

Introduction to Wireless Networks



Wireless devices are everywhere

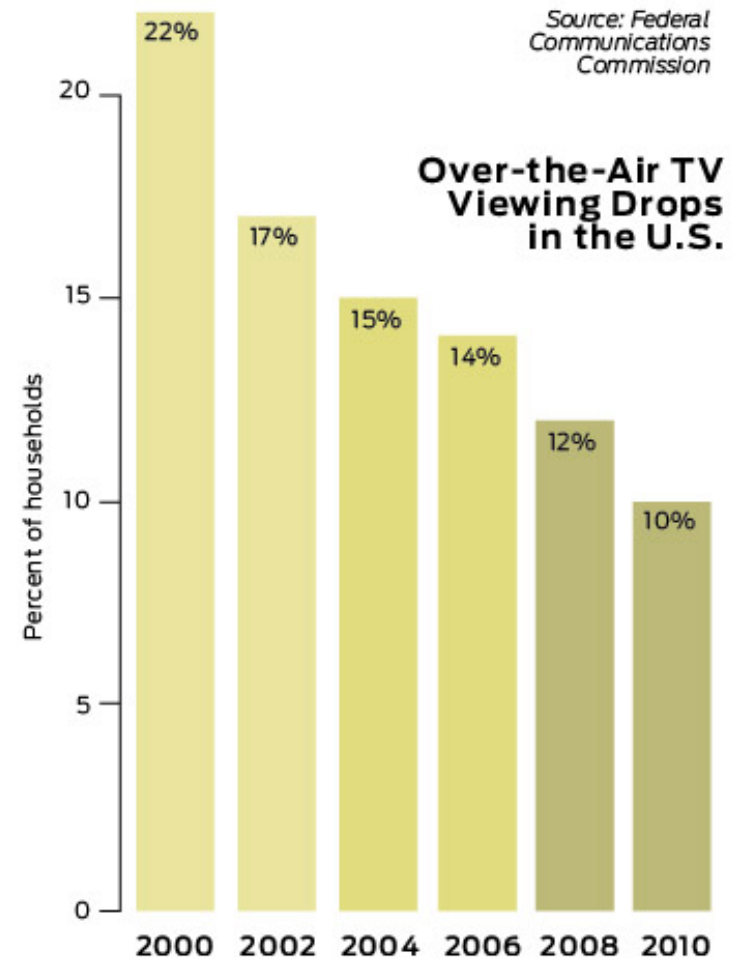
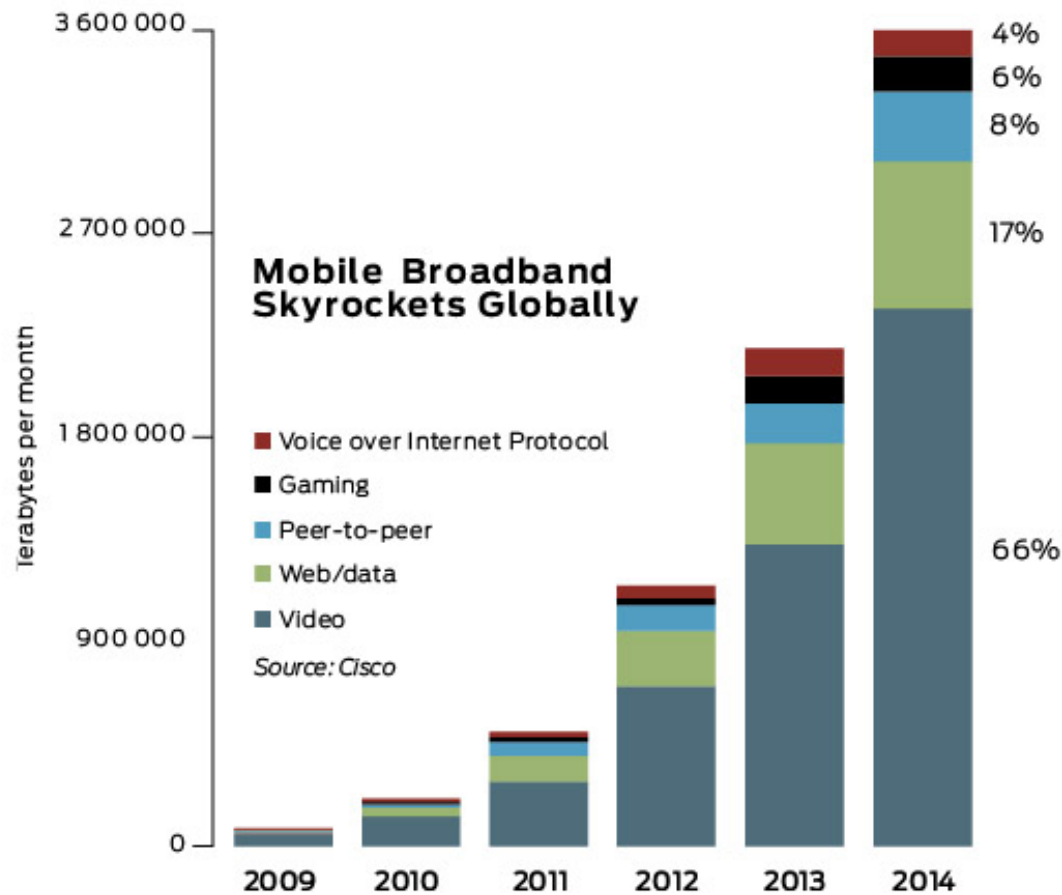
- Mobile computers (laptops, netbooks, tablets, handheld PCs, PDAs, ...)
- Mobile phones (incl. smartphones)
- Wireless headsets, keyboards, mice, clickers, ...
- Bus/train cards (e.g., Ridacard for Lothian Buses, London Oyster card)
- Cordless phones
- Remote controls, smart TVs and home appliances
- Garage/car door openers, baby monitors, radio-controlled toys, ...

An exciting field with remarkable success stories

- Mobile phone, a huge success
 - [As of 2015, 98.62% of world population use mobile phones](#)
 - Having a transformational impact in Africa and emerging economies
 - [Number of smartphone users reached 1.87 billion in 2015](#)
 - Data traffic has exceeded voice traffic on mobile networks several years ago and doubling every six months



Mobile Broadband Traffic Trends



CHANGING TASTES: The amount of data being sent wirelessly over the Internet has shot up globally [left], while the small fraction of television-owning households that rely on over-the-air broadcasts has been steadily diminishing in the United States [right].

