Lecture 1

Examples of Wireless Applications

- how many wireless communication applications can you list?
- why is wireless an advantage for these applications?
- what are some examples of wired communications systems? why *aren't* they wireless?

Advantages

- main advantages: mobility and wide-area broadcasting
- other?

Disadvantages

- cost
- limited spectrum
- security
- other?

Growth of Wireless

- microelectronics has driven the growth of wireless communications over last 30 years
- how many had a cell phone in your family 10 years ago? 5? 2? 1? now?

Important Cellular Standards

- AMPS ("Advanced Mobile Phone System). 1983. first-generation US analog cellular system. 850 MHz. FM. 30 kHz per channel.
- GSM (originally "Groupe Special Mobile"). 1990. most popular second-generation (digital) cellular system. developed in Europe. 900 MHz. GMSK. 200 kHz per 8 or 16 time slots. Also used in US at 1.9 GHz for PCS.
- IS-54 ("Digital AMPS"). 1991. US digital cellular standard. 850 MHz. $\pi/4$ DQPSK. 30 kHz per 3 time slots.
- IS-95 ("CDMA"). 1993. Qualcom's proprietary digital cellular standard. second-generation (digital) system. 850 MHz. QPSK/BPSK. 1.25 MHz for ? users (CDMA).
- PHS (Personal "Handyphone" System). 1993. low-cost, short-range Japanese digital cellular. 1.8 GHz. $\pi/4$ DQPSK. 300 kHz for ? users.
- IMT-2000/3GPP/CDMA-2000. 2002?. third-generation (digital) system, still in development stage. 1.9 GHz. BPSK/QPSK. 4 (?) MHz for ? users (W-CDMA).

Cordless Telephones

- household systems: "wireless extension cord"
- second-generation digital systems to allow mobility in workplace and public use with limited-coverage in urban areas
- low-power, outgoing calls only, no roaming, small cells, TDMA and TDD, low-cost
- CT-2 (cordless telephone standard #2): (UK "Rabbit", "Orange").
- DECT: (Digital European Cordless Telephone)

Paging

- simplex, digital
- high-power multicast transmitters
- FLEX: Motorola
- POCSAG: European

Terminology

- mobile - mobile radio user, typically attached to vehicle
- portable - mobile radio user, typically hand-held
- base - fixed radio terminal, typically in good (high) location and connected to wired network (PSTN
- cell - geographical area serviced by a base station
- simplex - communication in one direction only
- duplex, full-duplex - communication in both directions at same time
- half-duplex - communication in both directions, one direction at a time
- HLR - home location register, unique storage location for a user's authentication and billing information
- FDMA - frequency-division multiple access - bandwidth divided into channels by frequency
- TDMA - time-division multiple access - bandwidth divided into slots by time
- CDMA - code-division multiple access - bandwidth divided into codes by correlators
- FDD - frequency division duplex - different communication directions use different frequencies
- TDD - time division duplex - different communication directions use different time slots
- PSTN - public switched telephone network - the conventional public phone network
- backbone - the wired network
- forward channel - from base to mobile
- reverse channel - from mobile to base
- control channel - channel (time slot or channel) used to send control information (page a mobile, make a call, etc)
- traffic channel - channel used to send the user's voice or data
- RSSI - received signal strength indicator - circuit (or it's output) indicating the received signal strength
- roamer - mobile operating outside its normal service area
- handoff - command to mobile to use a base in another cell for its traffic channel
- MSC - mobile switching center - telephone switch that also controls base stations
- page - message to mobile that there is an incoming call (or containing message data for simplex pagers)
- transceiver - receiver/transmitter combination
- duplexer - device that allows transmitter and receiver to be connected to same antenna
- SMR - specialized mobile radio, private cellular network
- PCS - personal communication system/service - typically second-generation cellular-like services operating at 1.8 GHz, typically including enhanced network services (but many other meanings)
- FPLMTS/IMT-2000 - ITU standardization group trying to develop a standard for a 3-rd cellular system
- ANSI/IEEE/ETSI/ITU - other standards bodies
- LEO - low earth orbit, also the satellites providing cellular satellite service from these orbits

Wavelength

- propagation velocity: $c = 300$ m/μs
- wavelength: $\lambda = c/f = 300/f$ (f in MHz)

Overview of Cellular Radio

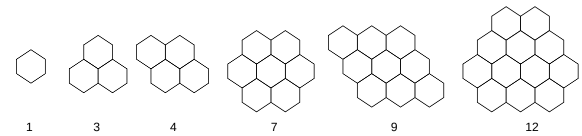
- the cellular concept has made mass-market “cellular” service possible
- uses “frequency reuse” to provide radio telephone service to a large number of uses with a fixed frequency allocation
- the geographical service area is divided into a number of “cells” (each cell being 1-10 km in radius)
- each cell is assigned a set of radio channels
- these same channels can be reused by cells that are sufficiently far away that they don’t interfere with each other
- by reducing the sizes of the cells we can increase number of times the channels are reused and increase the total number of users that can be supported

