Global versus Local Call Admission Control in CDMA Cellular Networks

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ABSTRACT

We design and implement global and local CAC algorithms for CDMA networks, and compare their network throughput for various mobility scenarios. The global CAC algorithm is inherently optimized and uses global information in making every call admission decision; it yields the best possible performance but has an intensive computational complexity. The design of the local CAC algorithm uses global information but its implementation in each cell uses only local information; it only requires the number of calls currently active in that cell and thus is very simple to implement. We show that our optimized local CAC algorithm achieves almost the same performance as our global CAC algorithm for a given call arrival rate profile.

Keywords: CDMA, Call Admission Control, Mobility, Network Throughput, Optimization.

1. INTRODUCTION

Due to the dependence of code division multiple access (CDMA) capacity on interference contributed by every call in neighboring cells, the design of a CDMA network call admission control (CAC) algorithm is relatively harder than the design of a CAC algorithm for a TDMA or FDMA network [1]–[5]. There are two approaches that most CAC algorithms fall under – local and global [6], [7]. 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 global CAC algorithm takes the entire network into account to make every call processing decision.

Since the quality of a call in a CDMA network is affected by many other calls present in the network, global CAC algorithms offer the most precise control over call admission policy. But such algorithms, even though optimal (in the sense that they minimize the blocking probabilities), carry sheer amount of computational complexity and are not easily scalable [8].

In this paper, we design, analyze, and simulate a global CAC algorithm with arbitrary call arrival rates. Our global CAC algorithm has a computational complexity that is exponential in the number of cells. We also design, analyze, and simulate a local CAC algorithm by formulating an optimization problem that maximizes the network throughput using signal-to-interference constraints as lower bounds. The solution to this problem is the maximum number of calls that can be admitted in each cell. The design is optimized for the entire network and a given call arrival rate profile, and the implementation is simple and considers only a single cell for admitting a call.

Both algorithms also take mobility of users into account. There are several mobility models that have been discussed in the literature [9]–[17]. The mobility model that we use is presented in [18] where a call stops occupying a cell either because user mobility has forced the call to be handed off to another cell, or because the call is completed.

We compare our global and optimized local CAC algorithms in terms of implementation complexity and performance. Our global CAC algorithm, even though inherently optimized for any call arrival rate profile, bears the overhead of real time interference calculations for every arriving call. On the other hand, our local CAC algorithm performs its optimization calculations in advance and uses the solution obtained for call admission control decisions. Consequently, our local CAC is much simpler to implement. The simulation results show that the optimized local CAC achieves almost the same performance as our global CAC in terms of network throughput for a given call arrival rate profile.

The remainder of this paper is organized as follows. In section 2, we present our traffic and mobility model. In sections 3 and 4, we describe our global and local CAC algorithms, respectively. In section 5, simulation results are presented and compared to analytical results. Finally, the conclusions drawn from this paper are summarized in section 6.

2. TRAFFIC AND MOBILITY MODEL

Feasible Call Configuration

Consider a multi-cell CDMA network with spread signal bandwidth of W, information rate of R bits/s, voice activity factor of α, and background noise spectral density of N_0. Assuming a total of M cells with n_i calls in cell i, the bit energy to interference density ratio in cell i is given by [19]

$$\left(\frac{E_b}{I_0}\right)_i = \frac{E_b}{\alpha(RE_b)\left(n_i - 1 + I_i\right)/W + N_0}, \quad \text{for} \quad i = 1, ..., M, \tag{1}$$

where I_i is the total relative inter-cell interference at cell i caused by every user in the network. To achieve a required bit error rate we must have $\left(\frac{E_b}{I_0}\right)_i \geq \Gamma$ for some constant Γ. Thus, the number of simultaneous calls in each cell must satisfy

$$n_i + I_i \leq \frac{W/R}{\alpha}\left(\frac{1}{\Gamma} - \frac{1}{E_b/N_0}\right) + 1 \triangleq c_{eff}, \quad \text{for} \quad i = 1, ..., M. \tag{2}$$

A set of calls $(n_1, ..., n_M)$ satisfying the above equations is said to be a feasible call configuration, i.e., one that satisfies the $\frac{E_b}{I_0}$ constraints. The right hand side of (2) is a constant which is determined by system parameters and by the desired maximum bit error rate, and can be regarded as the total number of effective channels, c_{eff}, available to the system.