An exciting field with remarkable success stories

- Mobile phone, a huge success
 - As of 2015, 98.62% of world population use mobile phones
 - Having a transformational impact in Africa and emerging economies
 - Number of smartphone users reached 1.87 billion in 2015
 - Data traffic has exceeded voice traffic on mobile networks several years ago and doubling every six months
- Widespread deployment of WiFi (802.11) – homes, office, campuses, hotspots, ...
 - WiFi, by far the most successful wireless Internet access technology
 - Community wireless networks mushrooming everywhere
- Newer evolved versions of mobile and Wi-Fi technologies (being) deployed:
 - 4G/LTE (based on OFDMA, MIMO, carrier aggregation, HetNets)
 - 802.11n/ac (also based on OFDM, MIMO and channel bonding)
- 5G on the horizon
 - Multi-service virtualized and softwarized architecture, ultra dense small cell networks, massive MIMO, mmWave comms, visible light comms, ...



(Some) Benefits of Wireless Communication

- Convenience of untethered access
- Enables mobility, i.e., anytime, anywhere access
- Can reach areas where wired access solutions are expensive to deploy (e.g., satellite/wireless access for remote areas)
- Can be easier and faster to deploy
- Extend the reach of wired network infrastructure (e.g., mesh networks)
- Enable manifold app scenarios (e.g., Internet of Things)



