Wireless data networks
Introduction

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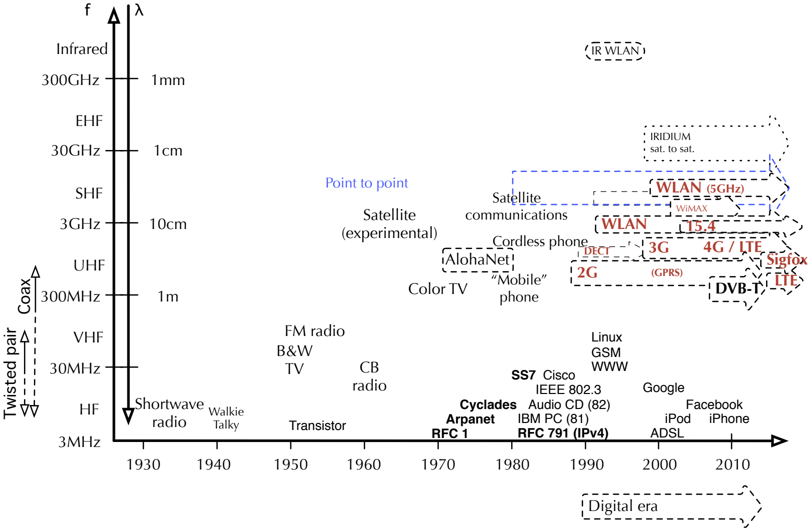
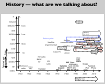
History — what are we talking about?

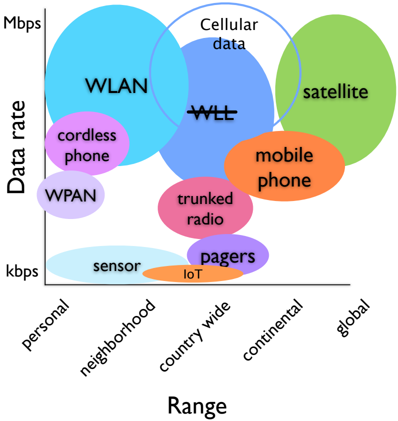




We will talk about wireless LANs, mobile networks, satellite

1. Very high data rates – compare with baseband transmission media ! (Except optical fiber)
2. RFC 1: “Host Software” by Steve Crocker, 1969
3. The big arrows refer to digital technologies
4. Point to point (in blue): high data rate wireless links for data and/or telephony, *e.g.* running SDH – note the earlier conversion to digital…
5. In red: Widely deployed consumer oriented technologies
6. 2 trends: higher and higher carrier freq., wider channels (the vertical axis has a log scale!)

Many different use of the wireless channel



Many different use of the wireless channel

Many different use of the wireless channel

1. Both “scales” are “logarithmic”…
2. Trunked radio : firefighters, police…
3. Mobile networking
   - Cellular 2G, 3G… : much more than just radio links : …accounting, mobility management…

★ Wireless LAN (802.11)

★ WLL = Wireless local loop (802.11, 802.16 (a.k.a. WiMAX))

★ Wireless personal area network (802.15.1—Bluetooth)
   - High rate, short range, low power consumption

★ Sensor networks (802.15.4—Zigbee)
   - Low power consumption

* Ad hoc networks (Mobile multihop network)
   - Routing
   - Performance issues

4. SigFox, LoRa : “long” range (tens of km) for IoT

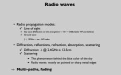
Radio waves

- Radio propagation modes:
  - ✓ Line of sight
  - ✓ Sky wave (Reflection on the ionosphere — 70 $\rightarrow$ 300km)(for HF and bellow)
  - ✓ Ground wave

