Lecture 22: Wireless systems

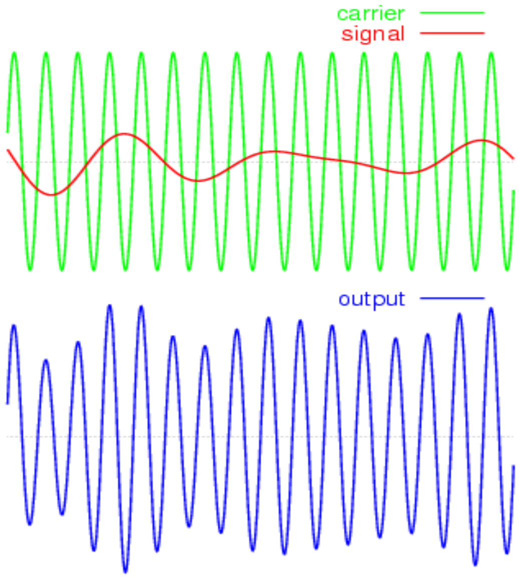
- how radio works
- radio spectrum allocation

- examples of wireless systems
  - cell phones
  - Wi-Fi
  - Bluetooth
  - RFID
  - GPS

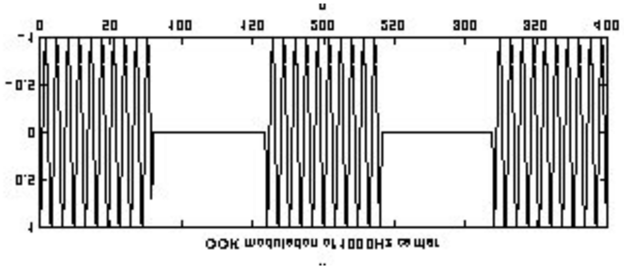
- tradeoffs
  - spectrum, power, range, size, weight, mobility, ...

- non-technical issues
  - privacy, security, regulation, competition, ...

Radio



- **electromagnetic radiation to carry information**
  - without wires => "wireless"
- **radiation is a wave of a particular frequency (in Hz)**
- **transmitter "modulates" the wave to impose information on it**
  - amplitude (AM): change the power level
  - frequency (FM): change the frequency around a central value
  - digital: on/off
  - …



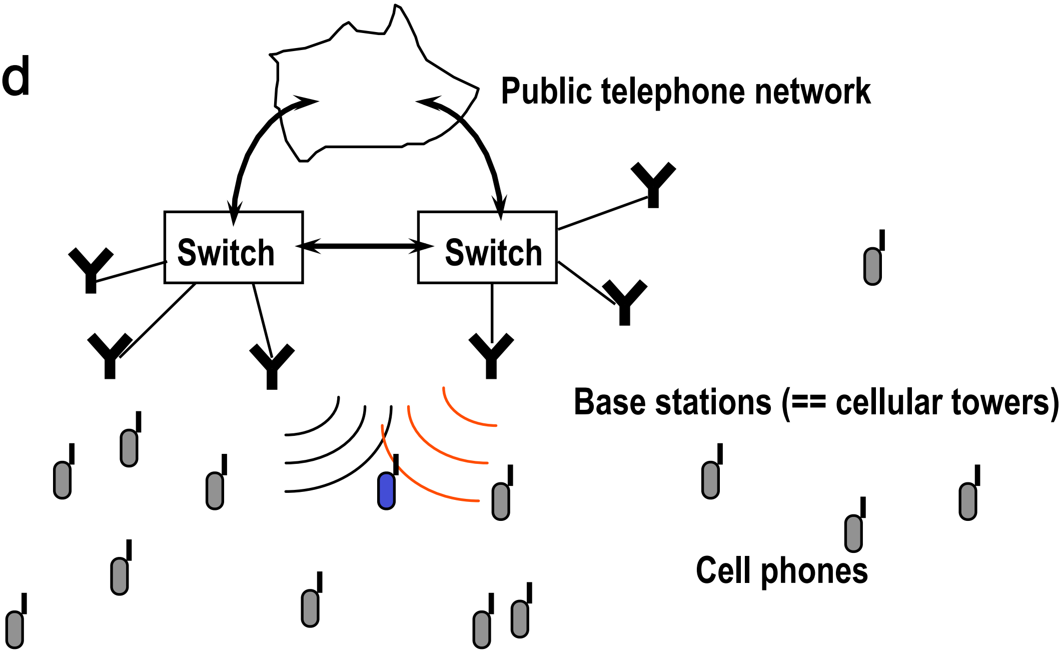
- **receiver demodulates to recover the information**
  - received signal strength varies directly with power level, and decreases with square of distance ("inverse square law")
  - higher frequencies (shorter wavelengths) go shorter distances, penetrate obstacles less well

