Reduction of Cochannel Interference on the Downlink of a CDMA Cellular Architecture with Directional Antennas

M. A. Salam, E. S. Khosravi, and O. Kandara
Department of Computer Science, Southern University
P.O. Box 9221, Baton Rouge, LA 70813
E-mails:{salam, khosravi, kandara}@cmps.subr.edu
Telephone: (225) 771-2060, Fax: (225) 771-4223

Abstract

This paper presents an updated architecture for a code division multiple access (CDMA) wireless communication systems with directional antennas. Cochannel interference for the proposed CDMA architecture is considered and analyzed. An analytic expression for the proposed method is derived. The performance of the proposed architecture is evaluated by means of computer simulation. The result shows that the proposed method with highly directional antennas provides better signal-to-noise (S/N) ratio than the existing cochannel interference reduction methods. A significant reduction of cochannel interference is achieved compared to sectoring and omnidirectional architectures in the proposed microzoning architecture with directional antennas.

Keywords: spread-spectrum, code division multiple access (CDMA), cochannel interference, microzoning.

1. Introduction

Code division multiple access wireless communication systems have grown very remarkably since the first commercial mobile cellular telecommunications service was launched. Code division multiple access is a digital wireless technology that uses a spread-spectrum techniques to scatter a digital radio signal across a wide range of frequencies [1] [2]. In spread-spectrum communication systems, the bandwidth of the transmitted signal is much greater than the message signal and the transmitted bandwidth is determined by some function that is independent of the message and is known to the receiver. In cellular network communication systems, interference is the major limiting factor for performance evaluation. The two major types of system-generated cellular interferences to high-performance digital wireless communication systems are cochannel interference (CCI) and intersymbol interference (ISI). ISI distortion is manifested in the temporal spreading and consequent overlap of individual pulses to the degree that the receiver cannot reliably distinguish between changes of state, *i.e.*, between individual signal elements. There are many techniques that are used to mitigate the degradation due to intersymbol interference**.** CCI, on the other hand, refers to the interference caused between two cells transmitting on the same frequency (frequency reuse) within a network. CCI limits the quality and capacity (number of users) of wireless networks. There are many techniques that are used to reduce the CCI. Our research is focused on the reduction of cochannel interference by utilizing the proposed microzoning cellular architecture. In this paper, the effect of cochannel interference of CDMA wireless communication systems that utilize microzoning architectures is examined and compared to sectoring and omnidirectional architectures.

2. Cochannel Interference

Frequency reuse implies that in a given coverage areas there are several cells that use the same set of frequencies. These cells are called cochannel cells and the cochannel interference refers to the interference caused between two cells transmitting on the same frequency within a network. The frequency reuse ratio is defined as the ratio of the distance between cells using same frequency and the cell radius [4]. To reduce cochannel interference, cochannel cells need to be physically separated by a minimum distance to provide sufficient isolation due to propagation [3]. We can minimize the cochannel interference through the proposed architecture designed for cellular networks. It is shown that cochannel interference could be reduced by antenna sectorization.

A cellular network must be designed to maximize the signal-to-interference (S/I) ratio. Here the S/I ratio is the signal-to-cochannel interference ratio. One of the ways to maximize the S/I ratio is to increase the frequency reuse distance, i.e. increase the distance between cells using the same set of transmission frequencies. The S/I ratio determines the frequency reuse distance of a cellular network. The generalized expression for the S/N ratio of either the forward or reverse link of a CDMA system can be expressed by equation (1) [5].

$$\frac{S}{N}=\left[\left(\frac{E_b}{N_0}\right)^{-1}+\left(\frac{S}{I}\right)^{-1}_{in-cell}+\left(\frac{S}{I}\right)^{-1}_{CCI}\right]^{-1} \tag{1}$$

In (1), E_b/N_0 is the S/N ratio due to additive white Gaussian noise, $E_b = P_0\, T_b$ is the average bit energy, T_b is bit duration, and P_0 is the average transmitted power from the reference base station to the desired user in the reference cell for the forward link and is the average transmitted power from the reference mobile to the base station in the reference cell for the reverse link. For a CDMA system utilizing asynchronous pseudo-noise codes for each user, the multi-user intra-cell interference term is represented as equation (2) [5].

$$\left(\frac{S}{I}\right)^{-1}_{in-cell}=\frac{2}{3N}\sum_{k=1}^{K_0}\frac{P_k}{P_0} \tag{2}$$

where N is the system processing gain, K_0 is the number of users in the reference cell, P_k is the average transmitted power from the reference base station to the kth user in the reference cell as received by the reference user for the forward link and is the average transmitted power from the kth user in the reference base station as received by the reference base station for the reverse link.

