FDMA/TDMA/CDMA

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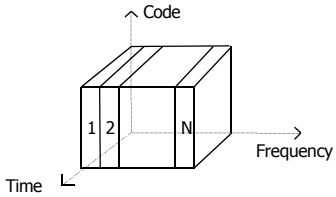
Frequency Division Multiple Access

- Individual channels (frequency) to individual users
- On demand channel assignment

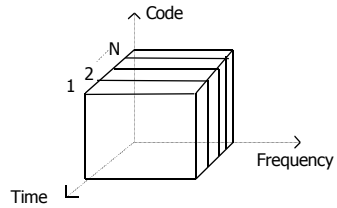


FDMA Features

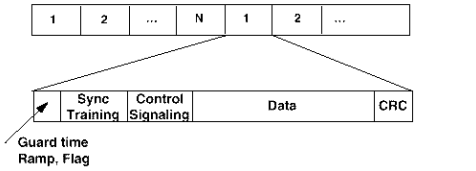
- If channel not in use, sits idle
- Channel bandwidth relatively narrow (30kHz), ie, usually narrowband systems
  - Symbol time >> average delay spread ⇒ little or no equalization required
- Simplest
- Best suited for analog links
- Continuous transmission implies no framing or synchronization bits needed
- Requires tight filtering to minimize interference
- Usually combined with FDD for duplexing

Time Division Multiple Access

- Divide radio spectrum into time slots



Time Division Multiple Access



- Only 1 user allowed to either transmit or receive in a slot
- Slots assigned cyclically
- Non-continuous transmission: buffer and burst
- Digital data and modulation must be used
- Guard time allows for different prop delays bet mobile and BS
- 20～30 % of data rate is overhead
- Tradeoffs in overhead, size of data payload, and latency

TDMA: Features

- Advantages:
  - Shares single carrier frequency with multiple users
  - Non-continuous transmission makes handoff simpler (mobile assisted handoff possible)
  - Slots can be assigned on demand (concatenation and re-assignment): bandwidth supplied on demand
  - Less stringent power control due to reduced interuser interference
- Disadvantages:
  - Higher synchronization overhead
  - Equalization necessary for high data rates
  - Frequency/slot allocation complexity
  - Pulsating power envelop: interference with other devices

FDD & TDD

- Frequency Division Duplex (FDD)
  - Two distinct frequencies for uplink and downlink
  - Frequency separation must be coordinated
- Time Division Duplex (TDD)
  - Two distinct sets of time slots on the same frequency for uplink and downlink
  - No need for RF duplexer
- Can combine with FDMA/TDMA
  - FDD/TDMA/FDMA: PDC
  - TDD/TDMA/FDMA: PHS

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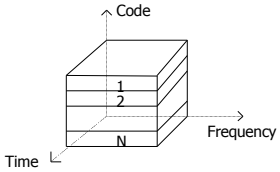
Code Division Multiple Access

- All users use same frequency and may transmit simultaneously
- Narrowband message signal multiplied by wideband spreading signal, or codeword
- Each user has its own pseudo-codeword (orthogonal to others).
- Receivers detect only the desired codeword. All others appear as noise.
- Receivers must know transmitter's codeword.



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Spread Spectrum

- Techniques known since 1940s and used in military communications systems since 1950s
- "Spread" the radio signal over a wide frequency range several magnitudes higher than minimum requirement
  - Processing gain: Gp = Rchip / R
  - Rchip: code (chipping rate), R: information rate
- Better interference immunity and multiple access ability
- Bandwidth efficient for multi-user systems.
- Two main techniques: frequency hopped (FH) and direct sequence (DS) or CDMA.

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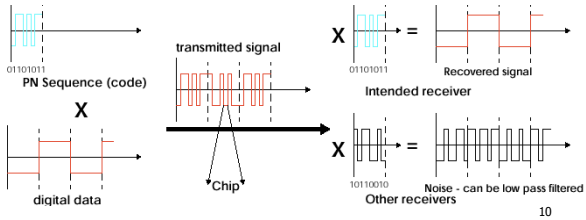
Direct Sequence SS

- Direct Sequence SS
  - Bits sampled ("chipped") at higher frequency
  - Signal energy "spread" over wider frequency



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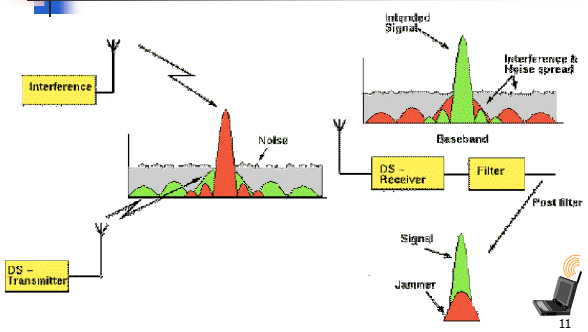
DS-CDMA Signal



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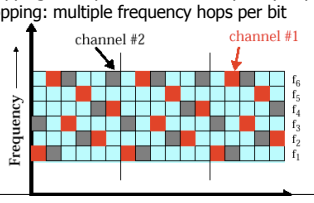
Frequency Hopping SS

- Pseudo-random frequency changes randomizes channel occupancy
- At any given time, FH signal occupies only a single, narrow channel; makes MA possible
- FHMA is a fast (channel) changing FDMA
- Slow hopping: multiple bits before frequency hop
- Fast hopping: multiple frequency hops per bit



