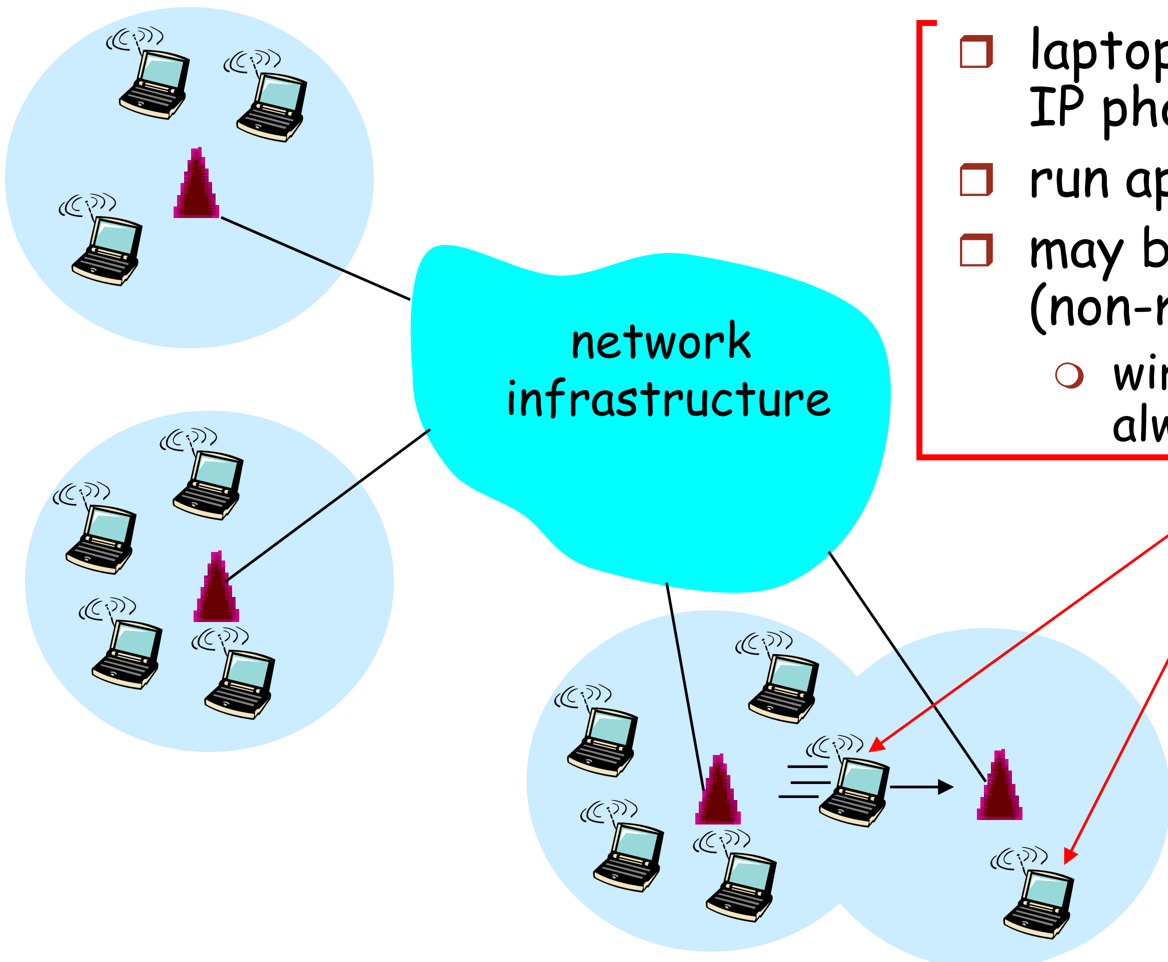
Wireless networking:

Instructor course: Dr.Hanal Abuzant

Special topics in wireless (66554)

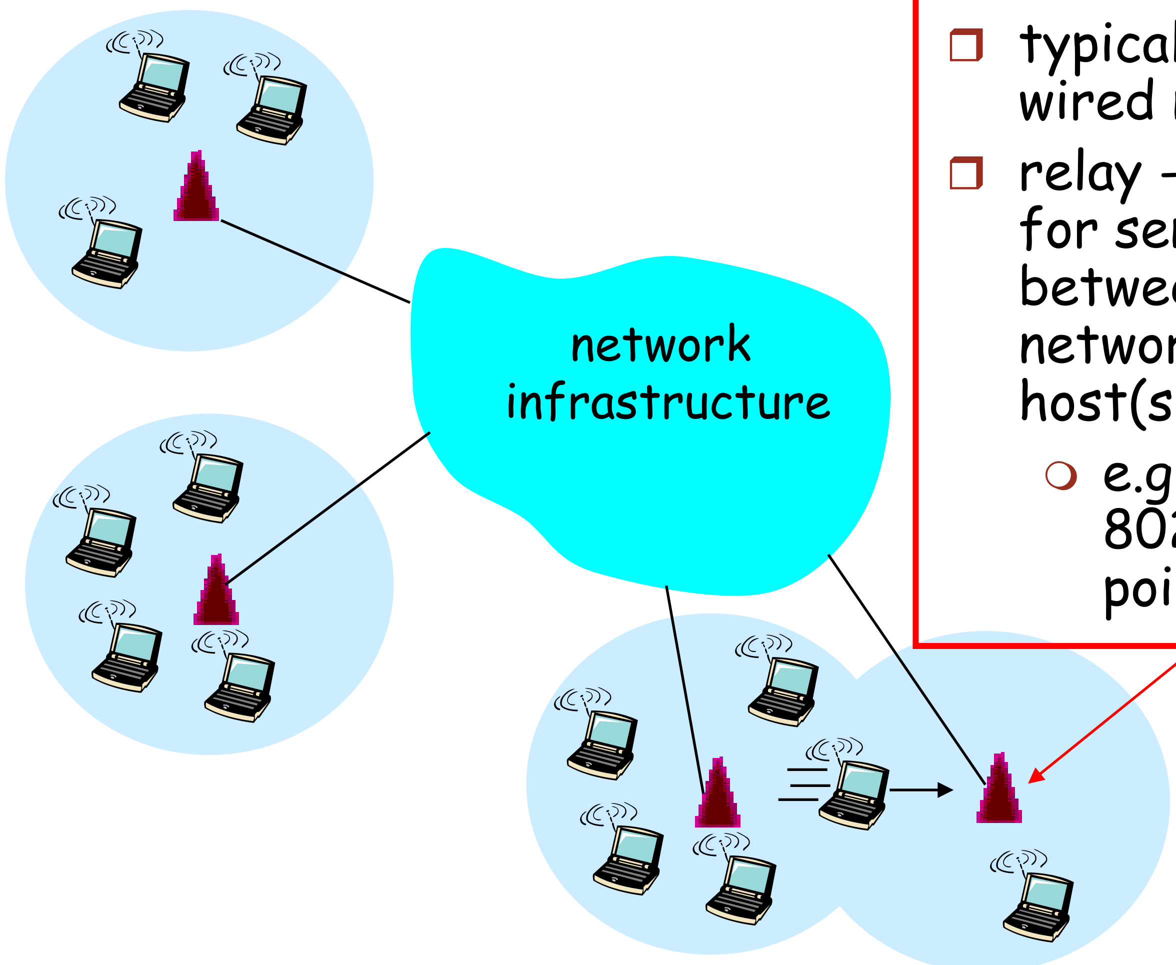
Elements of a wireless network



wireless hosts 

- laptop, PDA(Tablets), IP phone
- run applications
- may be stationary (non-mobile) or mobile
  - wireless does *not* always mean mobility

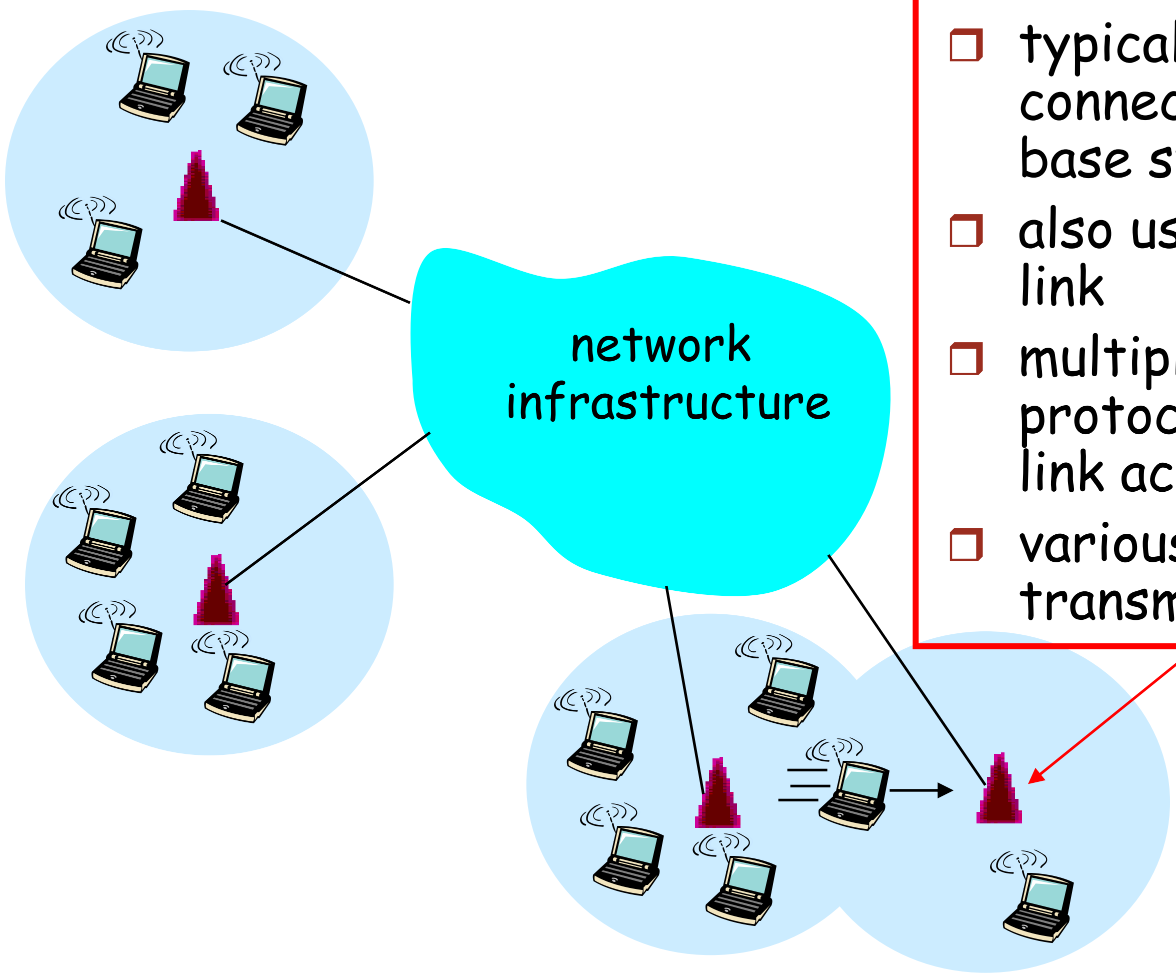
Elements of a wireless network



base station

- typically connected to wired network
- relay - responsible for sending packets between wired network and wireless host(s) in its “area”
  - e.g., cell towers 802.11 access points

