

ESTIMATING THE CAPACITY OF A MULTICELL CDMA SYSTEM USING CONCENTRIC CIRCLE GEOMETRY

Idigo V. E¹., Akpado K.A¹., Nsionu I.I².

¹Department of Electrical/Electronic and Computer Engineering.
Nnamdi Azikiwe University, Awka, Nigeria.

²Department of Computer Engineering, Federal Polytechnic, Oko.

ABSTRACT

To determine the capacity of a multicell CDMA System, this paper used the concentric circle geometry in conjunction with a propagation path loss model to determine interference from adjacent cell users. The concentric circle geometry offers analytical advantages for analyzing the effects of co-channel cells. This technique is appealing because, once the area of a cell of interest is specified, it becomes easy to specify an entire system of surrounding cells that each occupy the same coverage area. Further more, once the interference effects of a single cell within surrounding layer is specified, one can simply multiply the effects of a single cell by the number of cells within the surrounding layer. The research showed: that the capacity of CDMA systems is interference limited, and therefore, any reduction in the interference will cause a linear increase in the capacity of CDMA systems.

Key words: Multicell, CDMA, concentric circle geometry, interference.

1. Introduction

Channel capacity for a radio system can be defined as the maximum number of channels or users that can be provided in a fixed frequency band. Radio capacity is a parameter which measures spectrum efficiency of a wireless system. This parameter is determined by the required carrier-to-interference ratio (C/I) and the channel bandwidth, Bc.

In a cellular system, the interference at a base station receiver will come from the subscriber units in the surrounding cells. This is called reverse channel interference. For a particular subscriber unit, the desired base station will provide the forward channel interference.

The capacity of CDMA systems is interference limited. Therefore, any reduction in the interference will cause a linear increase in the capacity of CDMA. Put another way, in a CDMA system, the link performance for each user increases as the member of users decreases.

This paper describes how to estimate the capacity of a multicell CDMA system using the concentric circle geometry with a propagation path loss model to determine interference from adjacent cell users. The concentric circle geometry is appealing because, once the area of the cell of interest is specified, it becomes easy to specify an entire system of surrounding cells that occupy the same coverage area. In general, the concentric circle geometry offers analytical advantages for analyzing the effects of Co-channel cells.

2. Capacity Of CDMA With Multiple Cells

In actual CDMA cellular systems that employ separate forward and reverse links, neighboring cells share the same frequency, and each base station controls the transmit power of each of its own in- cell users. However, a particular base station is unable to control the power of users in neighboring cells, and these users add to the

noise floor and decrease capacity on the reverse link of the particular cell of interest.

The transmit powers of each out-of-cell user will add to the in-cell interference (where users are under power control) at the base station receiver. The amount of out -of-cell interference determines the frequency reuse factor, f , of a CDMA cellular system. Ideally, each cell shares the same frequency and the maximum possible value of f ($f=1$) is achieved. In practice, however, the out-of-cell interference reduces f significantly.

The frequency reuse factor for a CDMA system on the reverse link is defined as [1].

$$f = N_o / N_o + \sum_i U_i N_{ai} \quad (1)$$

and the frequency reuse efficiency, F ; is defined as:

$$F = f \times 100\% \quad (2)$$

where N_o is the total interference power received from the $N-1$ in-cell users, U_i is the number of users in the i -th adjacent cells and N_{ai} is the average interference power for a user located in the i -th adjacent cell.

Within the cell of interest, the desired user will have the same received power as the $N-1$ undesired in-cell users when power control is employed, and the average received power from users in an adjacent cell can be found by:

$$N_{ai} = \sum_j N_{ij} / U_i \quad (3)$$

Where N_{ij} is the power received at the base station of interest from the j th user in the i th cell.

Each adjacent cell have a different number of users, and each out-of-cell user will offer different level of interference depending on its exact transmitted power and location relative to the base station of interest. The variance of N_{ai} can be

computed using standard statistical techniques for a particular cell.

3. Propagation Path Loss Versus Frequency Reuse Analysis Using Concentric Circle Cellular Geometry.

An analysis to determine how the propagation path loss impacts the frequency reuse of a CDMA system using concentric circle cellular geometry considers the interference from both in-cell and out-of-cell users. This technique also considers all cells to have equal geographic area and specifies the cell of interest to be a circular cell which is located in the center of all surrounding cells. Interfering cells are wedge-shaped and are arranged in layers around the center cell of interest. The center cell is circular while the surrounding cells are wedge-shaped. Each cell, however, covers the same area.

