Impact of Interference Model on Capacity in CDMA Cellular Networks

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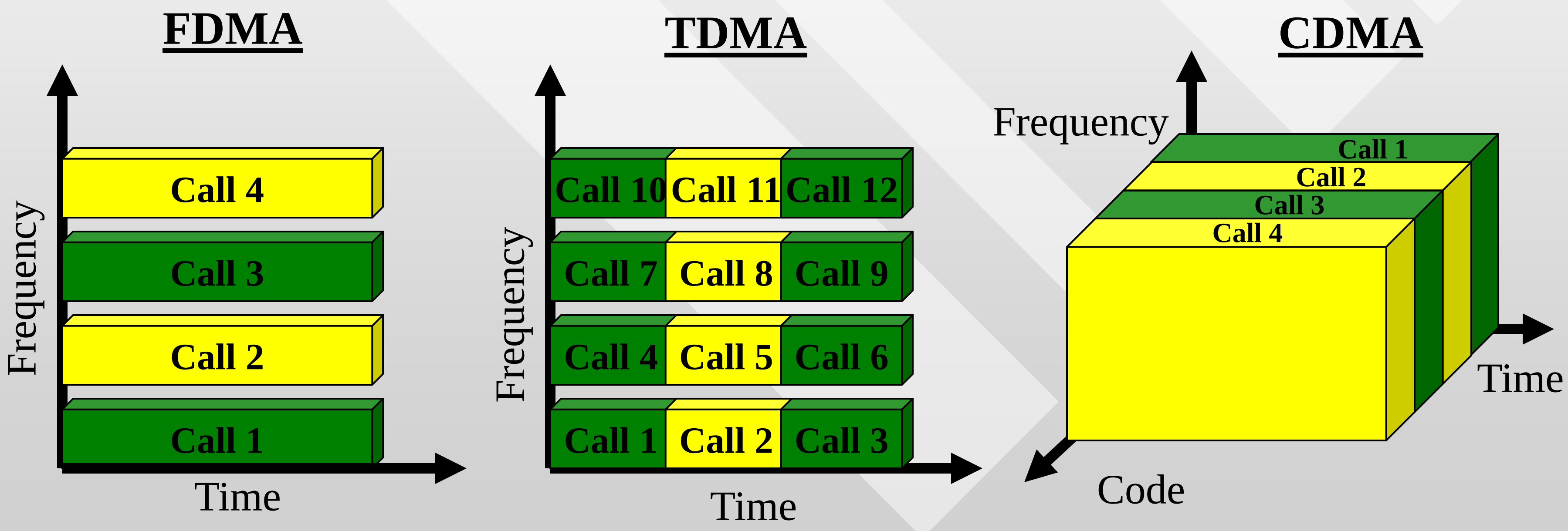
Outline

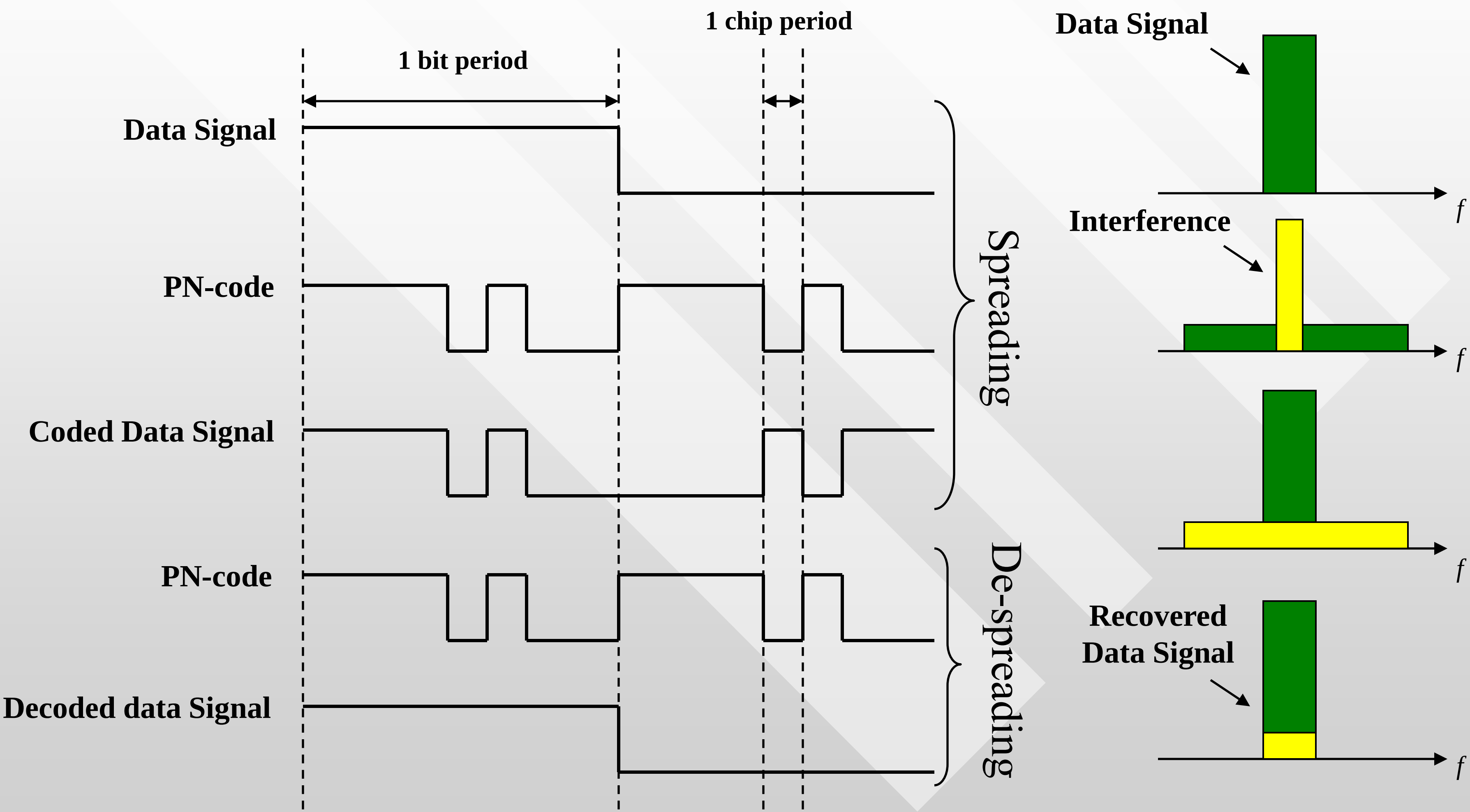
- Introduction to CDMA networks
- Average interference model
- Actual interference model
- Optimized capacity
- 2D Gaussian user model
- Conclusions

