Lecture 1

Chapter 1: Computer Networks and the Internet

1.1 What is the Internet

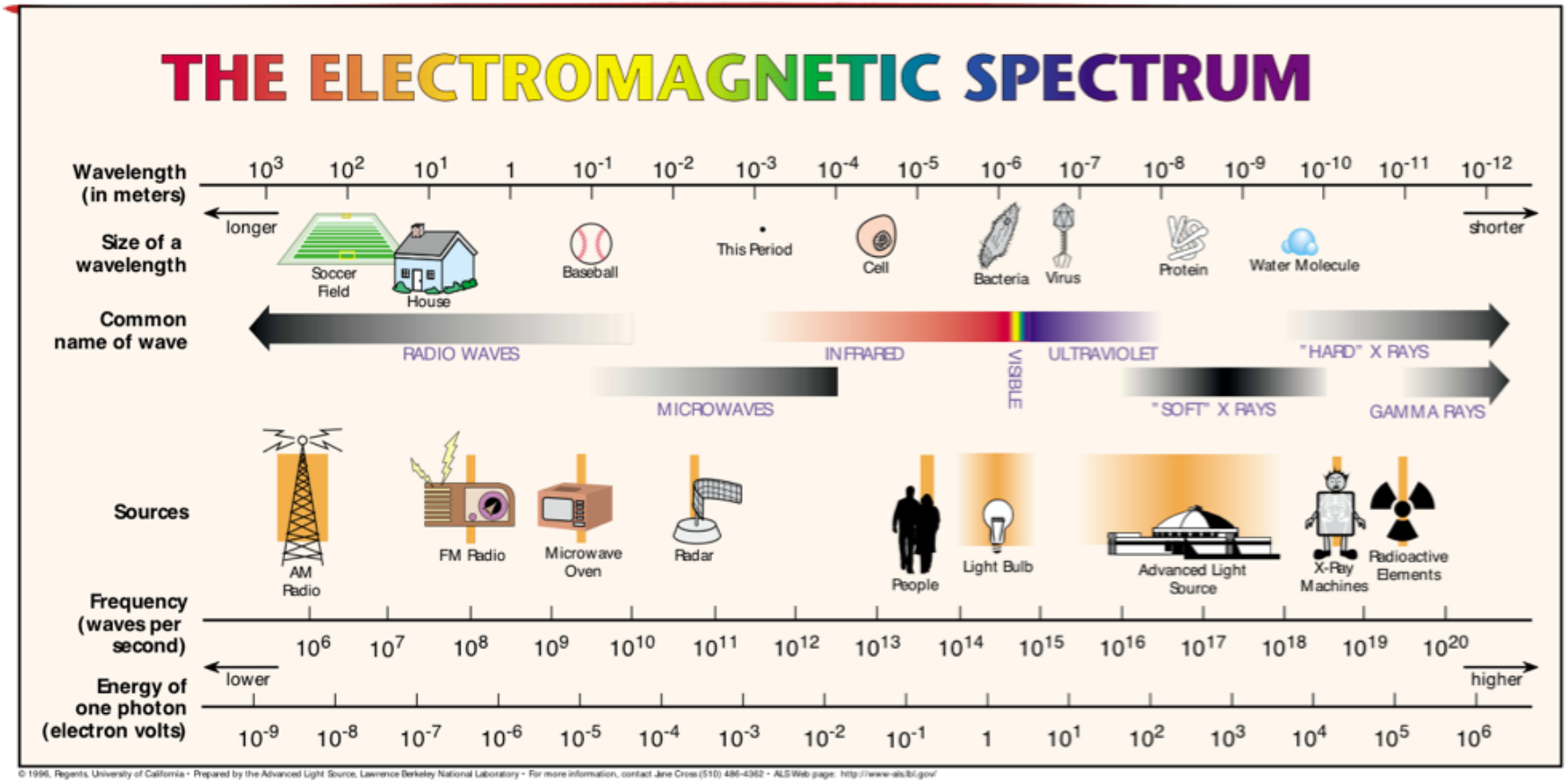
1.2 The Network Edge

The Electromagnetic Spectrum

- Electromagnetic waves produced by the motion of electrically charged particles
- Also called "electromagnetic radiation" (EMR) because they radiate from the particles
- Travel through space, air & other substances.
- EMR has a dual "personality:" Act like waves, and a stream of massless particles (called "photons")
- Higher energy correlates with shorter wavelengths
- Light used to "see" an object must have a wavelength $\lesssim$ the object.
- Humans see items illuminated with wavelengths about the size of a bacterium

http://www2.lbl.gov/MicroWorlds/ALSTool/EMSpec/EMSpec.html.951213

The Electromagnetic Spectrum



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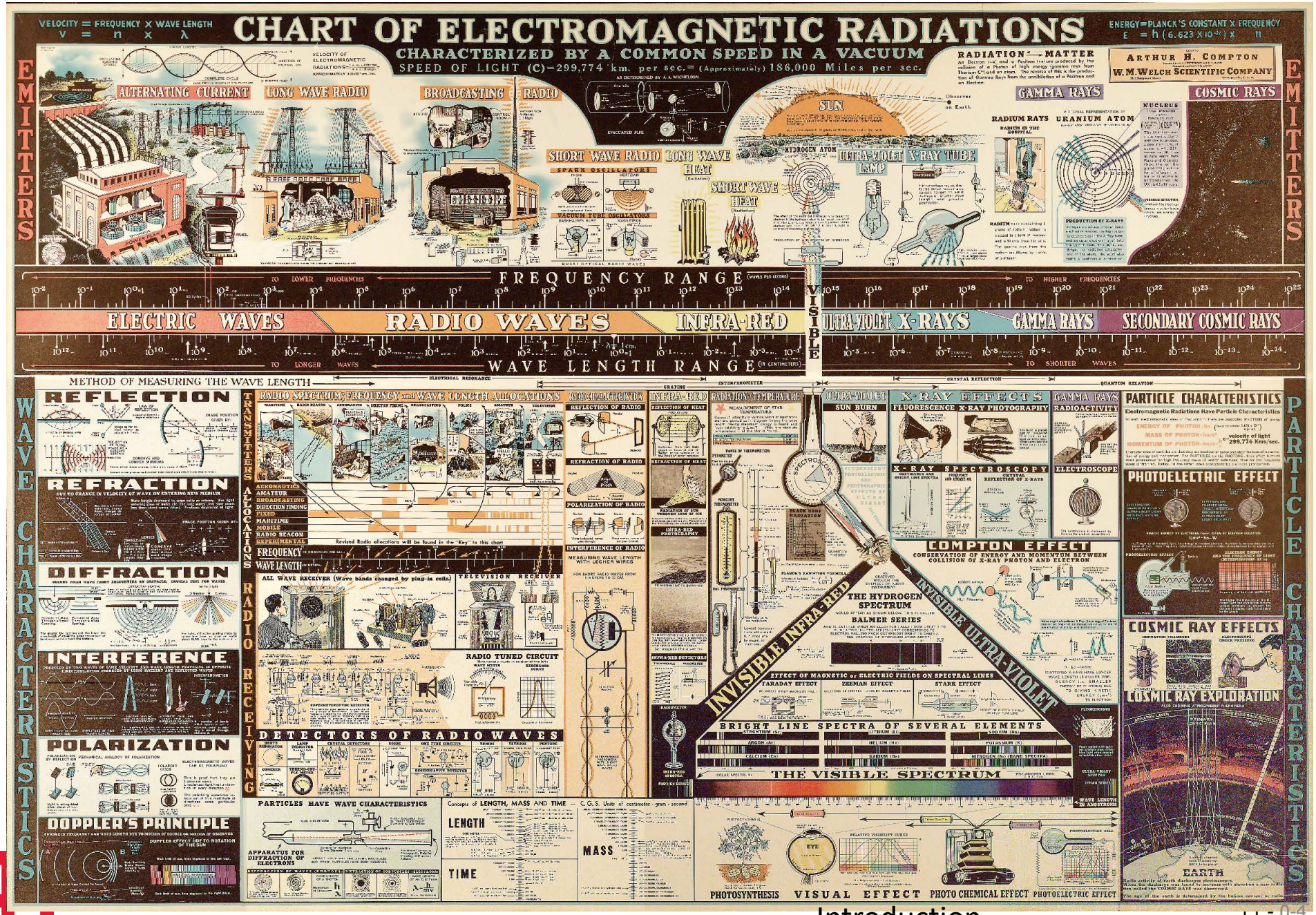
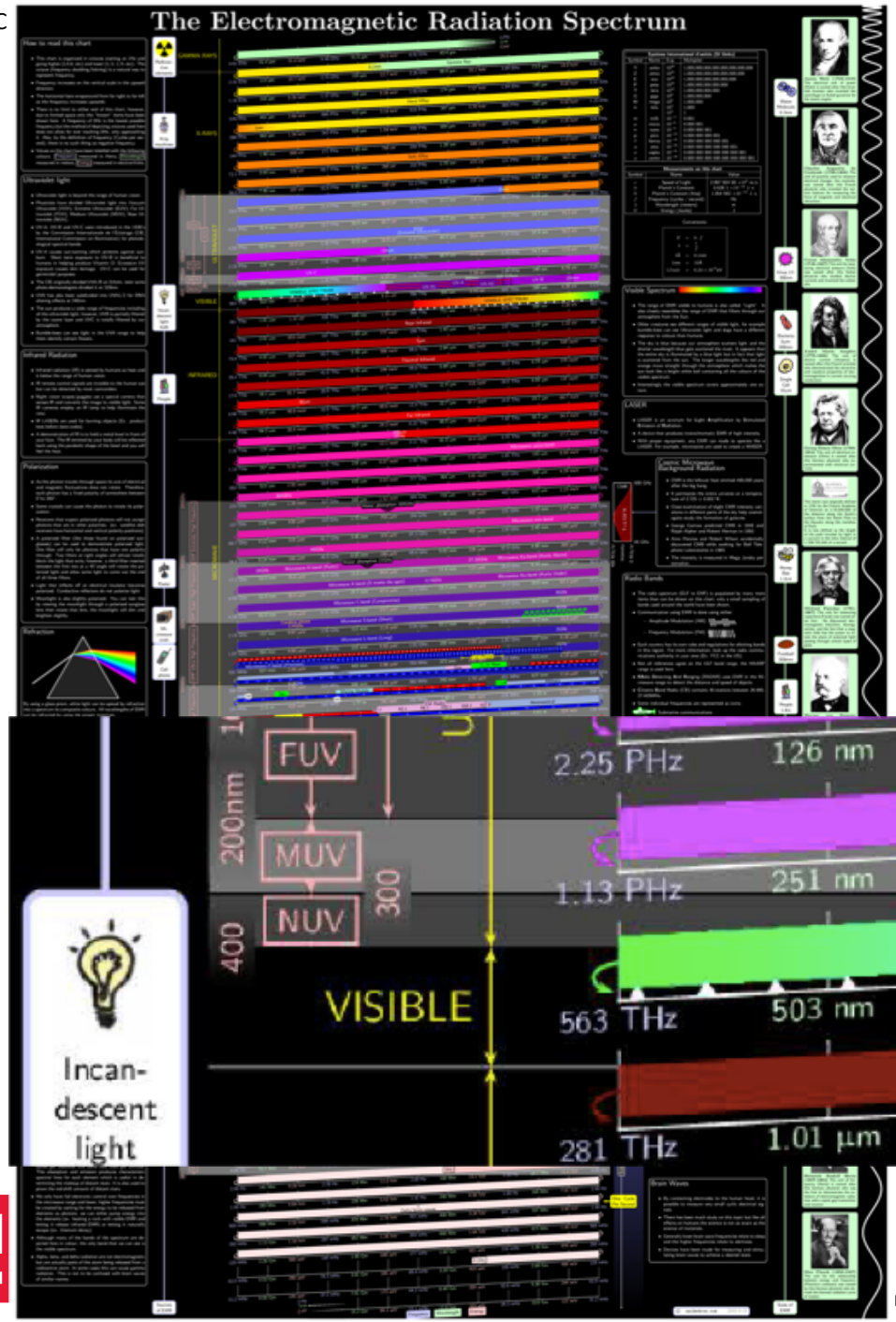
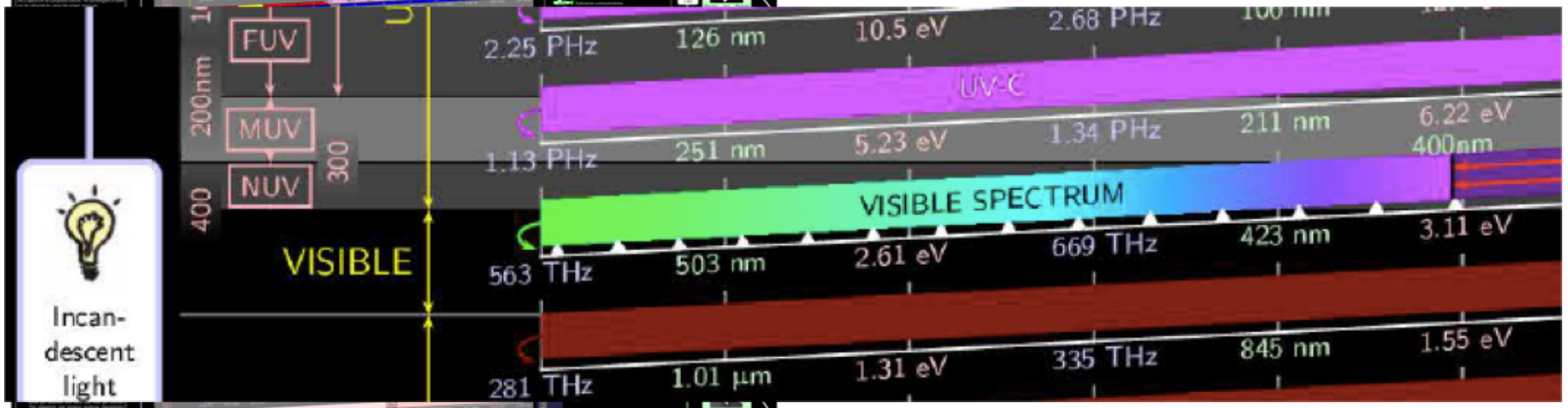
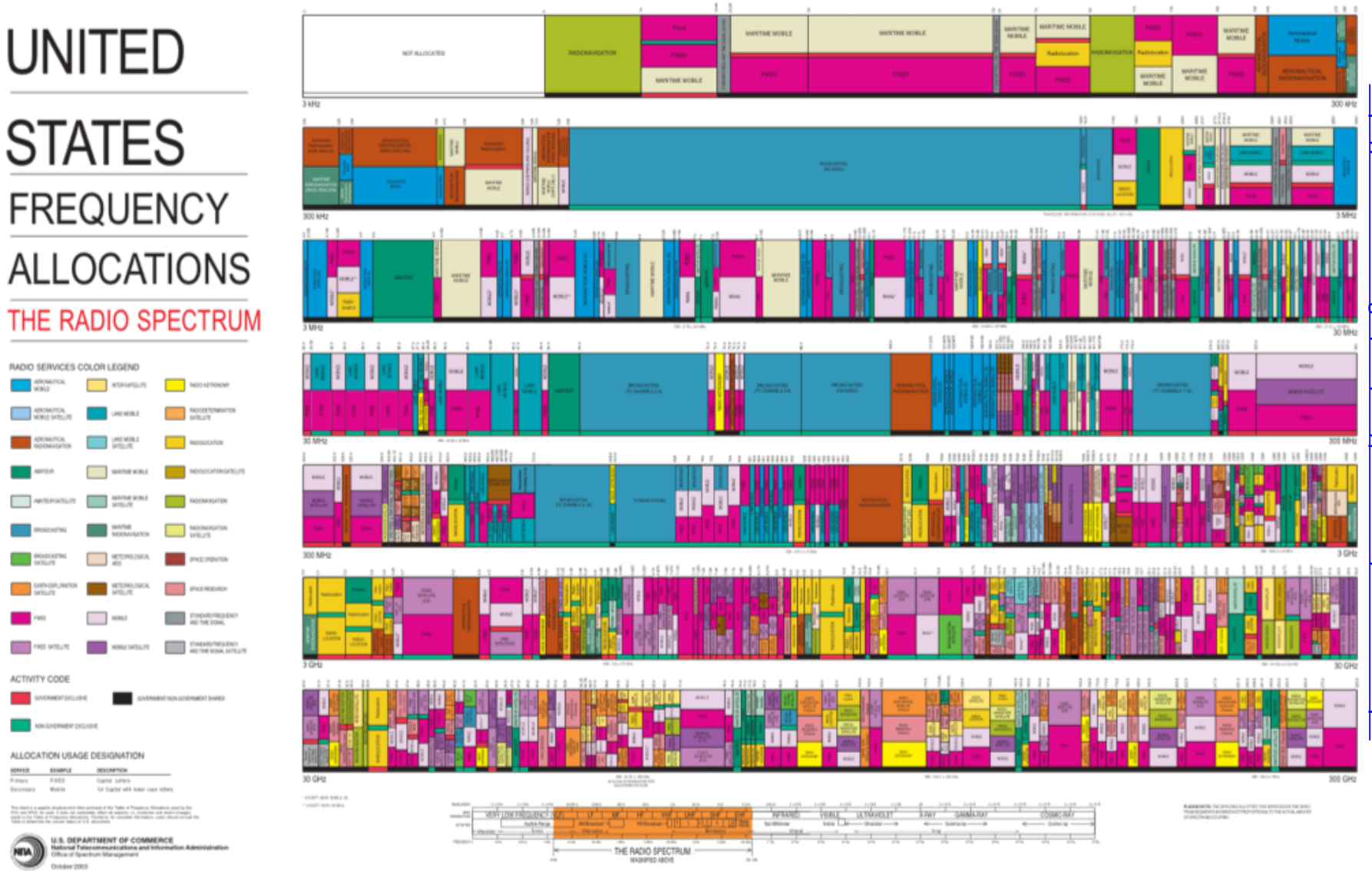




- Values on the chart have been labelled with the following colours: Frequency measured in Hertz, Wavelength measured in meters, Energy measured in electronVolts.





https://www.ntia.doc.gov/files/ntia/publications/2003-allochrt.pdf

Industry Canada Industrie Canada

RADIO SPECTRUM ALLOCATIONS IN CANADA

Radio waves use the electromagnetic spectrum. The lowest frequencies have the longest radio waves and the highest frequencies have the shortest radio waves.

