Mobile communications

- Mobile communications is wireless – and almost all wireless communications is radio
- Wireless and radio basics: Electromagnetic waves, transmission, reception, bandwidth

EM waves and early radio

- Radio makes use of electromagnetic radiation propagating through free space
- James Clerk Maxwell showed that a changing electric field induces a changing magnetic field, and vice versa (circa 1861-73)
- Maxwell's Equations showed that electromagnetic waves, composed of changing electric and magnetic fields coupled with each other, can propagate in free space
- Heinrich Hertz devised the first experiment proving the existence of EM waves (1886) – a spark gap transmitter and receiver
- Hertz on the applications of EM waves: "It's of no use whatsoever"
- First uses of radio in communication: 1893-1895; various inventors (Tesla, Marconi, Popov)
- Basic radio system

(Fig. 1)

- transmitter induces alternating current in the transmitting antenna; antenna induces alternating magnetic field; EM wave propagates; EM wave induces alternating electric field in the receiving antenna; electric field induces alternating current in the receiver
- Alternation: Relatively high frequencies are needed

Signal transmission

(Fig. 2)

- f_c is the carrier frequency
- x(t) is a waveform to be transmitted (Baseband signal)
- Modulation: multiply by sinusoid at carrier frequency f_c
- i.e. boost frequency components

(Eq. 1)

Signal reception

(Fig. 3)

- y(t) is the current induced in the receiver antenna
- Amplification: $Ay(t) = x(t)\cos(2\pi f_c t)$
- Demodulation: multiplied by the same sinusoid

(Eq. 2)

- We now have x(t) and high-frequency components – lowpass filter to get rid of them
- And we have recovered x(t)
- **Noise:** The received signal y(t) might be extremely weak, so that the random thermal motions of electrons in the amplifier are significant by comparison
- These random motions introduce an additive, random noise term
- In fact the amplifier output is $x(t)\cos(2\pi f_c t) + n(t)$
- More about this later

Bandwidth

- Under the Fourier transform, x(t) can be represented as a collection of sinusoids: X(f) – can go back and forth between the two domains. (i.e., x(t) and X(f) are equivalent)
- The bandwidth of x(t) is the largest f such that X(f) is negligible
- Generally, larger bandwidth = more quickly changing signal = more information (Nyquist sampling)
- Telephone line: 8 kHz; CD-quality audio: 20 kHz; NTSC video: 6 MHz
- Let X(f) and X*(f) represent Fourier transforms of signals each with bandwidth B

(Fig. 4)

- modulate X(f) with carrier frequency f_c
- (example, for each f < B)
- modulate X*(f) with carrier frequency f_c+2B

(Fig. 5)

- Demodulate X(f) with frequency f_c – and lowpass filter
- Demodulate X*(f) with frequency f_c+2B – and lowpass filter

(Fig. 6)

- Thus two (or more) signals can share frequency space, as long as their bandwidth is finite

Wireless Spectrum

- The collection of all wireless devices in the world must work together to share all the available bandwidth (the wireless spectrum).
- The effectiveness of an antenna at a given frequency is highest if its length is proportional to the wavelength (usually $\lambda/4$ or $\lambda/2$), and $\lambda = c/f$ (c = speed of light = 3×10^8 m/s)
- E.g. f = 1 MHz, λ = 300 m; f = 100 MHz, λ = 3 m; f = 1 GHz, λ = 0.3 m
- This sets a practical limit on the lowest frequencies that are usable (also, less bandwidth is available)

- Atmospheric absorption limits the highest frequencies to around 300 GHz (contemporary applications do not go above 100 GHz) – beyond this is infrared