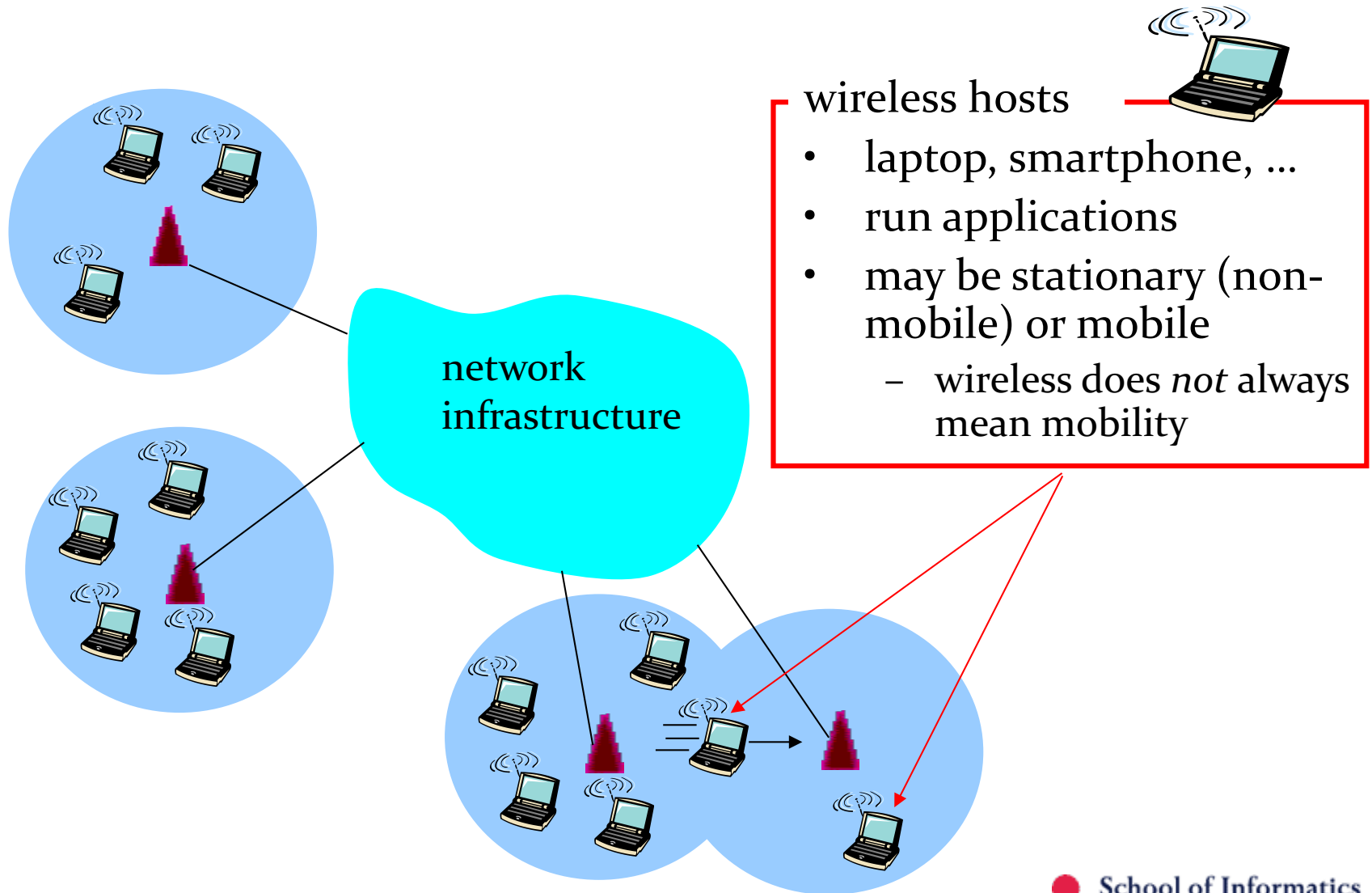
Wireless Networks

Characteristics and Challenges

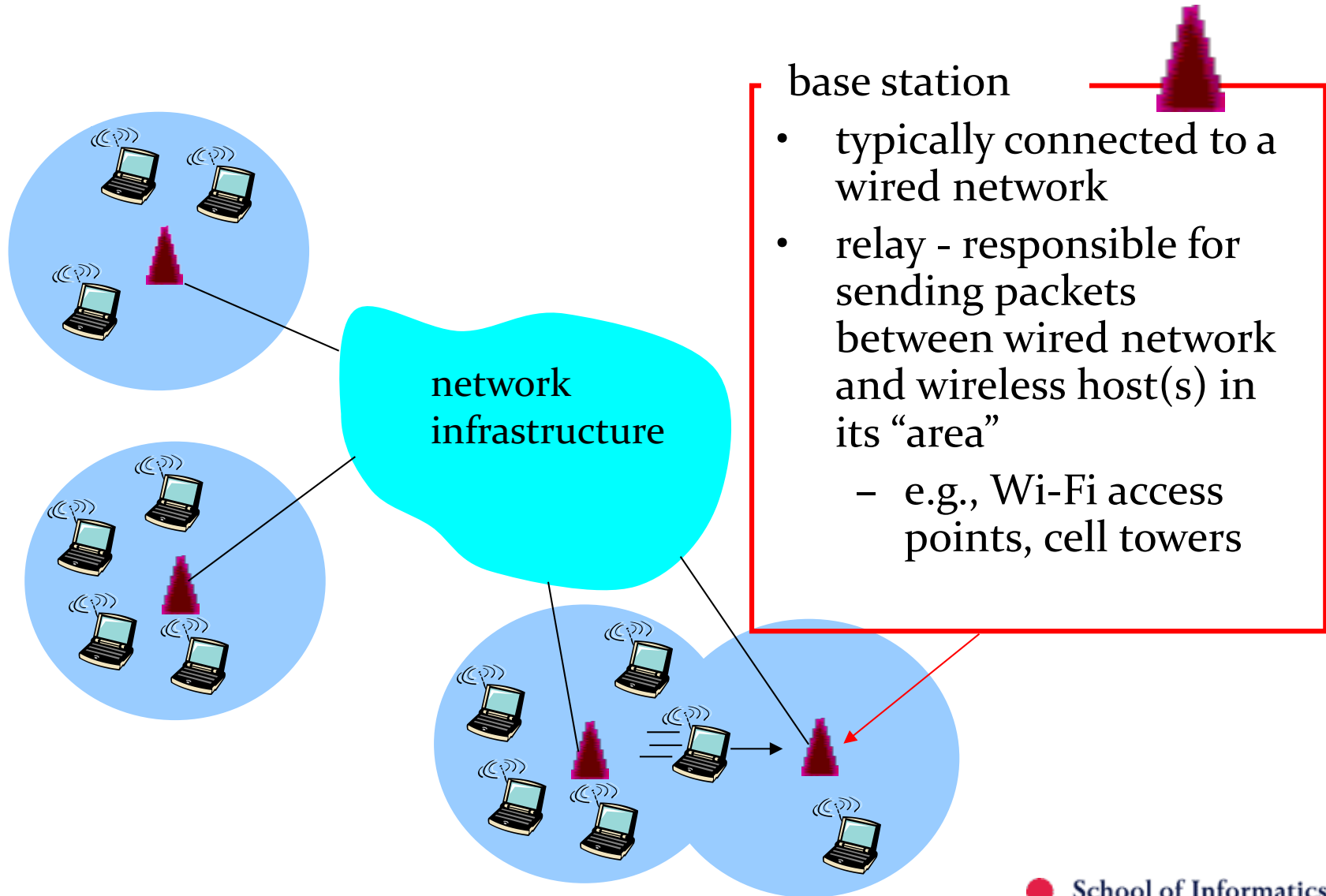
- Channel: path loss + shadowing + fading
 - Complex time-varying function of locations of communicating entities and the environment
- Multiple access interference
 - Wireless, a shared broadcast medium with possibility of spatial reuse
 - Receiver-side interference and hidden terminals
- Mobility
 - Handoff + location management for seamless access
- Energy
 - Mobile devices are battery powered
 - Battery energy density increase since 1990 by only a factor of three
 - Compare with 1200 times increase for disk capacity and several hundred times increase in CPU speed
 - Wireless interfaces among the major power consumers
- Security (e.g., eavesdropping) and Privacy (e.g., location) concerns



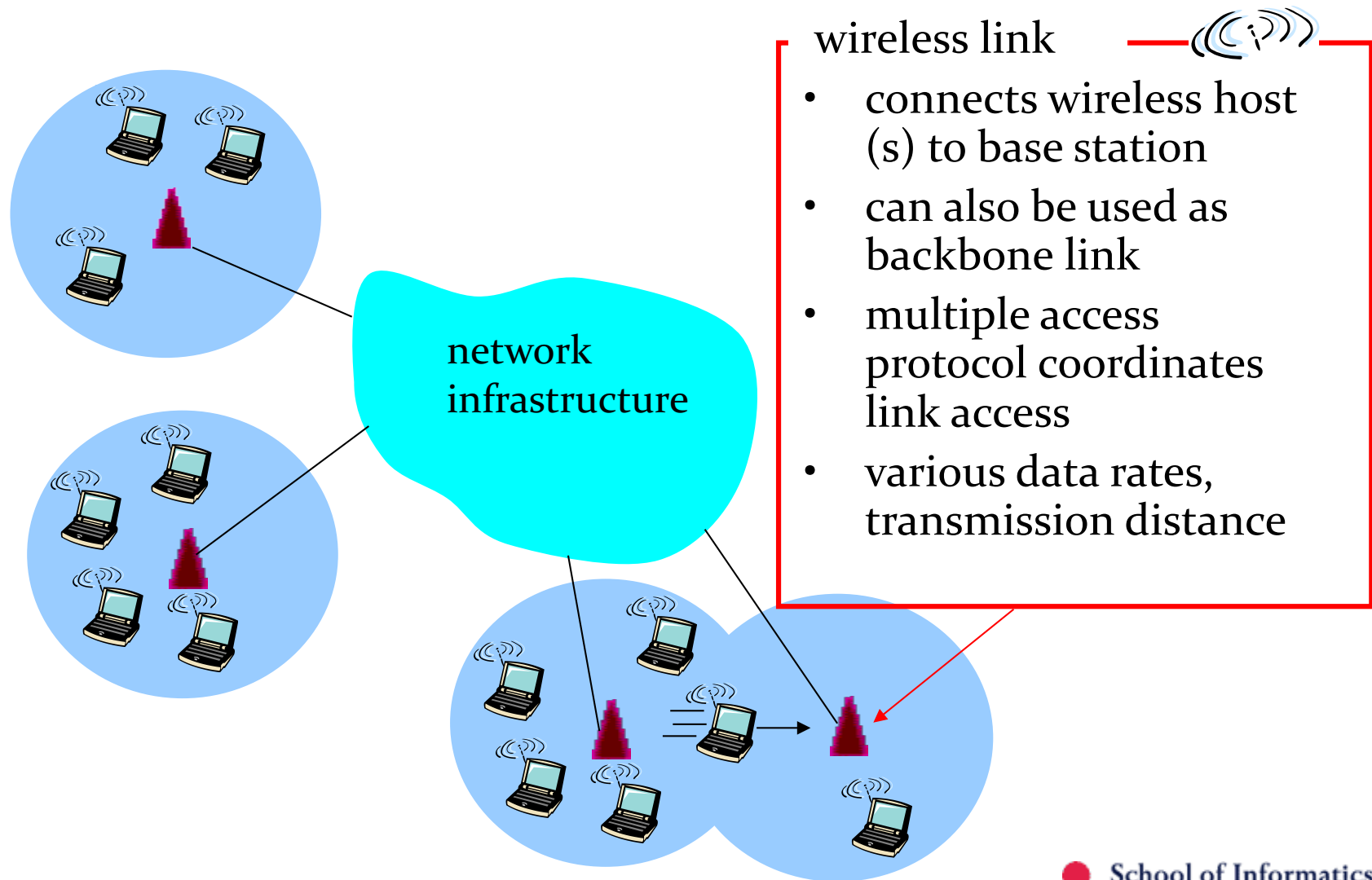
A Simple and Common Wireless Network Model