Cluster Size and Reuse Factor

- model cells as hexagonal areas
- only some cluster sizes/patterns can be used to tessellate (cover all the area using a regular pattern)
- allowed cluster sizes such that the cluster size, N is $N = i^2 + ij + j^2$
- some possible values:

i	j	N
0	1	1
0	2	4
0	3	9
0	4	16
1	1	3
1	2	7
1	3	13
2	2	12
2	3	19

- cluster shapes:



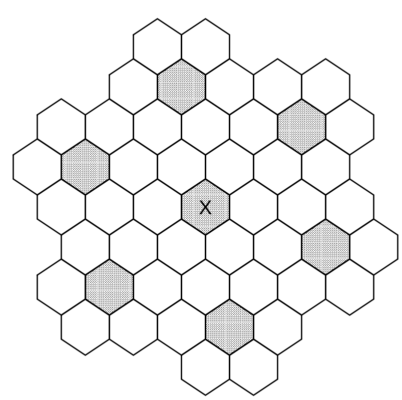
- while hexagonal cells are useful approximation for system design, propagation conditions and site availability will determine the actual coverage areas

Channel Assignment and Capacity

- a fixed set of channels, S is available
- typically divided evenly with k channels per cluster of N cells so that $S = kN$
- if a system has M clusters, the total number of available channels in the system is $C = MS = MkN$
- frequency reuse factor is $1/N$ (or often just “N”)
- if the number of cells is fixed, a smaller N results in more channels per cell (larger k) and thus a higher capacity

Co-Channel Interference

- value of N is determined by interference considerations: we must make sure that at the minimum re-use distance (determined by the cluster size and geometry) no cell will cause interference to its neighbours
- example of potential co-channel interferers in other clusters:



- interference is determined by ratio of desired to interfering signal strengths
- signal strength is determined by path loss (covered later) and distance
- the SIR (signal to interference ratio) is:

$$SIR = \frac{S}{I} = \frac{S}{\sum_{i=1}^{N} I_i}$$

where I_i is the interference power of the i'th base (on the forward channel)

Cell Splitting

- as usage grows, a cell can be split into smaller cells using the same cluster size
- the SIR will still be maintained

Channel Assignment

- most cellular systems use fixed channel assignment
- some improvement is possible by using dynamic channel assignment where more channels can be assigned to one cell within a cluster
- we still need to ensure that minimum re-use distance is maintained
- many systems use manually-tuned filters and it's not practical to reallocate channels

Handoff

- mobile users may travel out of a cell
- base (and/or mobile) determines this by measuring quality of link to current base and to adjacent bases
- if another base would provide better service, a channel is allocated in that base and the mobile switches channels
- hysteresis built into system to avoid too-frequent handovers
- "soft" handover (a mobile receiving from multiple bases) is possible in some systems.

Other Interference Sources

- ACI (Adjacent Channel Interference) is interference due to imperfect channelization filters
- intermodulation distortion (IMD) is due to mixing of signals at two (or more) frequencies to produce a signal at another frequency
- both ACI and IMD can be reduced by proper selection of channel sets

Grade of Service

- GOS is probability that user will not be able to make a call (because all channels are in use) at, for example, the busiest hour of the day (or week)
- the number of channels required to meet a desired GOS depends not only the traffic (calls per hour and duration) but also on the number of channels per cell
- the more channels the system has, the higher the average usage can be while still meeting the GOS requirements
- (details later)

Antenna Basics

Power Density

- power density at a given distance d in far field (see below) is the total transmitted power divided by the area of a sphere of radius d:
  $P_d = P_t/(4\pi d^2)$

Directivity and Gain

- directivity (D): ratio maximum power density to average power density.
- gain (G): ratio of maximum power density to power density of a reference antenna. relative to reference antenna. includes effect of losses.
- typical reference antennas: isotropic (dBi), dipole (dBd)
- will assume dB relative to a lossless isotropic radiator if reference antenna is not given

Effective Aperture

- effective aperture is the ratio of power delivered by an antenna to the power density:

  $A_e = P_r/P_d$

  so that the received power is the power density times the effective area:

  $P_r = P_d A_e$

- for any antenna, the effective area is also given by:

$$A_e = \frac{\lambda^2}{4\pi} D$$

  this equation relates directivity (unitless) to effective aperture (square metres)

- if the gain is defined relative to a lossless isotropic radiator ($G = D$):

$$G = \frac{4\pi}{\lambda^2} A_e$$

- received power, P_r, assuming transmitted power, P_t, is given by Friis Transmission Formula:

  $P_r = \frac{P_t A_{et} A_{er}}{\lambda^2 d^2}$

  or, using antenna gains (again, referred to lossless isotropic) G_t and G_r:

  $P_r(d) = \frac{P_t G_t G_r \lambda^2}{(4\pi)^2 d^2}$

- note that power drops off as square of distance

EIRP

- EIRP effective isotropic radiated power is:

  $EIRP = P_t G_t$

- it is the power that would need to be fed to a lossless isotropic radiator to produce the same power density

