# Presentation Outline

- Historical Overview
- **Radio Fundamentals**
- US Developments in PCS
- Mobile Data
- Satellite Systems
- Problems with existing schemes
- Wireless Overlay Networks
- US Government Research Initiatives

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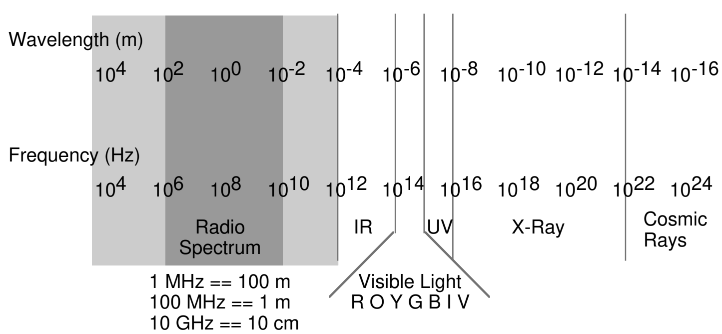
# Radio Basics




| | |
|---|---|
| < 30 KHz | VLF |
| 30 - 300 KHz | LF |
| 300 KHz - 3 MHz | MF |
| 3 - 30 MHz | HF |
| 30 - 300 MHz | VHF |
| 300 MHz - 3 GHz | UHF |
| 3 - 30 GHz | SHF |
| > 30 GHz | EHF |

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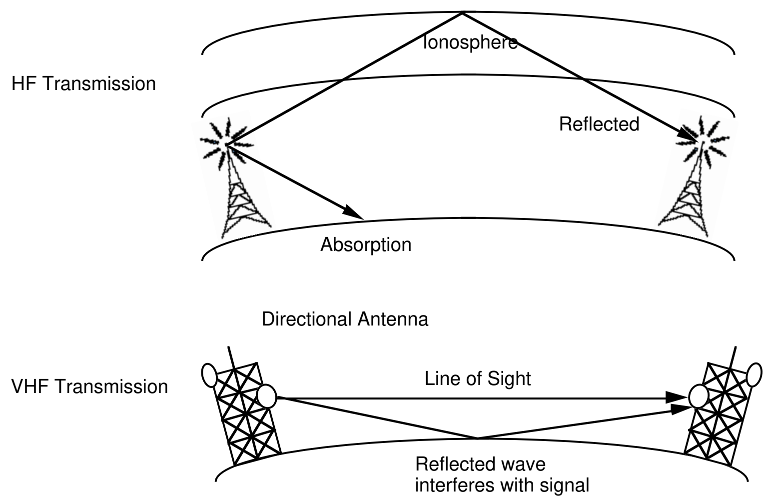
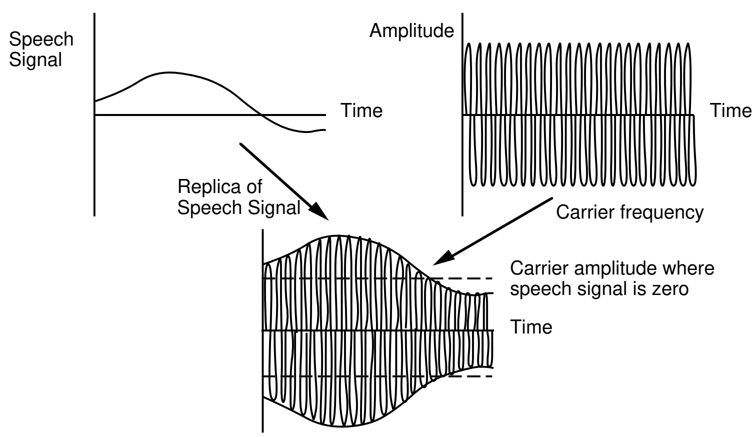
# Radio Basics