A Simple and Common Wireless Network Model



A Simple and Common Wireless Network Model



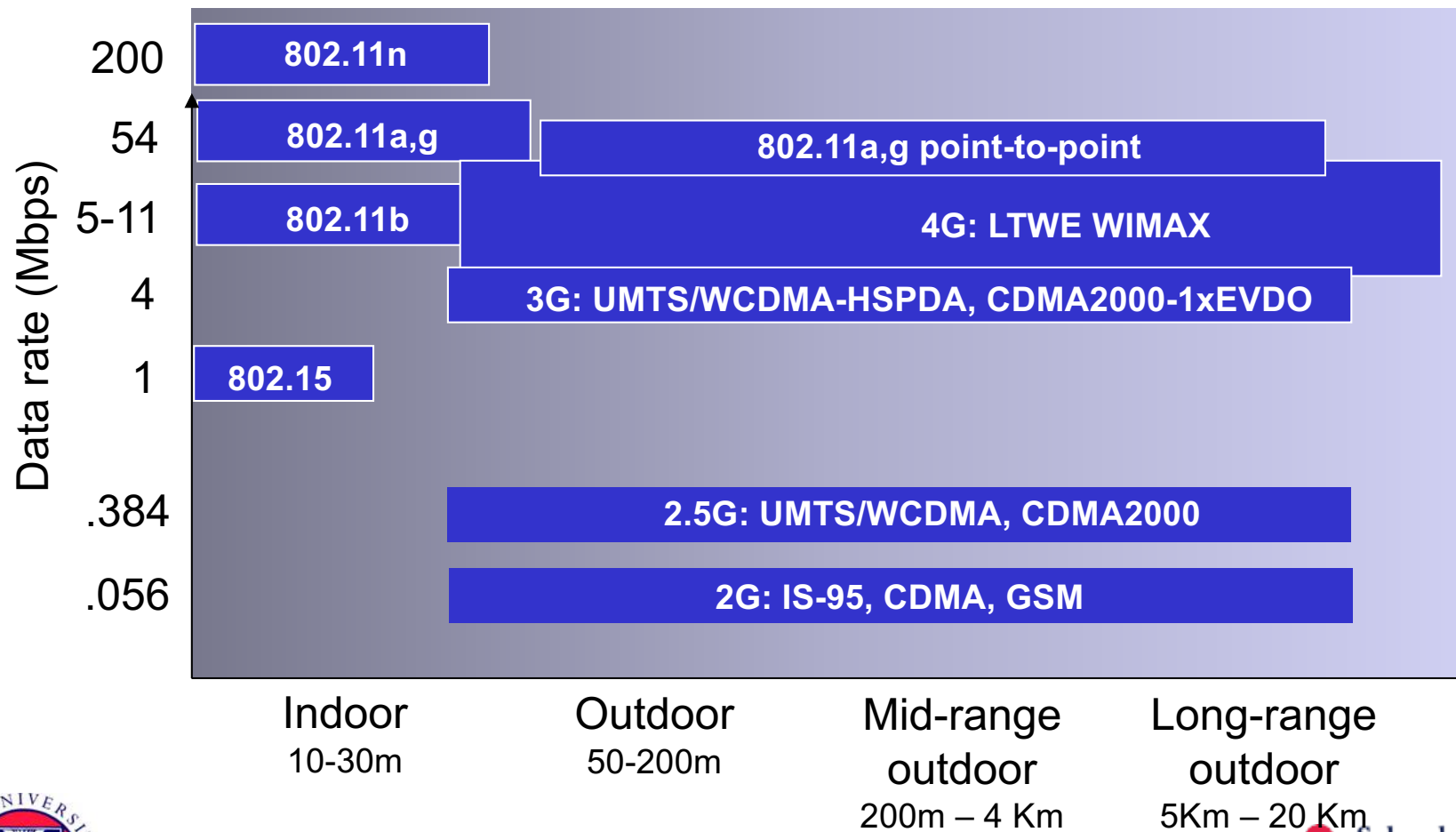
A Taxonomy of Wireless Networks

	single hop	multiple hops
infrastructure (e.g., APs)	host connects to base station, which connects to larger Internet (e.g., Wi-Fi, cellular, WiMax)	host may have to relay through several wireless nodes to connect to larger Internet (e.g., mesh nets)
no infrastructure	no base station, no connection to larger Internet (e.g., Bluetooth, ad hoc nets, Wi-Fi Direct)	no base station, no connection to larger Internet. May have to relay to reach another given wireless node (e.g., MANET, VANET)

Another Classification...

- Wide area wireless networks
 - Cellular (mobile phone and data) networks (e.g., 3G, 4G)
 - Broadband wireless access networks (e.g., WiMax, MMDS, LMDS)
 - Satellite networks
 - Paging systems
- Multihop wireless networks
 - Wireless mesh networks
 - Sensor networks
 - Mobile ad hoc networks (MANETs)
 - Vehicular ad hoc networks (VANETs)
- Wireless local area networks
 - Wi-Fi/802.11, HIPERLAN/2, cordless phones
- Short-range wireless networks
 - Bluetooth (e.g., wireless headset for mobile phones)
 - Zigbee: low-cost, low-power sensor network applications
 - Ultrawideband: high-bandwidth applications (e.g., wireless USB)
 - RFID (e.g., Lothian bus cards)

