Global versus Local Call Admission Control in CDMA Cellular Networks

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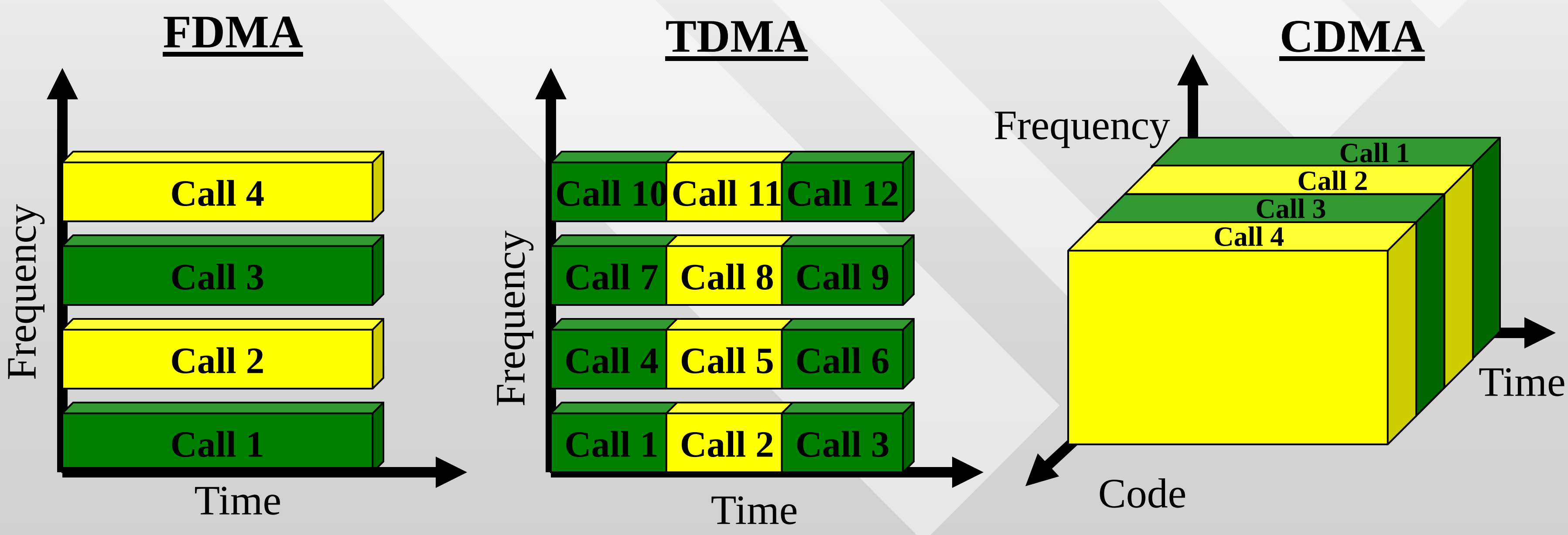
Outline

- Interference model impact on capacity
- Global call admission control
- Local call admission control
- Global vs local
- Conclusions

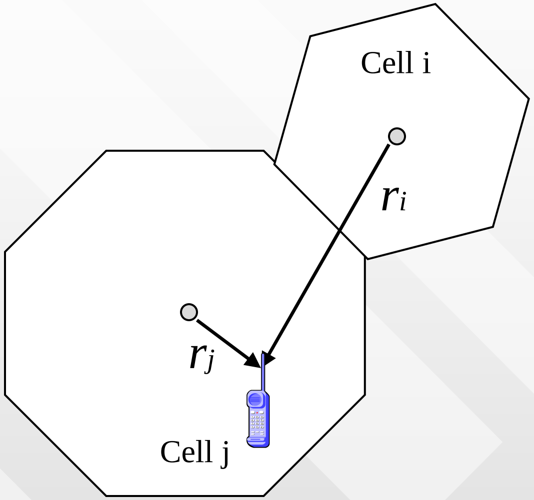
Code Division Multiple Access (CDMA) Overview

- Multiple access schemes



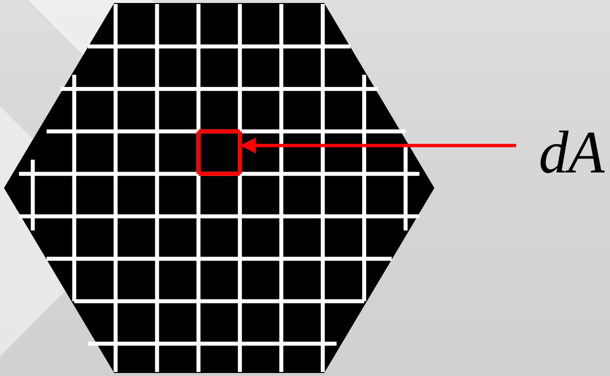
Relative Average Inter-cell Interference Model

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



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

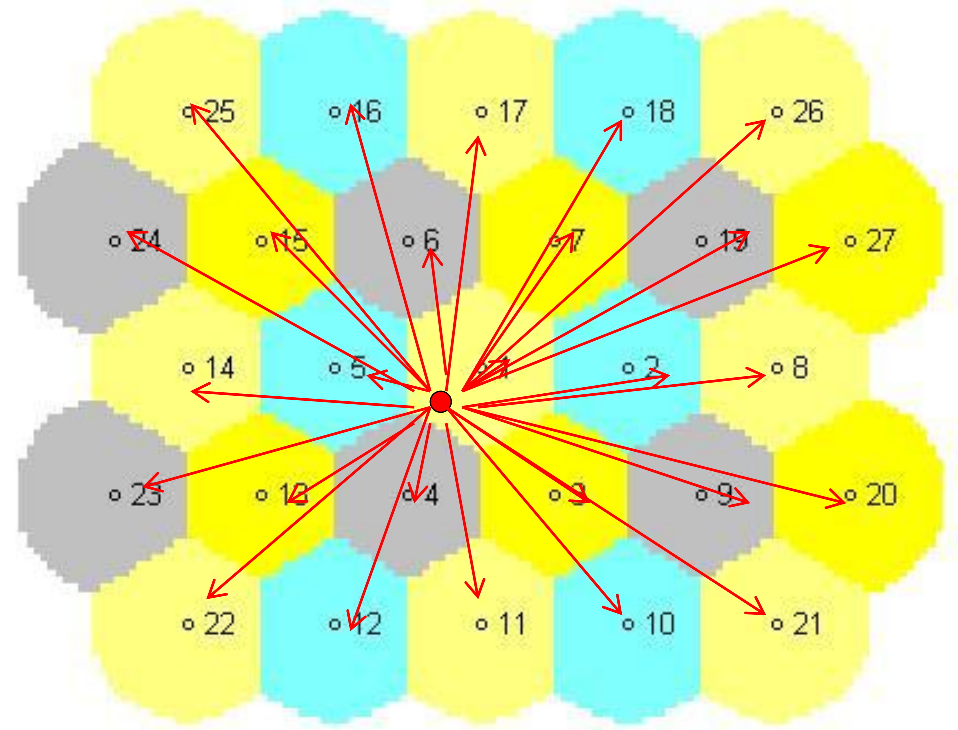
$$I_{ji} = e^{(\gamma\sigma_s)^2}\,\frac{n_j}{A_j}\iint_{Cj}\frac{r_j^m(x,y)}{r_i^m(x,y)}\,dA(x,y) \quad \text{—— (B)}$$



Back

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

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

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

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

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

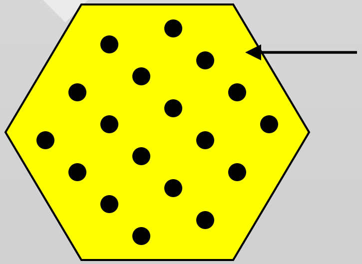
Relative Actual Inter-cell Interference Model

- 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

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

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

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



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

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

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

- 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

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

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

Back

Global Call Admission Control (CAC)

- A CAC algorithm decides whether or not a network shall accept a call.
- Designing a CAC algorithm for CDMA is harder than designing for TDMA or FDMA.
  - Self interference.
  - Affects the entire network.
- A global CAC algorithm takes the entire network in account for every call making decision.

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

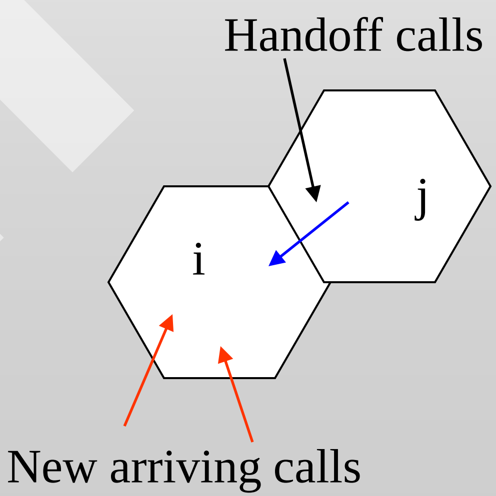
- Handoff calls (v_{ji}): calls that have moved from cell *j* to an adjacent cell *i*.