Mobility Model

The call arrival process to cell i is assumed to be a Poisson process with rate λ_i independent of other call arrival processes. The call dwell time is a random variable with exponential distribution having mean $1/\mu$, and it is independent of earlier arrival times, call durations and elapsed times of other users. At the end of a dwell time a call may stay in the same cell, attempt a handoff to an adjacent cell, or leave the network. Define q_{ii} as the probability that a call in progress in cell i remains in cell i after completing its dwell time. In this case a new dwell time that is independent of the previous dwell time begins immediately. Let q_{ij} be the probability that a call in progress in cell i after completing its dwell time goes to cell j. If cells i and j are not adjacent, then $q_{ij} = 0$. We denote by q_i the probability that a call in progress in cell i departs from the network.

This mobility model is attractive because we can easily define different mobility scenarios by varying the values of these probability parameters [20]. For example, if q_i is constant for all i, then the average dwell time of a call in the network will be constant regardless of where the call originates and what the values of q_{ii} and q_{ij} are. Thus in this case, by varying q_{ii}'s and q_{ij}'s we can obtain low and high mobility scenarios and compare the effect of mobility on network throughput [21].

3. GLOBAL CAC ALGORITHM

The call admission requirements that must be met in order to guarantee the quality of service is that the total simultaneous calls must satisfy

$$C_i(t) = n_i(t) + I_i(t) \leq c_{eff} \quad \text{for} \quad i = 1, ..., M, \tag{3}$$

for every time unit t. A new call or a handoff call arriving in cell i is blocked if this call leads to a violation of any of the above inequalities, i.e., causing interference that no longer meets the $\left(\frac{E_b}{I_0}\right)$ constraints from (2).

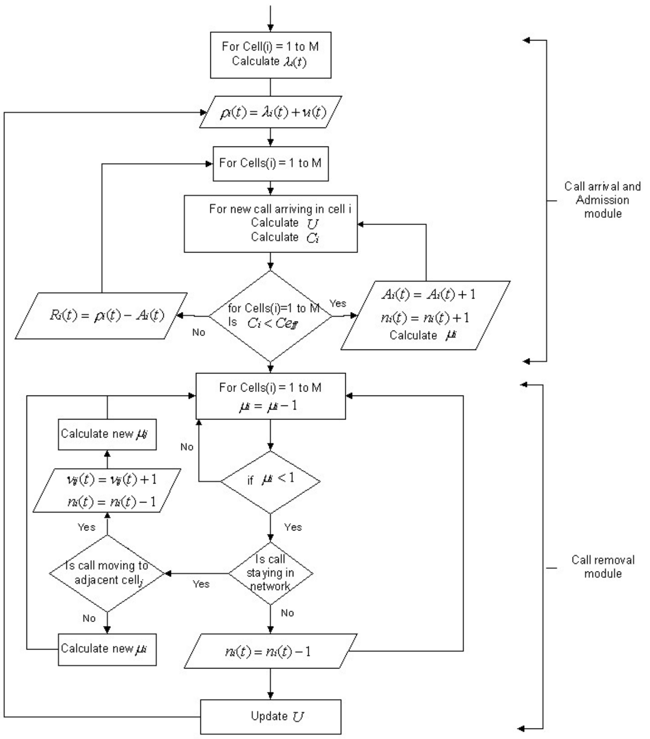

Fig. 1. Flowchart of the network simulator for our global CAC algorithm.

Simulator Model

The simulator is constructed as a sequential state machine running in a loop, where every loop cycle corresponds to a single time unit. It consists of two modules that are executed in sequential order – call arrival and admission module, and call removal module as shown in Fig. 1. The call arrival control is responsible for cell selection and determining arrival rates for each cell. The call admission control, implements the global CAC algorithm by enforcing the conditions specified by (3). Finally, the call removal control relocates and removes users depending on the mobility parameters.

