Lecture 22
Wireless systems

Wireless systems

- includes issues of
  - hardware
    processors, storage, peripherals, networks, ...
    representation of information, analog vs. digital, bits & bytes
  - software
    applications, operating system
    organization of information, file systems, ...
    algorithms: searching, sorting, compression
  - communications,
    Internet, Web, TCP/IP, protocols
    bandwidth, speed, caching
    compression, error detection and correction
  - security and privacy; cryptography
  - intellectual property and ownership
  - social & legal & policy concerns

Wireless systems (2)

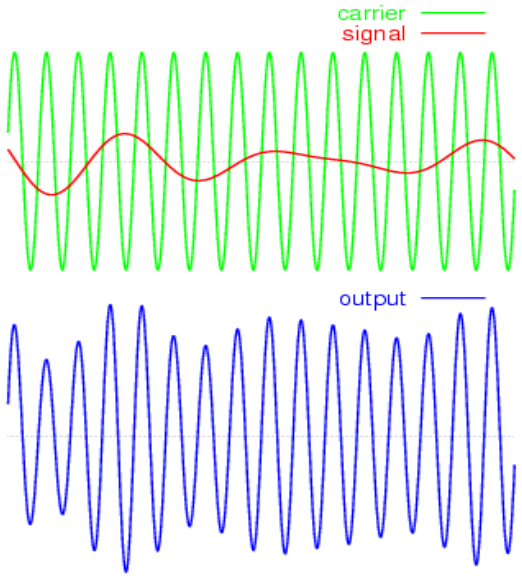
- how radio works
- radio spectrum allocation
- examples if wireless systems
  - cell phones
  - Wi-Fi
  - Bluetooth
  - RFID: prox cards, E-ZPass, store tags, passports, ...
  - GPS

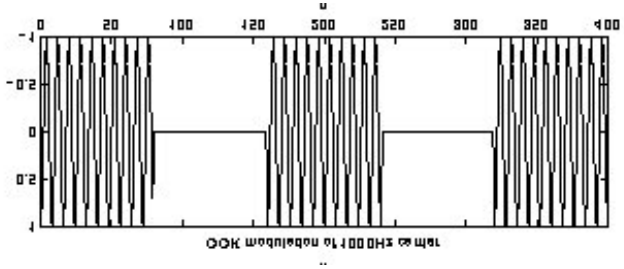
- tradeoffs
  - spectrum, power, range, size, weight, mobility