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

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

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

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



Global CAC Algorithm

- A new call is accepted if the following set of equations still hold upon acceptance.

$$C_i = n_i + I_i \le c_{eff}\ ,$$
$$\text{for } i = 1,\ldots,M$$

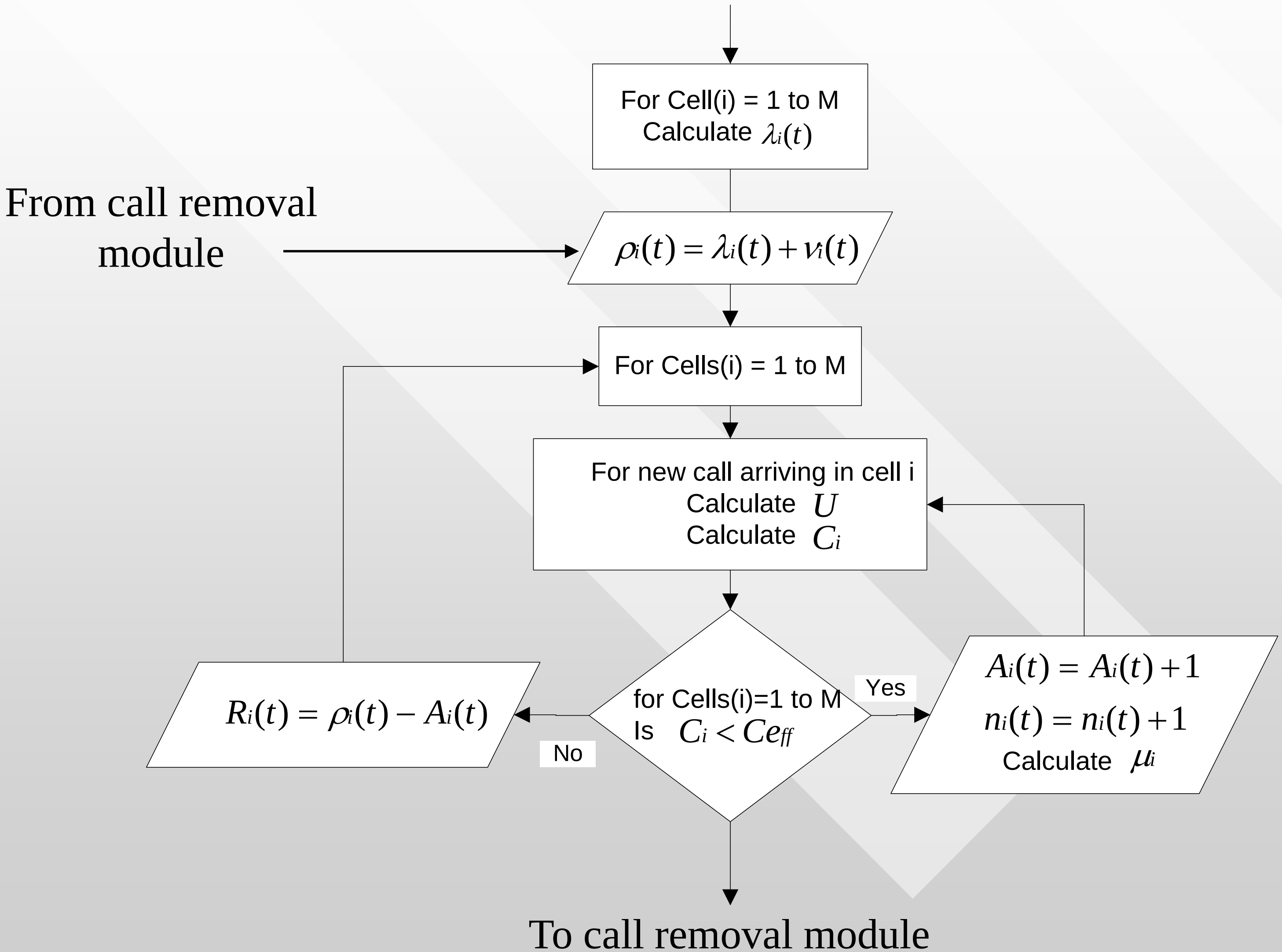
- Actual Interference case:

$$C_i(t) = n_i(t) + \sum_{j=1}^{M} U[j,i] \quad \text{for } i = 1,\ldots,M$$

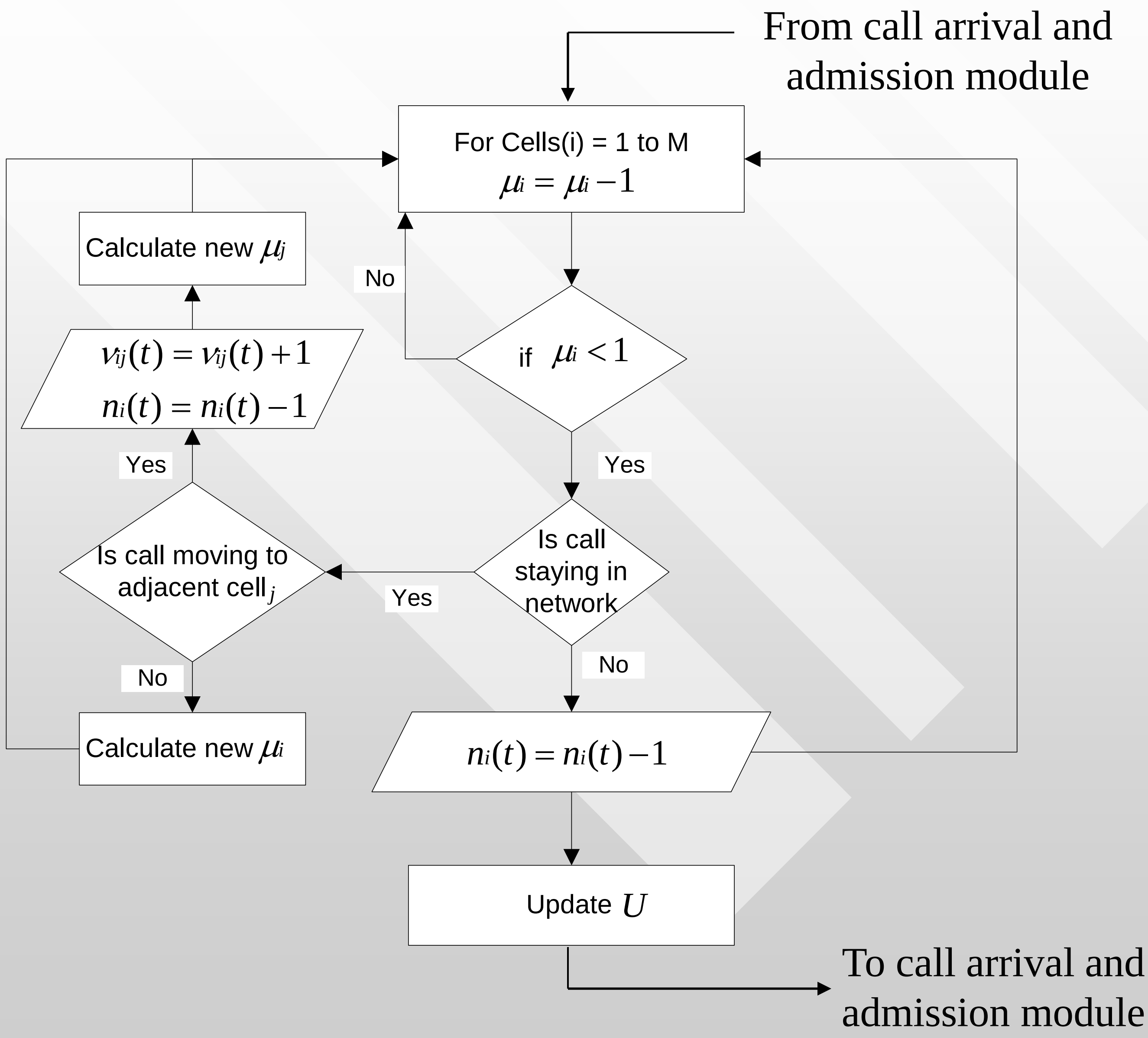
- Average Interference case:

$$C_i(t) = n_i(t) + \sum_{j=1}^{M} n_j F[j,i] \quad \text{for } i = 1,\ldots,M$$

Simulator – Call Arrival and Admission Module (Global CAC)



Simulator – Call Removal Module (Global CAC)



Performance Measurements

- Network throughput: Number of calls per unit time that are admitted and stay in the network till termination.

$$H_T = \frac{1}{T}\sum_{t=1}^{T}\left[\sum_{i=1}^{M}\left(A_i(t) - \nu_i(t)\right)\right]$$

- Blocking probability: For a cell, it is the ratio of rejected calls to total offered traffic to that cell.

$$(B_T)_i = \frac{1}{T}\sum_{t=1}^{T}\left[\frac{R_i(t)}{\rho_i(t)}\right]$$

Local Call Admission Control

- A local CAC algorithm considers only a single cell for making a call admittance decision even though its design may look at the network as a whole.

- A simple approach: Find N, the maximum number of users that are allowed in a cell, which is the same for all the cells in the network.
  - Disadvantage: Inefficient

Traditional CAC Algorithm

- Define network throughput

$$H = \sum_{i=1}^{M} \left\{ \lambda_i \left(1 - B_i\right) - B_i \left(\rho_i - \lambda_i\right) \right\}$$

- A traditional CAC algorithm is formulated that calculates N, the maximum number of calls allowed in each cell. The optimization problem is given by

