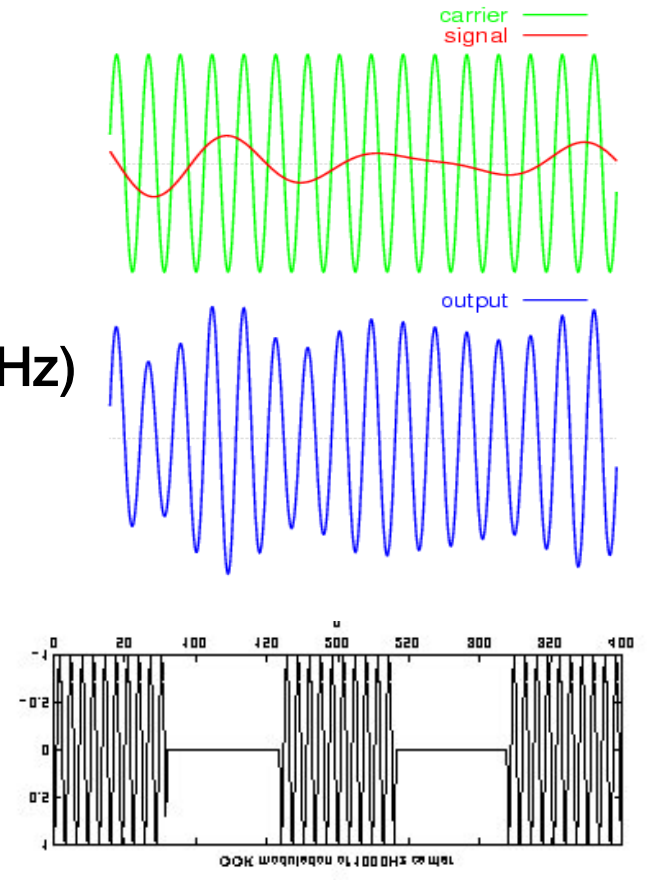


# Lecture 22: Wireless systems

- **how radio works**
- **radio spectrum allocation**
- **examples of 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**
  - privacy, security, regulation, competition, ...

