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
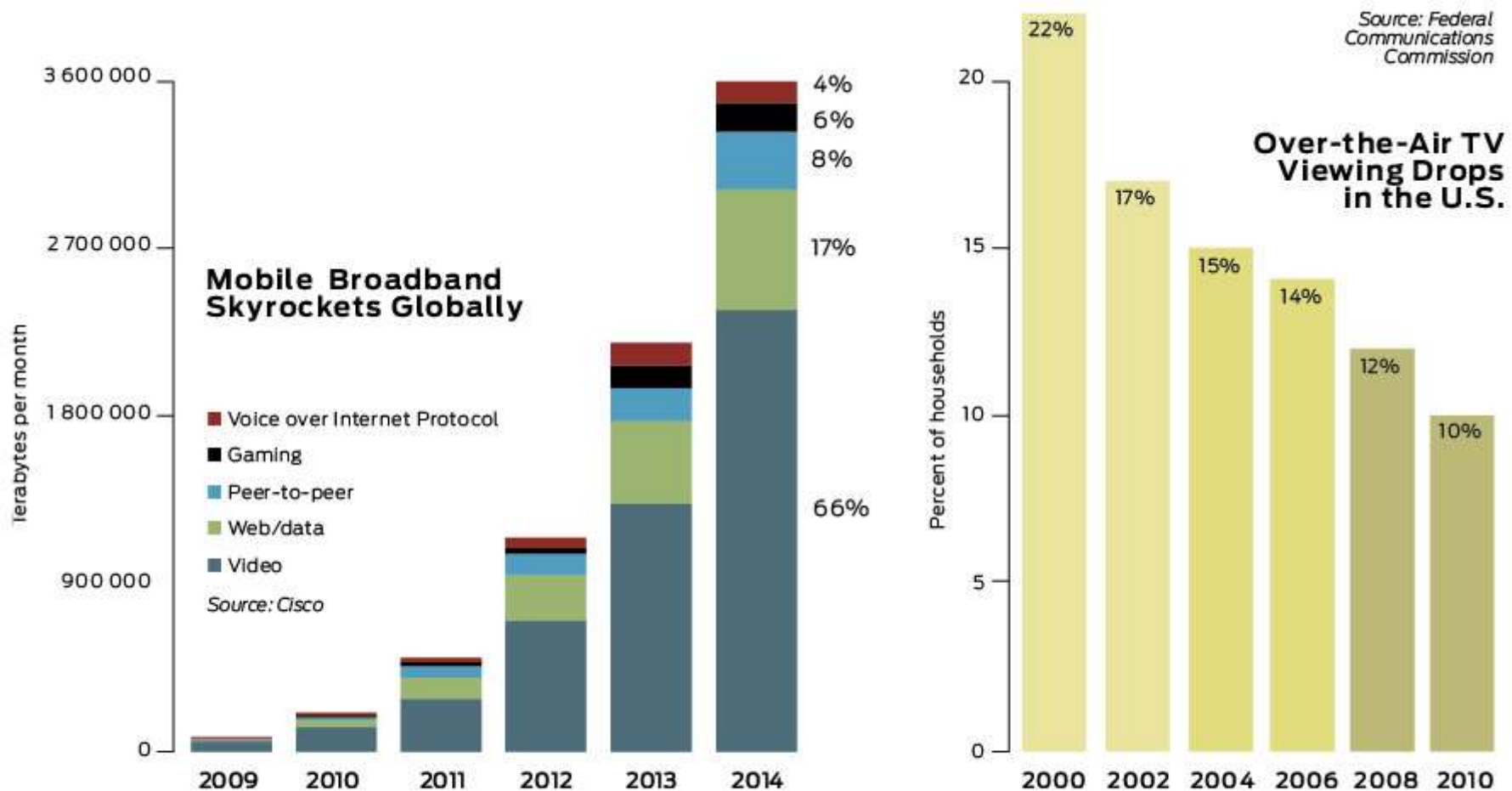- Garage/car door openers, baby monitors, radio-controlled toys, …

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

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Mobile Broadband Traffic Trends

Mobile Broadband Skyrockets Globally

Terabytes per month

- Voice over Internet Protocol
- Gaming
- Peer-to-peer
- Web/data
- Video

Source: Cisco

4%
6%
8%
17%
66%

2009 2010 2011 2012 2013 2014

Source: Federal Communications Commission

Over-the-Air TV Viewing Drops in the U.S.

