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Impact of the Various Tiers of Interfering Cells on CDMA Systems

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Abstract:- In this paper, using a simulation and modelling technique, the sensitivity of other-cells interference factor and the probability of blockage versus the addition of the various tiers of neighbouring cells has been studied. Situations with tiers of neighbouring cells are considered and for two scenarios, when the mobile chooses as home cell the nearest base station, and when it compares two base stations and chooses the base station with the stronger signal. It is concluded that it is usually enough to consider only three tiers of neighbouring cells to get a good understanding of the performance issues of the CDMA home cell. The simulation results confirm that by choosing the better of two base stations a significant reduction in other-cells interference can be achieved compared to choosing the closest base station. The other-cells interference factor is found and compared with the upper bound results obtained in earlier studies.

Key Words:- CDMA, other-cells interferences, number of tiers

1. INTRODUCTION

Mobile communications has enjoyed rapid growth during the last decade. As the amount of bandwidth available remains the same, capacity planning becomes an important issue in cellular systems. CDMA system capacity decreases with the amount of interference. In CDMA all calls interfere with one another as they all use the same frequency range. Each base station not only receives interference from mobiles in the home cell (intra-cell interference) but also from mobiles located in neighbouring cells (inter-cell interference). Earlier researchers have looked at various number of tiers of interfering cells (from one tier in [1,2] to two tiers in [3] to five tiers in [4]) to investigate the performance of the CDMA systems. There is little in the literature to determine how many tiers of neighbouring cells are to be included in the system model to get a certain precision in blocking probability results. In this paper, the effect of the various tiers on the CDMA system is investigated. It is determined that it is enough to consider only three tiers of neighbouring cells in order to get a good understanding of the performance issues of a CDMA home cell.

The organization of this paper is as follows. In the next section the system model is discussed. The simulation results are then presented. The last section presents conclusions.

2. SYSTEM MODEL

A cellular CDMA system (a home cell and tiers of neighbouring cells) is considered with a base station located at the center of each cell (Figure 1). Calls are considered to suffer log-normal shadowing (but not Rayleigh fading [5]). All cells are assumed to be homogeneous in every respect and users are assumed to be uniformly distributed over the cell area. The reverse link (mobile to base station) is investigated as it is the limiting link due to its inferior performance compared to the forward link [6,7].

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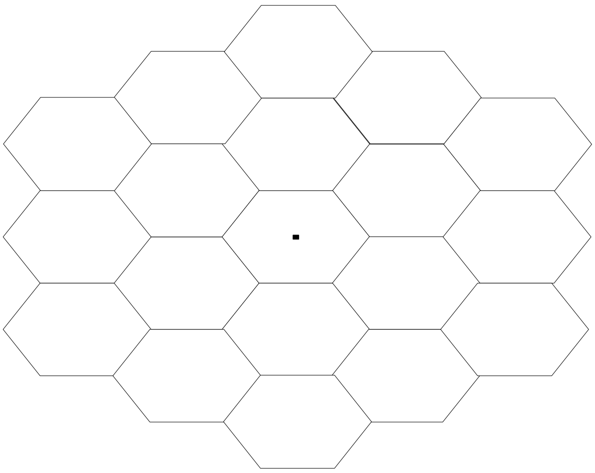

Figure 1: A home cell and two tiers of neighbouring cells.

The CDMA system is modelled as a M/M/∞ system (Figure 2) [5,8,9,10]. Calls are assumed to arrive in the system with Poisson distributed probability with mean arrival rate λ calls/second. Calls remain in the system with a negative exponentially distributed call holding time with mean $1/\mu$ seconds/call. When a call is accepted it remains in the system during its call holding time.

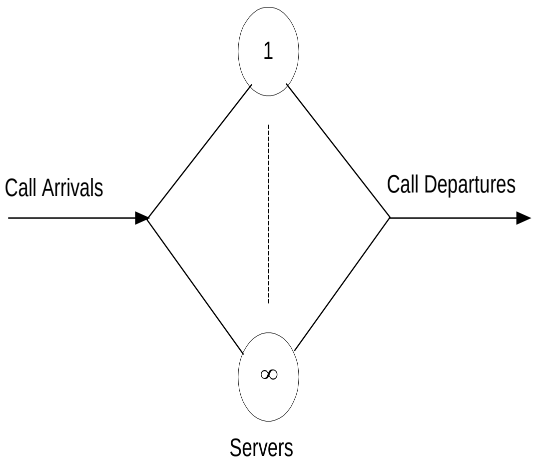

Figure 2 **:** Call arrivals, service, and departures for *M/M/∞* system

Handoff request arrivals also follow a Poisson distribution [9,11]. The sum of two Poisson process (with λ_1 and λ_2) is another Poisson process with $\lambda=\lambda_1+\lambda_2$ (Figure 3) [12]. We define the total arrival rate λ as the sum of the normal call arrival rate λ_1 and handoff traffic λ_2. The probability density function is given by:

$$f(t) = (\lambda_1 + \lambda_2)e^{-(\lambda_1+\lambda_1)t} \quad (1)$$

No priority is given to handoff calls.

