# On the Capacity of a cellular CDMA system.

Agenda

- Background
- Single Cell CDMA capacity
- Performance Improvement through Sectorization and Voice-activity Monitoring
- Power Control
- Reverse link capacity (Multiple cell)
- Forward link capacity (Multiple cell)
- Comparisons
- Conclusion

Background

- CDMA advantages:-
  - Inherent Privacy
  - Anti-jam characteristics
  - Immunity to frequency selective noise
  - Multipath mitigation (due to RAKE receivers)
 - Soft handoff
  - Power saving
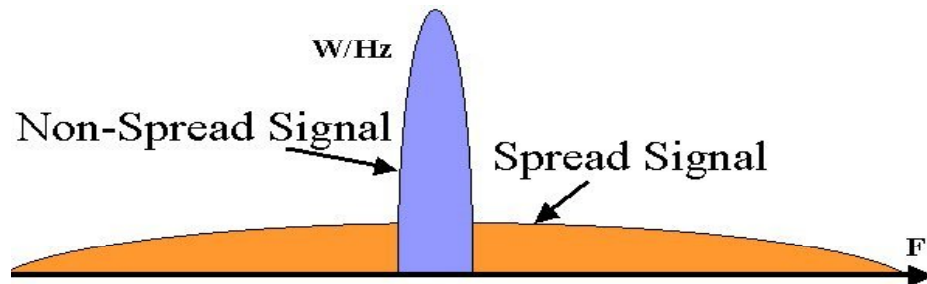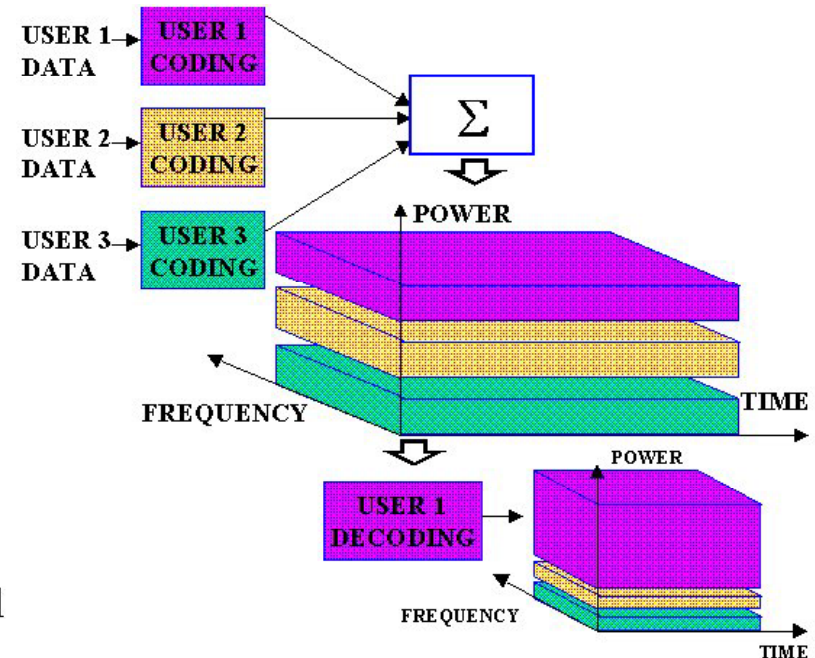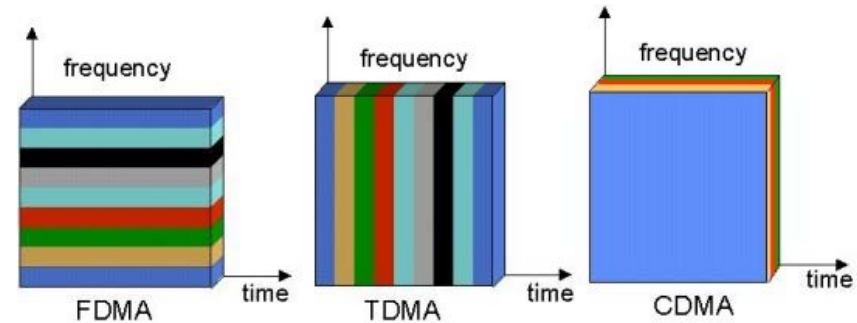
CDMA disadvantages