Percent of households

22%
17%
15%
14%
12%
10%

2000 2002 2004 2006 2008 2010

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

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  - 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 – homes, office, campuses, hotspots, …
  - WiFi, by far the most successful wireless Internet access technology
  - Community wireless networks mushrooming everywhere
- Several newer technologies being deployed or in development – MIMO (802.11n/ac), OFDMA (4G/LTE), TV white spaces, mmWave comms, visible light comms, …
- 5G on the horizon

(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)
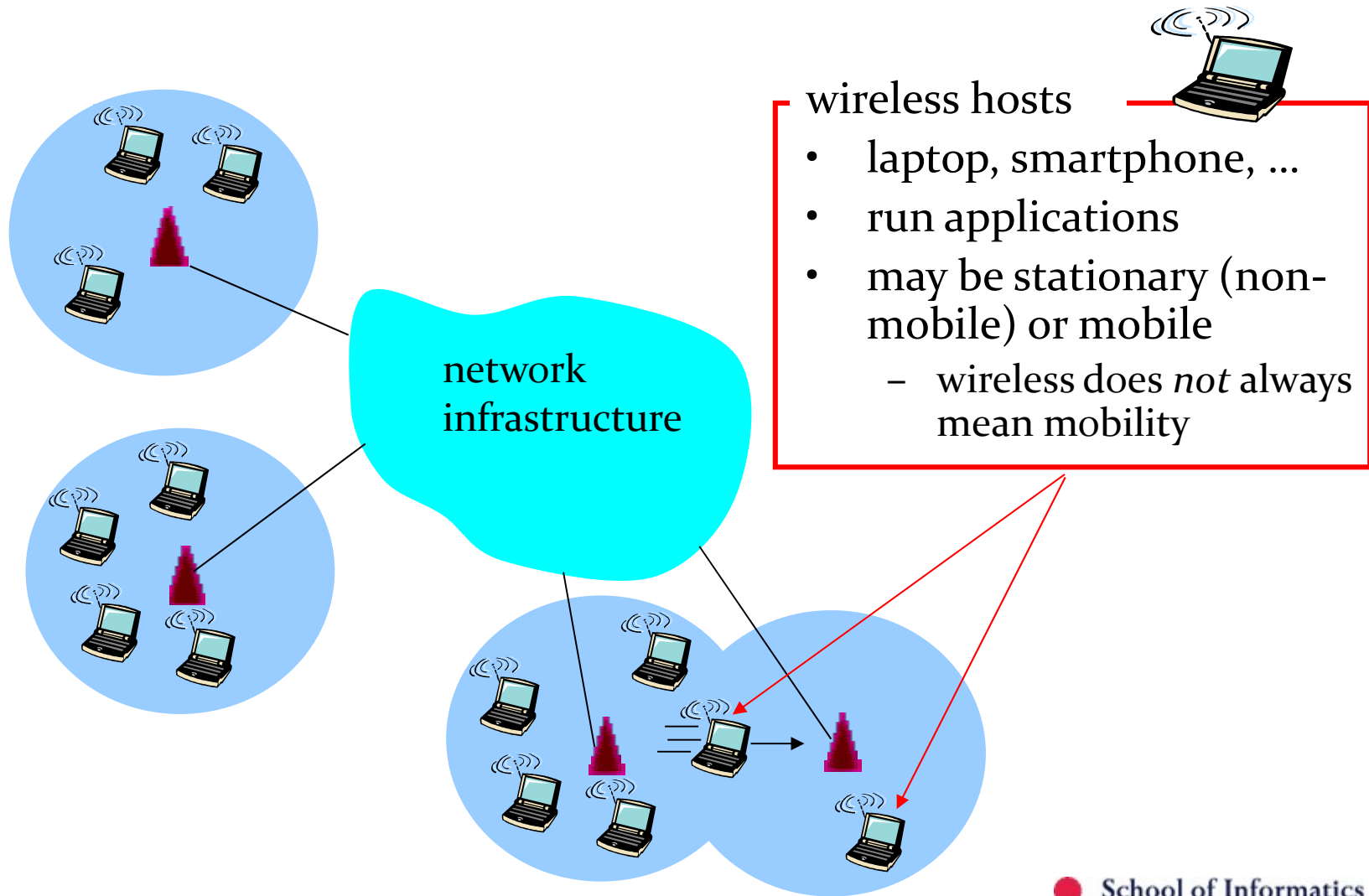- Enable manifold app scenarios (e.g., Internet of Things)