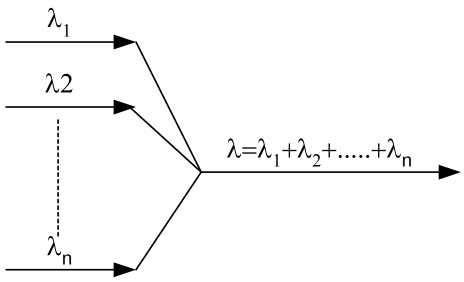

Figure 3**:** Addition of Poisson Processes is another Poisson Process

There is no limit on the number of calls accepted to the system (soft capacity) as long as they meet the required call quality. Any calls not meeting this required quality are blocked from entering the system.

3. BLOCKING PROBABILITY

CDMA capacity is interference limited. With greater interference, fewer calls can be accepted to the system as the quality of calls decreases. In a CDMA system, each base station not only receives interference from mobiles in the home cell (intra-cell interference) but also from mobiles located in neighbouring cells (inter cell interference). The interference received from other cells depends on the signal strength received from the mobiles making the calls. The propagation model used assumes that attenuation is proportional to the product of the *m*th power of the distance *(r)* and a lognormal random number (ξ) representing shadowing with mean zero and standard deviation of σ_ξ dB, that is

Home cell

$$S = S_t r^{-m} 10^{\xi/10} \quad (2)$$

where S_t and S are the transmitted and received power respectively.

The interference from the *j*th mobile in neighbouring cell *i* is expressed as (figure 4):

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$$(I)_{ij} = S\frac{r_m^{\ m}}{10^{\xi_m/10}}.\frac{10^{\xi_0/10}}{r_0^{\ m}} = S(r_m/r_0)^m 10^{\xi_o-\xi_m/10} \tag{3}$$

$$(I/S)_{ij} = (r_m/r_0)^m 10^{\xi_0-\xi_m/10} \tag{4}$$

The total other-cell interference I_o is the interference produced by all users who are power controlled by other base stations. Assuming a CDMA system with *M* outer cells and *N* users per cell, then the total other user interferences-to-signal ratio $(I/S)_o$ is [5]:

$$(I/S)_o = \sum_{i=1}^{M}\sum_{j=1}^{N} I_{ij}/S \tag{5}$$

On each call arrival, the total interference is determined from which the blocking condition can be checked. This involves repeatedly generating for each user a random location of r_m between 0 and 1 and uniform random variable θ between 0 and 2π. The value of r_0 can be calculated for each neighbouring cell's interfering calls.

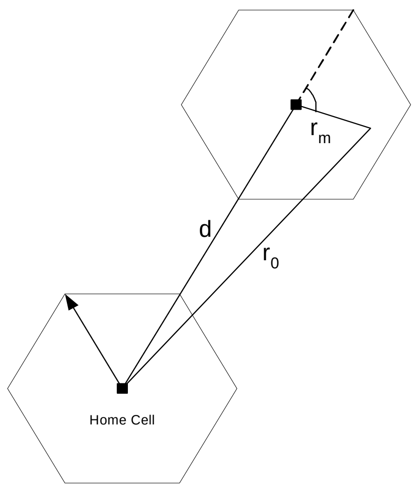

Figure 4: Interfering call distance to home cell

Using equations (4,5), the received power from interfering cells at the home base station is then calculated by considering the path loss exponent *m* and shadowing parameter ξ_o-ξ_m. For each interfering call, a lognormal differential shadowing parameter, ξ_o-ξ_m , is generated with mean zero and total standard deviation $\sigma_T = \sigma_\xi\sqrt{2}$ (If independent lognormal variables ξ_m and ξ_o have mean zero and variance of σ_ξ^2, ξ_o-ξ_m has mean zero and variance $2\sigma_\xi^2$).

