routers
- links of various media
- applications
- protocols
- hardware, software

Question:

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

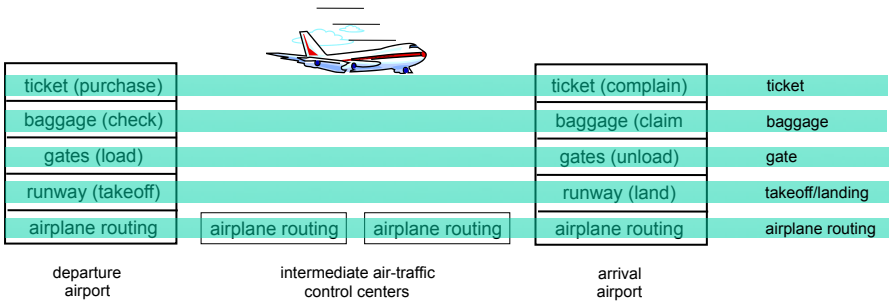
…. or at least our discussion of networks?

Organization of air travel



- a series of steps

Layering of airline functionality



layers: each layer implements a service

- via its own internal-layer actions
- relying on services provided by layer below

Why layering?

dealing with complex systems:

- explicit structure allows identification, relationship of complex system's pieces
  - layered *reference model* for discussion
- modularization eases maintenance, updating of system
  - change of implementation of layer's service transparent to rest of system
  - change in gate procedure doesn't affect rest of system
  - allow a common context
- layering considered harmful?

Protocol layers

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- Cada camada permite:
  - cooperação entre entidades do mesmo nível protocolar que comunicam entre si... criando um contexto comum
- Comunicação por níveis ou camadas
  - conjunto de regras que regem a comunicação entre intervenientes, i.e. entre entidades ao mesmo nível funcional
  - uma entidade é uma abstração de um ou mais processos computacionais
  - as regras ou funções protocolares são implementadas pelas entidades de uma camada ou nível protocolar
  - as funções protocolares são variadas e têm âmbitos ou contextos distintos, e.g. endereçamento

Protocolar functions: Examples

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- geração de sinais
- definição interfaces
- sincronização
- formatação dados
- endereçamento
- detecção de erros
- correcção de erros
- controlo de fluxo
- formatação de msgs
- encaminhamento msgs
- transporte de msgs
- verificação de msgs
- recuperação de msgs
- independência dados
- privacidade/segurança
- gestão da comunicação

Grouping protocolar functions

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- Noção de organização protocolar
  - agrupamento e estruturação de tarefas em níveis ou camadas funcionais, hierárquicas, com funções independentes e bem definidas -> constituição de uma pilha de protocolos
- Noção de serviço de comunicação
  - o resultado das tarefas executadas pela camada protocolar N para realização da função da camada superior (N+1), podendo envolver o recurso a serviços da camada N-1
  - cada camada protocolar oferece um serviço à camada superior e solicita um serviço à camada inferior através de primitivas específicas

ISO/OSI reference model

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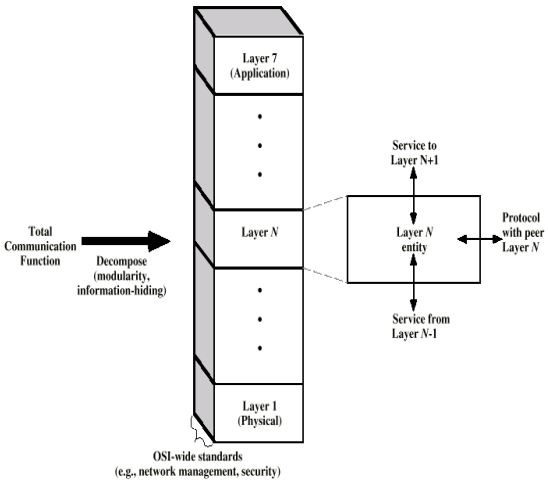
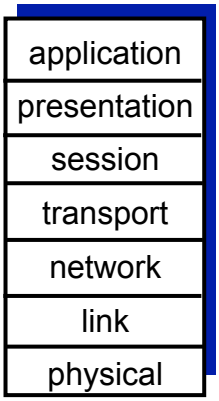
- Modelo protocolar de referência OSI da ISO.
  7 camadas funcionais:
  - camada de aplicação
  - camada de apresentação
  - camada de sessão
  - camada de transporte
  - camada de rede
  - camada de ligação lógica
  - camada física

