Cell Placement in a CDMA Network

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Outline

- **CDMA inter-cell effects**
- **Network capacity**
- **Sensitivity analysis**
 - **Base station location**
 - **Pilot-signal power**
 - **Reverse power of the mobiles**
- **Numerical results**

Problem Statement

- **How to match cell design to user distribution for a given number of base stations?**
 - **CDMA network capacity calculation**
 - **Reverse signal power and power control**
 - **Pilot-signal power**
 - **Base station location**

Inter-Cell Interference

$$I_{ji} = E \left[\iint_{C_j} \frac{r_j^m(x,y) 10^{\zeta_j/10}}{r_i^m(x,y) / X_i^2} \rho(x,y) dA(x,y) \right]$$

m is the path loss exponent.

ζ_i is the decibel attenuation

due to shadowing, and has zero mean and standard deviation σ_s .

$$E[X_i^2 / \zeta_i] = 10^{-\zeta_i/10}$$

$\rho(x, y)$ is the relative user density.

Soft Handoff

- User is permitted to be in soft handoff to its two nearest cells.

Soft Handoff

$$I_{ji} = \iint_{\text{region (a)}} \frac{r_j^m}{r_i^m} \mathbb{E} \left[10^{\zeta_j/10} X_i^2 / r_j^m 10^{\zeta_j/10} < r_i^m 10^{\zeta_i/10} \right] \rho dA(x,y)$$

$$I_{ki} = \iint_{\text{region (b)}} \frac{r_k^m}{r_i^m} \mathbb{E} \left[10^{\zeta_k/10} X_i^2 / r_k^m 10^{\zeta_k/10} < r_i^m 10^{\zeta_i/10} \right] \rho dA(x,y)$$

$$I_{ji} = \iint_{\text{region (c)}} \frac{r_j^m}{r_i^m} \mathbb{E} \left[10^{\zeta_j/10} X_i^2 / r_j^m 10^{\zeta_j/10} < r_k^m 10^{\zeta_k/10} \right] \rho dA(x,y)$$

$$I_{ki} = \iint_{\text{region (c)}} \frac{r_k^m}{r_i^m} \mathbb{E} \left[10^{\zeta_k/10} X_i^2 / r_k^m 10^{\zeta_k/10} < r_j^m 10^{\zeta_j/10} \right] \rho dA(x,y)$$

Inter-Cell Interference Factor

- K_{ji} : per user inter-cell interference factor from cell j to cell i
- n_j users in cell j produce an amount of interference in cell i equal to $n_j K_{ji}$

Capacity Region

$$\frac{E_b/N_o}{\alpha(E_b/N_o) \left(n_i - 1 + \sum_{j=1}^M n_j \kappa_{ji} \right) / (W/R) + 1} \geq \left(\frac{E_b}{I_o} \right)_{\text{req}}$$

for $i = 1, \dots, M$.

$$n_i + \sum_{j=1}^M n_j \kappa_{ji} \leq \frac{W/R}{\alpha} \left(\frac{1}{E_b/I_o} - \frac{1}{E_b/N_o} \right) + 1 \stackrel{\Delta}{=} c_{\text{eff}}$$

for $i = 1, \dots, M$.

Equal Capacity

- **Equal Capacity: $N = M n$, where:**

$$n = \min_{1 \leq i \leq M} \left[\frac{c_{eff}}{1 + \sum_{j=1}^M \kappa_{ji}} \right]$$

N is the network capacity

M is the total number of cells

Network Capacity, N

$$\max \quad \sum_{i=1}^M n_i,$$

$$\text{subject to} \quad n_i + \sum_{j=1}^M n_j \kappa_{ji} \leq c_{eff},$$

$$\text{for } i = 1, \dots, M.$$

- Reverse power of mobiles
- Pilot-signal power
- Base station location

Power Compensation Factor

- **Fine tune the nominal reverse power of the mobiles**
- **PCF defined for each cell**
- **PCF is a design tool to enhance the capacity of the entire network**

Power Compensation Factor (PCF)

- Interference is linear in PCF

$$I_{ji} = \mathbb{E} \left[\iint_{C_j} \frac{\beta_j r_j^m 10^{\zeta_j/10}}{r_i^m / X_i^2} \rho_j dA \right]$$

$$n_i + \sum_{j=1}^M n_j \frac{\beta_j \kappa_{ji}}{\beta_i} \leq c_{eff} \quad \text{for } i = 1, \dots, M.$$

- Find the sensitivity of the network capacity N w.r.t. the PCF

Sensitivity w.r.t. PCF

$$n = \min_{1 \leq i \leq M} \left[\frac{c_{eff} \beta_i}{\beta_i + \sum_{j=1}^M \beta_j \kappa_{ji}} \right]$$

Let i^* be the index that minimizes the above equation.

