CDMA Network Design

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Outline

- **CDMA overview and inter-cell effects**
- **Network capacity**
- **Sensitivity analysis**
  - **Base station location**
  - **Pilot-signal power**
  - **Transmission 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**

CDMA Capacity Issues

- **Depends on inter-cell interference and intra-cell interference**
- **Complete frequency reuse**
- **Soft Handoff**
- **Power Control**
- **Sectorization**
- **Voice activity detection**
- **Graceful degradation**

Relative Average Inter-Cell Interference

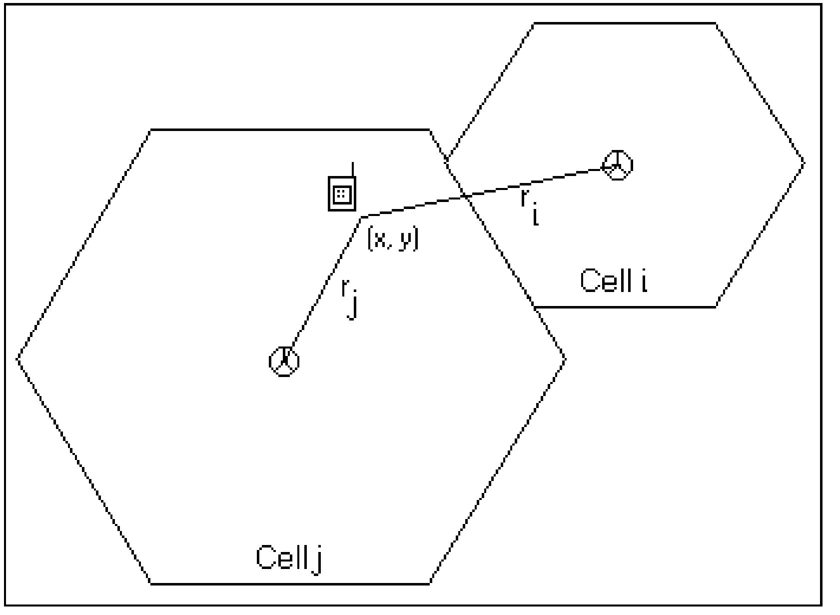
$$I_{ji} = \mathrm{E}\left[\iint_{C_j} \frac{r_j^m(x,y)10^{\zeta_j/10}}{r_i^m(x,y)/\chi_i^2} \omega_j dA(x,y) \right]$$

m is the path loss exponent.

ζ_i is the decibel attenuation due to shadowing, and has zero mean and standard deviation σ_s.

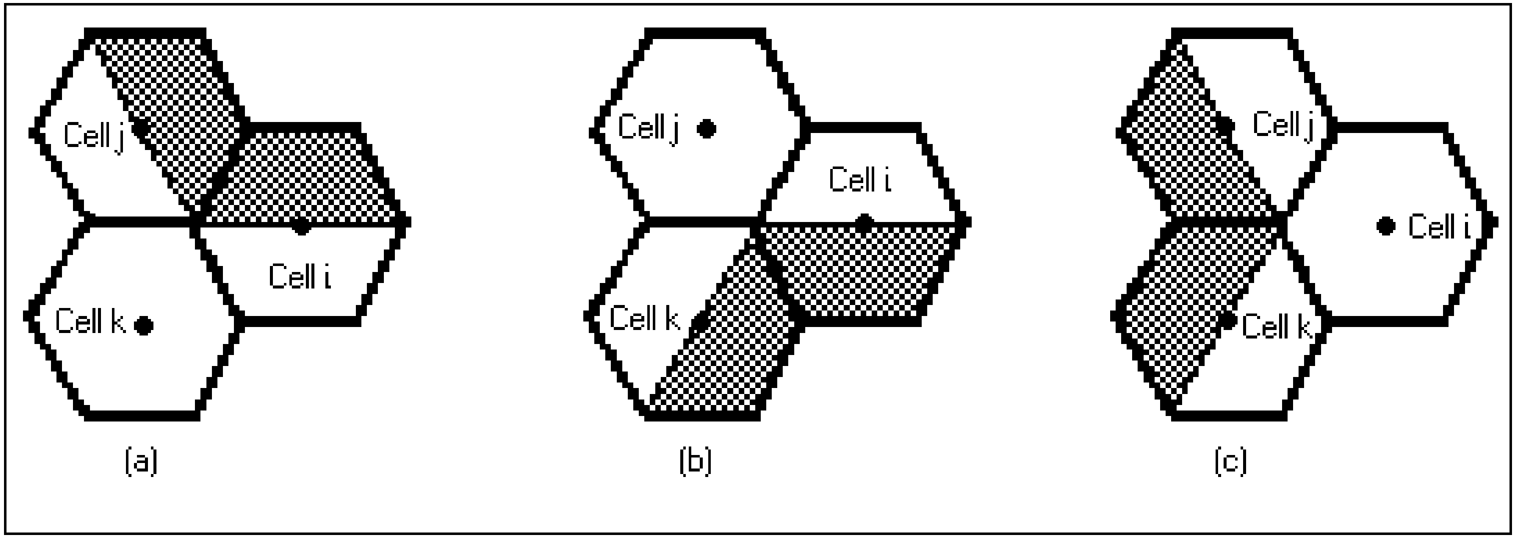
$$\mathrm{E}\left[\chi_i^2 | \zeta_i\right] = 10^{-\zeta_i/10}$$

$$\omega_j = \frac{n_j}{\mathrm{Area}(C_j)}$$



Soft Handoff

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



Soft Handoff

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

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

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

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

Inter-Cell Interference Factor

κ_{ji} per user inter-cell interference factor from cell j to cell i.

n_j users in cell j produce a relative average interference in cell i equal to $n_j \kappa_{ji}$.

Capacity Region

$$\frac{E_b}{\alpha(n_i - 1)E_b R/W + \alpha \sum_{j=1}^{M} n_j \kappa_{ji} E_b R/W + N_0} \geq \left(\frac{E_b}{I_0}\right)_{\text{req}}$$

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

$$n_i + \sum_{j=1}^{M} n_j \kappa_{ji} \leq \frac{W/R}{\alpha}\left(\frac{1}{\left(\frac{E_b}{I_0}\right)_{\text{req}}} - \frac{1}{\frac{E_b}{N_0}}\right) + 1 \overset{\Delta}{=} c_{\text{eff}}$$

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

Network Capacity

$$\max_{(n_1,\dots,n_M)} \quad \sum_{i=1}^{M} n_i, \text{ (network capacity)}$$

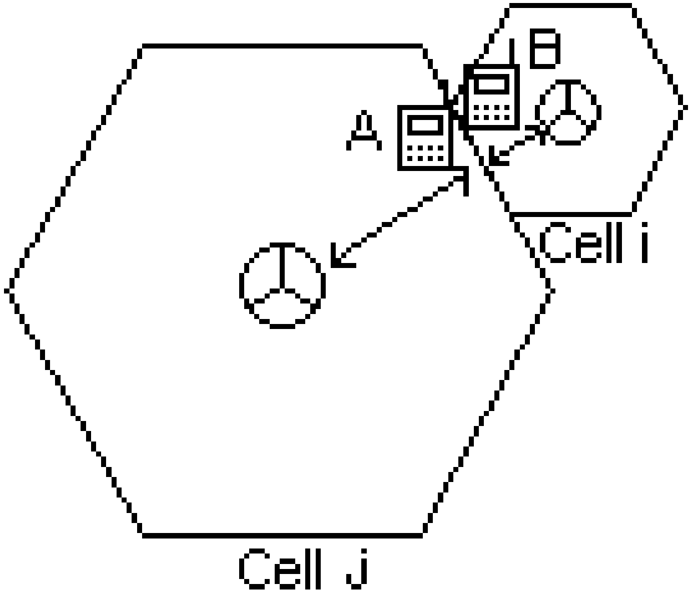
$$\text{subject to} \quad n_i + \sum_{j=1}^{M} n_j \kappa_{ji} - c_{eff} \le 0,$$

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

- **Transmission power of mobiles**
- **Pilot-signal power**
- **Base station location**

Power Compensation Factor

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



Power Compensation Factor (PCF)