Call Arrival and Admission Module: The module is comprised of two parts, call arrival control and call admission control. The call arrival control generates actual arrival rates for each cell as input to the network and computes the total offered traffic to each cell. The total offered traffic $\rho_i(t)$ to cell i for time unit t is calculated as

$$\rho_i(t) = \lambda_i(t) + \nu_i(t) \quad \text{for} \quad i = 1, ..., M, \tag{4}$$

where $\nu_i(t)$ are the calls that moved to cell i at time $t-1$. Note that $\nu_i(1) = 0$, for $i = 1, ..., M$. The call arrival control then selects each call randomly for a randomly chosen cell, and passes it to the call admission control along with the location of this new call.

In order to determine if the call can be admitted, the call admission control computes C_i to check if the conditions given by (3) will still hold if the call is allowed to enter the network. Traditionally, the total interference contributed by a cell has been viewed as an approximation, determined by simply multiplying the number of users in that cell by the average per-user inter-cell interference factor offered by that cell [22]. In other words, a user placed anywhere within a cell generated the same amount of inter-cell interference. In this paper, we calculate the average interference using that approach. We also use a second more realistic approach and calculate the actual interference as a function of the actual distance of each user from each base station.

Average Interference: If average interference is used, let F_{ji} be the average per-user inter-cell interference factor of cell j to cell i [23]. F_{ji} are elements in a two dimensional matrix F with $i, j = 1, ..., M$. Consequently, the total relative average inter-cell interference experienced by cell i is simply the summation of the product of number of calls n_j in cell j and their respective per-user interference factor F_{ji}:

$$I_i = \sum_{j=1}^{M} n_j F_{ji} \quad \text{for} \quad i = 1, ..., M. \tag{5}$$

Since matrix F can be computed in advance, the above calculation is adequately fast since it requires only M lookups in the matrix. However, the interference caused by a user is independent of its location within a given cell. In this case, the new set of $C_i\left(t\right)$ is calculated as

$$C_i\left(t\right) = n_i\left(t\right) + \sum_{j=1}^{M} n_j\left(t\right) F\left[j, i\right] \quad \text{for} \quad i = 1, ..., M. \tag{6}$$

The computational complexity of the global CAC algorithm using average interference is $O(M)$.

Actual Interference: If the actual distance of each user k from its serving base station is used to calculate interference, the matrix F cannot be used. Instead, a new matrix U is computed and updated in order to account for the actual increase in interference due to admitting the new call:

$$U\left[j, i\right]\left(t\right) = U\left[j, i\right]\left(t\right) + \left(U_{ji}\right)_k \quad \text{for} \quad ij = 1, ..., M, \tag{7}$$

where, $U\left[j, i\right]\left(t\right)$ contains the current total relative actual inter-cell interference exerted by cell j to cell i and $\left(U_{ji}\right)_k$ is the relative actual interference offered by user k in cell j to cell i. Now, the new set of $C_i\left(t\right)$ is calculated as

$$C_i\left(t\right) = n_i\left(t\right) + \sum_{j=1}^{M} U\left[j, i\right]\left(t\right) \quad \text{for} \quad i = 1, ..., M. \tag{8}$$

The computational complexity of the global CAC algorithm using actual interference is $O(M^2)$.

If the inequalities in (3) still hold for the new C_i's, then the call is allowed to enter the network, otherwise the call is rejected.

Let $A_i\left(t\right)$ be the number of calls admitted in cell i during time unit t. If the call is admitted, $A_i\left(t\right)$ and $n_i\left(t\right)$ are increased by one, its dwell time is calculated, and the control is passed back to the call arrival control. The cycle continues until all the arriving calls for this time unit have been processed. The number of rejected calls $R_i\left(t\right)$ for cell i during this time unit is calculated by subtracting $A_i\left(t\right)$ from the total offered traffic $\rho_i\left(t\right)$.