Code Division Multiple Access (CDMA) Overview

- Multiple access schemes

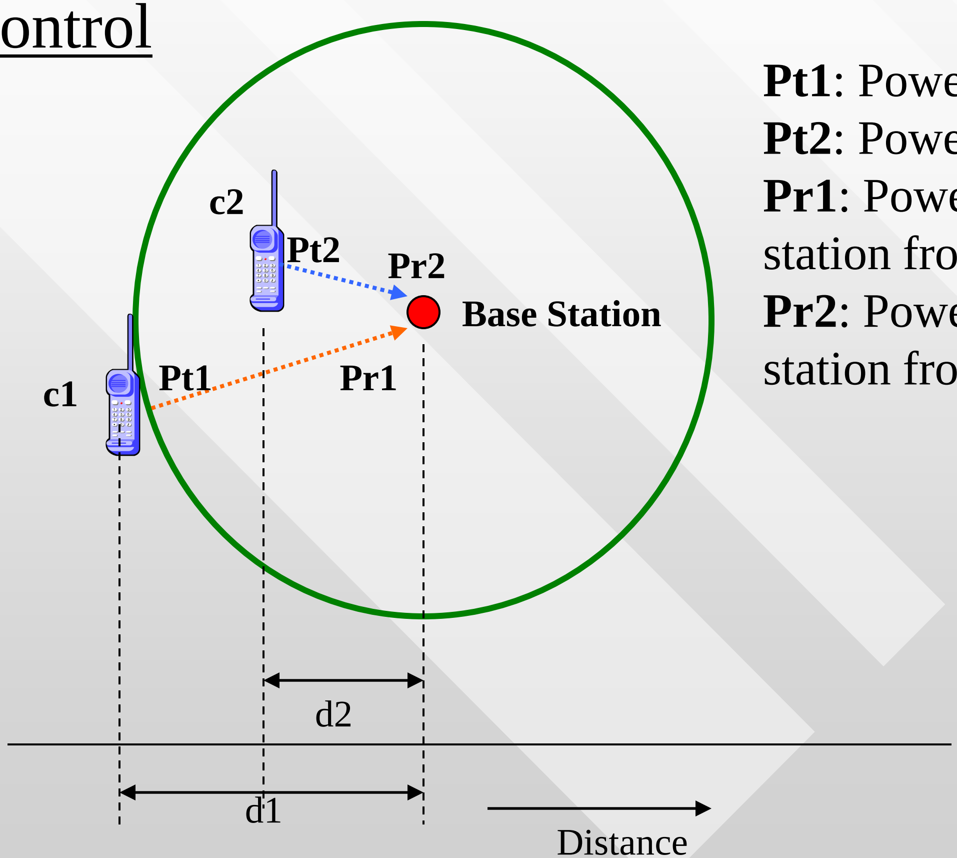


Spread Spectrum: Direct Spreading



Factors Affecting Capacity

- Power Control

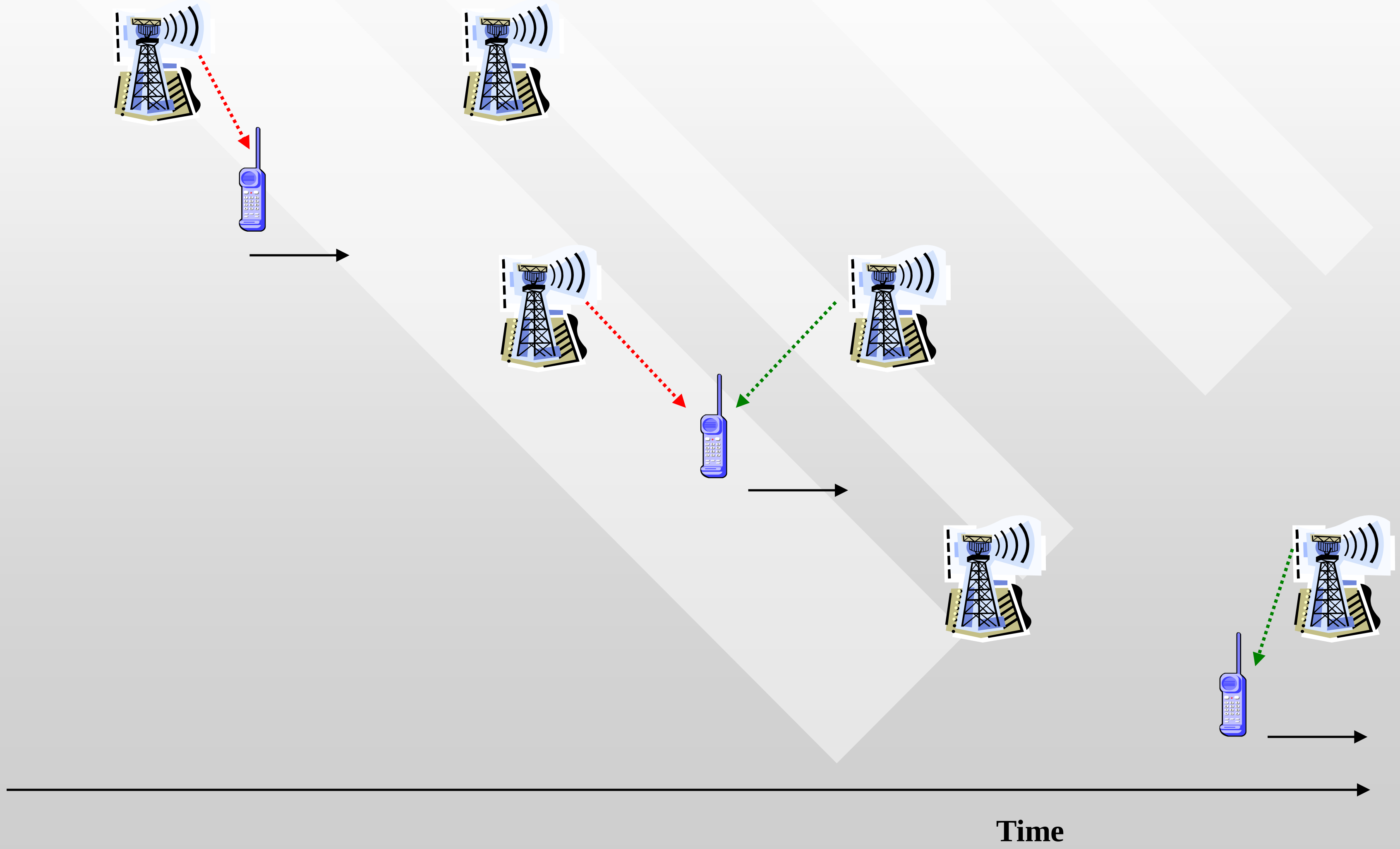


Pt1: Power transmitted from c1
Pt2: Power transmitted from c2
Pr1: Power received at base station from c1
Pr2: Power received at base station from c2

Pr1 = Pr2

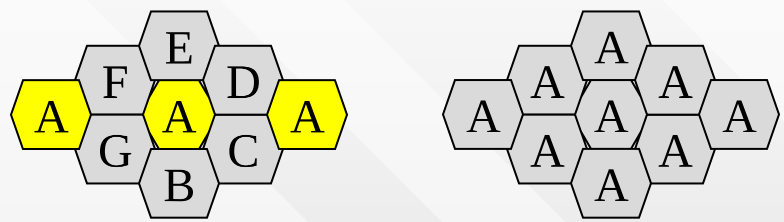
Factors Affecting Capacity (cont.)

- Soft handover of calls



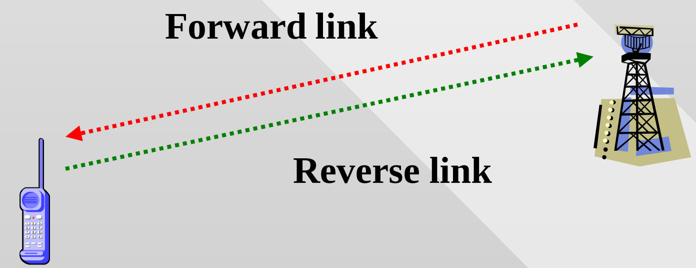
Factors Affecting Capacity (cont.)