- **Interference is linear in PCF**

$$I_{ji} = \mathrm{E}\left[\iint_{C_j} \frac{\beta_j r_j^m 10^{\zeta_j/10}}{r_i^m / \chi_i^2} \omega_j \, dA \right]$$

$$n_i + \sum_{j=1}^{M} n_j \frac{\beta_j \kappa_{ji}}{\beta_i} \le c_{eff}(\beta_i) \ \text{ for } \ i = 1, \ldots, M.$$

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

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

$$\max_{\underline{\beta}} \quad \sum_{i=1}^{M} n_i, \quad \text{(network capacity)}$$

$$\text{subject to} \quad 1 \le \underline{\beta} \le \underline{\beta}^{\max},$$

$$n_i + \sum_{j=1}^{M} n_j \frac{\beta_j \kappa_{ji}}{\beta_i} - c_{eff}(\beta_i) \le 0,$$

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

Optimization using Location

$$\max_{\underline{L}} \quad \sum_{i=1}^{M} n_i, \quad \text{(network capacity)}$$

$$\text{subject to} \quad n_i + \sum_{j=1}^{M} n_j \frac{\beta_j \kappa_{ji}(C_j, L_i)}{\beta_i} - c_{eff}^{(i)} \le 0,$$

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

Optimization using Pilot-signal Power

$$\max_{\underline{T}} \quad \sum_{i=1}^{M} n_i, \quad \text{(network capacity)}$$

$$\text{subject to} \quad n_i + \sum_{j=1}^{M} n_j \frac{\beta_j \kappa_{ji}(C_j, L_i)}{\beta_i} - c_{eff}^{(i)} \le 0,$$

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

Combined Optimization

$$\max_{\underline{\beta},\underline{L},\underline{T}} \quad \sum_{i=1}^{M} n_i, \quad \text{(network capacity)}$$

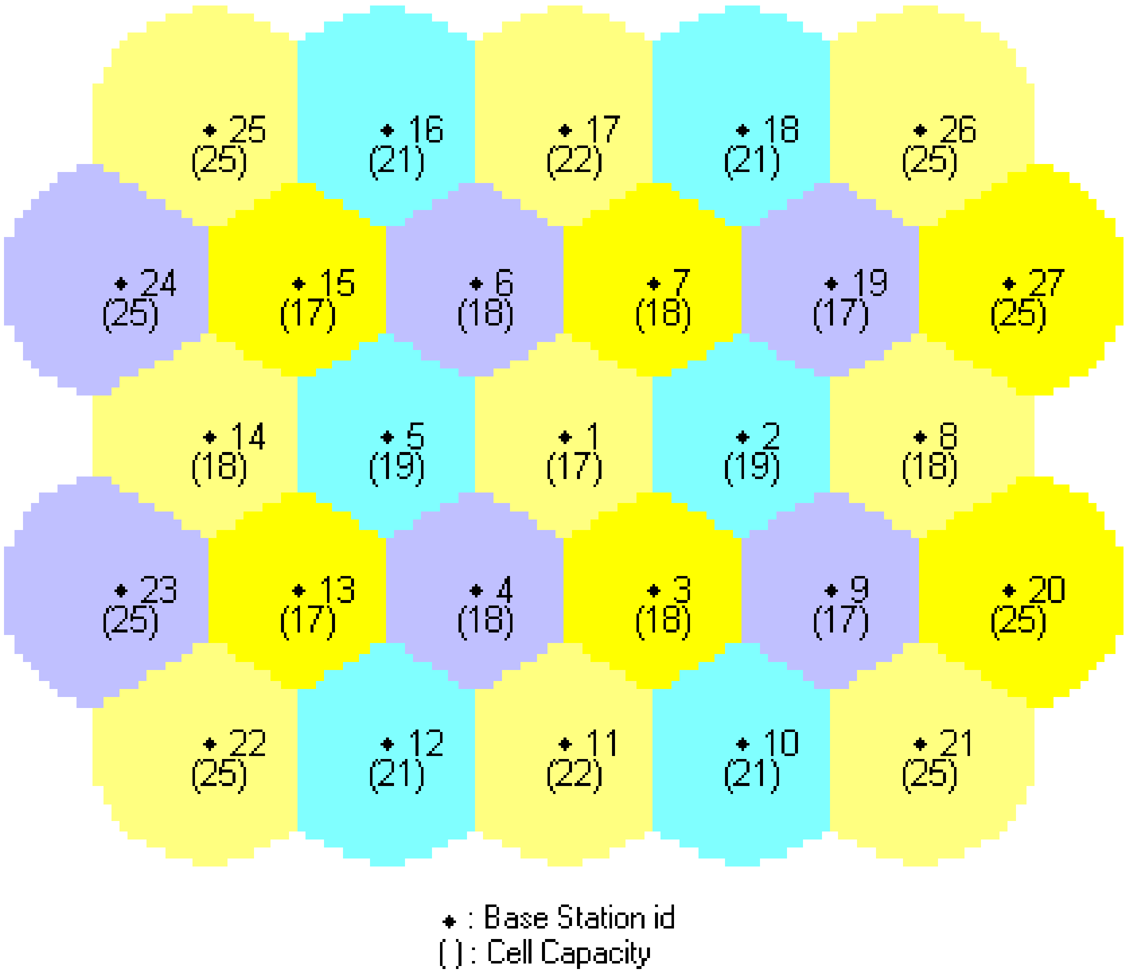
$$\text{subject to} \quad 1 \le \underline{\beta} \le \underline{\beta}^{\max},$$

$$n_i + \sum_{j=1}^{M} n_j \frac{\beta_j \kappa_{ji}(C_j, L_i)}{\beta_i} - c_{eff}(\beta_i) \le 0,$$

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

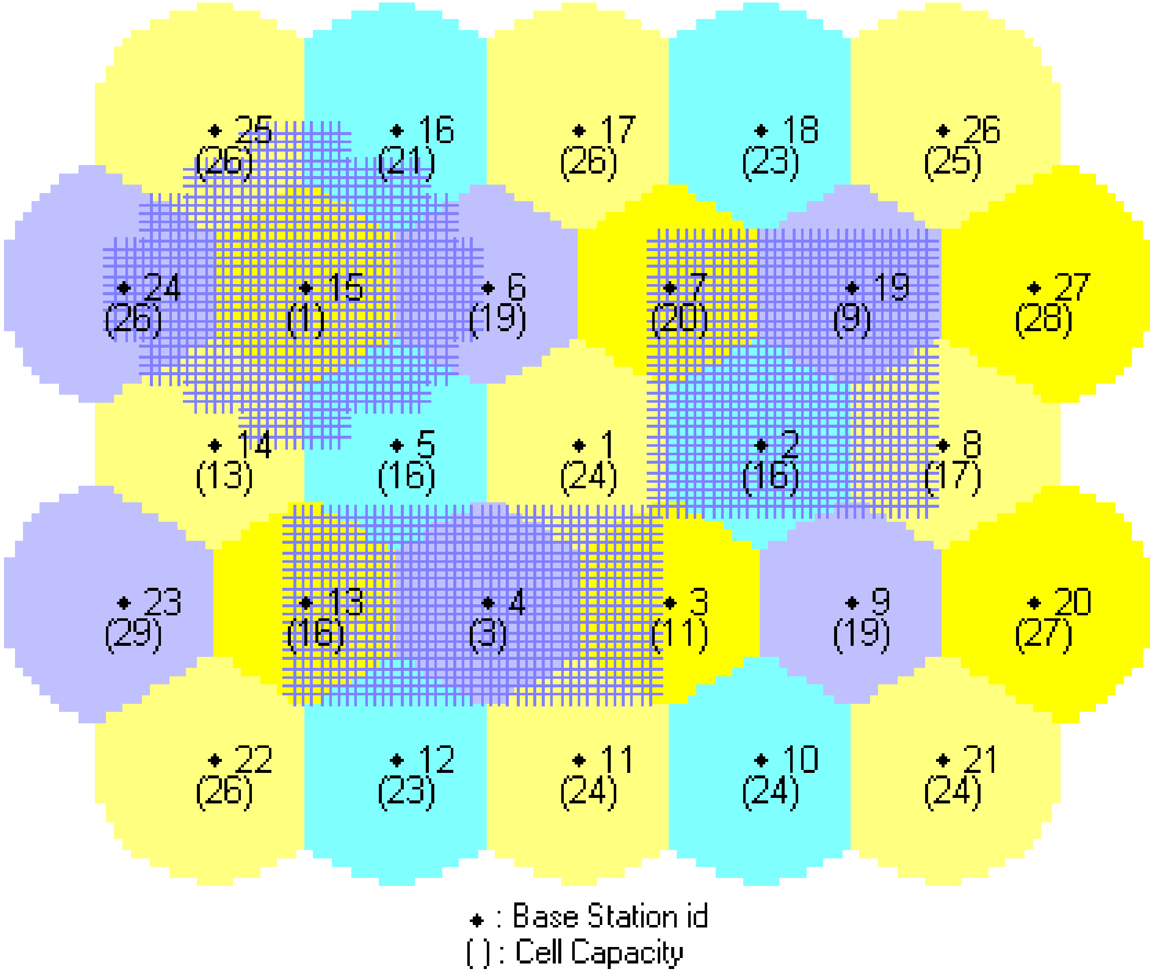
Twenty-seven Cell CDMA Network

- **Uniform user distribution profile.**
- **Network capacity equals 559 simultaneous users.**
- **Uniform placement is optimal for uniform user distribution.**



