

# Co-Channel Interference Reduction on the Forward Channel of a Wideband CDMA Cellular System

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## Abstract

Wideband code-division multiple access (CDMA) systems are interference-limited, and so must utilize some form of interference reduction in order to maintain an acceptable quality of service and capacity. In this paper, co-channel interference for several different CDMA architectures is evaluated. For wideband CDMA systems such as W-CDMA and cdma2000 with carrier stealing, co-channel interference is significantly reduced by the implementation of either microzoning or sectoring. The disadvantage of microzoning is that intra-cell interference is no longer ideally zero on the forward channel, as it is with sectoring and omnidirectional architectures. For wideband CDMA systems such as cdma2000 without carrier stealing, co-channel interference is reduced by both microzoning and sectoring architectures even more than in the case of W-CDMA and cdma2000 with carrier stealing. In this case, since forward channel intra-cell interference remains ideally zero, the significant reduction of co-channel interference by microzoning makes microzoning clearly superior to omnidirectional architectures.

## 1 Introduction

To meet the increasing demands for high data rate applications and greater mobility, a third generation of cellular service is being developed. This third generation standard will support such applications as wireless full Internet access and high quality image and video transmission. Third generation wireless communications standards being developed envision the use of wideband code-division multiple access (CDMA). Wideband CDMA systems are expected to offer high data rate services, up to 2 Mbps, which cannot currently be provided by existing cellular systems. Two of the new wideband cellular systems being considered to implement the third generation standard feature code-division multiple access (CDMA) and are referred to as wideband CDMA (W-CDMA) and cdma2000, previously known as Wideband cdmaOne [1, 2].

When utilizing CDMA in a cellular system, the signal-to-noise ratio ( $S/N$ ) is a significant factor in determining the quality of service experienced by the user. Co-channel

interference and intra-cell interference are typically the primary sources of noise in cellular mobile radio systems; although, it is a mistake to completely ignore the effects of additive white Gaussian noise (AWGN). In classical frequency-division multiple access (FDMA) systems, the  $S/N$  can be increased by using either multi-cell clusters, sectoring, or microzoning. Multi-cell per cluster architectures reduce capacity as compared to one-cell per cluster architectures and are not being seriously considered for third generation wireless wideband CDMA systems. Consequently, in this paper, only one-cell per cluster architectures are considered. Sectoring also reduces capacity, while microzoning does not. The effect of both sectoring and microzoning on co-channel interference is in general different for W-CDMA and cdma2000 systems as well as for FDMA systems. In this paper, the effect on co-channel interference and capacity of CDMA wireless systems, both W-CDMA and cdma2000, that utilize either microzoning or sectoring architectures will be examined and compared to omnidirectional architectures.

## 2 Co-Channel Interference

The generalized expression for the  $S/N$  of either the forward or reverse link of a CDMA system can be expressed as

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

where the terms on the right-hand side will be defined in the following paragraphs. Equation (1) is an extension of one given in [3].

In (1),  $E_b/N_0$  is the  $S/N$  ratio due to AWGN alone, with  $N_0$  being the one-sided noise power spectral density,  $E_b = P_0 T_b$  the average bit energy,  $T_b$  the 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 (PN) codes for each user, the multiuser intra-cell interference term is represented as [4]

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

where  $N$  is the system processing gain,  $K_0$  is the number of users in the reference cell, and  $P_k$  is the average transmitted power from the reference base station to the  $k^{\text{th}}$  user in the reference cell as received by the reference user for the forward link and is the average transmitted power from the  $k^{\text{th}}$  user in the reference cell to the reference base station as received by the reference base station for the reverse link. Since the reference base station transmits to all users in the reference cell synchronously, Walsh-Hadamard (W-H) orthogonal spreading codes can be used on the forward channel to significantly reduce the multiuser interference within the reference cell. For sectoring and omnidirectional architectures, intra-cell interference on the forward channel is effectively zero [5].