Wireless Networks
Characteristics and Challenges

- <mark>Channel: path loss + shadowing + fading</mark>
  - 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 <mark>seamless access</mark>
- 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
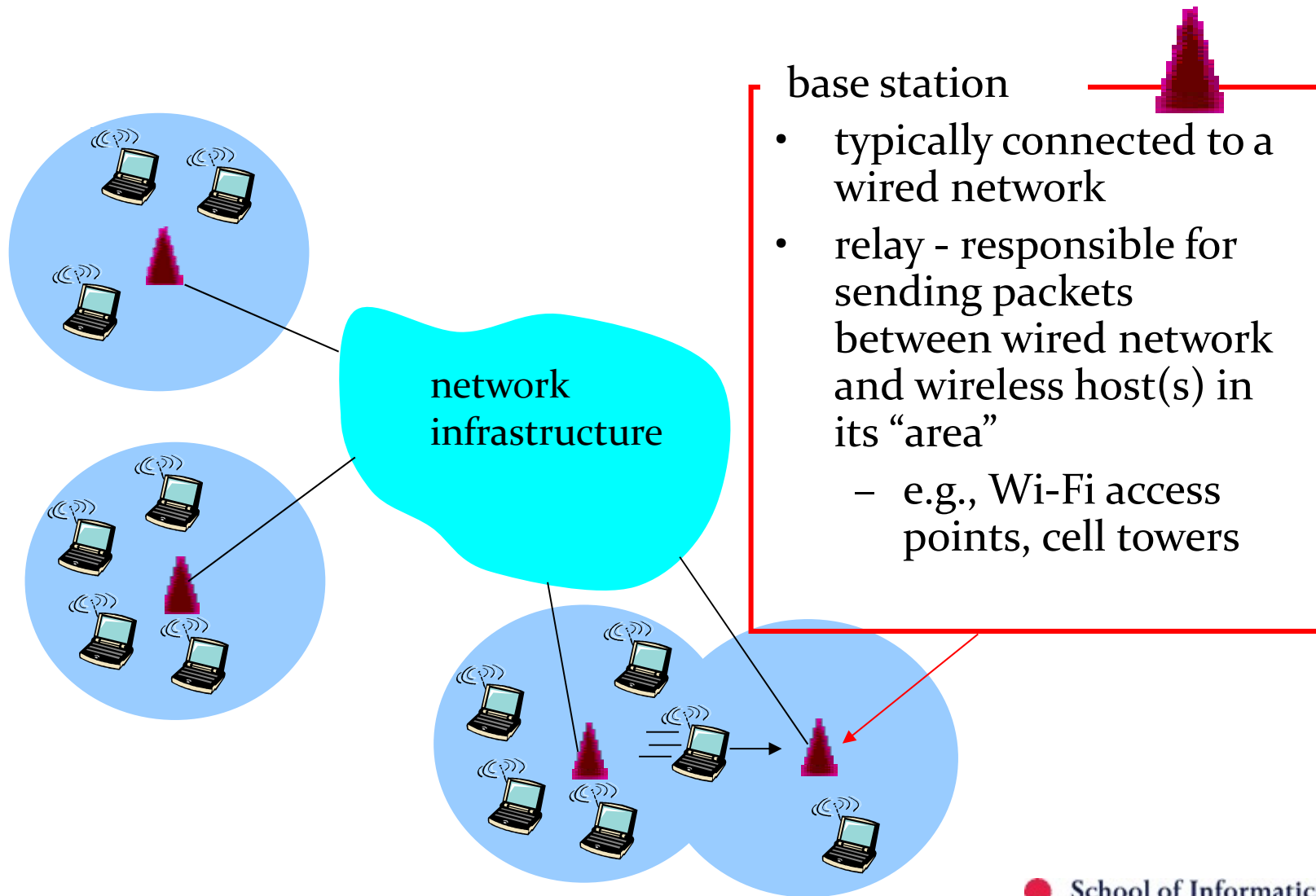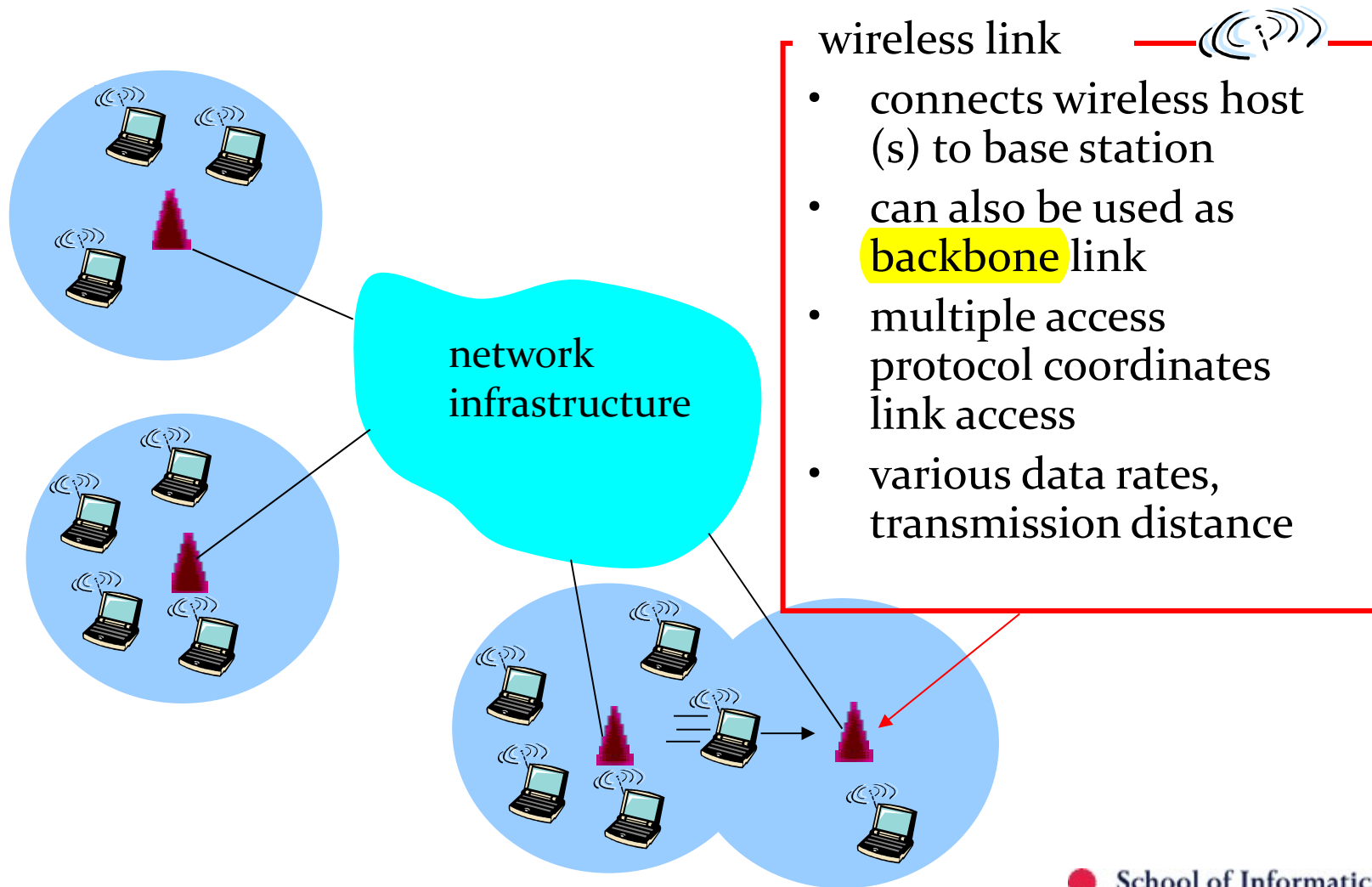- Security (e.g., eavesdropping) and Privacy (e.g., location) concerns

