Subscriber Maximization in CDMA Cellular Network

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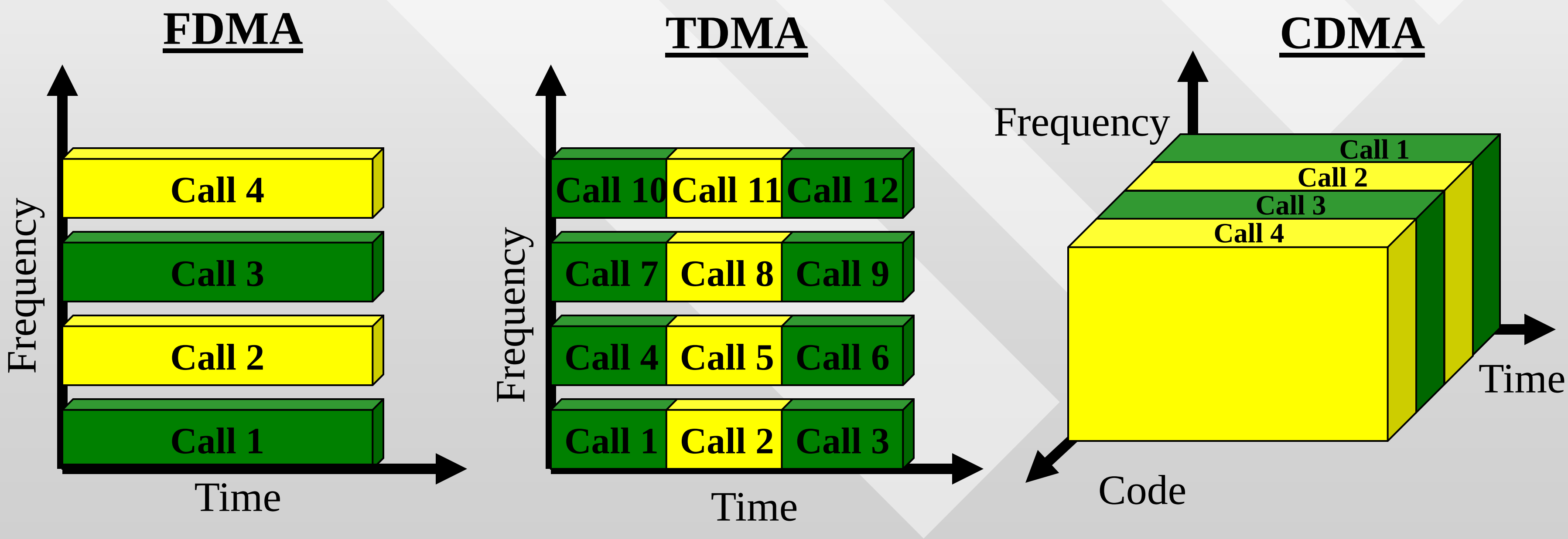
Outline

- Overview of CDMA
- Traffic and Mobility Model
- Subscriber Optimization Formulation
- Numerical Results
- Conclusions

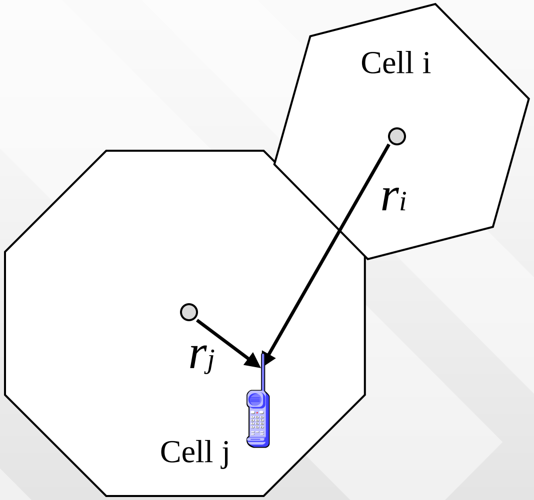
Code Division Multiple Access (CDMA) Overview