Each cell's base station is assumed to transmit a unique PN code in addition to the W-H code unique to each user. Since signals from other cells' base stations arrive at the reference user asynchronously even when the system is designed to be inter-cell synchronous, the multiuser interference due to transmissions from base stations other than the reference base station (co-channel interference) is approximated by

$$\left(\frac{S}{I}\right)_{\text{CCI}}^{-1} = \sum_{i=1}^{i_0} \frac{2}{3N} \left( \sum_{k=1}^{K_i} \frac{P_{ik}}{P_0} \right) \quad (3)$$

where  $i_0$  represents the number of co-channel cells in the system,  $K_i$  is the number of users within the  $i^{\text{th}}$  co-channel cell, and  $P_{ik}$  represents the average transmitted power from the  $i^{\text{th}}$  co-channel's base station to the  $k^{\text{th}}$  user in that co-channel cell as received by the reference user. In practice, only the first-tier co-channel cells (cells adjacent to the reference cell) significantly affect  $(S/I)_{\text{CCI}}$ . The effect on  $(S/I)_{\text{CCI}}$  of the second-tier co-channel cells (cells adjacent to the first-tier co-channel cells) can be included in the overall  $S/N$  expression, but due to its relatively negligible effect, the effect of second-tier co-channel cells will be omitted.

Assuming perfect power control at the base stations, we can replace the power ratios implicit in the  $S/N$  expression with distance ratios. The received power from a co-channel cell is inversely proportional to the distance from the appropriate corresponding co-channel cell transmitter to the reference mobile's location raised to the appropriate propagation path loss exponent for that cell; that is,

$$P_{ik} \propto 1/R_i^{n_i} \quad (4)$$

where  $R_i$  is the distance from the  $i^{\text{th}}$  base station-transmitter to the reference user and  $n_i$  is the propagation path loss exponent from the  $i^{\text{th}}$  cell to the reference user. Likewise, the received power from the reference cell base station at the reference mobile is inversely proportional to the distance from the appropriate reference cell transmitter to the reference mobile's location, raised to the propagation path loss exponent for the reference cell; that is,

$$P_0 \propto 1/R_0^{n_0} \quad (5)$$

where  $R_0$  is the distance from the appropriate reference cell transmitter to the reference user and  $n_0$  is the propagation path loss exponent for the reference cell. Assuming the constant of proportionality is the same for all base stations, we get

$$\frac{P_{ik}}{P_0} = \frac{R_0^{n_0}}{R_i^{n_i}} \quad (6)$$

The evaluation of  $S/N$  for an arbitrary location within the reference cell is both difficult and unnecessary. Systems must be designed for the smallest expected  $S/N$ ; hence, the evaluation of the worst case  $S/N$  is sufficient. For a worst case analysis, the mobile unit is located on its reference cell's boundary for omnidirectional and sectoring architectures. Although the cell boundary is any point on the perimeter of the cell, for purposes of this paper, the boundary is considered to be at the farthest location from the center of the cell to truly represent the worst case. As such, the cell radius  $R$ , the distance from the center of the cell to any of the six vertices of the cell, where each cell is assumed to be hexagonal, is used as the position of the reference mobile for omnidirectional and sectoring architectures. For microzoning architectures, co-channel interference is worst at the center of the cell, and  $S/N$  will be evaluated there in this case.

### 3 Microzoning

Microzoning is a term used to describe a cellular system where the cells have been divided into smaller zones, usually three. Microzoning is different from cell sectoring in that the antennas are located at the outer edges of each of the zones and radiate back toward the interior of their cells. One key difference between sectoring and microzoning is the effect on capacity. With microzoning, the trunking efficiency is preserved, while it is reduced by a factor of three for a  $120^\circ$  sectoring architecture and a factor of six for a  $60^\circ$  sectoring architecture. Therefore, for bandwidth constraints such that a maximum of  $N$  users per cell, and therefore per microzone, are allowed, then  $N/3$  users per sector are allowed for  $120^\circ$  sectoring and  $N/6$  users per sector are allowed for  $60^\circ$  sectoring.

More than one microzone of a co-channel cell may be transmitting at a time on the same frequency band in a W-CDMA system and in a cdma2000 system with carrier

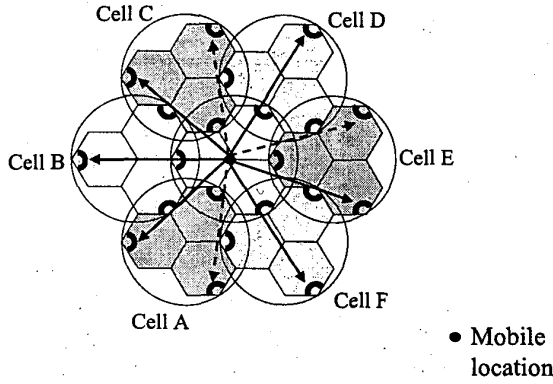


Figure 1: Wideband CDMA microzoning.

stealing. As a result, more than one microzone per co-channel cell may produce interference at the mobile unit. On the other hand, since cdma2000 is a multicarrier system, without carrier stealing only one microzone of a co-channel cell can transmit at the same time on the same frequency band, and only one microzone per co-channel cell can produce interference at the mobile unit.