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A Simple and Common Wireless Network Model

wireless hosts
- laptop, smartphone, …
- run applications
- may be stationary (non-mobile) or mobile
  - wireless does *not* always mean mobility

network infrastructure

A Simple and Common Wireless Network Model

base station
- typically connected to a wired network
- relay - responsible for sending packets between wired network and wireless host(s) in its "area"
  - e.g., Wi-Fi access points, cell towers

network infrastructure

A Simple and Common Wireless Network Model

network infrastructure

wireless link
- connects wireless host (s) to base station
- can also be used as backbone link
- multiple access protocol coordinates link access
- various data rates, transmission distance

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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)

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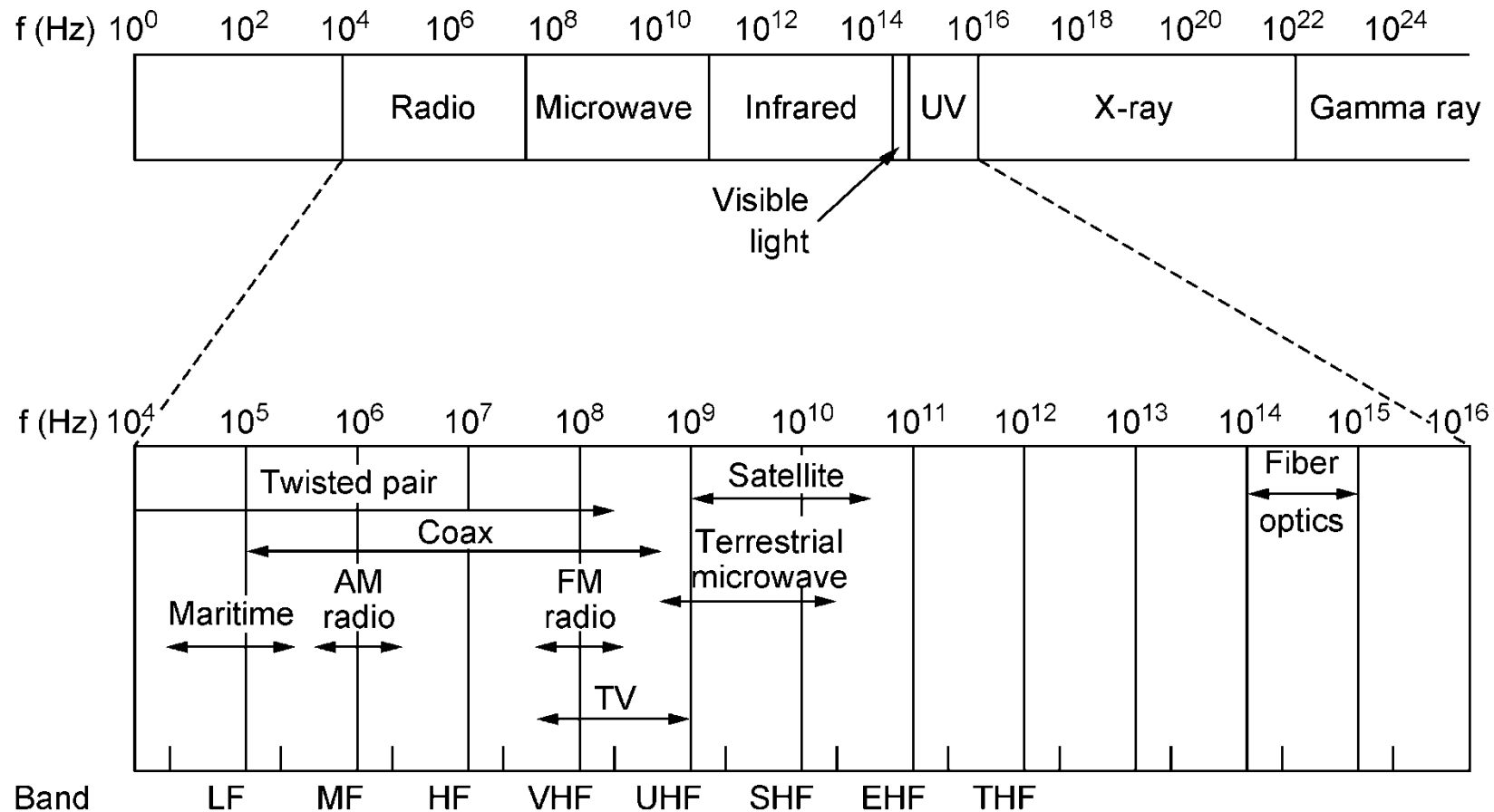# Rate/Range Characteristics of Select Wireless Technologies
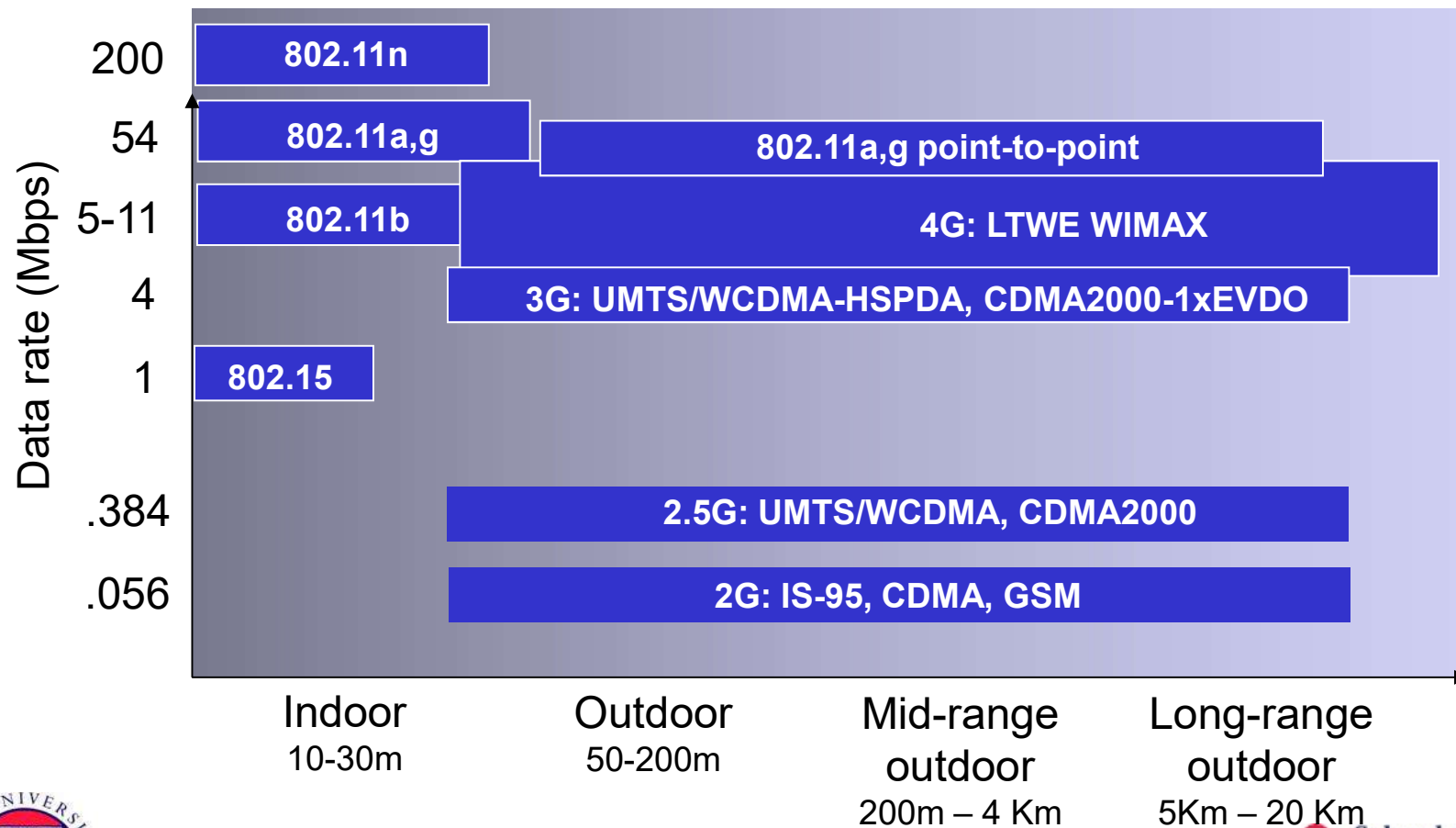
Other Classifications