- Near-Far problem – mandatory power control
- Precise power control possible by spending more power on power control messages.
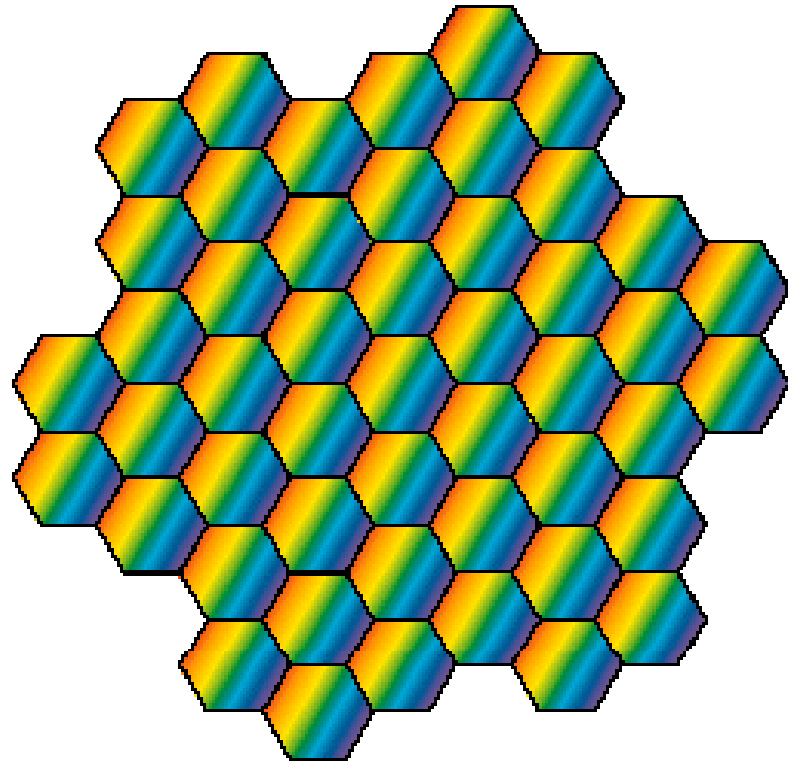- Synchronization is required

Background (cont'd)

- Area of concern: CAPACITY
- FDMA/TDMA are Bandwidth limited
- CDMA – Interference limited
- Reduction in interference – direct and linear increase in capacity
  - Voice activity monitoring (squelching)
  - Spatial Isolation (Multisectored antennas)
  - Frequency reuse
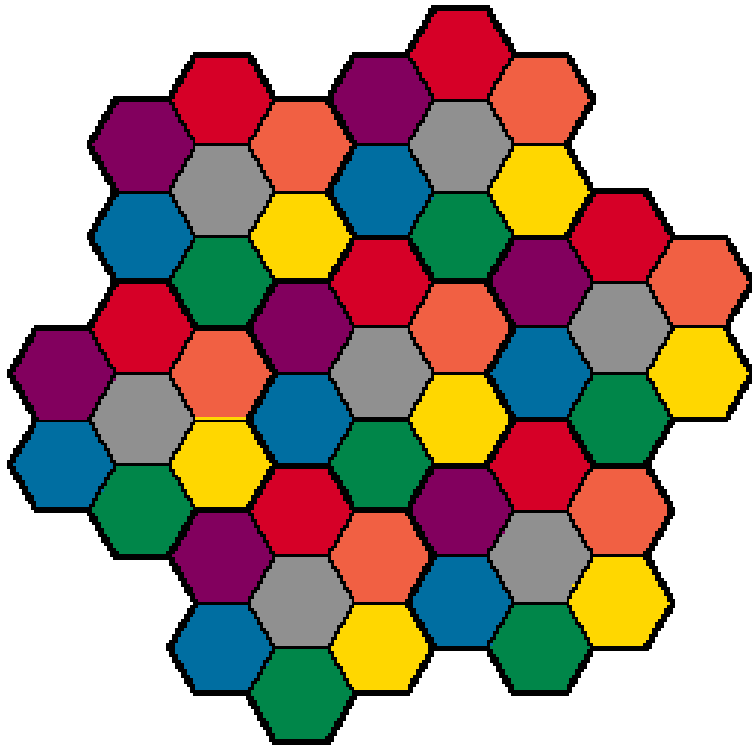
FDMA cells with
reuse K = 7.