In code division multiple access, the cochannel interference from all surrounding cells is allowed in order to maximize efficiency but must be controlled. A variety of optimization techniques are used to mitigate the cochannel effects. The following strategies are deployed to reduce the effect of cochannel interference: antenna orientation and location in a cell, cell power adjustments, and the orientation of cell-specific information downloaded to mobile systems. In the following sections, we discuss various CDMA cellular architectures with various antenna orientations and antenna location in microzones.

3. Proposed Architecture for CDMA Cellular Network

Previously, various cellular network architectures have been proposed to reduce the cochannel interference [5][6][7]. The present proposed cellular architecture shown in Fig. 1 is an modified architecture which provides better performance compared to [5][6][7]. In Fig. 1 cells are represented by circles and individual microzones are represented by hexagons circumscribed within each circle. The proposed architecture consists of three microzones per cell for a CDMA system. The semi-circles represent the 120-degree directional microzone antennas. The triangular unit in the center cell represents the mobile unit. Each antenna is located at the outer edge of each cell. The outer cell microzone antennas radiate back towards the center cell microzone where the mobile unit is located. The dotted lines represent the distance from the mobile unit to the interfering microzone. The distances between antennas and mobile unit can be calculated based on the geometrical law of cosines. For example, the distance (oy) between the mobile unit located at the center cell at o and the antenna in microzone (F1) at y can be computed as:

$$\begin{aligned} oy &= \sqrt{(xy)^2+(ox)^2-2(xy)(ox)\cos\theta} \\ &= \sqrt{(2R)^2+(4R)^2-2(2R)(4R)\cos 120} \\ &= \sqrt{28}R \end{aligned}$$

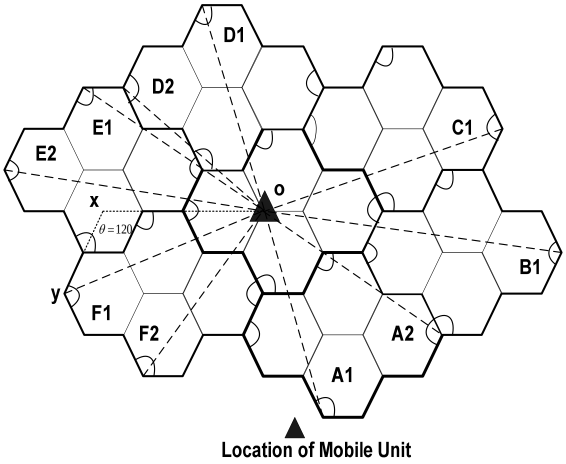

Fig. 1. Proposed 4-microzone per cell CDMA architecture with 120-degree directional antennas.

Here R is the radius of the microzone. All these distances are computed in a similar way. Multi-cell per cluster architecture reduces capacity as compared to one-cell per cluster architecture and is not being seriously considered for third generation CDMA wireless communication systems. Consequently, in the proposed method, one-cell per cluster architecture is considered. The proposed architecture provides better performance than the conventional cell architectures of 60-degree sectoring, 120-degree sectoring, and omnidirectional architectures. For CDMA systems with carrier stealing, the resulting cochannel interference at the location of the mobile unit can be obtained by the following equation:

$$\left(\frac{S}{I}\right)_{CCI}^{-1} = \frac{2(2R)^{n_0}}{3N}\left[\begin{array}{l} K_{A1}\left(\sqrt{21}R\right)^{-n_{A1}} + K_{A2}\left(\sqrt{27}R\right)^{-n_{A2}} \\ + K_{B1}\left(\sqrt{27}R\right)^{-n_{B2}} + K_{C1}\left(\sqrt{39}R\right)^{-n_{C1}} \\ + K_{D1}\left(\sqrt{21}R\right)^{-n_{D1}} + K_{D2}\left(\sqrt{19}R\right)^{-n_{D2}} \\ + K_{E1}\left(\sqrt{27}R\right)^{-n_{E1}} + K_{E2}\left(\sqrt{43}R\right)^{-n_{E2}} \\ + K_{F1}\left(\sqrt{21}R\right)^{-n_{F1}} + K_{F2}\left(\sqrt{28}R\right)^{-n_{F2}} \end{array}\right] \quad (3)$$