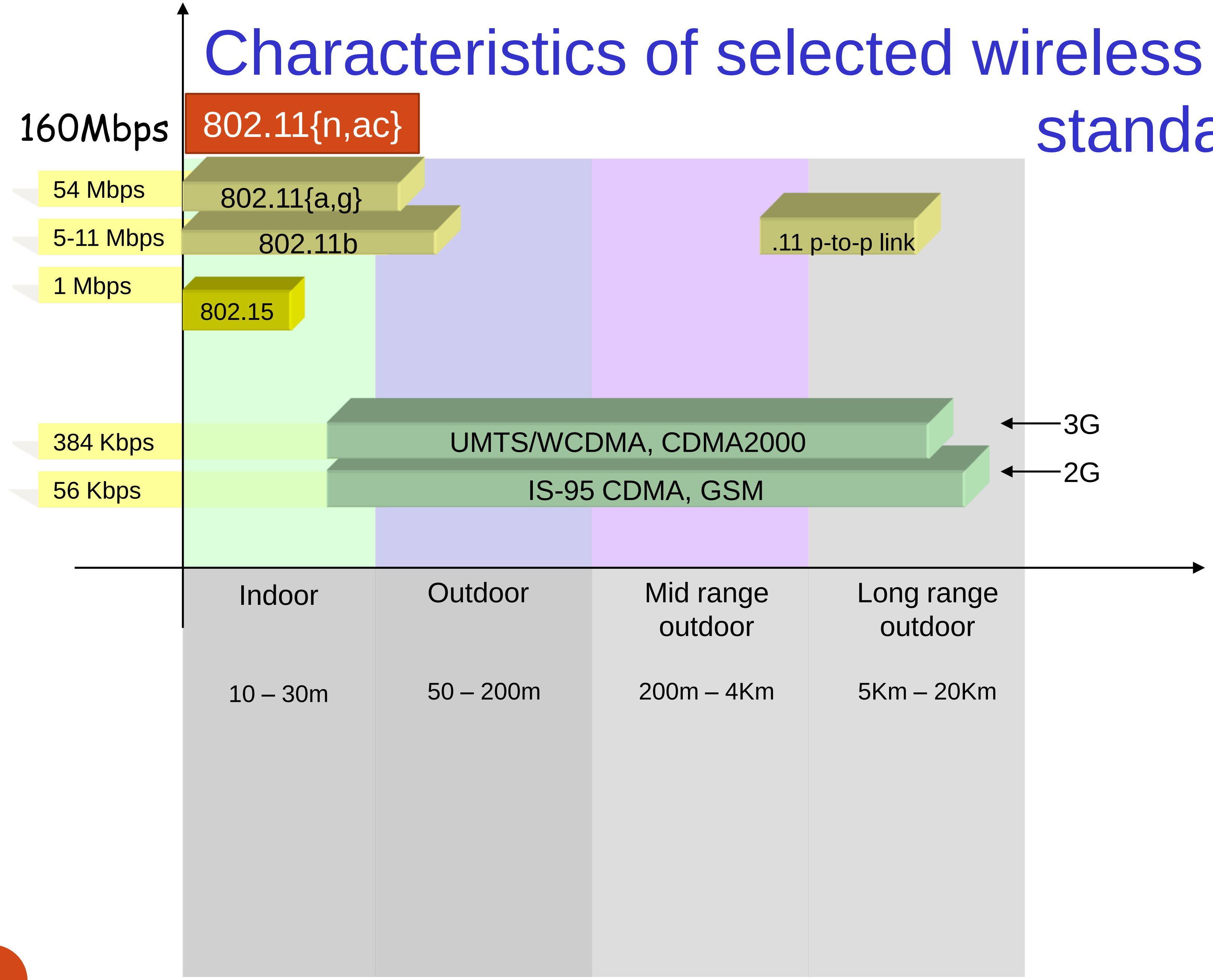
Elements of a wireless network



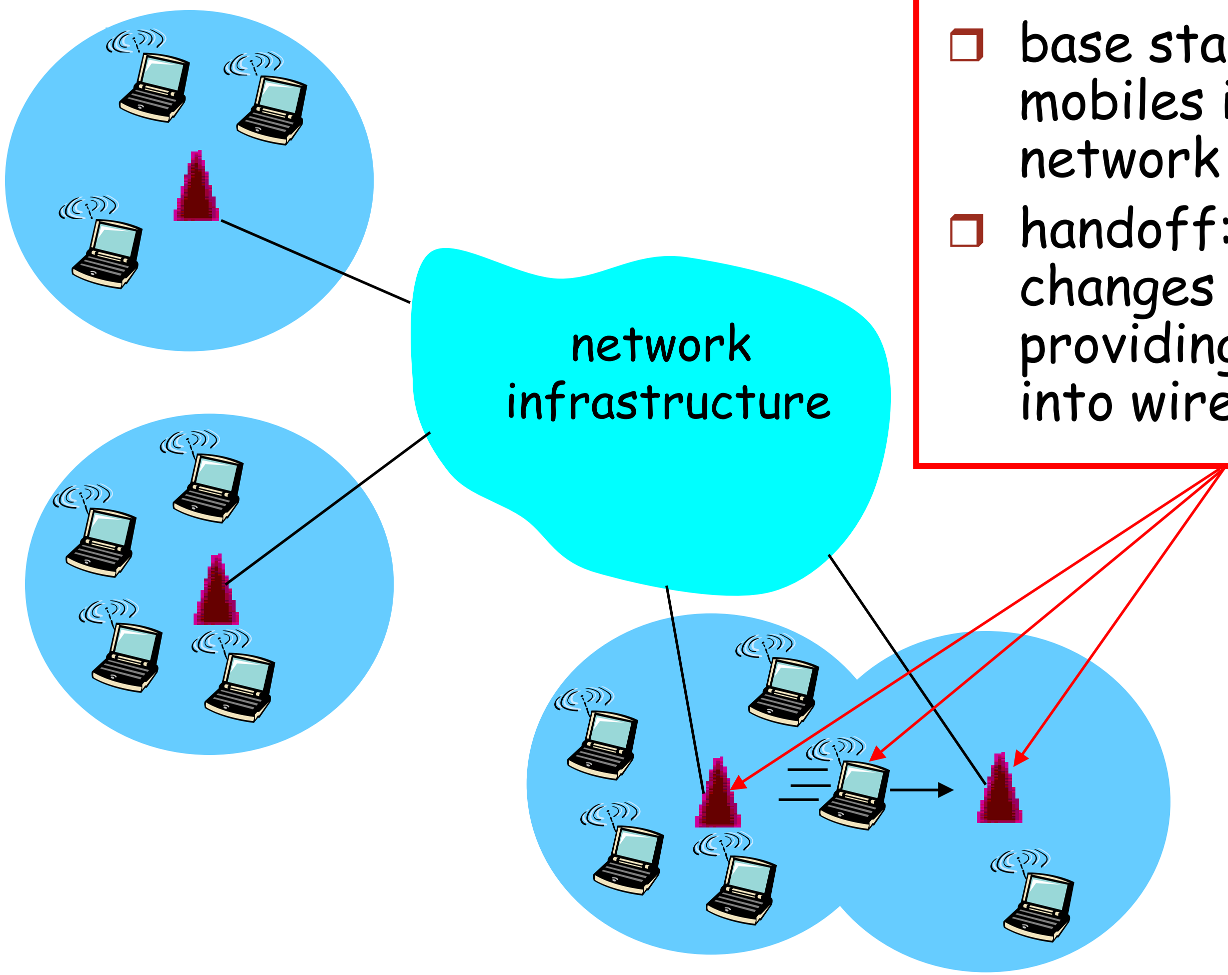
wireless link

- typically used to connect mobile(s) to base station
- also used as backbone link
- multiple access protocol coordinates link access
- various data rates, transmission distance

Characteristics of selected wireless link standards



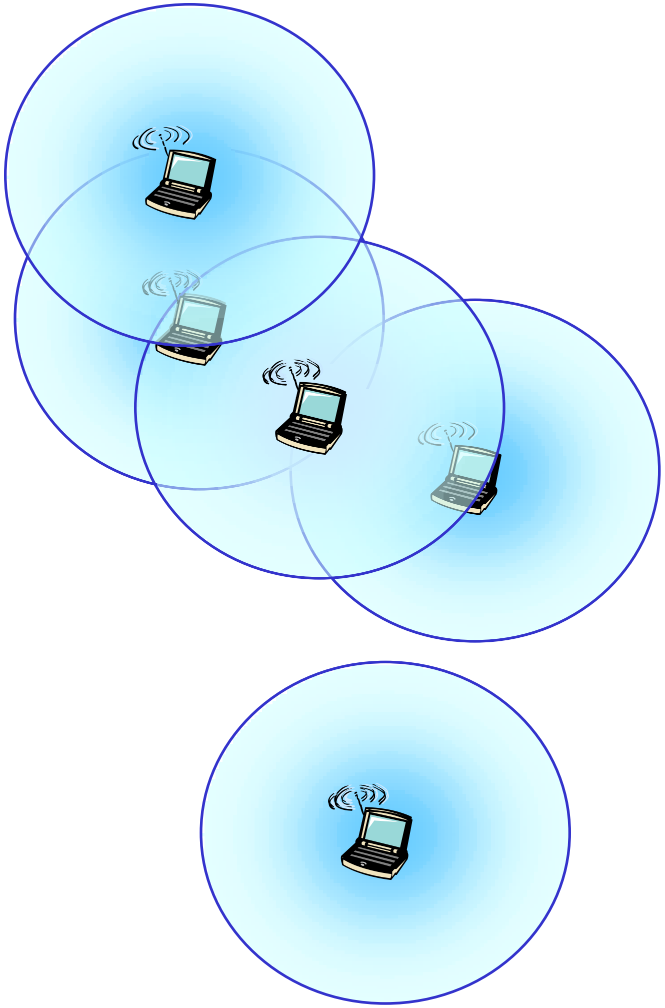
Wireless operation modes



infrastructure mode

- base station connects mobiles into wired network
- handoff: mobile changes base station providing connection into wired network