A principal disadvantage of using microzoning with W-CDMA or cdma2000 with carrier stealing is that intra-cell interference is no longer zero since transmissions from the various reference cell microzone transmitters as received in the reference microzone will in general no longer be orthogonal. Intra-cell interference remains zero for cdma2000 systems without carrier stealing.

In Figure 1, a one-cell per cluster CDMA microzoning system is shown where cells are represented by circles and individual microzones are represented by shaded hexagons circumscribed within each cell circle. The microzone transmitters are designated by black semi-circles. Each microzone transmitter lies on the outer edge of its microzone, and hence, the outer edge of its cell as well. The microzone antennas radiate back toward the center of the cell with a 120° radiation pattern. The solid lines represent the distance from the reference user to interfering microzone transmitters within the context of an FDMA system or a cdma2000 system without carrier stealing. In either W-CDMA or cdma2000 systems with carrier stealing, additional interference is potentially generated by the top microzone of cell C, the top zone of cell E, and the bottom microzone of cell A. The distances from the mobile unit to the additional interfering microzone transmitters are denoted by the dashed lines. As previously mentioned, only one-cell per cluster architectures will be analyzed in this

paper. Although increasing the number of cells per cluster does improve the  $S/N$  slightly, it is not sufficient to warrant the associated overhead accompanying the division of the spectrum into sub-bands and the resulting loss of capacity. At this time, only one-cell per cluster systems are being considered for third generation wireless systems.

The worst case co-channel interference for a microzoning system occurs when the mobile unit lies in the center of a cell, equally far from each microzone transmitter. At this location, the distance from the desired microzone transmitter to the mobile is twice the radius of the microzone and intra-cell interference is zero. It must be noted in passing that for distances only slightly away from cell center the intra-cell interference will not be zero for W-CDMA systems or cdma2000 systems with carrier stealing since the W-H codes transmitted by the different microzone transmitters of the reference cell will not, in general, be orthogonal. Orthogonality, and thus zero intra-cell interference, is maintained for cdma2000 systems without carrier stealing. In Figure 1, the mobile unit is shown just to the left of the center point of the cell, so it falls under the control of the left-most microzone of the reference, or center, cell. For W-CDMA systems and cdma2000 systems with carrier stealing, the resulting first-tier co-channel interference at this location can be obtained as

$$\begin{aligned} \left(\frac{S}{I}\right)_{CCI}^{-1} = & \frac{2(2R_z)^{n_0}}{3N} \left[ K_{A1} \left( \sqrt{19} R_z \right)^{-n_{A1}} \right. \\ & + K_{B1} (5R_z)^{-n_{B1}} + K_{C1} \left( \sqrt{19} R_z \right)^{-n_{C1}} \\ & + K_{D1} (5R_z)^{-n_{D1}} + K_{E1} \left( \sqrt{19} R_z \right)^{-n_{E1}} \\ & + K_{F1} (5R_z)^{-n_{F1}} + K_{A2} \left( \sqrt{19} R_z \right)^{-n_{A2}} \\ & + K_{C2} \left( \sqrt{19} R_z \right)^{-n_{C2}} \\ & \left. + K_{E2} \left( \sqrt{19} R_z \right)^{-n_{E2}} \right] \end{aligned} \quad (7)$$

where  $R_z$  is the microzone radius. In (7), the subscripts  $K_{A1}$  through  $K_{F1}$  represent the number of users in the interfering microzones of the co-channel cells indicated by solid lines in Figure 1, and  $K_{A2}$ ,  $K_{C2}$ , and  $K_{E2}$  represent the number of users per microzone in the additional interfering microzones of cells A, C, and E, respectively, indicated by the dashed lines in Figure 1. 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 cell is  $n_0$ .