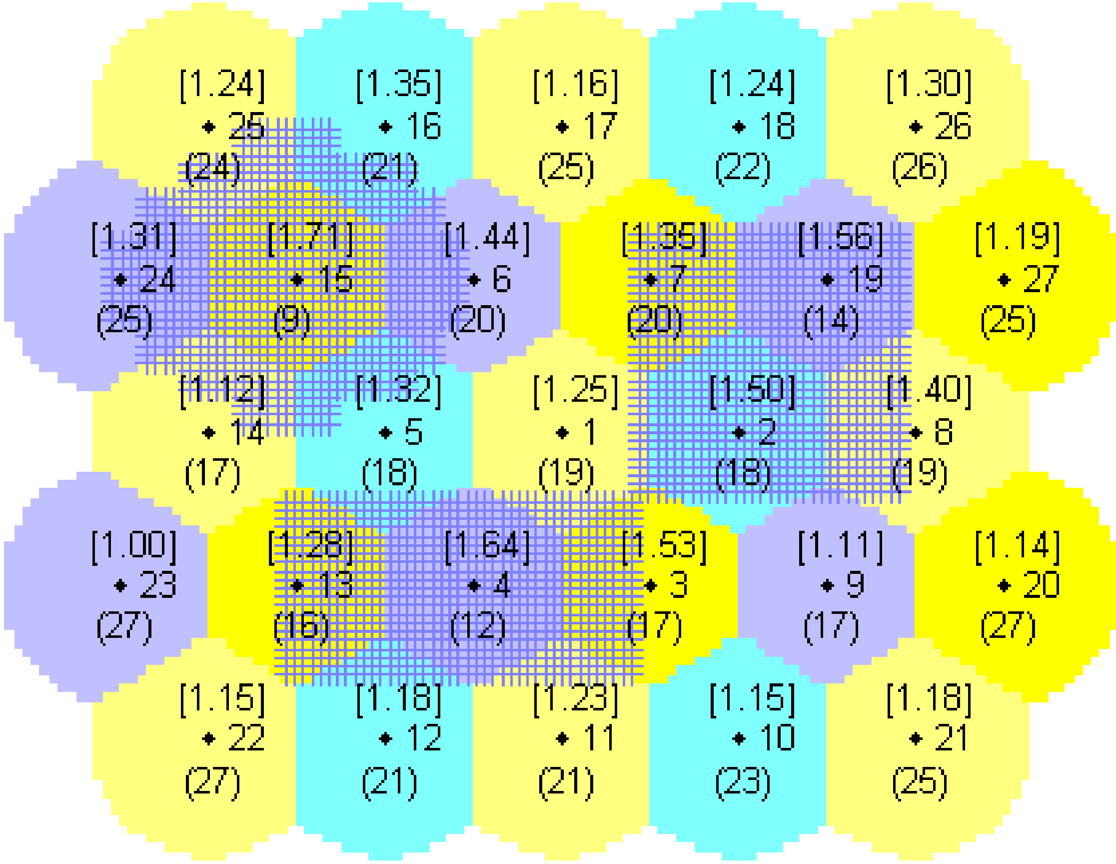
Three Hot Spot Clusters

- **All three hot spots have a relative user density of 5 per grid point.**
- **Network capacity decreases to 536.**
- **Capacity in cells 4, 15, and 19, decreases from 18 to 3, 17 to 1, and 17 to 9.**



Optimization using PCF

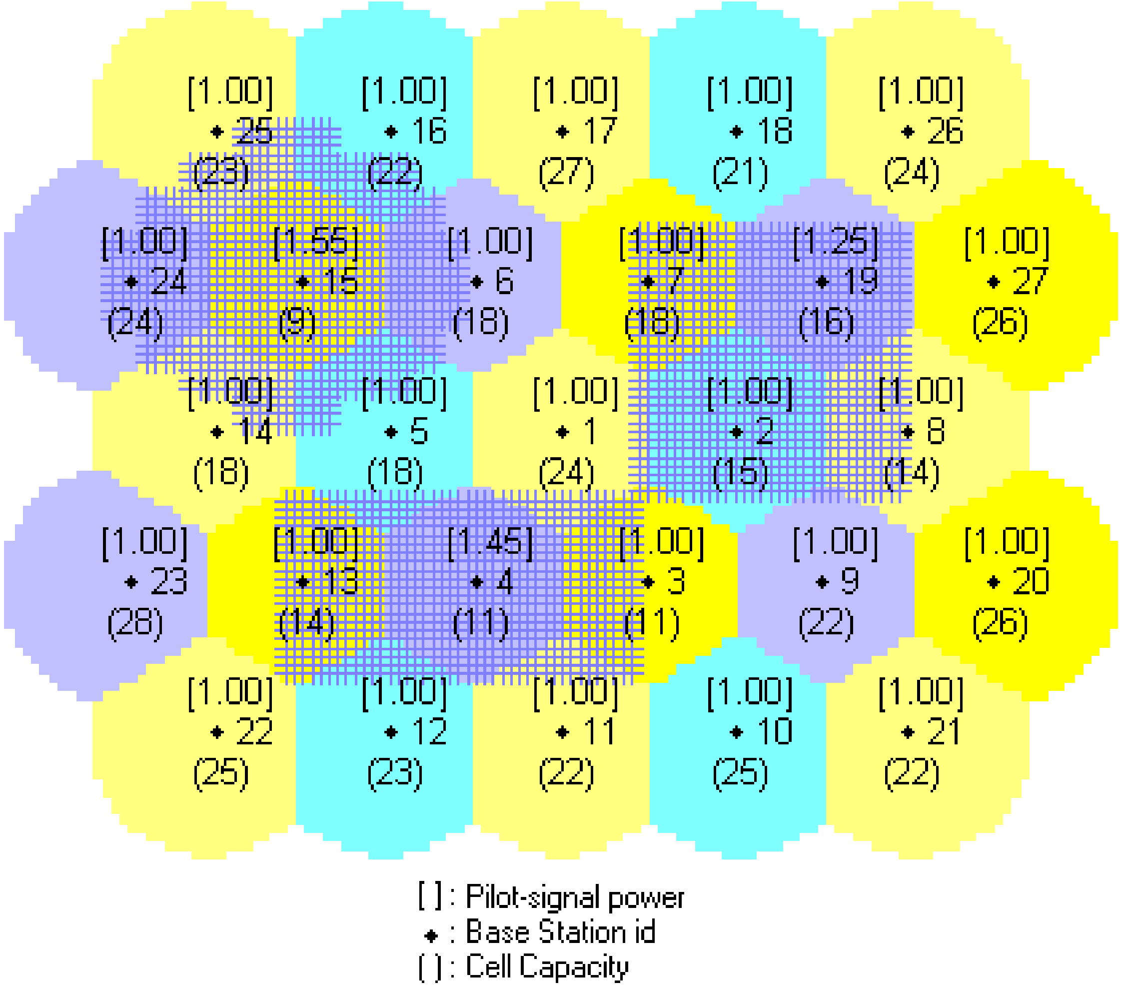
- **Network capacity increases to 555.**
- **Capacity in cells 4, 15, and 19, increases from 3 to 12, 1 to 9, and 9 to 14.**
- **Smallest cell-capacity is 9.**



