ENEL 673
CDMA AND NARROWBAND MULTIUSER DETECTION WITH ANTENNA ARRAYS

PART I: FADING CHANNEL COMMUNICATIONS

1. THE MOBILE COMMUNICATIONS PROBLEM

1.1 Objectives

- Mobile communications technology serves several purposes:
    - freedom to communicate without being tied to a physical location;
    - rapid deployment of communications services;
    - communications into remote areas;
    - etc.

1.2 Services

- A wide variety of services is commonly offered over radio:
    - Paging. Tone or alphanumeric. Minimal demands on bandwidth, power. Single channel enough for an entire city.
    - Private dispatch systems. Voice and/or data. Dispatcher or mobile initiates. Limited capacity. May "trunk" (i.e., pool) several channels to gain efficiencies.

- Cellular. Public. Reuse of spectrum in other cells, so unlimited geographic coverage. Very large capacity. Digital voice, data messages.
- Personal communications (PCS). Voice, data, internet, fax, video (?). Small, cheap transceivers. User is independent of particular transceiver. Huge capacity required.
- Fixed wireless between two stationary points. Backhaul from base stations, cable replacement in last hop to home. High data rates, high bandwidth, high carrier frequency.
- Others… mobile satellite, aeronautical,

- In most services, the radio channel is the "last link," providing access to the wireline infrastructure

- One way to characterise the design problem:
    - maximise Erlang/(MHz-km^2);
    - while maintaining acceptable quality.

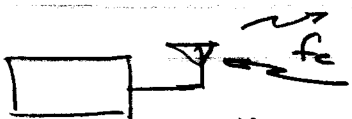
1.3 Underlying Structures

- Mobile is radio-based. Several existing and proposed bands:

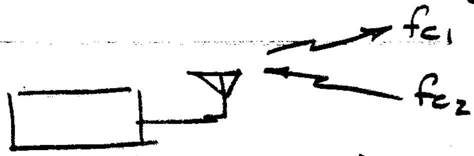
  150 MHz 450 MHz 800-900 MHz 1.8-2 GHz 2.4 GHz and up