Radio waves are characterized according to their frequency, the unit for which is the hertz (Hz). The frequency is determined by the number of complete waves propagated through a medium past a fixed point in one second. Thus, the frequency of a signal where one wave passes a fixed point in one second is one hertz. A kilohertz (kHz) represents 1000 waves passing a point in one second, or 1000 hertz. One megahertz (MHz) is 1000 kilohertz and a gigahertz (GHz) is 1000 megahertz.

The spectrum is divided into a number of frequency bands, each possessing characteristics peculiar to it which determine the usage appropriate to that band. Each band has been allocated by international agreement at a World Radiocommunication Conference (WRC) to one or more radio services or for specific usages. Sponsored by the International Telecommunication Union (a United Nations agency), WRCs are held to extend, review and revise frequency allocations among the various uses.

After WRCs, or when Canada's needs change, Industry Canada allocates specific frequency bands to services to satisfy domestic communications requirements as shown on this chart. The official regulatory provisions that pertain to frequency allocations in Canada are contained in the Canadian Table of Frequency Allocations and the related spectrum policies.

Among radio spectrum users are broadcasters, taxis, building and other construction trades, air transportation, radio amateurs, marine transportation, telecommunications carriers, electrical power utilities, trucking companies, police, and federal, provincial, territorial and municipal departments and agencies.

This chart is based on the 2014 *Canadian Table of Frequency Allocations*, which was developed from decisions of World Radiocommunication Conferences, including WRC-12. The chart provides a graphic representation of Canadian electromagnetic spectrum allocations.

For further information on spectrum utilization or radio systems policy matters, contact the Engineering, Planning and Standards Branch, Industry Canada, Ottawa (e-mail: **spectrum.engineering@ic.gc.ca**) or one of its offices listed in Radiocom Information Circular RIC-66.

ATTRIBUTION DES FRÉQUENCES RADIOÉLECTRIQUES AU CANADA

Les ondes radioélectriques utilisent le spectre électromagnétique. Aux fréquences les plus basses correspondent les ondes radio les plus longues et aux fréquences les plus élevées, les ondes radio les plus courtes.

Les ondes radio se caractérisent par leur fréquence, qui se mesure en hertz (Hz). La fréquence est déterminée par le nombre d'ondes complètes franchissant un point fixe d'un support en une seconde. On dira donc d'un signal pour lequel une onde franchit un point fixe en une seconde qu'il a une fréquence de 1 hertz. Le kilohertz (kHz) équivaut à 1 000 ondes par seconde, soit 1 000 hertz, le mégahertz, à 1 000 kilohertz et le gigahertz (GHz), à 1 000 mégahertz.

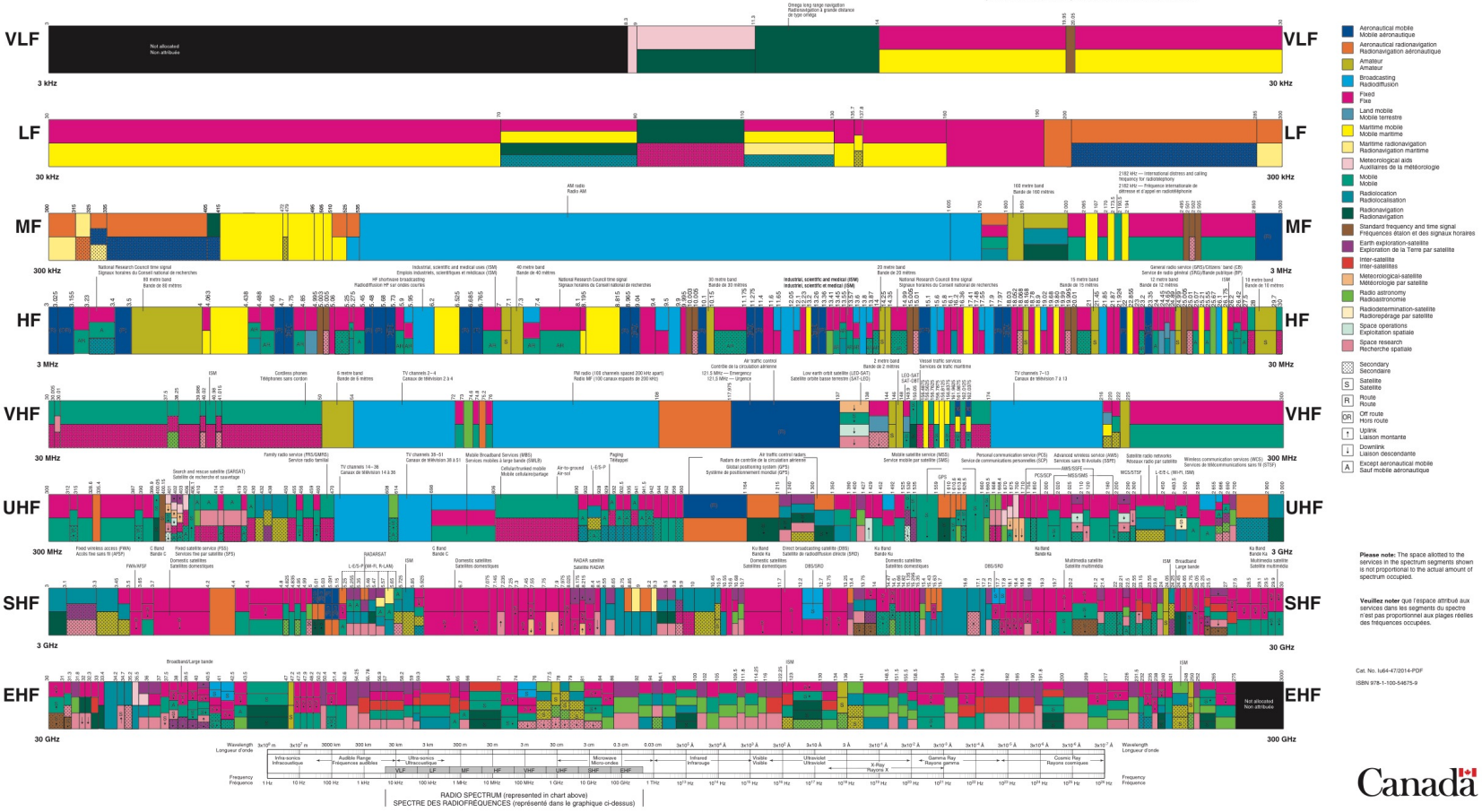
Le spectre se compose de bandes de fréquences possédant chacune des particularités qui en déterminent l'utilisation. Chaque bande est attribuée à un ou plusieurs services radio ou à des usages déterminés par voie d'accords internationaux signés à une Conférence mondiale des radiocommunications (CMR), Organisées sous l'égide d'un organisme des Nations Unies, l'Union internationale des télécommunications, les CMR ont pour but d'étendre, d'étudier et de réviser l'attribution des bandes de fréquences.

À l'issue de chacune de ces conférences ou quand des changements s'imposent au Canada, Industrie Canada attribue des bandes de fréquences particulières à certains services, de manière à s'adapter aux besoins du pays en matière de communications, comme l'illustre le graphique ci-dessous. Les dispositions officielles de la réglementation touchant l'attribution des fréquences au Canada figurent dans le Tableau canadien d'attribution des bandes de fréquences et dans les politiques connexes d'utilisation du spectre.

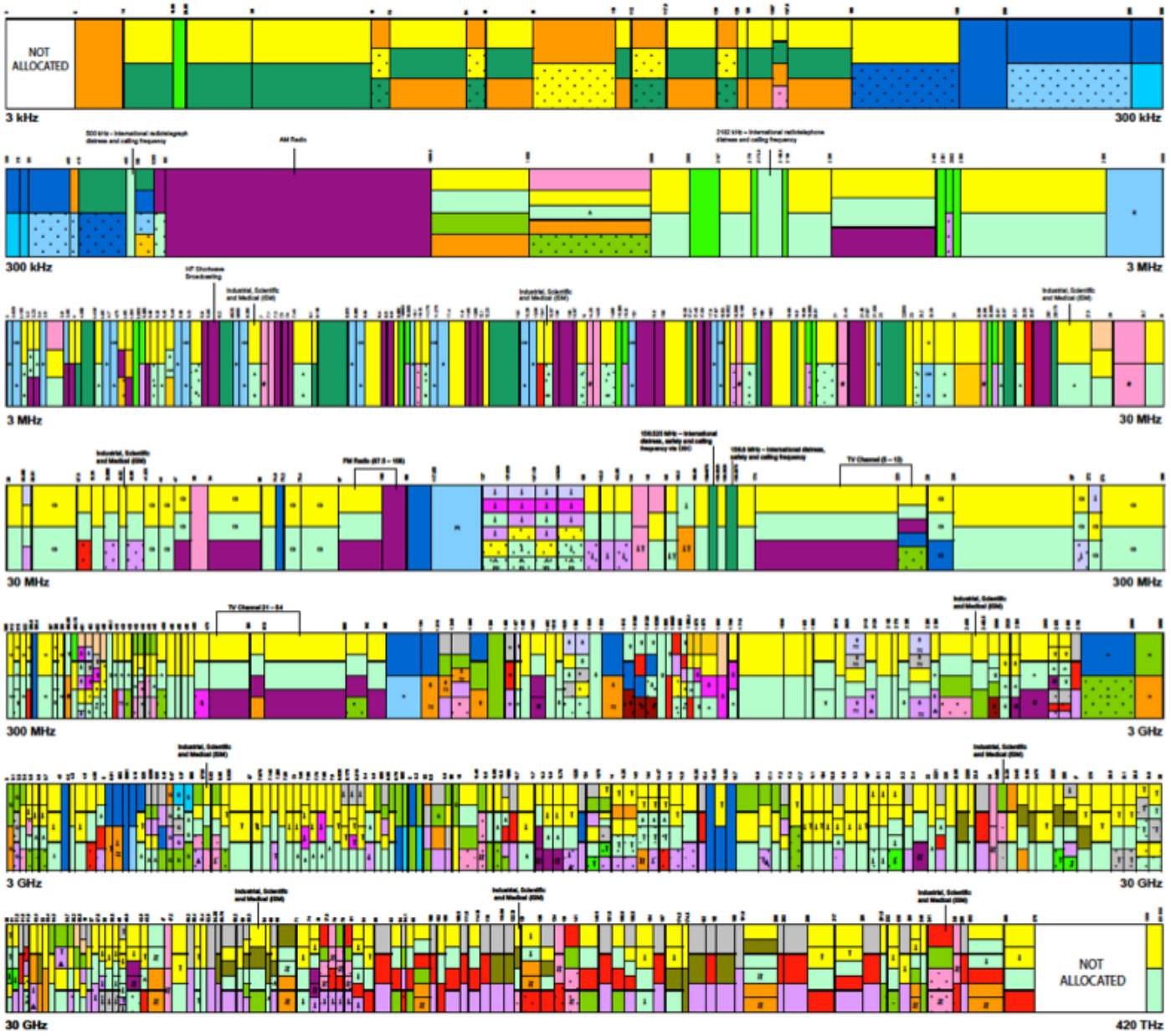
Parmi les utilisateurs du spectre radioélectrique, on compte les radiodiffuseurs, les compagnies de taxi, l'industrie du bâtiment et d'autres secteurs de la construction, les transporteurs aériens, les radioamateurs, les transporteurs maritimes, les entreprises de télécommunications, les services publics d'électricité, les entreprises de camionnage, la police, ainsi que les ministères ou organismes fédéraux, provinciaux, territoriaux et municipaux.

Ce graphique est fondé sur la version 2014 du Tableau canadien d'attribution des bandes de fréquences, résultant des diverses Conférences mondiales des radiocommunications, notamment la CMR-12. Ce graphique représente les attributions de fréquences radioélectriques au Canada.

Pour de plus ample renseignements sur les politiques d'utilisation du spectre ou des systèmes radio, veuillez communiquer avec la Direction générale du génie, de la planification et des normes, d'Industrie Canada à Ottawa (courriel: spectrum.engineering@ic.gc.ca), ou avec l'un des bureaux identifiés dans le Circulaire d'information sur les radiocom CIR-66.Industry Canada, Ottawa (e-mail: **spectrum.engineering@ic.gc.ca**) or one of its offices listed in Radiocom Information Circular RIC-66.



SPECTRUM ALLOCATIONS IN MALAYSIA



AERONAUTICAL MOBILE
AERONAUTICAL RADIONAVIGATION
AMATEUR
BROADCASTING
EARTH EXPLORATION SATELLITE
FIXED
INTER SATELLITE SERVICE
LAND MOBILE
MARITIME MOBILE
MARITIME RADIONAVIGATION
METEOROLOGICAL AIDS
METEOROLOGICAL SATELLITE
MOBILE
RADIO ASTRONOMY
RADIODETERMINATION SATELLITE
RADIOLOCATION
RADIONAVIGATION
SPACE OPERATIONS
SPACE RESEARCH
STANDARD FREQUENCY AND TIME SIGNAL
R ROUTE
OR OFF ROUTE
SATELLITE
SPACE-TO-SPACE
SPACE-TO-EARTH
EARTH-TO-SPACE
A EXCEPT AERONAUTICAL MOBILE
G EXCLUSIVE USE BY GOVERNMENT
DEEP SPACE
SECONDARY SERVICE

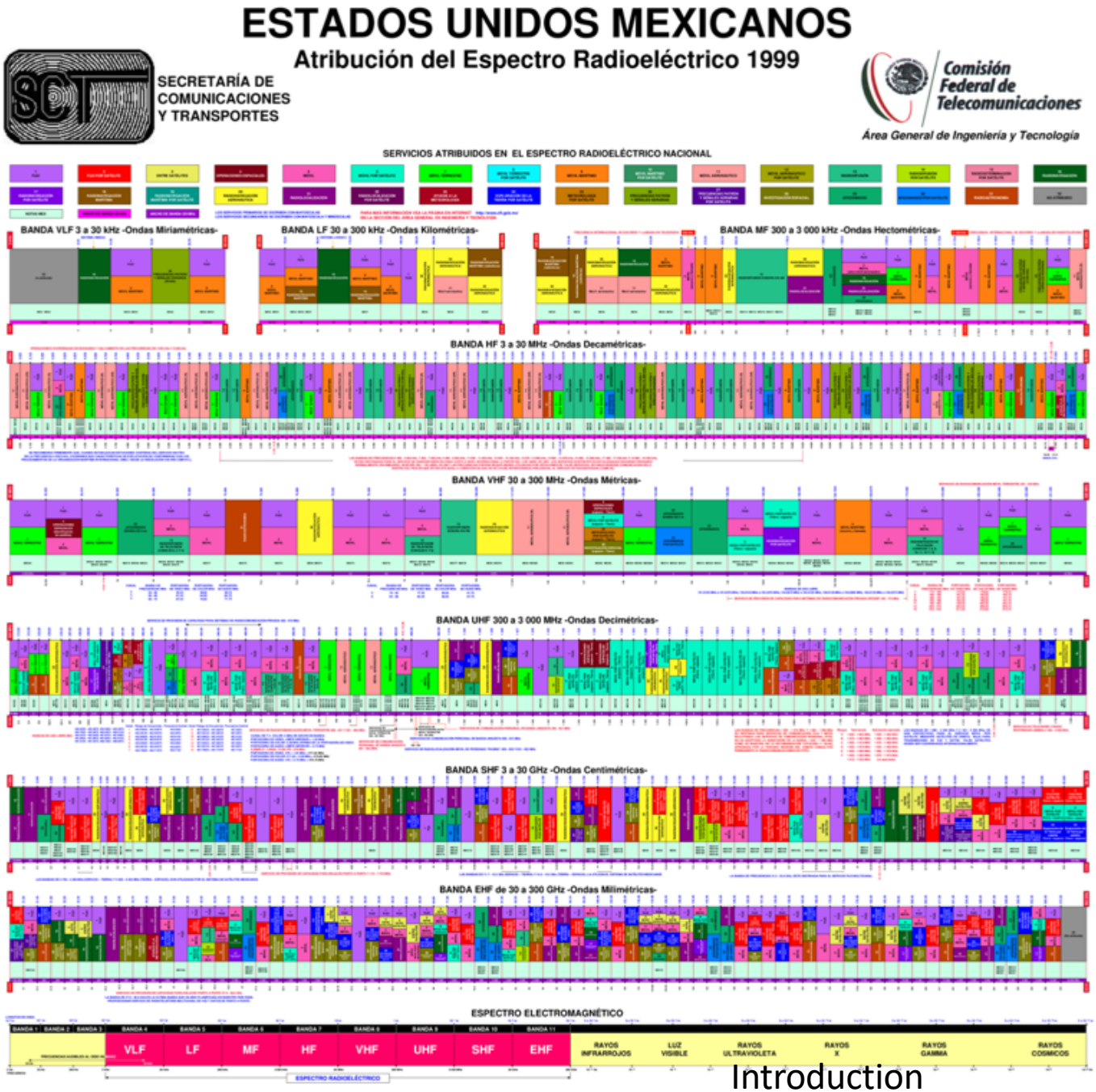
NOTE:

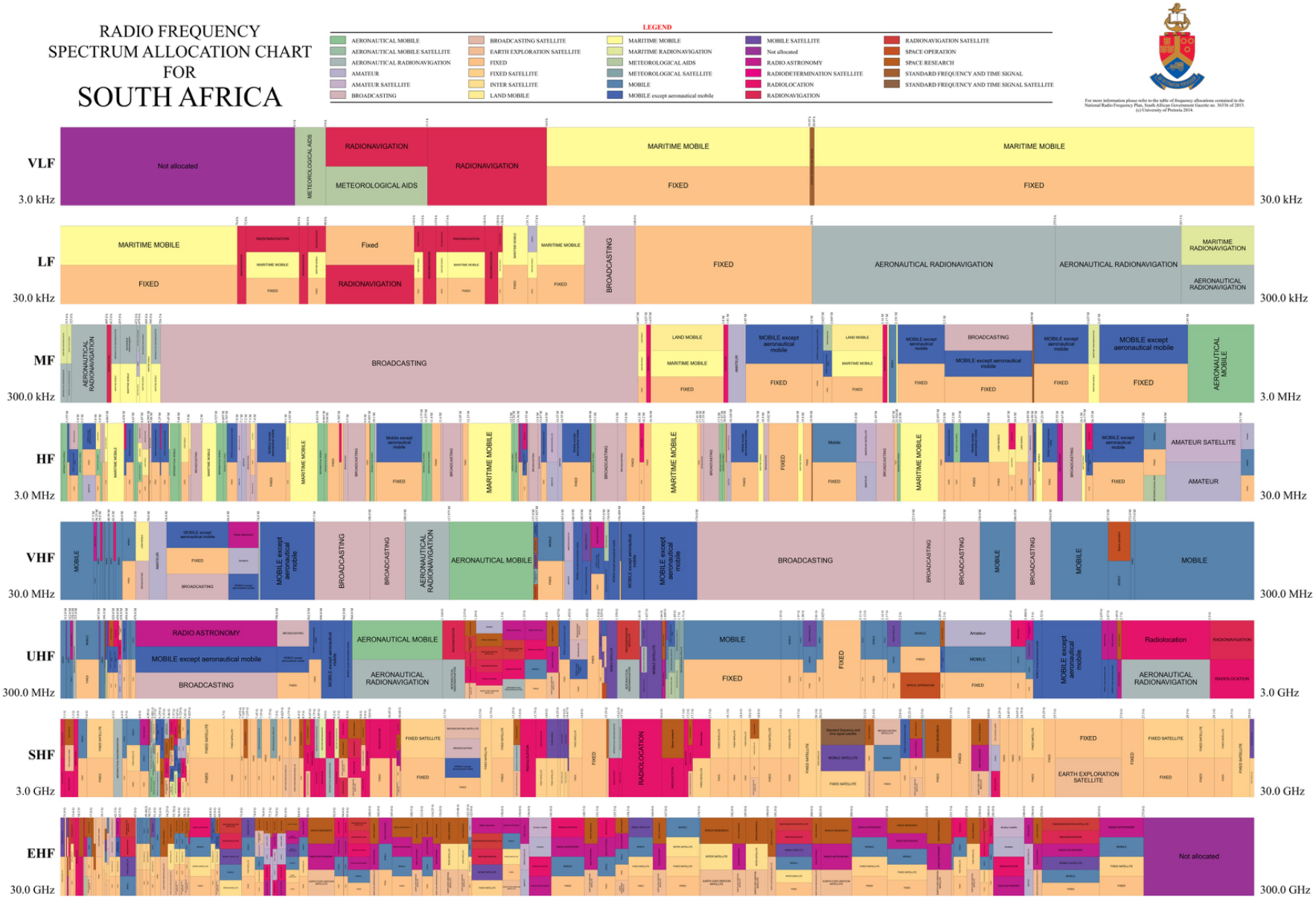
1) This chart should only be used for quick reference. For details of frequency allocations and footnotes, reference should be made to the Malaysian Spectrum Plan.

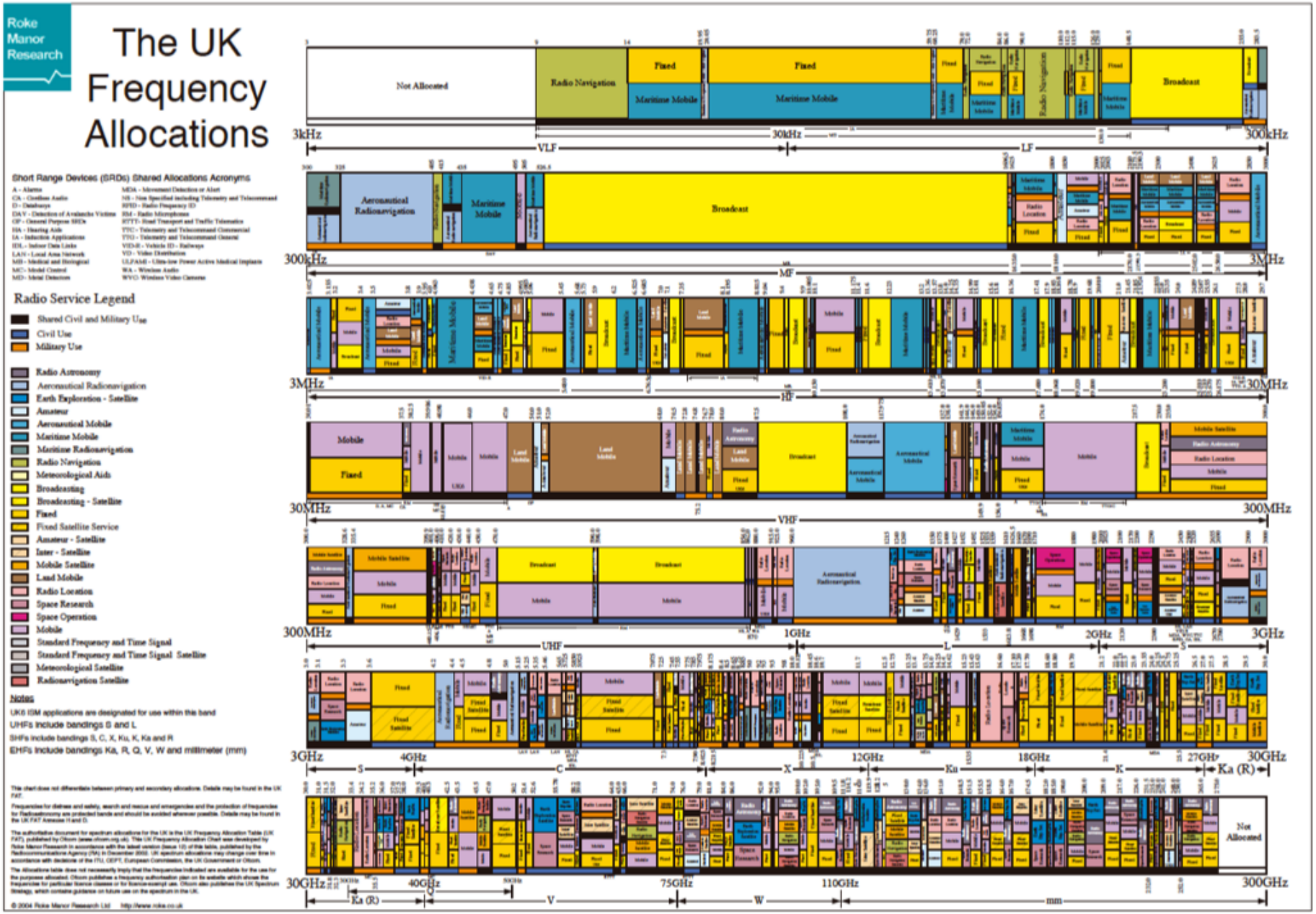
2) The spacing alloted to the services in the spectrum segments is not proportional to the actual amount of spectrum occupied.

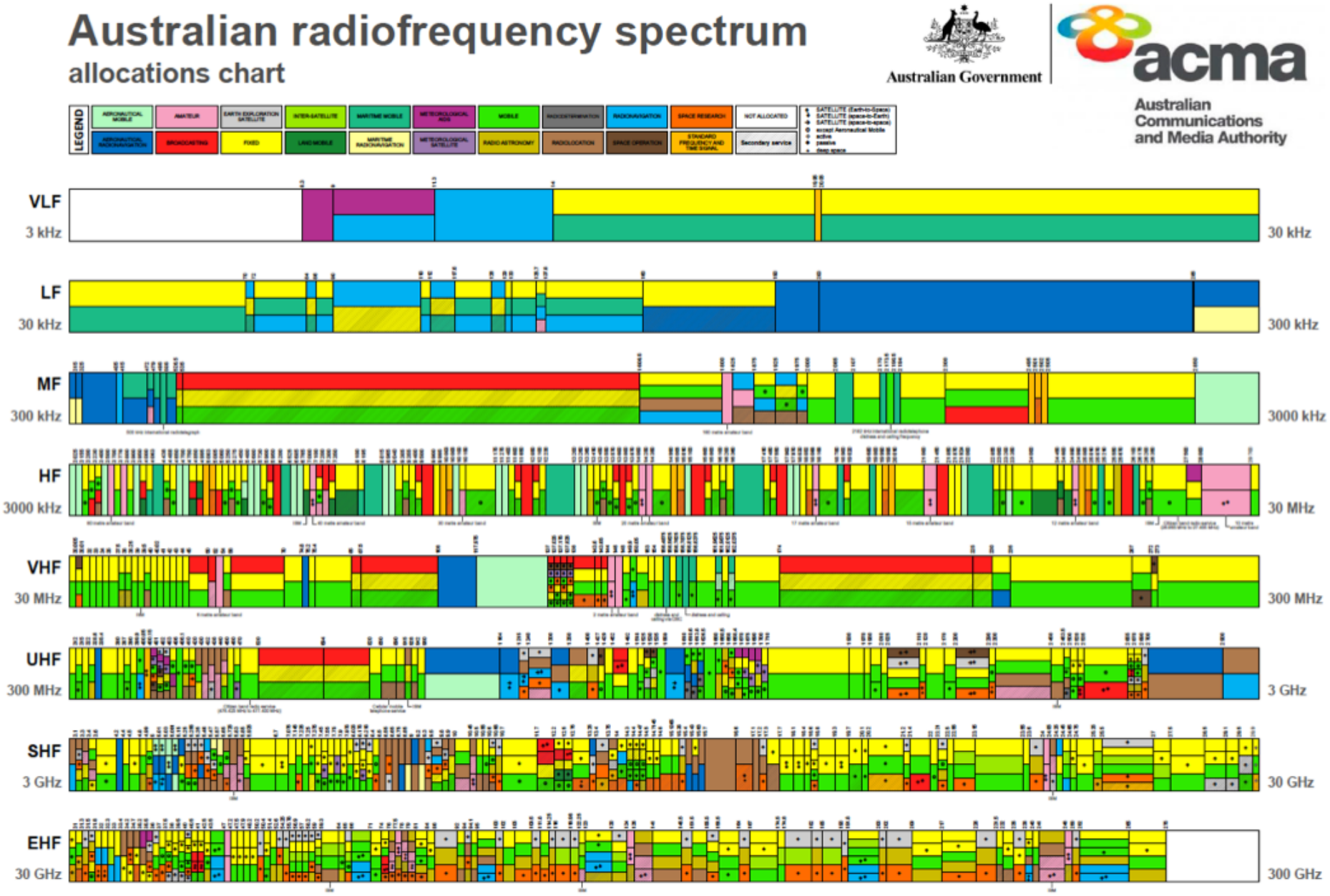
Issued as of June 2009

Suruhanjaya Komunikasi dan Multimedia Malaysia
Malaysian Communications and Multimedia Commission

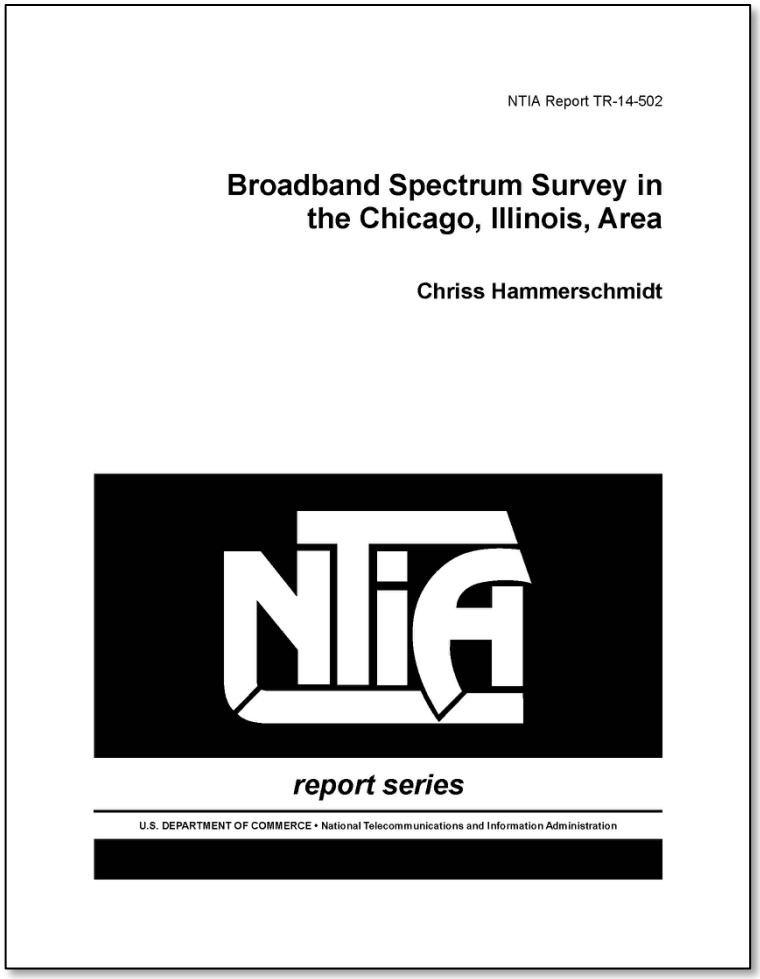

ESTADOS UNIDOS MEXICANOS
Atribución del Espectro Radioeléctrico 1999
SECRETARÍA DE COMUNICACIONES Y TRANSPORTES
Comisión Federal de Telecomunicaciones
Área General de Ingeniería y Tecnología
SERVICIOS ATRIBUIDOS EN EL ESPECTRO RADIOELÉCTRICO NACIONAL
BANDA VLF 3 a 30 kHz -Ondas Miriamétricas-
BANDA LF 30 a 300 kHz -Ondas Kilométricas-
BANDA MF 300 a 3 000 kHz -Ondas Hectométricas-
BANDA HF 3 a 30 MHz -Ondas Decamétricas-
BANDA VHF 30 a 300 MHz -Ondas Métricas-
BANDA UHF 300 a 3 000 MHz -Ondas Decimétricas-
BANDA SHF 3 a 30 GHz -Ondas Centimétricas-
BANDA EHF de 30 a 300 GHz -Ondas Milimétricas-
ESPECTRO ELECTROMAGNÉTICO
VLF
LF
MF
HF
VHF
UHF
SHF
EHF
RAYOS INFRARROJOS
LUZ VISIBLE
RAYOS ULTRAVIOLETA
RAYOS X
RAYOS GAMMA
RAYOS COSMICOS
ESPECTRO RADIOELÉCTRICO







So Who Measures Compliance?



- In the US, it's the job of the National Telecommunications and Information Administration

http://www.its.bldrdoc.gov/publications/2756.aspx

Example of a sampling station

- This one was done in Chicago on an NTIA campus
- Lots of automation and reconfiguration required to survey the entire radio spectrum

Sample Measurement #1

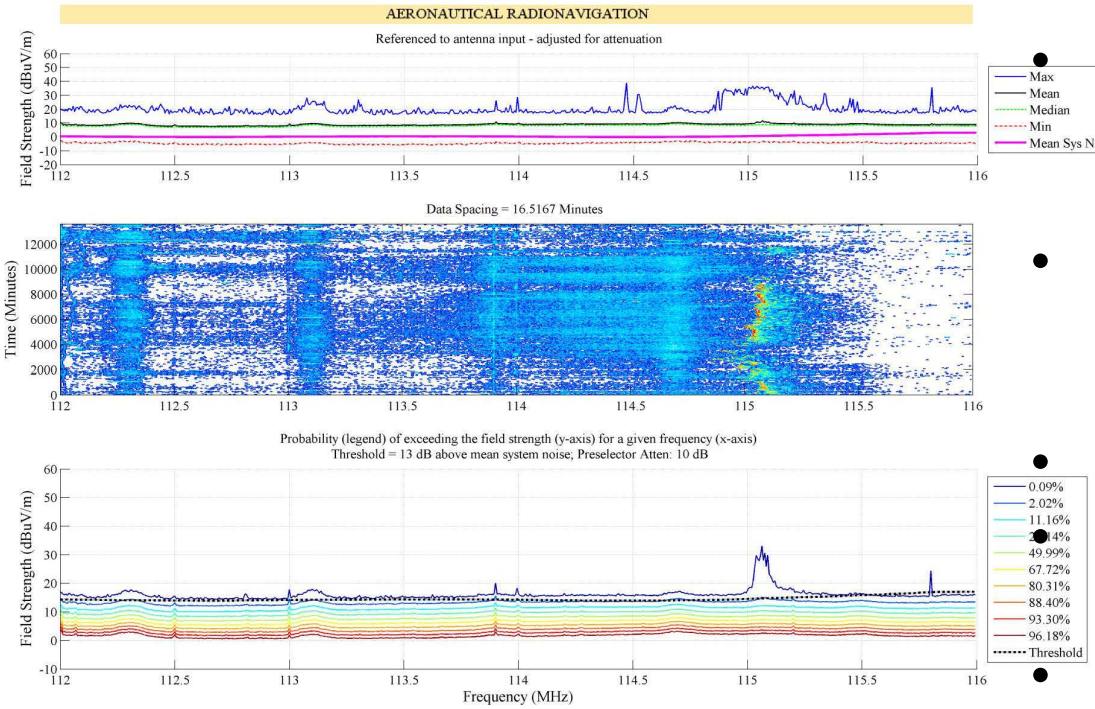


Figure 5. NTIA spectrum survey results from 112 to 116 MHz in Chicago, IL, September 2012.