The derivative $\frac{dn}{d\beta_k}$ can be calculated .

Sensitivity w.r.t. pilot-signal power

- **Increasing the pilot-signal power of one cell:**
 - **Increases intra-cell interference and decreases inter-cell interference in that cell**
 - **Opposite effect takes place in adjacent cells**

Sensitivity w.r.t. Location

- **Moving a cell away from neighbor A and closer to neighbor B:**
 - **Inter-cell interference from neighbor A increases**
 - **Inter-cell interference from neighbor B decreases**

Optimization using PCF

$$\begin{aligned} & \max_{\underline{\beta}} \quad \sum_{i=1}^M n_i, \quad (\text{network capacity}) \\ & \text{subject to} \quad 1 \leq \underline{\beta} \leq \underline{\beta}^{\max}, \\ & \quad \quad \quad n_i + \sum_{j=1}^M n_j \frac{\beta_j \kappa_{ji}}{\beta_i} \leq c_{eff}, \\ & \quad \quad \quad \text{for } i = 1, \dots, M. \end{aligned}$$

Optimization using Location

$$\begin{aligned} & \max_{\underline{L}} \quad \sum_{i=1}^M n_i, \quad (\text{network capacity}) \\ & \text{subject to} \quad n_i + \sum_{j=1}^M n_j \frac{\beta_j \kappa_{ji}(\underline{L})}{\beta_i} \leq c_{eff}, \\ & \text{for } i = 1, \dots, M. \end{aligned}$$

Optimization using Pilot-signal Power

$$\begin{aligned} & \max_{\underline{T}} \quad \sum_{i=1}^M n_i, \quad (\text{network capacity}) \\ & \text{subject to} \quad n_i + \sum_{j=1}^M n_j \frac{\beta_j \kappa_{ji}(\underline{T})}{\beta_i} \leq c_{eff}, \\ & \text{for } i = 1, \dots, M. \end{aligned}$$

Combined Optimization

$$\begin{aligned} & \max_{\underline{\beta}, \underline{L}, \underline{T}} \quad \sum_{i=1}^M n_i, \quad (\text{network capacity}) \\ & \text{subject to} \quad 1 \leq \underline{\beta} \leq \underline{\beta}^{\max}, \\ & \quad \quad \quad n_i + \sum_{j=1}^M n_j \frac{\beta_j \kappa_{ji}(\underline{L}, \underline{T})}{\beta_i} \leq c_{eff}, \\ & \quad \quad \quad \text{for } i = 1, \dots, M. \end{aligned}$$

Twenty-seven Cell CDMA Network

- Uniform user distribution profile.
- Equal capacity: 18 users per cell, i.e. 486.
- Network capacity becomes 565 without equal capacity constraint.
- Uniform layout is optimal for uniform user distribution.

♦ : Base Station id
() : Cell Capacity

Three Hot Spots

- Network capacity decreases to 540.
- Cells 4, 15, and 19 decrease from 17 to 1, 17 to 1 and from 17 to 9.
- These cells suffer the most from increase in intra-cell and inter-cell interference.

Optimization using PCF

- Network capacity increases to 555.
- Capacity in cells 4, 15 and 19 increases from 1 to 12, 1 to 9 and 9 to 14.
- Smallest capacity in any cell is now 9 instead of 1.

Optimization using Pilot-signal Power

- Network capacity increases to 552.
- Capacity in cells 4, 15, and 19 increases from 1 to 12, 1 to 10, and 9 to 15.
- Smallest capacity in any cell is 10.
- Pilot-signal power increases in these cells.

♦ : Base Station id
() : Cell Capacity
[] : Pilot-signal power

Optimization using Location

- Network capacity increases to 556.
- Capacity in cells 4, 15, and 19 increases from 1 to 14, 1 to 8, and 9 to 17.
- Smallest capacity in any cell is 8.
- Optimization places cells uniformly inside hot spot.

Combined Optimization

- Network capacity increases to 565.
- Smallest capacity in any cell is 13.

Conclusions

- **Cell Design Problem: given a user distribution, find the optimal location and pilot-signal power of the base stations and the reverse power of the mobiles to maximize network capacity.**
- **Uniform network layout is optimal for uniform user distribution.**
- **Combined optimization increases network capacity significantly for non-uniform user distribution.**