$$\max_{(N)} \quad H,$$

$$\text{subject to} \quad N + \sum_{j=1}^{M} NF[j,i] \le c_{eff},$$

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

Our Optimized Local CAC Algorithm

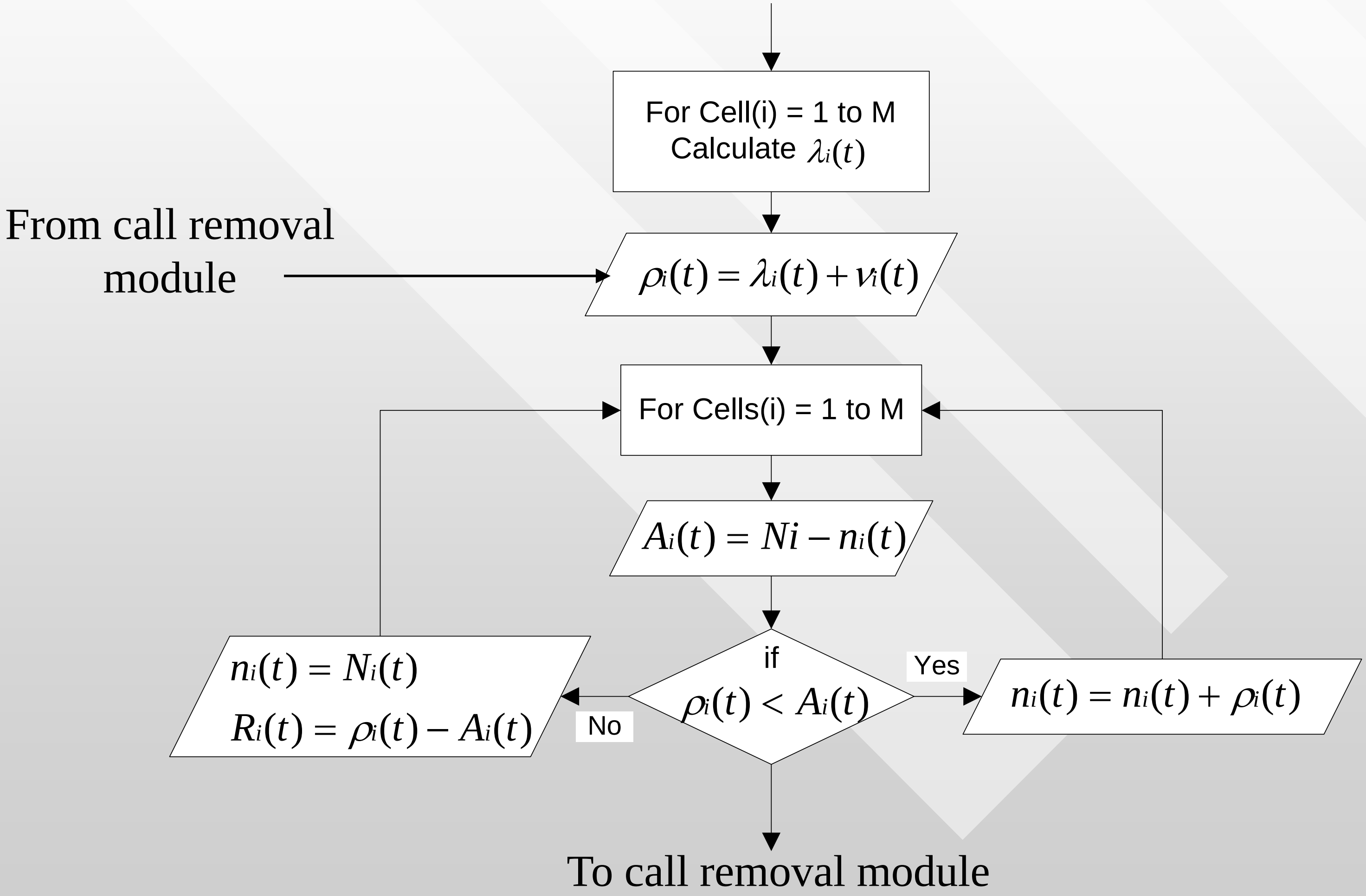
- Solve a constrained optimization problem that maximizes the network throughput with signal-to-interference ratio constraints as lower bounds.

$$\max_{(N,\ldots,N_M)} \quad H,$$

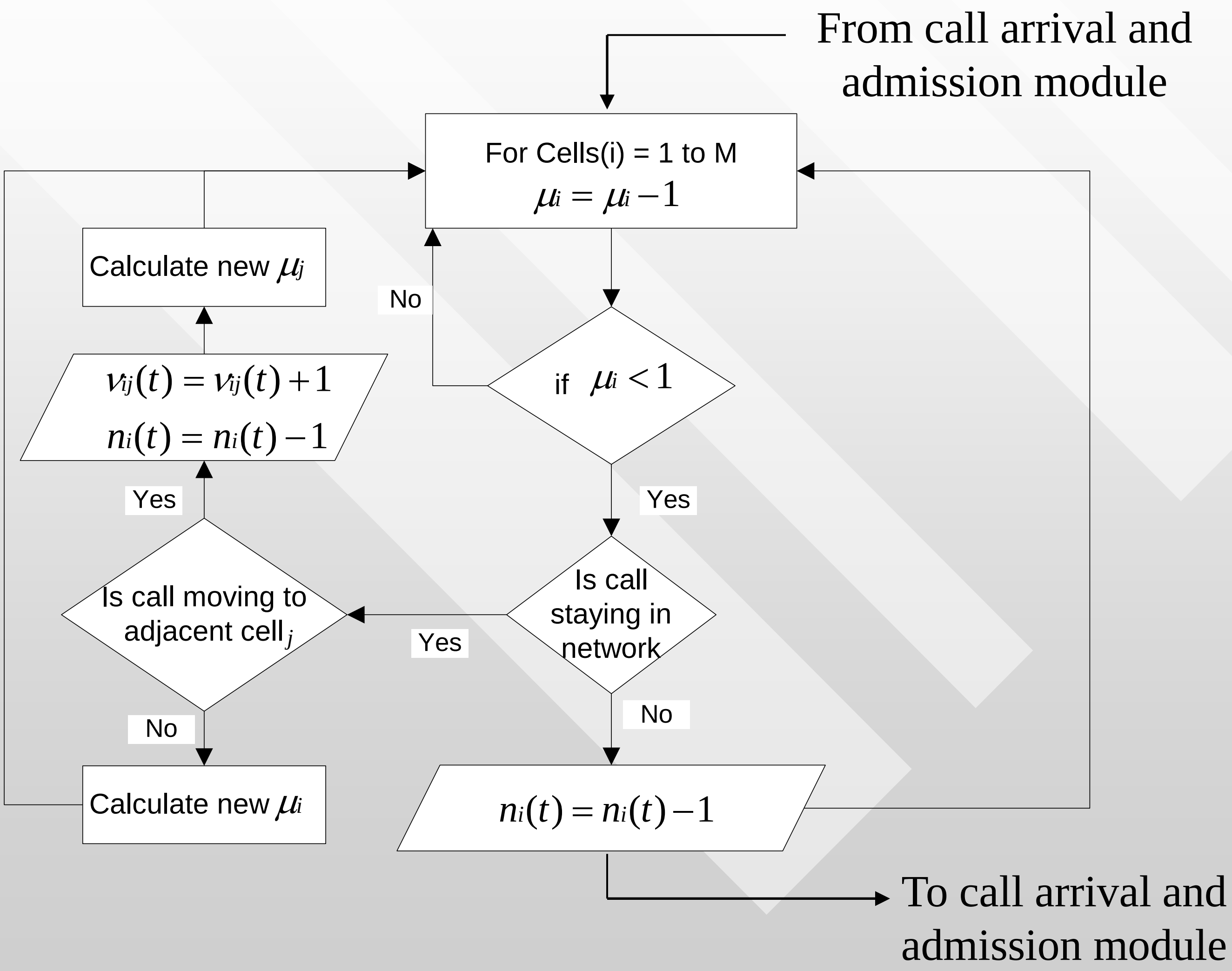
$$\text{subject to} \quad N_i + \sum_{j=1}^{M} N_j F[j,i] \le c_{eff},$$

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

Simulator – Call Arrival and Admission Module (Local CAC)



Simulator – Call Removal Module (Local CAC)



Global CAC vs Local CAC

Global

- Call admission based on all the calls present in the network.
- Slower.
- Inherently optimized.
- Adaptable.
- Complexity: O(M).

Local

- Call admission based on calls present in the cell under consideration only.
- Faster
- Optimized only for a given traffic distribution profile.
- Cannot compensate for big fluctuation in traffic.
- Complexity: O(1)

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

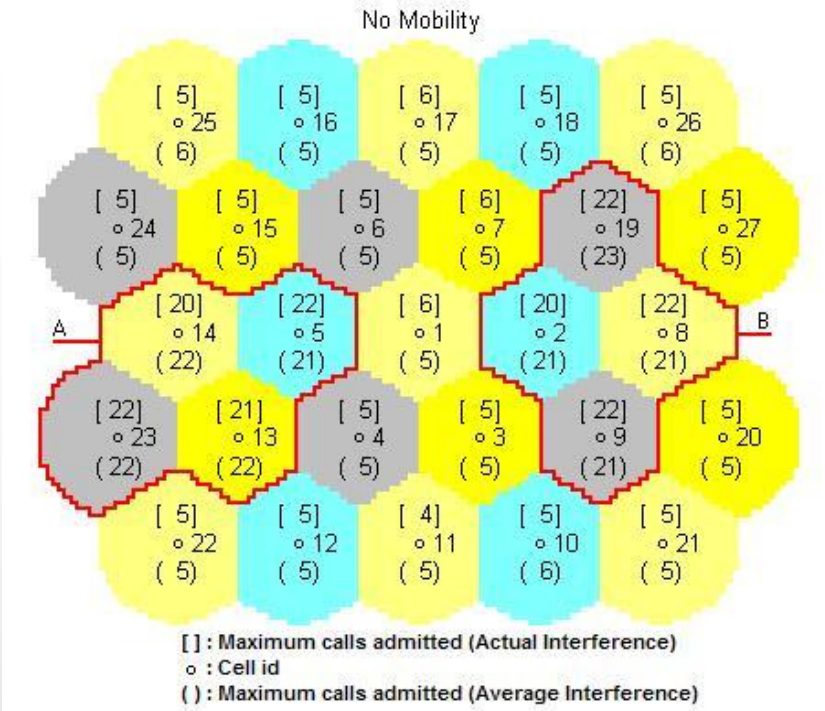
- Non-uniform traffic distribution
  - Group A (cells 5, 13, 14, 23) : 14 calls/time
  - Group B (cells 2, 8, 9, 19) : 14 calls/time
  - Rest of the cells : 3 calls/time
- C_{eff} = 38.25
- No mobility probabilities
  - $q_{ij} = 0$
  - $q_{ii} = 0.3$
  - $q_i = 0.7$