    $f < 2$MHz — ex.: AM radio

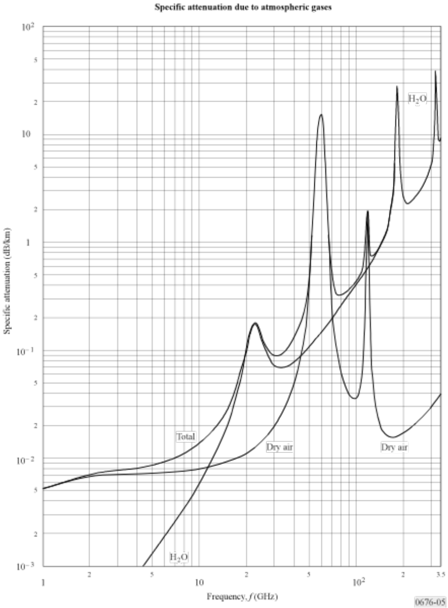
- Diffraction, reflections, refraction, absorption, scattering
  - ✓ Diffraction: λ @ 2.4GHz is 12.5cm
  - ✓ Scattering
    - ▸ The phenomenon behind the blue color of the sky
    - ▸ Radio waves: mostly on pointed or sharp metal edges

$\Rightarrow$ **Multi-paths, fading**



1. We are talking mostly about line of sight and/or reflected/scattered/diffracted waves in the context of this course
2. Light illustrates well how EM waves are reflected, but radio waves a more often diffracted and/or scattered – This causes some amount of retro-propagation that radars use for instance…
3. Multipath propagation cause randomly constructive or destructive interference ; obstacles may attenuate the signal. We speak of a "Fading channel"
4. (On the att. figure) Microwave ovens **do not** work at a special frequency *w.r.t.* water
5. The 2 peaks of dry air are due to absorption by 0_2

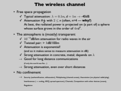
Radio waves (cont.)



Pressure: 1 013 hPa
Temperature: 15° C
Water vapour: 7.5 g/m³

The wireless channel

- Free space propagation
  - ✓ Typical attenuation: $\lambda = 0.1\mathrm{m}$, $d = 1\mathrm{m} \rightarrow$ **-40dB**
  - ✓ Attenuation $\# \frac{1}{d^n}$ with $2 \leq n$ (often, n=4 — **why?**)
    At best, the radiated power is projected on (a part of) a sphere whose surface grows in the order of $4\pi d^2$.
- The atmosphere is (mostly) transparent
  - ✓ 10^{-2}dB/km attenuation for radio waves in the air
  - ✓ Twisted pair: > 1dB/100m
  - ✓ Attenuation is exponential!
    (and so it makes sense to measure attenuation in dB)
  - ✓ Strong attenuation in concrete, metal; depends on λ
  - $\rightarrow$ Good for long distance communications
    (if only the world was flat…)
  - $\rightarrow$ Strong attenuation, even over short distances
- No confinement
  - $\rightarrow$ Security (authentification, obfuscation), Multiplexing (channel access), Association (no physical cable/plug), Interferences ($\rightarrow$ coding, ARQ, spread spectrum), Channels, Competition with other devices (ovens), Regulation



Radio transmissions have **very favorable** properties! And unavoidable

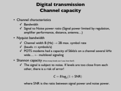
1. $X_{dB} = 10\log_{10}(X)$
   -40dB $\leftrightarrow \frac{1}{10000}$
2. Almost no signal absorption, but unavoidable dispersion
   $\rightarrow$ a large fraction of the signal is often lost as it radiates in "all directions"
3. Fading+No confinement are the 2 reasons why there is a *wireless networks* class!
4. Directional antennas allow to concentrate the power in one (or more… See antenna patterns) direction

Digital transmission
Channel capacity

- Channel characteristics
  - ✓ Bandwidth
  - ✓ Signal to Noise power ratio (Signal power limited by regulation, amplifier performance, distance, antenna…)
- Nyquist bandwidth
  - ✓ Channel width B (Hz) $\rightarrow$ 2B max. symbol rate
  - ✓ (bauds $\Leftrightarrow$ symbols/s)
  - ✓ POTS modems had a capacity of 56kb/s on a channel several kHz wide… $\leftarrow$ multilevel signaling
- Shannon capacity (How many levels can I use, how fast?)
  - ✓ The signal is subject to noise. If levels are too close from each other, there is a risk of error!