- *transceiver operation*

simplex

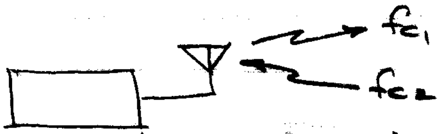


alternate talk, listen on a single carrier f_c



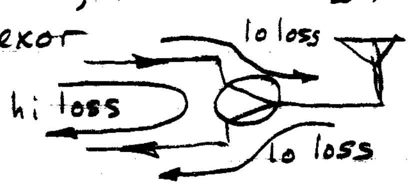
duplex

alternate talk on f_{c_1}, listen on f_{c_2}



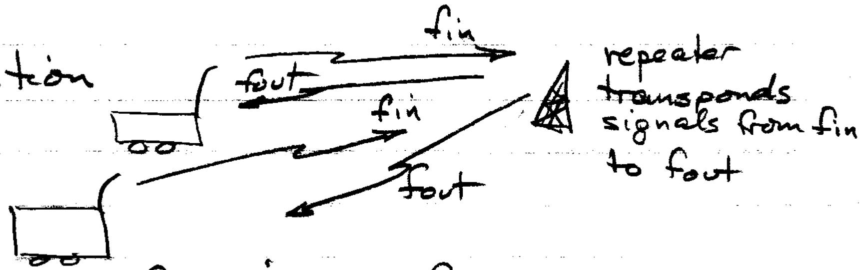
full duplex

simultaneous talk on f_{c_1}, listen on f_{c_2}.
need antenna duplexor



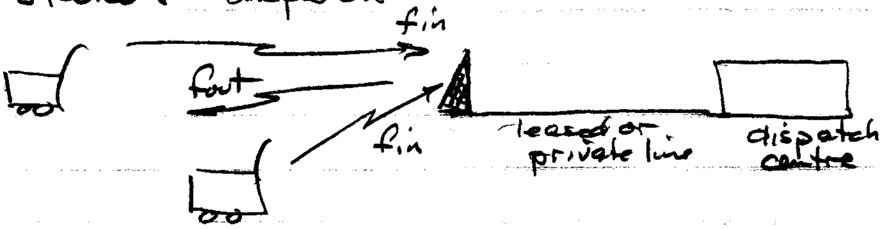
1.3

- repeater operation

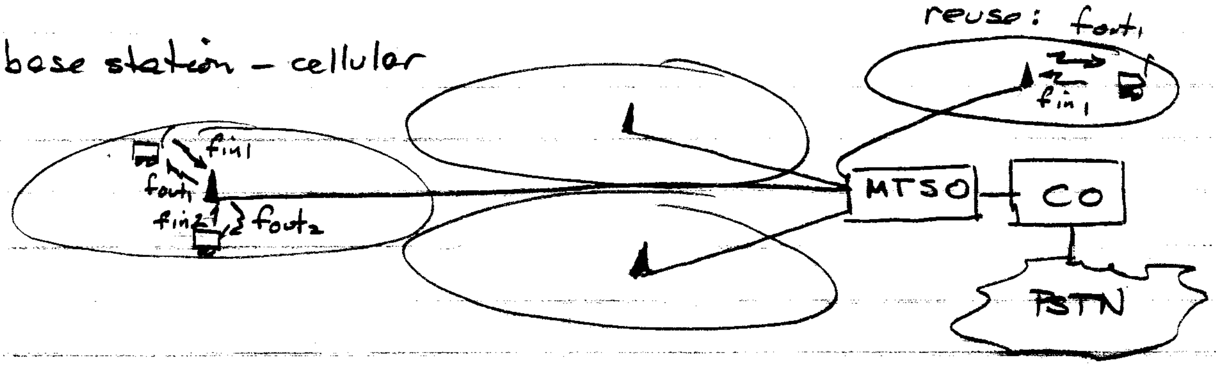


mobiles talk on fin, listen on fout

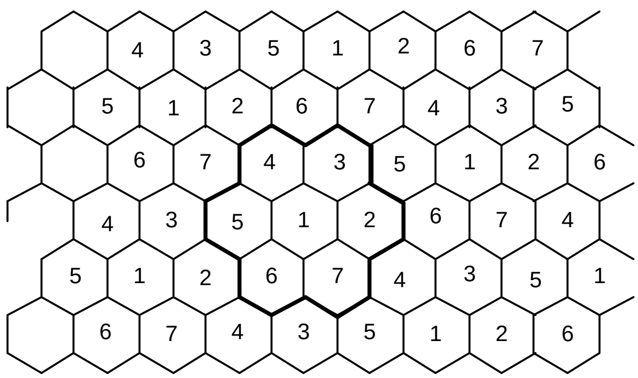
- base station – dispatch



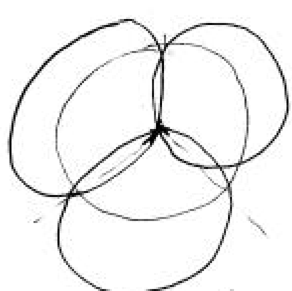
- base station – cellular



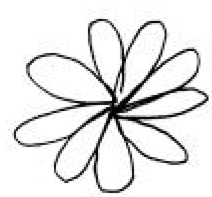
- Multiple access – how to share the communication resource (spectrum) among the users across some service area?
  - FDMA – the obvious one – allocate a frequency channel (a piece of spectrum) for a given connection
  - TDMA – can subdivide a single signal with bandwidth spanning the spectrum into a series of time slots – allocate a sequence of slots to a connection
  - SDMA – space division
    - by cellular organisation



    - by beamforming or similar antennas



tri sectored



multibeam

- CDMA – code division. Each user signal is multiplied by a unique wideband pseudo-random sequence, so each user occupies all time, all available spectrum. Users distinguished by sequence.

- Frequency hopping – users occupy a narrow band but shift centre frequency rapidly and pseudorandomly around the band.

- Combinations. E.g., GSM – several frequncy channels spaced by 200 kHz or so, each with 8 time slots; burst by burst FH. E.g. IS-95 – cellular, all cells have same frequency range, CDMA within each cell.