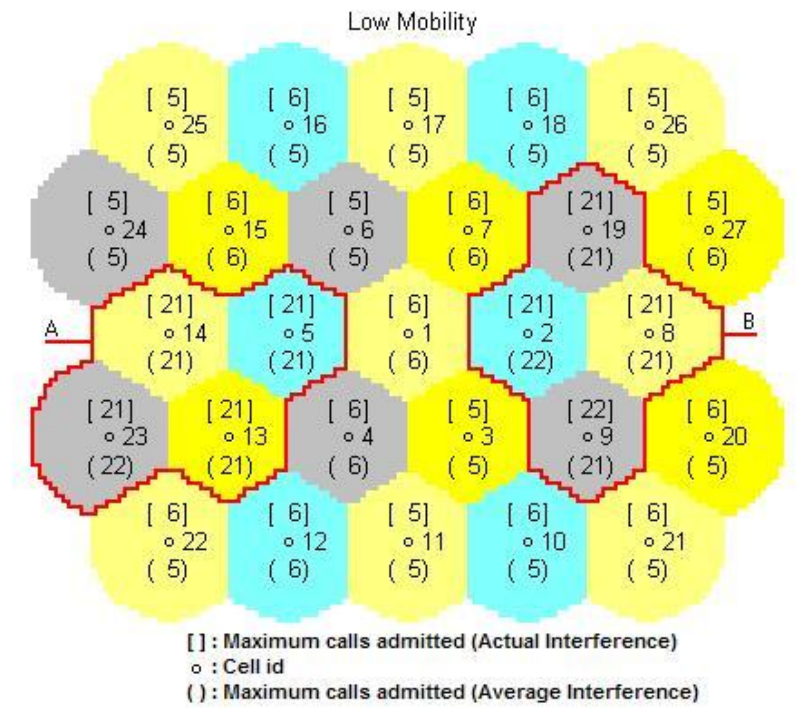
Low mobility probabilities

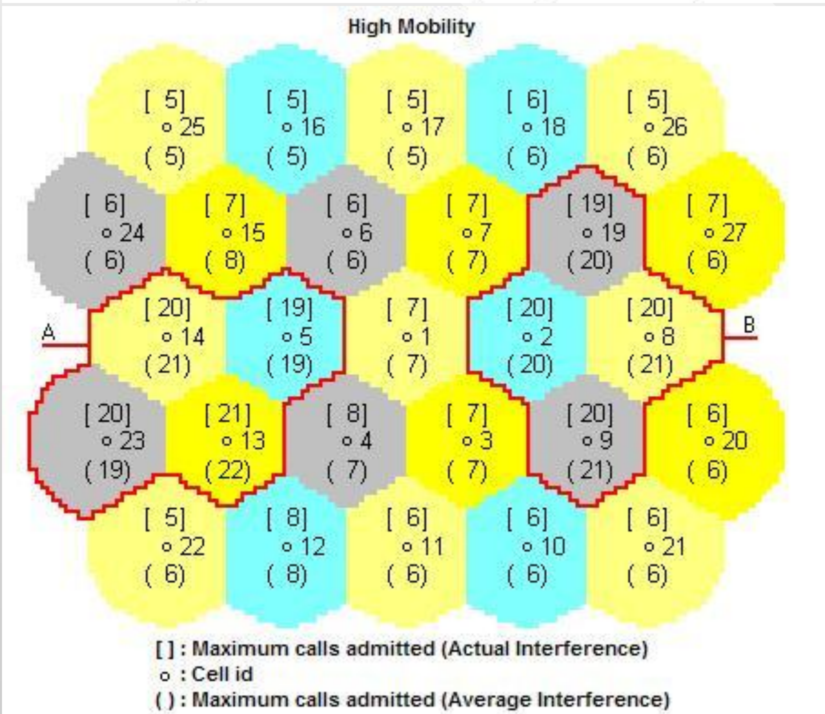
A_i	qij	qii	qi
3	0.020	0.240	0.700
4	0.015	0.240	0.700
5	0.012	0.240	0.700
6	0.010	0.240	0.700

High mobility probabilities

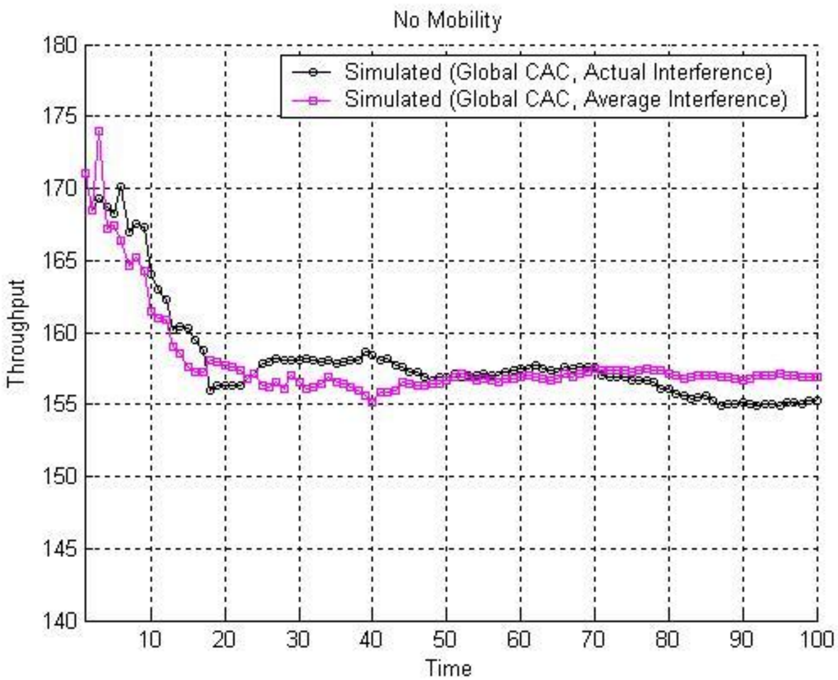
A_i	qij	qii	qi
3	0.100	0.000	0.700
4	0.075	0.000	0.700
5	0.060	0.000	0.700
6	0.050	0.000	0.700

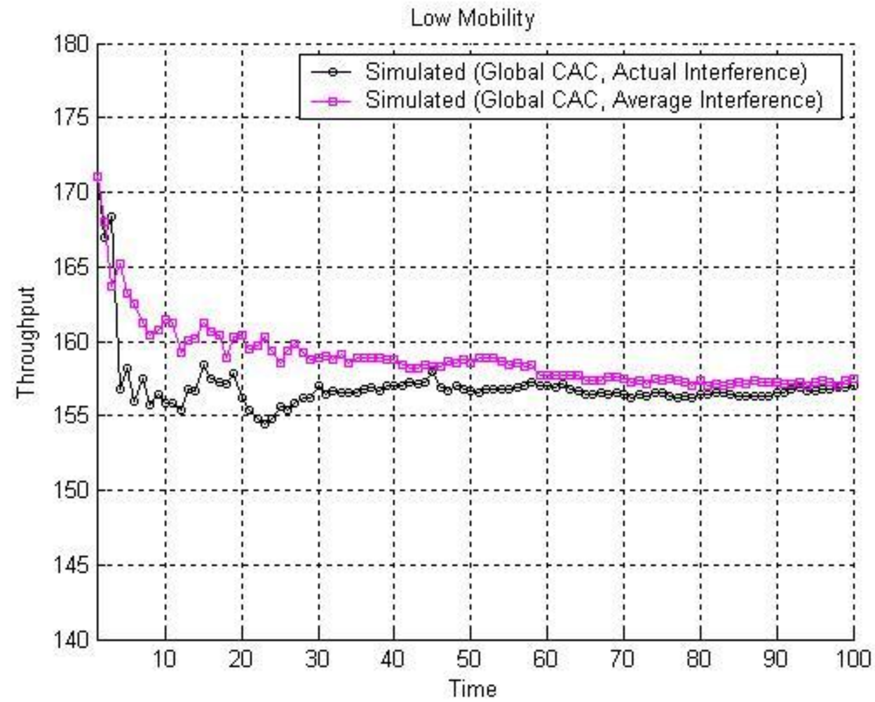


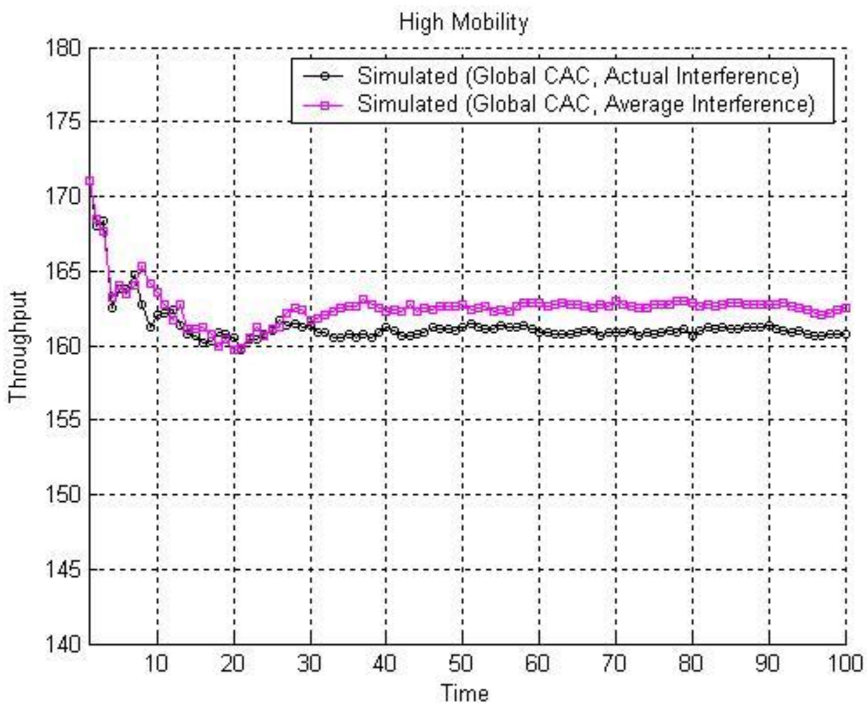




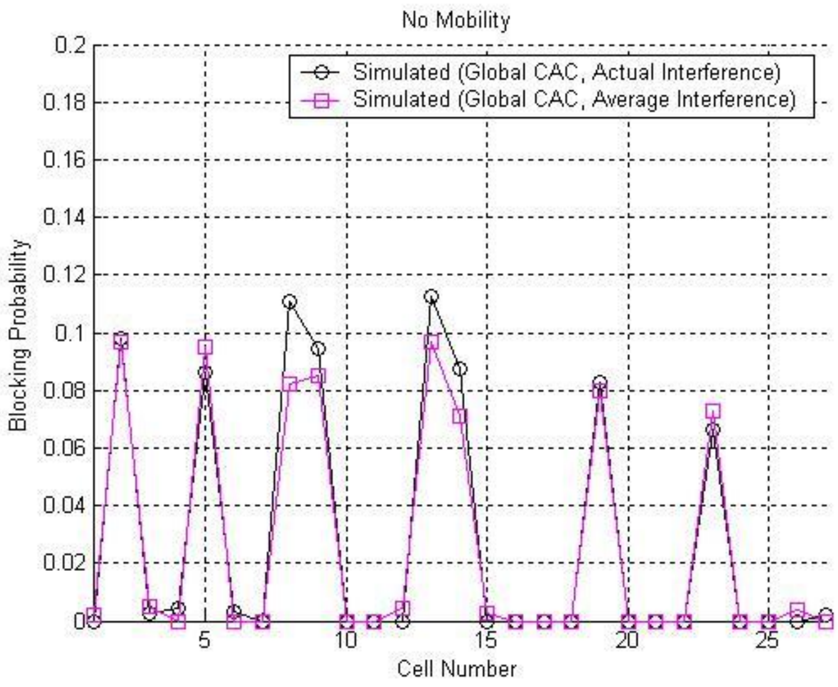
Maximum users admitted per cell for average and actual interference for the three mobility cases.

