

Proposed Model for Interference Estimation in Code Division Multiple Access

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Abstract

Cellular CDMA systems are usually affected by interference experienced by users in adjacent cells that decrease the Quality of Services in wireless communication network. Hence, interference is the limiting factor of capacity in CDMA cellular and it is one of the problems fighting against the high efficiency of any mobile network. In this paper, a mathematical model to estimate the average number of users contributing in inter-cell interference at the busy hours of CDMA network is proposed. As the power exponent value has significant affect on interferer signal attenuation and hence other-cells interference, measurements were carried through a drive test to determine the received power level at various distance from CDMA base stations at Baghdad. The results obtained show that the power exponent was 2.71. This value was applied in dual-slop path loss model to determine the expected interference factor, and the number of users that can be hold at each cell. Simulations showed that users at a boundary cell generate more interference than those close to the base station. Furthermore, it was denoted that greater number of users caused to increase the interference factor, and greater power exponent value result in interference factor reduction.

Keywords: CDMA, multiple access interference, cellular capacity

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1. Introduction

In a cellular network, in order to obtain high system capacity, the overall geographical area is split into small cells due to limited spectrum. Frequency reuse and multiple access are the mostly used techniques to obtain an efficient use for the available radio frequency spectrum [1]. The Code Division Multiple Access (CDMA) is a method of multiple access that is designed to serve large number of users sharing the same frequency spectrum, to discriminate one conversation from the other every user is allocated a unique code sequence is called as pseudo noise code [2]. In CDMA, the power emission from base station for call process depends on distance between base station (BS) and mobile station (MS). This means that BS emission power depends on users' density of in the cell. Furthermore, the greater distance between BS and MS mean the greater power emission, and vice versa [3]. In up-link case, all mobiles transmit using the same channels interfering with one another. Each base station not only receives interference from the mobiles within their coverage area (intra-cell interference) but also from mobiles existing in the surrounding cells (inter-cell interference) [4]. Interference experienced in CDMA communication systems is the major factor that limits the system capacity. Then the interference is increasing as the number of users' increase. Thus, this multi-user interference must be reduced to achieve the required capacity [5].

There had been several works on the estimation of interference in CDMA of wireless network through various techniques. In [6], proposed a modern framework to study the performance of wireless cellular networks utilizing a fluid model and analytical modes for interference focusing on the other-cell interference factor in downlink case. In [7], calculated the interference caused by adjacent cells surrounding a single desired cell with the help of distance ratio and the path loss component for various cases, where the interfering user remained stationary (static) and the moved randomly with respect to time (dynamic) for single tier of cells. In [8], presented the analyzation of interferences in a CDMA-based on dynamic channel assignment (DCA) algorithm with special confirmation on Adjacent Channel Interference (ACI) and Co-Channel Interference (CCI). In [9], used circular interference cellular model to investigate downlink co-channel interference in wireless networks, by uniformly spreading of the

interferers power along the circumference of the grid-shaping polygon. In [10], proposed an analytical execution for the estimation of the capacity of WCDMA system with effect of Co-Channel Interference (CCI) and the performance analysis is carried out in terms of sectorization, power control, and voice activity services.

However, the main goal of this paper is to characterize and evaluate the average other-cell interference caused by users in different location at busy and show how the interference affected with path loss exponent, then exhibit effect of interference on the capacity of cellular systems. This will be accomplished through the derivation of a mathematical model to determine the number of users contributing to the inter-cell interference and using two slop path loss model.

2. Proposed Model for Average Number of Interference

Assume that each cell in the typical cellular communication system illustrated in Figure 1, having an area of A_c around a cellular base station transceiver. For mathematical convenience, the hexagonal shape of the cell is approximated by a circle with R_c as the maximum cell radius. In each cell, the area covered by the ring of radius r , with small width dr will be $(2\pi r dr)$. When the cell is not fully covered by the base station, the fraction of the coverage within an area in which the transmitted signal strength from a mobile unit has the probability to contribute in traffic and interference is then the sum of the area associated with all thin rings from radius 0 to R_c multiplied by the corresponding coverage percentages $p_c(r)$.