- Spectrum band used

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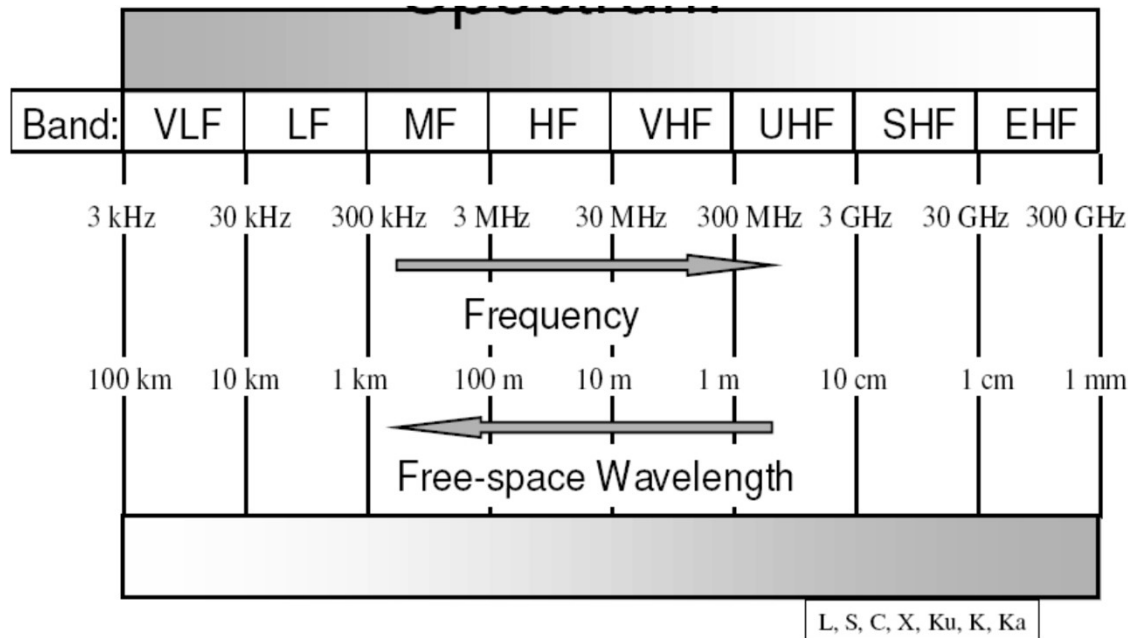
- Amount of power allowed/consumed
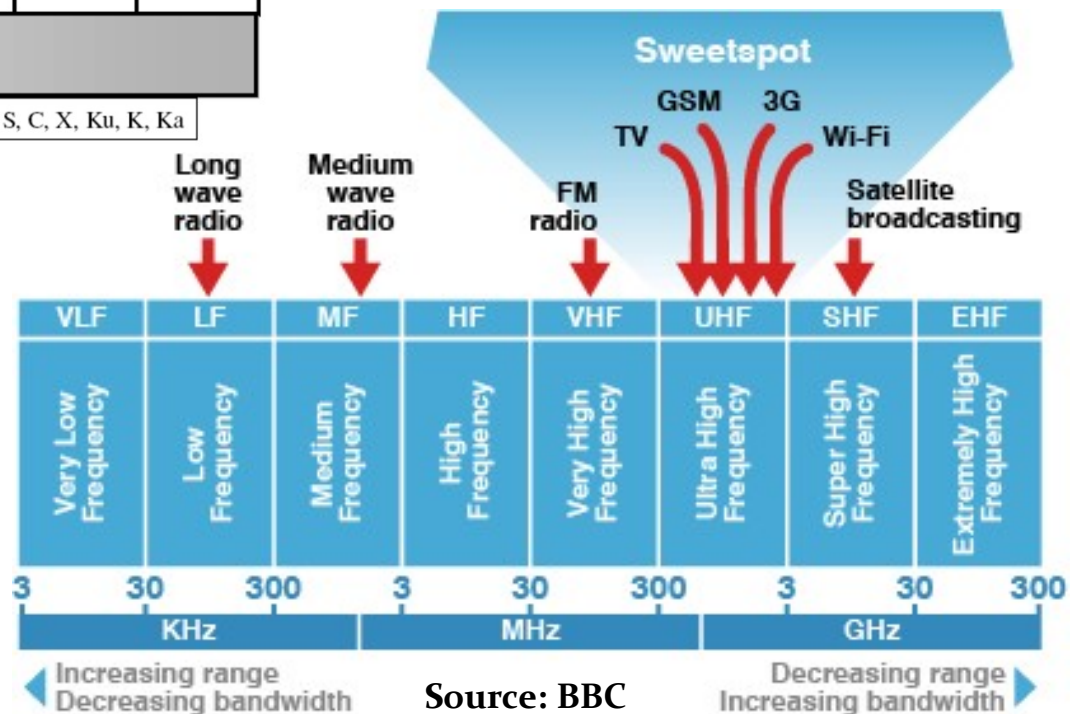
- …