The transmission quality of a CDMA call in terms of the energy per bit over total interference spectral density E_b/N_0 may be calculated as [13]:

$$\frac{E_b}{N_0} = \frac{S/R}{I/W} = \frac{S/R}{((N-1)S + I_o + \eta)/W} = \frac{W/R}{(N-1)+(I/S)_o + \eta/S} \tag{6}$$

where $(I/S)_o$ is the ratio of other-cells interference to the received signal strength (S) at the home base station, η is background noise, W/R is the Processing Gain, W is available spread bandwidth, and R is data rate. Taking voice activity (α) into consideration,

$$\frac{E_b}{N_0} = \frac{W/R}{\alpha(N-1) + \alpha(I/S)_o + \eta/S} \tag{7}$$

The CDMA system can now be simulated and E_b/N_0 calculated using (5) and (7) for every call arrival. The total interference at the home base station is determined from which the outage condition can be checked. If the required call quality of (E_b/N_0) is not achieved, the call is blocked. The simulated blocking probability is then obtained for a given Erlang traffic (λ/μ), by taking the ratio of the number of blocking events to the total number of call arrivals (Figure 5). The accuracy of the above model was tested in [14] where the results matched with the analytical results of [8].

The other-cells interference factor (*f*) can be calculated as the ratio of other-cells interference to within-cell interference,

$$f = \frac{I_o}{(N-1)S} = \frac{I_o/S}{N-1} = \frac{\sum_{i=1}^{M}\sum_{j=1}^{N}[(r_m/r_0)^m 10^{\xi_0-\xi_m/10}]_{ij}}{(N-1)} \tag{8}$$

Simulation results were obtained for the two scenarios when the home cell was chosen as: (a) the closest cell ($r_m<r_o$); and (b) the cell that provides the strongest signal, in which case the mobile will still choose the closest cell as home cell if [10]

$$(r_m/r_0)^m 10^{\xi_0-\xi_m/10} \le 1 \tag{9}$$

whereas it will choose the neighbouring cell if the RHS of equation 9 is greater than one.

4. RESULTS

The simulation is performed for one million arrivals and on each arrival the ratio of other-cell interferences I_o to within-cell interference (N-1)S is determined. These values are then averaged over the simulation period. Note that the value of S is not required when calculating the ratio in (8). The blocking probability is obtained by taking the ratio of the number of blocked calls to the total number of call arrivals (Figure 5). The simulation is started with one tier (a home cell and 6 interfering cells) and other-cells interference factor (f) and blocking probability is calculated. Next the second tier is added (a home cell and 18 interfering cells) and the same ratio is calculated. The additions of tiers are continued until any further addition has insignificant effect (Table 1).

For parameter values of σ_ξ=8dB (σ_T=11.3), W/R=125, E_b/N_0=5.012 (7dB), α=0.375 , S/η=-1dB, and m=4, and 21 Erlang of traffic per cell (λ/μ), the GoS (Grade of Service) and the ratio of other-cell interference to within-cell interference are calculated and tabled.

In Table 1, Column A is the other-cells interference factor (f) if the mobile chooses the closest cell as the home cell. Column B is the other-cells interference factor when the mobile compares the signal form the two nearest cell sites and chooses the better one as its home cell. The column %change is the percent change in the other-cells interference factor results as another tier is added. In the Table, 4th tier means tiers 1-4 inclusive.

Table 1 results indicate that a significant improvement is achieved if we use the better base station of the two nearest base stations (column B) as a measure for choosing the home cell compared to choosing the closest base station (column A) as home cell. The result clearly indicates that it would be enough to take into consideration the first three tiers and ignore the fourth tier onwards. This could be seen in % change column of data.

For total shadowing parameters of 10dB and 12 dB, the upper bound of parameter f is found in [15] to be 1.28 and 2.62. Using equation (8), the simulation results indicate the other-cells interference factor to be 0.52 and 0.68 respectively which is less than the upper bound values.

It was found that the average other-cells interference factor was essentially independent of the traffic load, a consequence of considering an assumed homogeneous system with a large number of call arrivals.

	A	%change	GoS	B	%change	GoS
1st tier	2.701	---	0.0100	0.545	---	0.0031
2nd tier	3.194	18.237	0.0190	0.605	11.009	0.0050
3rd tier	3.383	5.937	0.0230	0.630	4.132	0.0060
4th tier	3.451	1.998	0.0250	0.638	1.270	0.0064
5th tier	3.459	0.232	0.0260	0.640	0.313	0.0065
6th tier	3.460	0.029	0.1260	0.641	0.156	0.0066

Table1: effect of various tiers of cells on interference and blocking probability for m=4. and σ_ξ=8dB (σ_T=11.3)

5. CONCLUSIONS

The impact of the neighbouring cells on the performance of CDMA systems under perfect power control was investigated. It was noted that it is enough to consider only three tiers of neighbouring cells (and ignore the higher tiers) to get a good understanding of the performance issues of the CDMA home cell.