Fig. 1 illustrates the concentric circle geometry for a single layer of adjacent cells.

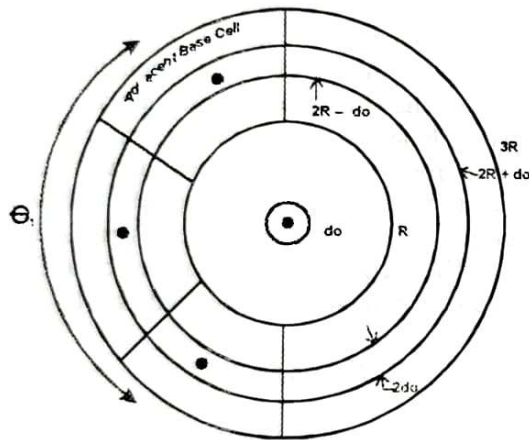


Fig. 1 The concentric circle cellular geometry proposed by Rappaport and Milstein [1].

Let the center cell of interest have radius R , and assume that there is some close-in distance d_0 such that all user in the center cell are located no closer than d_0 meters to the center base station and that all users in the cell of interest are located a distance d from the base station of interest such that $d_0 \leq d \leq R$. Then, a first layer of adjacent interfering cells is found on $R \leq d \leq 3R$, a second layer is located on $3R \leq d \leq 5R$, and the i th interfering layer is located on $(2i-1)R \leq d \leq (2i+1)R$. In each surrounding layer, there are M_i adjacent cells, where i denotes the layer number. If d_0 is assumed to be much less than R , then the area A of the center cell of interest [3] is:

$$A = \pi R^2 - \pi d_0^2 \approx \pi R^2 \quad (4)$$

Within the first surrounding layer of cells, let A_i denote the entire area of the region then neglecting d_0 ,

$$A_1 = \pi(3R)^2 - \pi R^2 = M_1 A \quad (5)$$

$$\Theta_1 = 2\pi/M_1 \quad (6)$$

Where M_1 is the number of wedge-shaped cells that span a particular angle Θ_1 .

The solution of equation (5) and (6), is $M_1 = 8$ and $\Theta_1 = 45^\circ$. This implies that there are eight-wedge-shaped cells in the first surrounding layer, each cell covering a span of 45° . By recursion, the area of the i th surrounding layer is related to the number of cells within the layer by

$$A_i = M_i A = i M_1 A = i 8 A, \quad i \geq 1 \quad (7)$$

$$\Theta_1 = \Theta_i / i = \pi/4i \quad (8)$$

From the analysis of this technique therefore, it is evident that the concentric circle geometry is appealing because, once the area of a cell of interest is specified, it becomes easy to specify an entire system of surrounding cells that each occupy the same coverage area. Furthermore, since each adjacent cell has geometry and angular span as any other cell within the surrounding layer, and since each cell within a particular layer has the same radial geometry to the center cell of interest, it becomes possible to consider the interference effects of just a single cell the surrounding layer. One can simply multiply the effects of a single cell by the number of cells within the surrounding layer.

4. Practical Determination Of Cdma Capacity Using Concentric Circle Geometry.

To find the capacity of a multi cell CDMA system the concentric circle geometry can be used in conjunction with propagation path loss model to determine interference from adjacent cell users (Sklar, B). Then, using equation (1), the frequency reuse factor can be found. Here the in-cell interference power N_0 is simply given by

$$N_0 = P_0 (U - 1) \approx P_0 U = P_0 K A \quad (9)$$

Where P_0 is the power received from any one of the U users in the center cell. K is the user density (i.e. the number of users per unit area).

Assumptions:

1. In general, it is practical to assume that any adjacent cells will also contain U user and will receive power P_0 from each of its own in-cell users.
2. In the adjacent cells, each subscriber is under power control within its own cell, and is distance d_1 from its own base station.
3. Propagation path loss laws are based on all distance greater than d_0 .
4. A small forbidden zone having width $2d_0$ is assumed to exist in all surrounding rings (see fig. 2).