  Designado ISO OSI-RM (ISO Reference Model for Open Systems Interconnection)
- Modelo protocolar TCP/IP: tem 4 camadas funcionais



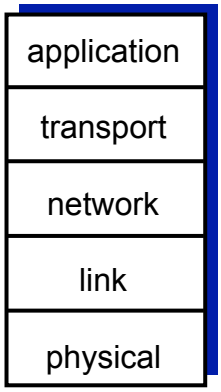
ISO/OSI reference model

- *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?



Internet protocol stack

- *application:* supporting network applications
  - FTP, SMTP, HTTP
- *transport:* process-process data transfer
  - TCP, UDP
- *network:* routing of datagrams from source to destination
  - IP, routing protocols
- *link:* data transfer between neighboring network elements
  - Ethernet, 802.11 (WiFi), PPP
- *physical:* bits "on the wire"



Internet protocol stack

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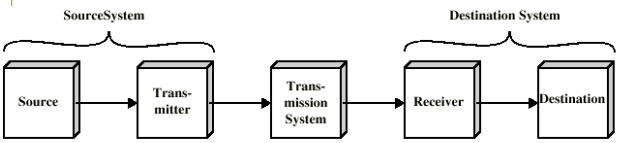

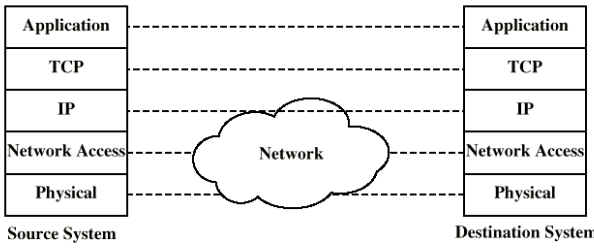

APLICAÇÃO
– SERVIÇOS DO UTILIZADOR
– HTTP, FTP, TELNET, ...
TRANSPORTE
– TCP: TRANSMISSÃO FIÁVEL E ORDENADA DE DADOS
– EXTREMO-A-EXTREMO
REDE
– IP: ENCAMINHAMENTO ATRAVÉS DE MÚLTIPLAS (SUB)REDES INTERLIGADAS (INTERNETWORKING)
– IMPLEMENTADO EM COMPUTADORES (HOSTS) E NÓS INTERMÉDIOS (ROUTERS)
LIGAÇÃO DE DADOS (ACESSO À (SUB)REDE)
– ACESSO À (SUB)REDE E COMUNICAÇÃO ENTRE ESTAÇÕES (HOSTS/ROUTERS/SW)s LIGADAS À MESMA (SUB)REDE
FÍSICO
– CARACTERÍSTICAS ELÉCTRICAS E MECÂNICAS DA LIGAÇÃO FÍSICA AO MEIO DE TRANSMISSÃO

[DCC,Stallings07]

Internet Protocols: Examples

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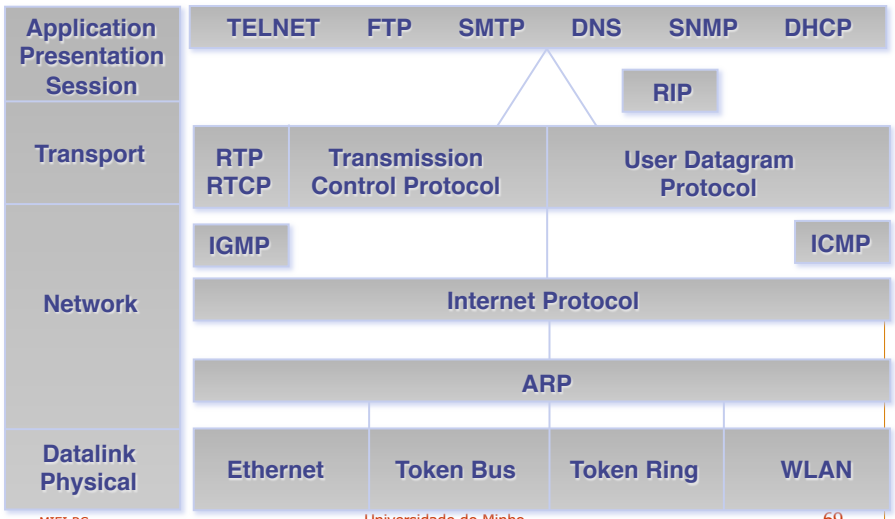