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

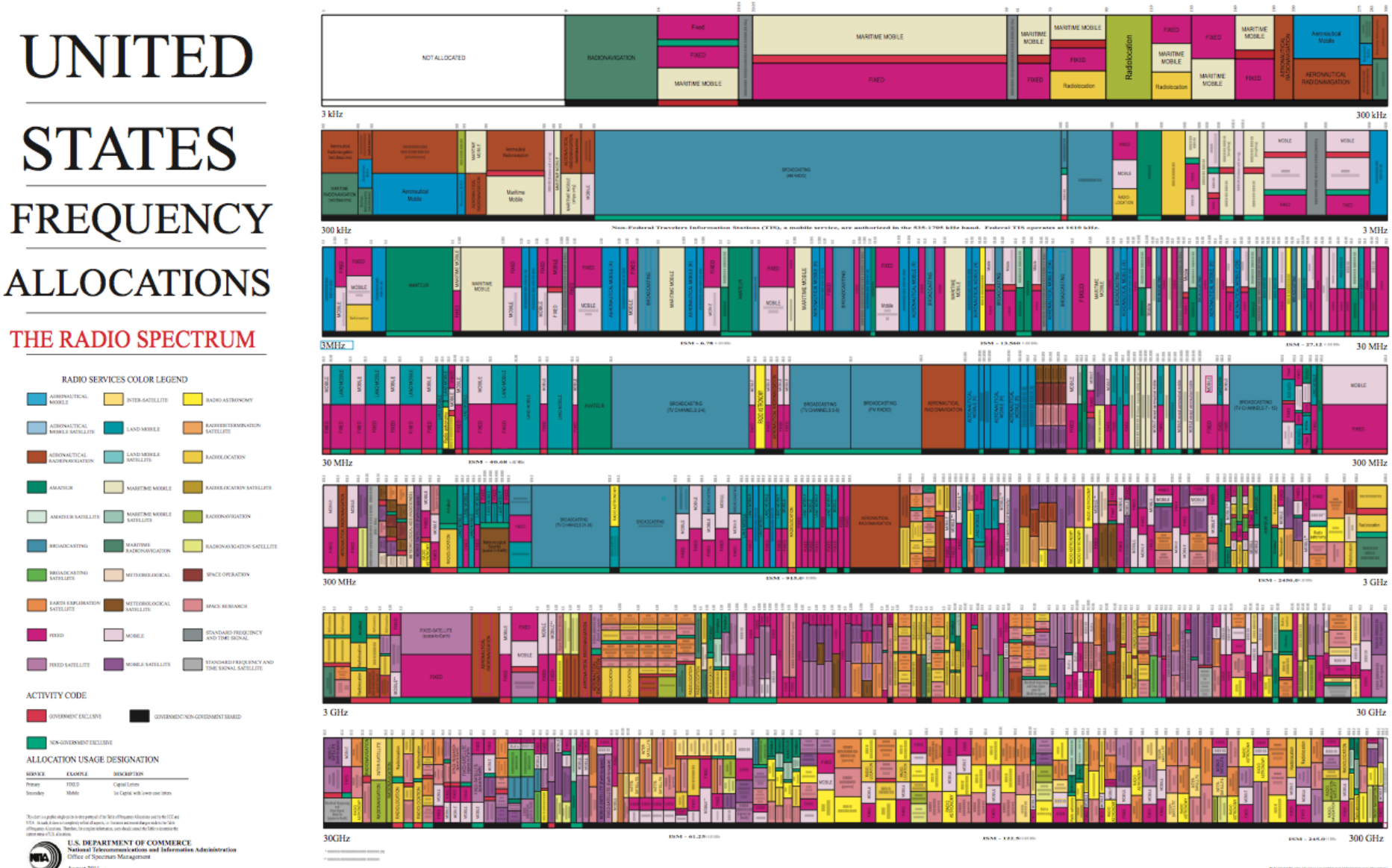
Radio

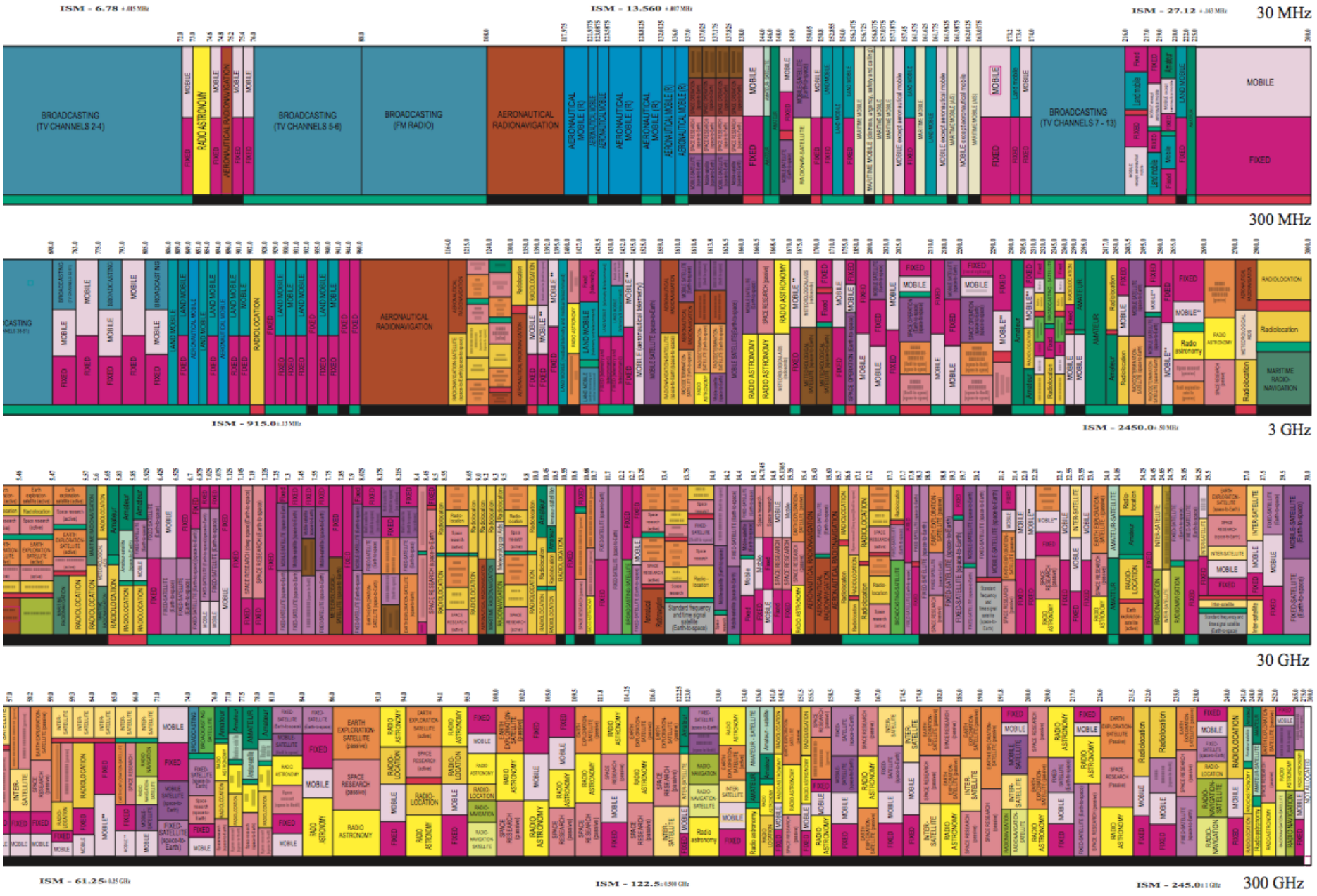
- electromagnetic radiation to carry information
  - without wires => "wireless"
- radiation is a wave of a particular frequency (in Hz)
- transmitter "modulates" the wave to impose information on it
  - amplitude (AM): change the power level
  - frequency (FM): change the frequency around a central 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")
  - higher frequencies (shorter wavelengths) go shorter distances, penetrate obstacles less well





RF spectrum


UNITED
STATES
FREQUENCY
ALLOCATIONS
THE RADIO SPECTRUM
RADIO SERVICES COLOR LEGEND
ACTIVITY CODE
GOVERNMENT EXCLUSIVE
GOVERNMENT/NON-GOVERNMENT SHARED
NON-GOVERNMENT EXCLUSIVE
ALLOCATION USAGE DESIGNATION
U.S. DEPARTMENT OF COMMERCE
National Telecommunications and Information Administration
Office of Spectrum Management
August 2011
NOT ALLOCATED
RADIONAVIGATION
Fixed
FIXED
MARITIME MOBILE
Radiolocation
Aeronautical Mobile
AERONAUTICAL RADIONAVIGATION
3 kHz
300 kHz
3 MHz
30 MHz
300 MHz
3 GHz
30 GHz
300 GHz