- Universal frequency use



TDMA or FDMA   CDMA

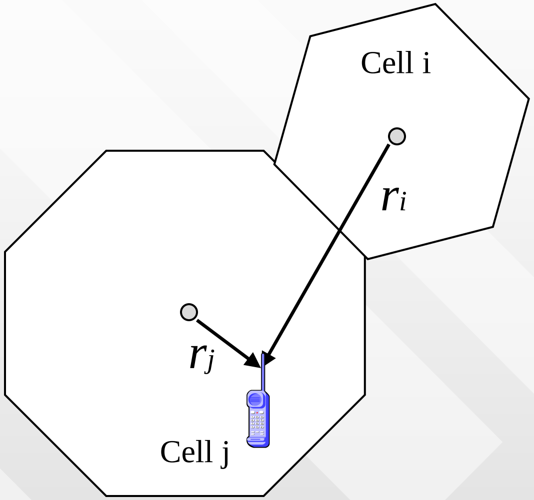
- Reverse link vs forward link



- Voice activity factor

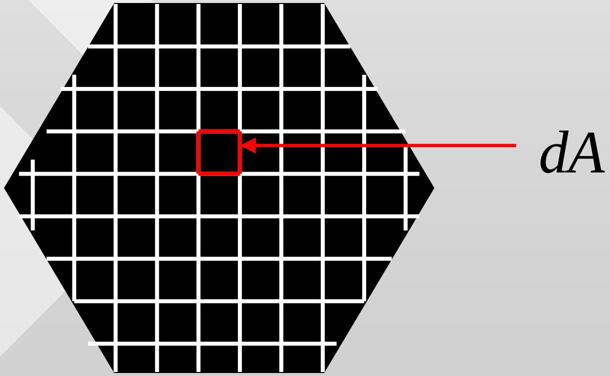
Relative Average Inter-cell Interference Model

I_{ji} = Relative average interference at cell i caused by n_j users in cell j



$$I_{ji} = \mathrm{E}\left[\iint_{Cj} \frac{r_j^m(x,y)10^{\zeta_j/10}}{r_i^m(x,y)/\chi_i^2}\,\frac{n_j}{A_j}\,dA(x,y)\right] \quad \text{— (A)}$$

$$I_{ji} = e^{(\gamma\sigma_s)^2}\,\frac{n_j}{A_j}\iint_{Cj} \frac{r_j^m(x,y)}{r_i^m(x,y)}\,dA(x,y) \quad \text{— (B)}$$



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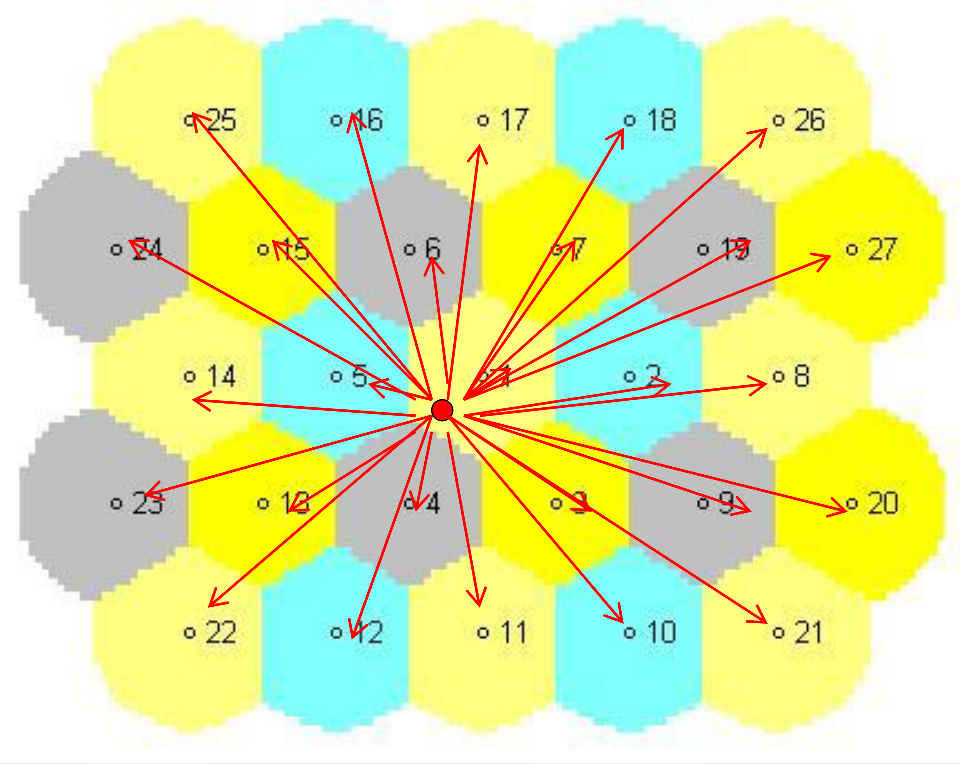
Interference Matrix

$$F[j,i]=\begin{pmatrix} 11 & 12 & 13 & \dots & \dots & 1M \\ 21 & 22 & & & & \\ 31 & 32 & & & & \\ \dots & \dots & & & & \\ \dots & \dots & & & & \\ M1 & M2 & & & & MM \end{pmatrix}$$

where $F[j,i]=I_{ji}/n_j$ for $i,\ j=1,\dots,M$,

and n_j is the number of users in cell j



$$I_2=1\times\begin{pmatrix} 11 & 12 & 13 & \dots & \dots & 1M \\ 21 & 22 & & & & \\ 31 & 32 & & & & \\ \dots & \dots & & & & \\ \dots & \dots & & & & \\ M1 & M2 & & & & MM \end{pmatrix}$$

$$I_2=1\times F[1,2]$$

Hence, the total relative average inter-cell interference experienced by cell i is

$$I_i=\sum_{j=1}^{M} n_j F[j,i] \quad \text{——} \ \text{Ⓒ}$$

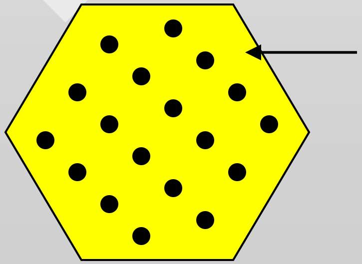
Relative Actual Inter-cell Interference Model

- Interference matrix *F* cannot be calculated in advance
- Instead, a new interference matrix *U* is computed as follows
- For a user *k* in cell *j*, the relative actual interference offered by this user to cell *i* is

$$\left(U_{ji}\right)_k = e^{(\gamma\sigma_s)^2}\left(\frac{r_j}{r_i}\right)^m \qquad \text{— (D)}$$

- Hence, the total relative actual inter-cell interference at cell *i* caused by every user in the network is

$$I_i = \sum_{j=1}^{M}\sum_{k=1}^{n_j}\left(U_{ji}\right)_k, \text{ for } i \neq j \qquad \text{— (E)}$$



Actual Interference Matrix *U*

- Example: for a new call in cell 2, compute row matrix U[2,i] for i = 1,…,M using equation D

$$U_{2i} = [21 \;\; 22 \;\; 23 \;\; \ldots\ldots \;\; 2M]$$

- Update 2nd row of interference matrix *U* by adding the above row matrix to it.