Call Removal Module: The module starts by reducing the dwell time of every call present in the network by one time unit. Then, for every call whose dwell time is less than one time unit, the following decision is made depending on the probability parameters: q_i, q_{ii}, and q_{ij}. The call can either leave the network, or stay in the network. If it is staying in the network, then it can either stay in the same cell with a new dwell time without being considered a new call, or it can move to one of its randomly selected adjacent cells. The handoff calls are considered as new calls, and are processed again through the call arrival and admission control module.

Network Throughput

The network throughput is defined as the number of calls per unit time that are admitted and stay in the network till termination without being dropped from the network. Since handoff calls are considered new admitted calls they are discounted from throughput calculation for time unit t since they have already been accounted for in time unit $t-1$. Thus, the network throughput H_T over a time T is given by

$$H_T = \frac{1}{T} \sum_{t=1}^{T} \left[\sum_{i=1}^{M} \left(A_i\left(t\right) - \nu_i\left(t\right)\right) \right]. \tag{9}$$

4. OPTIMIZED LOCAL CAC ALGORITHM

Our local CAC algorithm is constructed as follows. A constrained optimization problem is formulated in order to maximize network throughput with lower bounds on the signal-to-interference constraints in (2) [18]. The optimization problem is given by

$$\begin{aligned} \max_{(N_1,...,N_M)} \quad & \sum_{i=1}^{M} \left\{\lambda_i - B_i \rho_i\right\}, \\ \text{subject to} \quad & N_i + \sum_{j=1}^{M} N_j F_{ji} \leq \ c_{eff}, \\ & \text{for} \quad i = 1, ..., M, \end{aligned} \tag{10}$$

where B_i is the blocking probability in cell i and $\left(N_1, ..., N_M\right)$ are the maximum number of calls that are allowed to be admitted in each cell. The optimization problem in (10) is solved offline. Once $\left(N_1, ..., N_M\right)$ are determined, the local CAC algorithm for cell i will simply compare the number of calls currently active in cell i to N_i in order to accept or reject a new arriving call. Thus our optimized local CAC algorithm has a computational complexity that is $O(1)$.

Simulator Model

The functional flow and modular structure of our local CAC algorithm simulator is shown in Fig. 2.

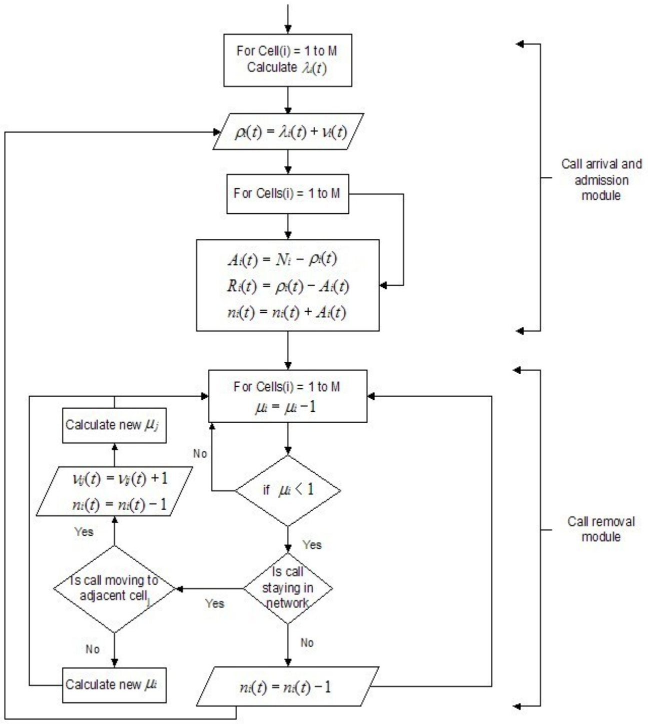

Fig. 2. Flowchart of the network simulator model for our local CAC algorithm.