1.4 Mobile Communication Problems

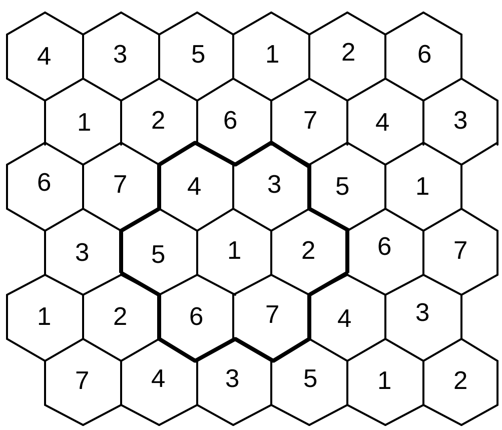
An effective mobile communications system requires solution of many fundamental or technological problems. Here are a few.

1.4.1 System Problems

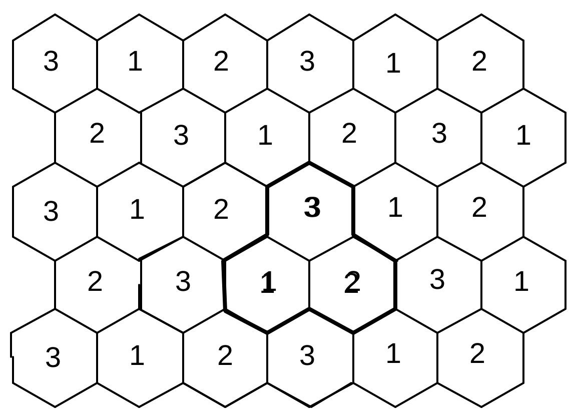
- Limited spectrum
    - The biggest problem. VHF, low UHF bands are saturated. Auctions saw high UHF spectrum going for tens of $M each.
    - Cellular systems attempt to beat traffic loads with frequency reuse and cell splitting. Even they have a limit defined by min cell size.

- Multiple access. We can subdivide frequency, time and space, as seen. How to allocate it?
    - In MRS, mobiles share a common inbound frequency. Which one talks at any time? Usual solutions are polling, ALOHA, CSMA variants.
    - What do we allocate? Capacity for a whole conversation? Or just a talkspurt? Or single packet?
    - In multichannel (trunked or cellular) systems, channels are temporarily assigned on a DAMA (demand assigned) basis. Simply removes the problem one step – now we have contention for use of the request channel.

- Interference – the other major problem
    - We can beat noise by increasing transmit power or lowering Rx noise figure (i.e., increasing sensitivity) – but if all Txs increase power, no change in relative interference level (C/I).
    - Cochannel interference (CCI). Interference on desired channel from (i) odd order IM products, or (ii) more commonly, from a cochannel transmitter in another cell, or (iii) from intracell transmitters in same band, as in CDMA or multiuser scenarios.
    - Protection ratio (usually for narrowband systems) is dB difference between desired and interference for reception of given quality. Smaller protection ratio allows closer spacing of cochannel cells, better frequency reuse.

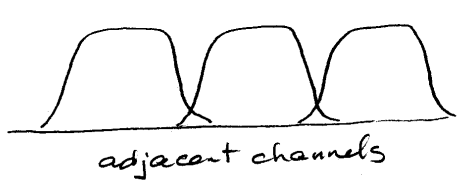


If 21 channels, cluster size 7, then 3 channels/cell.



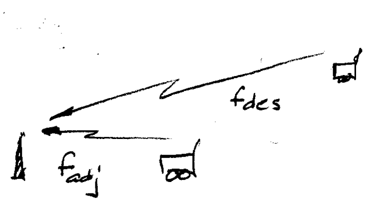
If 21 channels, cluster size 3, then 7 channels/cell.

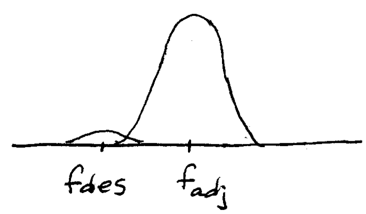
- Adjacent channel interference (ACI) – spillover of energy from adjacent channels.



Regulatory agencies specify “mask” applied to radiated power spectrum, or a simpler criterion, such as “power in adjacent channels must be 60 dB lower than on-channel power.” Some FDMA systems do not use adjacent channels in the same cell.