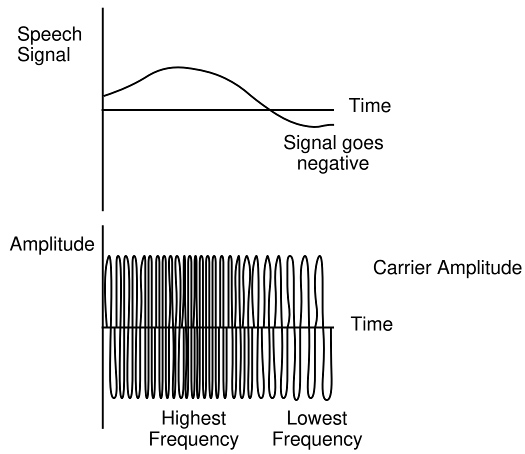

# Radio Basics

## Amplitude Modulation (AM)



# Radio Basics

## Frequency Modulation (FM)






# Digital Modulation Techniques

- **Carrier wave s:**
  - **$s(t) = A(t) * \cos[\Theta(t)]$**
  - **Function of time varying amplitude A and time varying angle $\Theta$**
- **Angle $\Theta$ rewritten as:**
  - **$\Theta(t) = \omega_0 + \varphi(t)$**
  - **$\omega_0$ radian frequency, phase $\varphi(t)$**
- **$s(t) = A(t) \cos[\omega_0 t + \varphi(t)]$**
  - **$\omega$ radians per second**
  - **relationship between radians per second and hertz**
    - » $\omega = 2 \pi f$

# Digital Modulation Techniques

- **Demodulation**
  - Process of removing the carrier signal
- **Detection**
  - Process of symbol decision
  - Coherent detection
    - » Receiver users the carrier phase to detect signal
    - » Cross correlate with replica signals at receiver
    - » Match within threshold to make decision
  - Noncoherent detection
    - » Does not exploit phase reference information
    - » Less complex receiver, but worse performance

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# Digital Modulation Techniques

| Coherent | Noncoherent |
|---|---|
| Phase shift keying (PSK) | FSK |
| Frequency shift keying (FSK) | ASK |
| Amplitude shift keying (ASK) | Differential PSK (DPSK) |
| Continuous phase modulation (CPM) | CPM |
| Hybrids | Hybrids |

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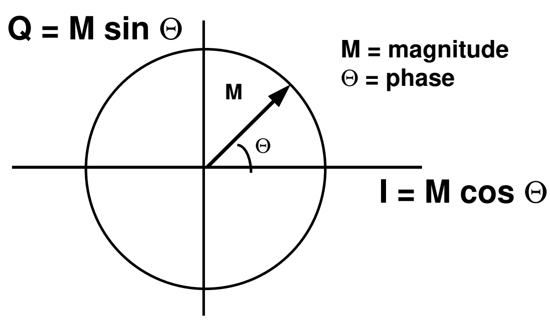
# Digital Modulation Techniques

- Modify carrier's amplitude and/or phase (and frequency)
- Vector notation/polar coordinates:

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# Considerations in Choice of Modulation Scheme

- High spectral efficiency
- High power efficiency
- Robust to multipath effects
- Low cost and ease of implementation
- Low carrier-to-cochannel interference ratio
- Low out-of-band radiation
- Constant or near constant envelope
  - Constant: only phase is modulated
  - Non-constant: phase and amplitude modulated

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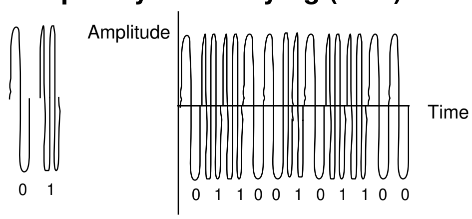
# Binary Modulation Schemes

- **Amplitude Shift Keying (ASK)**
  - Transmission on/off to represent 1/0
  - Note use of term “keying,” like a telegraph key
- **Frequency Shift Keying (FSK)**
  - 1/0 represented by two different frequencies slightly offset from carrier frequency