- 112-116MHz
- Typically white space in middle graph – levels <13dB threshold
- Signals appear to occupy all frequencies all the time
- This is impulsive noise
- P(115.1MHz>20dBµV/m) =0.09%
- P(all signals>1-2dBµV/m)=96.18%
  - Basically on the entire time

Sample Measurement #2

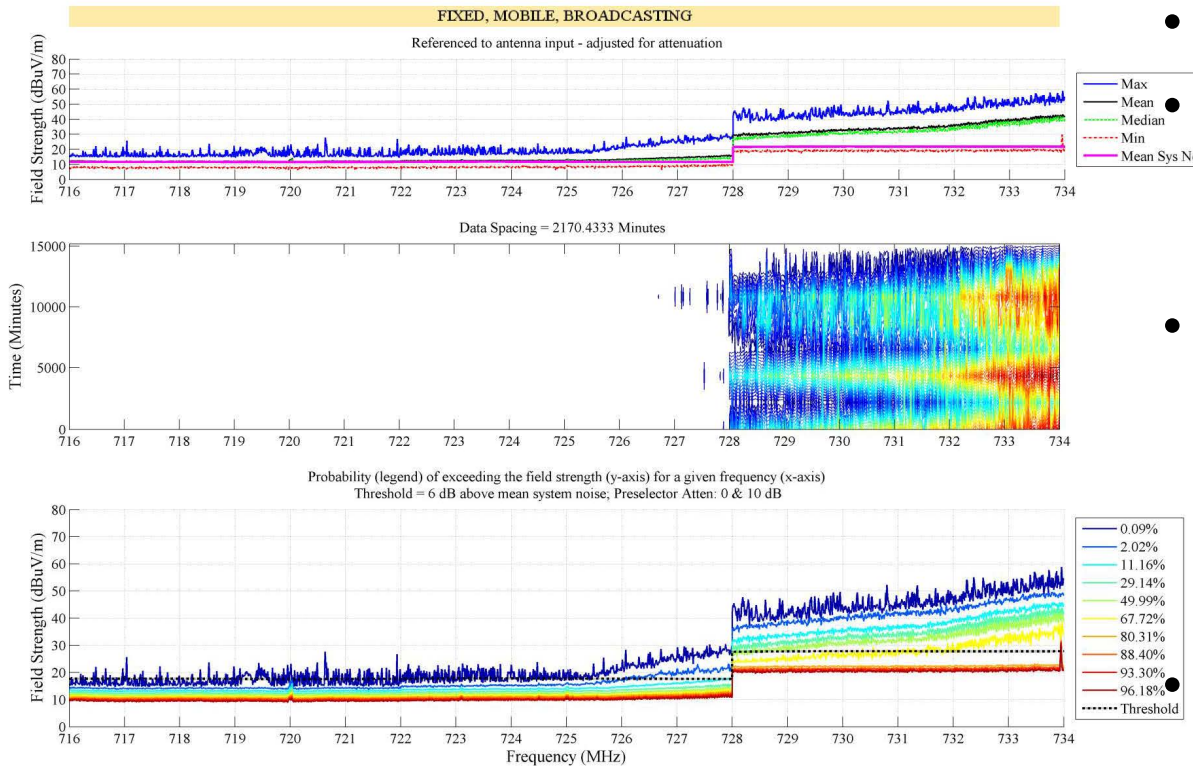


Figure 51. NTIA spectrum survey results from 716 to 734 MHz in Chicago, IL, September 2012.

- 716-734MHz
- Abrubt jump at 728MHz. 10dB attenuator added
- LTE signals present 728-763MHz, attenuation added to prevent system overloads
- Nothing prominent below 728

Sample Measurement #3

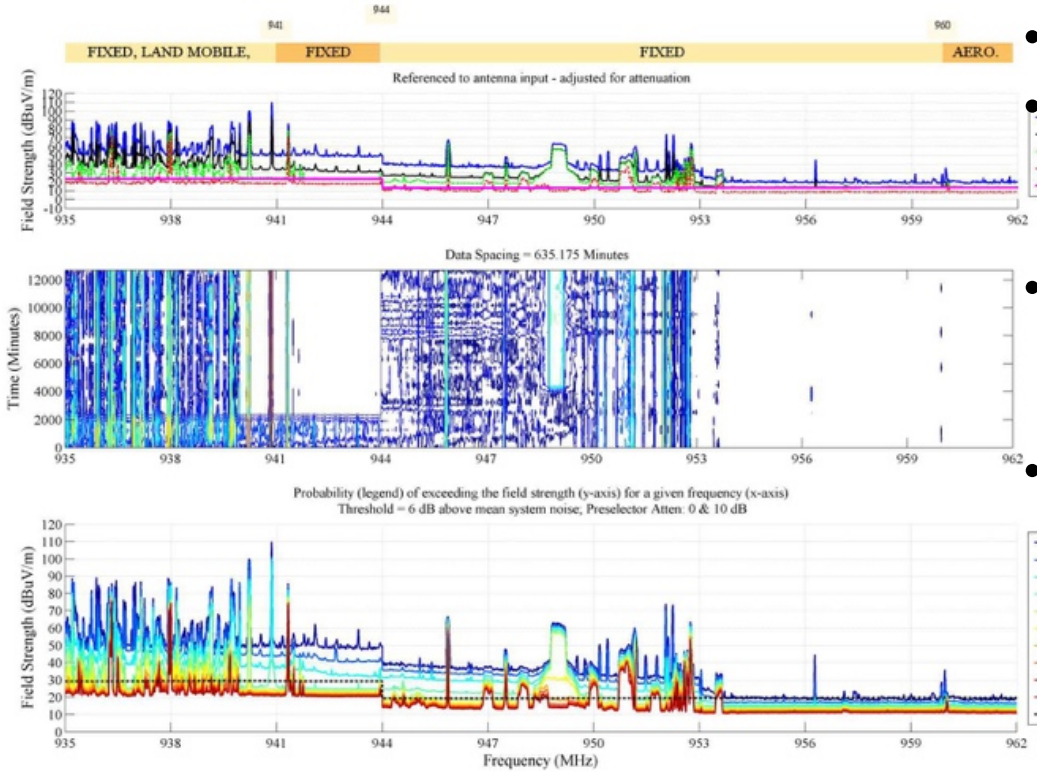


Figure 59. NTIA spectrum survey results from 935 to 962 MHz in Chicago, IL, September 2012.

- 935-962MHz
- Underlying signal <2000 minutes –added attenuation
- Those signals are now <6dB threshold and thus disappear
- 1 MHz-wide signal @948MHz:
  - For P(0.9-49.99), levels vary from 56-63 dBµV/m
  - @948MHz level ≈30dBµV/m, P(80.31%)
  - P(96.18%) >15 dBµV/m
  - >954.0MHz intermittent

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

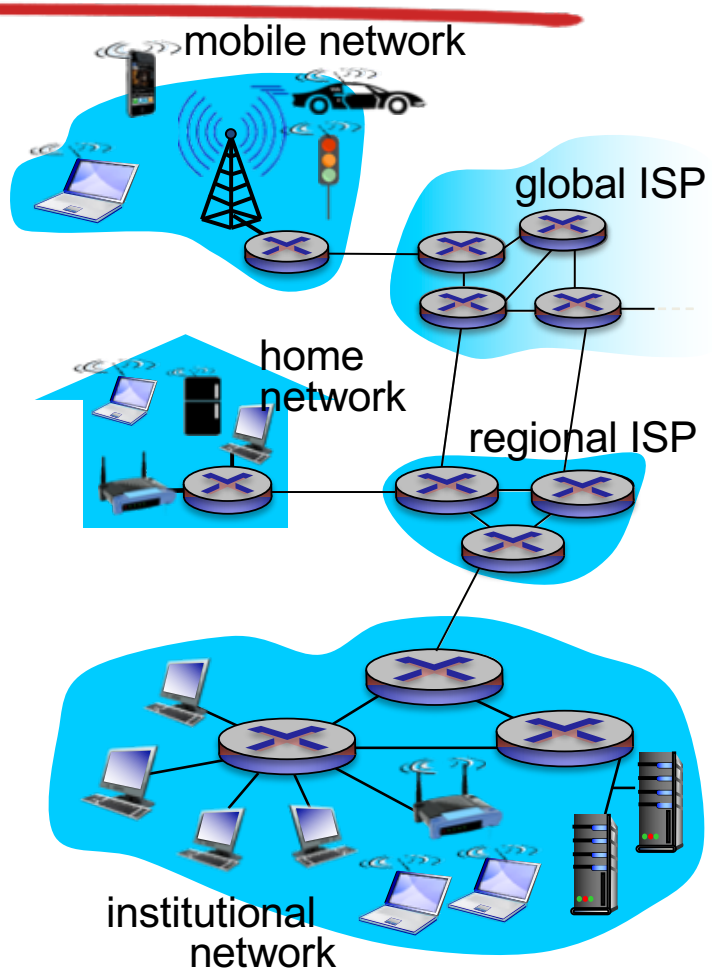
1.4 delay, loss, throughput in networks

1.5 protocol layers, service models

1.6 networks under attack: security

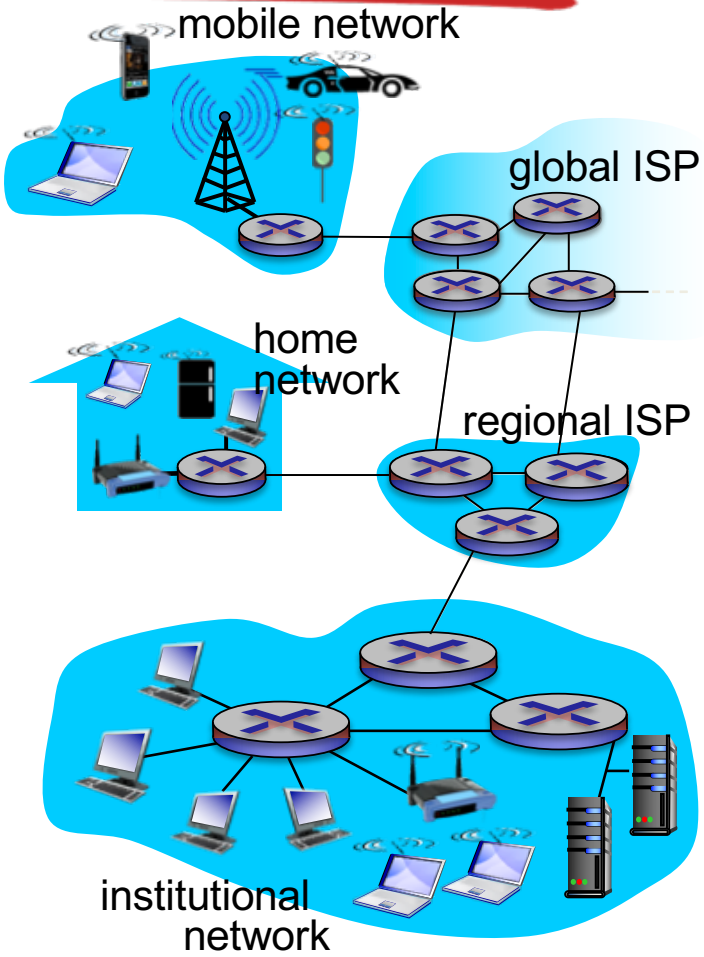
1.7 history

What's the Internet: "nuts & bolts"



What's the Internet: "nuts & bolts"

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



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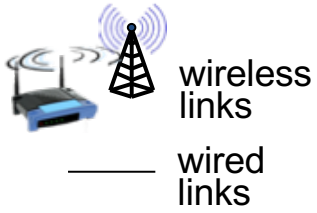
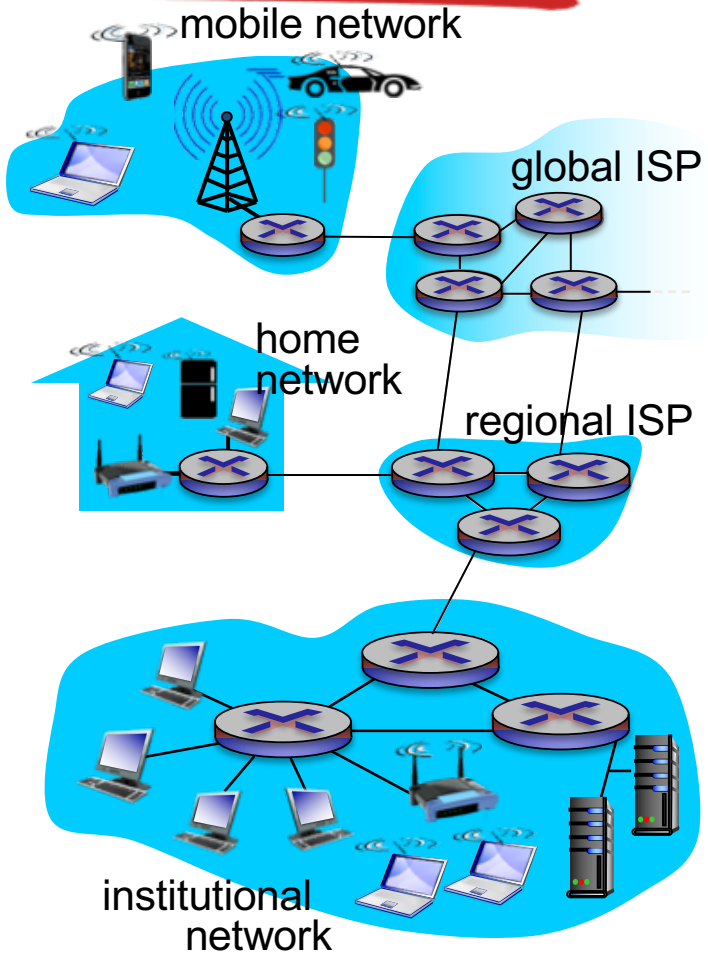


- *communication links*
  - fiber, copper, radio, satellite
  - transmission rate: *bandwidth*



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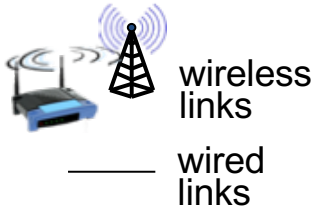
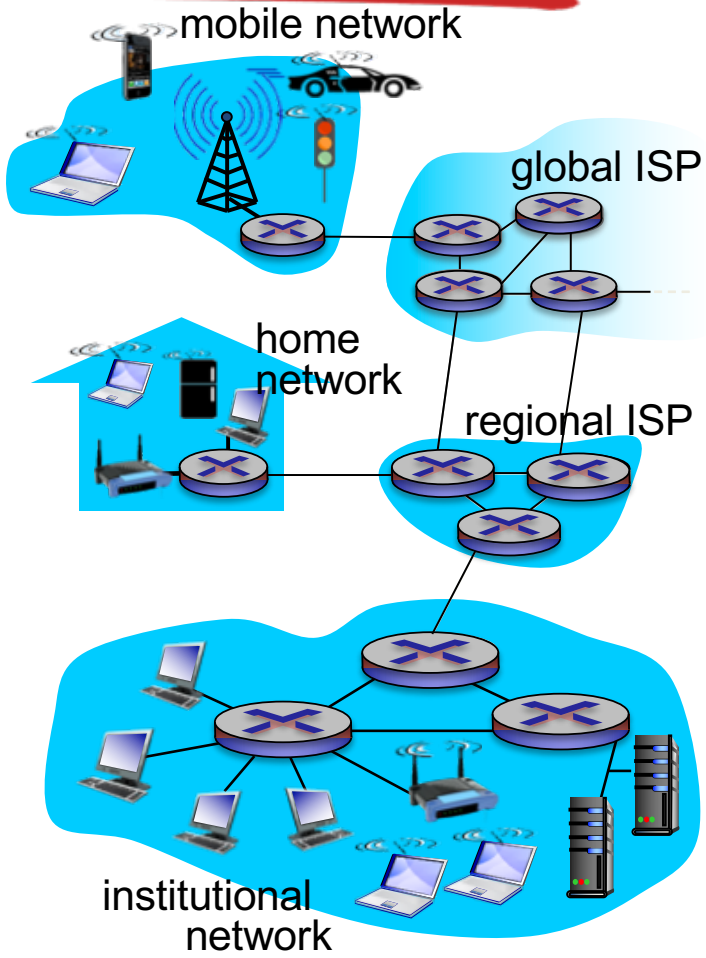