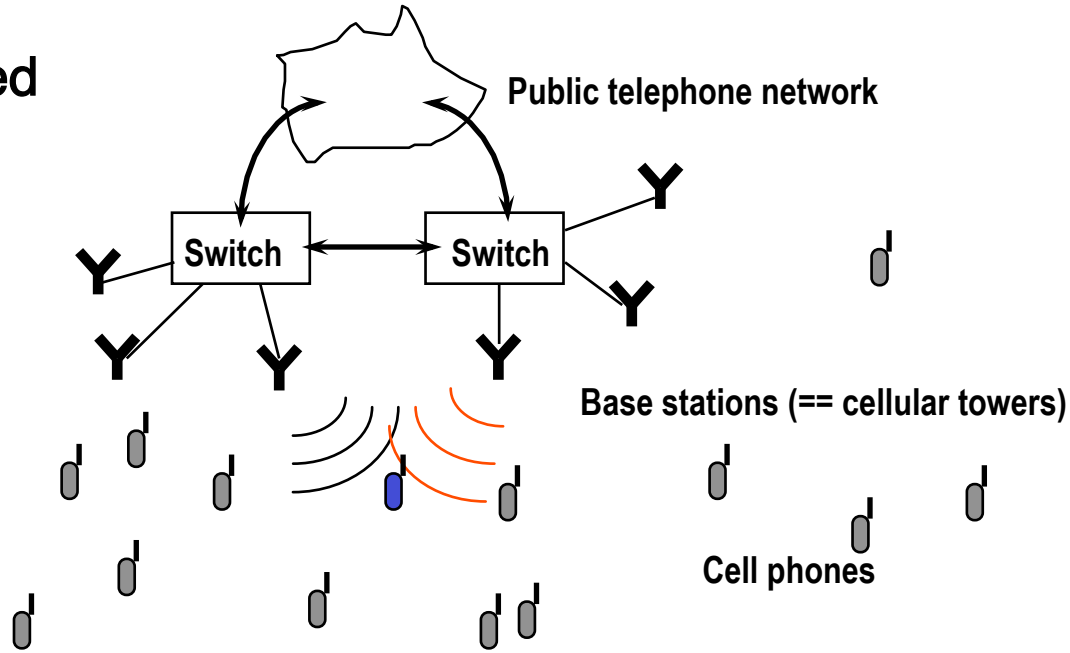

ISM – 6.78 ±.015 MHz
ISM – 13.560 ±.007 MHz
ISM – 27.12 ±.163 MHz
30 MHz
300 MHz
ISM – 915.0 ±.13 MHz
ISM – 2450.0 ±.50 MHz
3 GHz
30 GHz
ISM – 61.25 ±0.25 GHz
ISM – 122.5 ±0.500 GHz
ISM – 245.0 ±1 GHz
300 GHz

Cell phones 101

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

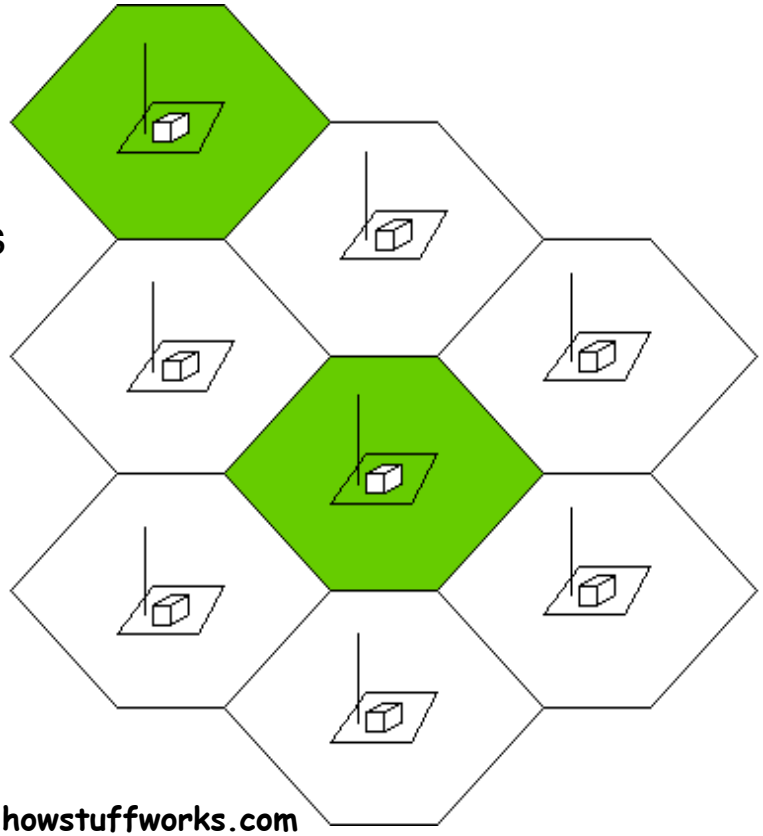
- moves long distances, at high speed, appears out of nowhere
- shares a very limited radio frequency spectrum with others
- operates with low power because it uses batteries