[ ] : Power compensation factor
◆ : Base Station id
( ) : Cell Capacity

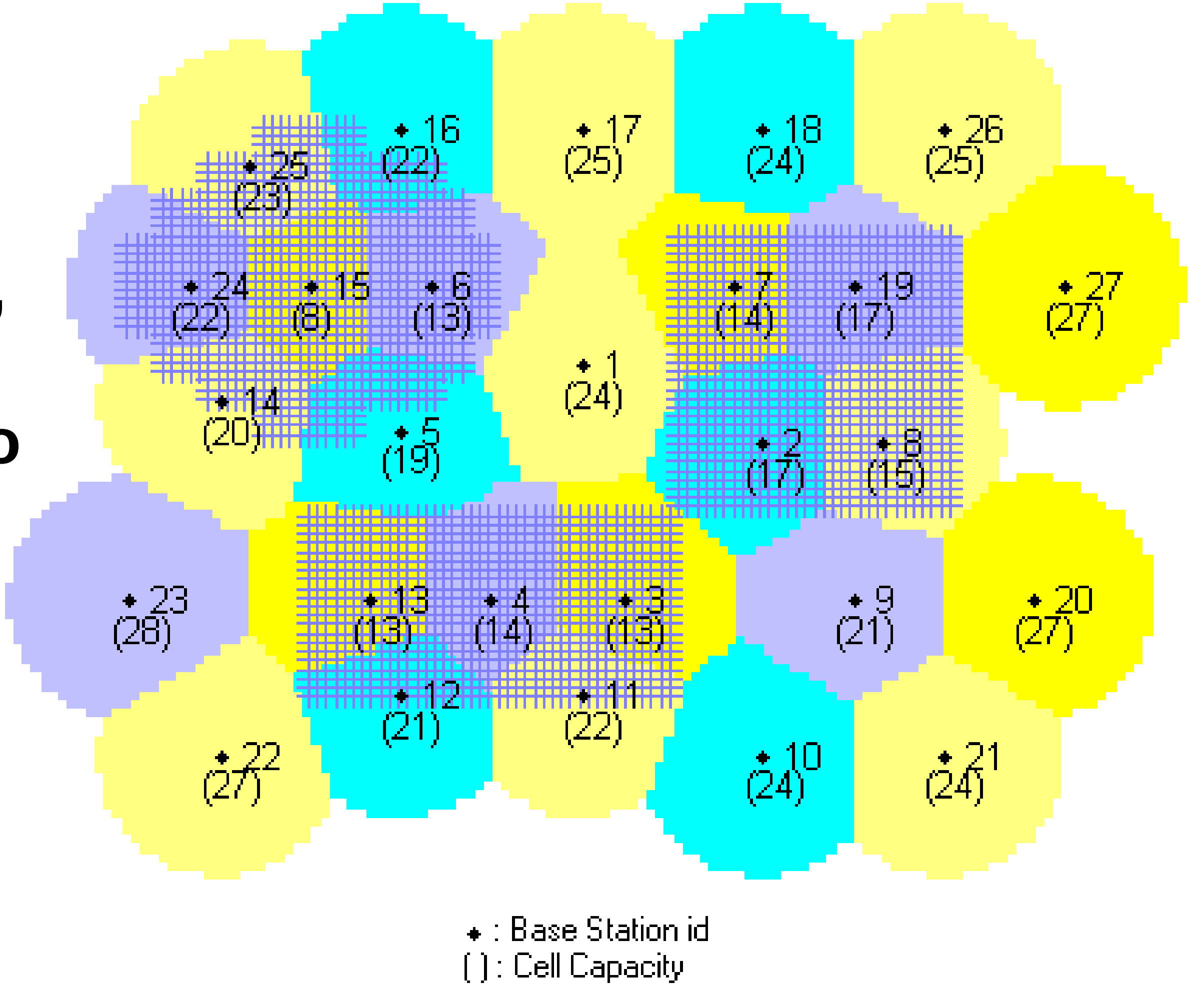
Optimization using Pilot-signal Power

- **Network capacity increases to 546.**
- **Capacity in cells 4, 15, and 19, increases from 3 to 11, 1 to 9, and 9 to 16.**
- **Smallest cell-capacity is 9.**