In equation (3), S is the desired signal power from the desired base station and I is the interference power. In Fig. 1, the cochannel microzones are labeled with A1 through F1. In equation (3), the subscripts K_{A1}, K_{A2}, K_{C1}, K_{C2}, K_{E1}, and K_{E2} represent the number of users in the interfering microzones of the neighboring cells, as shown in Fig. 1. Since 60-degree directional antenna is considered, cochannel interferences from microzones B1, D1, and F1 are negligible at the location of the mobile unit. The respective propagation path loss exponents have the same subscript, i.e., the propagation path loss exponent for the signal transmitted from microzone A_1 is n_{A1}. The propagation path loss exponent for the reference microzone is n_0 and N is the processing gain.

4. Existing CDMA Cellular Architectures

4.1 Microzoning

The capacity of cellular systems can be increased by splitting existing cells into smaller cells, thereby reusing the frequencies more often in geographic area [4]. Microzoning is a term used to describe a cellular system where the cells have been divided into smaller zones. In Fig. 2, a one-cell per cluster CDMA microzoning system is shown where cells are represented by circles and individual microzones are represented by hexagons circumscribed within each circle. The microzone antennas are designated by semi-circles. Each microzone antenna lies on the outer edge of its microzone. The microzone antennas radiate back toward the center of the cell with a 120-degree radiation pattern. The dotted lines represent the distance from the reference mobile unit to the interfering microzone antennas. For CDMA systems with carrier stealing, the cochannel interference for the microzoning architecture is obtained by equation (4) as:

$$\left(\frac{S}{I}\right)_{CCI}^{-1} = \frac{2(2R)^{n_0}}{3N}\left[\begin{array}{l} K_{A1}\left(\sqrt{19}R\right)^{-n_{A1}} + K_{A2}\left(\sqrt{19}R\right)^{-n_{A2}} \\ + K_{B1}(5R)^{-n_{B1}} \\ + K_{C1}\left(\sqrt{19}R\right)^{-n_{C1}} + K_{C2}\left(\sqrt{19}R\right)^{-n_{C2}} \\ + K_{D1}(5R)^{-n_{D1}} \\ + K_{E1}\left(\sqrt{19}R\right)^{-n_{E1}} + K_{E2}\left(\sqrt{19}R\right)^{-n_{E2}} \\ + K_{F1}(5R)^{-n_{F1}} \end{array}\right] \quad (4)$$

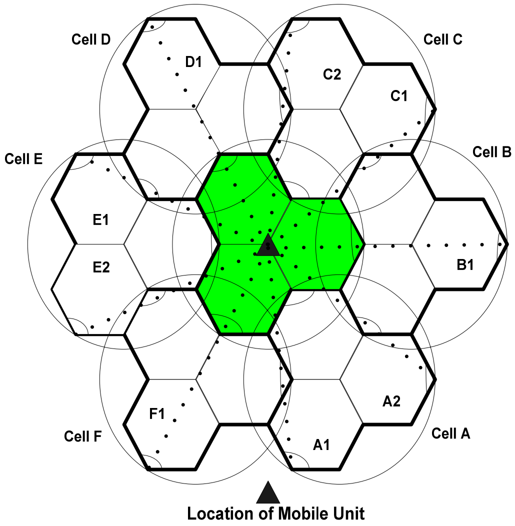

Fig. 2. Mayer's 3-microzone per cell CDMA architecture with 120-degree directional antennas

4.2 60-Degree Sectoring

Sectoring is also used to reduce the cochannel interference. In Fig. 3, each cell is represented as a hexagon, although in practice cells have irregular boundaries. In 60-degree sectoring scheme, it is assumed that only one-sixth of the total number of users per cell can be activated in a sector at one time.