**Frequency Shift Keying (FSK)**

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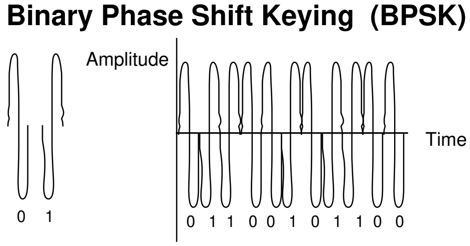
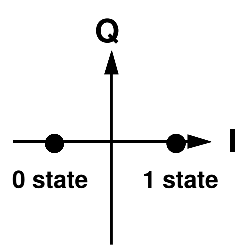
# Phase Shift Keying

- **Binary Phase Shift Keying (BPSK)**
  - Use alternative sine wave phase to encode bits
  - Simple to implement, inefficient use of bandwidth
  - Very robust, used extensively in satellite communications

**Binary Phase Shift Keying (BPSK)**

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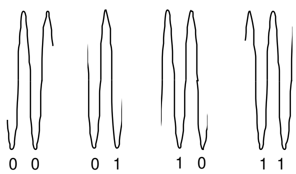
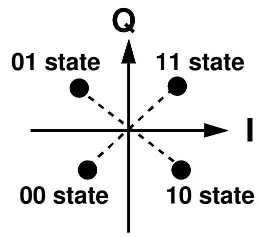
# Phase Shift Keying

- Quarternary Phase Shift Keying (QPSK)
  - Multilevel modulation technique: 2 bits per symbol
  - More spectrally efficient, more complex receiver

Quarternary Phase Shift Keying (QPSK)

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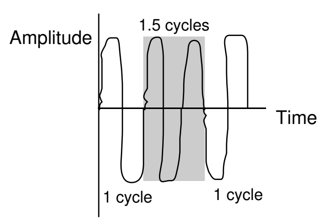
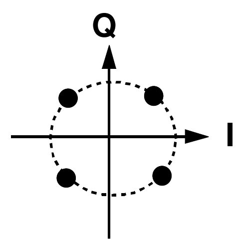
# Minimum Shift Keying

- Special form of frequency shift keying
  - Minimum spacing that allows two frequencies states to be orthogonal
  - Spectrally efficient, easily generated

Minimum Shift Keying (MSK)

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# Gaussian Minimum Shift Keying (GMSK)

- MSK + premodulation Gaussian low pass filter
- Increases spectral efficiency with sharper cutoff
- Used extensively in second generation digital cellular and cordless telephone applications
  - GSM digital cellular: 1.35 bps/Hz
  - DECT cordless telephone: 0.67 bps/Hz
  - RAM Mobile Data

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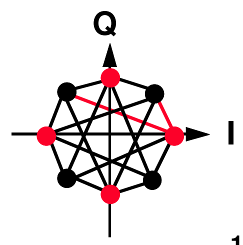
# $\pi$/4-Shifted QPSK

- Variation on QPSK
  - Restricted carrier phase transition to +/- $\pi$/4 and +/- $\pi$/4
  - Signaling elements selected in turn from two QPSK constellations, each shifted by $\pi$/4
- Popular in Second Generation Systems
  - North American Digital Cellular (IS-54): 1.62 bps/Hz
  - Japanese Digital Cellular System: 1.68 bps/Hz
  - European TETRA System: 1.44 bps/Hz
  - Japanese Personal Handy Phone (PHP)

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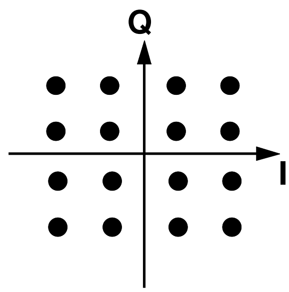
# Quadrature Amplitude Modulation

- **Quadrature Amplitude Modulation (QAM)**
  - Amplitude modulation on both quadrature carriers
  - $2^n$ discrete levels, n = 2 same as QPSK
- **Extensive use in digital microwave radio links**




16 Level QAM

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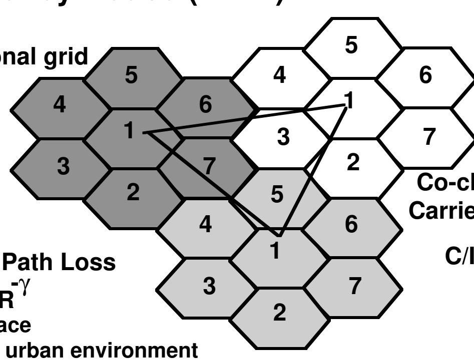
# Cellular Concept