- this makes life complicated



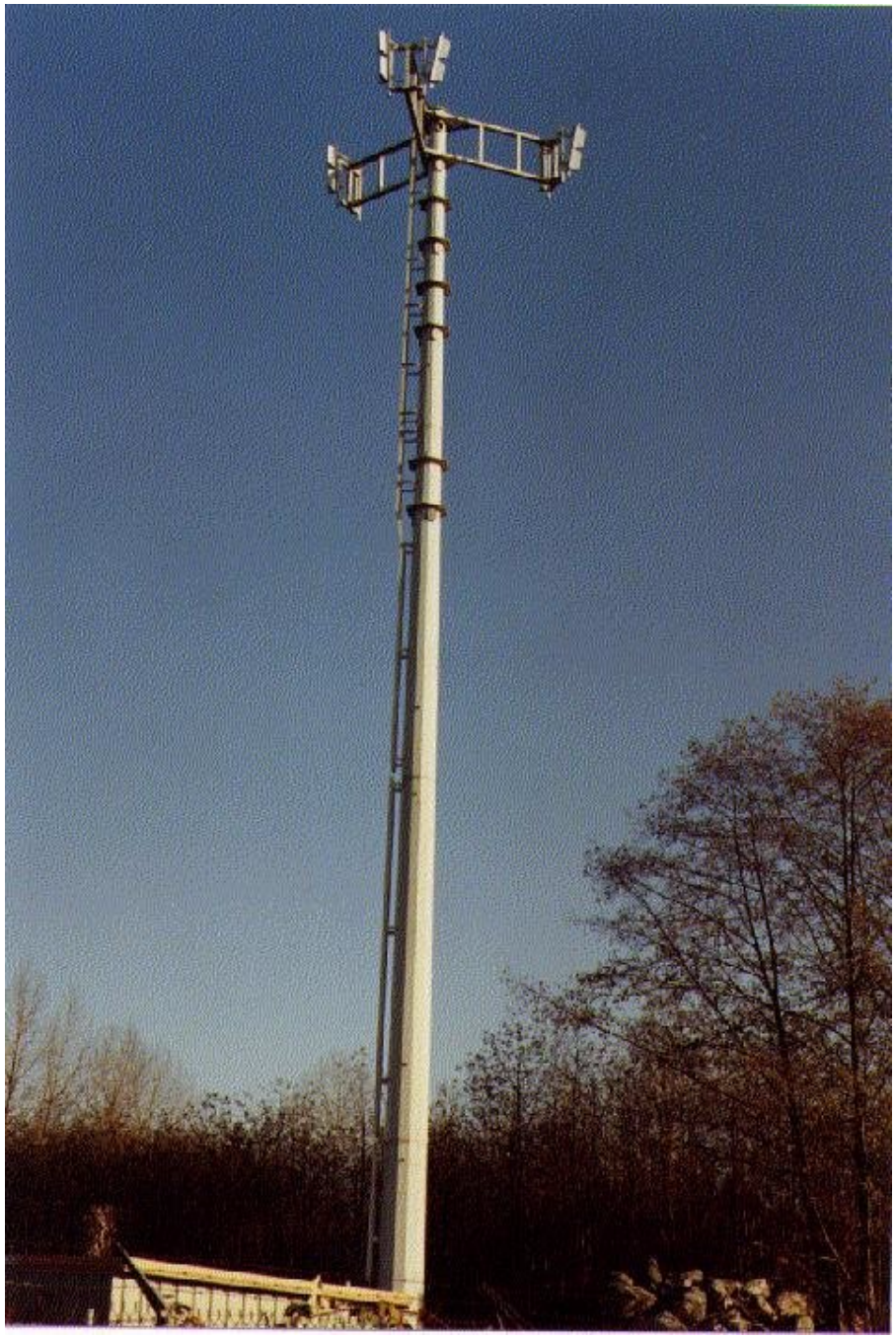
Cells (a very idealized and over-simplified picture)

- 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
  - competing carriers operate on different frequencies
- 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



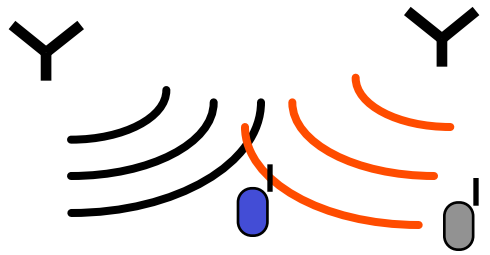
from www.howstuffworks.com

Not in my back yard!