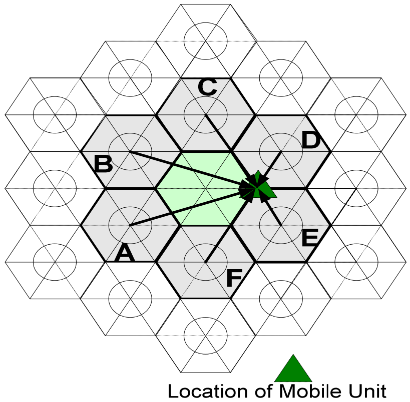

Fig. 3. 60-degree sectoring architecture

For CDMA wireless communication systems, the first-tier cochannel interference signal-to-interference ratio at the worst case location on the cell boundary is found to be equation (5) as:

$$\left(\frac{S}{I}\right)^{-1}_{CCI} = \frac{2R^{n_0}}{18N}\begin{bmatrix} K_A\left(\sqrt{7}R\right)^{-n_A} + K_B\left(\sqrt{7}R\right)^{-n_B} \\ + K_C\left(2R\right)^{-n_C} + K_D\left(R\right)^{-n_D} \\ + K_E\left(R\right)^{-n_E} + K_F\left(2R\right)^{-n_F} \end{bmatrix} \quad (5)$$

In equation (5), K_A through K_F are the number of users in each of the six first-tier cochannel cells, and n_A through n_F are the respective propagation path loss exponents. Second-tier cochannel cells are assumed to have negligible effect.

4.3 120-Degree Sectoring

In 120-degree sectoring scheme, it is assumed that only one-third of the total number of users per cell can be activated in a sector at one time. Fig. 4 illustrates the 120-degree sectoring architecture where each cell is represented as a hexagon. Here the reference cell is the center hexagonal cell. Surrounding cochannel cells are labeled with A through F, and n_A through n_F are the respective propagation path loss exponents. The solid arrow-lines represent the distance from the reference user to the interfering cell transmitters. In CDMA technology, a cell experiences interference from each of the cochannel cells. For CDMA wireless communication systems, the first-tier signal-to-cochannel interference ratio at the worst case location on the cell boundary is found by the following equation (6):

$$\left(\frac{S}{I}\right)^{-1}_{CCI} = \frac{2R^{n_0}}{9N}\begin{bmatrix} K_A\left(2R\right)^{-n_A} + K_B\left(\sqrt{7}R\right)^{-n_B} \\ + K_C\left(\sqrt{7}R\right)^{-n_C} + K_D\left(2R\right)^{-n_D} \\ + K_E\left(R\right)^{-n_E} + K_F\left(R\right)^{-n_F} \end{bmatrix} \quad (6)$$

In equation (6), K_A through K_F is the number of users in each of the six first-tier cochannel cells.

4.4 Omnidirectional Architecture

In this architecture, an omnidirectional antenna is placed at the center of each cell. The first-tier cochannel interference signal-to-interference ratio for the mobile unit on its cell boundary is given by equation (7) as:

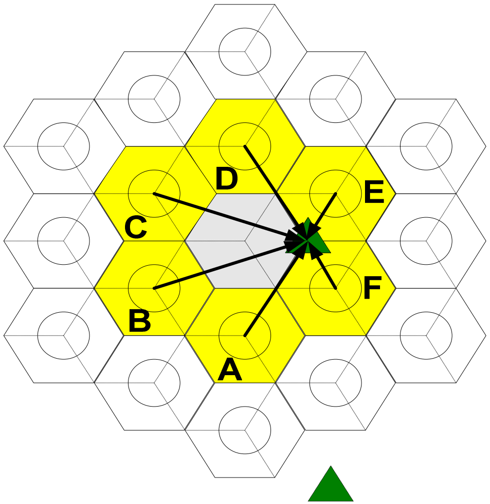

Fig. 4. 120-degree sectoring architecture

$$\left(\frac{S}{I}\right)^{-1}_{CCI} = \frac{2R^{n_0}}{3N}\begin{bmatrix} K_A\left(R\right)^{-n_A} + K_B\left(2R\right)^{-n_B} \\ + K_C\left(\sqrt{7}R\right)^{-n_C} + K_D\left(\sqrt{7}R\right)^{-n_D} \\ + K_E\left(2R\right)^{-n_E} + K_F\left(R\right)^{-n_F} \end{bmatrix} \quad (7)$$