Rate/Range Characteristics of Select Wireless Technologies



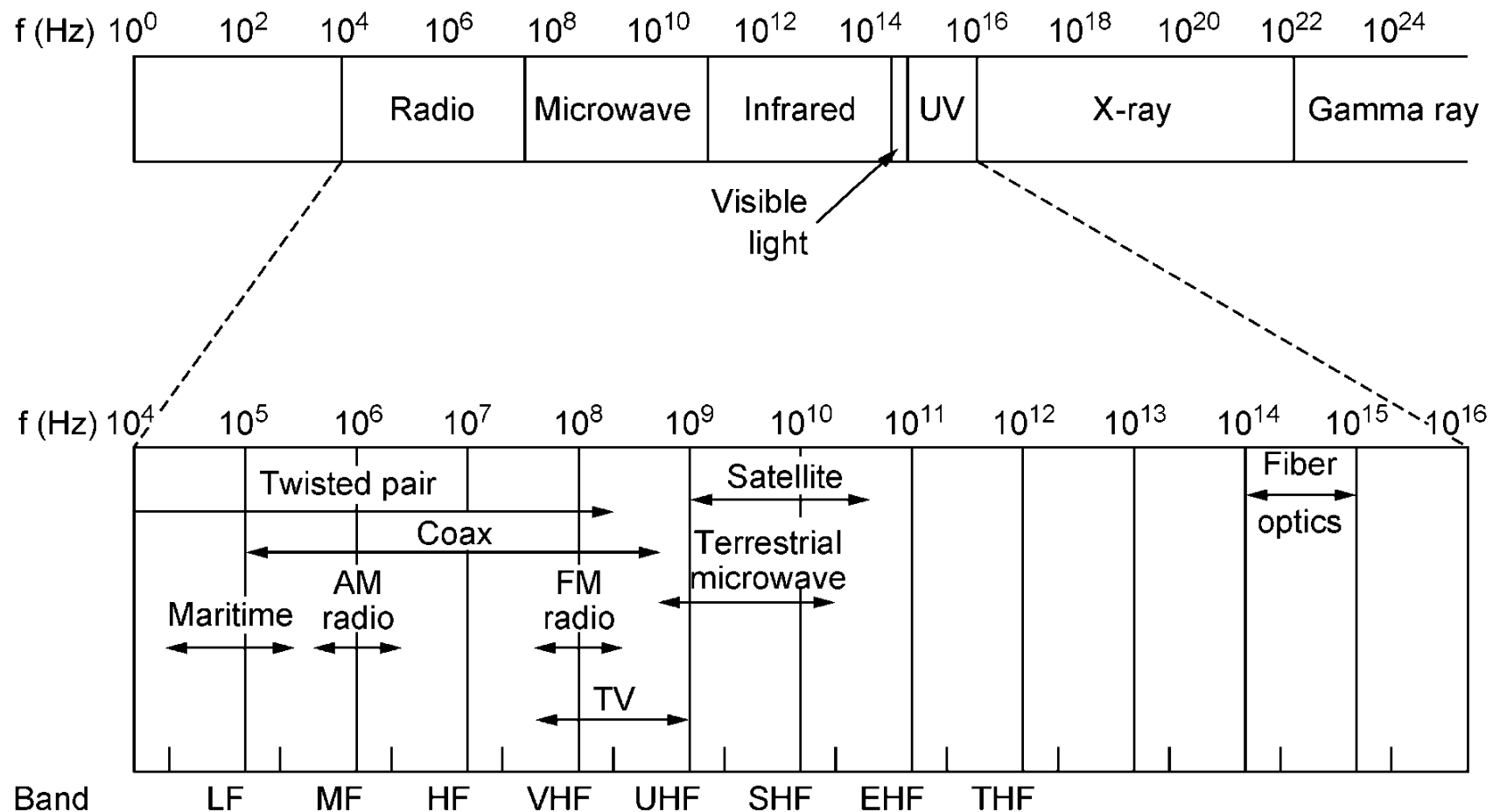
Other Classifications

- Spectrum band used
- Spectrum access model (e.g., licensed, license-exempt)
- Amount of power allowed/consumed
- ...