These classifications are not unrelated

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Electromagnetic Spectrum

Electromagnetic Spectrum (contd.)

| Band: | VLF | LF | MF | HF | VHF | UHF | SHF | EHF |

3 kHz   30 kHz   300 kHz   3 MHz   30 MHz   300 MHz   3 GHz   30 GHz   300 GHz

Frequency →

100 km   10 km   1 km   100 m   10 m   1 m   10 cm   1 cm   1 mm
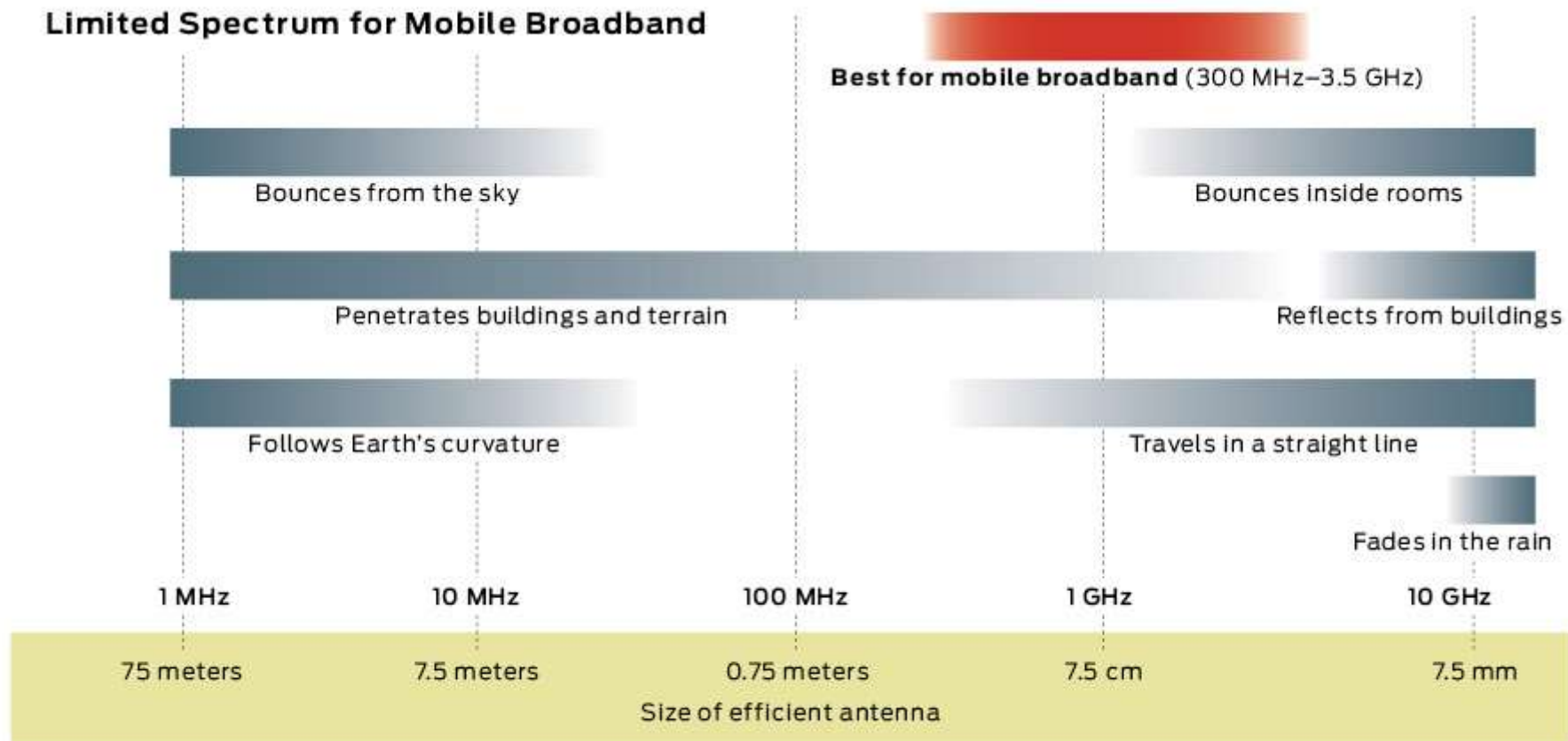
← **Free-space Wavelength**