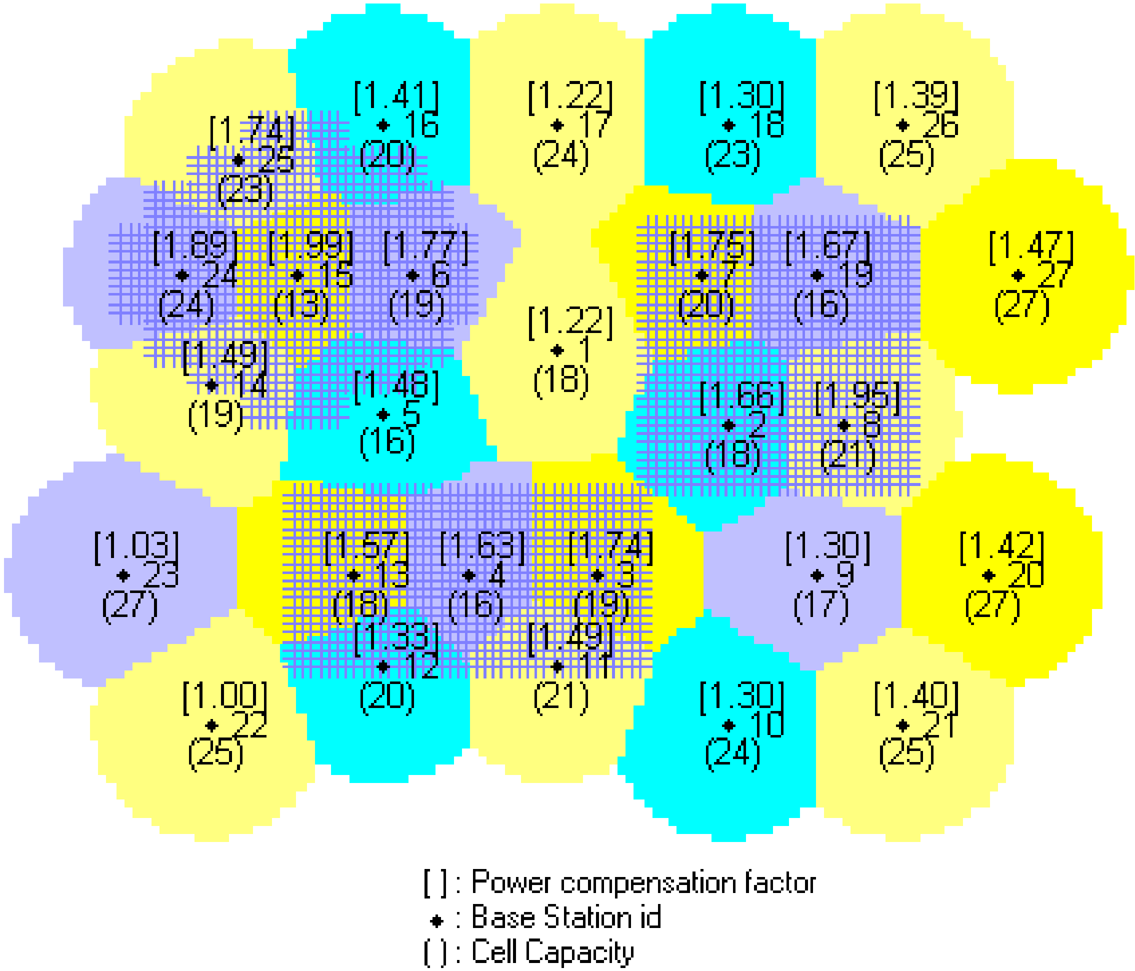
Optimization using Location

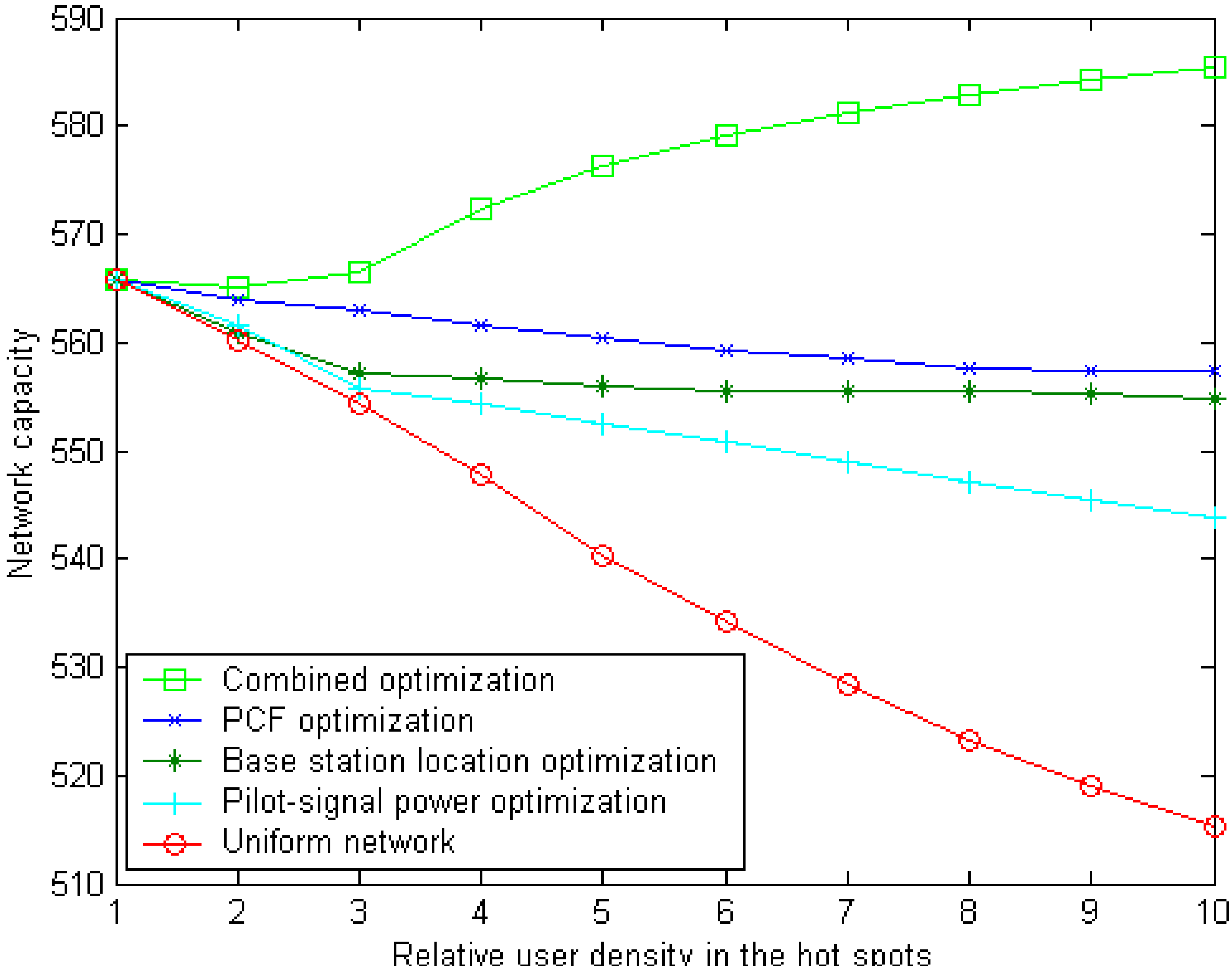
- **Network capacity increases to 549.**
- **Capacity in cells 4, 15, and 19, increases from 3 to 14, 1 to 8, and 9 to 17.**
- **Smallest cell-capacity is 8.**



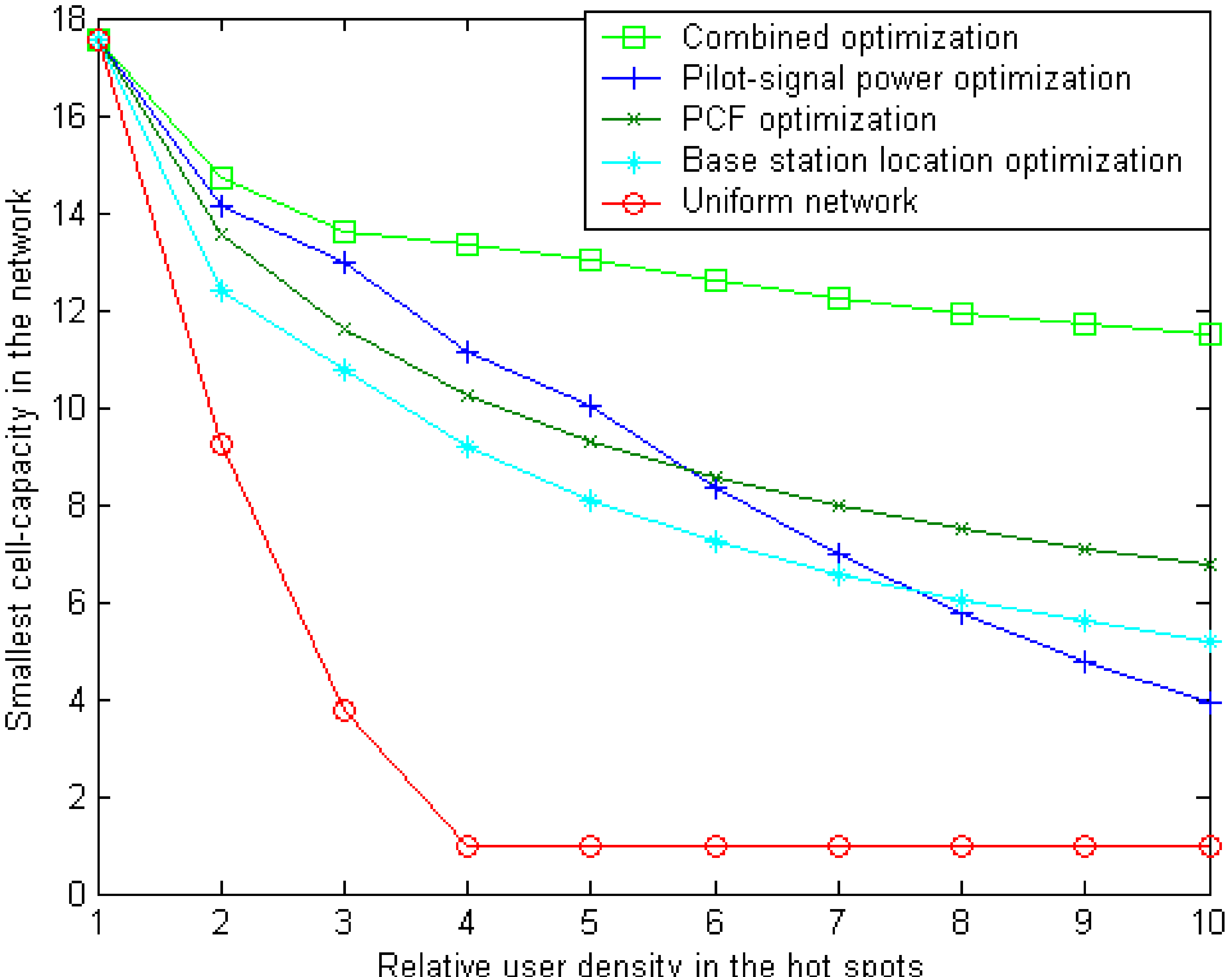
Combined Optimization

- **Network capacity increases to 565.**
- **Capacity in cells 4, 15, and 19, increases from 3 to 16, 1 to 13, and 9 to 16.**
- **Smallest cell-capacity is 13.**





590
580
570
560
550
540
530
520
510
1
2
3
4
5
6
7
8
9
10
Network capacity
Relative user density in the hot spots
Combined optimization
PCF optimization
Base station location optimization
Pilot-signal power optimization
Uniform network



Combined optimization
Pilot-signal power optimization
PCF optimization
Base station location optimization
Uniform network
Smallest cell-capacity in the network
Relative user density in the hot spots
0
2
4
6
8
10
12
14
16
18
1
2
3
4
5
6
7
8
9
10

Combined Optimization (m.c.)

$$\max_{\underline{\beta},\underline{L},\underline{T}} \quad \sum_{i=1}^{M} n_i, \quad \text{(network capacity)}$$