Call Arrival and Admission Module: The module is comprised of two parts, call arrival control and call admission control. The call arrival control generates actual arrival rates for each cell as input to the network and computes the total offered traffic to each cell using (4) and passes control to the call admission module.

The call admission module for our local CAC algorithm is much simpler to implement than our global CAC algorithm. Since $(N_1, ..., N_M)$ are known in advance (as a result of the optimization (10)) there is no need to calculate the inter-cell interference of each call. Thus the number of calls that can be admitted in cell i, $A_i(t)$, for time unit t is determined by comparing the total offered traffic, $\rho_i(t)$, to the maximum number of calls that can be admitted in cell i, N_i.

Call Removal Module: The call removal module for our local CAC algorithm is similar to the call removal module of our global CAC simulator model.

5. NUMERICAL RESULTS

The following results have been obtained for the twenty-seven cell CDMA network shown in Fig. 3. The base stations are located at the centers of a hexagonal grid whose radius is 1732 meters. Base station 1 is located at the center. The base stations are numbered consecutively in a spiral pattern. The COST-231 propagation model [24] with a carrier frequency of 1800 MHz, average base station height of 30 meters, and average mobile height of 1.5 meters is used to determine the coverage region. We assume the following for the analysis. The path loss coefficient is 4. The shadow fading standard deviation is 6 dB. The processing gain is 21.1 dB. The bit energy to interference ratio threshold, Γ, is 9.2 dB. The interference to background noise ratio is 10 dB. The voice activity factor is 0.375. For more details on the choice of these parameters refer to [23]. The per-user inter-cell interference factors are evaluated numerically by dividing the whole area into small grids of size 150 m by 150 m (for more detail see [19]).

TABLE I

THE LOW MOBILITY PROBABILITIES.

$\|\mathcal{A}_i\|$	q_{ij}	q_{ii}	q_i
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

- $\|\mathcal{A}_i\|$ is the number of cells adjacent to cell i.
- q_{ij} is the probability a call in cell i goes to cell j.
- q_{ii} is the probability a call in cell i stays in cell i.
- q_i is the probability a call in cell i leaves the network.

TABLE II

THE HIGH MOBILITY PROBABILITIES.

$\|\mathcal{A}_i\|$	q_{ij}	q_{ii}	q_i
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

Three mobility scenarios are considered: no mobility, low mobility, and high mobility of users. The following probabilities are chosen for the no mobility case: $q_{ij} = 0$, $q_{ii} = 0.3$ and $q_i = 0.7$ for all cells i and j. For the low and high mobility case, the mobility probability parameters are given in Tables I and II, respectively.

We choose the call arrival rates to be equal to 14 calls per unit time for all cells in Group A, i.e., (cells 5, 13, 14, and 23) and Group B, i.e., (cells 2, 8, 9, and 19). For the remaining cells, the call arrival rates are equal to 3 calls per unit time.

As can be seen from Figures 3, 4, and 5 for no mobility, low mobility, and high mobility, respectively, that there is very little difference (at most 1 per cell) between maximum users admitted in all the cells for the network using average interference and actual interference. This is because the users are uniformly distributed in each cell and thus using the average interference approximation yields very close results to the actual interference method.

Our global CAC algorithm is inherently optimized, and therefore it is expected to perform better than our local CAC algorithm. It is shown from Figures 6, 7, and 8, that indeed our global CAC algorithm throughput is always a little higher than our local CAC algorithm. However, the difference between our global CAC throughput and our local CAC throughput is between 1% and 3% for all the three mobility case.