- **Frequency Reuse (N = 7)**

Ideal hexagonal grid




Co-channel Interference
Carrier-Interference Ratio

$$C/I = \frac{1}{\sum_{k=1}^{N} \left[\frac{D_k}{R}\right]^{-\gamma}}$$

Reuse Radius    Cell Radius

18 dB rule of thumb

Propagation Path Loss

$C \approx R^{-\gamma}$

$\gamma = 2$, free space

$\gamma = 5.5$, dense urban environment

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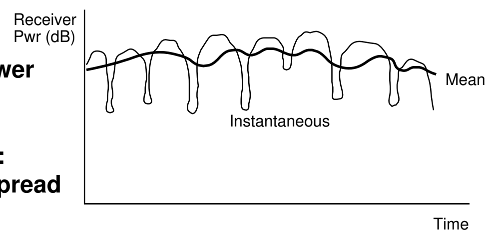
# Effect of Mobility on Communications Systems

- **Physical Layer**
  - Channel varies with user location and time
  - Radio propagation is very complex
    - » Multipath scattering from nearby objects
    - » Shadowing from dominant objects
    - » Attenuation effects
    - » Results in rapid fluctuations of received power

**Less variation the slower you move**

**For cellular telephony:**
**-30 dB, 3 $\mu$sec delay spread**

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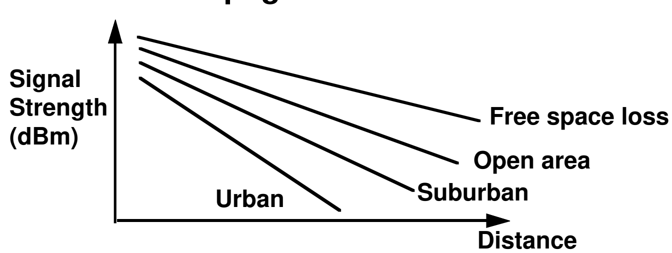
# Effect of Mobility on Communications Systems

- **Outdoor Radio Propagation**




**BER = $f$(signal stength)**

**Error rates increase as SNR decreases**

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# Effect of Mobility on Communications Systems

- **Indoor Propagation**
  - Signal decays much faster
  - Coverage contained by walls, etc.
  - Walls, floors, furniture attenuate/scatter radio signals
- **Path loss formula:**

  Path Loss = Unit Loss + 10 n log(d) = k F + l W

  where:

  Unit loss = power loss (dB) at 1m distance (30 dB)
  n = power-delay index (between 3.5 and 4.0)
  d = distance between transmitter and receiver
  k = number of floors the signal traverses
  F = loss per floor
  l = number of walls the signal traverses
  W = loss per wall

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# Outdoor Propagation Measurements

- **Urban areas**
  - RMS delay spread: 2 μsec
  - Min 1 μsec to max 3 μsec
- **Suburban areas**
  - RMS delay: 0.25 μsec to 2 μsec
- **Rural areas**
  - RMS delay: up to 12 μsec
- **GSM example**
  - Bit period 3.69 μsec
  - Uses adaptive equalization to tolerate up to 15 μsec of delay spread (26-bit Viterbi equalizer training sequence)

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## Outdoor-to-Indoor Measurements

- Penetration/“Building Loss”
  - Depends on building materials, orientation, layout, height, percentage of windows, transmission frequency
- Rate of decay/distance power law: 3.0 to 6.2, with average of 4.5
- Building attenuation loss: between 2 dB and 38 dB

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## Indoor Measurements

- Signal strength depends on
  - Open plan offices, construction materials, density of personnel, furniture, etc.
- Path loss exponents:
  - Narrowband (max delay spread < bit period)
    - » Vary between 2 and 6, 2.5 to 4 most common
    - » Wall losses: 10 dB to 15 dB
    - » Floor losses: 12 dB to 27 dB
  - Wideband (max delay spread > bit period)
    - » Delay spread varies between 15 ns and 100 ns
    - » Can vary up to 250 ns