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)
    digital phones multiplex several calls on one channel (GSM)
    or spread calls out over the whole spectrum (CDMA)
  - phones usually support multiple bands
    may use mulltiple 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 (usually removable) SIM card
  - SIM == Subscriber Information Module(flash memory)
  - may be able to replace card to use in a different environment

Mobile phone jargon

- technology "generations" are roughly 10 years long
  - lots of overlap in deployed systems
- 3G (~2000)
  - on the way out
- 4G (~2010)
  - typical frequency bands 800-900 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 (primarily at very short distances), up to 10 Gbps
  - higher density of devices supported (IoT) but at short ranges

Bluetooth

- short-range (10-100 m) low power (1 mw -> 1 m) 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

RFID, Near-field

- radio-frequency identification

- short range radio
  - usually passive system

- prox cards
- passports
- E-Zpass and similar toll system

- Near-field
  - about 4-5 cm range
  - contactless payment: cellphone to payment system
  - less range than Bluetooth but generally less power needed

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

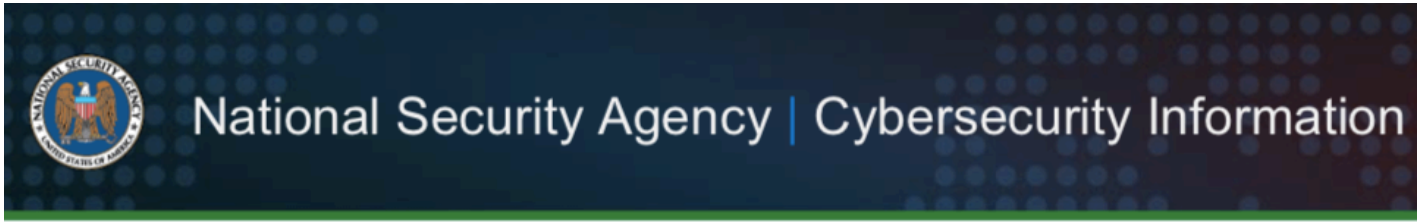
Location services for phones

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

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

- *the phone knows the accurate location and reports it back to carrier*

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



Limiting Location Data Exposure

(August, 2020)