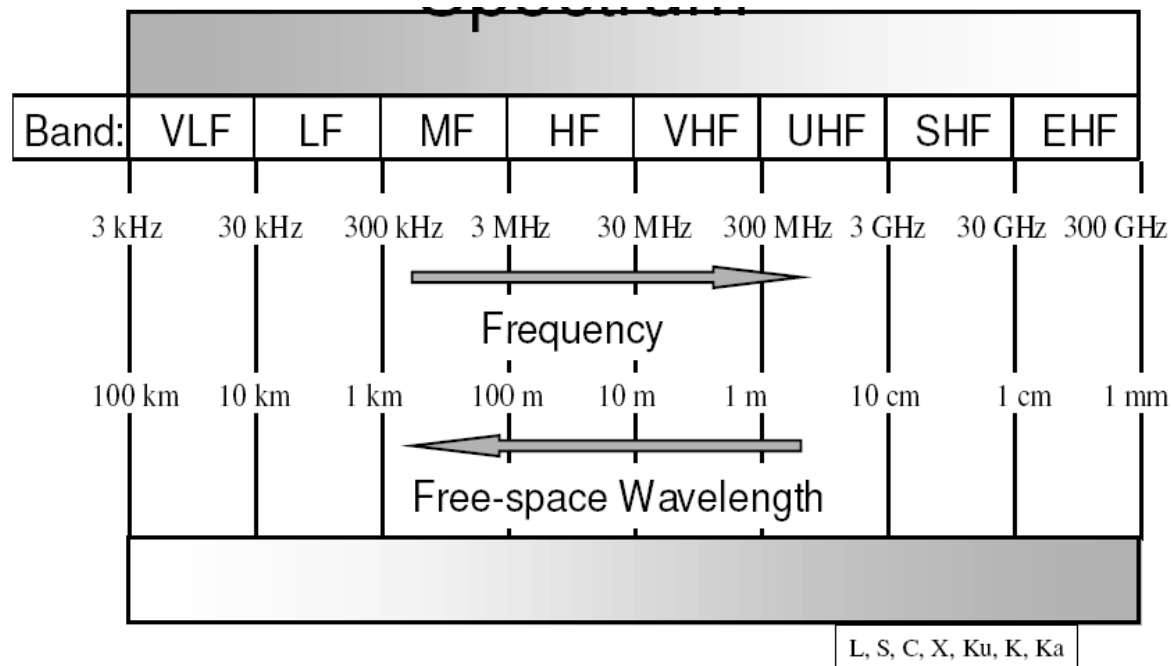
These classifications are not unrelated



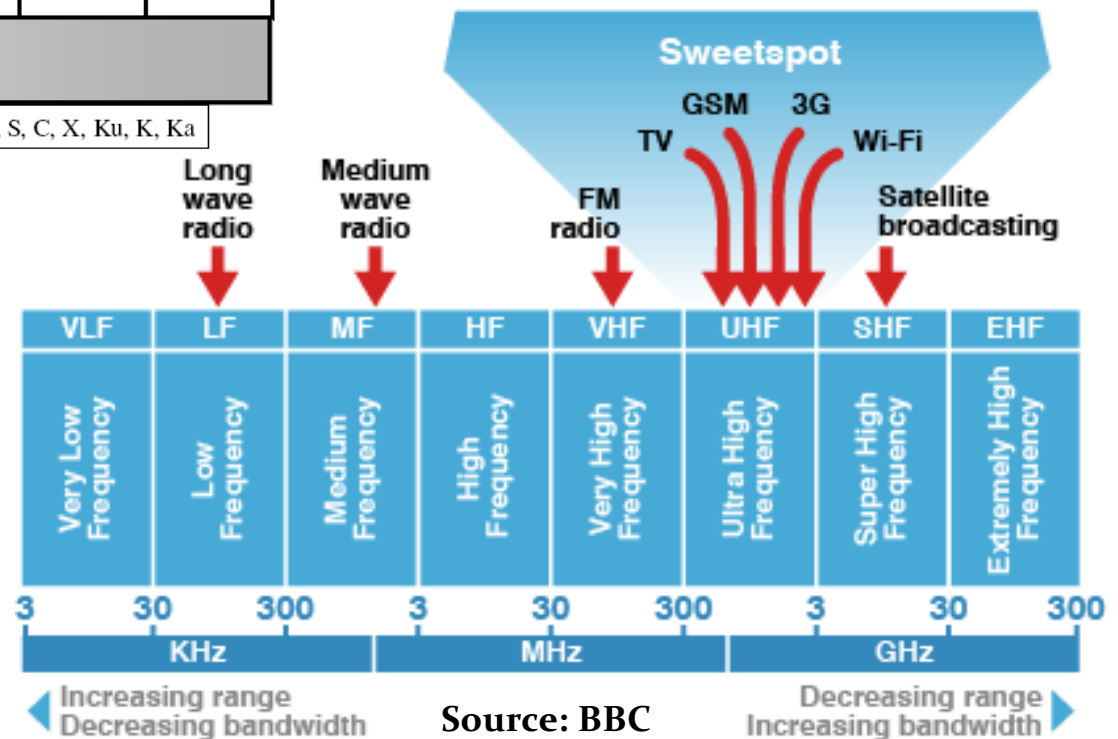
Electromagnetic Spectrum



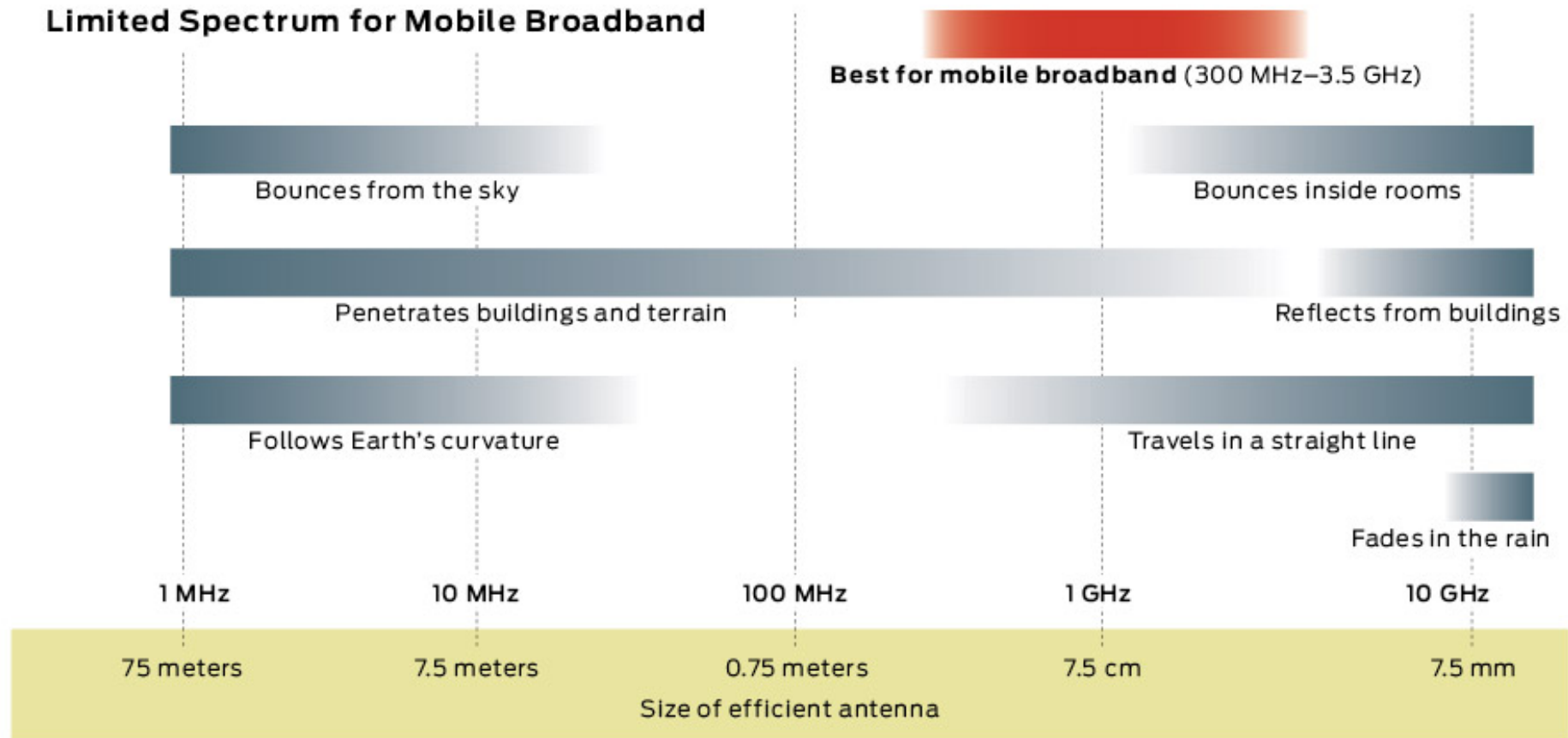
Electromagnetic Spectrum (contd.)



- Higher frequencies:
 - Larger bandwidths possible, smaller antennas
 - Range decreases as spreading loss increases and wavelength becomes smaller relative to obstructions



Electromagnetic Spectrum (contd.)



OPPORTUNITY WINDOW: The best frequencies for mobile broadband are high enough that the antenna can be made conveniently compact, yet not so high that signals will fail to penetrate buildings. This leaves a relatively narrow range of frequencies available for use [red band].