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# Error Mechanisms

- **Error Burst**
  - Results of fades in radio channels
    - » Doppler induced frequency/phase shifts due to motion can also cause loss of synchronization
    - » Errors increase as bit period approaches delay spread
  - Region of consecutive errors followed by stream of consecutive error-free bits
    - » Voice communication: $10^{-3}$ BER, 1 error bit in 1000
    - » Data communications: $10^{-6}$ BER, 1 error in 1,000,000

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# Error Mechanisms

- **Average Duration of a Fade**

$$ADF = \frac{\sqrt{2\pi}\,[\,e^{R^2} - 1]}{\beta\, v\, R}$$

Fade depth (ratio of RMS in dB)

Depends on $f$    Speed of mobile (m/s)

- **Some examples:**
  - 900 MHz, 50 km/hr -- undergoes ave fade depth of 20 dB
  - ADF = 0.962 ms
  - 0.5 m/s, ADF becomes 26.7 ms
  - Portables reside in fades for much longer time periods
  - Renders FEC techniques inoperative

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# Error Mechanisms

- Strategies for Overcoming Errors
  - Antenna diversity (+10 dB)
    - » Dual antennas placed a $\lambda$ / 2 separation
  - Forward error correction (FEC)
    - » Improve fade margin through coding gain
    - » Coding gain = signal energy per bit-to-noise ratio required to attain a particular error rate with and without coding
    - » Not very effective in slowly varying radio channels
    - » Block vs. Convolutional Codes, Interleaved vs. Non-Interleaved
  - Automatic Repeat Request (ARQ)
    - » Retransmission protocol for blocks in error
    - » Stop and Wait, Go Back N, Selective Repeat

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# Effect of Mobility on Communications Systems

- Data Link Layer
  - Fading radio channels, characterized by burst errors
  - Reliable communications interrupted by fades
- Network Layer
  - Rerouting due to movement
- Presentation Layer
  - Source coding for better spectrum efficiency
- Application Layer
  - Location dependent applications

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# Media Access

- **Aloha**
  - Transmit when desired
  - Positive ACK from receiver on independent link
  - Back off and retransmit if timeout
  - Slotted scheme reduces chance of collision
- **Carrier Sense/Multiple Access (CSMA)**
  - Listen before transmit
  - Back off and retransmit if collision detected
- **Inhibit Sense/Multiple Access**
  - Base station transmits busy tone
  - Transmit when not busy
  - Back off and retransmit if collision

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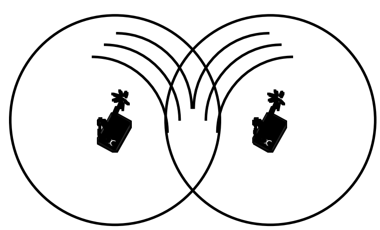
# Media Access

- **Hidden Terminals**
  - Cannot hear each other
  - Adds complexity to carrier sense methods



- **Near-Far Problem**
  - Near-by terminal over powers signal from the far-away terminal
  - Unfair access to channel

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# Time Division Multiple Access

- Multiple users share channel through time allocation scheme

| | | | | | | |
|---|---|---|---|---|---|---|
| 1 | 2 | ... | N | 1 | 2 | ... |

- Reuse in time, often combined with reuse in frequency (e.g., GSM, IS-54)

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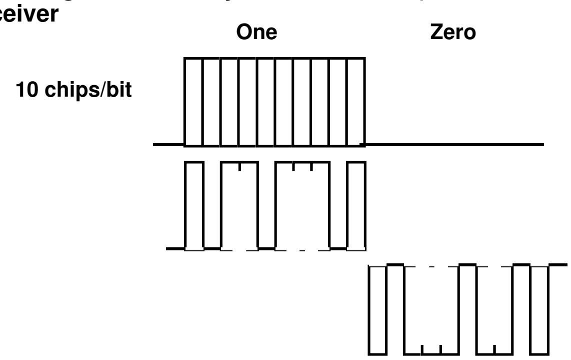
# Spread Sprectrum