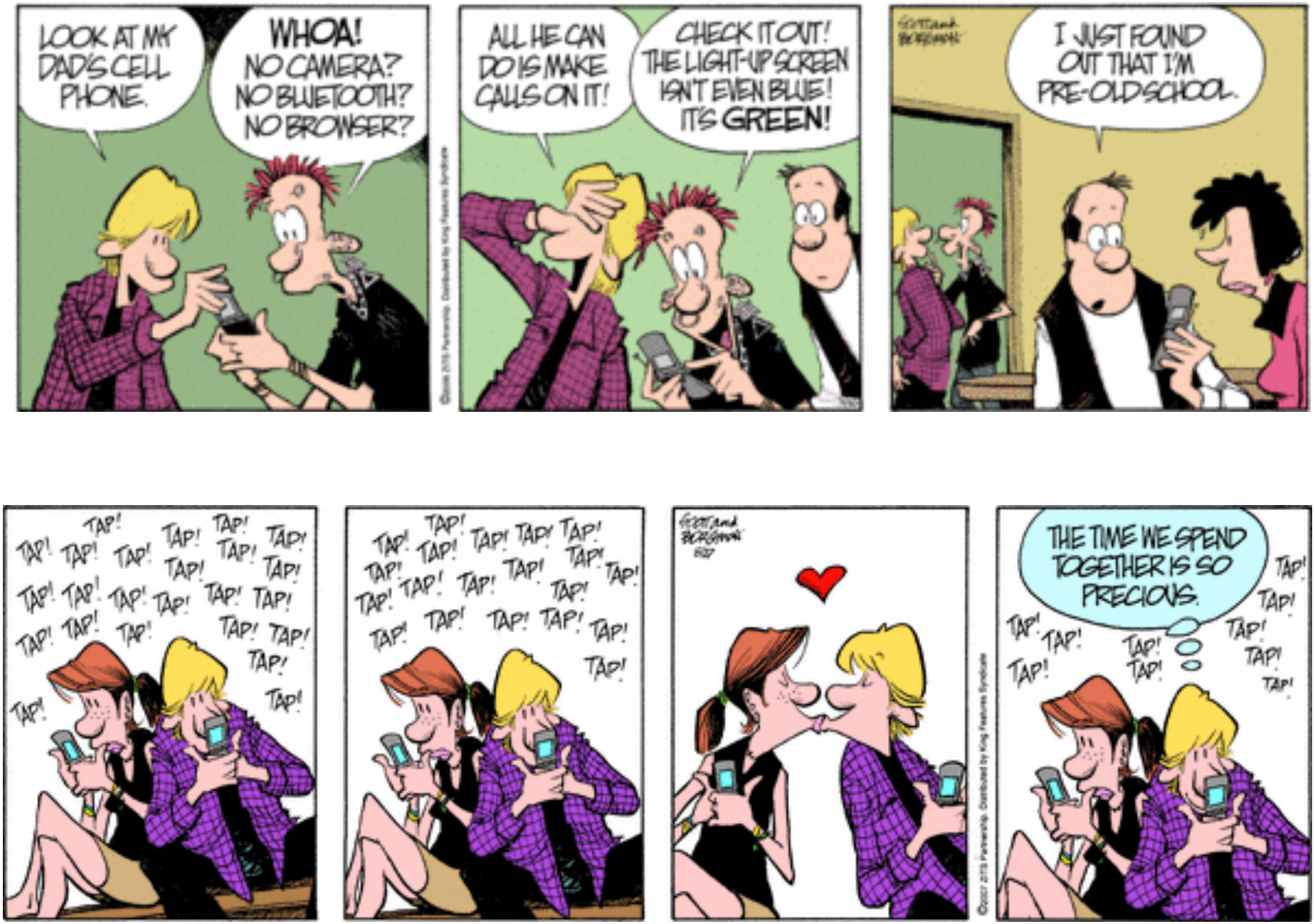
A mobile device provides geolocation data as a service to apps. This is known as location services, and users can disable them in the settings of a device. Perhaps the most important thing to remember is that disabling location services on a mobile device does not turn off GPS, and does not significantly reduce the risk of location exposure. Disabling location services only limits access to GPS and location data by apps. It does not prevent the operating system from using location data or communicating that data to the network.

Also important to remember is that GPS is not the same as location services. Even if GPS and cellular data are unavailable, a mobile device calculates location using Wi-Fi and/or BT. Apps and websites can also use other sensor data (that does not require user permission) and web browser information to obtain or infer location information.

Technology meets politics again

- should texting while driving be illegal (and enforced)?
  - how about just talking on a phone while driving? (Walking?)
- who determines where cell phone towers are permitted?
  - property rights versus eminent domain
- should cell phone jammers be legal?
  - in theatres, trains, etc.
- should StingRay devices be legal?

- location tracking and surveillance
  - FCC mandates that cell phones can be located within 125 meter radius
  - should real-time location info be available to law enforcement, etc.?
  - how should this evolve as GPS becomes universally available?
  - who can have access to what phone records under what circumstances?


LOOK AT MY DAD'S CELL PHONE.
WHOA! NO CAMERA? NO BLUETOOTH? NO BROWSER?
ALL HE CAN DO IS MAKE CALLS ON IT!
CHECK IT OUT! THE LIGHT-UP SCREEN ISN'T EVEN BLUE! IT'S GREEN!
I JUST FOUND OUT THAT I'M PRE-OLDSCHOOL.
TAP!
THE TIME WE SPEND TOGETHER IS SO PRECIOUS.