Cell phones 101

- all phones are part of the public switched telephone network
- a cell phone is connected by radio instead of wires

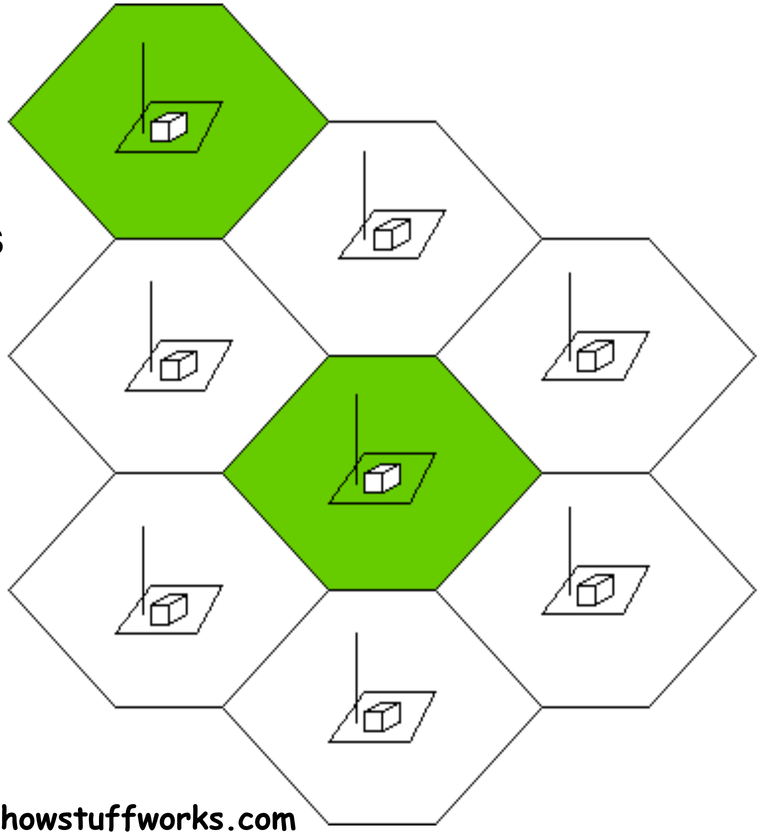
- moves long distances, at high speed, appears out of nowhere
- shares a very limited radio frequency spectrum with others
- operates with low power because it uses batteries

- this makes life complicated



Cells (a very idealized and over-simplified picture)

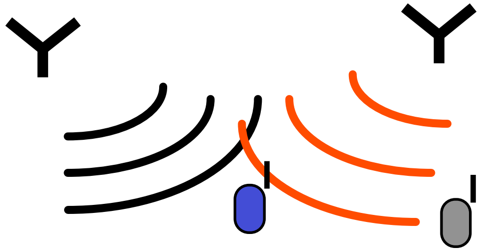
- divide geographical area into cells (notionally hexagonal)
- each cell has an antenna, handles all cell phones in its area
- available radio spectrum is divided into channels
  - two channels for one conversation, one for each direction (usually)
  - competing carriers operate on different frequency bands
- each cell gets 1/7 of the channels
  - adjacent cells can't use the same channels because of interference
  - non-adjacent cells can re-use channels



from www.howstuffworks.com

How it works

- when a phone is turned on, it broadcasts its ID ("registration")
  - nearest base station notices, validates with home system
    - registration uses encryption for fraud prevention
  - phone keeps broadcasting enough to keep in touch
- when the phone is called, the home system knows where it is
  - home system contacts base(s) where phone is
  - bases broadcast to where phone was last seen ("paging")
- phones talk to base with strongest signal
  - base and phone communicate over 2 agreed-upon channels (up, down)
  - phones continuously adjust power level to signal strength at base
    - uses less battery, creates less interference for other phones
- phones move from base to base and from system to system
  - base initiates handoff when signal gets weak
  - phone picked up by base with strongest signal
  - elaborate protocols at all levels