The simulation results showed that by choosing the better of two base stations as home cell a significant reduction in other-cells interference and blocking probability could be achieved compared to choosing the closest base station. It is found out that the upper bounds results of the other-cells interference factor obtained analytically in a previous study is significantly higher than the actual other-cells interference factor determined via simulation.

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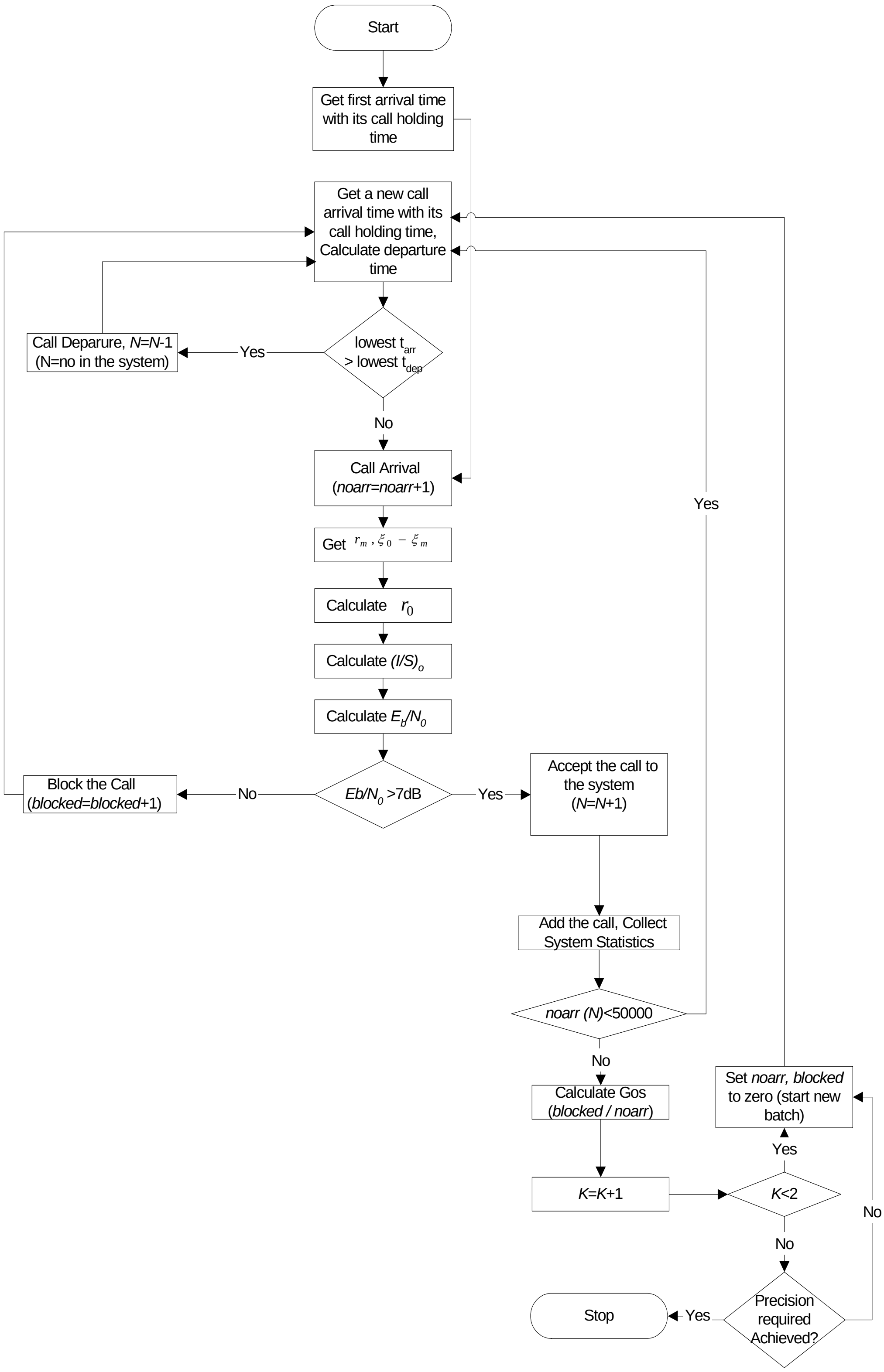

Figure 5: Blocking probability calculations in the simulation model.