- Multiple access schemes



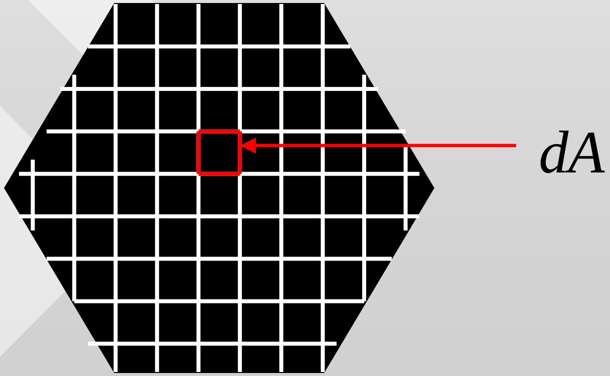
Relative Average Inter-cell Interference Model

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



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

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

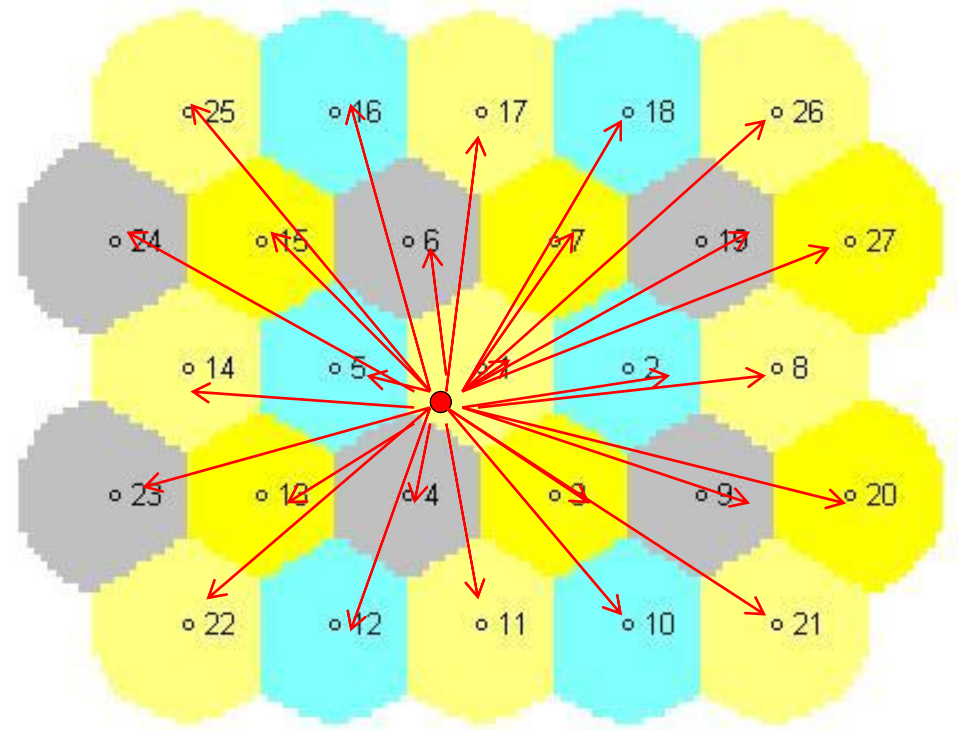


Interference Matrix

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

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



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

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

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

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

Capacity

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

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

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

- 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 the equation:

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

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

Mobility Model

- Call arrival process is a Poisson process with rate: λ
- Call dwell time is a random variable with exponential distribution having mean: $1/\mu$
- Probability that a call in cell i goes to cell j after completing its dwell time: q_{ij}
- Probability that a call in progress in cell i remains in cell i after completing its dwell time: q_{ii}
- Probability that a call will leave the network after completing its dwell time: q_i

Mobility Model – Handoff Calls

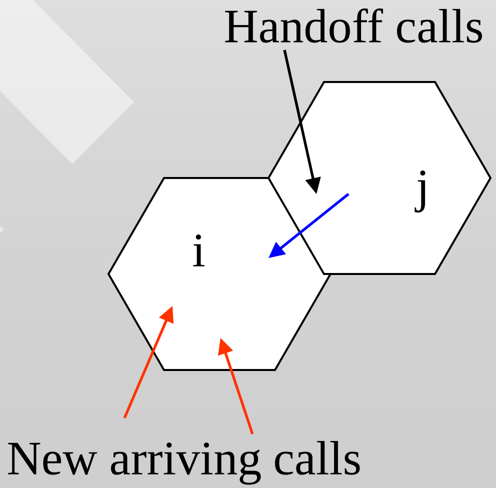
- Handoff calls (v_{ji}): calls that have moved from cell *j* to an adjacent cell *i*.