Equation (7) can also be applied to cdma2000 systems without carrier stealing by taking either  $K_{A1}$  or  $K_{A2}$  equal

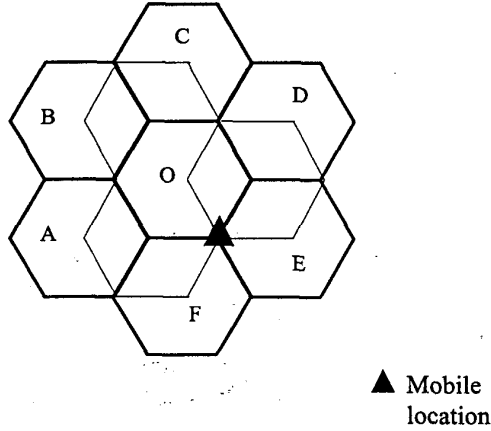


Figure 2: Co-channels for 120° sectoring systems.

to zero, either  $K_{C1}$  or  $K_{C2}$  equal to zero, and either  $K_{E1}$  or  $K_{E2}$  equal to zero. Furthermore, the maximum value of  $K_{A1}$  or  $K_{A2}$ ,  $K_{C1}$  or  $K_{C2}$ , and  $K_{E1}$  or  $K_{E2}$  is  $N/m$ , where  $m$  is the number of carriers per cell.

#### 4 Sectoring

Another technique for reducing co-channel interference is sectoring. Figure 2 is an illustration of 120° sectoring. Here, the reference cell is labeled cell O and shown as the center hexagon with the co-channel cells shown as the surrounding hexagons with labels A through F. To analyze the co-channel interference in a wideband CDMA system employing sectoring, it is useful to recall the difference between sectoring in an FDMA and a wideband CDMA system. Within the context of FDMA, a cell experiences co-channel interference from only a fraction of the total number of co-channel cells. On the other hand, for W-CDMA a cell experiences interference from each of the co-channel cells. For cdma2000 without carrier stealing, the effect of sectoring is similar to that of sectoring with FDMA. For example, in a one-cell per cluster W-CDMA system, all sectors of the cell are operating on the same frequency band, and although orthogonal spreading codes are used within each cell, interference from the co-channel cells will, in general, be received asynchronously by the desired mobile. In addition, each cell's forward channel utilizes a PN code unique to that cell. As a result, in a W-CDMA system one sector of each co-channel cell generates interference in the reference cell, but only the fraction of users located in that sector generate interference.

##### 4.1 120° Sectoring

In a 120° sectoring scheme, we assume that only one third of the total number of users per cell can be active

in a sector at any one time. For W-CDMA, the first-tier multiuser co-channel interference signal-to-interference ratio at the worst case location on the cell boundary is found to be

$$\left(\frac{S}{I}\right)_{\text{CCI}}^{-1} = \frac{2R^{n_0}}{9N} \left[ K_A (2R)^{-n_A} + K_B (\sqrt{7}R)^{-n_B} + K_C (\sqrt{7}R)^{-n_C} + K_D (2R)^{-n_D} + K_E (R)^{-n_E} + K_F (R)^{-n_F} \right] \quad (8)$$

where  $K_A$  through  $K_F$  are the number of users in each of the six first-tier co-channel cells,  $n_A$  through  $n_F$  are the respective propagation path loss exponents, and second-tier co-channel cells are assumed to have negligible effect. Equation (8) can be applied to cdma2000 systems without carrier stealing by letting  $K_C$ ,  $K_D$ , and  $K_E$  all equal zero.

##### 4.2 60° Sectoring

Next we consider the 60° sectoring method. In this scheme, we assume that only one-sixth of the total number of users per cell can be active in a sector at any one time. For W-CDMA, the first-tier co-channel interference signal-to-interference ratio at the worst case location on the cell boundary is found to be

$$\left(\frac{S}{I}\right)_{\text{CCI}}^{-1} = \frac{2R^{n_0}}{18N} \left[ K_A (\sqrt{7}R)^{-n_A} + K_B (\sqrt{7}R)^{-n_B} + K_C (2R)^{-n_C} + K_D (R)^{-n_D} + K_E (R)^{-n_E} + K_F (2R)^{-n_F} \right] \quad (9)$$

where  $K_A$  through  $K_F$  are the number of users in each of the six first-tier co-channel cells. Equation (9) can be applied to cdma2000 systems without carrier stealing by letting  $K_B$ ,  $K_C$ ,  $K_D$ , and  $K_E$  all equal zero.

#### 5 Omnidirectional Architecture

In an omnidirectional architecture, the first-tier co-channel interference signal-to-interference ratio for a mobile on its cell boundary is given by

$$\left(\frac{S}{I}\right)_{\text{CCI}}^{-1} = \frac{2R^{n_0}}{3N} \left[ K_A (R)^{-n_A} + K_B (2R)^{-n_B} + K_C (\sqrt{7}R)^{-n_C} + K_D (\sqrt{7}R)^{-n_D} + K_E (2R)^{-n_E} + K_F (R)^{-n_F} \right] \quad (10)$$

Equation (10) applies to both W-CDMA and cdma2000 systems.