- *communication links*
  - fiber, copper, radio, satellite
  - transmission rate: *bandwidth*

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



"Fun" Internet-connected devices

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

Web-enabled toaster +
weather forecaster

Tweet-a-watt:
monitor energy use

Internet
refrigerator

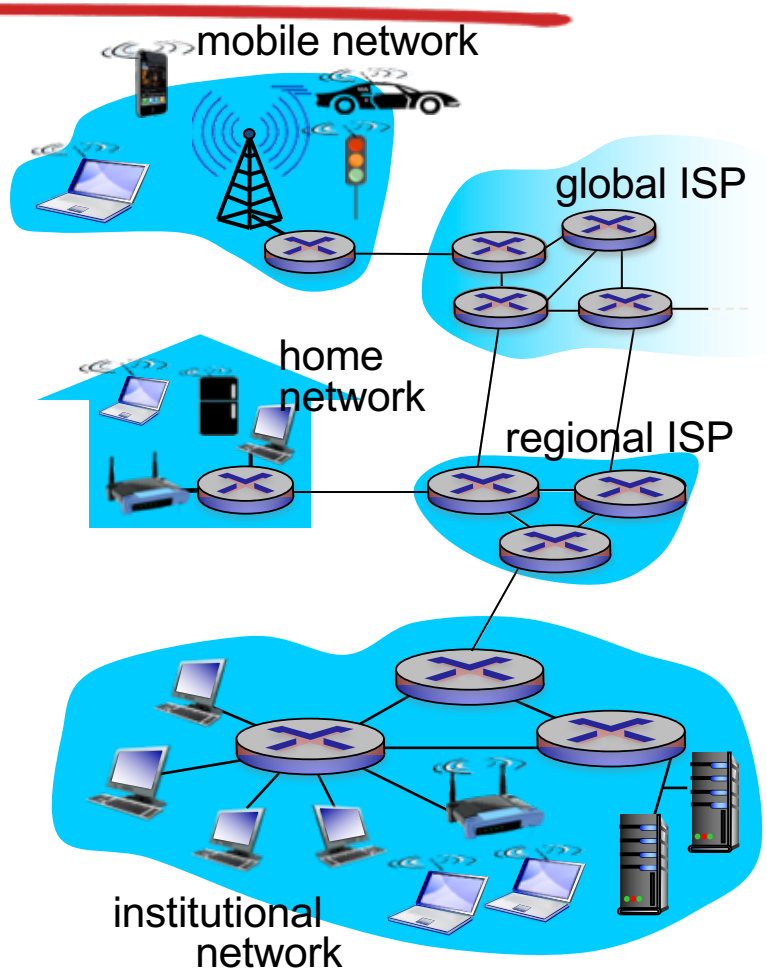
Slingbox: watch,
control cable TV remotely

sensorized,
bed
mattress

Internet phones

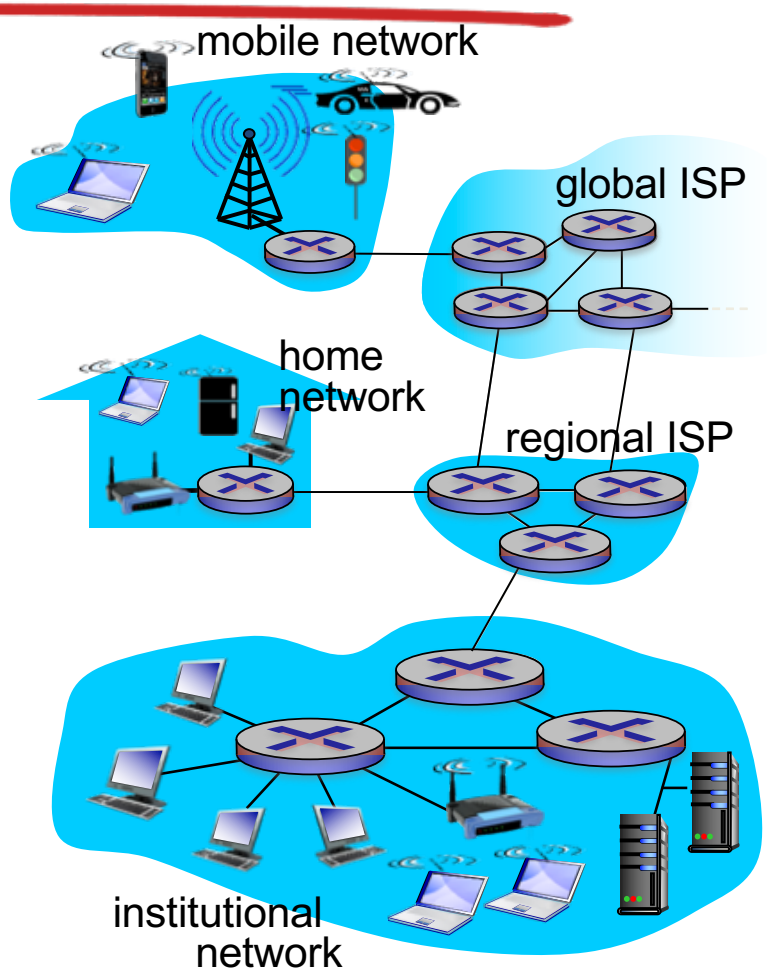
What's the Internet: "nuts & bolts"

- *Internet:* "network of networks"
  - Interconnected ISPs
- *protocols* control sending, receiving of messages
  - 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 messages sent

… specific actions taken when messages received, or other events

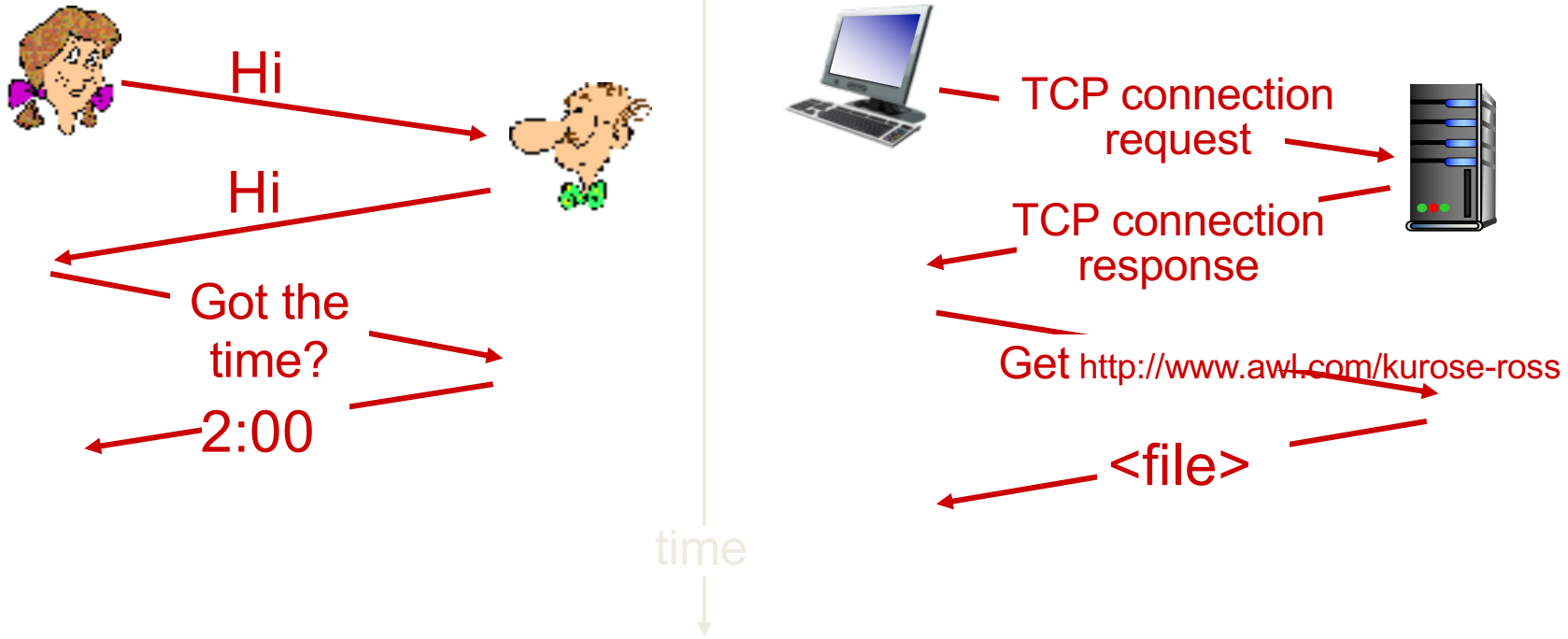
network protocols:

- 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 message transmission, receipt

What's a protocol?

a human protocol and a computer network protocol:



Q: other human protocols?

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

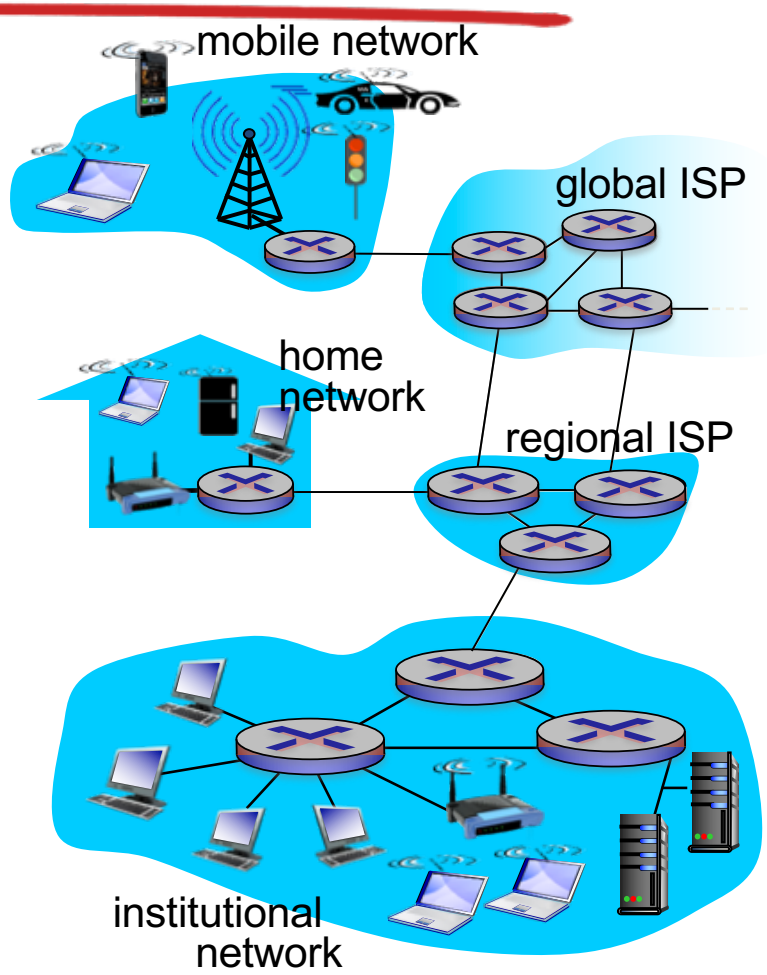
1.5 protocol layers, service models

1.6 networks under attack: security

1.7 history

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



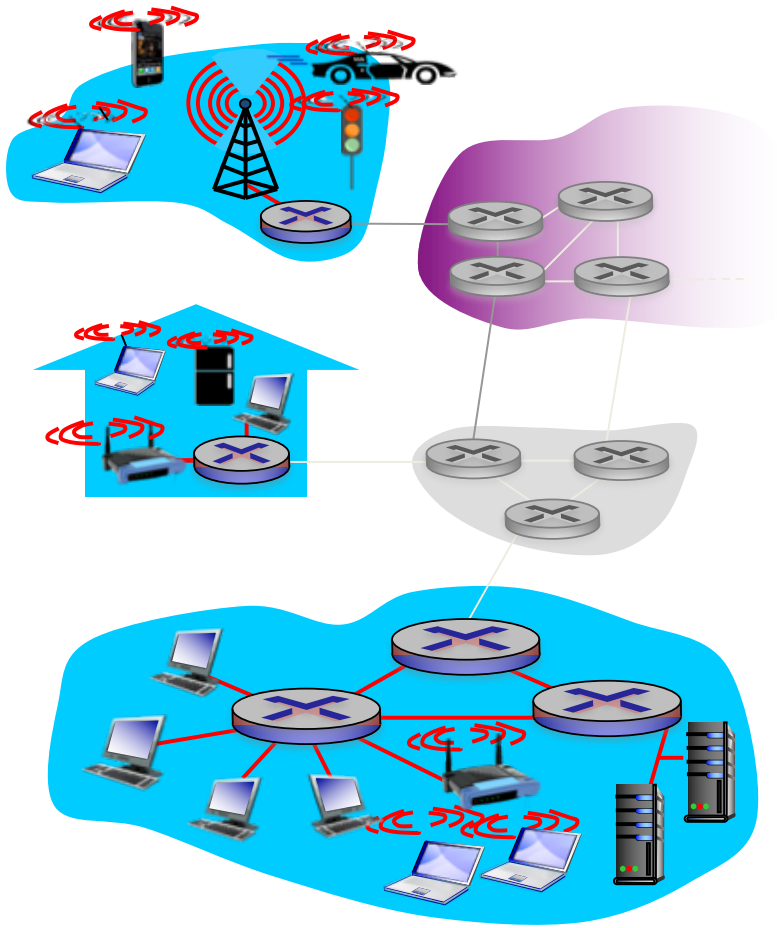
Access networks and physical media

Q: How to connect end systems to edge router?

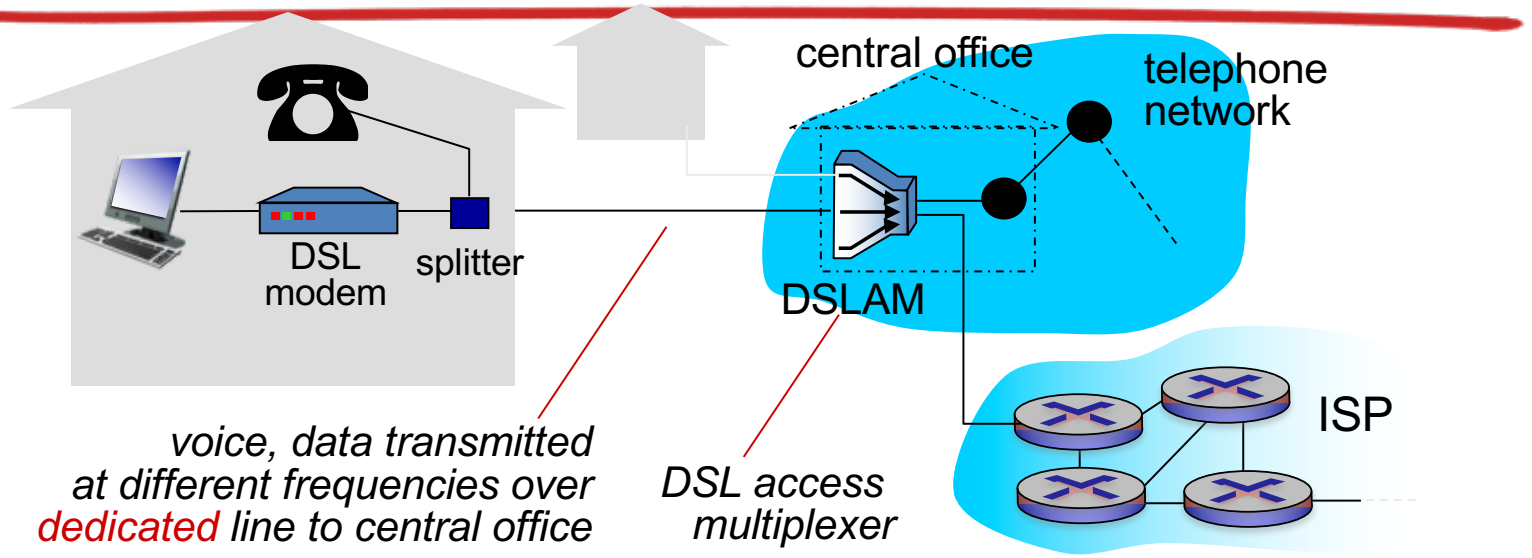
- residential access nets
- institutional access networks (school, company)
- mobile access networks

keep in mind:

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

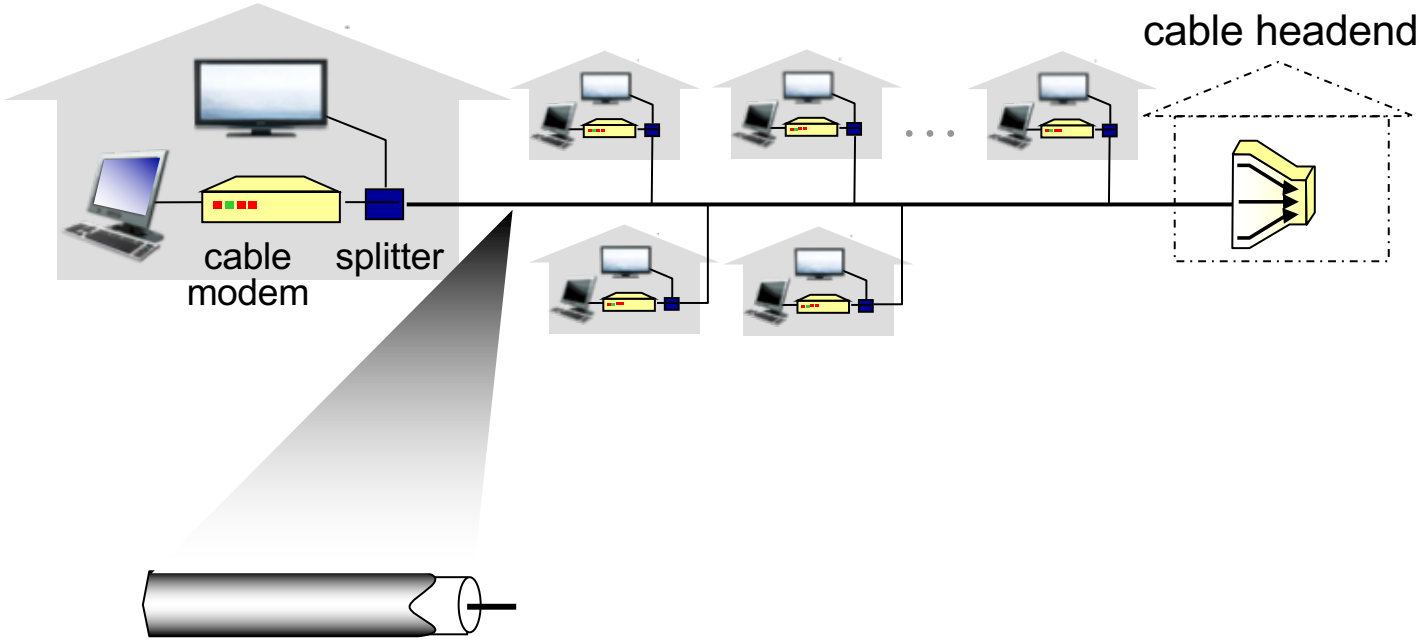


Access network: digital subscriber line (DSL)

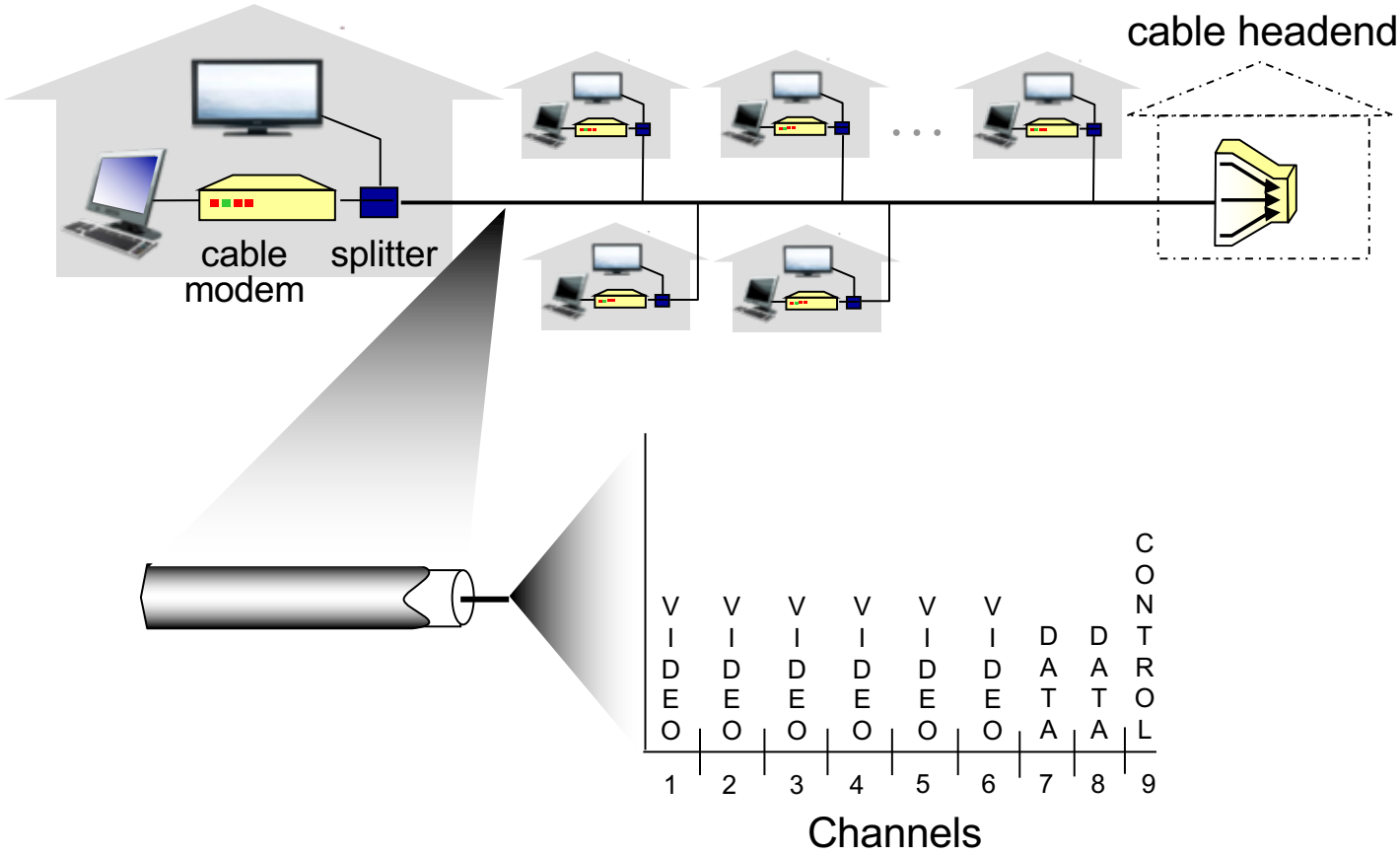


- use *existing* telephone line to central office DSLAM
  - data over DSL phone line goes to Internet
  - voice over DSL phone line goes to telephone net
- < 2.5 Mbps upstream transmission rate (typically < 1Mbps)
- < 24 Mbps downstream trans. rate (typically <10 Mbps)

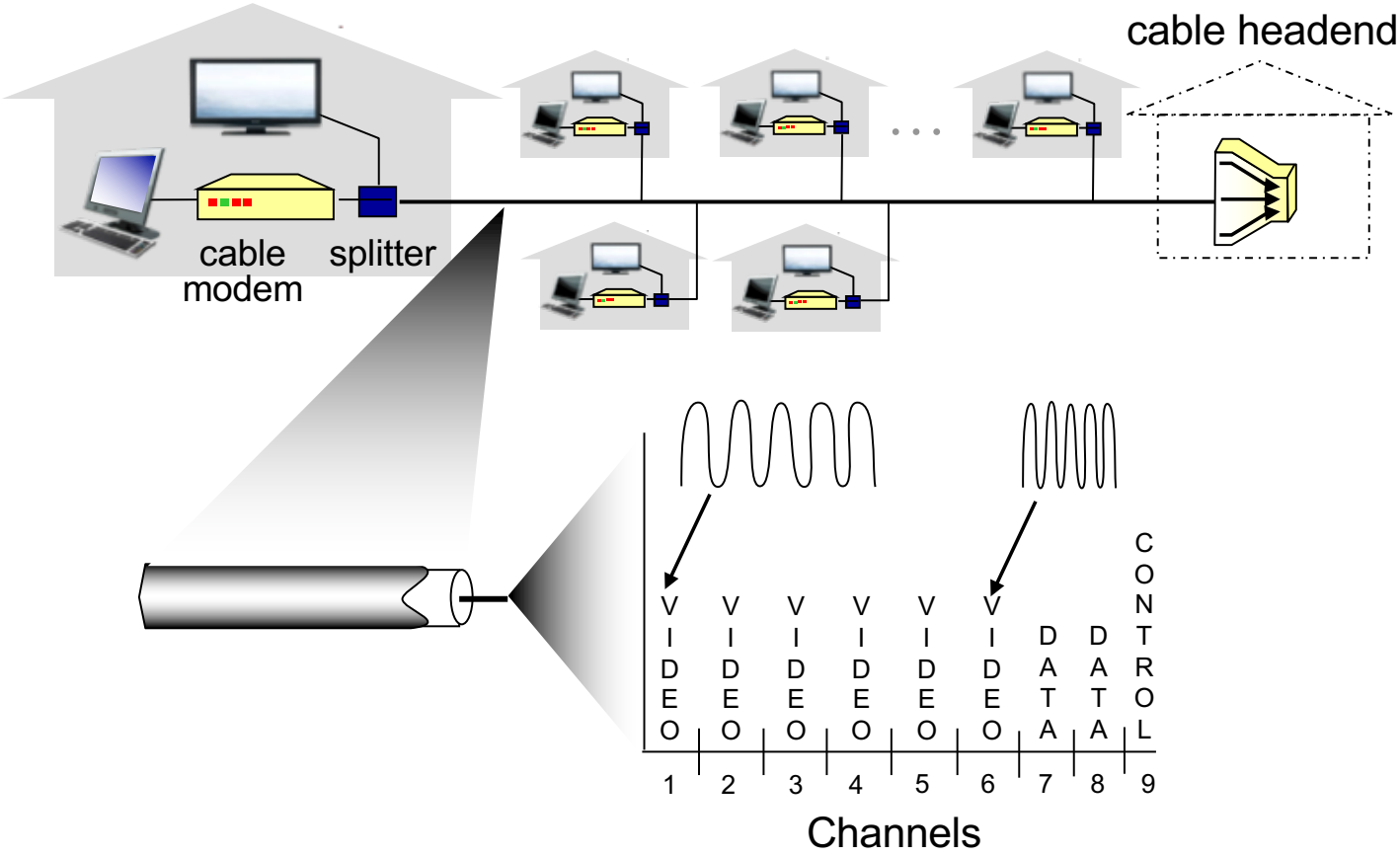
Access network: cable network



Access network: cable network

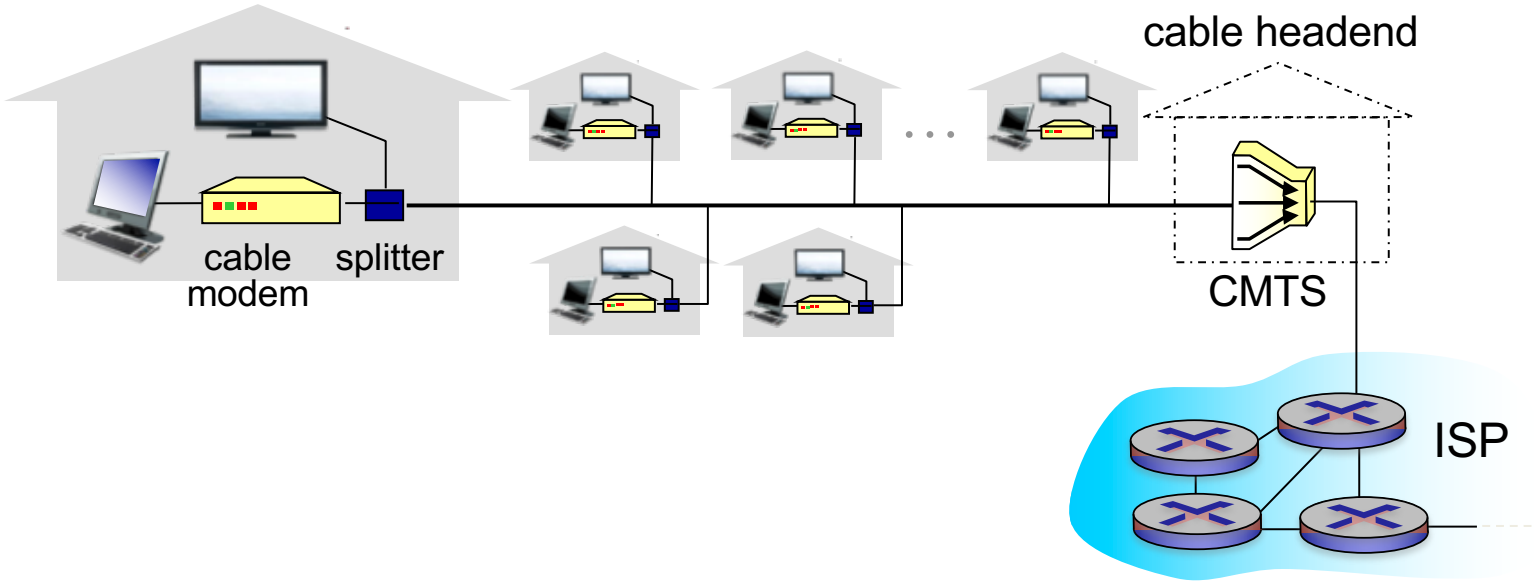


Access network: cable network



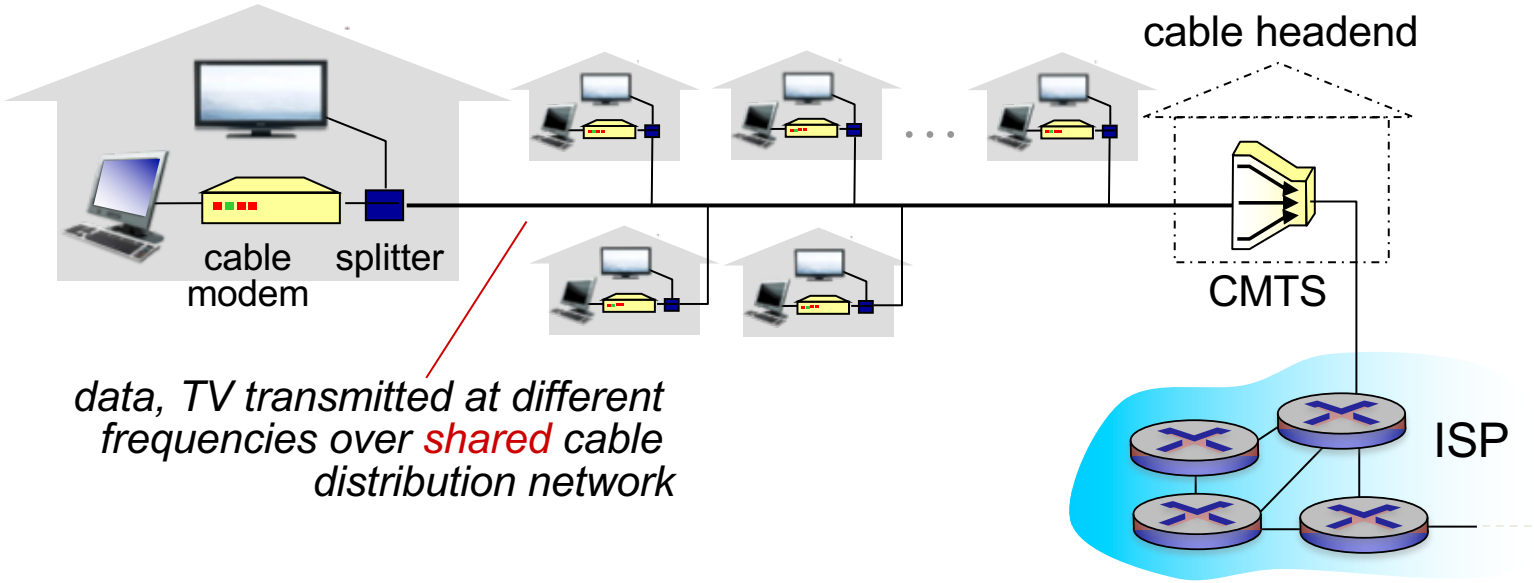
frequency division multiplexing: different channels transmitted in different frequency bands

Access network: cable network



- HFC: hybrid fiber coax
  - asymmetric: up to 30Mbps downstream transmission rate, 2 Mbps upstream transmission rate
- 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 network: cable network



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  - asymmetric: up to 30Mbps downstream transmission rate, 2 Mbps upstream transmission rate
- 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

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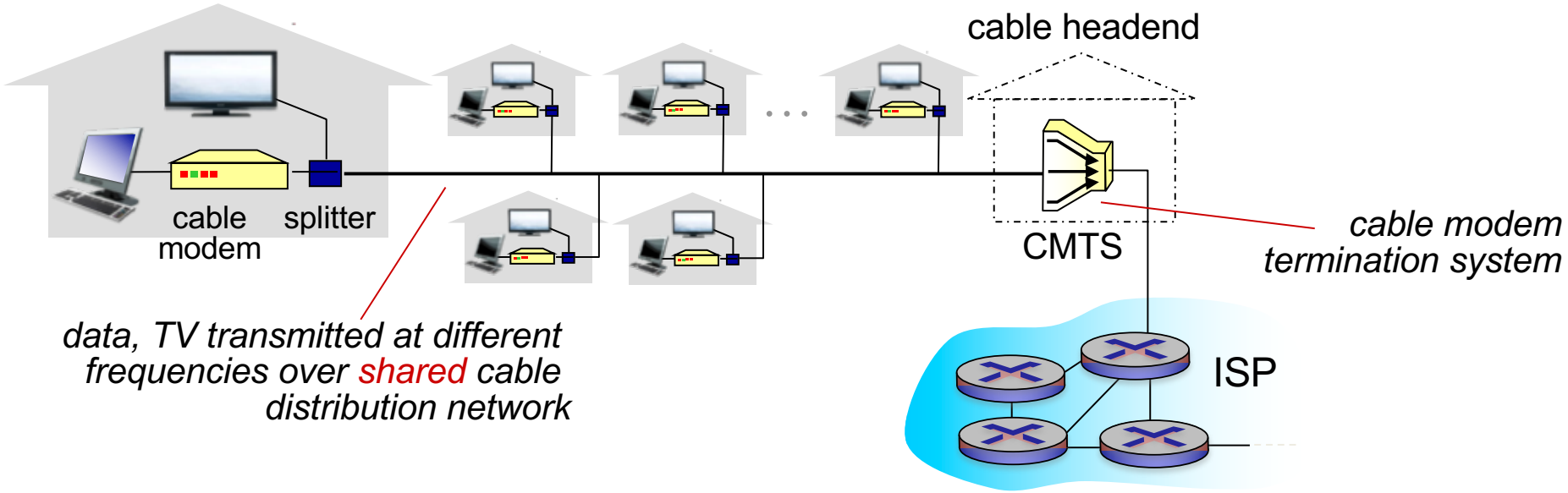