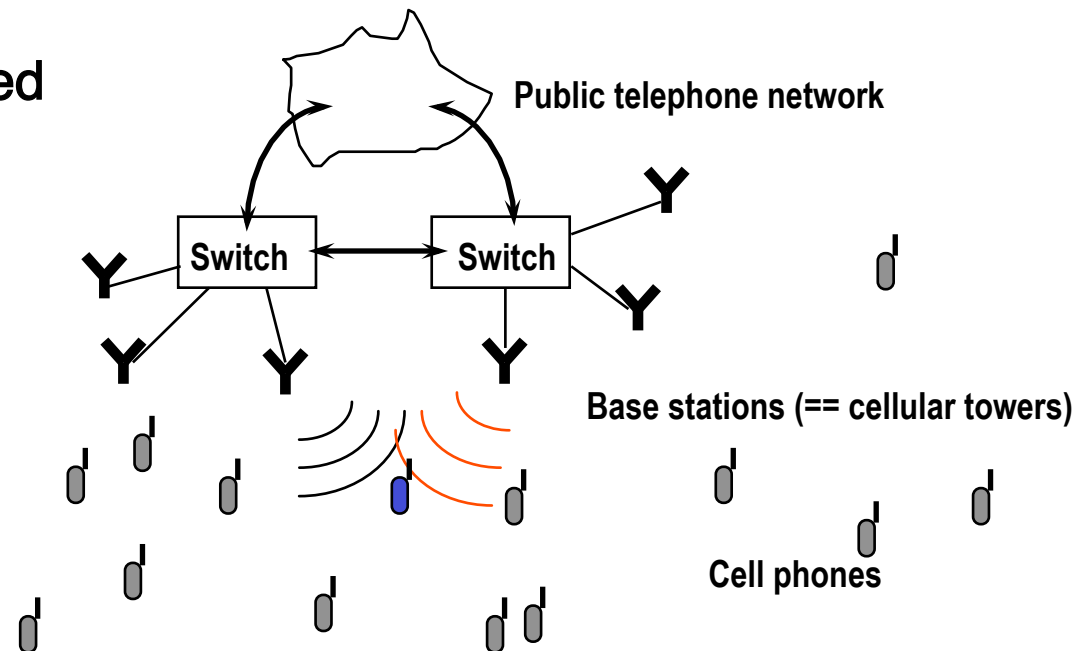
# Radio

- 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")
  - higher frequencies (shorter wavelengths) go shorter distances, penetrate obstacles less well



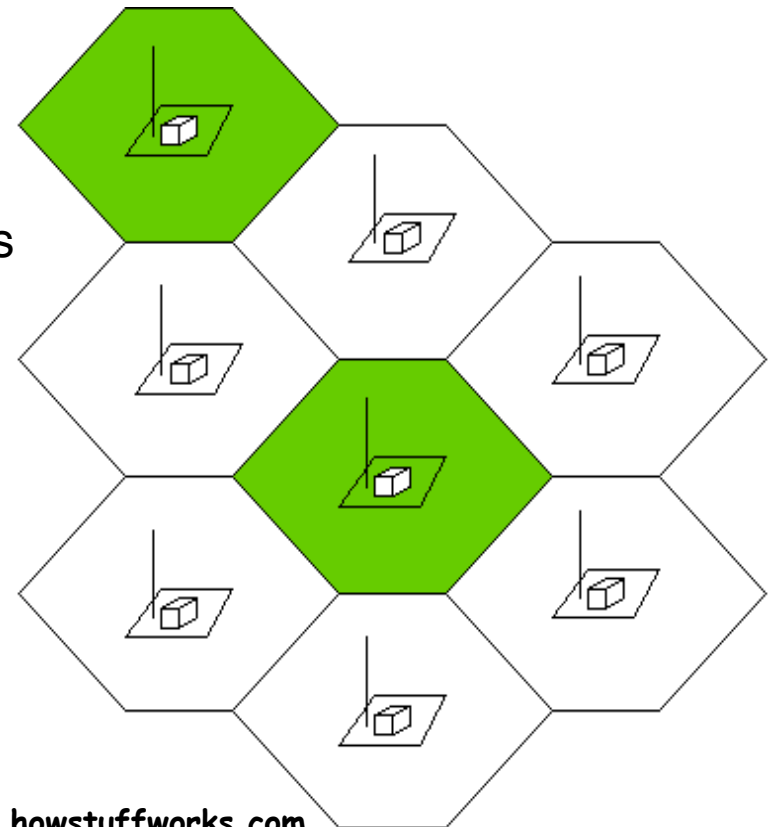
# Cell phones 101

- 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)

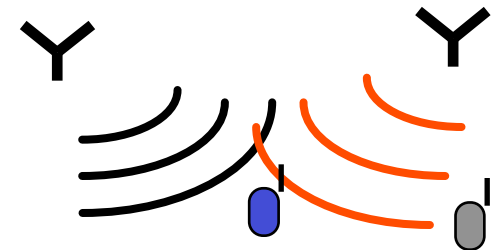
- divide geographical area into cells (notionally hexagonal)
- each cell has an antenna, handles all cell phones in its area
- available radio spectrum is divided into channels
  - two channels for one conversation, one for each direction
  - competing carriers operate on different frequency bands
- 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](http://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)
    - 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 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 (usually removable) SIM card**
  - SIM == Subscriber Information Module (flash memory)
  - may be able to replace card to use in a different environment

# Mobile phone generations

- **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, 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

# 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





# RFID, Near-field

- radio-frequency identification
- short range radio
  - usually passive system
- prox cards
- passports
- E-Zpass and similar toll systems
- near-field communication (NFC)
  - about 4-5 cm range
  - contactless payments: cellphone to payment system
  - shorter range than Bluetooth but 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
- **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, including 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?**