Spectrum Regulation

- Government agencies allocate and control the use of spectrum, only the prime portion (radio and microwave ranges)
 - UK: Office of Communications (Ofcom)
 - Europe: The European Conference of Postal and Telecommunications Administrations (CEPT)
 - US:
 - Commercial use: Federal Communications Commission (FCC)
 - Military use: Office of Spectral Management (OSM)
- Governments decide how much spectrum to allocate between commercial and military use
- Worldwide: ITU Radiocommunication (ITU-R) sector coordinates and harmonizes spectrum allocation globally
 - World Radiocommunication Conference (WRC)



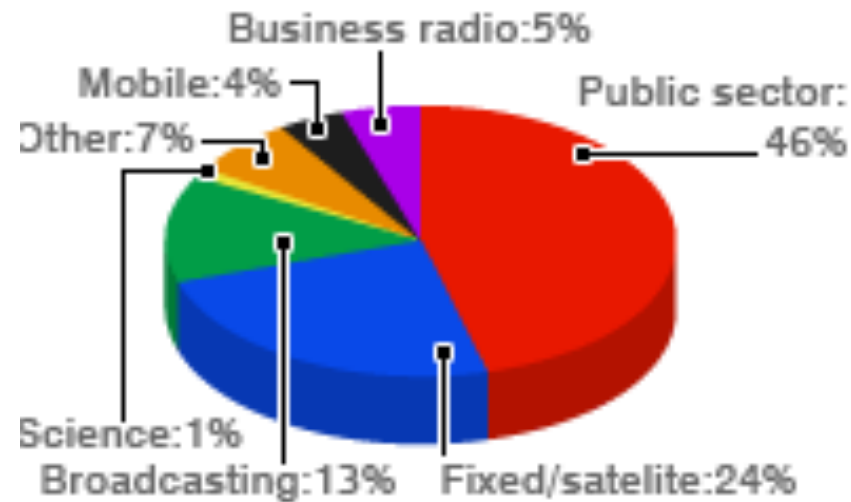
Spectrum Allocation

- Bands for specific commercial uses – cellular, satellite, AM radio, FM radio, etc.
- Bands for license-exempt use (e.g., Wi-Fi)
- Bands for government/military use

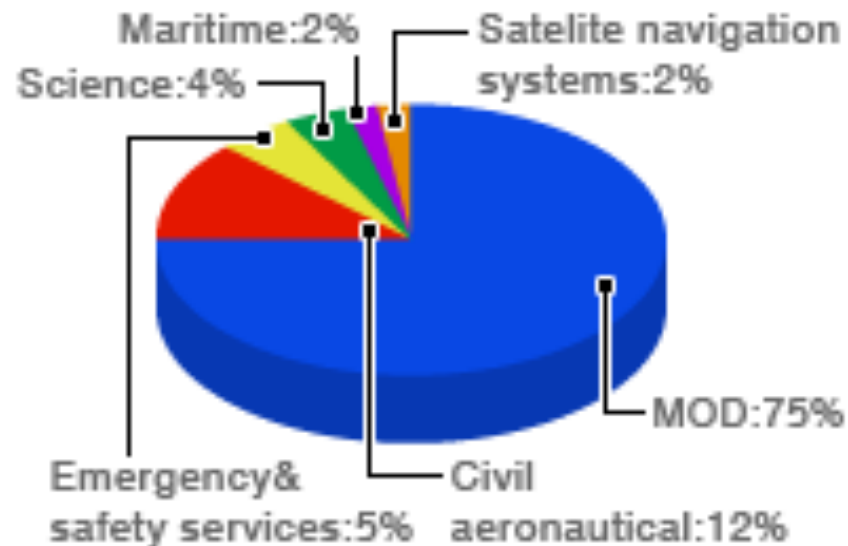


USE OF THE UK RADIO SPECTRUM

Use of UK radio spectrum



Public sector spectrum holdings below 15GHz



SOURCE: Ofcom

UK Spectrum Map

<http://www.ofcom.org.uk/static/spectrum/map.html>



[Ofcom homepage](#)

[Spectrum info](#)

[Terms of use](#)

[FAQ](#)

UK spectrum map

Last updated: 5th November 2014

The Interactive Spectrum Map is an easy way to browse and search how different spectrum bands are used in the United Kingdom. Use the dashboard to find out how spectrum is being used, by sector and by product/application. This map covers spectrum from 8.3 kHz to 275 GHz.

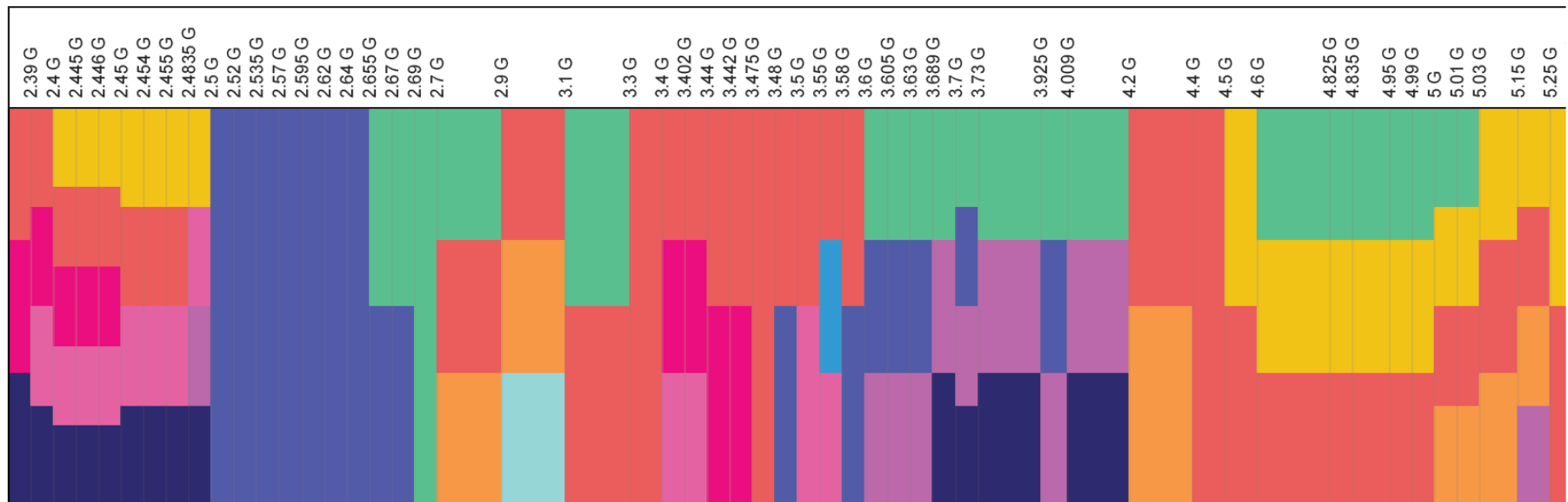
Search spectrum

Choose a predefined range or specific frequencies to kHz

Filter by sector



- | | | | | |
|---|--|--|---|--|
| <input checked="" type="checkbox"/> Space Science | <input checked="" type="checkbox"/> Licence exempt | <input checked="" type="checkbox"/> Public sector | <input checked="" type="checkbox"/> Amateur | <input checked="" type="checkbox"/> Broadcasting |
| <input checked="" type="checkbox"/> Aeronautical | <input checked="" type="checkbox"/> Maritime | <input checked="" type="checkbox"/> Business Radio | <input checked="" type="checkbox"/> Mobile and Wireless broadband | <input checked="" type="checkbox"/> PMSE |
| <input checked="" type="checkbox"/> Satellite | <input checked="" type="checkbox"/> Fixed Links | | | |