5. Propagation path loss model is used in analysis without having $d_1 < d_0$.

Fig. (2) illustrates how the distances are computed for inner and outer sector users within a first layer interfering cell. Using the law of cosines, within any cell in the i th layer.

$$d_1 = \sqrt{d^2 \sin^2 \Theta + (2R_i - d_0 - d \cos \Theta)^2}$$

for $(2i-1)R \leq d \leq (2i)R - d_0 \dots (10)$

$$d_1 = \sqrt{d^2 \sin^2 \Theta + (d \cos \Theta - 2R_i - d_0)^2}$$

for $(2i)R + d_0 \leq d \leq (2i+1)R \dots (11)$

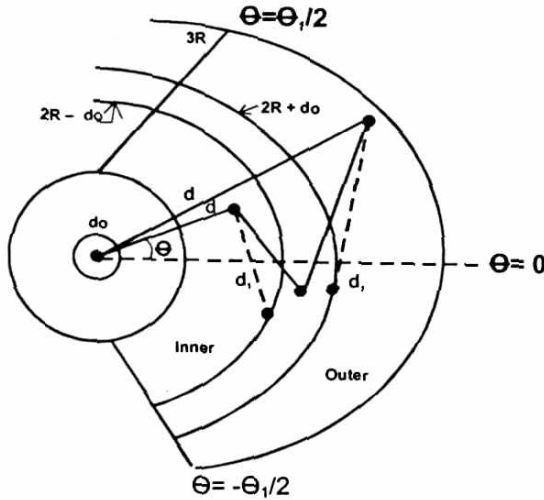


Fig. 2 Geometry for computing distance between adjacent users and the center base station of interest.

Therefore, using d_1 and d , the interference power P_{oij} at the center cell from the j th user in the i th interfering cell is given by:

$$P_{oij}(r, \Theta, d_0) = N_{ij} = P_o (d_1/d_0)^n (d_0/d)^n \dots (12)$$

Where n is the propagation path loss exponent which depends on a specific propagation environment.

Table 1 lists typical path loss exponents obtain in various mobile radio environment.

Table 1: Path loss exponents for different environment

Environment	Path-loss exponent, n
Free space	2
Urban area cellular radio	2.7 to 3.5
Shadowed urban cellular radio	3 to 5
In building line-of-sight	1.6 to 1.8
Obstructed in building	4 to 6
Obstructed in factories	2 to 3

The two factors on the right side of equation (12) represents the actual transmitter power radiated by the j th subscriber in the i th cell, multiplied by the propagation path loss from that

subscriber to the center base station receiver. By evaluating equation (12) for each user in an adjacent cell, it is possible to compute N_{ai} using equation (3) and then apply equation (1) to determine f .

5. Typical Simulation Results

Simulations which considered various users weighting factors as well as path loss exponents of $n = 2$, $n = 3$, and 4, and varying cell sizes were carried out by Rappaport and Milstein [5].

Table 2 [1] indicated typical results, which shows that f can range between 0.316 and 0.707 depending on the path loss exponent and the distribution of users. Thus, while a single cell CDMA system offers ideal frequency reuse ($f = 1$), the actual frequency reuse is a strong function of user distribution and path loss.

Table 2: f for Reverse Channel CDMA cellular system versus n for two system implementations.

d(km)	N	Frequency reuse efficiency		
		lower bound $W_1 = 3$ $W_2 = 0$	hex $W_1 = 1.38$ $W_2 = 0.78$	upper bound $W_1 = 1$ $W_2 = 1$
2	2	0.316	0.425	0.462
2	3	0.408	0.558	0.613
2	4	0.479	0.646	0.707
10	2	0.308	0.419	0.455
10	3	0.396	0.550	0.603
10	4	0.462	0.634	0.695

6. Conclusion

The capacity of CDMA systems is interference limited. Therefore, any reduction in the interference will cause a linear increase in the capacity of CDMA system. CDMA can reuse the entire spectrum for all cells and this results in an increase in capacity by a large percentage over the normal frequency reuse factor.

The concentric circle geometry used in this paper is appealing because, once the area of a cell of interest is specified, it becomes easy to specify an entire system of surrounding cells. This paper also shows that with the use of concentric circle geometry with a path loss model with each adjacent cell having the same radial geometry and angular span, the total interference effect can be estimated by simply multiplying the effect of a single cell by the number of cells within the surrounding layer.

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