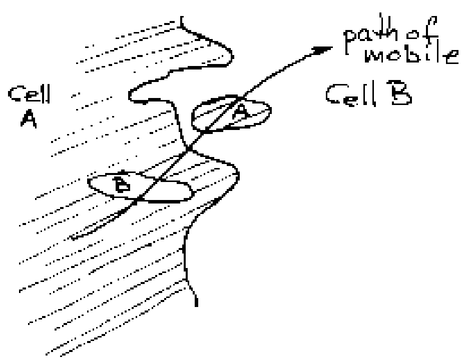
- Near/far problem. The adjacent channel interferer can be closer and much stronger than the desired signal.





A 30-40 dB difference means very stringent limits on out-of-band emission. Dynamic power control mitigates the problem – and is critical to success of CDMA (as will be seen).

- Handoff
    - Mobile can enter another cell during a conversation and must be switched to a different base for connection to PSTN. Change of frequency/time slot/code must be invisible.
    - Handoff is a system overhead. Increases with traffic intensity and/or smaller cells.
    - Who initiates? System, with other bases sensing mobile power? Mobile, sensing base powers?
    - Cells are not well defined geographically. Hysteresis to prevent thrashing, or soft handoff (multiple connections during the handoff)



    - Dynamic channel assignment to share load in adjacent cells (in channelised systems)
- Security/privacy
    - crypto for digital
    - nothing for analog

1.4.2 Propagation Problems

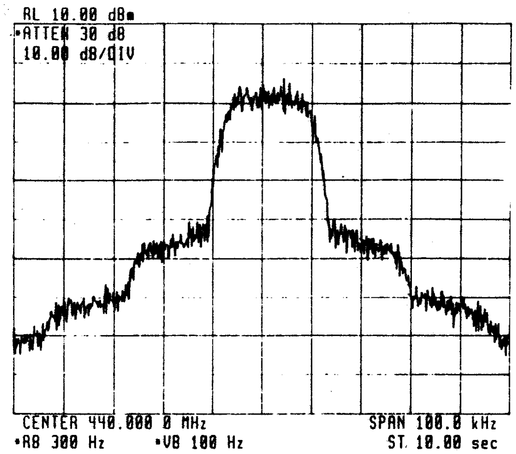
- Propagation loss. Average signal strength falls off faster than inverse square.
- Shadowing. Building clusters, hills, etc, produce variation about propagation loss.
- Fading. Random field caused by reflections from many small scatterers. As mobile passes through, it experience rapid fluctuations in amplitude and phase superimposed on shadowing.
- Dispersion. Delay differences among scatterers produce in-band distortion – ISI, if digital.

1.4.3 Technology Problems

- Battery drain. Over half the weight in some cell phones is the battery. Lighter/longer-lasting battery pack through:
    - better modulation, coding, detection, antennas
    - low power consumption circuitry
    - new battery technologies

- Imperfect components
    - Frequency reference. A 1 ppm crystal oscillator at 1 GHz has a 1 kHz frequency error. A shift of 1 kHz in (say) 19.2 kb/s is serious. Rapid phase drift across a packet.

- Nonlinearity in transmitter, primarily the power amp (PA). This causes intermodulation (IM) skirts on a data signal with variable amplitude (unlike FSK or GMSK). Reducing the signal level in the PA lowers the distortion due to saturation, but reduces power efficiency, too.



- Dynamic range in receiver. Simple mathematical model of receiver suggests that all unwanted channels can be removed by demodulation and filtering. In reality, an undesired signal 70 dB higher will swamp the limite dynamic ranges of those components.
- Noise. Dominated by Rx front end noise in 800 MHz band and higher. In 150 MHz, 450 MHz bands, have to consider ignition noise and other man-made noise.

1.5 Summary

- The problem:
    - Combine technology, modulation and coding, source coding (speech, image)
    - and organisation in time, frequency and space
    - to accommodate user demand that varies temporally, spatially and across different services.

1.6 Active Areas of Research

- Space-time (ST) coding. Multiple antennas allow "diversity" reception – protection against fades – but mobiles must be small and light. ST codes allow a base to use its antenna array to provide diversity to mobiles with a single antenna.

- Multiuser detection (MUD). Don't suppress other users by filtering – instead, detect all signals simultaneously, to reduce interference. Goal: more users in a time-frequency region, usually intracell.

- MIMO (multi-input, multi-output). Arrays at both ends of a (usually) fixed wireless link. Large capacity possible by exploiting the parallel channels in the same band.

- Iterative (turbo) detection. Moving to MUD in wireless. Data rates very close to theoretical capacity.