$$A_c = \int_{r=0}^{R_c} 2\pi r p_c(r) dr \quad (1)$$

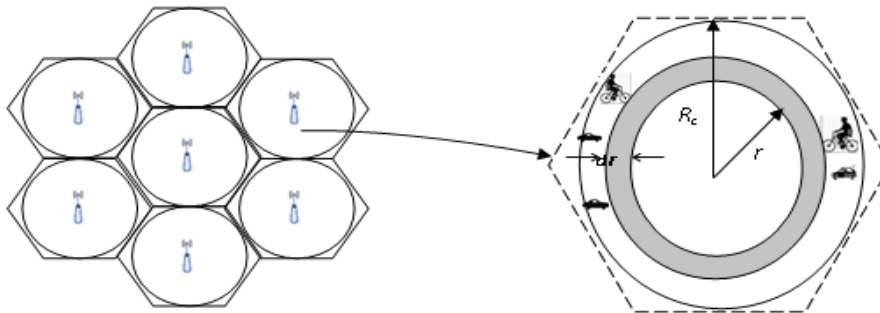


Figure 1. Cellular circular configuration

In this work, the approach used to characterize any cell state in the network depends on the number of users existing inside that cell. The average number of mobile units located inside the ring dr at time $t = 0$, can be found from the area covered by the ring $(2\pi r dr)$, and the average mobile density that represent the number of mobiles per unit area:

$$N = \int_{r=0}^{R_c} 2\pi r p_c(r) \rho_m dr = \pi R_c^2 p_c(r) \rho_m \quad (2)$$

where N is the average number of mobile units and ρ_m is the average mobile density mobile units/km². For purposes of this paper, a fully covered cell will be assumed; hence, the coverage percentages $p_c(r)$ will assumed to be equal to 1 for worst case truly representation. Assuming that (\bar{u}) is the average mobile unit speed in km/h, then the distance dr can be given as $(dr = \bar{u} dt)$, and the average number of mobiles entering the cell coverage area A_c within a

time dt , will be equal to the number of mobiles located within a ring of width dr and the average mobile density that represent the number of mobile units per unit area:

$$N = \int_{t=0}^t 2\pi r \rho_m \bar{u} dt \quad (3)$$

The average number of mobiles entering the whole cell area during a time period of length T can be given as:

$$N = \int_{t=0}^T 2\pi R_c \rho_m \bar{u} dt \quad (4)$$

Assuming that probability of mobile stations entering the area A_c is equal to m_1 , and probability of mobile units leaving the area A_c is equal to m_2 , the average number of mobiles crossing the area A_c during a time period of length T and contributing to the total traffic and interference will be:

$$N = (1 - m_2) \int_{t=0}^T 2\pi R_c \bar{u} \rho_m dt \quad (5)$$

In up-link, any user within the coverage area of any cell is said to be active if the ratio of received energy per chip to interference plus noise density ratio (E_b/N_t) at the base station is sufficient. The E_b/N_t ratio represents the signal-to-interference ratio (SIR) that is required from the mobile to have reliable link.

3. Propagation and Interference Modeling

3.1. Power Exponent Propagation Model

A radio propagation model is a mathematical/empirical formulation for characterizing radio wave propagation as a function of frequency, distance and other environmental conditions [11]. The Log-distance path loss model is used here as it takes in to consideration the decrease in received power due to the distance, as well as the energy loss in terms of an empirical path loss constant (n) [12]. The interference factor is depending on path loss exponent (n), so practical measurements in some ASIACELL sites in the city of Baghdad are taken to determine the exact value of (n). Figure 2 shows the map of the drive test for one of the ASIACELL sites at which the received power had been measured at different distance (in meter). Then the accurate power exponent value is determined by the least mean square error (LMS) approach which is a numerical optimization schemes that can be applied to reduce the error in calculating the power exponent value. The formula is used from [13] as:

$$F(n) = \sum_{i=1}^K (e_i)^2 = \sum_{i=1}^K [\text{measured } p_r(d_i) - \text{calculated } p_r(d_i)]^2$$

$$F(n) = \sum_{i=1}^K (e_i)^2 = \sum_{i=1}^K \left[p_{ri} - \left(p_r(d_o) - 10n \log_{10} \left(\frac{d_i}{d_o} \right) \right) \right]^2 \quad (6)$$

where (e_i) is the error between the measured and calculated values of the received signal power, and (p_{ri}) is the received power as measured in i_{th} measurement (in dBm) at the distance (d_i). Table 1 shows the obtained measurements at different distances from the base station of three sites in the city of Baghdad.