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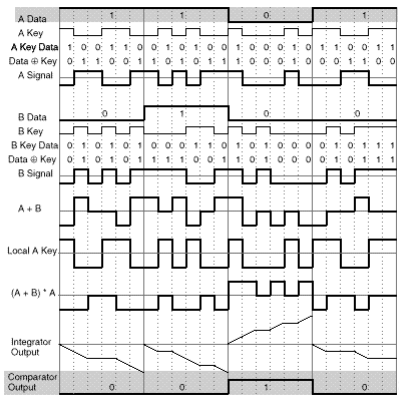
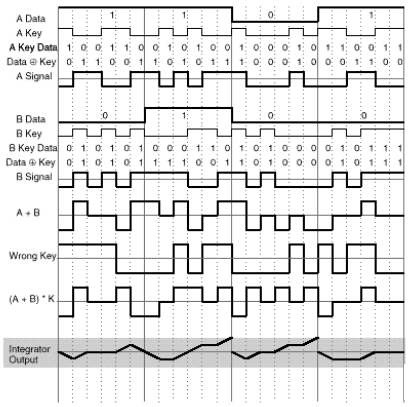
CDMA



Recovery of A channel

CDMA



Wrong key yields noisy output

Code Sample

10111100011001101001110001110001011110001100110100111000111000

$$\square pi(t)pj(t) = \begin{cases} 1 & \text{for } i=j \\ 0 & \text{otherwise} \end{cases}$$

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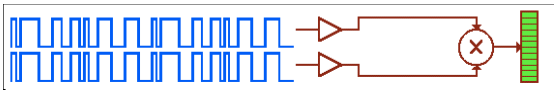
Correlation



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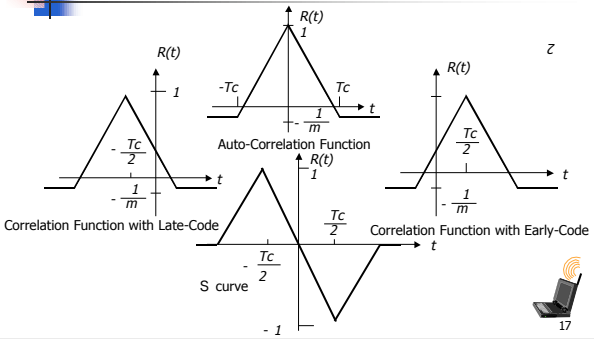
Delay Lock Loop(DLL)



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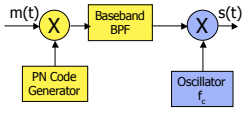
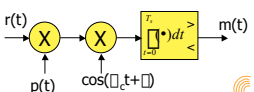
DS-SS: Direct Sequence Spread Spectrum

- m(t) = ±1 over symbol time Ts
- p(t) = ±1 over chip time Tc is the pseudo-random sequence. p(t) can be generated using a linear feedback shift register clocked by the chip clock.
- Ts = Gp Tc
- To demodulate, multiply s(t) by p(t) at receiver. Since $p^2(t) = 1$, the signal is recovered. Note that receiver must know p(t) and correct timing information.



DS-SS Transmitter



DS-SS Receiver

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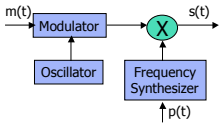
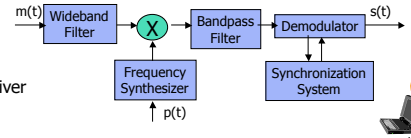
FH-SS: Frequency Hopping Spread Spectrum



FH-SS Transmitter



FH-SS Receiver

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CDMA System

- Power-Limited System: Cocktail party analogy
  - Band playing "random noise" while people talking
  - Need to extract conversation from the background din
  - If people speak in different languages, Gp is high, easier to distinguish individual speakers
  - If Gp is low, more difficult to distinguish between individuals
  - Now image that the Band starts playing even louder!
    - If becomes too loud, nobody can speak
    - Speakers try to talk more loudly, increasing the noise
    - Near-far problem
  - How to increase the # of attendees (capacity) at party:
    - Band agrees to play at low level (background noise)
    - Participants agree to speak MORE softly as new guests arrive
    - Host (base station) centralizes all conversations, requiring all guests to speak to him/her at the same relative sound level, no matter how far they are from the host (power control)

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CDMA: Features

- Soft capacity limit: system performance degrades for all users as number of users increase
- Wide frequency spectrum reduces fading
  - Rake receiver: Separate multipath signals of different delays by "chip" unit
- Cell frequency reuse 1 : No frequency planning
- Soft Handover increases capacity
  - "make before break" vs "break before make"
- Utilization of voice activity (talkspurts)

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Soft Handover

- Mobile moves towards edge of cell
- BS detects low RF power
- MTSO assigns mobile's spreading code to adjacent BS
- Both BS transmit same data to mobile
- Rays from both BSs are combined by the rake receiver
- Mobile moves further into new cell
- All fingers correlate with rays from new site
- MTSO instructs old BS to drop mobile's spreading code

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CDMA: Features (cont.)

- Power control necessary for mitigating near-far problem
  - Tradeoff between precision of power control and capacity
- Complex network support for implementing soft handoff
- Self-jamming problem due to spreading sequences not being exactly orthogonal.
- Inappropriate for ultra high rate wireless access
  - Tremendous width of BW necessary
  - Hardware complexity
  - Synchronization problem

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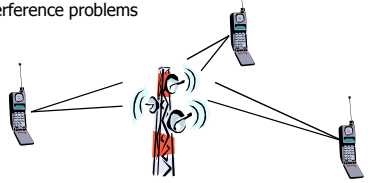
Space Division Multiple Access

- Controls radiated energy in space
- Use spot beam antennas
- Different areas may be served by same frequency: TDMA or CDMA; or different frequencies: FDMA
- Adaptive antennas dynamically adapt to number of users, etc
- Reverse link may be a problem: limited battery capability, interference problems



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