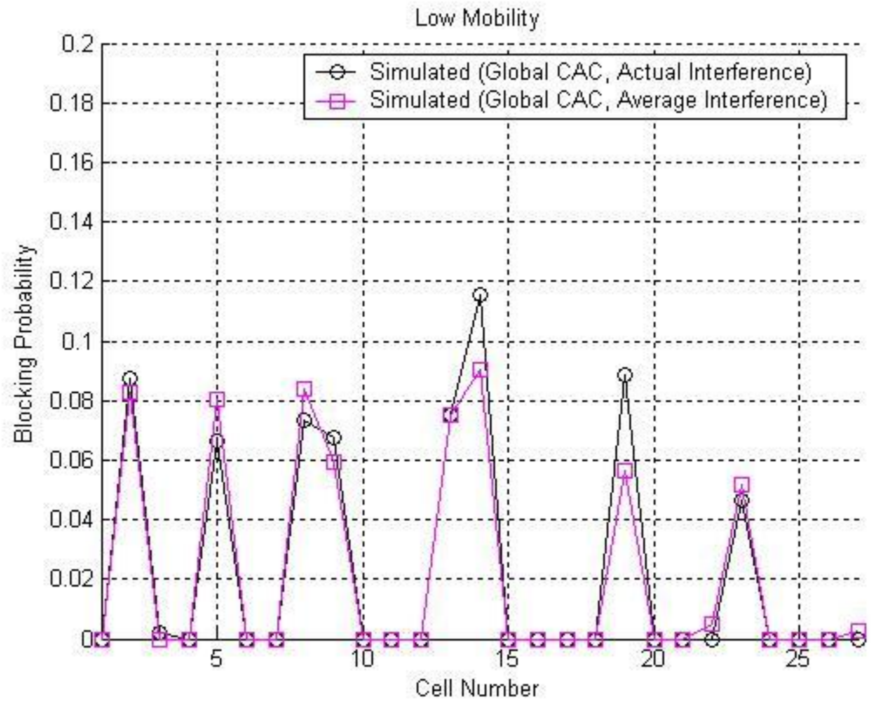


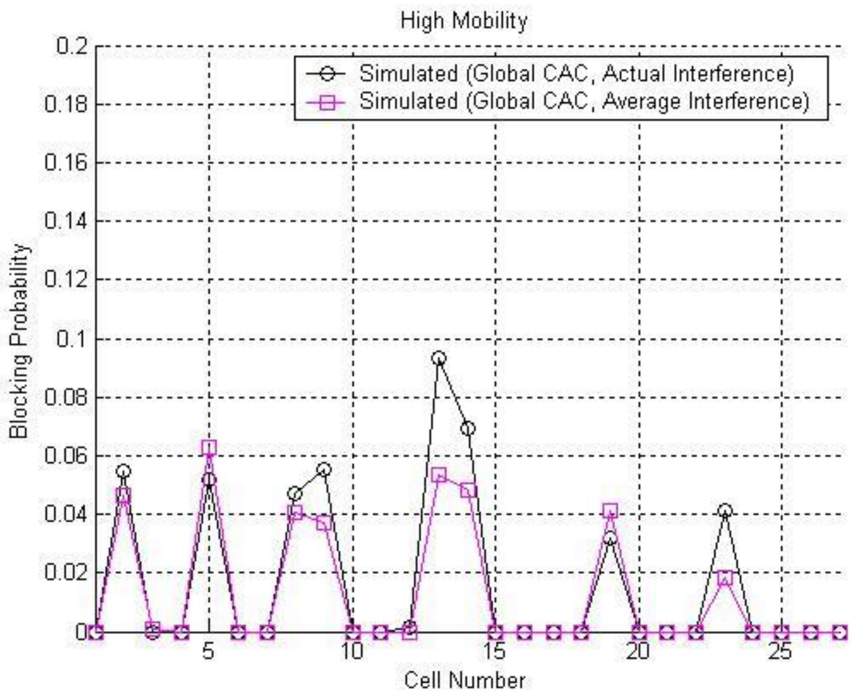




Network throughput for average and actual interference for the three mobility cases.



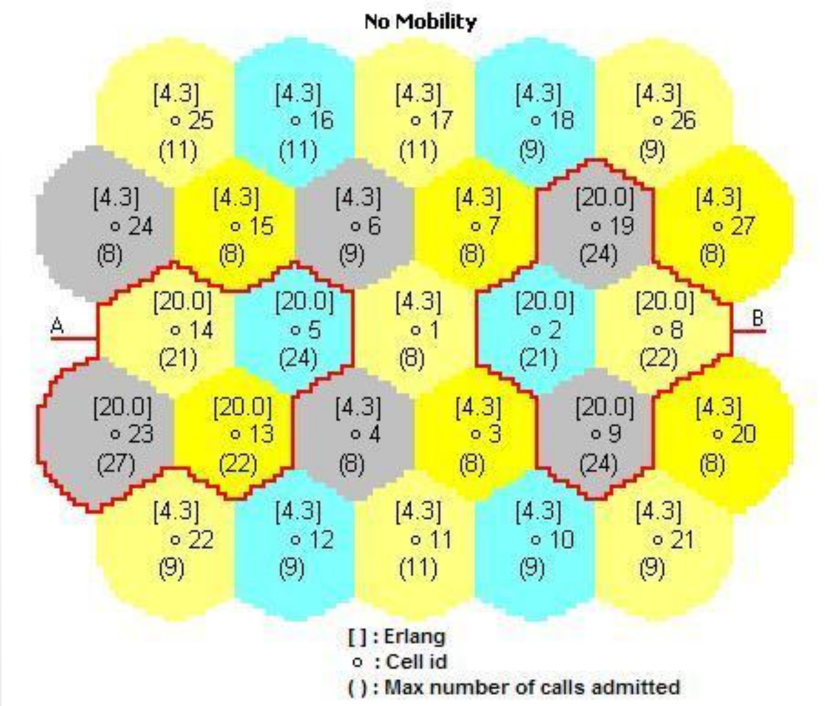


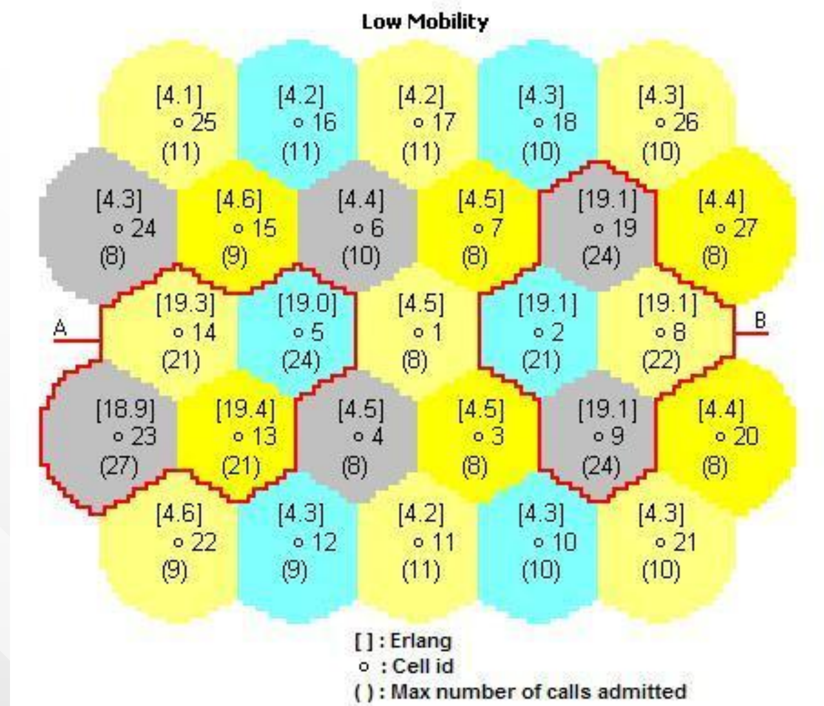


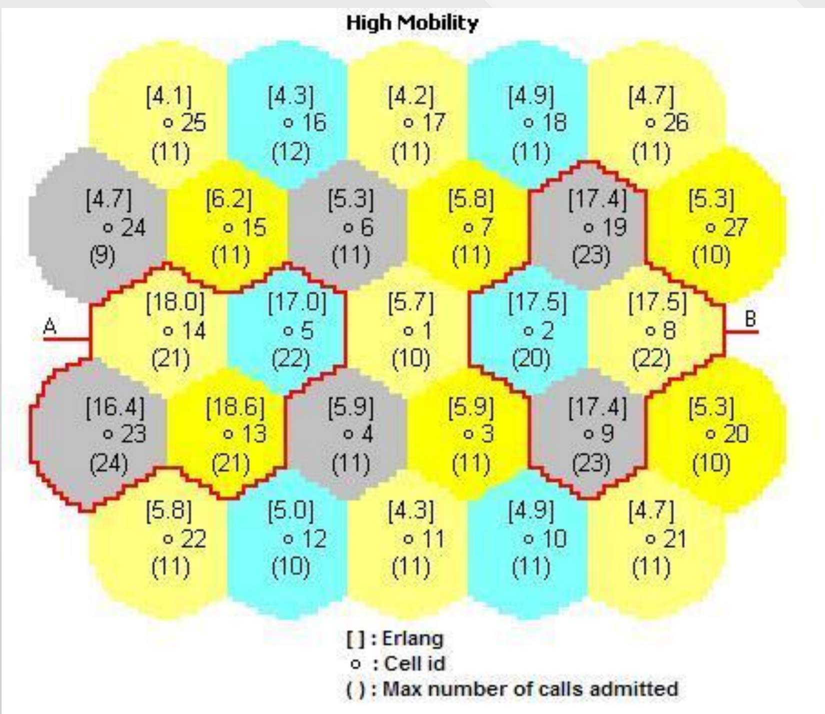
Blocking probability for average and actual interference for the three mobility cases.