$$U[j,i] = U_{2i} + \begin{pmatrix} 11 & 12 & 13 & \ldots & \ldots & 1M \\ 21 & 22 & & & & \\ 31 & 32 & & & & \\ \ldots & \ldots & & & & \\ \ldots & \ldots & & & & \\ M1 & M2 & & & & MM \end{pmatrix}$$

Capacity

• The capacity of a CDMA network is determined by maintaining a lower bound on the bit energy to interference density ratio, given by

$$\left(\frac{E_b}{I_0}\right)_i = \frac{E_b}{\alpha\left(RE_b\right)\left(n_i - 1 + I_i\right)/W + N_0} \quad \text{—— (F)}$$

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

- W = Spread signal bandwidth
- R = bits/sec (information rate)
- α = voice activity factor
- n_i = users in cell *i*
- N_0 = background noise spectral density

• Let τ be that threshold above which the bit error rate must be maintained, then by rewriting Eq. F

$$n_i + I_i \le \frac{W/R}{\alpha}\left(\frac{1}{\tau} - \frac{1}{E_b/N_0}\right) + 1 \triangleq c_{eff} \quad \text{—— (G)}$$

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

Back

Capacity Cases

- Equal capacity: all cells have an equal number of users

$$n_i = \text{n for all } i$$

- Optimized Capacity: A set of users in each cell obtained by solving following optimization problem

$$\begin{aligned} &\max_{\underline{n}} && \sum_{i=1}^{M} n_i , \\ &\text{subject to} && n_i + I_i \le c_{eff} , \\ & && \text{for } i = 1, \ldots, M . \end{aligned} \qquad \text{— (H)}$$

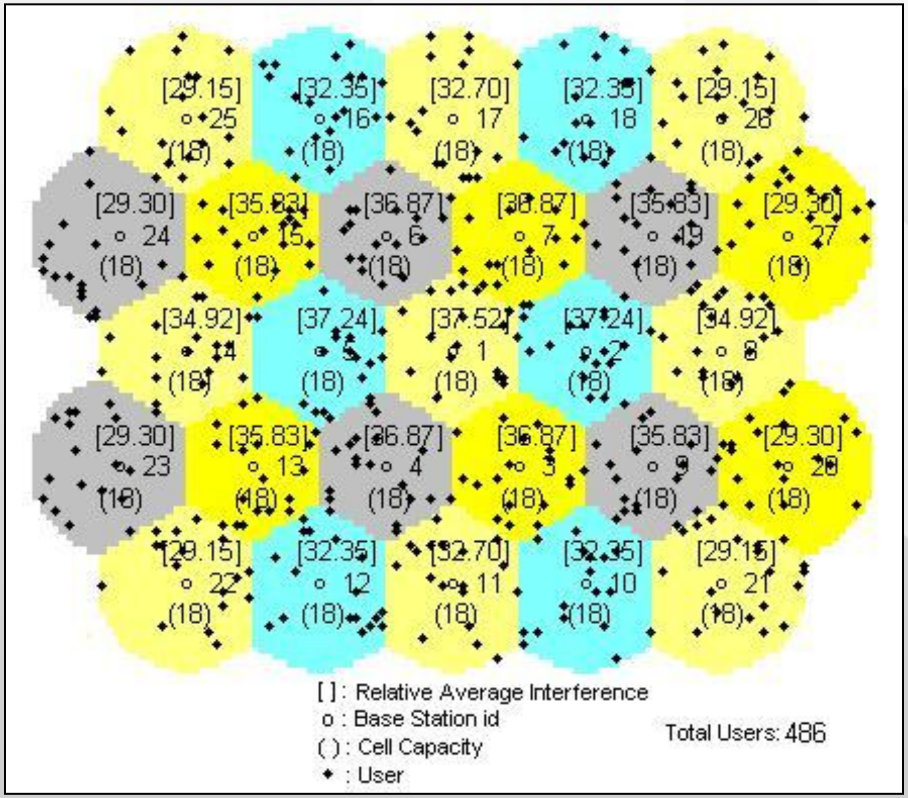
Simulations

- <u>Network configuration</u>
  - COST-231 propagation model
  - Carrier frequency = 1800 MHz
  - Average base station height = 30 meters
  - Average mobile height = 1.5 meters
  - Path loss coefficient, m = 4
  - Shadow fading standard deviation, σ_s = 6 dB
  - Processing gain, W/R = 21.1 dB
  - Bit energy to interference ratio threshold, τ = 9.2 dB
  - Interference to background noise ratio, I_0/N_0 = 10 dB
  - Voice activity factor, α = 0.375

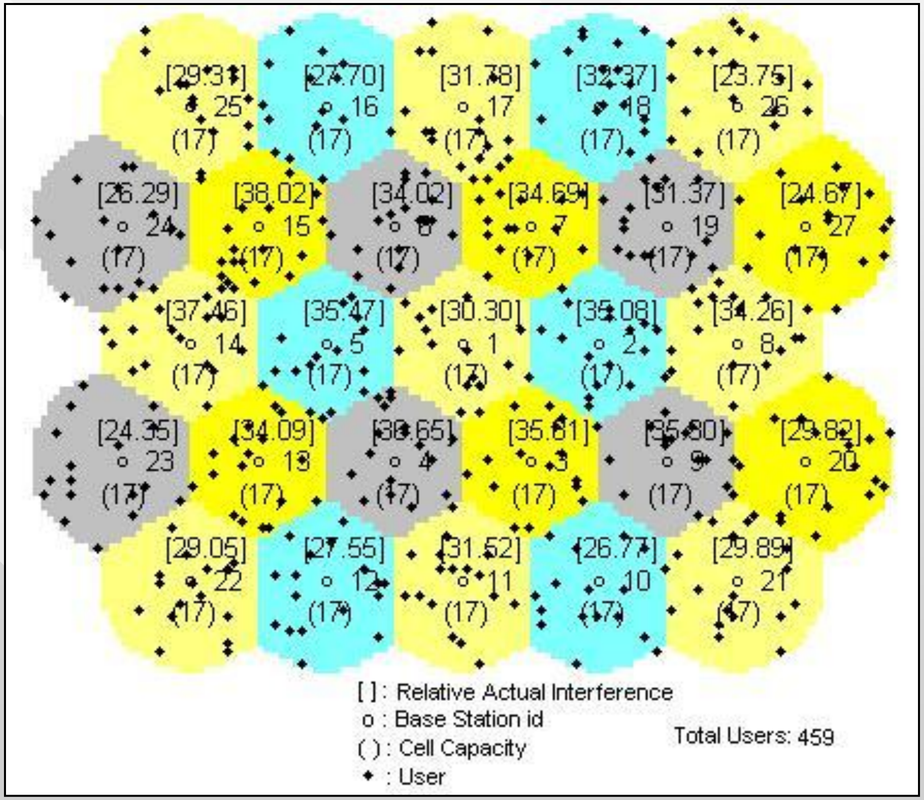
- These values in Eq. G give upper bound on the relative interference in every cell, c_eff = 38.25.