Figures 6, 7, and 8 also show the throughput obtained using actual interference and average interference for the

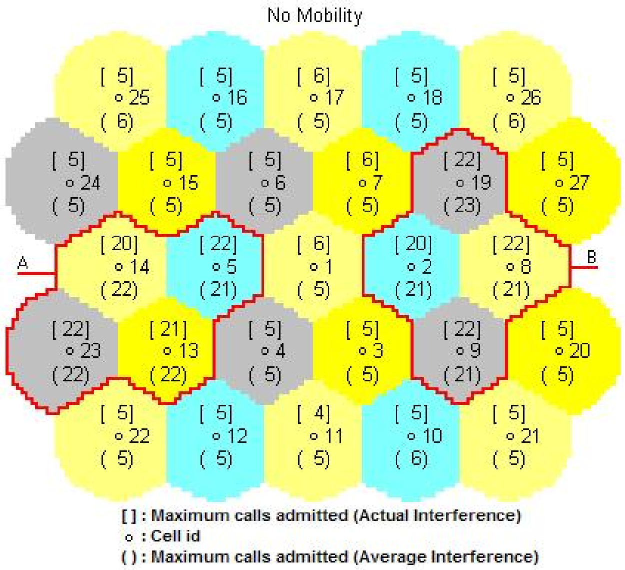

Fig. 3. Maximum users admitted per cell for average and actual interference for no mobility case.

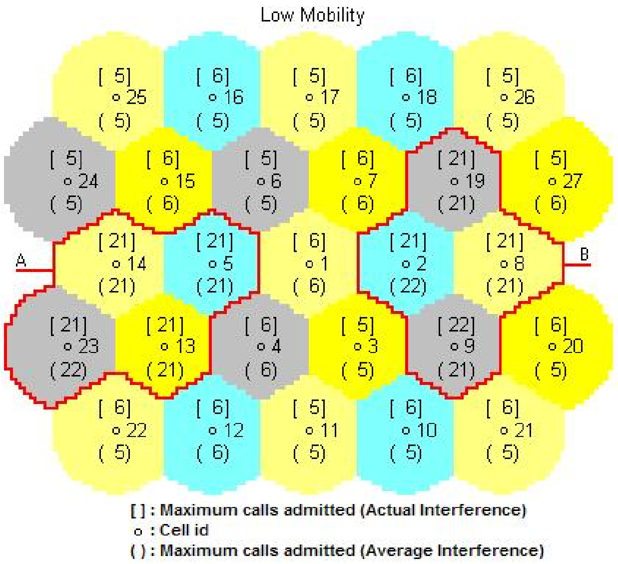

Fig. 4. Maximum users admitted per cell for average and actual interference for low mobility case.

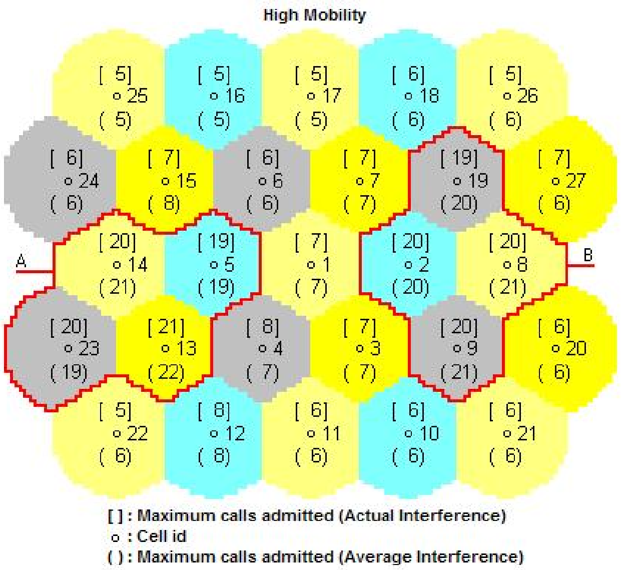

Fig. 5. Maximum users admitted per cell for average and actual interference for high mobility case.