Results Global CAC

- Network throughput is always a little higher for average interference in all the three mobility cases.
- Blocking probabilities are a little higher for actual interference for all three mobility cases.
- Blocking probability is around 10% in all the three mobility cases for the cells with high demand.
- Throughput is highest and blocking probability is lowest for the high mobility case.

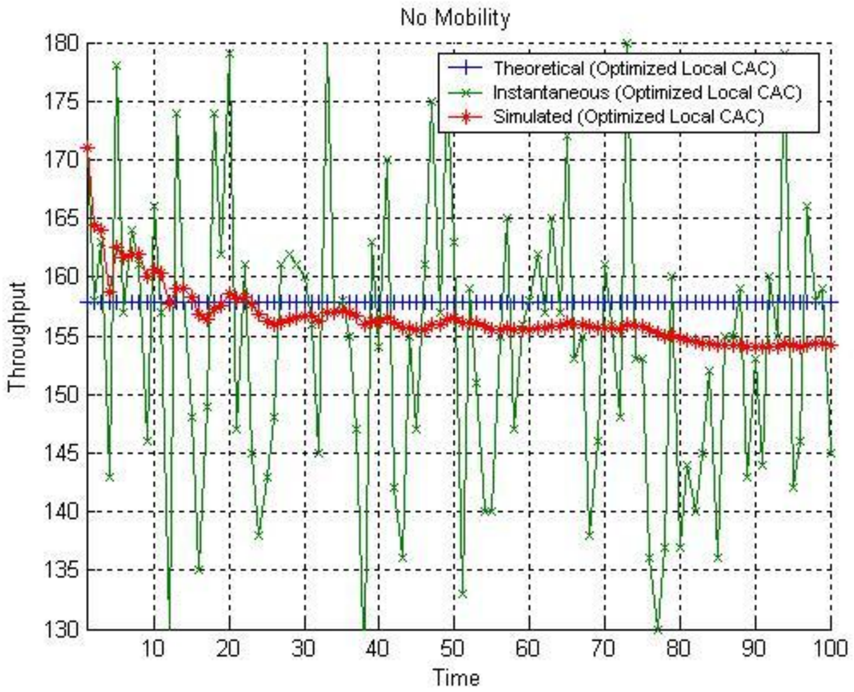


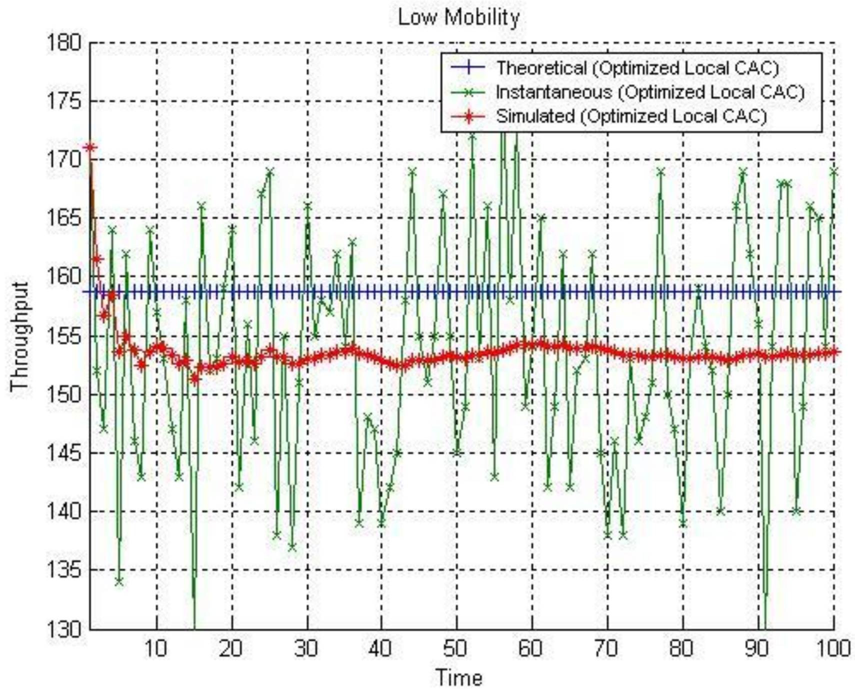


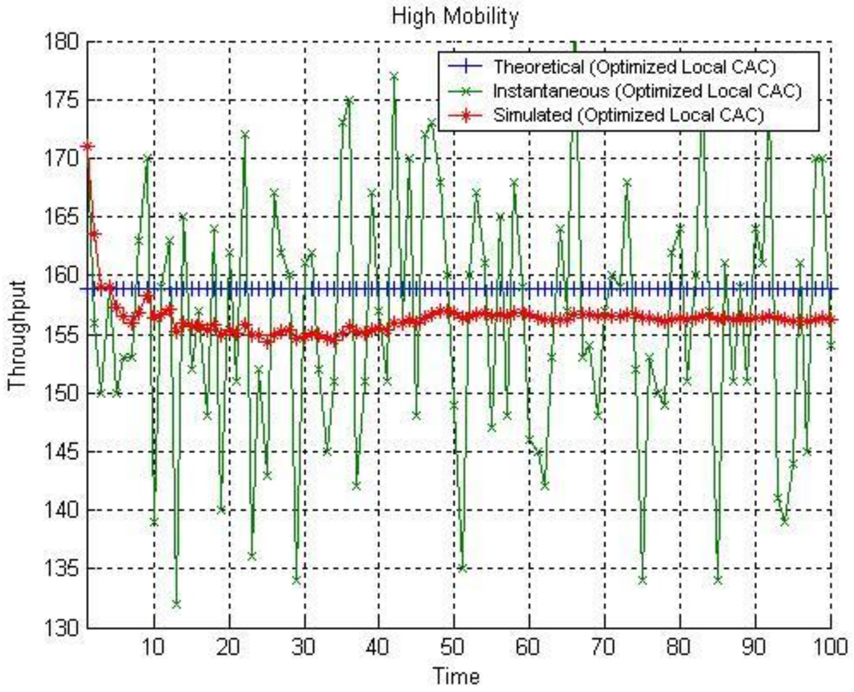


Erlang traffic and maximum number of calls allowed to be admitted per cell for all three mobility cases.

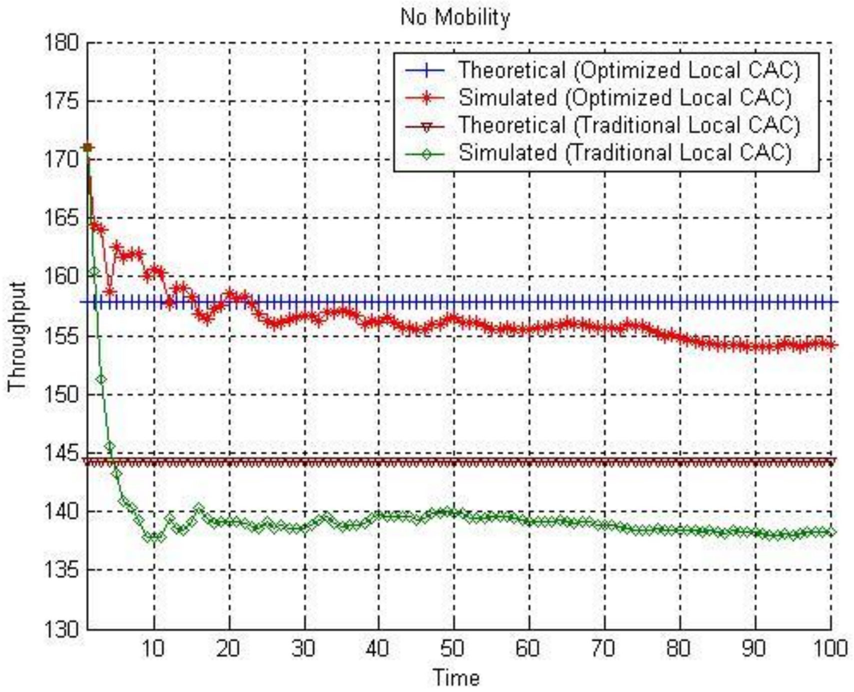
⇧ High mobility has an equalizing effect on non-uniform traffic distribution.