Wireless operation modes



Ad hoc mode

- no base stations
- nodes can only transmit to other nodes within link coverage
- nodes organize themselves into a network: route among themselves

Wireless Link Characteristics

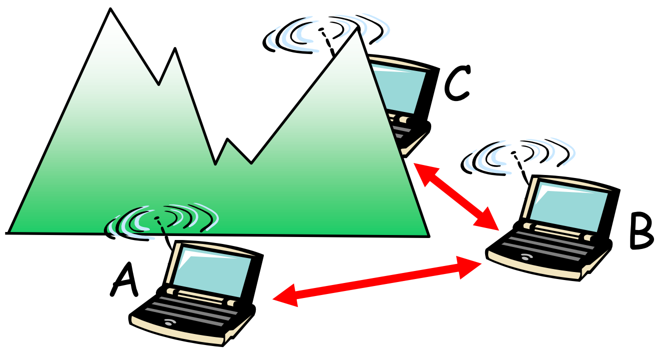
Differences from wired link ….

- decreased signal strength: radio signal attenuates as it propagates through matter or obstacles(path loss)
- interference from other sources: standardized wireless network frequencies (e.g., 2.4 GHz) shared by other devices (e.g., phone); devices (motors) interfere as well
- multipath propagation: radio signal reflects off objects ground, arriving ad destination at slightly different times

…. make communication across (even a point to point) wireless link much more “difficult”

Wireless network characteristics

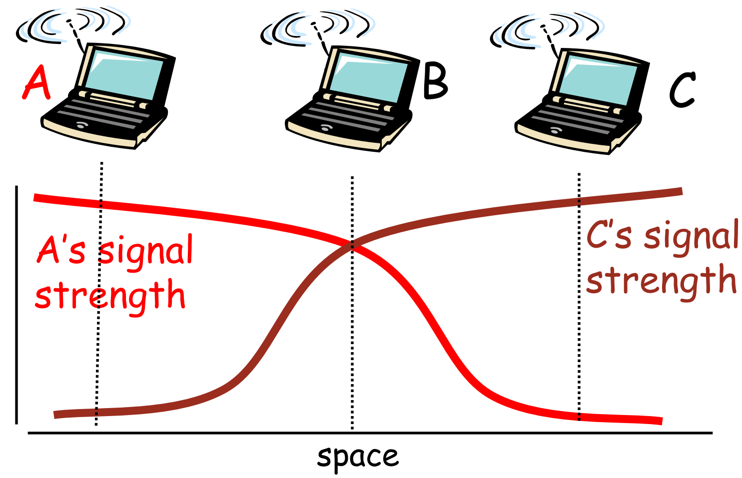
Multiple wireless senders and receivers create additional problems (beyond multiple access):



Hidden terminal problem

- B, A hear each other
- B, C hear each other
- A, C can not hear each other

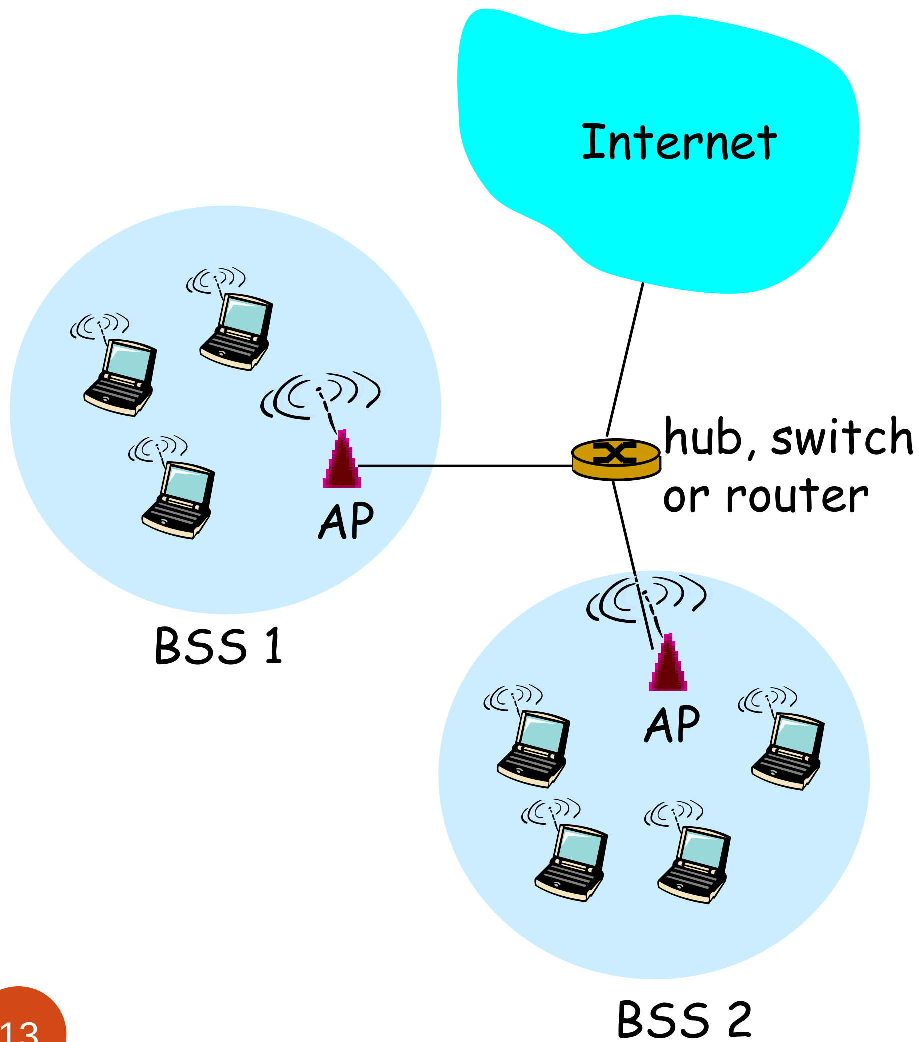
means A, C unaware of their interference at B



Signal fading:

- B, A hear each other
- B, C hear each other
- A, C can not hear each other interferring at B

802.11 LAN architecture



- wireless host communicates with base station
  - base station = access point (AP)
- Basic Service Set (BSS) in infrastructure mode contains:
  - wireless hosts
  - access point (AP): base station
  - ad hoc mode: hosts only

RF- basics

RF Power Definitions

- **dBm** – power referred to 1 mW

  P_{dBm}=10log(P/1mW)

  0dBm = 1mW

  20 dBm = 100mW

  30 dBm = 1W

  Example:

  -110dBm = 0.00001nW

- Rule of thumb:

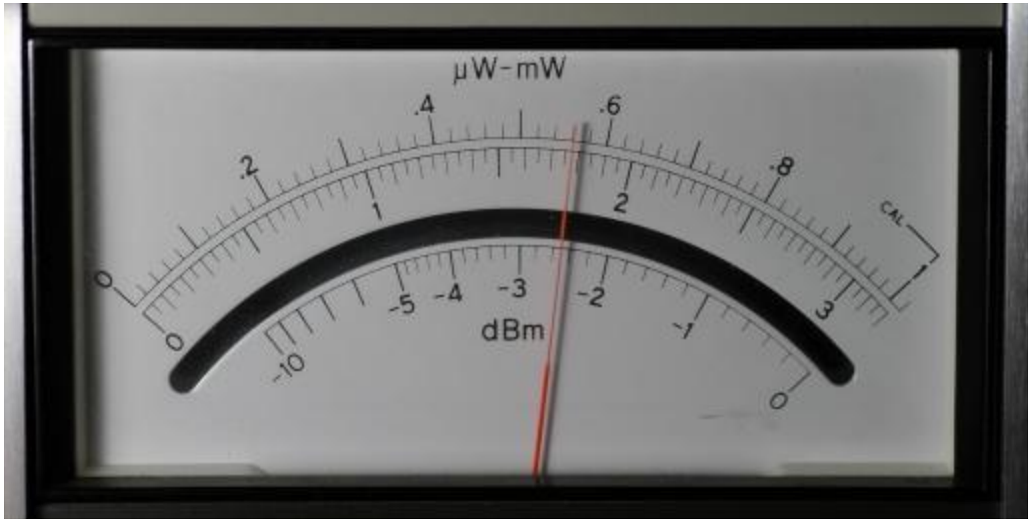
  6dB increase => twice the range

  3dB increase => roughly doubles the dbm power

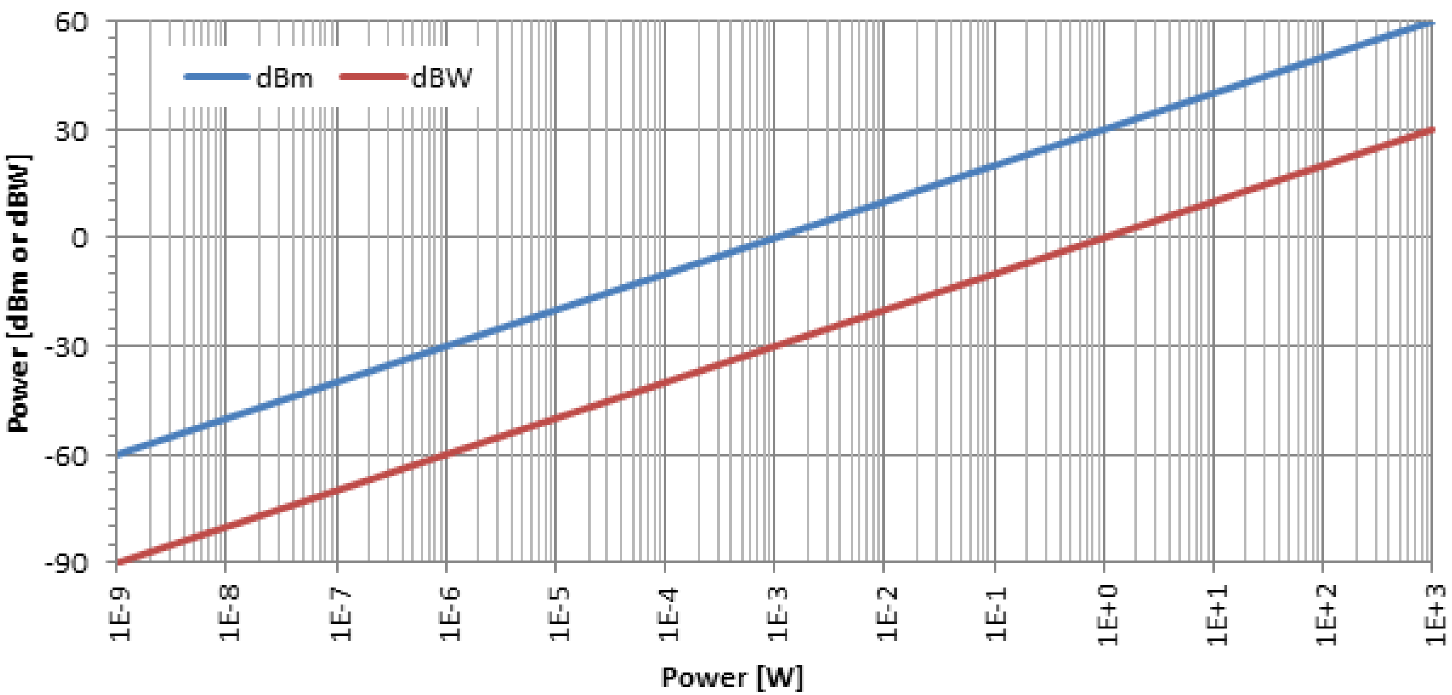
•Classes of transmitters

- •Class 1: Outputs 100 mW for maximum range
  - •Power control mandatory
  - •Provides greatest distance
- •Class 2: Outputs 2.4 mW at maximum
  - •Power control optional
- •Class 3: Nominal output is 1 mW
  - •Lowest power

Why dbm?



μW-mW
dBm
CAL

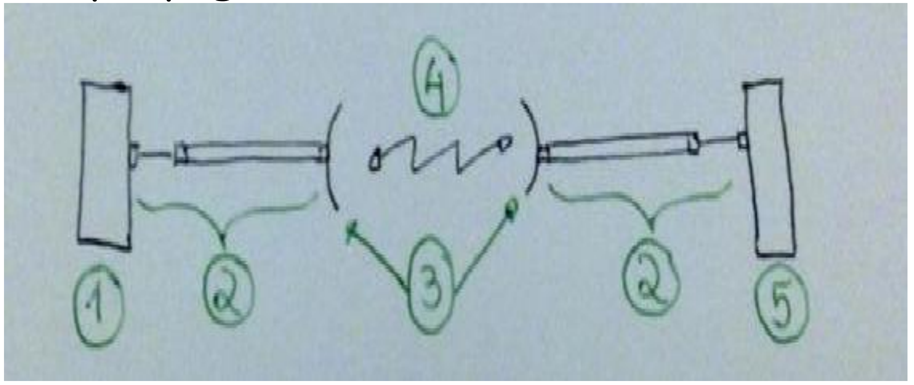


dBm
dBW
Power [dBm or dBW]
Power [W]
60
30
0
-30
-60
-90
1E-9
1E-8
1E-7
1E-6
1E-5
1E-4
1E-3
1E-2
1E-1
1E+0
1E+1
1E+2
1E+3

decibel conversions			
x factor	**+ factor**	**x factor**	**+ factor**
1 000 000 000	+90	0.000 000 001	-90
100 000 000	+80	0.000 000 01	-80
10 000 000	+70	0.000 000 1	-70
1 000 000	+60	0.000 001	-60
100 000	+50	0.000 01	-50
10 000	+40	0.000 1	-40
1 000	**+30**	0.001	-30
100	+20	0.01	-20
10	**+10**	0.1	-10
4	+6	0.25	-6
2	**+3**	0.5	-3
1	**0**		

Question?

Consider a standard wireless link, where we have a transmitter (1) and a receiver (5), Antennas (3), Cables, Jumpers and Connectors (2) and Free Space propagation media (4).



Using real values, let's do the math and see, from the transmitted power, how much power we have at receiver. So with values close to reality, we have:

Transmitter Power = 40 Watts

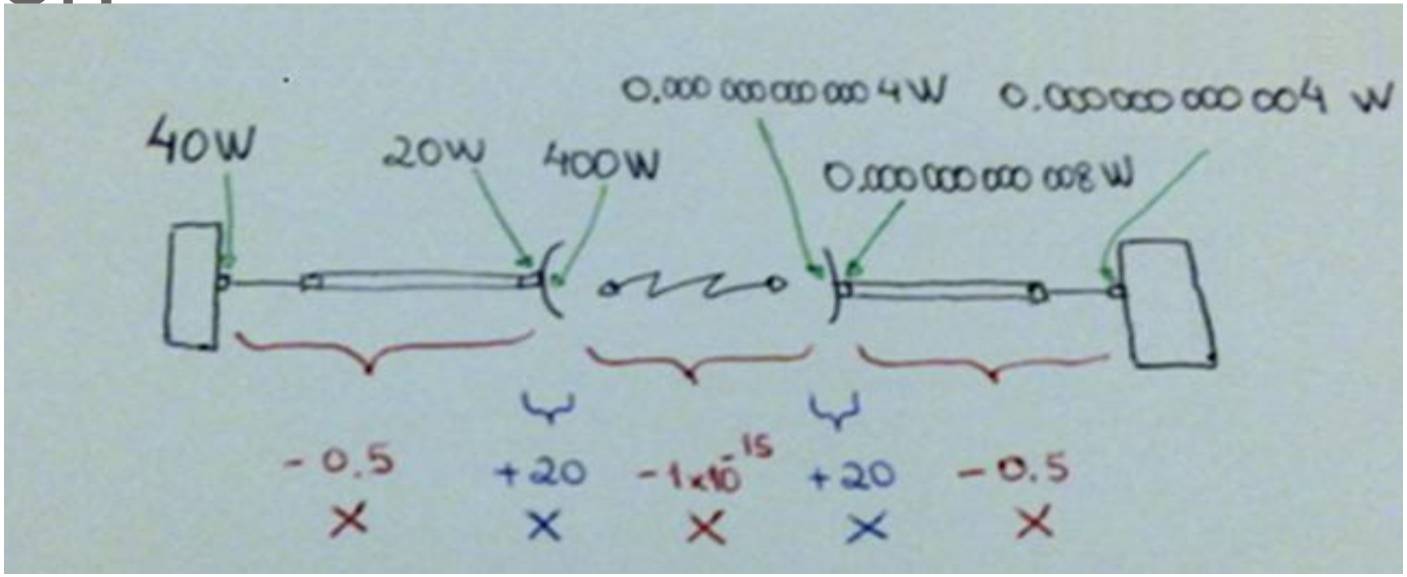
Cables and connectors loss = - 0.5 (Half Power)

Antenna Gain = 20 + times in the Power

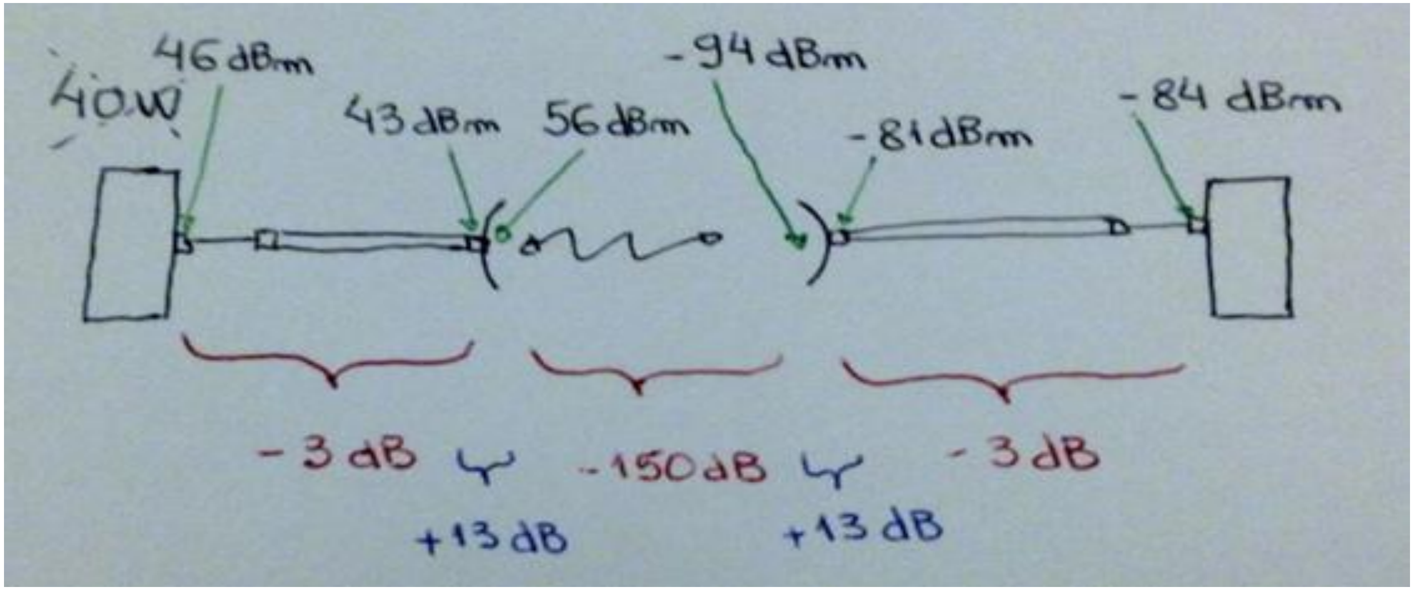
Free Space Loss = - 0.000 000 000 000 000 1 times of Power

Answer:

By power (w)