Range of 2.38 - 7.1 GHz



US Spectrum Dashboard

<http://reboot.fcc.gov/reform/systems/spectrum-dashboard>



HOMEABOUT REBOOTEVENTSINITIATIVESREFORMFCC LEADERSHIPBLOGFCC.GOV/DATA

Home » Reform » Systems » Spectrum Dashboard

Spectrum Dashboard

Browse Spectrum Bands

Browse Using a Map

Search by Name

Advanced Search

Browse Spectrum Bands (225 MHz - 3700 MHz)

Frequency Range:
 to
MHz

Radio Service:
Select Radio Service(s):
1390 - 1392 MHz
1392 - 1395 MHz
1432 - 1435 MHz
1670 - 1675 MHz
3650 - 3700 MHz
700 MHz
AWS - 1
AWS - 2
Amateur

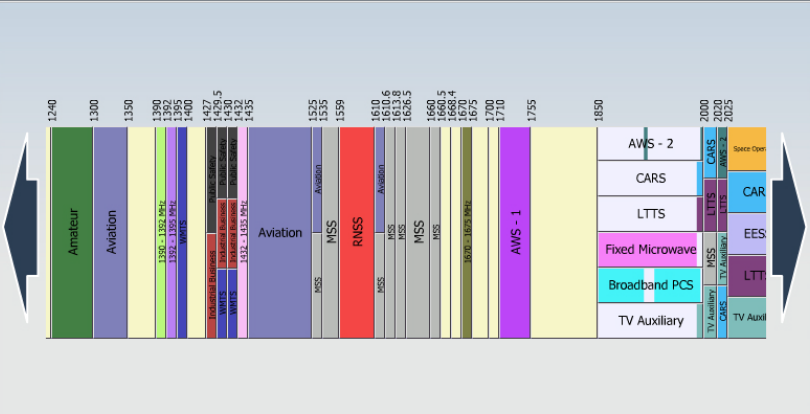
Frequency Purpose (Tags):
Select Tags:
Broadband
Fixed Wireless
Mobile Radio
Personal Use
Phone
Radar
Radio
Safety of Life
Satellite

SearchClear

Select Using Frequency Band:

Select Using Frequency Band:
Browse non-federal spectrum bands by entering a frequency range, selecting one or more tags or by using the graphical tool.
To use the graphical tool, click in a box to display the range of frequencies for the service(s) or click in a box and drag your cursor to select a wider range of frequencies. The frequencies will appear in the Frequency Range box.

Zoom



Highlighted sections represent the portion of the band that can be used for the listed service.



Spectrum Access Models

1. Licensed or exclusive use spectrum

– Past:

1. Beauty Contest

- ❑ Organizations interested in the spectrum make a proposal on serving public interest by getting a block of spectrum; regulator makes the “best” pick.

2. Lottery

- ❑ Hold a lottery for a spectrum block among interested organizations

– Current:

➤ Auctions (e.g., UK 4G spectrum auction in 2013)

- ❑ Auction the spectrum block in question and give it to top bidders, subject to auction rules set a priori



Spectrum Access Models

2. License-Exempt / Unlicensed / Spectrum Commons
 - E.g., 2.4GHz (Wi-Fi, Bluetooth, ZigBee, ...)
3. License-Exempt White Space Access or Secondary Spectrum Commons
 - E.g., 5GHz Wi-Fi, White spaces in TV bands
4. Spectrum Underlay
 - operates as a secondary user in a frequency band with other primary users (e.g., Ultra Wide Band or UWB)
5. Soft/Exclusive Secondary Licenses
 - a) Licensed/Authorized Shared Access (via leasing or rights transfer to secondary users)
 - b) Pluralistic Licenses
 - c) Overlay Auction Licenses



US Licensed Spectrum Allocation

Example

AM Radio	535-1605 KHz
FM Radio	88-108 MHz
Broadcast TV (Channels 2-6)	54-88 MHz
Broadcast TV (Channels 7-13)	174-216 MHz
Broadcast TV (UHF)	470-806 MHz
3G Broadband Wireless	746-764 MHz, 776-794 MHz
3G Broadband Wireless	1.7-1.85 MHz, 2.5-2.69 MHz
1G and 2G Digital Cellular Phones	806-902 MHz
Personal Communications Service (2G Cell Phones)	1.85-1.99 GHz
Wireless Communications Service	2.305-2.32 GHz, 2.345-2.36 GHz
Satellite Digital Radio	2.32-2.325 GHz
Multichannel Multipoint Distribution Service (MMDS)	2.15-2.68 GHz
Digital Broadcast Satellite (Satellite TV)	12.2-12.7 GHz
Local Multipoint Distribution Service (LMDS)	27.5-29.5 GHz, 31-31.3 GHz
Fixed Wireless Services	38.6-40 GHz

US Unlicensed Spectrum Allocation

ISM Band I (Cordless phones, 1G WLANs)	902-928 MHz
ISM Band II (Bluetooth, 802.11b WLANs)	2.4-2.4835 GHz
ISM Band III (Wireless PBX)	5.725-5.85 GHz
NII Band I (Indoor systems, 802.11a WLANs)	5.15-5.25 GHz
NII Band II (short outdoor and campus applications)	5.25-5.35 GHz
NII Band III (long outdoor and point-to-point links)	5.725-5.825 GHz



Standards

- Standards required for interoperable products and systems
- Lead to economies of scale and push down prices
- Some relevant standards development groups
 - IEEE (US)
 - 3GPP: collaboration between groups of telecoms associations incl. ETSI
 - IETF for Internet Standards (incl. those concerning wireless and mobile networking)
 - ITU
 - ISO
- Standardization process imperfect and political
 - Participants often have an agenda that conflicts with what is best
 - Can take a long time
 - Difficult to change once widely adopted