Table 1. Empirical Data for Three Sites (Practical Measurements)

Site 1		Site 2		Site 3	
$d_o = 36.6$	$p_r(d_o) = -55.6$	$d_o = 58.1$	$p_r(d_o) = -61.5$	$d_o = 46.8$	$p_r(d_o) = -65.7$
(d_i)	p_{ri}	(d_i)	p_{ri}	(d_i)	p_{ri}
57.5	-56.1	83.14	-67.2	52.43	-68.8
66.2	-63.4	110.3	-68.7	69.1	-69.4
96.29	-67	126.7	-69.3	85.4	-72.1
110.1	-68.7	153.8	-71.2	104.9	-74.4
124.7	-69.2	175.4	-75.5	125.4	-78
152.9	-71.6	185.6	-76.5	136.2	-80.9
177.8	-73.6	201	-76.7	177	-81
197.6	-74.5	232.4	-77.3	186.1	-86
210.9	-74.8	252.9	-78	200.1	-86.4



Figure 2. Site 1 in the city of Baghdad

Applying (6) using the obtained measurements for site_1:

$$F(n) = \sum_{i=1}^K (e_i)^2 = [(-56.1 + 55.6 + 1.96n)^2 + (-63.4 + 55.6 + 2.57n)^2 + (-67 + 55.6 + 4.19n)^2 + (-68.7 + 55.6 + 4.78n)^2 + (-69.2 + 55.6 + 5.32n)^2 + (-71.6 + 55.6 + 6.21n)^2 + \dots]$$

By differentiating $F(n)$ relative to (n) and setting it to zero yields the values of (n) . The values of n for the other two sites were calculated by the same method. Power exponent value (n) for site_1=2.6064, Power exponent value for site_2=2.6611, Power exponent value for site_3=2.8804. So, the average value of the power exponent value was calculated to be 2.7159.

3.2. Interference Modeling

A typical cellular configuration illustrated in Figure 3 is considered. All cells in the system are identical and a base stations of omnidirectional architecture are assumed to be located at the center of each cell. The distance between the reference cell A (at the center of the figure) and the center of any one of the interfering cells is denoted as D . For the moment, a single reference cell and one interfering cell will be considered for interference analysis at up-link case. Let the mobile user j be located at the reference cell A at a distance of r_o from its serving base station, and the mobile i be located at interfering cell B at a distance (d_i) from its serving base station.

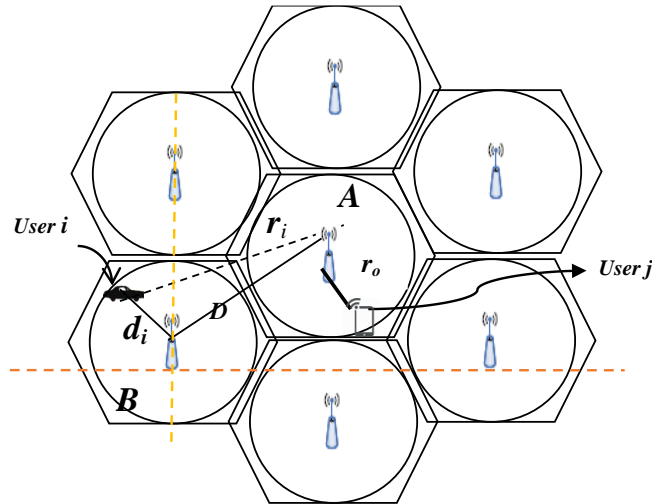


Figure 3. Interfering and interfered cells representation

The power of the mobile i received at its serving base station (p_{ri}) can be determined by using Two-slop path loss propagation model as:

$$p_{ri} = \frac{K}{(d_i)^\alpha (1 + d_i/g)^n} P_i \tag{7}$$

where (P_i) is the power transmitted by the mobile user i to its serving base station, K is a constant that depends on operating frequency, antenna heights and gains of both base station and mobile, and (α) is the propagation path loss exponent (ranges from 2-4), (n) is extra path loss exponent which is typically range (2-6). And (g) is break point distance $g = (4h_b h_m / \lambda)$ where h_b is base station height, h_m is mobile station height and (λ) is wave length [14]. The power transmitted by the i -th user at the interfering cell (B) will be received by all other users located at the same cell. Therefore, it will be the user contribution in intra-cell interference (same cell interference) that is proportional to its distance. The signal transmitted by the user i will be also received simultaneously by other base stations operating in the network causing an instantaneous co-channel interference (inter-cell interference). The interference P_i caused by user i to the reference cell (A) at distance r_i can be expressed as:

$$P_i = \frac{K}{(r_i)^\alpha (1 + r_i/g)^n} P_i \tag{8}$$

$$K P_i = P_{ri} [(d_i)^\alpha (1 + d_i/g)^n]$$

$$P_i = \left(\frac{(d_i)^\alpha (1 + d_i/g)^n}{(r_i)^\alpha (1 + r_i/g)^n} \right) P_{ri} \tag{9}$$