By power(dbm)



dBm Typicals

For more information: http://en.wikipedia.org/wiki/DBm

dBm level	Power	Notes
80 dBm	100 kW	**Typical transmission power of** FM radio station **with 30-40 miles range**
60 dBm	1 kW	**Typical combined radiated RF power of** microwave oven **elements**
36 dBm	4 W	**Typical maximum output power for** a Citizens' band radio station **(27 MHz) in many countries**
30 dBm	1 W	**Typical RF leakage from a microwave oven - Maximum output power for** DCS 1800 MHz **mobile phone**
27 dBm	500 mW	**Typical** cellular phone **transmission power**
20 dBm	100 mW	Bluetooth Class 1 radio, **100 m range (maximum output power from** unlicensed FM transmitter**). Typical** wireless router transmission **power**.
18 dBm	70mW	**Maximum output power of a Typical** WLAN **card**
4 dBm	2.5 mW	Bluetooth Class 2 radio, **10 m range**
0 dBm	1.0 mW	Bluetooth standard (Class 3) **radio, 1 m range**
−10 dBm	100 µW	**Typical max** received **signal power (−10 to −30 dBm)** of a wireless network
−70 dBm	100 pW	**Typical range of** Wireless received **signal power over** a network
−127.5 dBm	0.178 fW	**Typical** received signal **power from** a **GPS satellite**

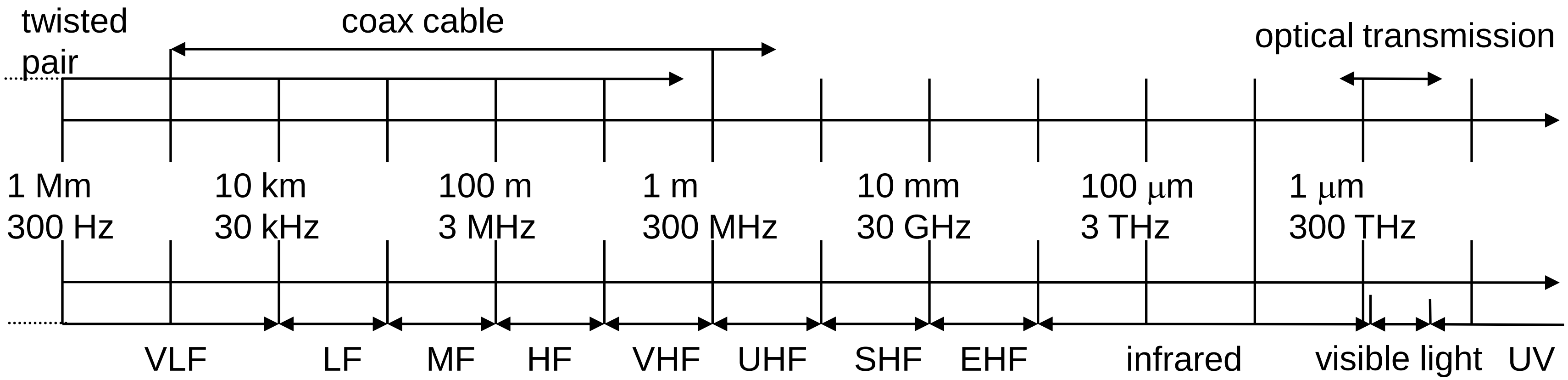
- **Sensitivity** :Lowest input power with acceptable link quality at receiver (ex -70dbm)

gain: maximum output power at transmitter (ex 18dbm)

Frequency regulations

- Frequencies from 9KHz to 300 MHZ in high demand (especially VHF: 30-300MHZ)
- Two unlicensed bands
  - Industrial, Science, and Medicine (ISM): 2.4 GHz
  - Unlicensed National Information Infrastructure (UNII): 5.2 GHz
- Different agencies license and regulate
  - www.fcc.gov - US
  - www.etsi.org - Europe
  - www.itu.org - International co-ordination
- Regional, national, and international issues
- Procedures for military, emergency, air traffic control, etc

Frequencies for communication



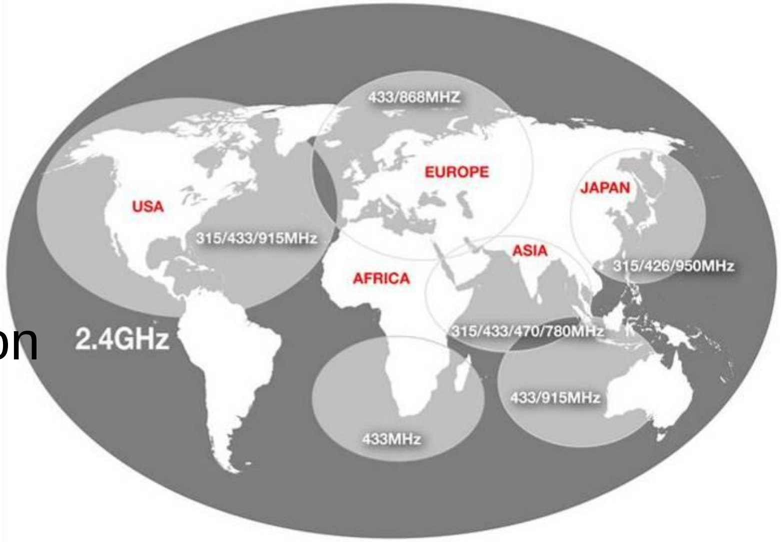
- VLF = Very Low Frequency
- LF = Low Frequency
- MF = Medium Frequency
- HF = High Frequency
- VHF = Very High Frequency

UHF = Ultra High Frequency
SHF = Super High Frequency
EHF = Extra High Frequency
UV = Ultraviolet Light

- Frequency and wave length: $\lambda = c/f$
- wave length λ, speed of light $c \cong 3 \times 10^8$ m/s, frequency f

Wireless frequency allocation

- Radio frequencies range from 9KHz to 400GHZ (ITU)

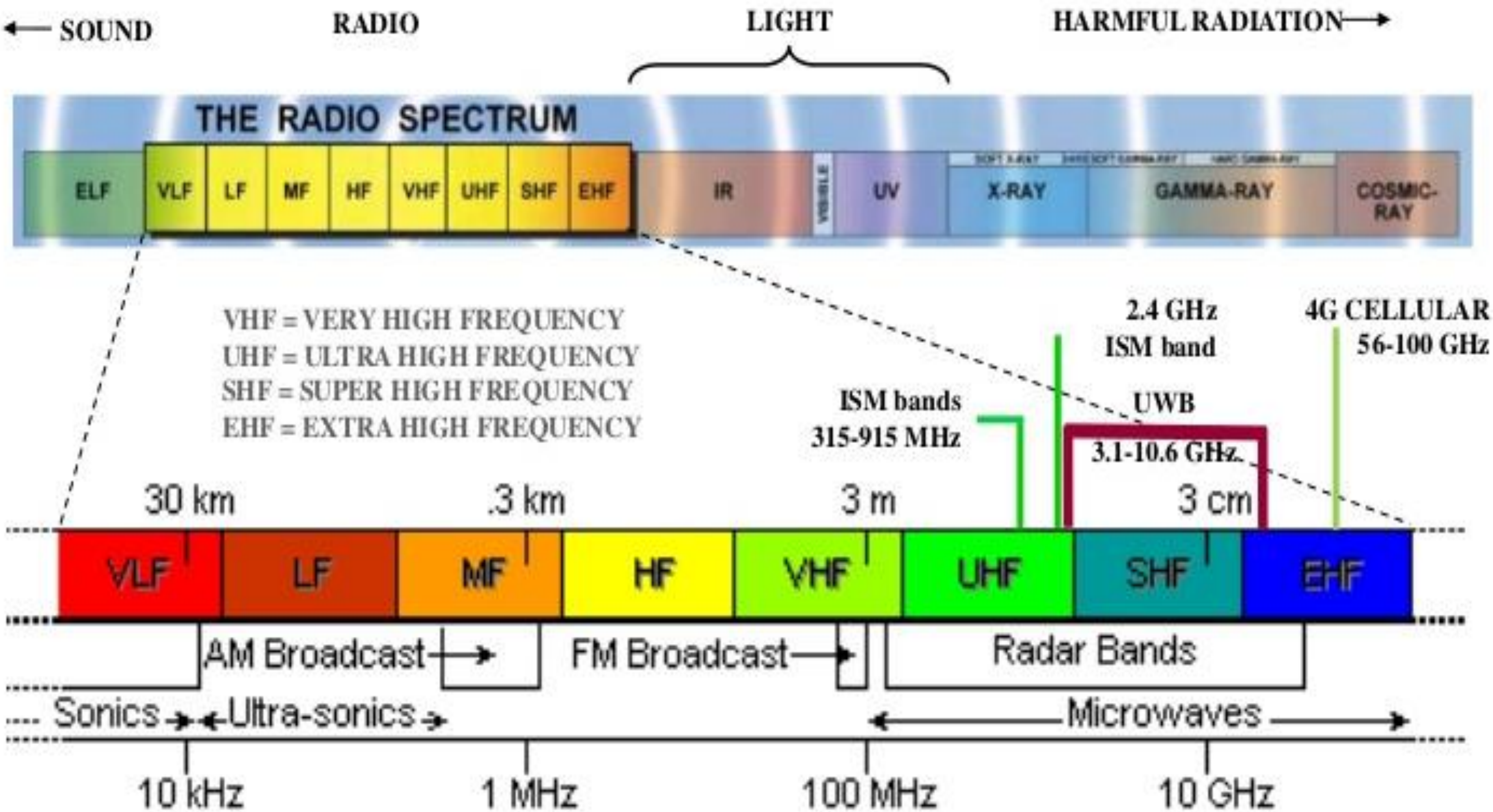


- Microwave frequency range
  - 1 GHz to 40 GHz
  - Directional beams possible
  - Suitable for point-to-point transmission
  - Used for satellite communications
- Radio frequency range
  - 30 MHz to 1 GHz
  - Suitable for omni-directional antennas
- Infrared frequency range
  - Roughly, $3x10^{11}$ to $2x10^{14}$ Hz
  - Useful in local point-to-point multipoint applications within confined areas

Factors affecting wireless system design

- Frequency allocations
  - What range to operate? May need licenses.
- Multiple access mechanism
  - How do users share the medium without interfering?
- Antennas and propagation
  - What distances? Possible channel errors introduced.
- Signals encoding
  - How to improve the data rate?
- Error correction
  - How to ensure that bandwidth is not wasted?