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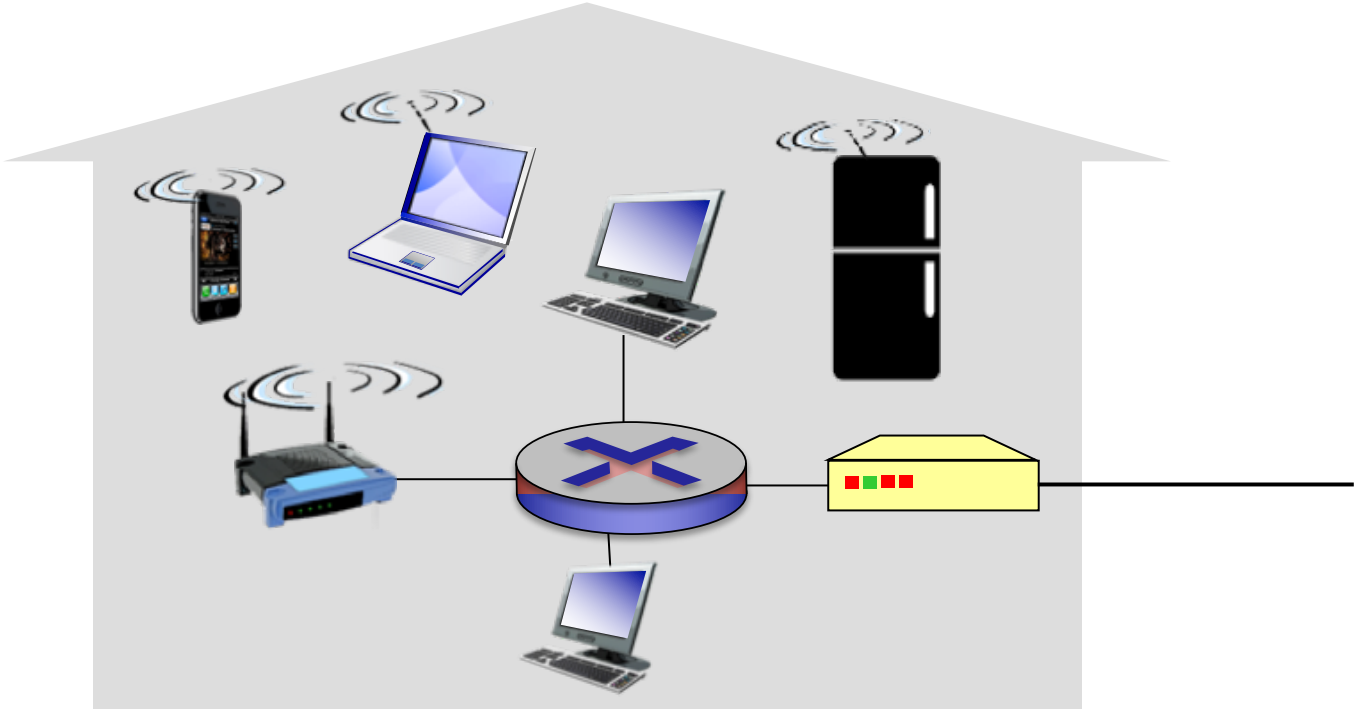

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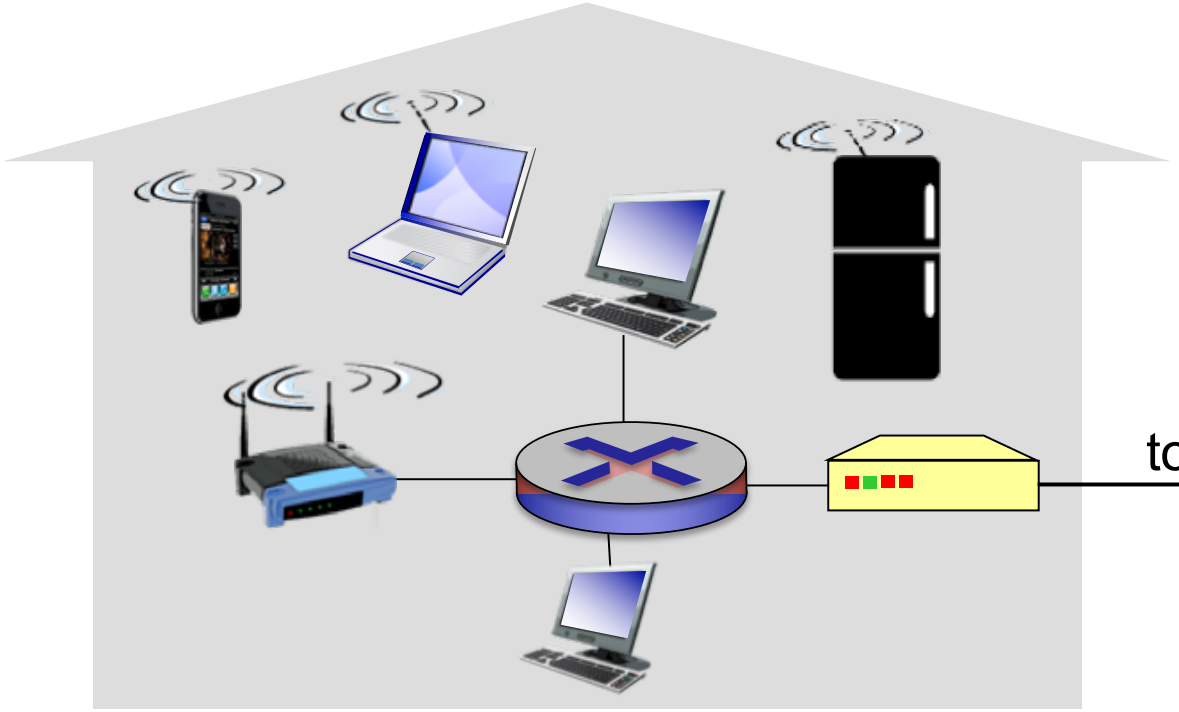

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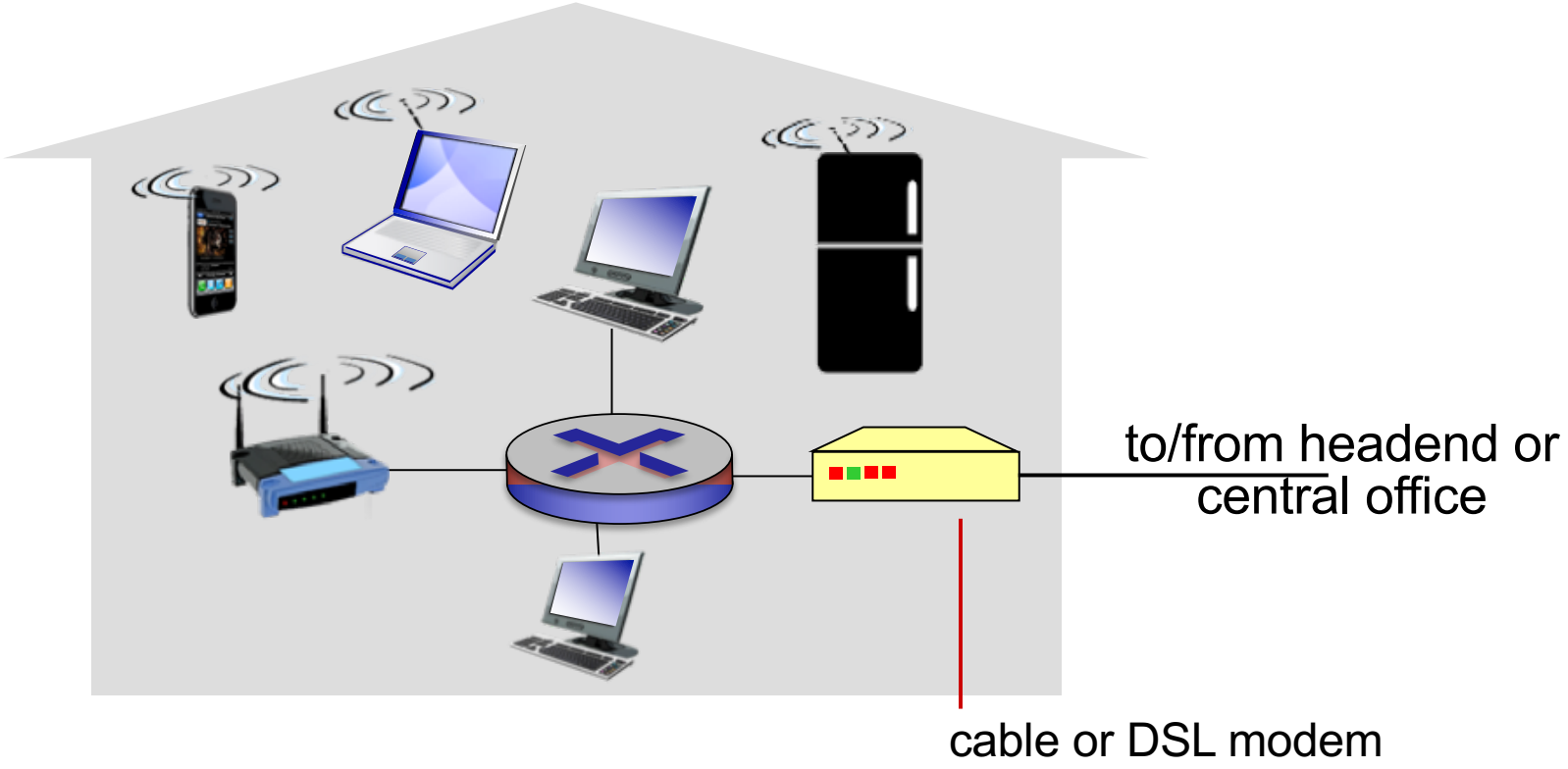

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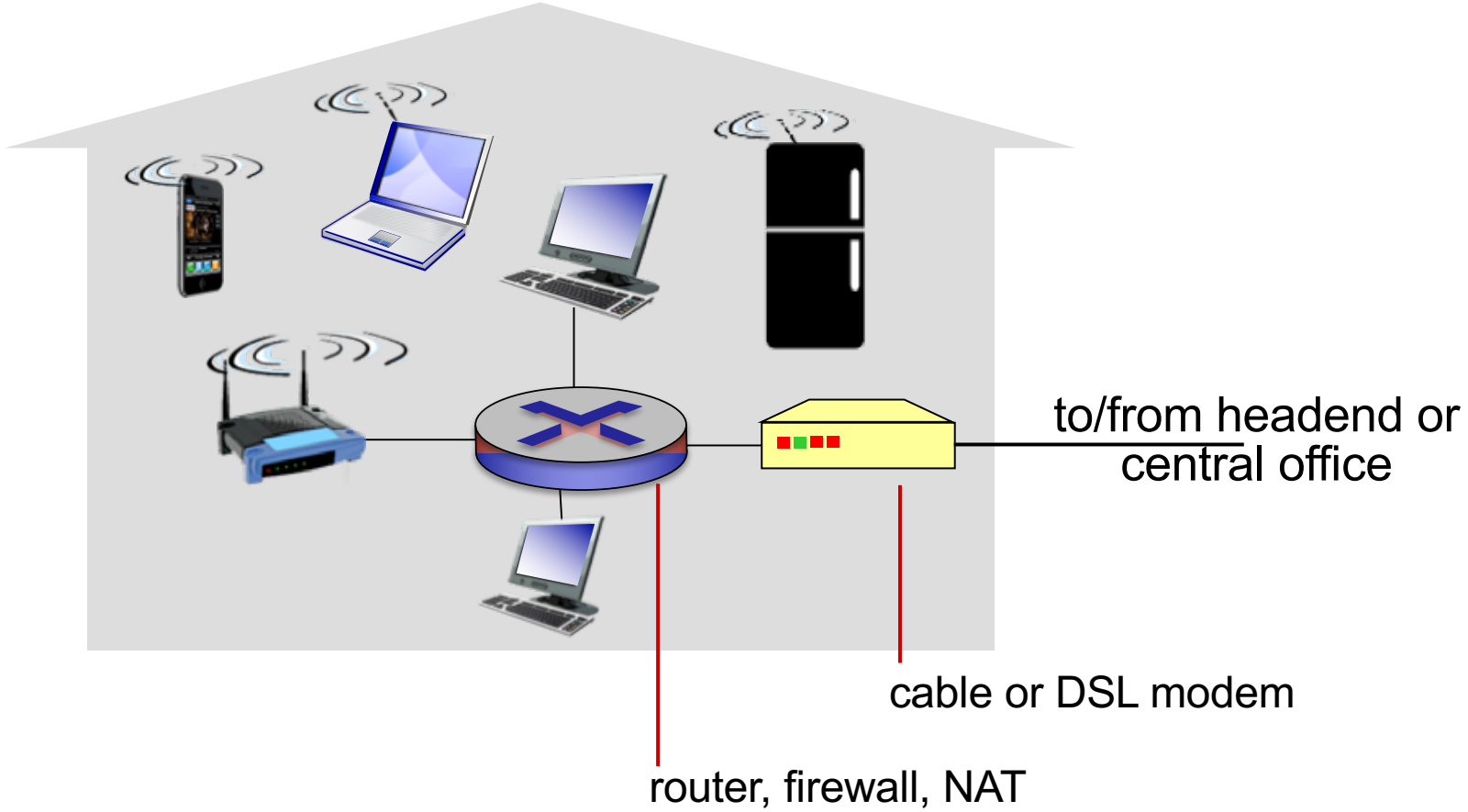

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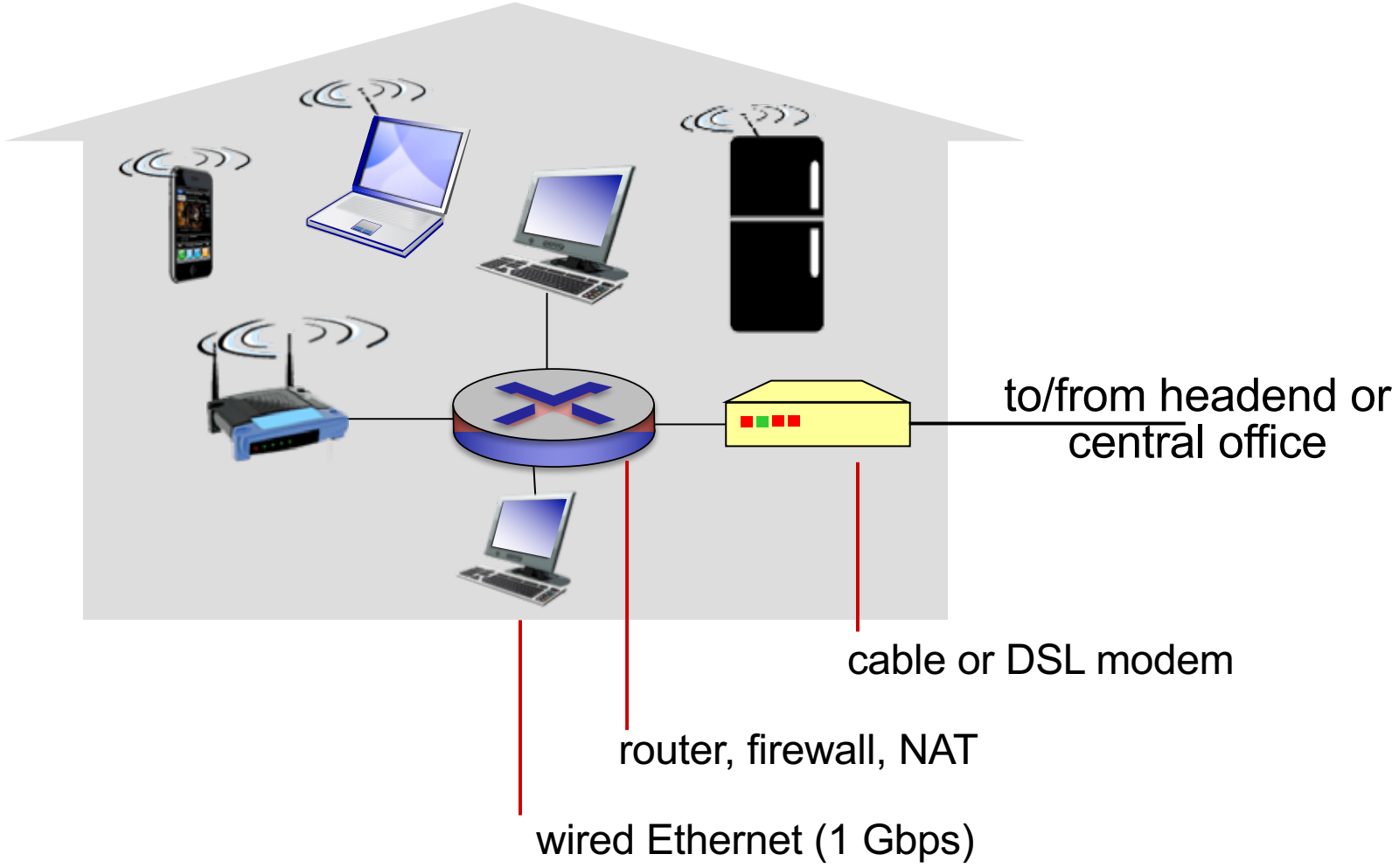