CDMA cells with
reuse K = 1.

Single Cell CDMA capacity

- Coherent Modulation for forward link
    - Pilot signal helps in demodulation in a fading environment
    - Pilot signal provides for power control, mobile adjusts its power inversely with received signal
- Non-coherent Modulation for reverse link
    - Power efficiency considerations for battery operated handheld units

Single cell CDMA capacity (cont'd)

- S – signal power, N users, SNR
- R – rate, W – Bandwidth, Eb/No – Bit energy-to-noise density ratio, n – background noise

$$N = 1 + \frac{W/R}{E_b/N_0} - \frac{\eta}{S}$$

- W/R – Processing gain, Eb/No defines BER required for satisfactory performance (10^-3 or higher)
- Diversity and coding.
- Performance of forward link better than reverse link.

Performance Improvement through Sectorization & Voice-activity Monitoring

- Goal – Increase N
- Can use improved coding and modulation. Leads to diminishing returns and Shannon's limit
- Sectorization – 120 degree sectors, interference sources reduced to 1/3, capacity increased by nearly the same amount
- Voice-activity Monitoring – speakers only active for 35% - 40% of time

Performance Improvement through Sectorization & Voice-activity Monitoring

- Voice activity factor = 3/8, Ns = # of users/sector = N/3

- Average

$$\frac{\overline{E_b}}{N_0} = \frac{W/R}{(N_s - 1) \propto + (\eta/S)}$$

  - Thus, average users/cell increased by a factor of almost 8 (theoretical) and 5 to 6 (practical)

  - Makes CDMA capacity competitive with FDMA/TDMA

Power Control

- Single most important system requirement

- Subscriber units – transmit as much below (or above) a nominal level as the received power level is above (or below) its nominal level. (dynamic range of almost 80 dB)

- Closed loop power control tracks variations due to path loss and shadowing (slow), modelled as log-normal.
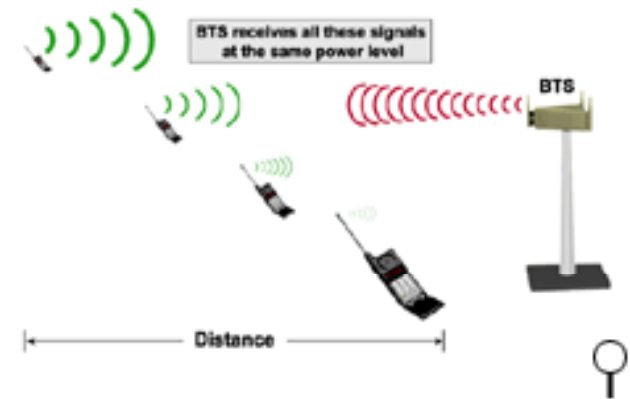
Power Control in Multiple cell system

- Maximum pilot power rather than minimum distance decides where the subscriber belongs
- Interference levels from subscribers in other cells varies
  - Inversely to distance in the path to the subscriber's cell site (how much is the other user far away from BS of the user)
  - According to the distance from the interfering user to his own cell site (how much are other users far away from their BS)

Reverse link capacity (Multiple cell)

- The distance between subscriber and cell site is r, ξ is a Gaussian random variable with std. dev. = 8dB & zero mean.

- The interference from the user in another cell site is

$$\frac{I(r_0, r_m)}{S} = \left(\frac{10^{(\xi_0/10)}}{r_0^4} \right) \left(\frac{r_m^4}{10^{(\xi_m/10)}} \right)$$