L, S, C, X, Ku, K, Ka

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

Sweetspot

GSM   3G

TV   Wi-Fi

Long wave radio   Medium wave radio   FM radio   Satellite broadcasting

| VLF | LF | MF | HF | VHF | UHF | SHF | EHF |

| Very Low Frequency | Low Frequency | Medium Frequency | High Frequency | Very High Frequency | Ultra High Frequency | Super High Frequency | Extremely High Frequency |

3   30   300   3   30   300   3   30   300

KHz   MHz   GHz

◄ Increasing range
Decreasing bandwidth   **Source: BBC**   Decreasing range
Increasing bandwidth ►

Electromagnetic Spectrum (contd.)

Limited Spectrum for Mobile Broadband

Best for mobile broadband (300 MHz–3.5 GHz)

Bounces from the sky

Bounces inside rooms

Penetrates buildings and terrain

Reflects from buildings

Follows Earth's curvature

Travels in a straight line

Fades in the rain

1 MHz	10 MHz	100 MHz	1 GHz	10 GHz
75 meters	7.5 meters	0.75 meters	7.5 cm	7.5 mm

Size of efficient antenna

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].

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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 Commision (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

- Business radio: 5%
- Mobile: 4%
- Other: 7%
- Public sector: 46%
- Science: 1%
- Broadcasting: 13%
- Fixed/satelite: 24%
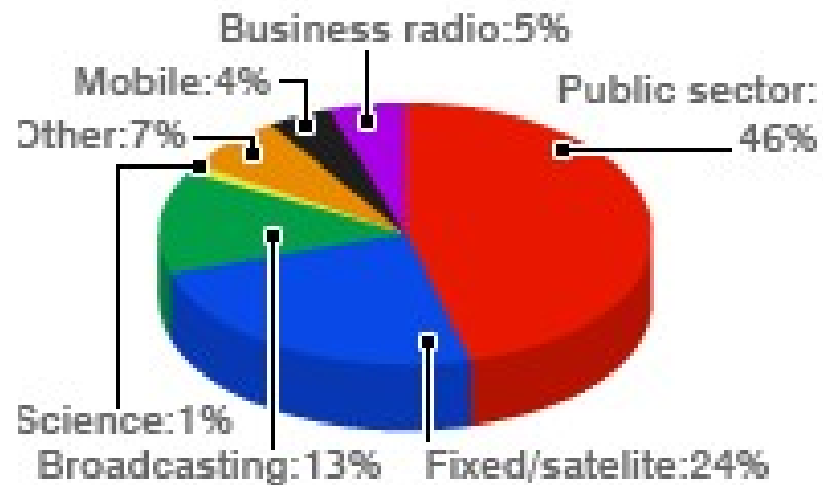
Public sector spectrum holdings below 15GHz

- Maritime: 2%
- Satelite navigation systems: 2%
- Science: 4%
- MOD: 75%
- Emergency& safety services: 5%
- Civil aeronautical: 12%

SOURCE: Ofcom

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UK Spectrum Map

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

US Spectrum Dashboard
http://reboot.fcc.gov/reform/systems/spectrum-dashboard
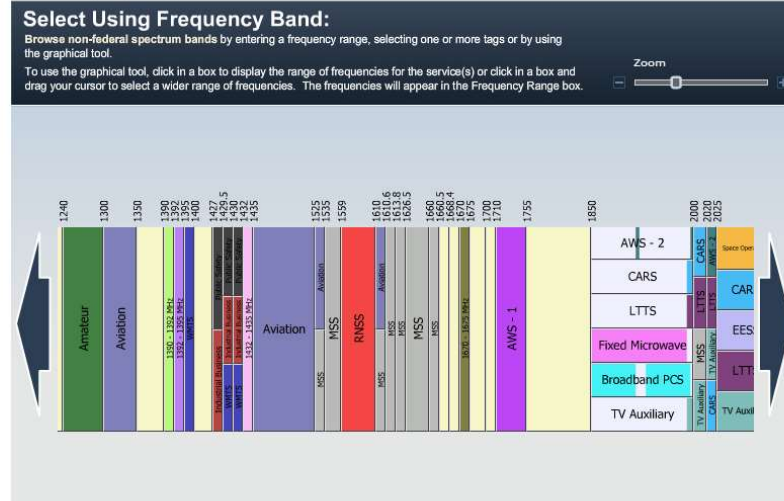
Spectrum Access Models

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

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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., 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

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

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

Systems Architecture

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

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