$$\nu_{ji} = \lambda_j (1 - B_j) q_{ji} + (1 - B_j) q_{ji} \sum_{x \in A_j} \nu_{xj}$$

$$\nu_{ji} = (1 - B_j) q_{ji} \rho_j$$

- B_j : Call blocking probability for cell *j*
- *Aj* : Set of cells adjacent to cell *i*
- ρ_j : Total offered traffic to cell *j*

$$\rho_j = \lambda_j + \sum_{x \in A_j} \nu_{xj} = \lambda_j + \nu_j$$



Admissible States

- A new call is accepted if the following inequality still holds upon acceptance, where N_i is the maximum number of calls allowed to be admitted in cell *i:*

$$n_i \le N_i, \quad \text{for } i = 1, \ldots, M$$

- The blocking probability for cell *i* becomes:

$$B_i = \frac{A_i^{N_i} / N_i!}{\sum_{k=0}^{N_i} A_i^k / k!}, \quad \text{where} \quad A_i = \frac{\rho_i}{\mu_i}$$

Maximization of Subscribers

- Solve a constrained optimization problem that maximizes the number of subscribers subject to upper bounds on the blocking probabilities and lower bounds on the bit energy to interference ratios:

$$\max_{(\lambda_1,\ldots,\lambda_M),(N_1,\ldots,N_M)} \quad \sum_{i=1}^{M} \lambda_i,$$

$$\text{subject to} \quad B_i \le \eta,$$

$$N_i + \sum_{j=1}^{M} N_j F[j,i] \le c_{eff},$$

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

Simulations

- Network configuration
  - 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, $\sigma_s = 6$ dB
  - Processing gain, $W/R = 21.1$ dB
  - Bit energy to interference ratio threshold, $\tau = 9.2$ dB
  - Interference to background noise ratio, $I_0/N_0 = 10$ dB
  - Voice activity factor, $\alpha = 0.375$