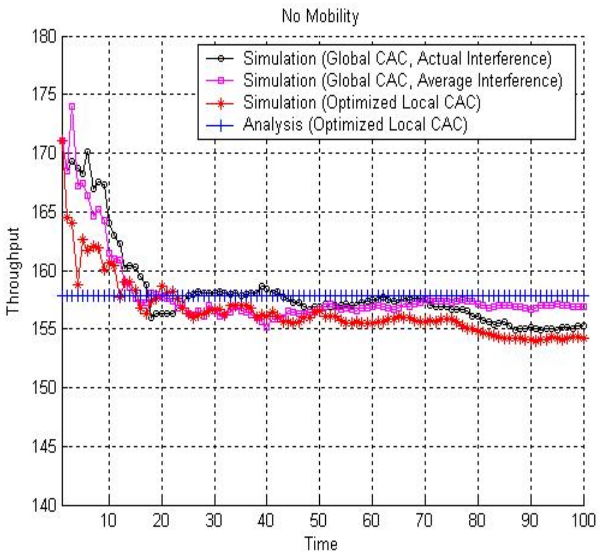

Fig. 6. Network throughput for our optimized local CAC and global CAC algorithms for no mobility case.

three mobility cases. Although the difference seen is not significant, the network throughput for average interference is a little higher than the network throughput for actual interference in all three cases. The throughput is highest for the high mobility case because the high mobility starts to equalize the call arrival rates thus lowering the blocking probabilities, which leads to a gain in throughput.

6. CONCLUSIONS

We compare our global CAC algorithm and local CAC algorithm in terms of computational complexity and performance. The computational complexity of the global CAC algorithm using average interference is $O(M)$ and using actual interference is $O(M^2)$, while the computational complexity of our optimized local CAC is $O(1)$. Our results show that the difference between our optimized local CAC algorithm's performance and our global CAC algorithm's performance is small enough (less than 3%) to justify the small tradeoff in throughput for the huge reduction in computational complexity. Our simulation results also show that the difference in the maximum users admitted for the global CAC algorithm when using relative actual interference and relative average interference is too small to warrant the incursion of heavy computational load involved in the former case.

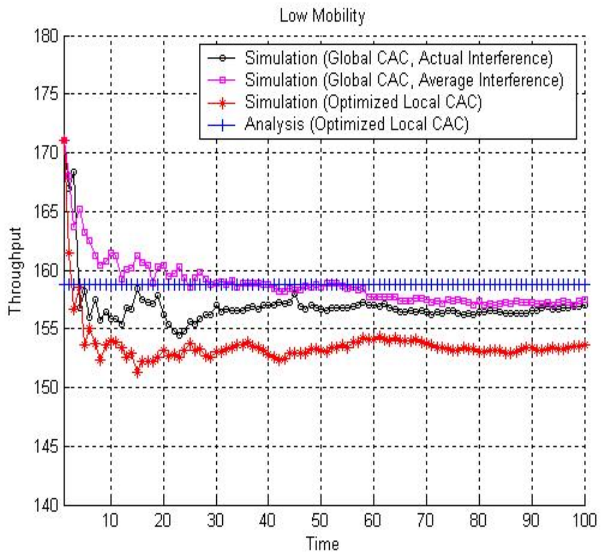

Fig. 7. Network throughput for our optimized local CAC and global CAC algorithms for low mobility case.

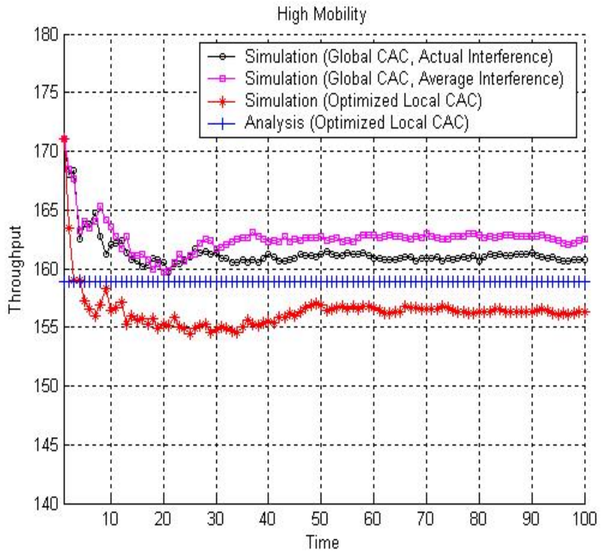

Fig. 8. Network throughput for our optimized local CAC and global CAC algorithms for high mobility case.

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