- Direct Sequence SS
  - Bits sampled ("chipped") at higher frequency
  - Signal energy "spread" over wider frequency
  - Advantageous diversity recombination ("correlation") at receiver

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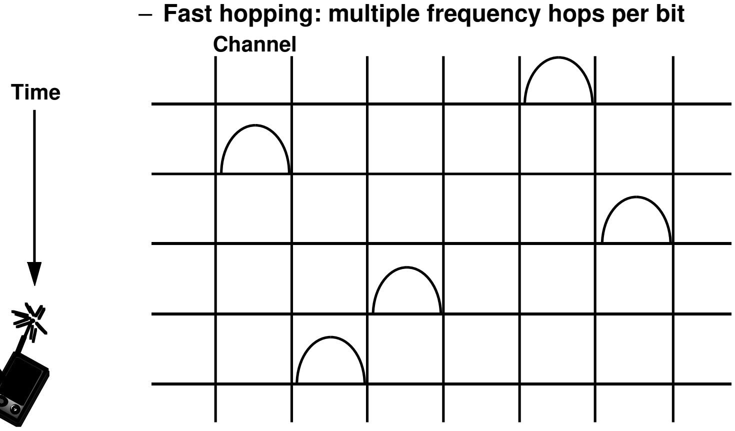
# Spread Spectrum

- Frequency Hopping SS
  - Slow hopping: multiple bits before frequency hop
  - Fast hopping: multiple frequency hops per bit

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# Code Division Multiple Access

- A strategy for multiple users per channel based on orthogonal spreading codes
- Multiple communicators simultaneously transmitting using direct sequence techniques, yet not conflicting with each other
- Developed by Qualcomm as IS-95
  - Special soft handoff capability

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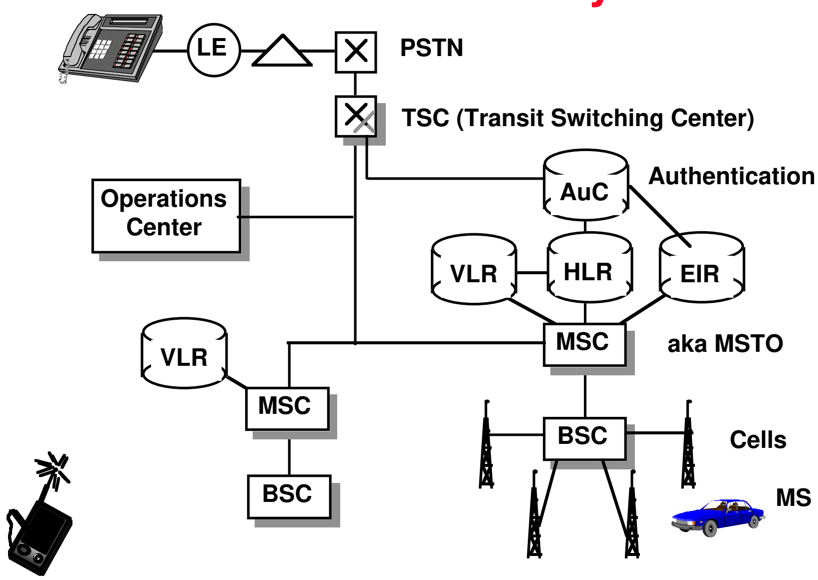
# Cellular Phone Systems

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# North American Analog Cellular System (AMPS)

Mobile XMIT

| Mobile XMIT | 824.04 | 825.03 | 835.02 | | 845.01 | 846.51 |
|---|---|---|---|---|---|---|
| | A' 33 CHs | A 333 Channels | A Cntl | B Cntl | B 333 Channels | A' 50 CHs | B' 83 CHs |
| Base XMIT | 869.04 | 870.03 | 880.02 | | 890.01 | 891.51 |

Base XMIT

416 30 KHz channels for each of two operators (B wireline)

Traffic Control Channels (TCH):
21 reserved control channels in each band

In-band Signaling Tones (e.g., disconnect, RTS dialed digits, Ack handoff order, Alert, measured in 50-1800 ms)