Simulations – Equal Capacity

- Average interference
  - Users in each cell: 18

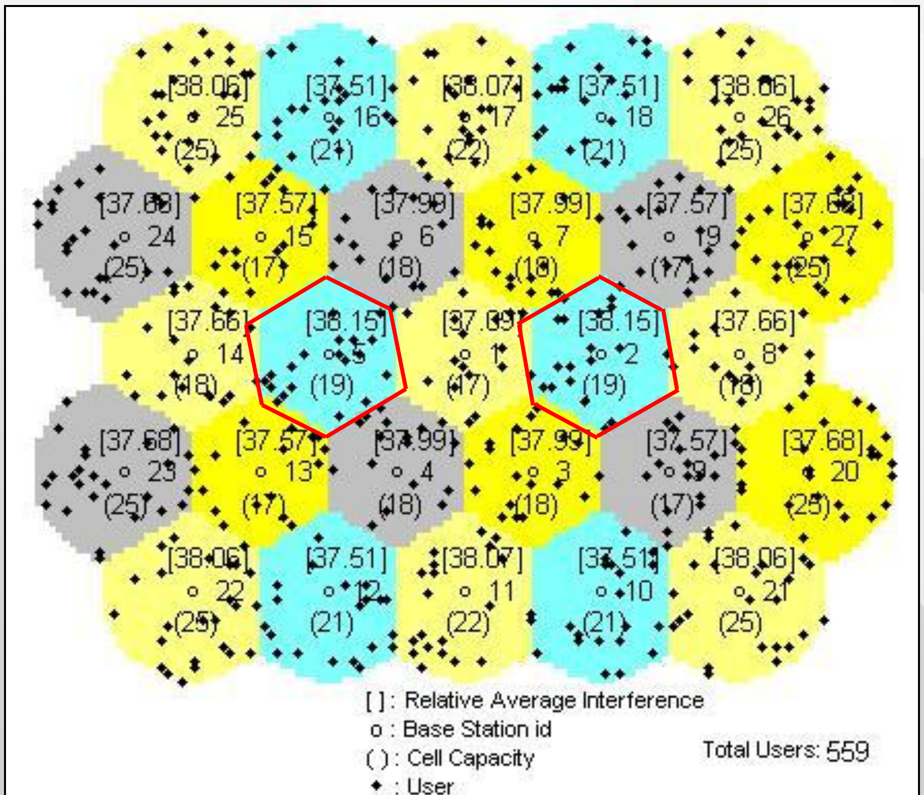


- Actual interference
  - Users in each cell: 17

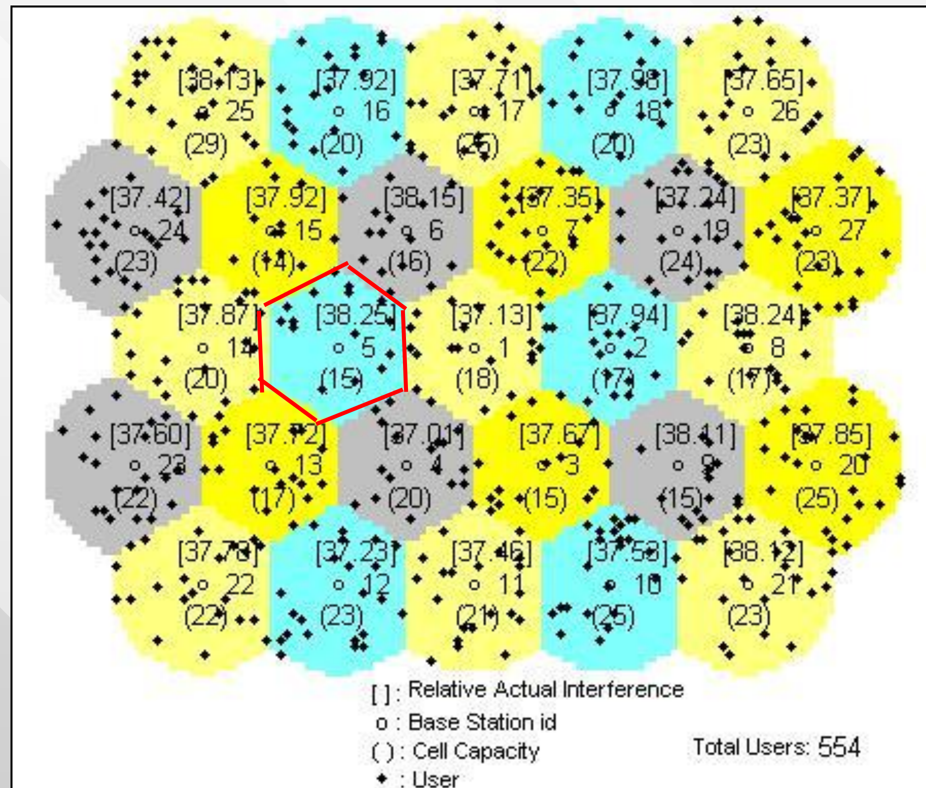


Simulations – Optimized Capacity Vs Actual Interference Capacity

- Optimized Capacity using average interference = 559