Encapsulation

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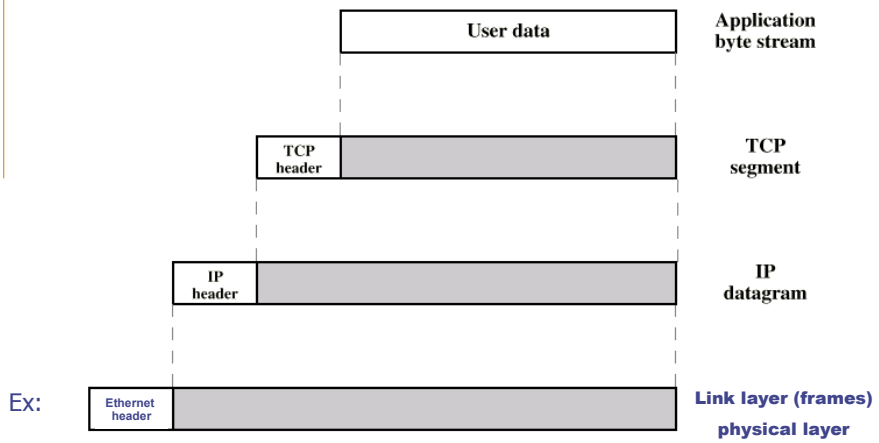
Estratégia: *encapsulamento* da unidade dados na camada inferior



[DCC,Stallings07]

Encapsulation (in more detail)

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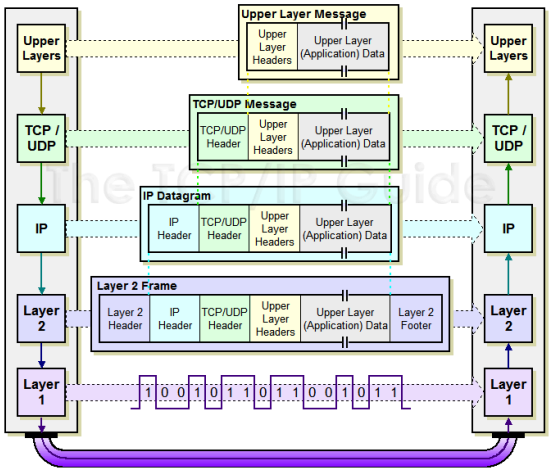

Encapsulation (in more detail)

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Exemplo: desencapsulamento de tráfego aplicacional FTP

```
-------- MAC HEADER --------

Frame size is 67 (0x0043) bytes
Destination = station 0050FC5CE9AB, pc4
Source      = station 0050FC5CE9B0, pc2
Ethertype = 0800 (IPv4)
```

```
-------- IP HEADER --------

Version = 4, Header length = 20 bytes
Diff Serv Field = 0xC0 (DSCP 0x30: Class Selector 6; ECN: 0x00)
 1 1 0 0  0 0 . .  = DSCP: Class Selector 6 (0x30)
 . . . .  . . 0 .  = ECN-Capable Transport (ECT): 0
 . . . .  . . . 0  = ECN-CE: 0
Total length = 53 bytes
Identification = 5974
Flags = 0x4
  . 1 .  . . . .  = don't fragment
  . . 0  . . . .  = last fragment
Fragment offset = 0 bytes
Time to live = 60
Protocol = 6 (TCP)
Header checksum = AFA0 (correct)
Source address = [192.168.89.12], pc2.labcom.uminho.pt
Destination address = [192.168.89.14], pc4.labcom.uminho.pt
No options
```

```
-------- TCP HEADER --------

Source port = 1062
Destination port = 21 (FTP)
Sequence number = 532928015
Acknowledgment number = 549440112
Data offset = 20 bytes
Flags = 0x18
  . . 0 .  . . . .  = (No urgent pointer)
  . . . 1  . . . .  = Acknowledgment
  . . . .  1 . . .  = Push
  . . . .  . 0 . .  = (No reset)
  . . . .  . . 0 .  = (No SYN)
  . . . .  . . . 0  = (No FIN)
Window = 33580
Checksum = CE68 (correct)
No TCP options
[13 byte(s) of data]
```

```
-------- FTP data --------

PASS Visita<0D0A>
```