Simulations – Network Parameters

No mobility probabilities

- $q_{ij} = 0$
- $q_{ii} = 0.3$
- $q_i = 0.7$

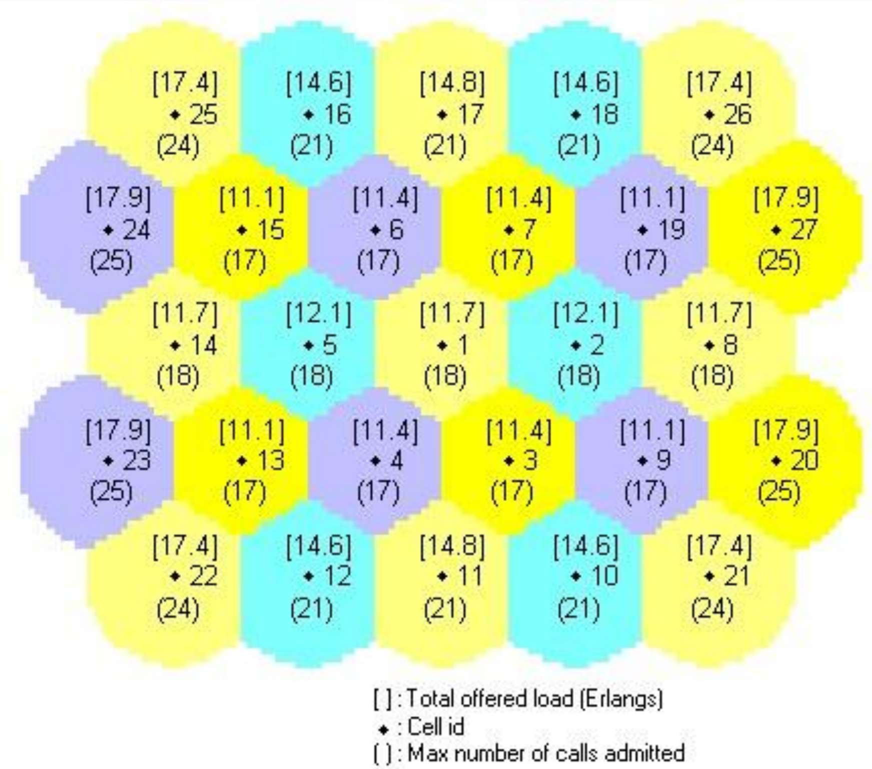
Low mobility probabilities

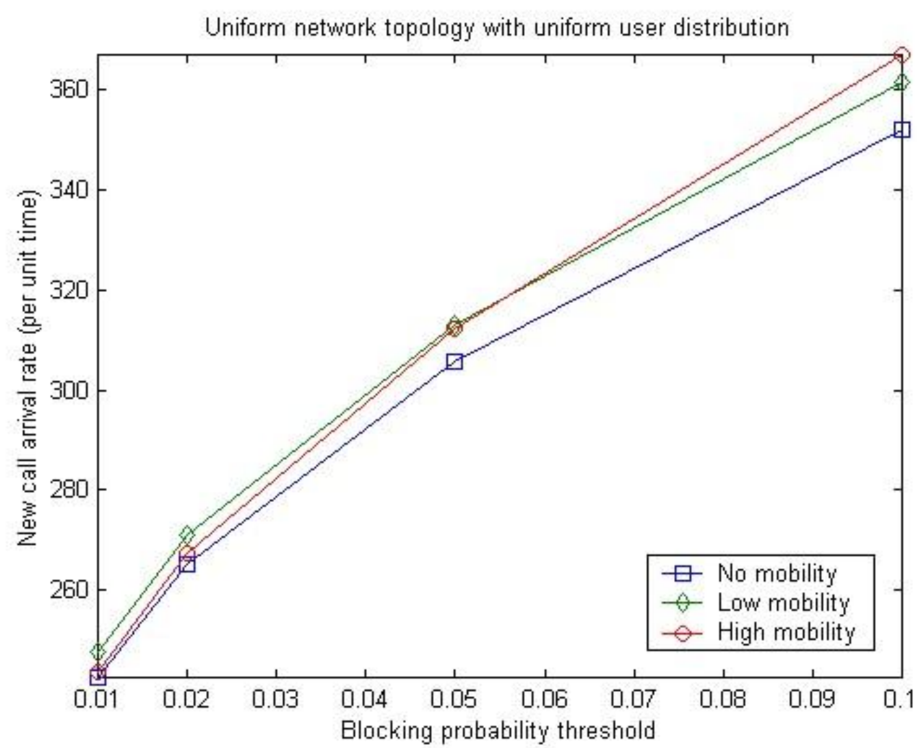
A_i	qij	qii	qi
3	0.020	0.240	0.700
4	0.015	0.240	0.700
5	0.012	0.240	0.700
6	0.010	0.240	0.700

High mobility probabilities

A_i	qij	qii	qi
3	0.100	0.000	0.700
4	0.075	0.000	0.700
5	0.060	0.000	0.700
6	0.050	0.000	0.700

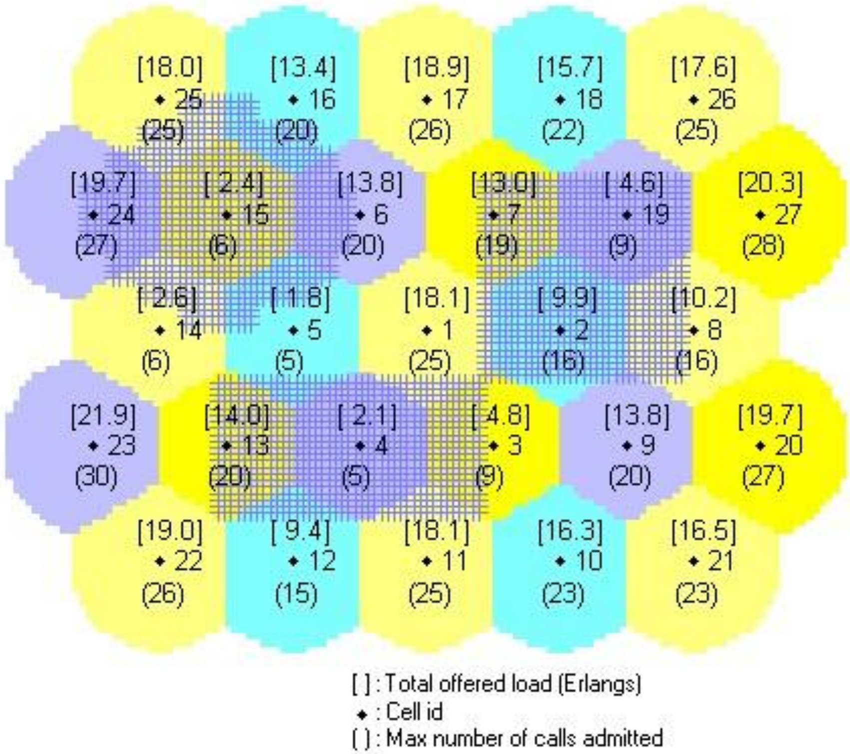
Traditional Network Topology and Uniform User Distribution