Electromagnetic Spectrum



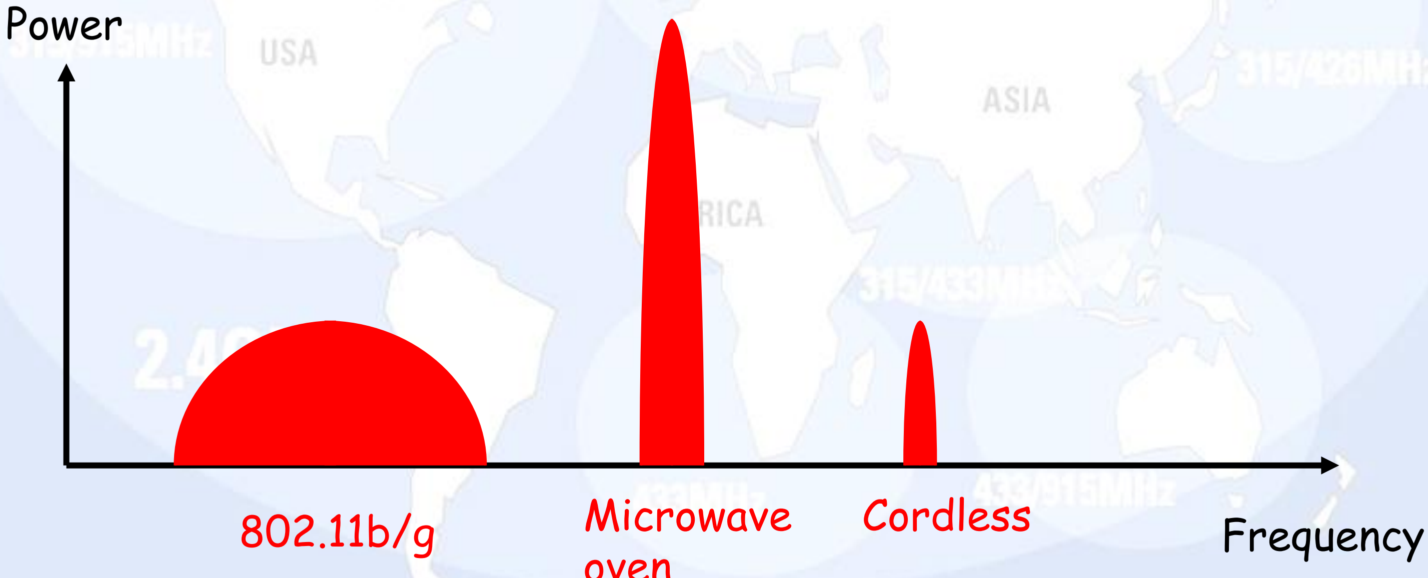
The "World-Wide" 2.4 GHz ISM Band

The 2400–2483.5 MHz band is available for license-free operation in most countries

- 2.4 GHz Pros
  - Same solution for all markets without SW/HW alterations
  - Large bandwidth (83.5MHz) available, allows many separate channels and high datarates
  - 100% duty cycle is possible
  - More compact antenna solution than below 1 GHz
- 2.4 GHz Cons
  - Shorter range than a sub 1 GHz solution (same output power)
  - Many possible interferers are present in the band

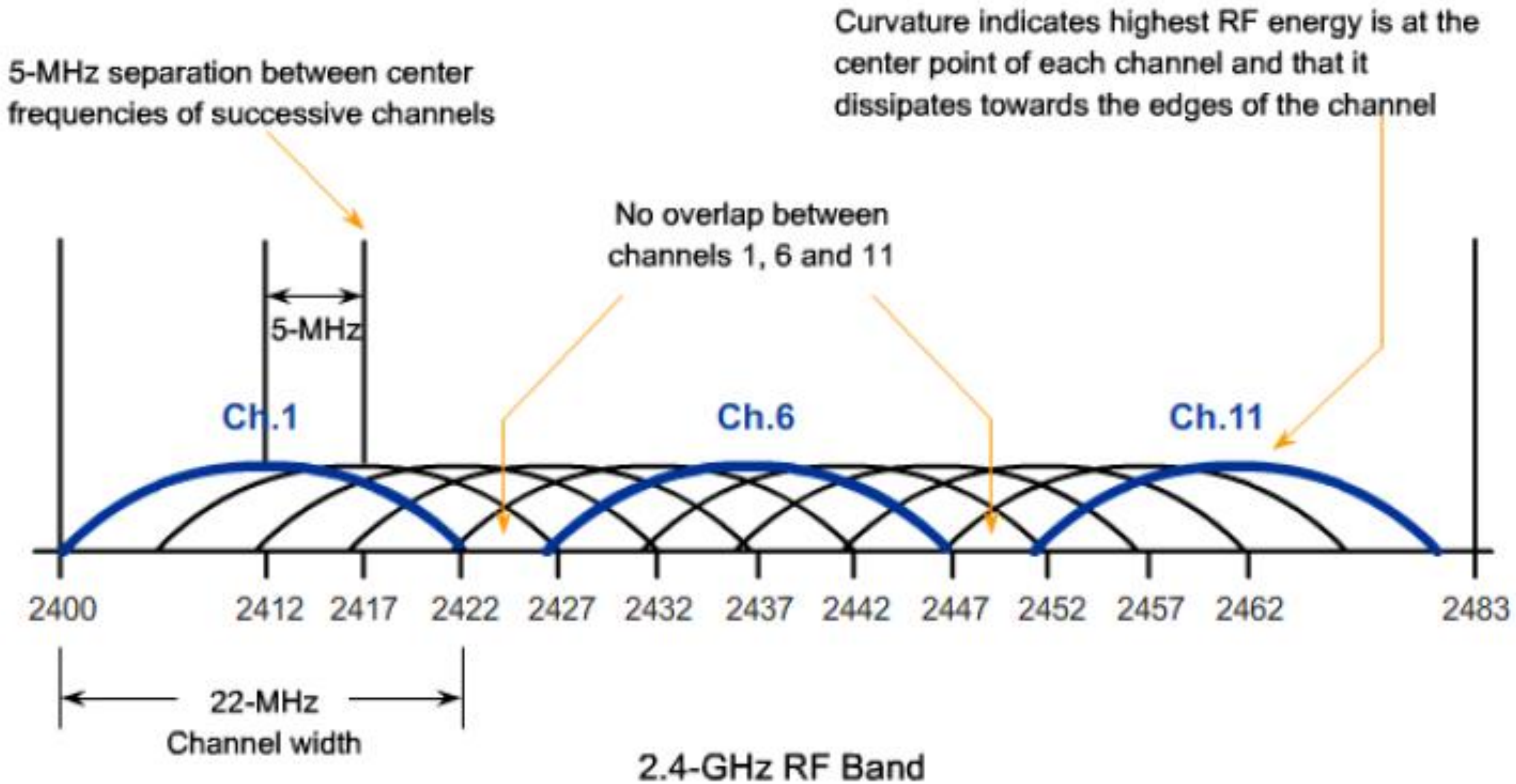
2.4 GHz ISM-band devices

- Due to the world-wide availability of the 2.4GHz ISM band it is getting more crowded day by day
- Devices such as Wi-Fi, Bluetooth, ZigBee, cordless phones, microwave ovens, wireless game pads, toys, PC peripherals, wireless audio devices occupy the 2.4 GHz frequency band

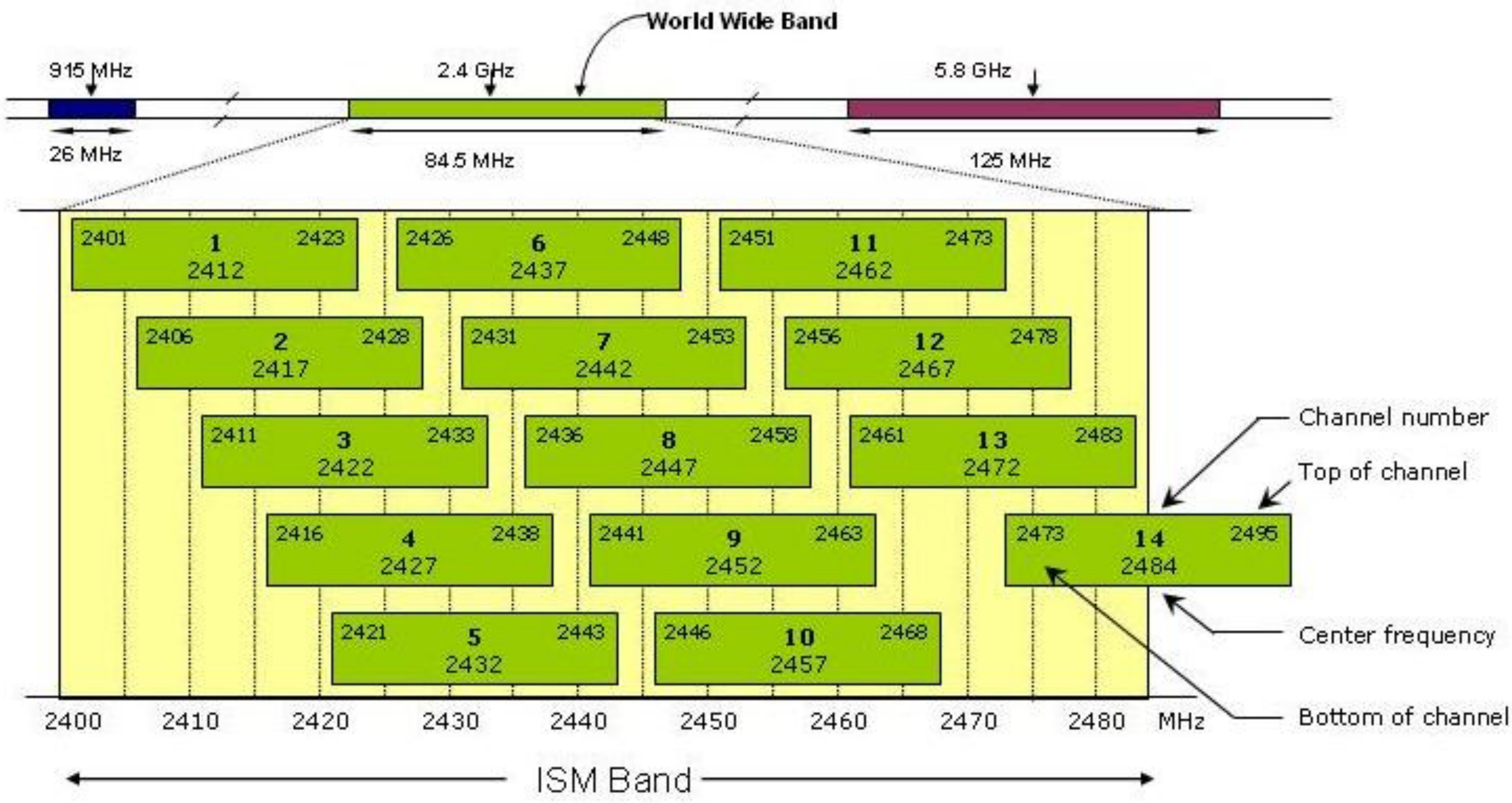


Source: Eliezer & Michael, TI

- Wireless mode
- Wireless Network Name: SSID
- Wireless Channel:



WiFi Channels in the 2.4GHz Space



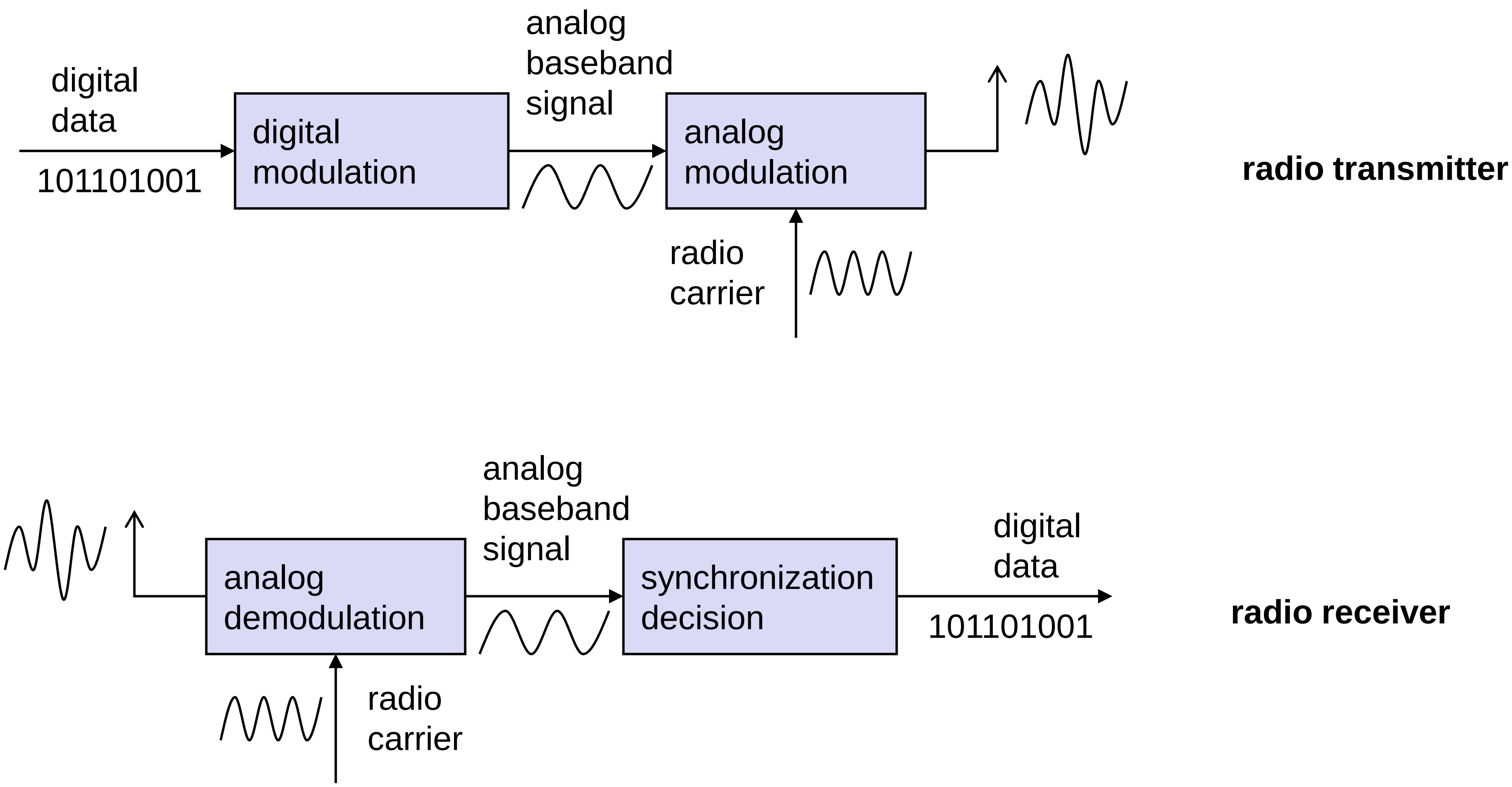
802.11: Channels, association

- 802.11b: 2.4GHz-2.485GHz spectrum divided into 11 or 13 (depending on country regulations) channels at different frequencies
  - AP admin chooses frequency for AP
  - interference possible: channel can be same as that chosen by neighboring AP!
- host: must *associate* with an AP
  - scans channels, listening for *beacon frames* containing AP's name (SSID) and MAC address
  - selects AP to associate with
  - may perform authentication
  - will typically run DHCP to get IP address in AP's subnet

Modulation

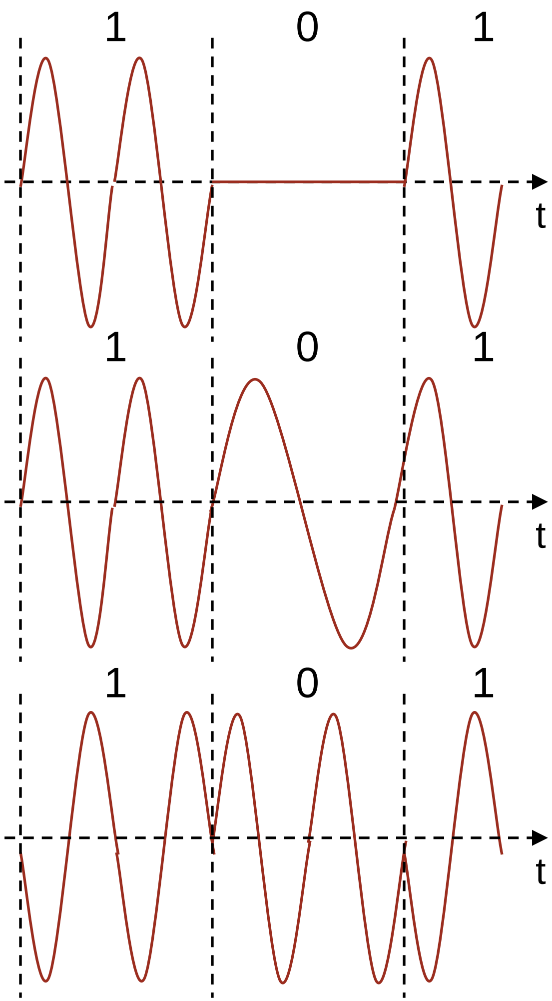
- Digital modulation
  - digital data is translated into an analog signal (baseband)
  - ASK, FSK, PSK
  - differences in spectral efficiency, power efficiency, robustness
- Analog modulation
  - shifts center frequency of baseband signal up to the radio carrier
- Motivation
  - smaller antennas (e.g., $\lambda/4$)
  - Frequency Division Multiplexing
  - medium characteristics
- Basic schemes
  - Amplitude Modulation (AM)
  - Frequency Modulation (FM)
  - Phase Modulation (PM)

Modulation and demodulation



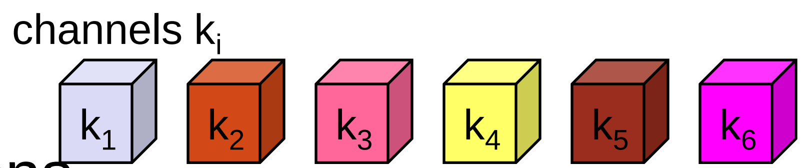
Digital modulation

- Modulation of digital signals known as Shift Keying
- Amplitude Shift Keying (ASK):
  - very simple
  - low bandwidth requirements
  - very susceptible to interference
- Frequency Shift Keying (FSK):
  - needs larger bandwidth
- Phase Shift Keying (PSK):
  - more complex
  - robust against interference
- Many advanced variants

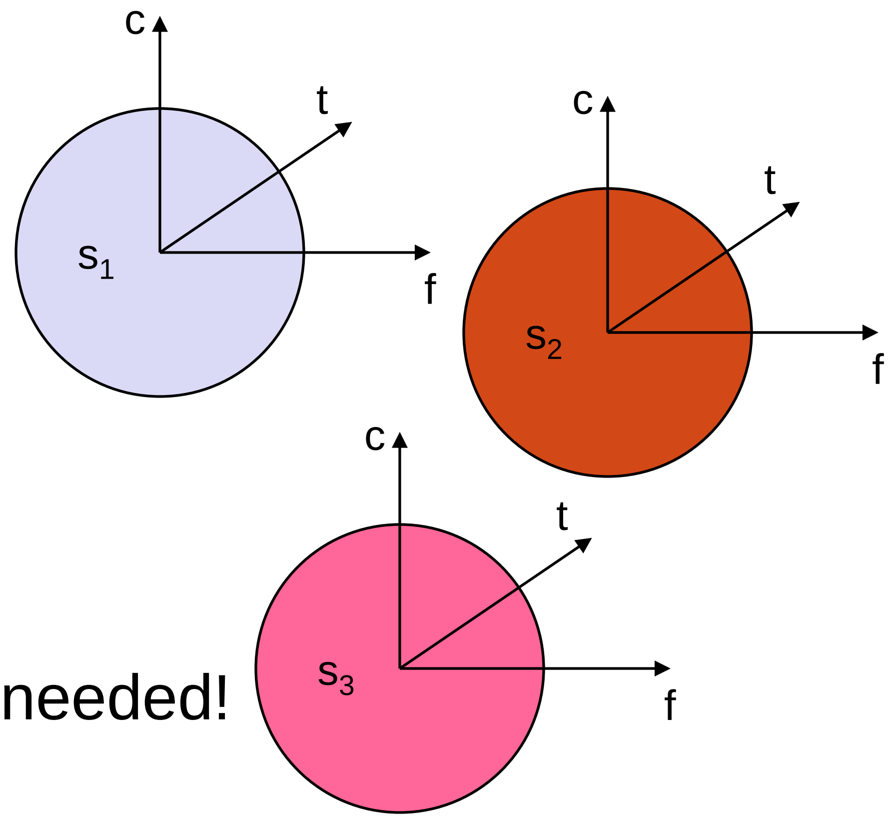


Multiplexing Mechanisms

Multiplexing



- Multiplexing in 4 dimensions
  - space (s_i)
  - time (t)
  - frequency (f)
  - code (c)