5. Simulation Results

A comparison of the proposed architecture, Mayer's microzoning, 60-degree sectoring, 120-degree sectoring, and omnidirectional antenna architectures is shown in Fig. 5. The simulation is computed for a CDMA system with a processing gain of 128, propagation path loss exponents of 4, and 24 users per cell. The propagation path loss exponents for all the architectures are considered same value. In the simulation, cochannel interference signal-to-interference ratio is computed only for the worst case location of the mobile unit. The proposed cellular architecture provides better gain in S/N ratio than other methods that reduce cochannel interference. For example, in Fig. 5, at E_b/N_0=20 dB, the improvement in gain in S/N ratio over the Mayer's microzoning, 60-degree sectoring, 120-degree sectoring, and omnidirectional antenna is approximately 0.56 dB, 2.26 dB, 3.95 dB, and 7.54 dB, respectively. Also at E_b/N_0=25 dB, the improvement in S/N ratio compared to Mayer's microzoning, 60-degree sectoring, 120-degree sectoring, and omnidirectional antenna is approximately 0.67 dB, 2.67 dB, 4.47 dB, and 8.23 dB, respectively.

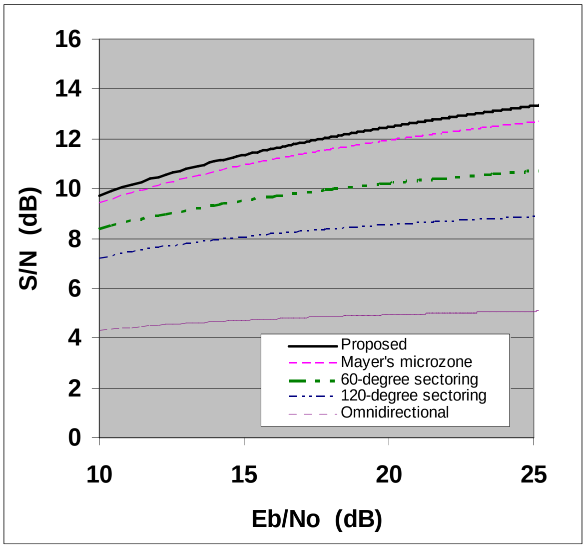

Fig. 5. Comparison of CDMA architecture with a processing gain of 128, 24 users per cell, and propagation path loss exponents of 4

One of the most important issues in CDMA scheme is the number of admissible user per cell for a given available total bandwidth, for given radio propagation conditions, and for a required transmission quality [8]. In Fig. 6, the number of users per cell is plotted against S/N for different architectures where in each case the processing gain is 128, the propagation path loss exponents are taken to be 4, and E_b/N_0=25 dB. As can be seen, the S/N ratio associated with the omnidirectional systems quickly falls below acceptable level. The proposed microzing, with the highest S/N ratio of all the architectures, accommodates the maximum number of users while maintaining an adequate S/N ratio.

6. Conclusion

A comparative study has been provided for various cellular architectures with different antenna arrangements. The simulation was conducted for the proposed CDMA cellular architecture and as well as for Mayer's microzoning, 60-degree sectoring, 120-degree sectoring, and omnidirectional antenna architectures. The computer simulations and mathematical analysis have shown that proposed architecture exhibits significant performance than existing architectures. The proposed method out-performed the Mayer's microzoning, sectoring, and omnidirectional methods and achieved a better S/N ratio as compared to other methods. Further work will involve additional cellular architectures based on microzing and sectoring schemes that will further improve the overall signal-to-cochannel interference ratio.

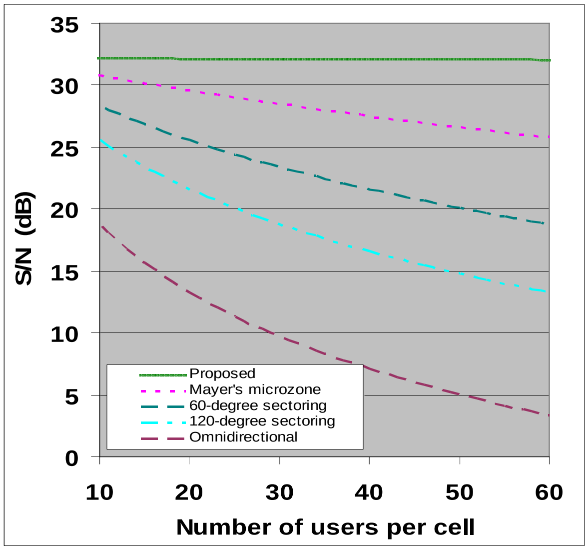

Fig. 6. Comparison of CDMA architectures with a processing gain of 128, E_b/N_0=25 dB, and propagation path loss exponents of 4

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