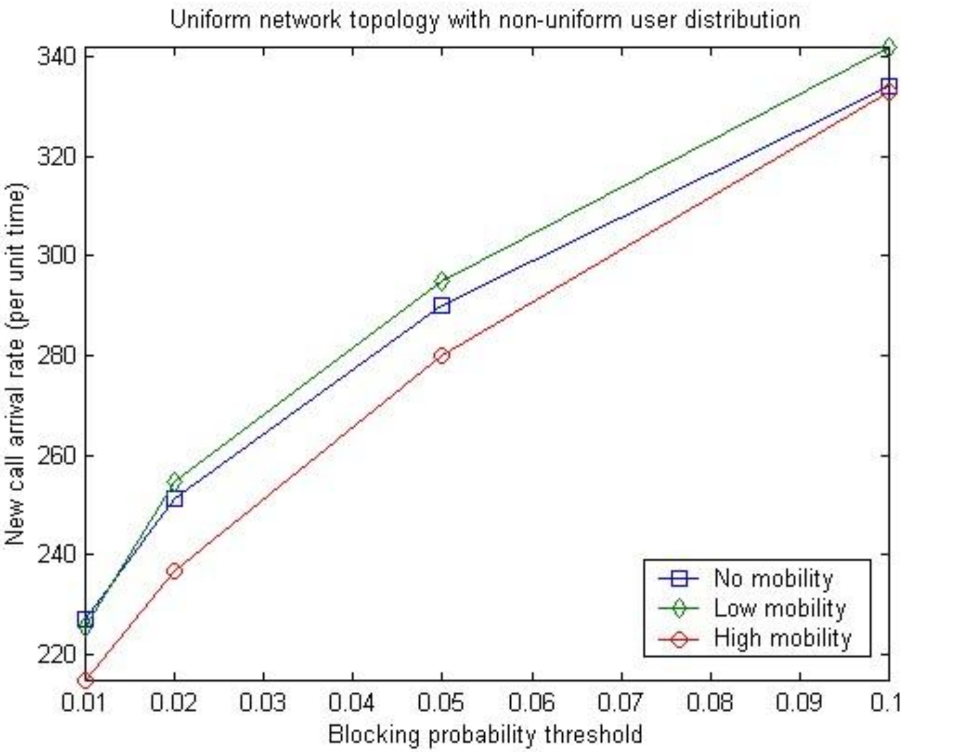




- Maximum subscribers is 15,140.