$$= \left(\frac{r_m}{r_0} \right)^4 10^{(\xi_0 - \xi_m)/10} \leq 1$$

First term due to attenuation caused by distance and blockage to the given cell site. Second term is the effect of power control to compensate for corresponding attenuation to the cell site of the out-of-cell interferer.
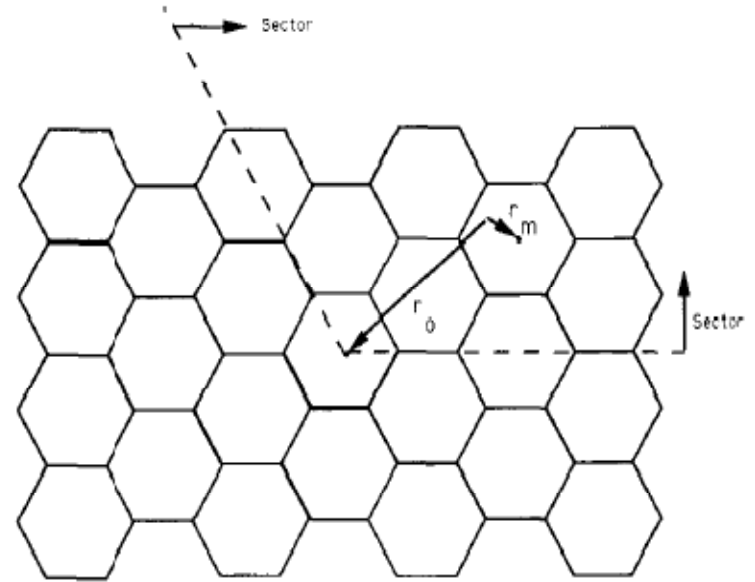
Reverse Link capacity (Multiple cell)

- The first and second order moments of (I/S) are evaluated numerically and found as

E (I/S) <=0.247Ns and Var (I/S) <=0.078Ns

- Taking this interference

$$E_b/N_0 = \frac{W/R}{\sum_{i=1}^{N_s-1} x_i + (I/S) + (\eta/S)}$$

- The required performance is achieved with probability P = Pr(BER<10^-3) = Pr(Eb/No>=5)

- Outage probability is

$$1 - P = \Pr(\text{BER} > 10^{-3}) = \Pr\left(\sum_{i=1}^{N_s} x_i + I/S > \delta\right)$$

where
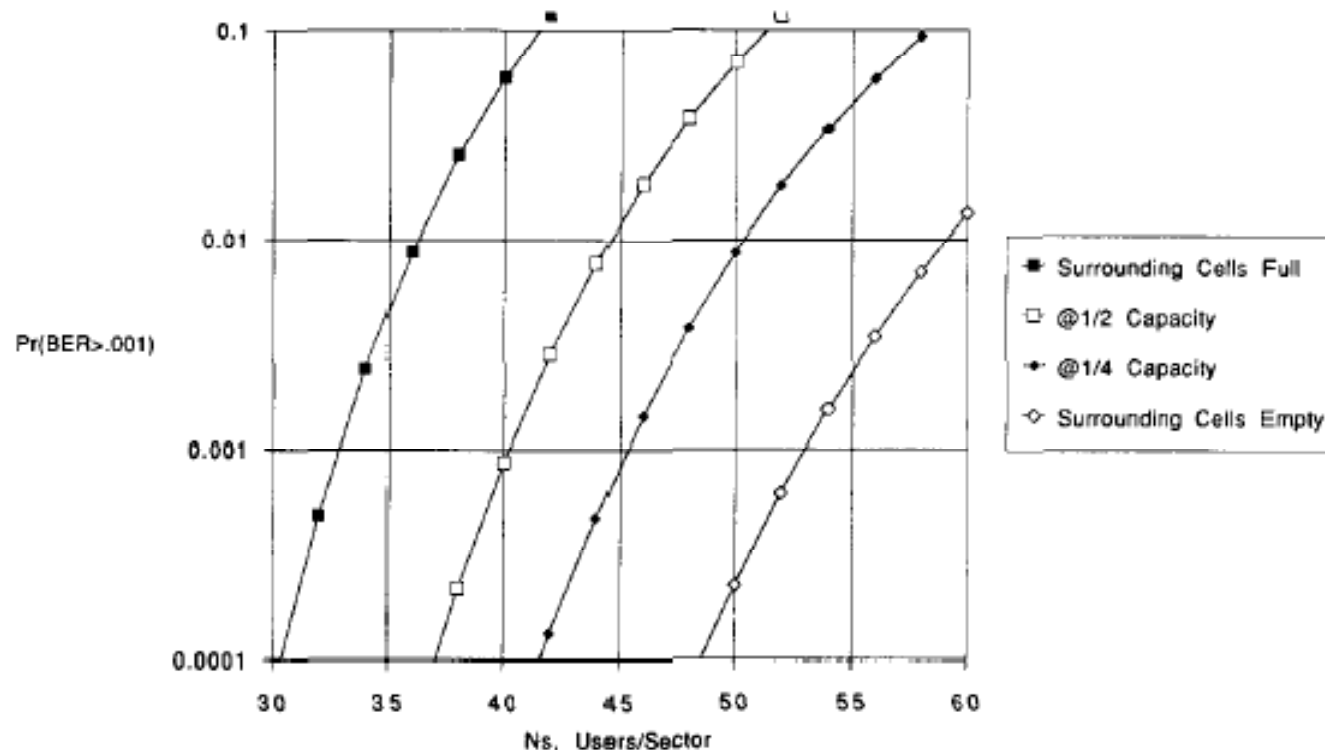
$$\delta = \frac{W/R}{E_b/N_0} - \frac{\eta}{S}, \qquad E_b/N_0 = 5.$$