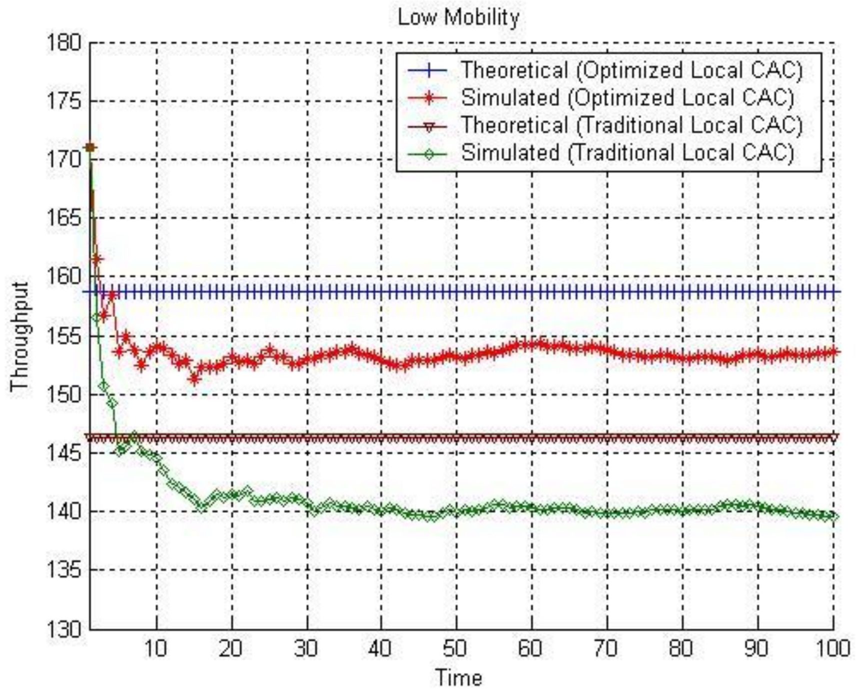


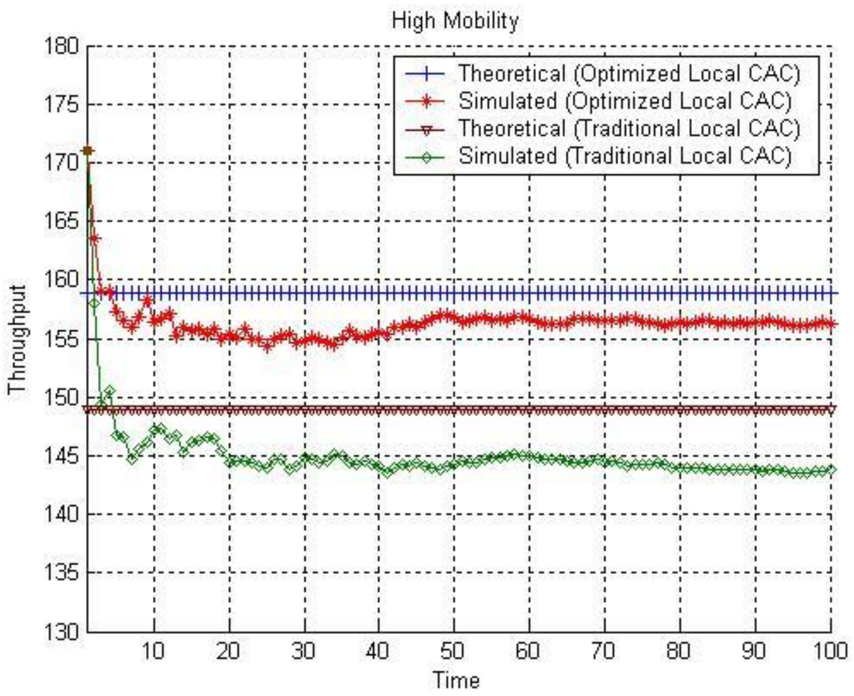




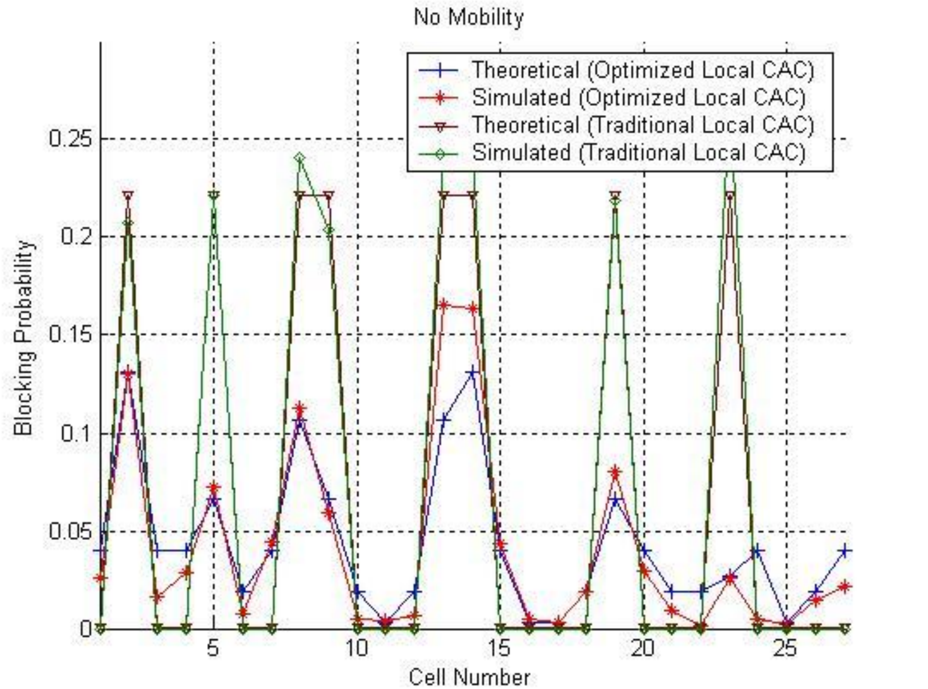
Network throughput for our optimized local CAC for all three mobility cases.

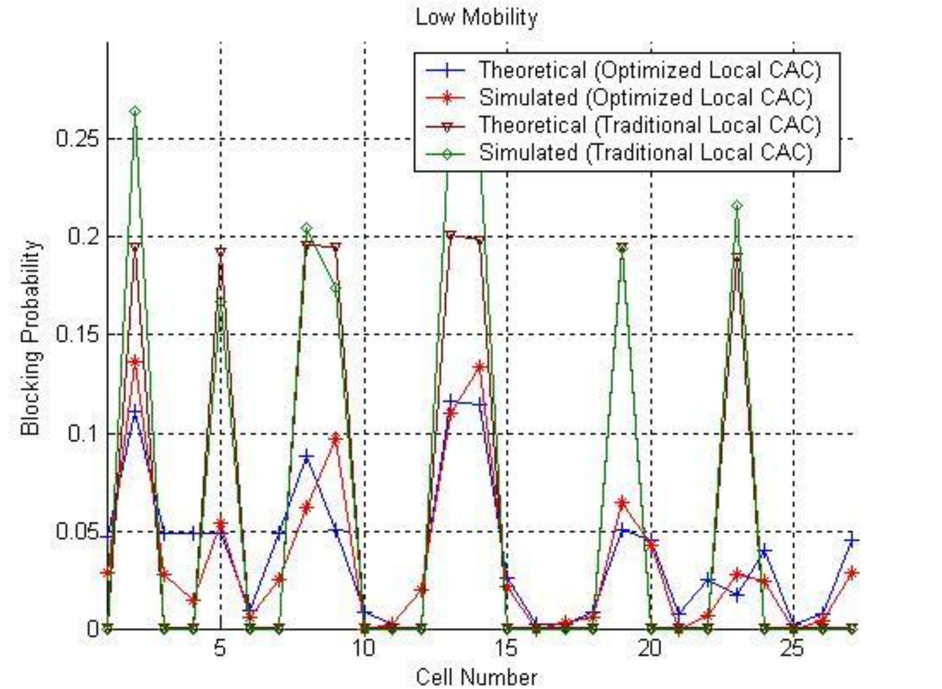


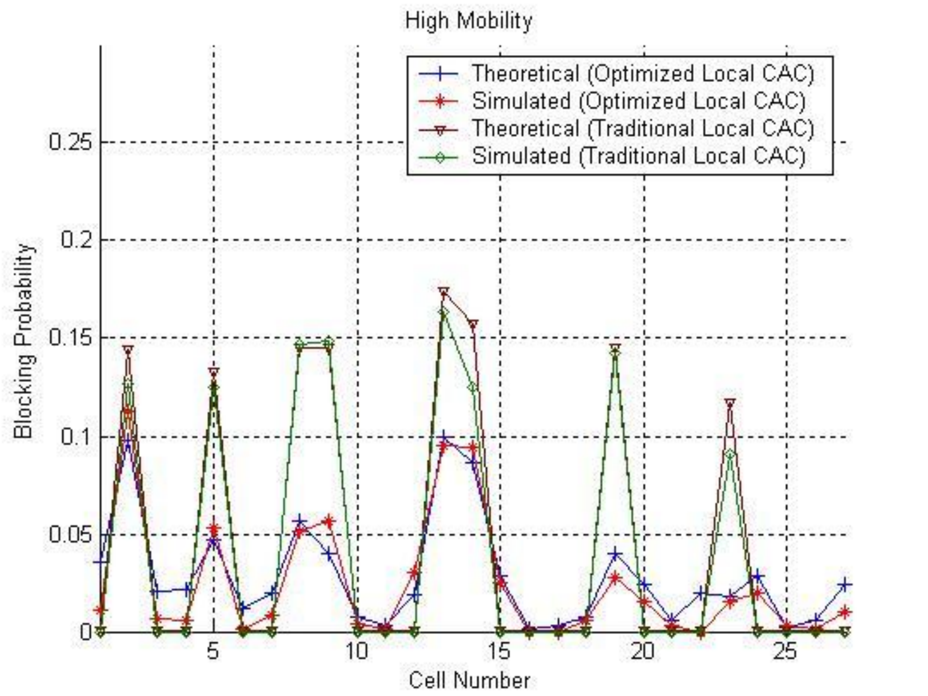




Theoretical and simulated network throughput for our optimized local CAC and traditional CAC for all three mobility cases.