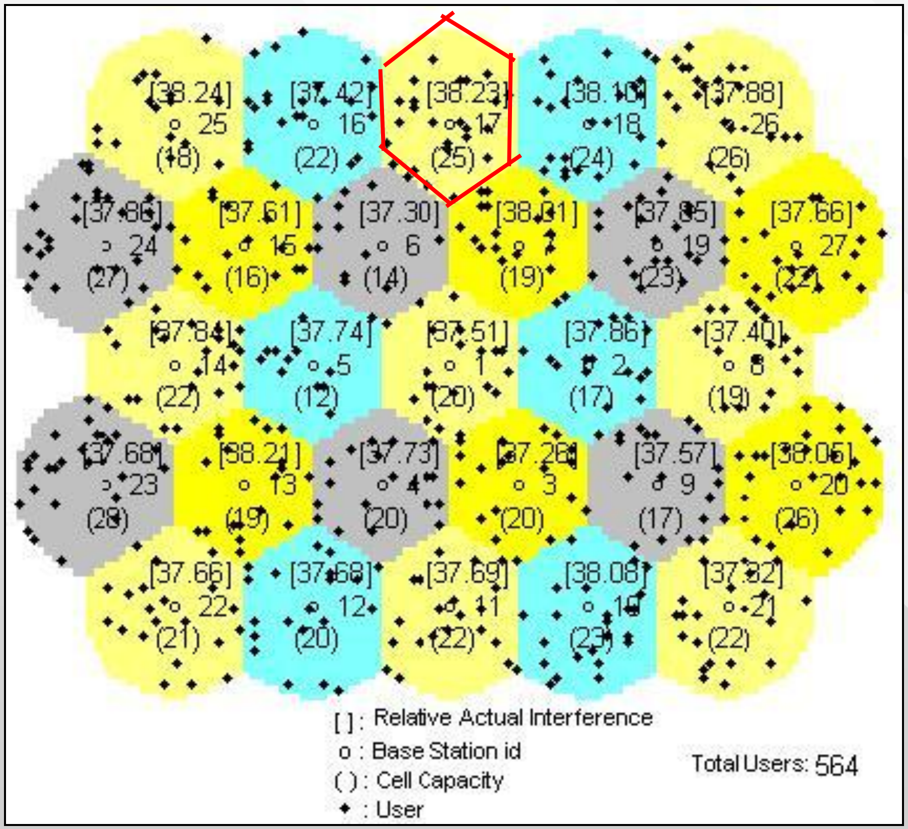


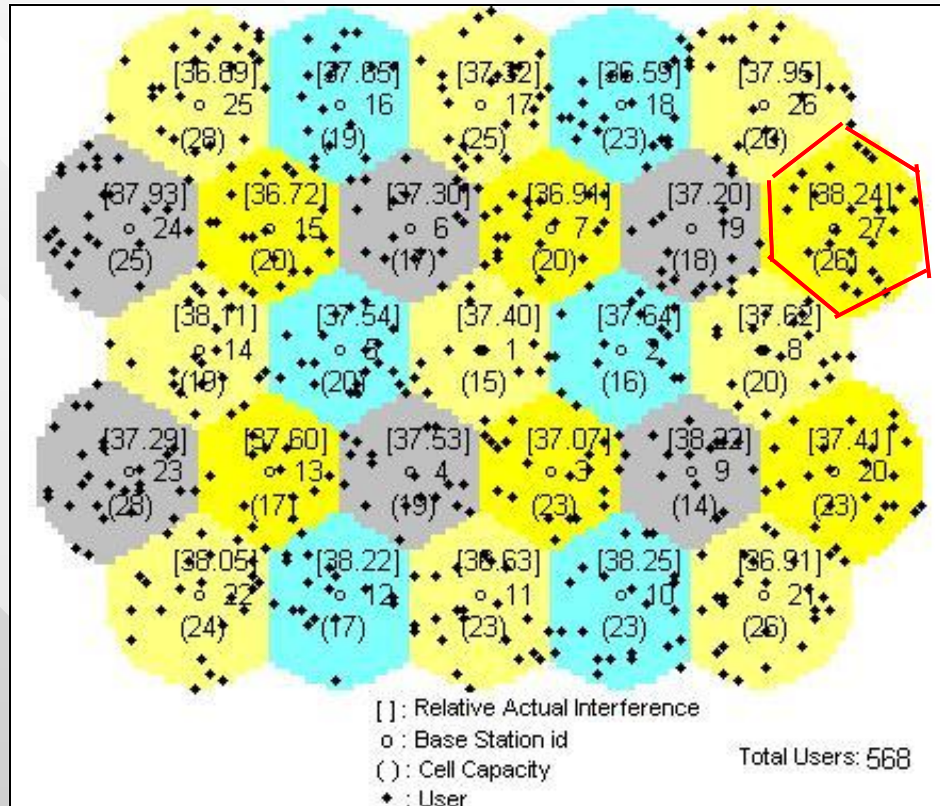
- Simulated Capacity using actual interference = 554



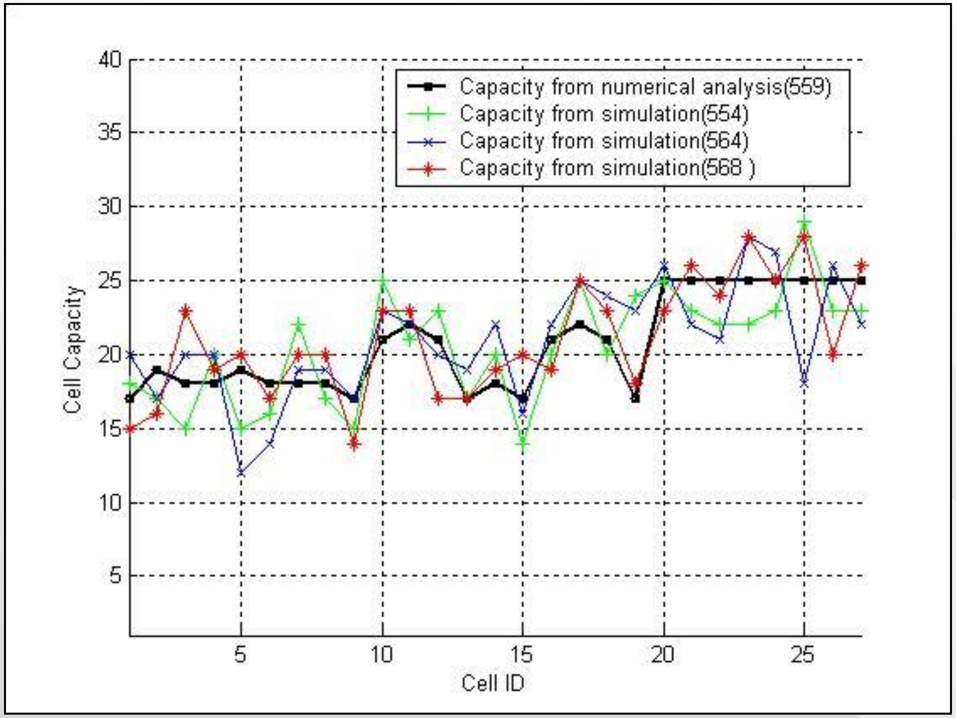
More Simulations – Actual Interference

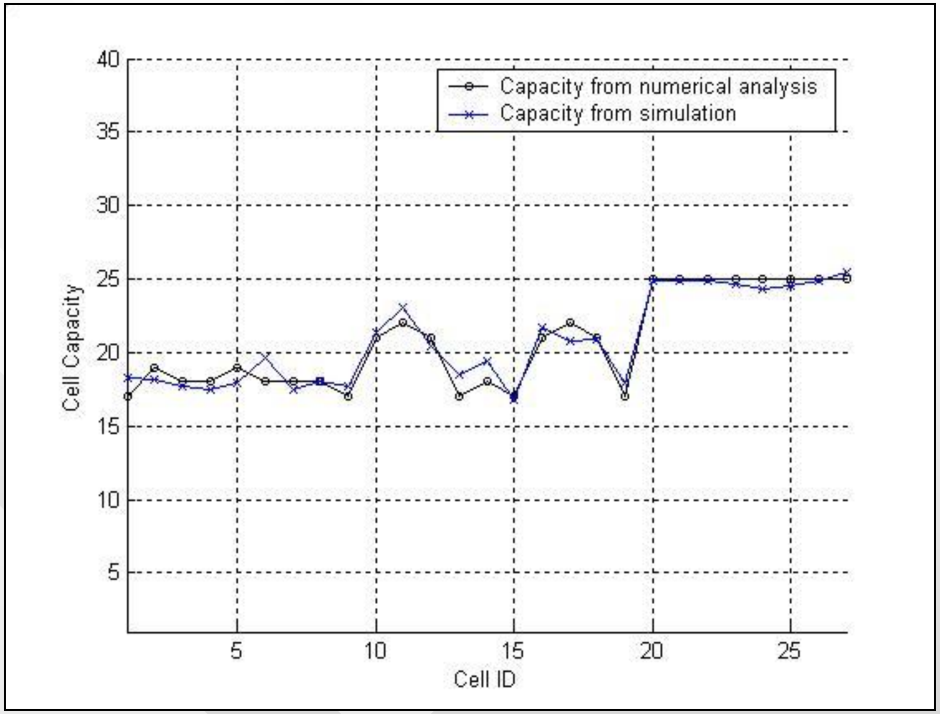
- Simulated Capacity = 564
- Simulated Capacity = 568