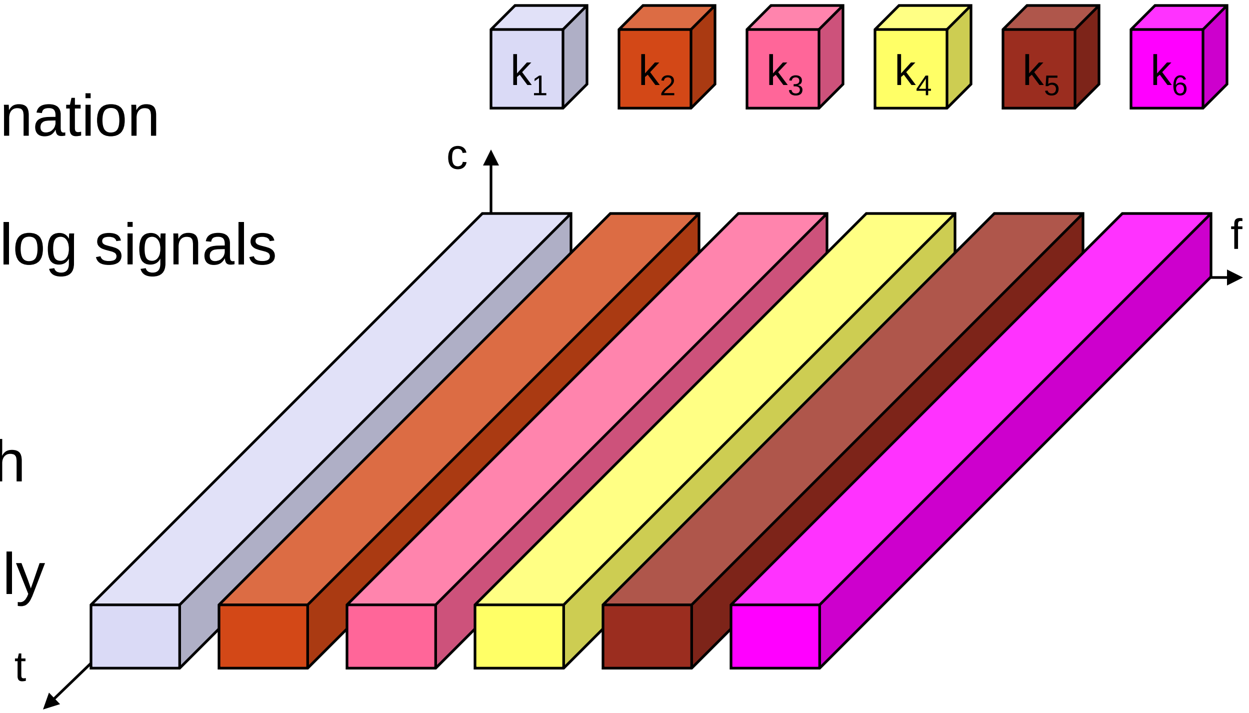
- Goal: multiple use of a shared medium

- Important: guard spaces needed!

Frequency multiplex

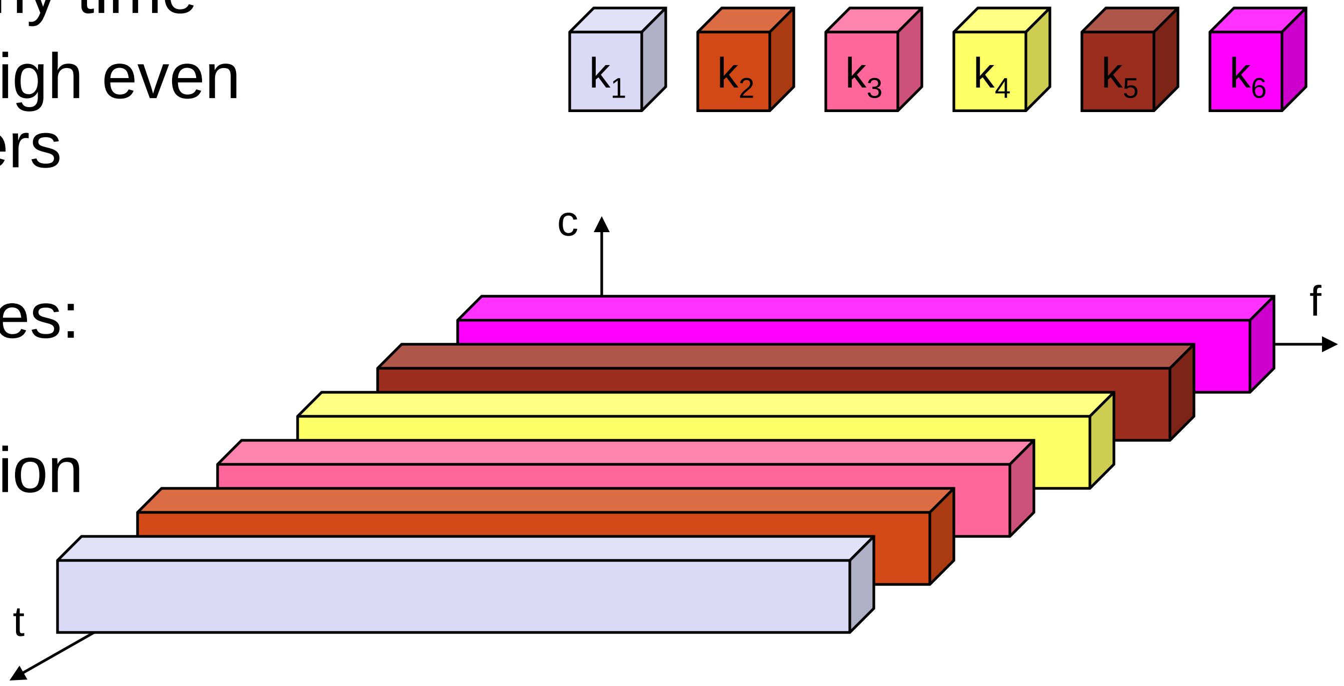
- Separation of the whole spectrum into smaller frequency bands
- A channel gets a certain band of the spectrum for the whole time
- Advantages:
- no dynamic coordination necessary
- works also for analog signals

- Disadvantages:
- waste of bandwidth if the traffic is distributed unevenly
- inflexible
- guard spaces



Time multiplex

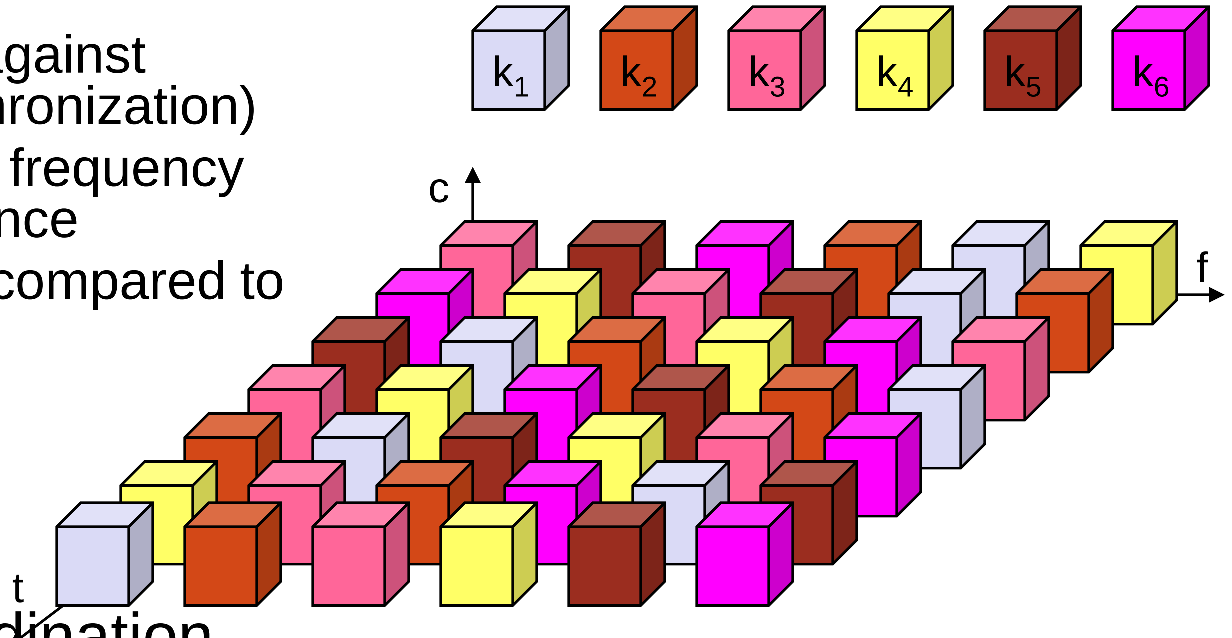
- A channel gets the whole spectrum for a certain amount of time
- Advantages:
- only one carrier in the medium at any time
- throughput high even for many users



- Disadvantages:
- precise synchronization necessary

Time and frequency multiplex

- Combination of both methods
- A channel gets a certain frequency band for a certain amount of time
- Example: GSM
- Advantages:
  - better protection against tapping (i.e. synchronization)
  - protection against frequency selective interference
  - higher data rates compared to code multiplex



- but: precise coordination required

Code multiplex

- Each channel has a unique code
- All channels use the same spectrum at the same time
- Advantages:
  - bandwidth efficient
  - no coordination and synchronization necessary
  - good protection against interference and tapping
- Disadvantages:
  - lower user data rates
  - more complex signal regeneration
- Implemented using spread spectrum technology