Reverse Link Capacity (Multiple cell)

- As Xi is Binomial and I/S is a Gaussian random variable the previous expression reduces to

$$1 - P = \sum_{k=0}^{N_s-1} \Pr\left(I/S > \delta - k \Big| \sum x_i = k\right) \Pr\left(\sum x_i = k\right)$$

$$= \sum_{k=0}^{N_s-1} \binom{N_s - 1}{k} \propto^k (1 - \propto)^{N_s-1-k} \cdot Q\left(\frac{\delta - k - 0.247 N_s}{\sqrt{0.078 \, N_s}}\right)$$

Forward Link Capacity (Multiple cell)

- Power control on forward link according to the need of individual subscribers in the cell site.

- Mobile's omnidirectional antenna measures power from its own BS and the total energy received from all BS.

- Both measurements sent back to its own BS

- Eb/No required on forward link is lesser for same BER(10^-3) because of coherent modulation

Forward Link Capacity (Multiple Cell)

- The outage probability is

$$1 - P = \Pr\left(\text{BER} > 10^{-3}\right) = \Pr\left(\sum_{i=1}^{N_s} f_i > \delta'\right)$$

where, $\quad f_i \triangleq \left(1 + \sum_{j=2}^{K} S_{T_j}/S_{T_1}\right)_i, \qquad i = 1, \cdots, N_s \qquad \sum_{i=1}^{N_s} f_i \leq \dfrac{\beta W/R}{E_b/N_0} - \sum_{i=1}^{N_s} \dfrac{\eta}{S_{T_{1_i}}} \triangleq \delta'$

  - fi is the relative received cell power measurements
  - S_{T1} is the power from own BS, fraction of which is useful, the rest is noise along with power from other BS (S_{Tj})
  - β is power devoted to subscribers, 1-β is power devoted to pilot
  - K is taken as 19 to consider interferers from second ring

Forward link capacity (Multiple Cell)