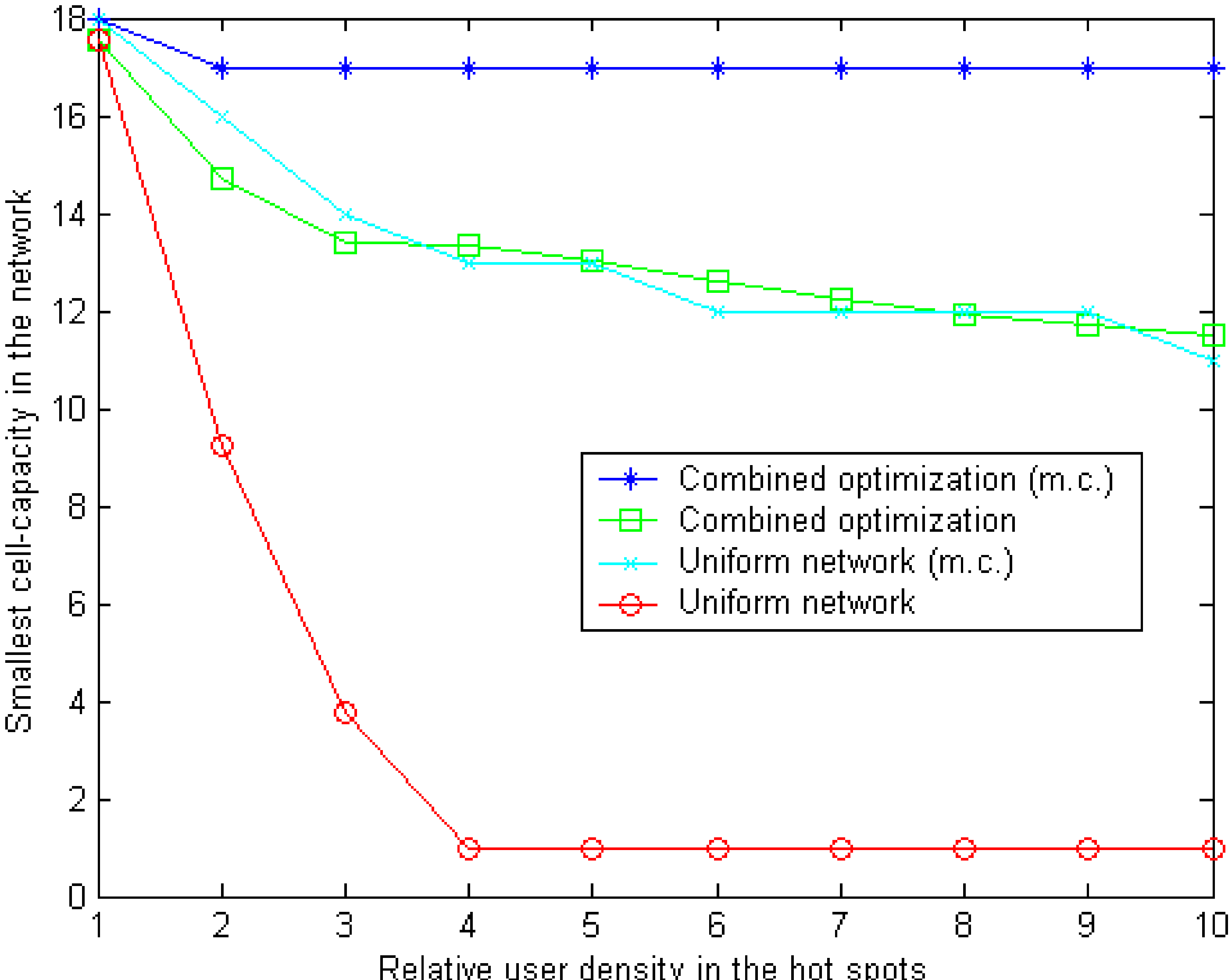
subject to

$$1 \le \underline{\beta} \le \underline{\beta}^{\max},$$

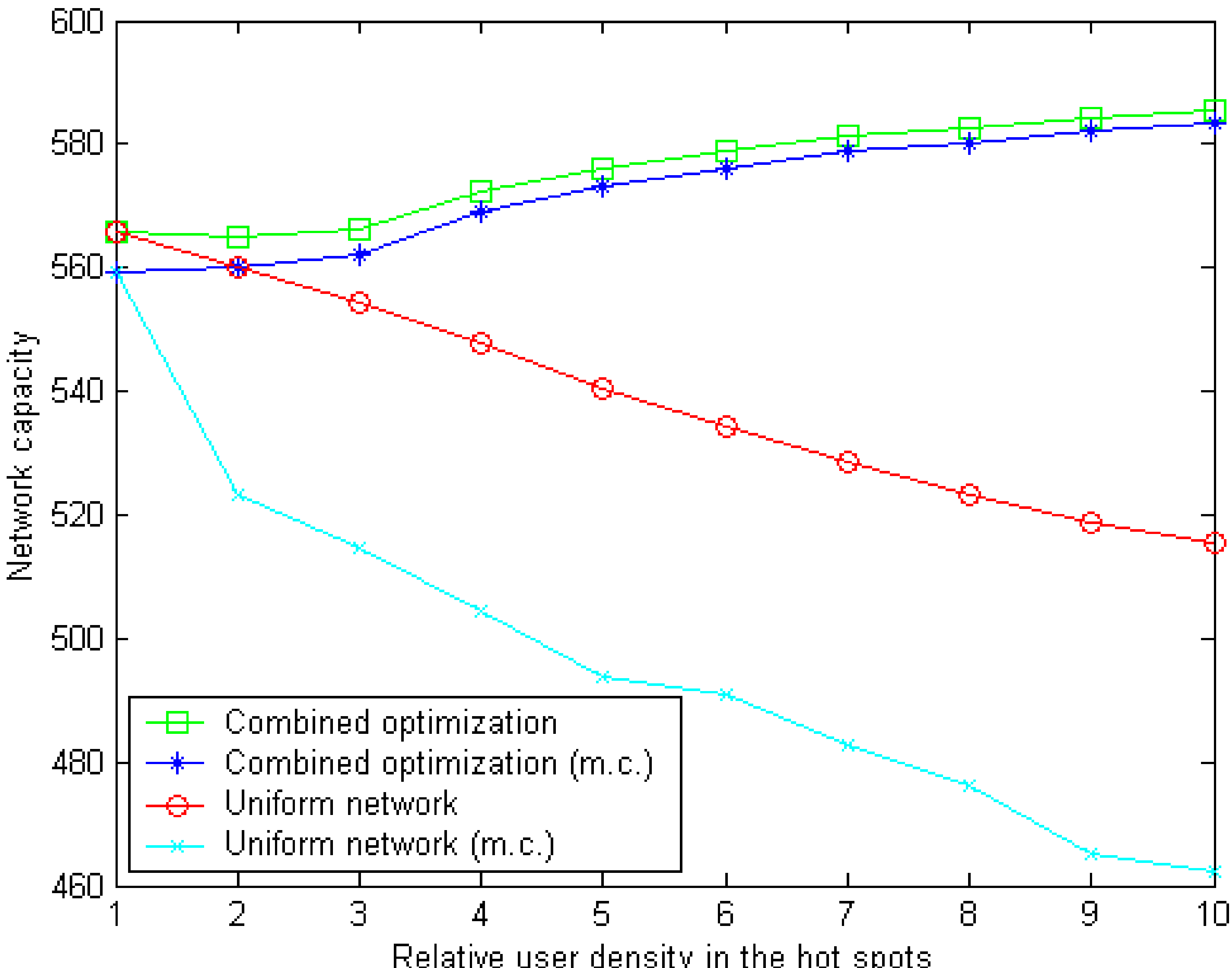
$$n_i + \sum_{j=1}^{M} n_j \frac{\beta_j \kappa_{ji}(C_j, L_i)}{\beta_i} - c_{eff}(\beta_i) \le 0,$$