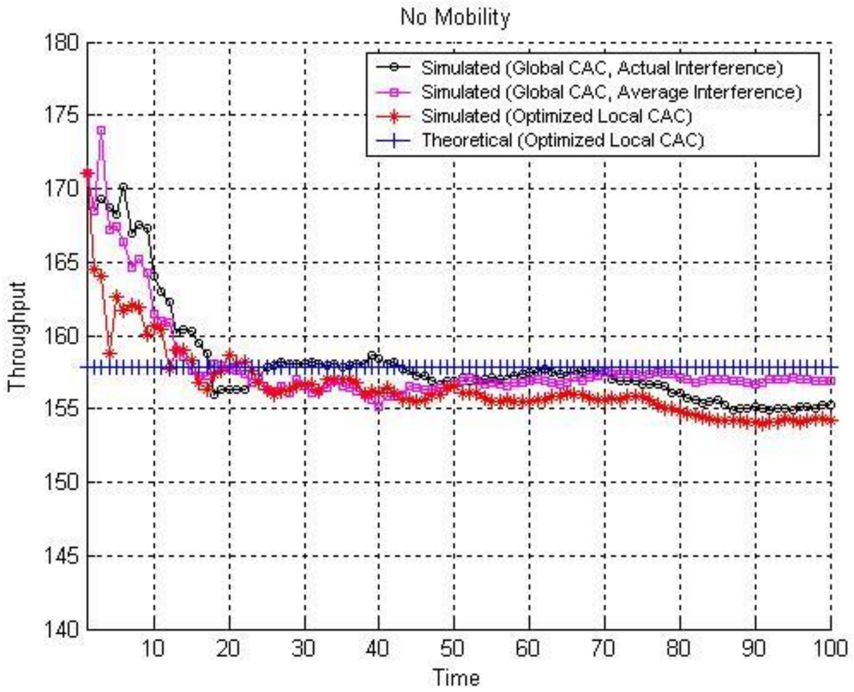


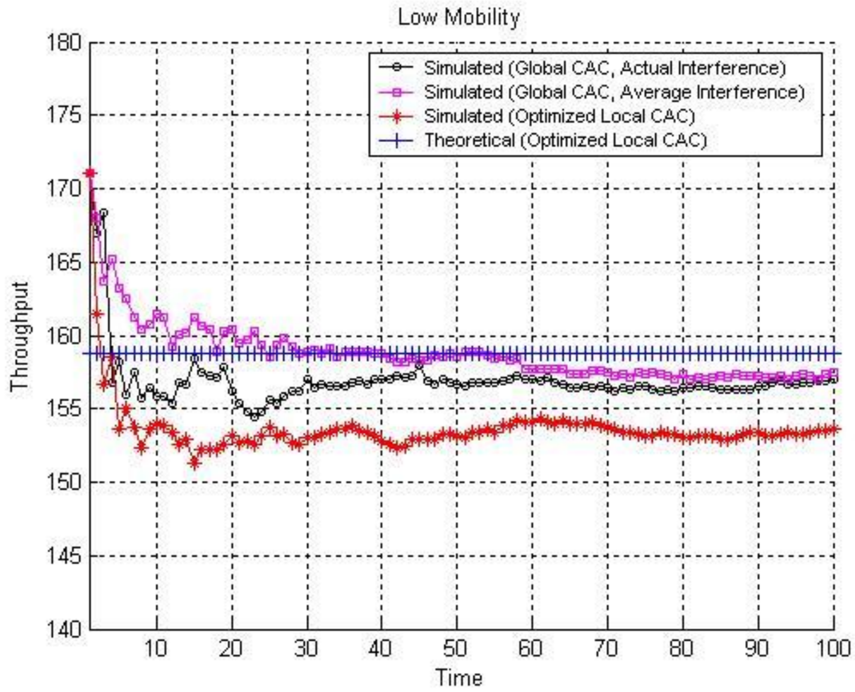


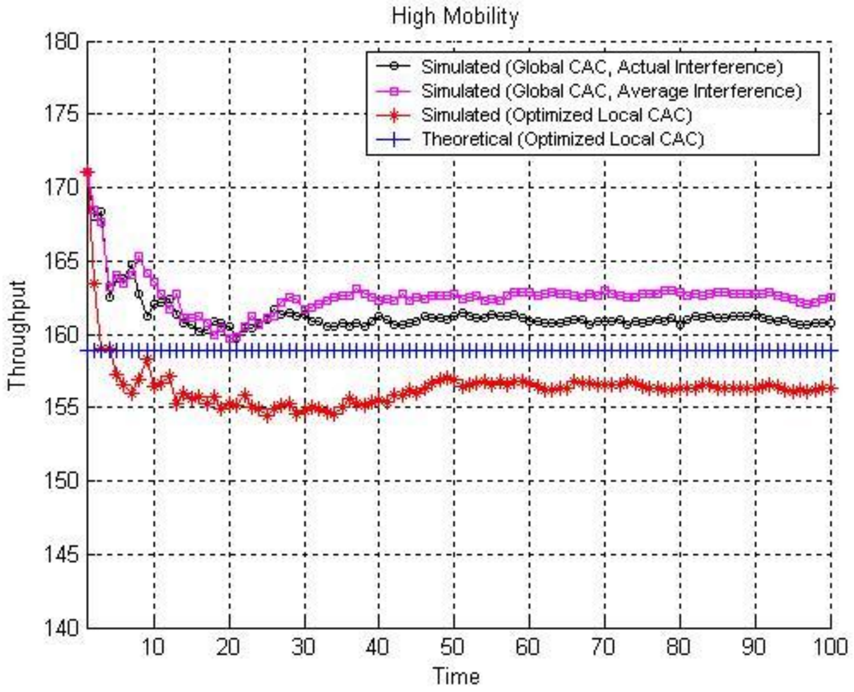
Theoretical and simulated blocking probability for our optimized local CAC and traditional CAC for all three mobility cases.

Results Local CAC

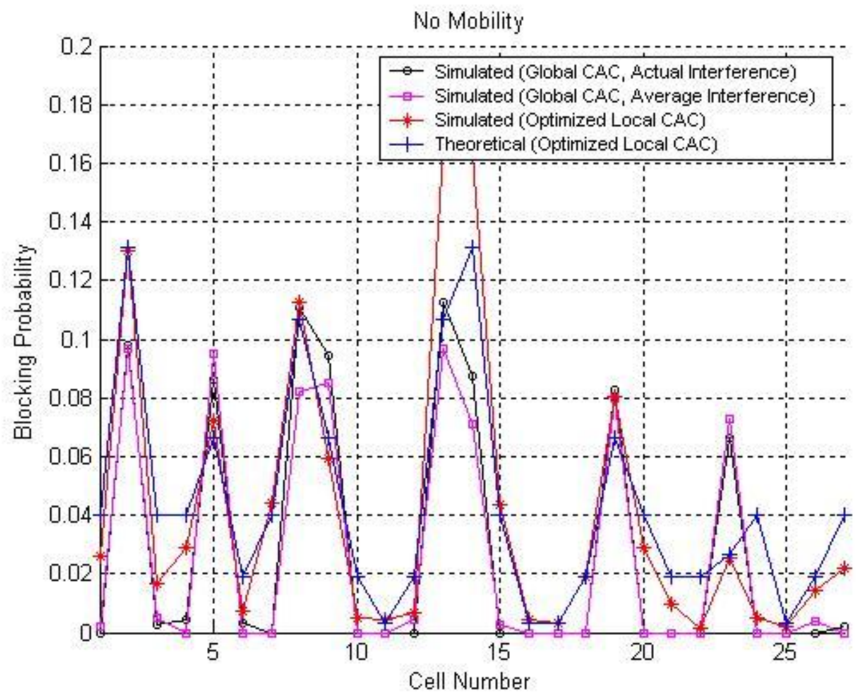
- Our optimized local CAC algorithm adapts in response to the traffic demand due to users' mobility.
- Our local CAC network throughput is higher than traditional CAC throughput by nearly 13%.
- Our local CAC algorithm strikes a good balance between the blocking probabilities of the low and high traffic cells.

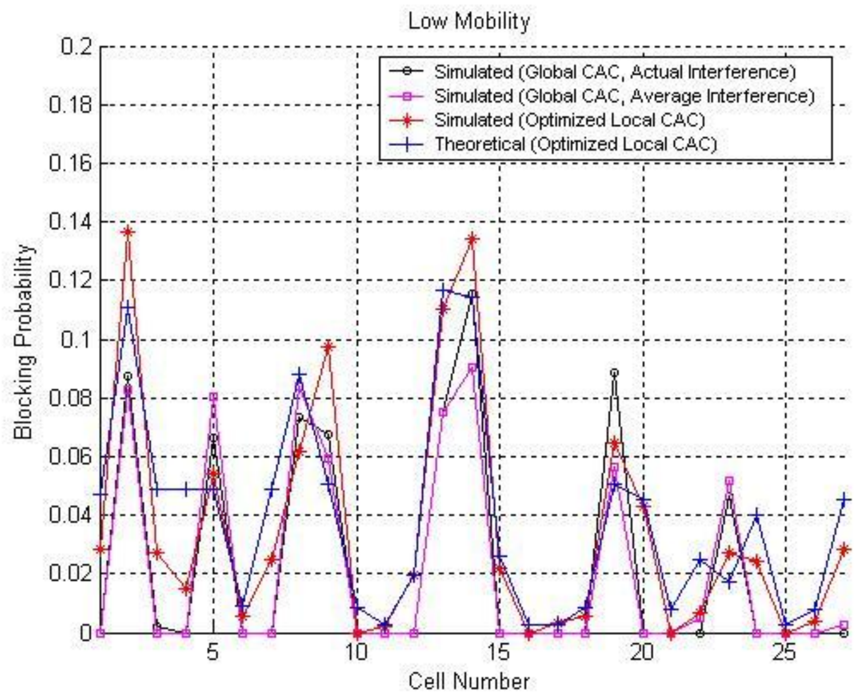


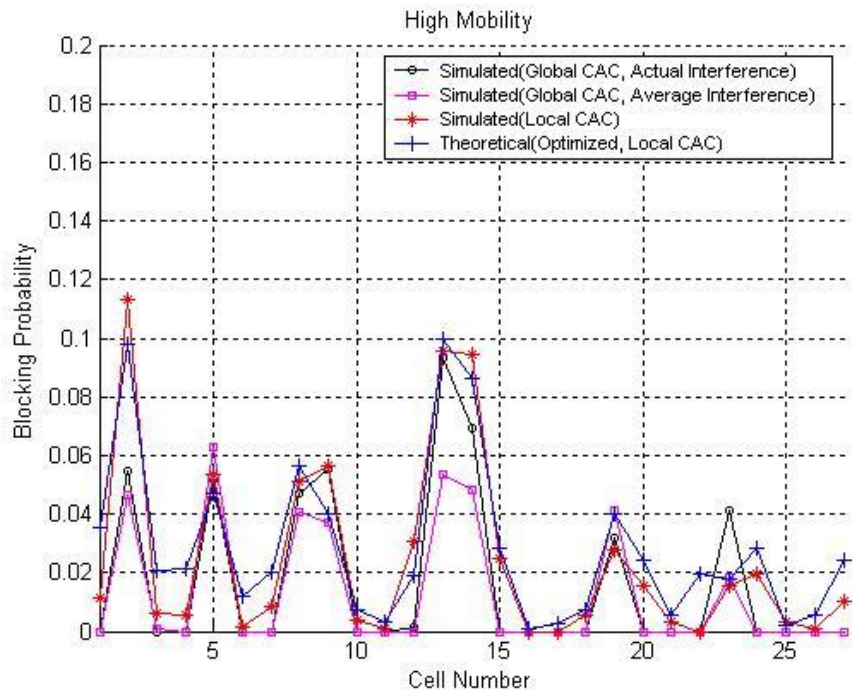




Network throughput for our optimized local and global CAC algorithms.







Blocking probability for our optimized local and global CAC algorithms.

Summary

- High mobility results in highest throughput because it equalizes non-uniform traffic.
- Our optimized local CAC algorithm performance is better than traditional CAC algorithm.
- Our optimized local CAC algorithm performance is just as good as a global for a given traffic distribution.