- Probability analyzed using Monte Carlo simulations
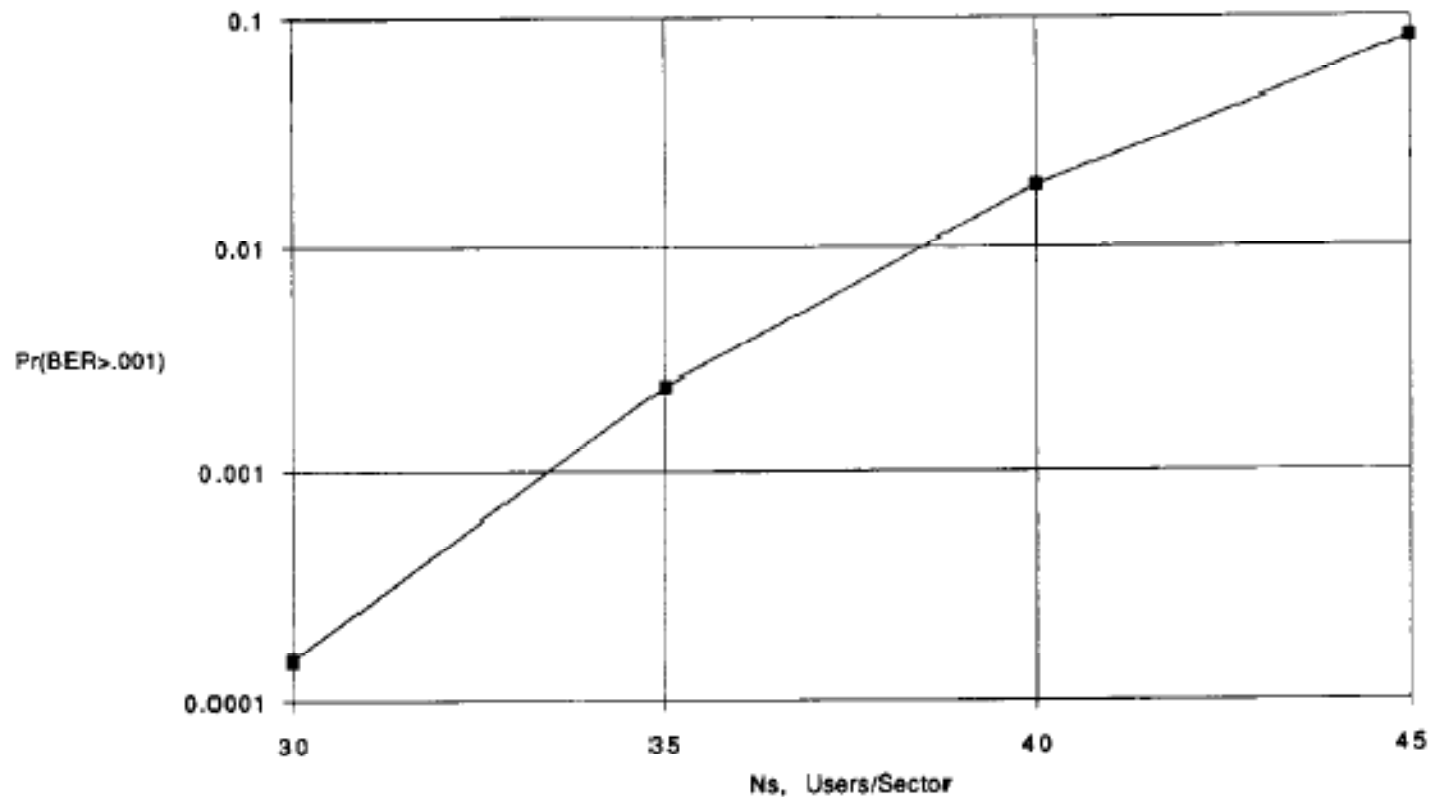
Comparisons

- Both graphs are theoretically pessimistic (upper bounds) assuming moderately accurate power control

- Parameters chosen W = 1.25 MHz, R = 8Kbps, vaf = 3/8, sectorization = 3, δ = 30 and δ' = 38

- With these parameters, reverse link can support 36 users/sector or 108 users/cell and forward link can support 38 users/sector and 114 users/cell

- With 30 KHz channels and 3 sectors/cell and reuse factor of 7, analog FM/FDMA supports less than 6 users/cell for a 1.25 MHz band

- This represents 18-fold increase in capacity

- Proposed digital TDMA shares a channel between 3 users (3-fold better than analog FM/FDMA), but CDMA still 6-fold better than this.

Comparison

- Soft Blocking – Capacity depends on neighbors

- There is an asymptotic abrupt catastrophic breakdown in performance at a critical rate of growth of the number of users with the number of chips in the PN sequence.
  - If K = # of users, n = dimensionality

    and if K exceeds n/(2log n) then, there will be guaranteed errors and K>n will produce unrecoverable errors

Further Improvement

- CDMA capacity can be further increased by narrower sectoring, lower bit rate vocoder algorithm, mixed modulation
- CDMA QoS is also higher due to 'Soft Handoff' (requires less power)
- For unequal cells, can use PCF (power compensation factor to increase capacity)
- Capacity can also be increased by using adaptive antennas