Encapsulation (in more detail)

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Exemplo: desencapsulamento de tráfego aplicacional TFTP

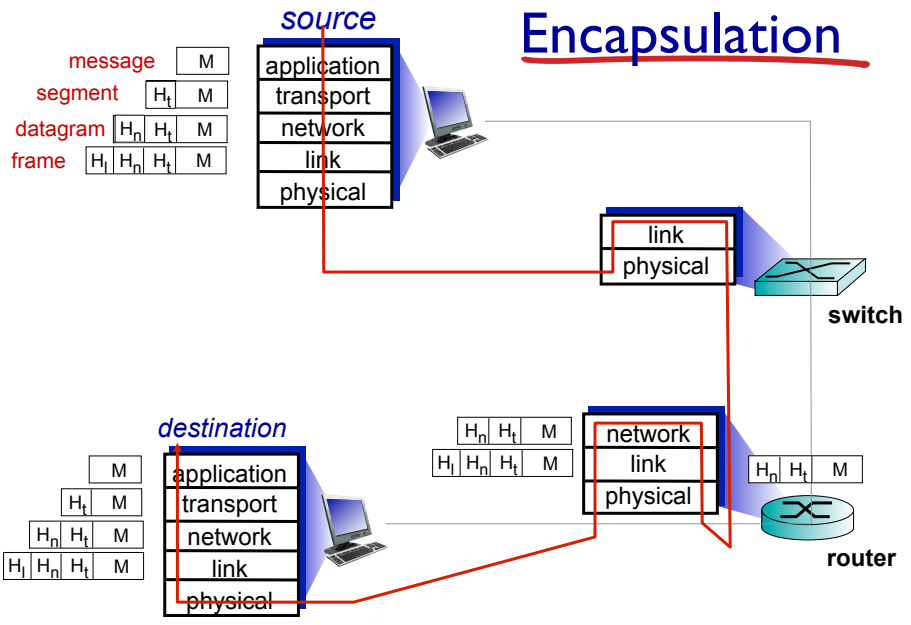
```
-------- MAC HEADER --------

Frame size is 60 (0x003C) bytes
Destination = station 0050FC5CE9B0, pc2
Source      = station 0050FC5CE9B1, pc3
Ethertype = 0800 (IPv4)
```

```
-------- IP HEADER --------

Version = 4, Header length = 20 bytes
Diff Serv Field = 0x00 (DSCP 0x00: Default; ECN: 0x00)
 0 0 0 0  0 0 . .  = DSCP: Default (0x00)
 . . . .  . . 0 .  = ECN-Capable Transport (ECT): 0
 . . . .  . . . 0  = ECN-CE: 0
Total length = 32 bytes
Identification = 5827
Flags = 0x0
  . 0 . .  . . . .  = may fragment
  . . 0 .  . . . .  = last fragment
Fragment offset = 0 bytes
Time to live = 30
Protocol = 17 (UDP)
Header checksum = 0EFF (correct)
Source address = [192.168.89.13], pc3.labcom.uminho.pt
Destination address = [192.168.89.12], pc2.labcom.uminho.pt
No options
```

```
-------- UDP HEADER --------

Source port = 1897 (TFTP)
Destination port = 1035
Length = 12
Checksum = 7D51 (correct)
```

```
-------- Trivial file transfer --------

Opcode = 4 (Ack)
Block number = 1

[Normal end of "Trivial file transfer".]
```


Encapsulation



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!*