For identical equally loaded cells, the average inter cell interference to the reference cell from all mobile users in all of the interfering cells in the first-tier of co-channel cells can be expressed as:

$$(P_i(r_i))_{total} = \sum_{n=1}^{L_o} \sum_{i=1}^N P_i = 6 N E (P_i) \tag{10}$$

where $l_o=6$ is the number of co-channel cells in the first tire of the system and $E(p_i)$ represents the average expected power received from the i -th interfering mobile station that depends on user location with respect to the reference cell. The desired user SIR can be defined as the ratio of the averaged received power to the sum of interfering received signal power. Therefore, the signal-to-interference ratio (SIR) of any mobile user j at the reference cell can be given as:

$$(SIR)_j = \frac{G_p P_r(r_o)}{I_{total}} = \frac{G_p P_r(r_o)}{I_{MA} + N_{thermal}} = \frac{G_p P_r(r_o)}{I_{intra} + I_{inter} + N_{thermal}} \tag{11}$$

where $P_r(r_o)$ is the power received by the reference base station from the desired user j that is located at a distance r_o , G_p is processing gain ($G_p = \text{system band width} / \text{data rate}$), I_{MA} is the multiple access interference power that includes the intra-cell interference and the inter-cell interference, and $N_{thermal}$ is the thermal noise.

$$(SIR)_j = \frac{G_p P_r(r_o)}{(M - 1) P_r + \sum_{i=1}^m P_i(r_i)} = \frac{G_p P_r(r_o)}{(M - 1) P_r + 6 N E[P_i(r_i)]} \tag{12}$$

$$M = \frac{1 + (G / SIR_j)}{1 + 6 N E[P_i(r_i)]} \tag{13}$$

where (M) is the system capacity which is equivalent to the number of users the system can support While maintaining a good signal to interference ratio [15].

4. Simulation

Matlab simulation is used to estimate interference factor and its effect on capacity. The process of simulation for CDMA systems is taken into account the traffic in cell at busy time, the environment of signal propagation (propagation loss exponent) and distribution of users in the cell. The basic parameters used for the simulation are presented in Table 2.

Table 2. Simulation Parameters

parameter	value	parameter	value	parameter	value
Cell Radius (R_c)	1 Km	Mobile station height (h_m)	1.5 m	Base-station height (h_b)	15 m
Speed of Mobile (u)	60 Km/hr	Time period (T)	8-10 hr	Signal-to interference ratio (SIR)	8 dB
Power exponent (α)	2	Mobile density (ρ_m)	10/Km ²	Processing gain (G)	128
Extra path loss (n), Baghdad city	2.71	Probability mobile leaving (m_2)	0.4	Carrier Frequency	2100 MHz

4.1. Results and Analysis

Figure 4 illustrate result of the average interference and the variance determination with the number of users (m) in a single cell, distance D between the interfering cell and reference cell equal to (2 Km) and propagation model of Baghdad city (2.71). the plot shows when the number of user contribution in interference increases, lead it to increase in interference experienced by the users in the desired cell, this is due to the fact that the average interference is a summation of interferences from each user.

Figure 5 show average other-cell interference generated by interfering user increases with (d) and effect extra path loss exponent on interference, where the different values of extra propagation path loss exponent (n) are used. Due to fact that, the users at cell center and users at the boundary of cell generate different interference to neighboring cells. In order to obtain purpose (SIR), mobile users at the boundary using the highest transmit powers, Therefore,

highest interference is caused to the surrounding cells, that limiting the number of acceptable users in the reference cell.