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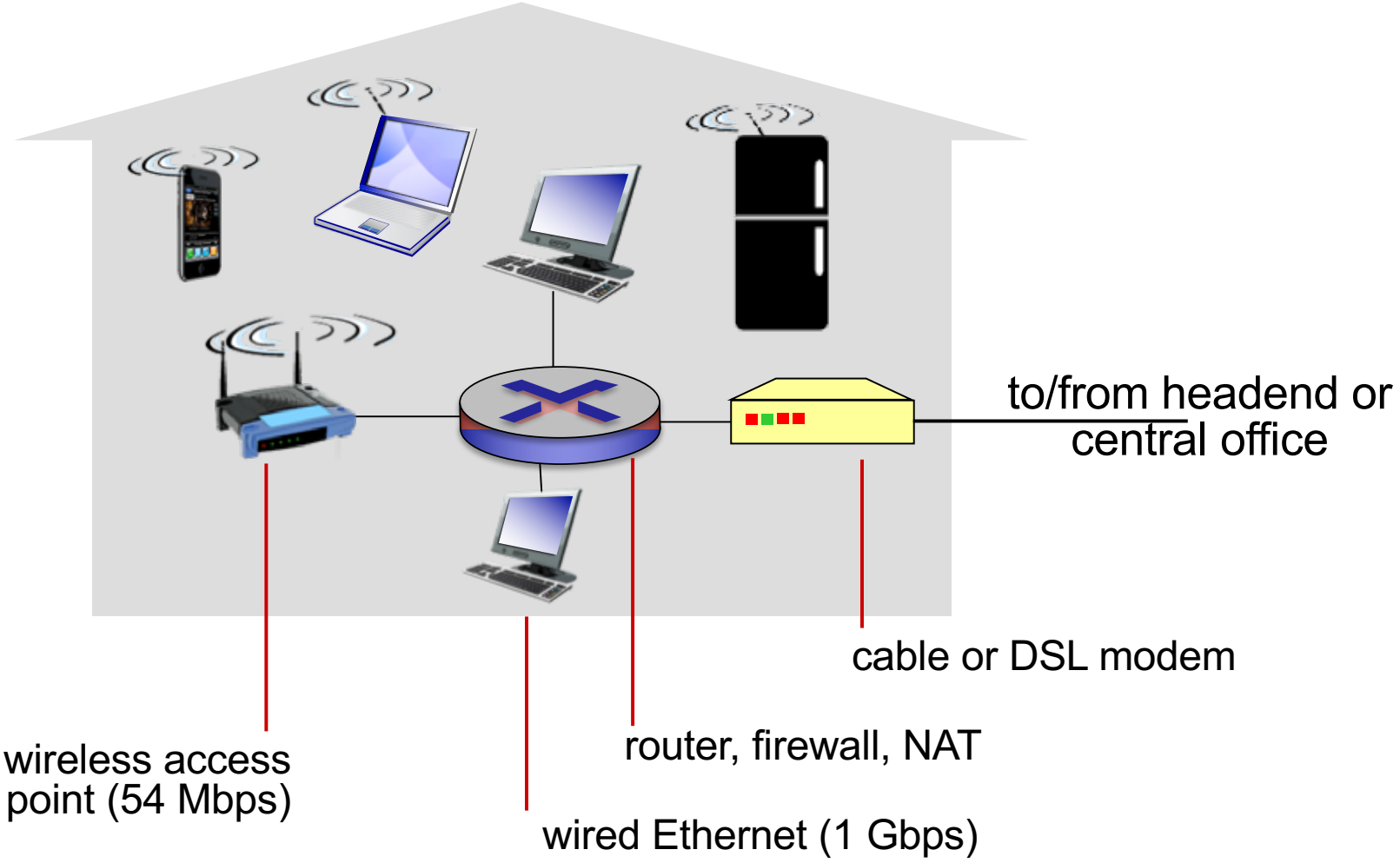

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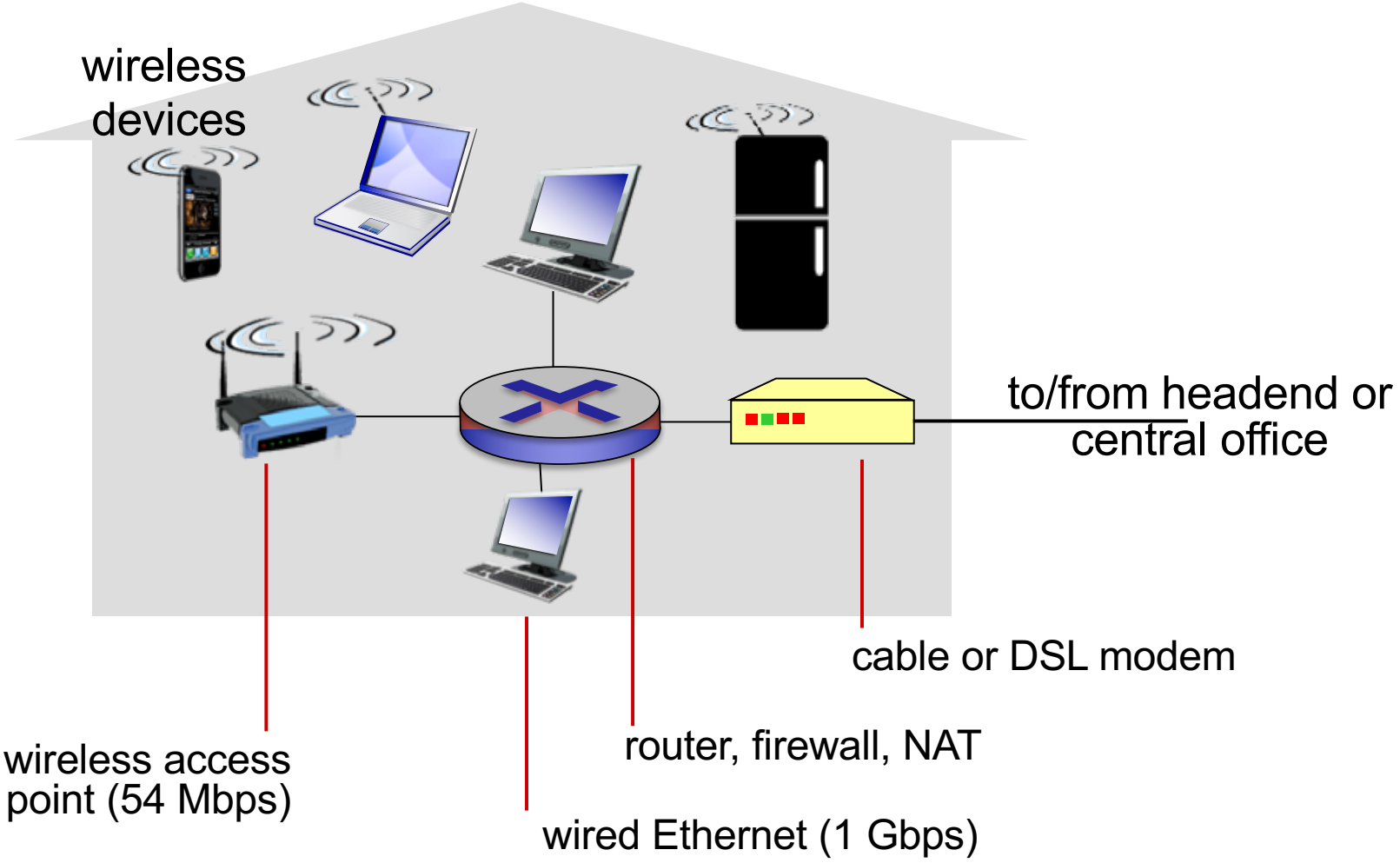

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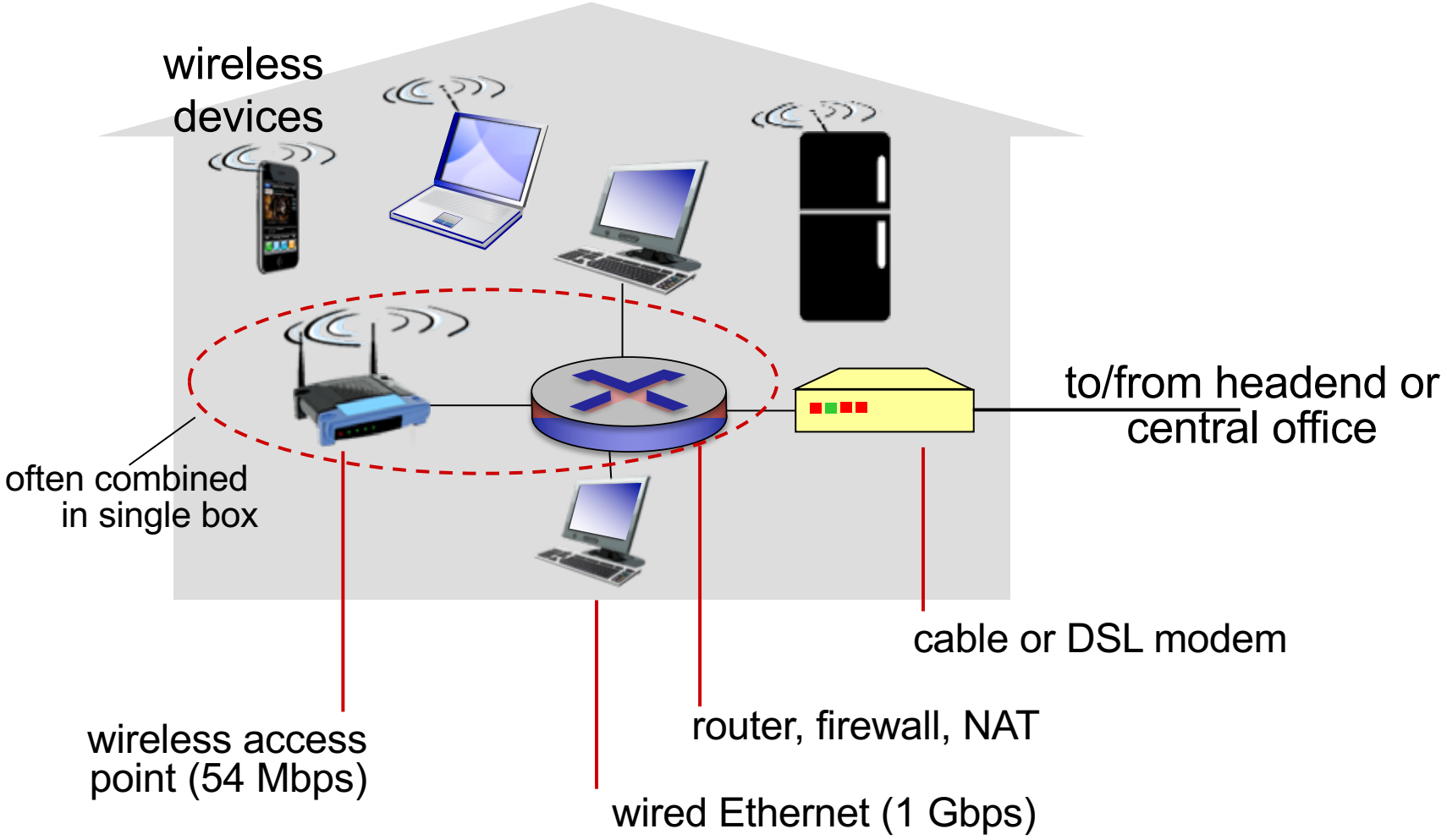
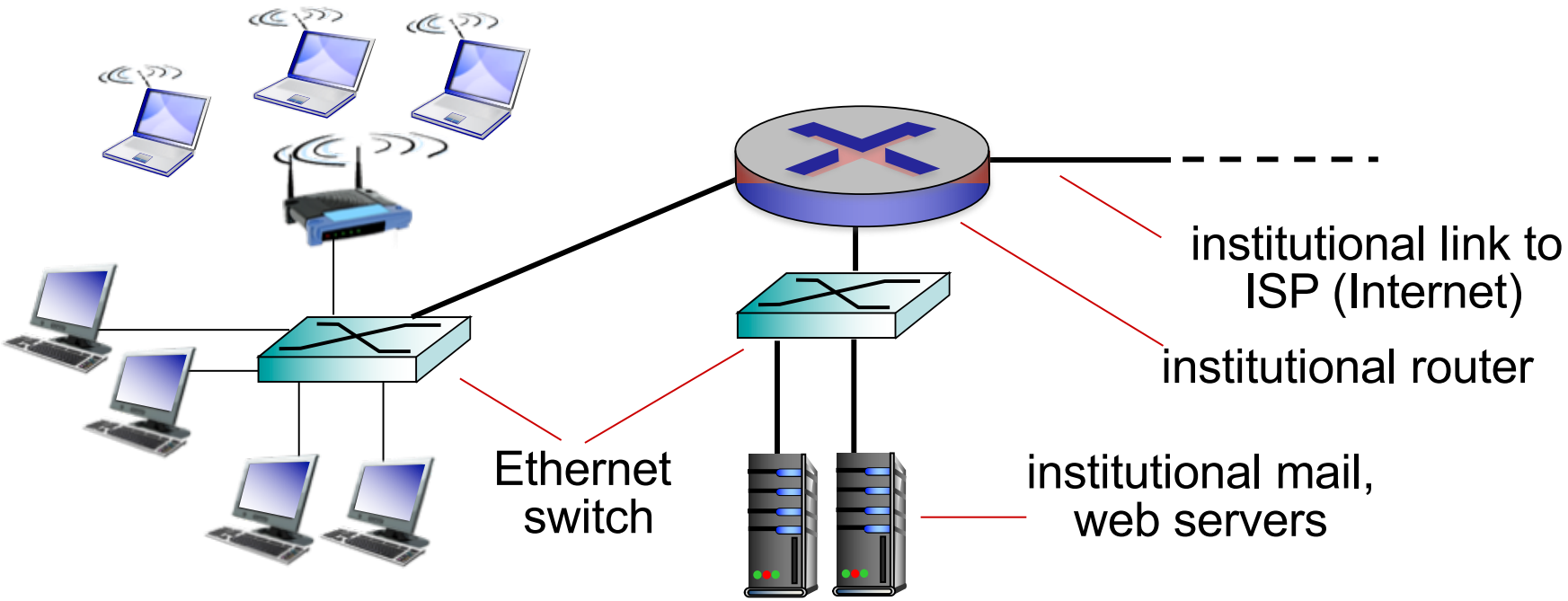


Enterprise access networks (Ethernet)



- 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, 450 Mbps transmission rate

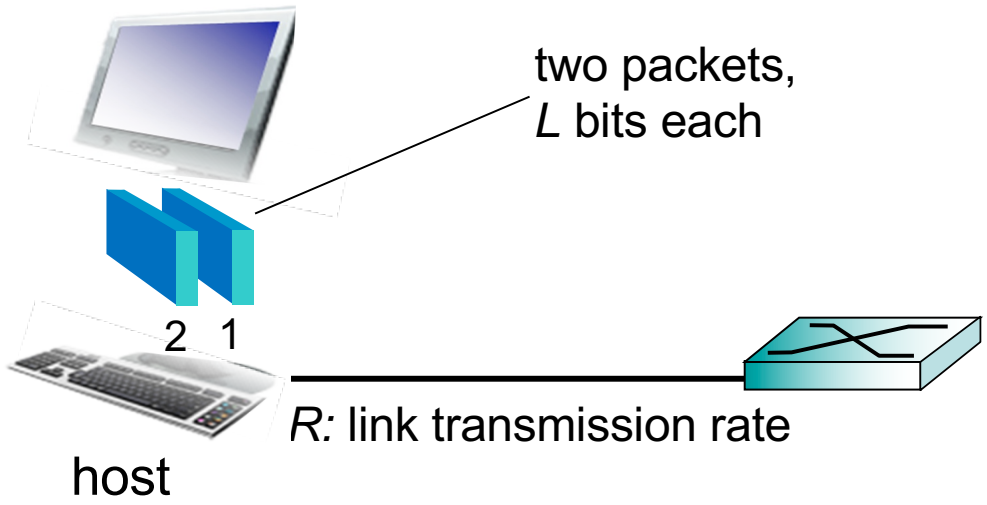
wide-area wireless access

- provided by telco (cellular) operator, 10's km
- between 1 and 10 Mbps
- 3G, 4G: LTE

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 Gbps Ethernet
  - Category 6: 10Gbps

Physical media: coax, fiber

coaxial cable:

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

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 Gbps 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)
  - 54 Mbps
- wide-area (e.g., cellular)
  - 4G cellular: ~ 10 Mbps
- satellite
  - Kbps to 45Mbps channel (or multiple smaller channels)
  - 270 msec end-end delay
  - geosynchronous versus low altitude