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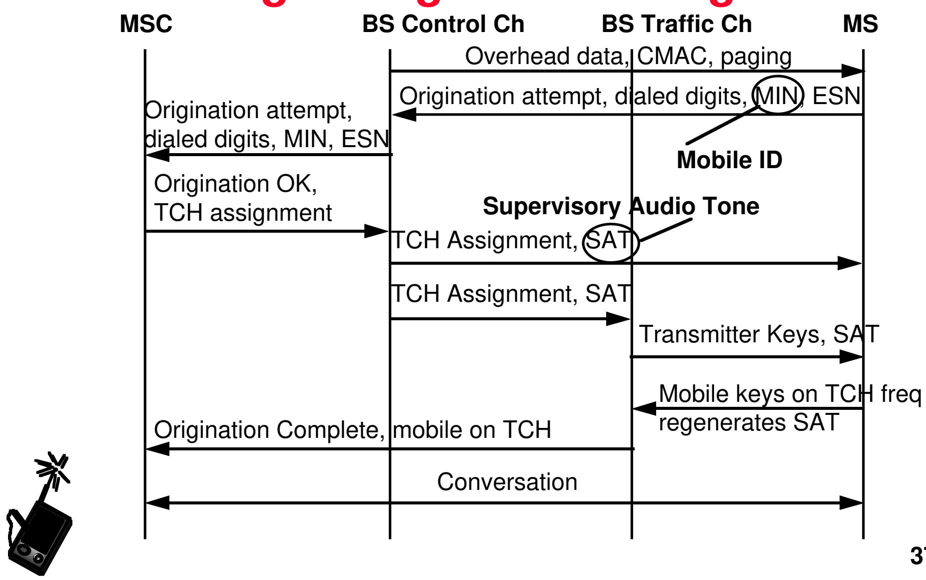
# AMPS Signalling: Mobile Origination

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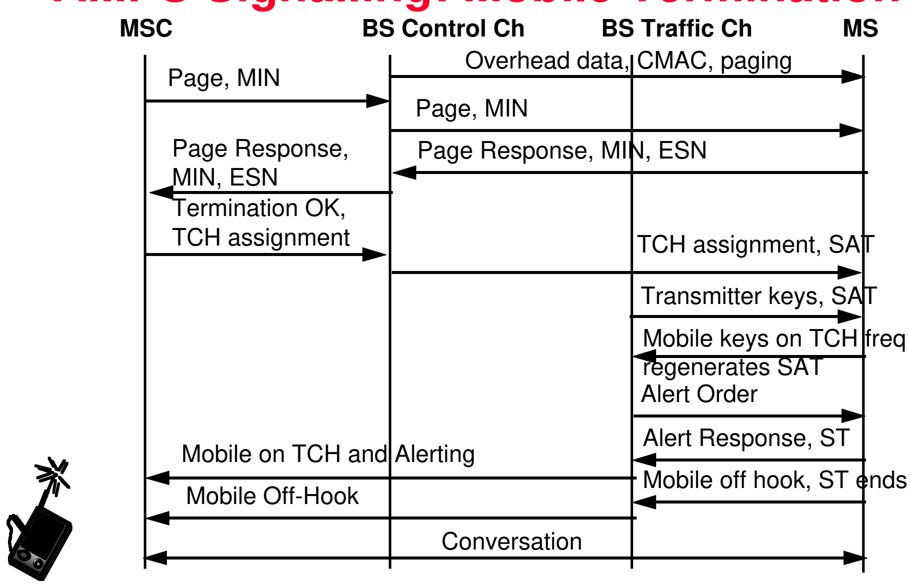
# AMPS Signalling: Mobile Termination