Individual Cell Capacity Comparison

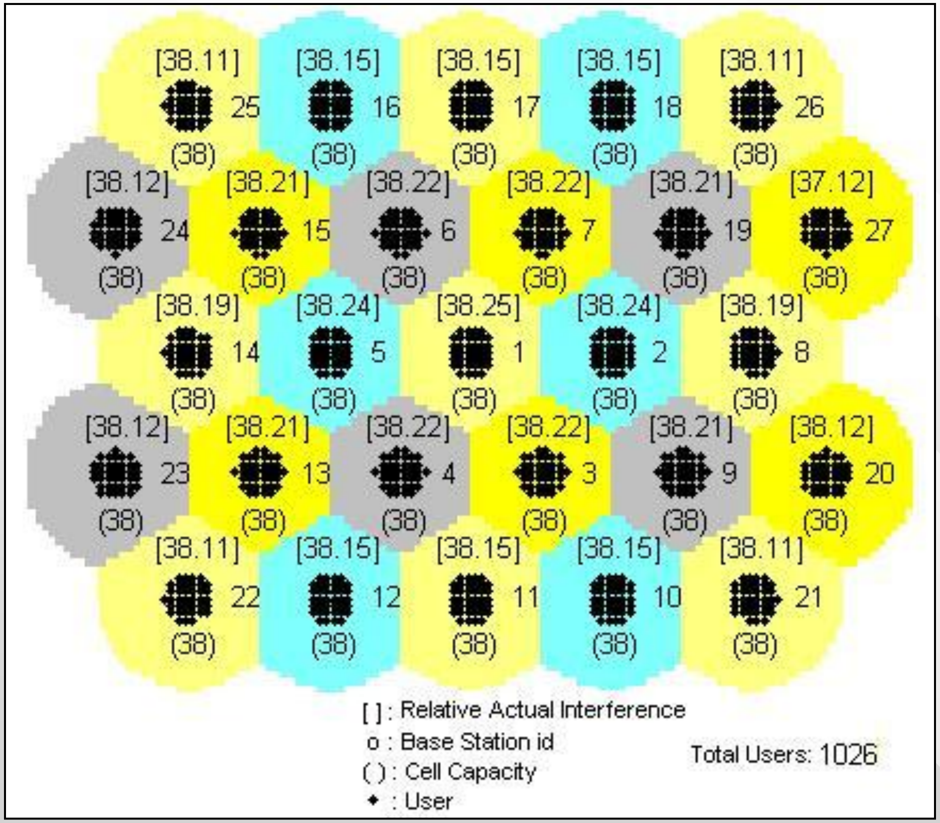


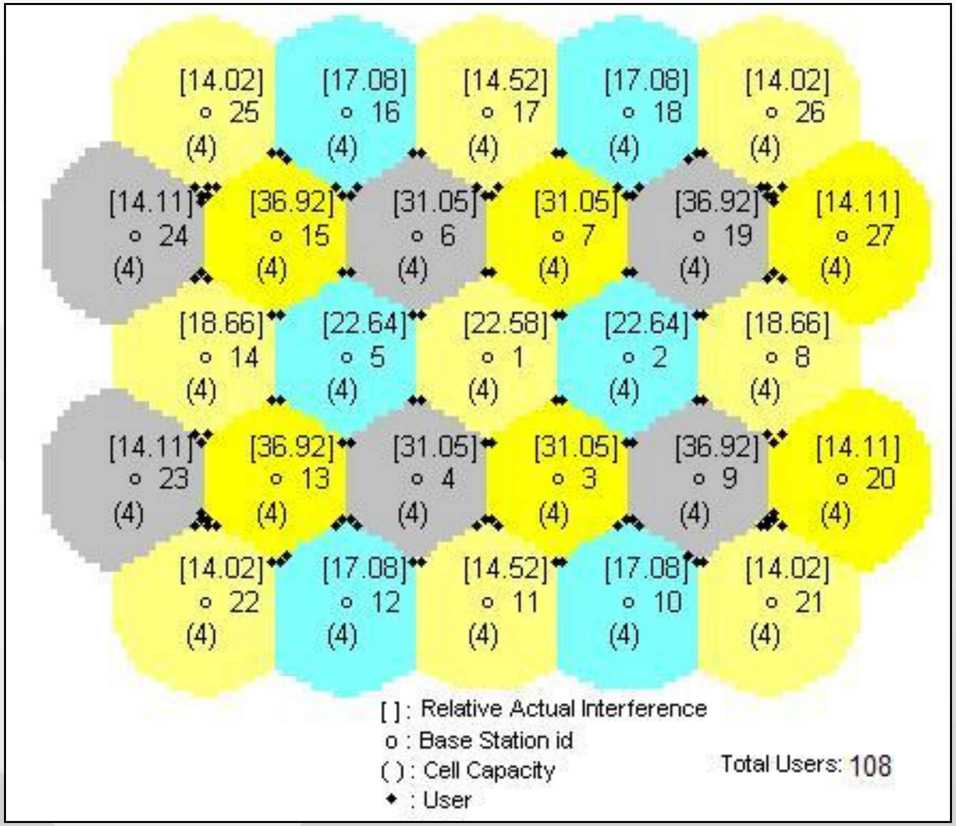


• Comparison of cell capacity for 3 simulation trials.

• Comparison of average cell capacity for 50 simulation trials.

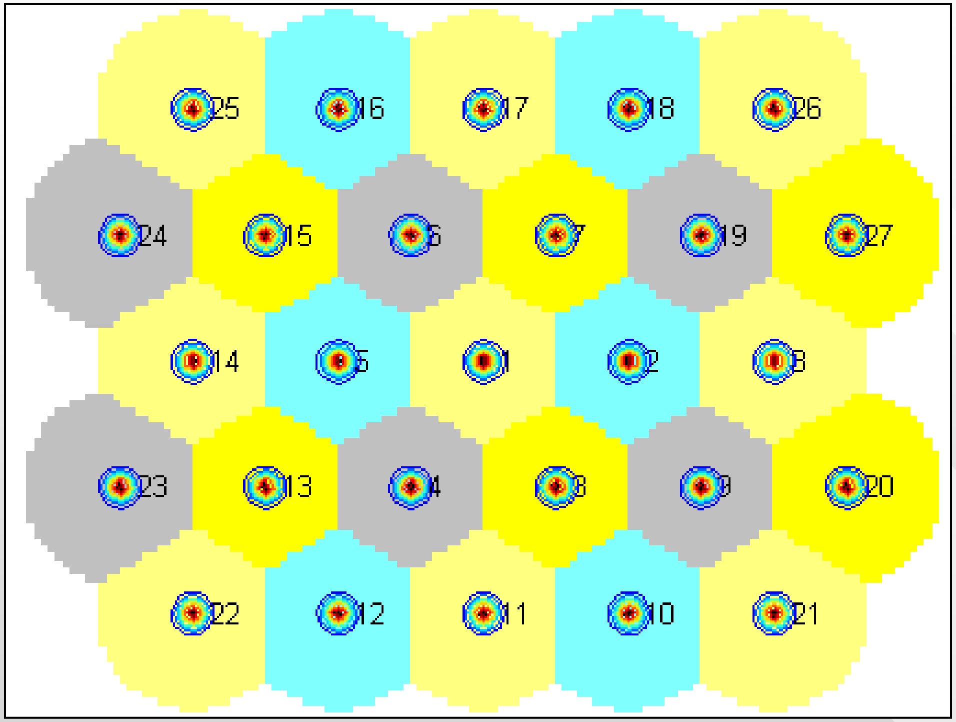
Extreme Cases Using Actual Interference – Non-Uniform Distribution