$$C = B \log_2(1 + \mathrm{SNR})$$

where SNR is the ratio between signal power and noise power.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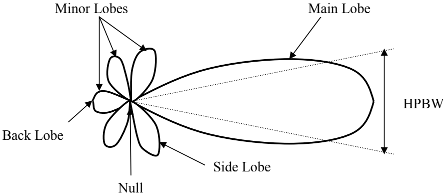
where SNR is the ratio between signal power and noise power.

The **fundamentals**: how much information can be conveyed?

1. The Nyquist formula tells **how quickly** symbols can follow each other on the channel
2. What **really** matters is the channel capacity, which tells **at most** how many bits/s can/could be carried, theoretically
3. The Shannon capacity is easy to remember:
   * If the band is twice as large, the capacity should double ($C \# B$)
   * For many levels, if the signal to noise ratio is doubled, twice as many levels can be used ($C \approx \# \log_2(\text{SNR})$)
   * If SNR=0 $\rightarrow$ C=0
4. **Important**: the Shannon formula also applies to cases where SNR $\ll 1$, *i.e.* $C \ll B$ — Generally means a spread spectrum technique is used!

Physical layer for wireless

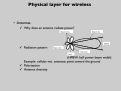
- Antennas
  - ✓ Why does an antenna radiate power?
  - ✓ Radiation pattern



(HPBW: half power beam width)

Example: cellular net. antennas point toward the ground

  - ✓ Polarization
  - ✓ Antenna diversity



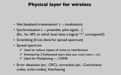
Wait? How does it work?

1. Any movement of electric charges will create an EM field that is going to attract/repulse charges further away – it's that simple…
2. Charges move in a wire in which a standing wave is present
3. There are no perfect omnidirectional antennas, nor perfect directional antennas…
4. Polarization: that gives us 2 channels to play with!
5. Antenna diversity: as interferences go from constructive to destructive over
   - Short distances
   - Various time scales

   Having several antennas allows to choose the one with the best signal (on receiver side)
   And there is more (MIMO…)

Physical layer for wireless

- Not baseband transmission! ($\rightarrow$ modulation)
- Synchronisation ($\rightarrow$ preamble, pilot signal…)
  (Ex.: for AM, to which level does a logical "1" correspond?)
- Scrambling (if not done for spread spectrum)
- Spread spectrum
  - ✓ Used to reduce impact of noise or interference
  - ✓ Invented by 2 hollywood stars (see `www.hedylamarr.at`)
  - ✓ Used for Multiplexing $\Rightarrow$ CDMA
- Error detection (ex.: CRC), correction (ex.: Convolution codes, turbo codes), Interleaving



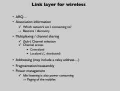
No, but I mean, how does it work, *really*?

1. A standing wave… That means there is a carrier frequency
2. Synchro: **When and what** are the transitions coding the information
3. Scrambling: mix with a pseudo random sequence so that is looks like noise.
   Why?
   - To make sure there are transitions for clock recovery
     (or make sure all levels are used evenly… So that the power is not too low/high, for instance…)
   - To avoid radiating in a narrow band
   - **Not** for **obfuscation**!!
4. Spread spectrum: use more bandwidth than would be necessary at first… Spread the information over a wide freq. band. A simple example is **frequency hopping**
   * Multiplexing and interference mitigation may be combined
5. And as things still go wrong often, error detection and correction (combined with interleaving) are often used

Link layer for wireless

- ARQ…
- Association information
  - ✓ Which network am I connecting to?
  - $\rightarrow$ Beacons / discovery
- Multiplexing / channel sharing
  - ✓ (Sub-) Channel selection
  - ✓ Channel access
    - ▸ Centralized
    - ▸ Localized ($\subsetneq$ distributed)
- Addressing (may include a relay address…)
- Fragmentation/reassembly
- Power management
  - ✓ Idle listening is also power consuming