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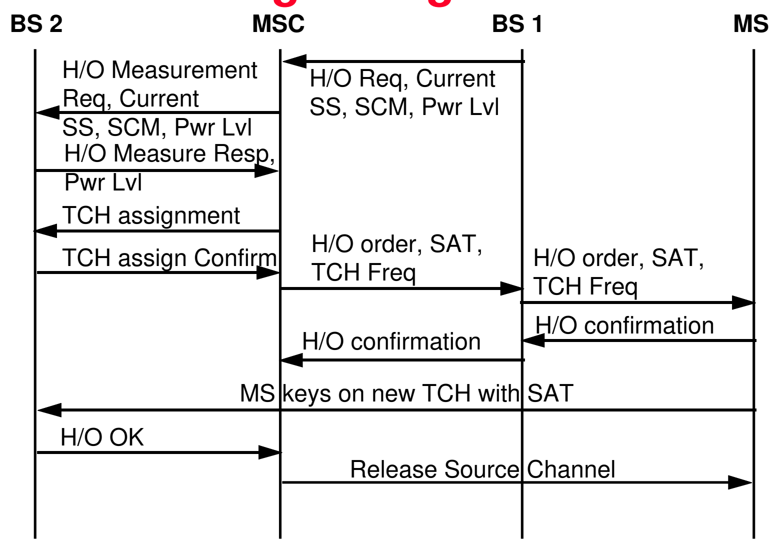
# AMPS Signalling: Handoff

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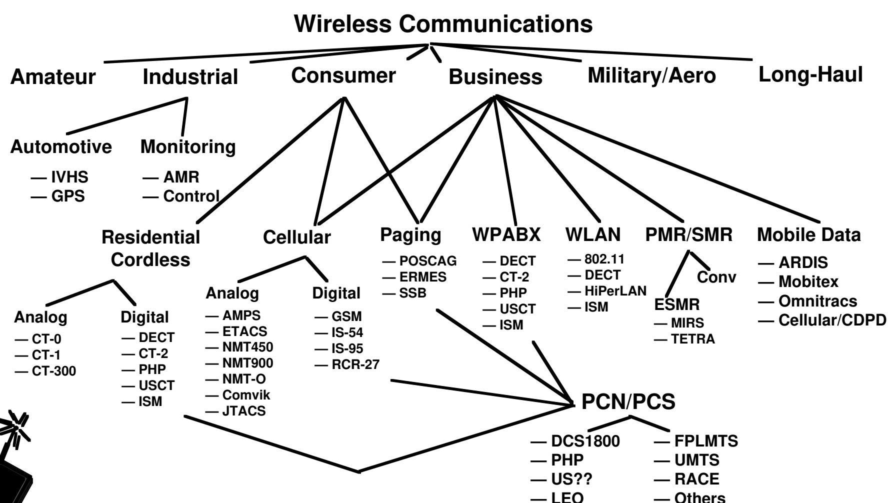
# The Wireless Universe

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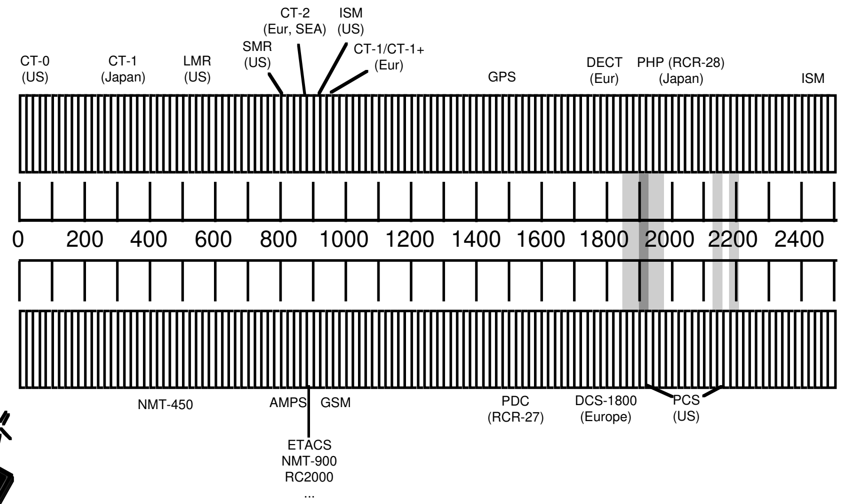
# Wireless Spectrum

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