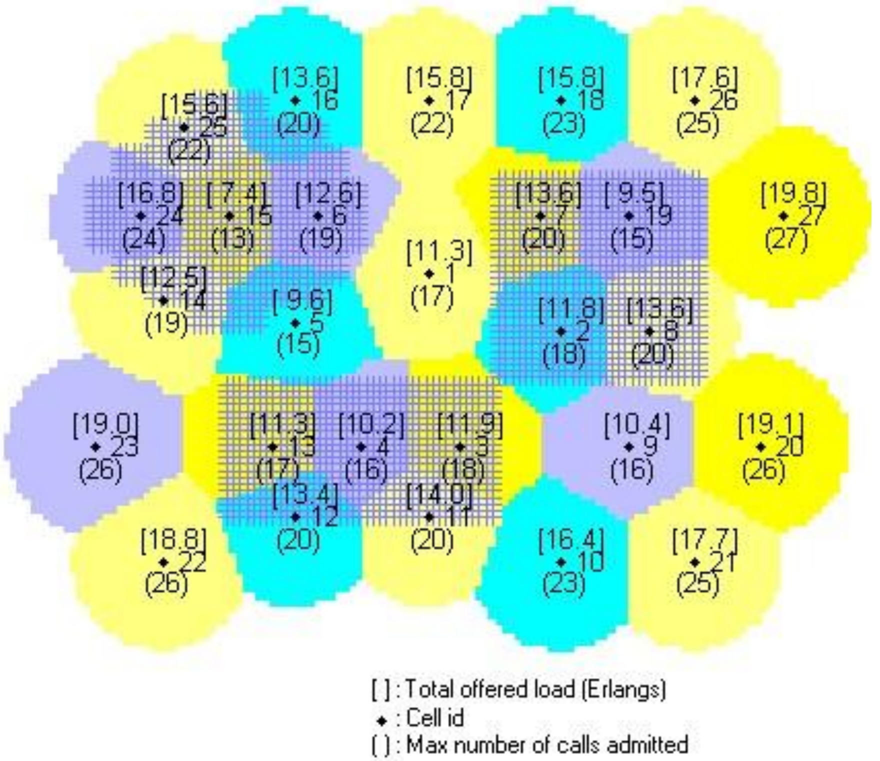
Traditional Network Topology and Non-Uniform User Distribution

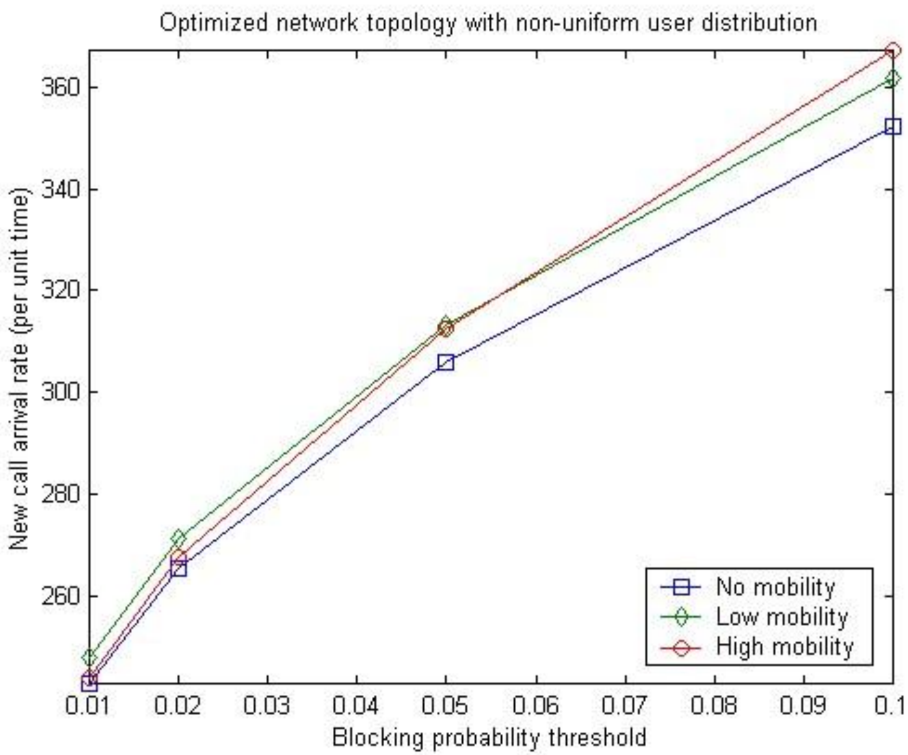




- Maximum subscribers drops to 14,224.

Optimized Network Topology and Non-Uniform User Distribution





- Maximum subscribers increases to 15,164.

Summary

- Calculate the maximum number of subscribers that a CDMA cellular network can handle for a given grade-of-service, quality-of-service, network topology, user distribution profile, and mobility.
- Solution yields the maximum number of calls that should be admitted in each cell to guarantee the given requirements above.