$$n_i \ge \lfloor n_{\min} \rfloor,$$

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



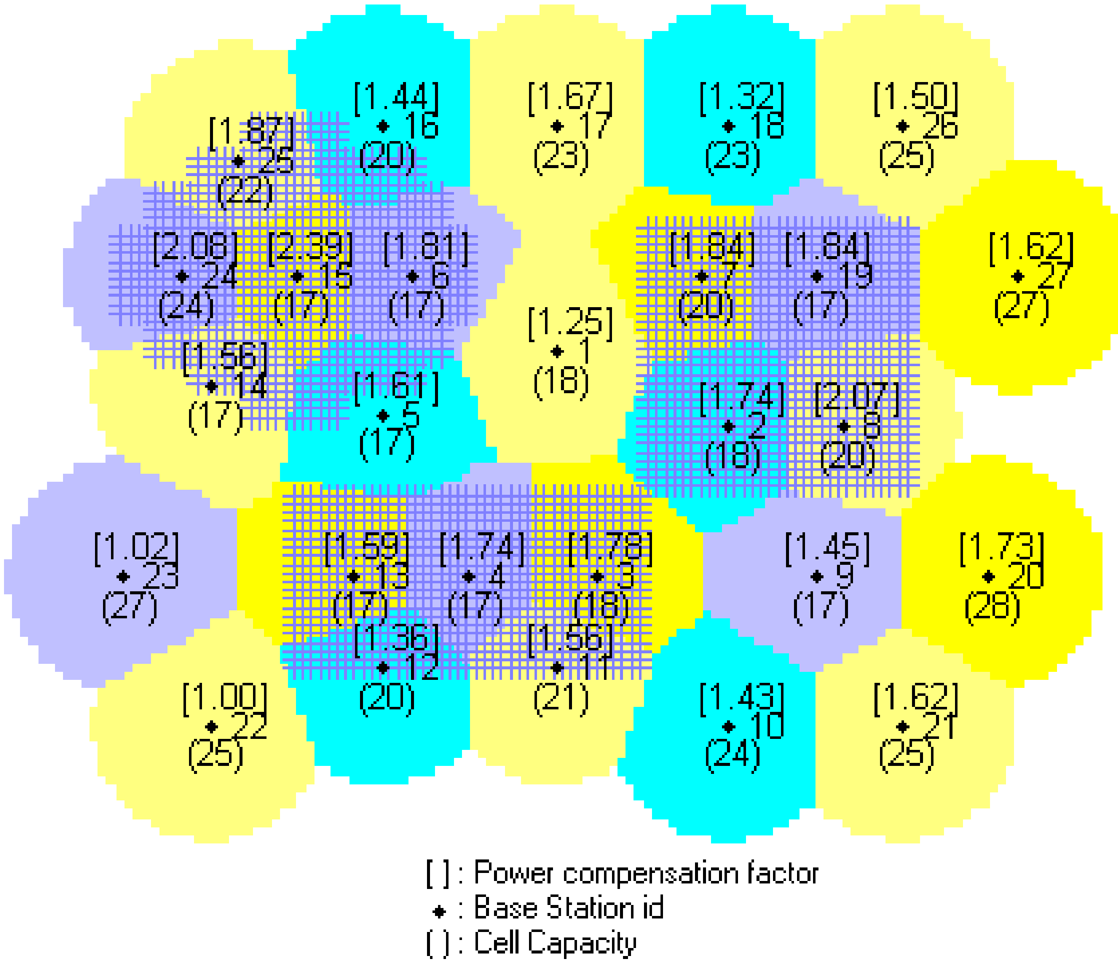
Smallest cell-capacity in the network
Relative user density in the hot spots
0
2
4
6
8
10
12
14
16
18
1
2
3
4
5
6
7
8
9
10
Combined optimization (m.c.)
Combined optimization
Uniform network (m.c.)
Uniform network

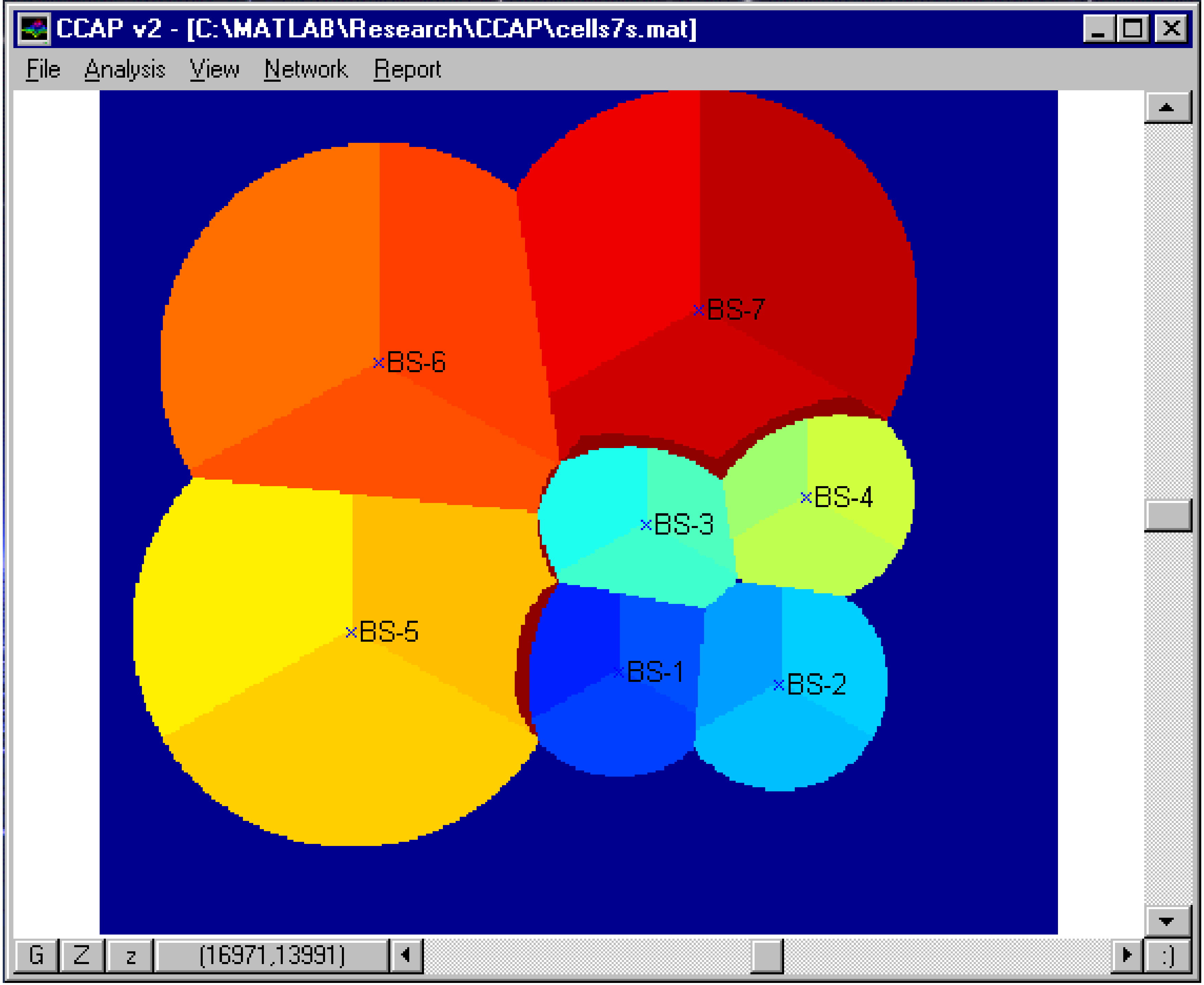


600
580
560
540
520
500
480
460
Network capacity
1
2
3
4
5
6
7
8
9
10
Relative user density in the hot spots
Combined optimization
Combined optimization (m.c.)
Uniform network
Uniform network (m.c.)

Combined Optimization (m.c.)

- **Network capacity increases to 564.**
- **Capacity in cells 4, 15, and 19, increases from 3 to 17, 1 to 17, and 9 to 17.**
- **Smallest cell-capacity is 17.**