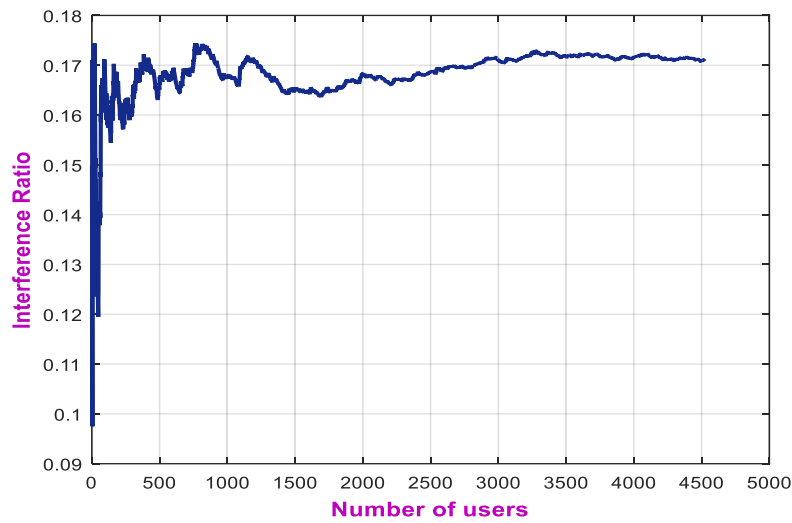


Figure 4. Plot of other-cell interference factor versus number of users, D=2 Km

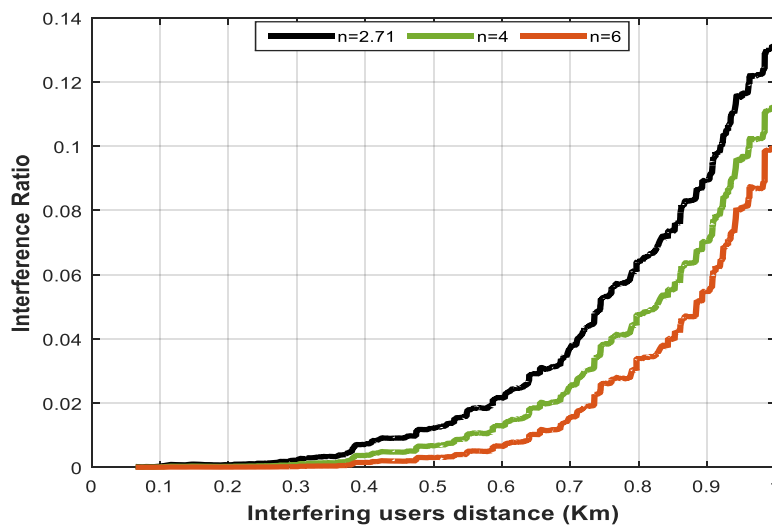


Figure 5. Average Interference VS user distance with different (n), R=1 Km

The Figure 6 display a sacrificial value of capacity (number of users that the cellular system can uphold without the quality of service any user falls under the minimum required). The capacity for this case is calculate for using different propagation exponent and taking into account interference factor, threshold SIR and processing gain. The result show that When interfering user near to center of its' cell, then gives low value of interference for neighboring cell, so the desire system can support nearly (41) users without losing a call, and when the user at boundary of its' in interfering cell, the desired cell can hold (37) users at propagation path loss exponent of Baghdad (n=2.71). This show the inversely proportional between interference and capacity.

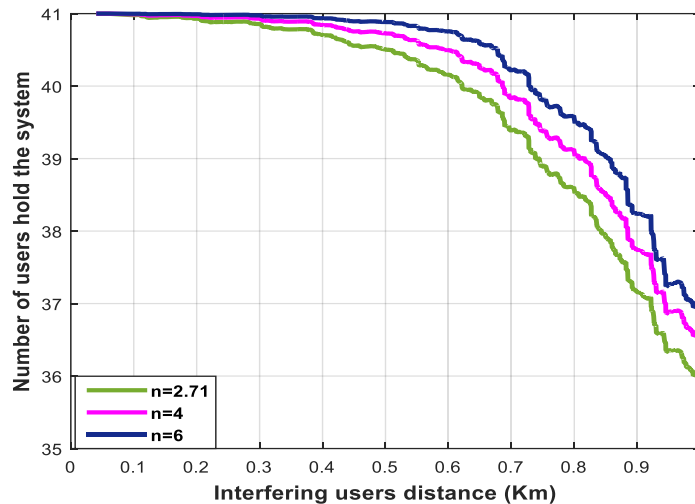


Figure 6. Illustration the capacity of system

5. Conclusion

Mathematical model is proposed for calculation number of interference user. Then, these users are populated on a single interfering cell, it is concluded that increasing the number of user caused the rise the interference factor. Also the analysis showed that users at a boundary cell generate more interference than those close to the base station. By using the fact that the interference factor depends on the location of each user and its effect on capacity is plotted. Model of Baghdad city and its effect on interference factor is estimated, after that, the effect of different path loss on interference ratio is shown that greater path loss exponent denoted decrease in interference factor.

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