    $\Rightarrow$ Paging of the mobiles



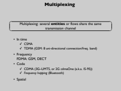
OK, we know how to transmit (streams of) **bits**, now we need to send **frames**, to the **intended recipient**, **share** the medium with other people *etc.*

1. ARQ: Automatic Repeat reQuest. Data networks generally use L2 ACKs (802.11, UMTS acknowledged RLC) to combat
   – Collisions
   – Interferences
   – Fading
2. There are beacons in almost all wireless networks: tells the "user" that a link is available
3. Multiplexing: see next slide…
4. Addressing is generally more complex in wireless networks than wired network where the medium identifies the immediate source/destination (think about PPP links: they do not have L2 addresses!)
5. Radios are often battery powered $\rightarrow$ it's good to shut down the radio as much as possible. Then, it does not allow to communicate!

Multiplexing

Multiplexing: several **entities** or flows share the same transmission channel

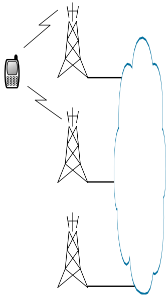
- In time
  - ✓ CSMA
  - ✓ TDMA (GSM: 8 uni-directional connection/freq. band)
- Frequency
  FDMA: GSM, DECT
- Code
  - ✓ CDMA (3G–UMTS, or 2G cdmaOne (a.k.a. IS-95))
  - ✓ *Frequency hopping* (Bluetooth)
- Spatial

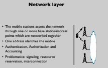


1. CSMA: Carrier Sense Multiple Access $\leftrightarrow$ listen before talk. WIreless specific Variant: /CA (Collision Avoidance: listen longer before talk…)…
2. TDMA: Time division MA, senders own the channel periodically
3. CDMA: Code Division MA: Combined MUX and spread spectrum
4. Spatial MUX: directional antennas, many “relays” (access points, base stations…)

Network layer

- The mobile stations access the network through one or more base stations/access points which are networked together
- One address identifies the mobile
- Authentication, Authorization and Accounting
- Problematics: signaling, ressource reservation, interconnection





We just talked about spatial re-use. That means the “relays” need to be networked. Mobiles (more generally wireless devices) need to be accessible wherever they are.
This is a network of wires (mostly) but it’s an important part to build a wide(r) scale wireless **network**! (Out of a bunch of wireless **links**)…

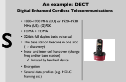
1. This is not only a telecom network problematic, this kind of infrastructure also exists for wireless LANs – and DECT networks too!

An example: DECT

Digital Enhanced Cordless Telecommunications

- 1880–1900 MHz (EU) or 1920–1930 MHz (US); (G)FSK
- FDMA + TDMA
- 32kb/s full duplex basic voice call
- The base station beacons in one slot ($\rightarrow$ discovery)
- Intra- and inter-cell handover (change freq and/or base station)
  - ✓ Initiated by handheld device
- Encryption
- Several data profiles (e.g. HDLC framing *etc.*)

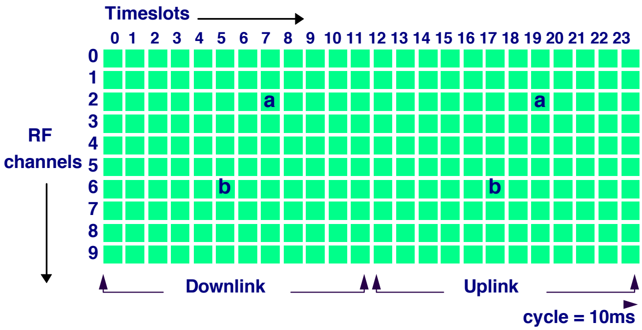
An example: DECT Digital Enhanced Cordless Telecommunications



1. Typical of system designed with voice calls as the main application: TDMA also used in
   - GSM
   - Iridium
2. Does not use any spread spectrum technique