How it works, continued

- multiple frequency bands (different in different parts of the world)
  - divided into channels (frequency multiplexing)

    most phones use IP packets (4G LTE)
  - phones support multiple bands

    may use multiple frequency bands concurrently (5G)

- channels carry both voice and control information (including data)
  - digital speech is highly compressed (~1 bit/speech sample)
  - elaborate coding & error correction for speech & control information
  - power turned off when nothing is being sent

- phone stores user info on SIM card
  - SIM == Subscriber Information Module (flash memory)
  - may be able to replace card to use in a different environment

- IMEI (intl mobile eqpt id) is specific to phone: dial `*#06#`

Mobile phone generations

- technology "generations" are roughly 10 years long
  - lots of overlap in deployed systems
- 3G (~2000)
  - going, going, gone...
- 4G (~2010)
  - typical frequency bands 800-900 MHz, 1700-1900 MHz, 2.5 GHz, 5 GHz
  - supports 100 Mbps moving, 1 Gbps stationary (in theory)
  - 4G LTE ("Long-term evolution")

    a roadmap for evolution from 3G to 4G; a plan, not a strict definition
- 5G (~2020)
  - up to three bands, one of which is very high frequency (25-40 GHz)
  - similar to 4G for normal use
  - higher bandwidth (at short distances), up to 10 Gbps, mainly for data
  - higher density of devices supported (IoT) but at short ranges

Wi-fi

- Wi-Fi: a trademark of the Wi-Fi Alliance
  - 800+ companies
- uses IEEE 802.11 family of standards / protocols
  - standards for speeds, modulation techniques, ...
- usually uses 2.4 GHz or 5 GHz frequency bands
  - subdivided into20 MHz sub-channels
- bandwidth varies widely
  - 0.5 Gbps to 10 Gbps for 802.11ax
- unique 48-bit MAC address for each wi-fi device
  - just like Ethernet

Bluetooth

- short-range (10-100 m) low power (1 mw) wireless
- 2.402 GHz to 2.480 GHz

- used for
  earbuds, speakers
  keyboards, mice
  watches
  game consoles
  in-car systems
  ...

Harald Bluetooth
King of Denmark
958-986

GPS (Global Positioning System)

- **31 satellites, each broadcasting time & its location**
  - altitude ~ 20 km, frequency ~ 1575 MHz
  - at least 6 are visible at any time

- **receiver calculates its position using distances to 3 or more satellites**
  - distances computed by careful measurement of time
  - accuracy typically within 15 m for civilian systems
  - additional inputs or use of encrypted info reduces this to < 1 m

- **GPS is 1-way, passive**

Location services for phones

- cell phones know approximate location by triangulation on base station signals, within about 125 meter radius

- cell phones have GPS receivers so position is known within about 5 to 10 meters
  - this can be augmented with ground-based signals, incuding wi-fi
  - the result is a very accurate computation of phone's location

- the phone knows the accurate location and reports it back to the carrier
  - and potentially lots of others

- if "location services" is turned on, location is available to apps as well

Technology meets politics

- should texting while driving be illegal (and enforced)?
  - how about just talking on a phone while driving? (Walking? Self-driving car?)
- who determines where cell phone towers are permitted?
  - property rights versus eminent domain
- should cell phone jammers in be legal in theaters, trains, etc.?
- should StingRay devices be legal?
- location tracking and surveillance
  - who can have access to what phone records under what circumstances?
  - FCC mandates that cell phones can be located within 125 meter radius
  - should real-time location info be available to law enforcement, etc.?
- should you be forced by law enforcement to unlock your phone?
- under what circumstances?
  - e.g., is entering the country different from a traffic stop?
  - what information can they access?
- should end-to-end encrypted systems like Signal be regulated?
- how about end-to-end encrypted mail?