- often used to specify power density limits

Conversion to dB, dBm, dBW

- dB $= 10 \log(p_2/p_1) = 20 \log(v_2/v_1)$

- dBm is relative to 1 mW, dBW relative to 1 W

Far Field

- in the far field radial field components are negligible, only have transverse components (those perpendicular to direction of propagation)

- for "practical purposes" (computing field strengths within a few percent error) the far-field or "Fraunhoffer" region is:

$$d > \frac{2D^2}{\lambda}$$

  where D is largest dimension of antenna

Free-Space Path Loss Calculations

- path loss: ratio between received and transmitted powers (computation may or may not include antenna gains)

- in free-space the power density (and thus field strength) drops off as $1/d^2$

- textbook uses concept of "reference distance," d_0 which is the path loss or power at a reference distance

- path loss is then $P_r(d) = P_r(d_0)(d_0/d)^2$

Field Strength

- intrinsic impedance of free space is $\eta = 120\pi$ ohms

- power density in far field is $P_d = E^2/\eta W/m^2$

Available Power

- if the antenna is connected to a matched (for maximum power transfer) load, the voltage at the antenna terminals will be half of the open-circuit voltage and the power delivered to the load will be a quarter of the received power, $P_r/4$

Large-Scale Propagation Prediction

- propagation loss is the loss of signal power between transmitter and receiver

- some simple models (2-ray and knife-edge diffraction) provide insight into the mechanisms involved

- for practical purposes use empirical models derived from measurements or geometrical models plus corrections derived from measurements

- it's not possible to predict path loss at any given location, instead models are statistical (described by a probability distribution, mean and variance, etc.)

- we'll concentrate on path loss models and link budget design

Non-LOS Propagation Mechanisms

- most wireless systems (exceptions being satellite and terrestrial point-to-point) do not have LOS paths

- instead 3 mechanisms provide propagation when no LOS present: reflection, diffraction, and scattering:

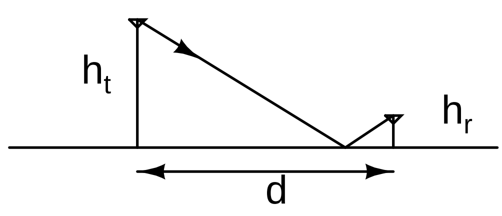
- reflection from a large (relative to λ) surface (e.g. the ground)

- re-radiation from sharp edges (e.g. rooftops)

- reflection from many small (relative to λ) surfaces (e.g. trees)

Ground Reflection (2-ray) Model

- simple model for propagation over ground



- assume two components arrive at receiver: one LOS and one reflected from the ground

- for small angle of incidence assume reflection coefficient $\Gamma = -1$

- at large distances (compared to the antenna heights) the two components will have approximately equal amplitude and a small phase difference:

$$\theta_\delta = \frac{2\pi\delta}{\lambda}$$

where δ is the path length difference:

$$\delta \approx \frac{2h_t h_r}{d}$$

- for large d ($\gg \sqrt{h_t h_r}$)

$$P_r \approx P_t G_t G_r \frac{h_t^2 h_r^2}{d^4}$$

- for this model path loss varies as d^4, square of antenna heights and is independent of frequency.

- approximation does not apply for short distances (see text for other equations)

Diffraction

- phenomena which causes propagation around obstructions

- diffraction fields can be computed using Huygen's principle: each point on a wavefront launches additional "wavelets"

- results available for simple cases (e.g. single knife-edge)

Fresnel Zones

- regions where the path difference between direct and diffracted (or reflected) rays is a multiple of $\lambda/2$

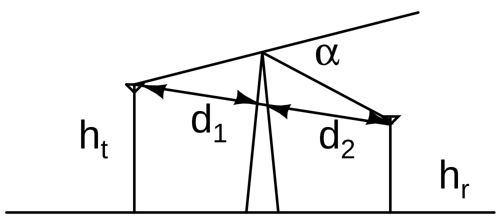
- cause alternate destructive and constructive interference

Diffraction Loss

- due to blockage of some of the "wavelets"
- not all wavelets contribute equally, most contribution from wavelets within first Fresnel zone
- as approximation, if no obstructions within first Fresnel zone then can ignore diffraction loss

Knife-Edge Diffraction Loss

- approximation to path loss due to diffraction over, e.g., roof tops
- computed from Fresnel-Kirchoff diffraction parameter, ν and the Fresnel integral, $F(\nu)$
- ν depends on geometry:



$$\nu = \alpha\sqrt{\frac{2d_1d_2}{\lambda(d_1+d_2)}}$$

- $F(\nu)$ is computed numerically or from graphs
- diffraction loss is added to free space loss

Link Budgets

- a link budget is the wireless system designer's most important tool
- link budget accounts for all signal gains and losses between the transmitter and receiver
- typically includes dozens of effects
- allows comparison of system design alternatives (e.g. transmitter power vs. antenna gain) and can help meet overall system goals
- path loss is a critical component since it is the single largest loss and often has the largest uncertainty