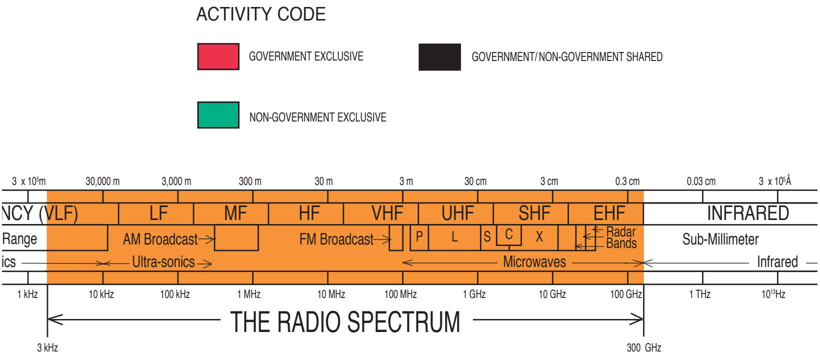
An example: DECT

Digital Enhanced Cordless Telecommunications (cont.)



http://www.dect.org/userfiles/file/General%5CDECT%20Background/DECT_Technical%20Document_1997.pdf

Radio spectrum—FCC Freq. alloc.

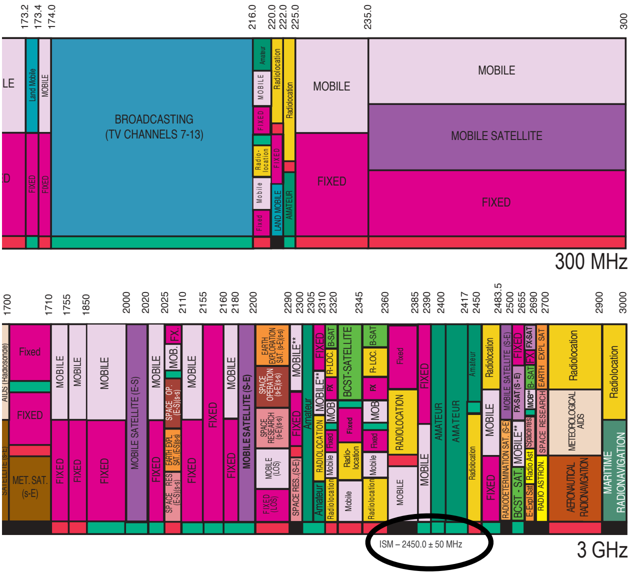


http://www.ntia.doc.gov/osmhome/allochrt.pdf

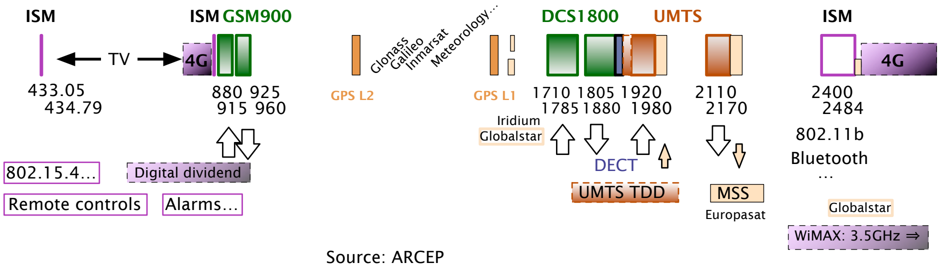
http://www.fcc.gov/oet/spectrum/table/fcctable.pdf

http://www.itu.int/ITU-D/study_groups/SGP_2002-2006/JGRES09/CEPT2.pdf

Radio spectrum—FCC Freq. alloc. (cont.)



Radio spectrum UHF — France



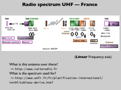
(**Linear** Frequency axis)

What is this antenna over there?

⇒ `http://www.cartoradio.fr`

What is the spectrum used for?