CCAP v2 - [C:\MATLAB\Research\CCAP\cells7s.mat]
File
Analysis
View
Network
Report
BS-7
BS-6
BS-3
BS-4
BS-5
BS-1
BS-2
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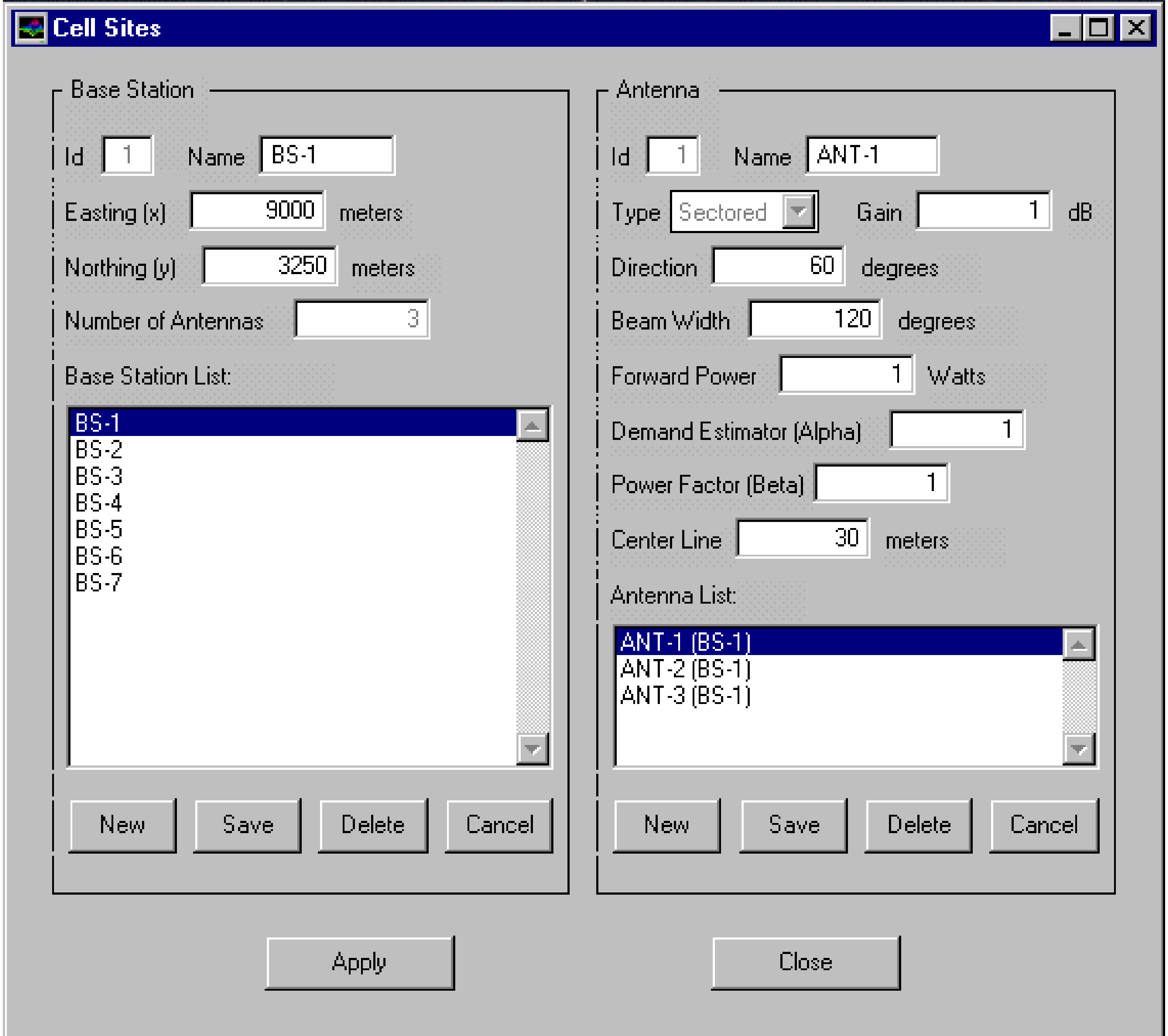
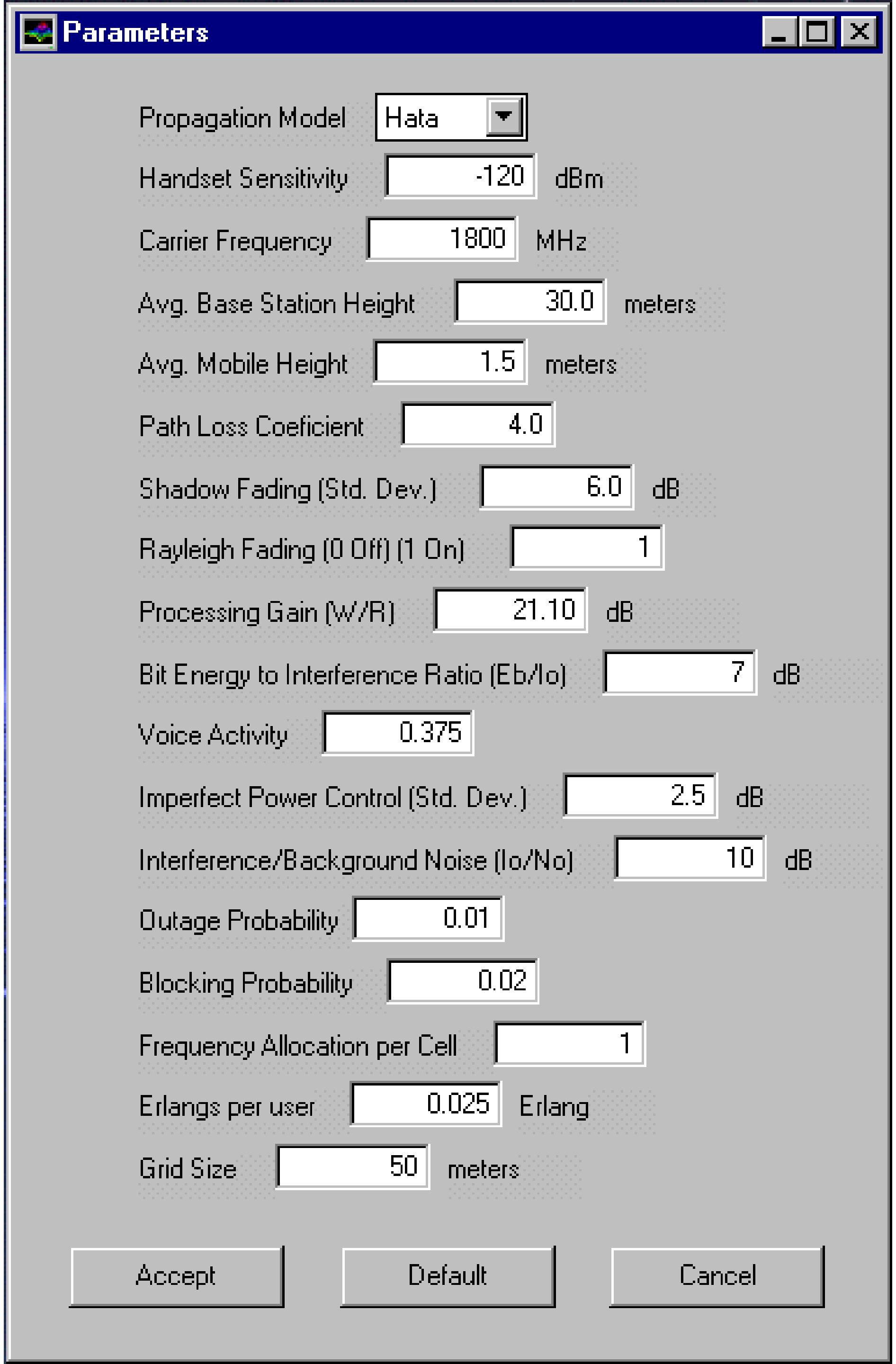

Cell Sites
Base Station
Id
1
Name
BS-1
Easting (x)
9000
meters
Northing (y)
3250
meters
Number of Antennas
3
Base Station List:
BS-1
BS-2
BS-3
BS-4
BS-5
BS-6
BS-7
New
Save
Delete
Cancel
Antenna
Id
1
Name
ANT-1
Type
Sectored
Gain
1
dB
Direction
60
degrees
Beam Width
120
degrees
Forward Power
1
Watts
Demand Estimator (Alpha)
1
Power Factor (Beta)
1
Center Line
30
meters
Antenna List:
ANT-1 (BS-1)
ANT-2 (BS-1)
ANT-3 (BS-1)
New
Save
Delete
Cancel
Apply
Close


Parameters
Propagation Model
Hata
Handset Sensitivity
-120
dBm
Carrier Frequency
1800
MHz
Avg. Base Station Height
30.0
meters
Avg. Mobile Height
1.5
meters
Path Loss Coeficient
4.0
Shadow Fading (Std. Dev.)
6.0
dB
Rayleigh Fading (0 Off) (1 On)
1
Processing Gain (W/R)
21.10
dB
Bit Energy to Interference Ratio (Eb/Io)
7
dB
Voice Activity
0.375
Imperfect Power Control (Std. Dev.)
2.5
dB
Interference/Background Noise (Io/No)
10
dB
Outage Probability
0.01
Blocking Probability
0.02
Frequency Allocation per Cell
1
Erlangs per user
0.025
Erlang
Grid Size
50
meters
Accept
Default
Cancel

Conclusions

- **Solved cell design problem: given a user distribution, found 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.**