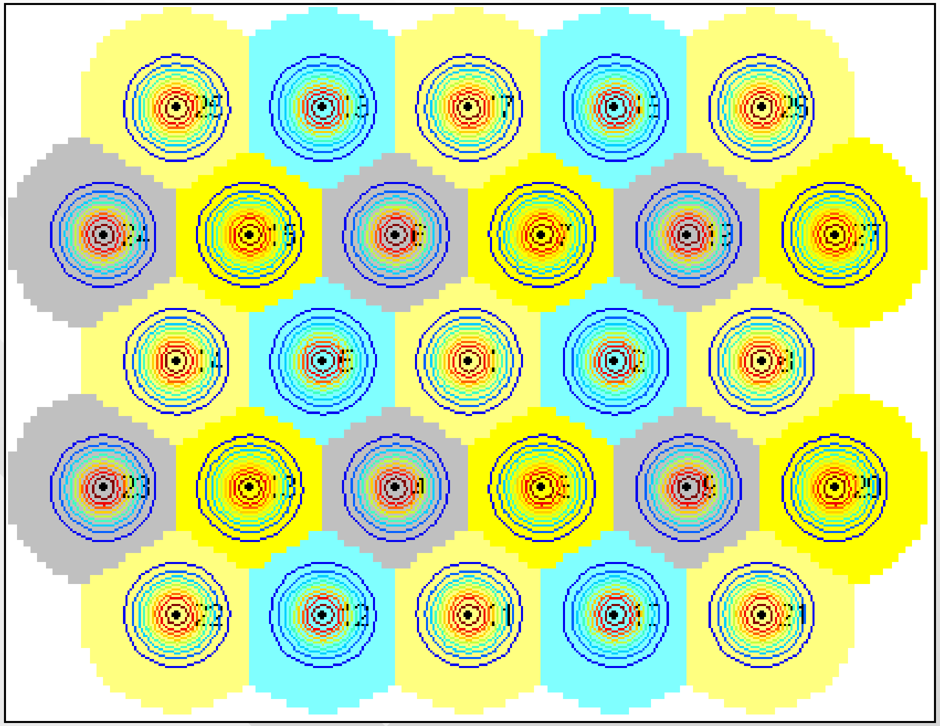




- Maximum network capacity of 1026 with best case non-uniform user distribution
- Maximum network capacity of 108 with worst case non-uniform user distribution

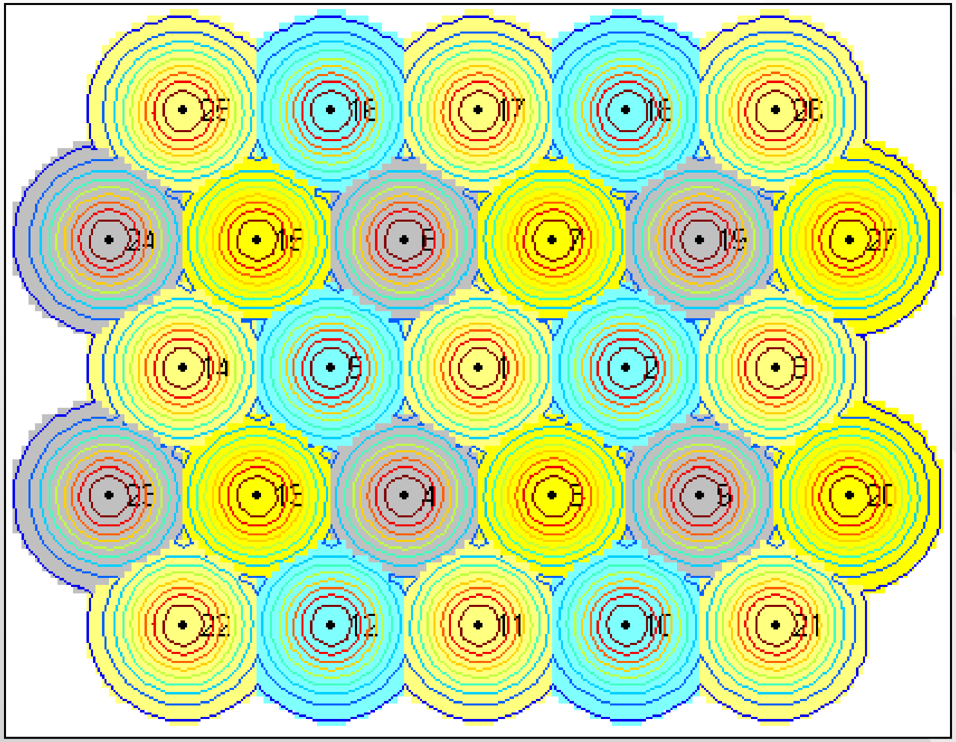
Model User Distribution by 2D Gaussian

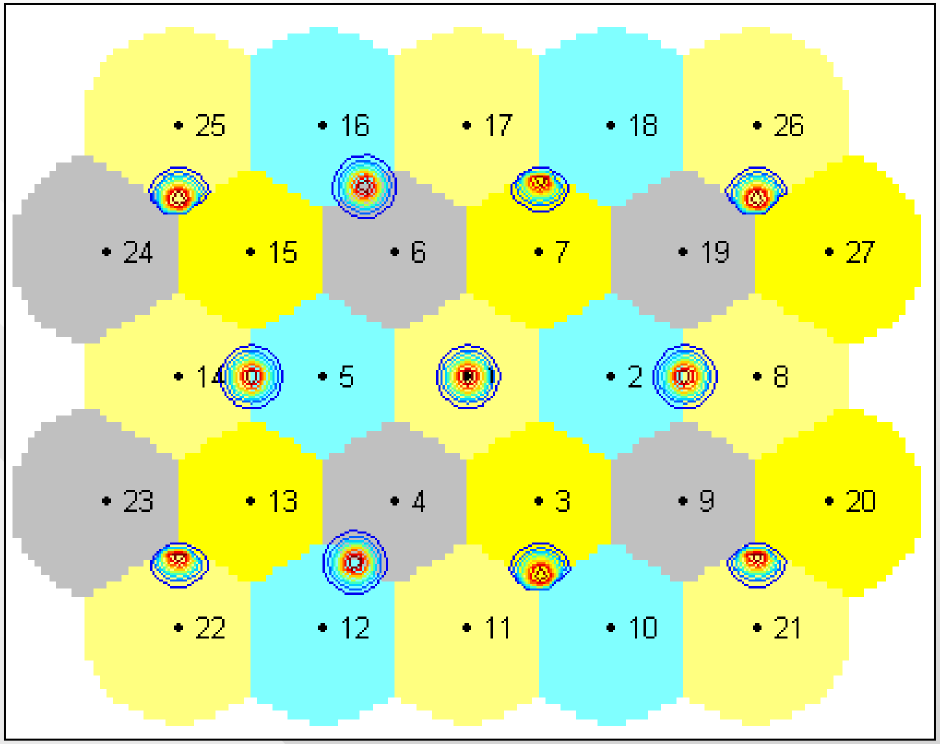




- Mean = 0 and standard deviation = 200
- Mean = 0 and standard deviation = 500

Model User Distribution by 2D Gaussian





- Mean = 0 and standard deviation = 900

- Non-zero mean, standard deviation between 100-300

Conclusions

- Actual interference model is computationally intensive.
- Capacity obtained using average interference is close to the capacity obtained using actual interference for uniform user distribution.
- Average interference model cannot predict extreme variations in network capacity under non-uniform user distribution.
- Can use 2D Gaussian distribution to model uniform and non-uniform user distribution.