⇒ `http://www.anfr.fr/fr/planification-international/tnrbf/tableau-derive.html`

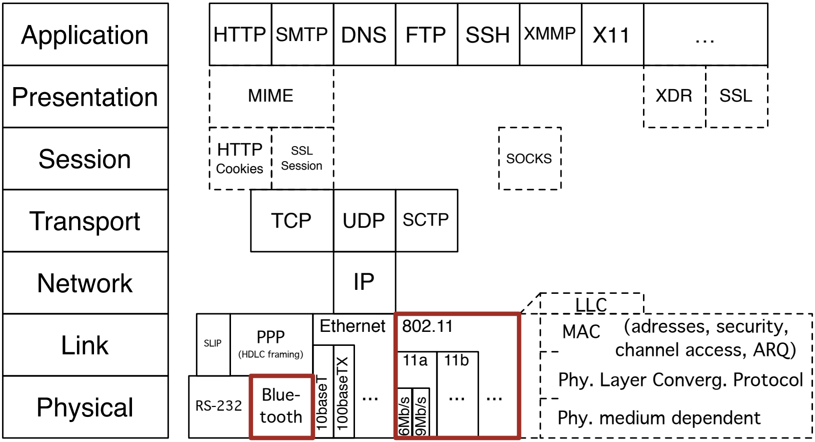


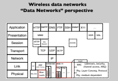
1. Avalanche beacons operate in MF band (457kHz)
2. Globalstar is a mobile satellite telecom operator, the LEO satellite reflects the signal to a base station located not too far away.
3. GPS L2 was added to the GPS system, used to remove ionosphere distorsions

Microwave transmissions

Example of a tower for long distance wireless transmissions

Wireless data networks
"Data Networks" perspective

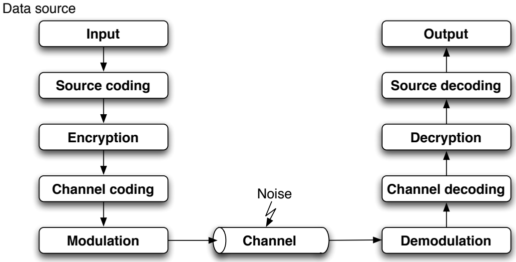


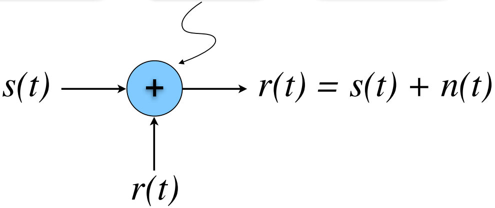


The focus in this course will be quite a bit on L2, a pinch of L1, a grain of L3

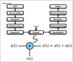
1. BT appears as a byte-carrying PHY layer here, but it obviously has a L2, and even data profiles, so there is more to it than that…
2. 802.11 has more sublayers than just PHY/link… As all IEEE-defined standards, it does not care mentioning what type of PDU is carried, so LLC is needed!
3. SCTP is a transport protocol mostly used today to carry telecom signaling (call setup…) in IP packets. It could be used for other things.
4. This is a *“data network”-centric* picture. Telecom networks are not build around IP, except for the latest generation!

Wireless data networks
“Information Theory” perspective





Wireless data networks
“Information Theory” perspective



1. Source coding $\Leftrightarrow$ sampling, digitization, compression (remove/trim information)
2. Encryption $\Leftrightarrow$ ensure integrity, confidentiality, authentication (add some data)
3. Channel coding $\Leftrightarrow$ Data protection through redundancy (add –a lot of– data)
   Hamming error correcting code: max. rate ECC.
   Otherwise typically rate is 3/4, 1/2, 1/3 ($\leftarrow$ this the ratio of the actual data to the amount of bits transmitted)…
   Interleaving
4. Modulation $\Leftrightarrow$ attach the data to a physical carrier
5. *N.B.:* In wireless networks there can be more than one link. In cellular networks, source coding often happens in other places than just the end points