## 6 Results

There are typically 128 total orthogonal spreading codes on the forward channel of the envisioned third generation wireless systems; however, since a few of the channels are utilized for overhead purposes such as pilot tone, paging, and synchronization, the number of codes typically available for user assignment is 125 [5]. A comparison between microzoning, 60° sectoring, 120° sectoring, and omnidirectional antenna architectures for a W-CDMA system with a processing gain of 128, propagation path loss exponents of three, and twenty-four users per cell is shown in Figure 3. As can be seen, for sufficiently large  $E_b/N_0$ , microzoning exhibits approximately a 2 dB improvement over 60° sectoring, a 4.5 dB improvement over 120° sectoring, and a 9 dB improvement over the omnidirectional system. Note that the microzoning results also apply to cdma2000 systems with carrier stealing.

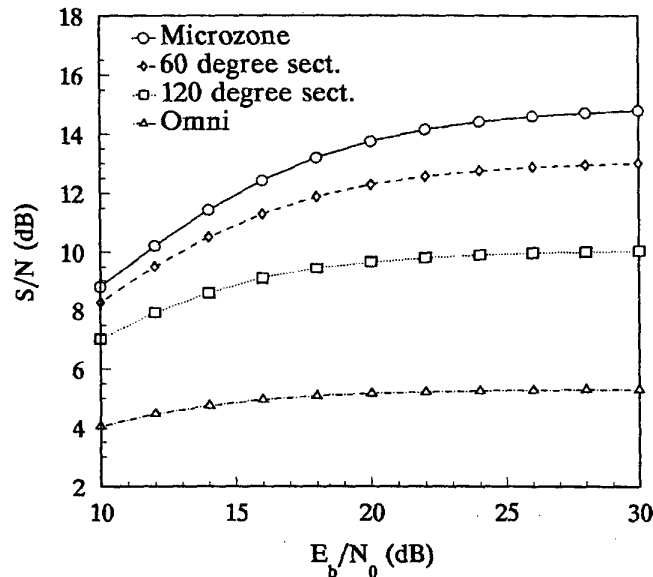


Figure 3: Comparison of CDMA architectures with a processing gain of 128, 24 users per cell, and propagation path loss exponents equal to three.

In Figure 4, 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 three, and  $E_b/N_0=25$  dB. As can be seen, the  $S/N$  associated with the omnidirectional system quickly falls below an acceptable level. Microzoning, with the highest  $S/N$  of all systems, accommodates the maximum number of users while maintaining an adequate  $S/N$ . For cdma2000 systems without carrier stealing, the  $S/N$  for microzoning, 120° sectoring, and 60° sectoring im-

proves by about 2 dB, 3 dB, and 8 dB, respectively. Hence, a cdma2000 system without carrier stealing offers a dramatic improvement in  $S/N$  over W-CDMA systems and cdma2000 systems with carrier stealing and at the same time avoids the problem of nonzero intra-cell interference.

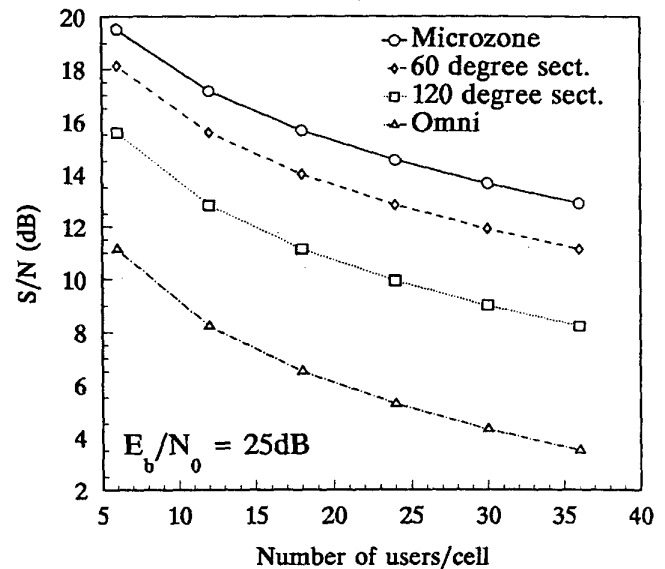


Figure 4: Comparison of CDMA architectures with a processing gain of 128 and propagation path loss exponents equal to three.

The plots of signal-to-noise ratios shown in Figures 5 and 6 are similar to those shown in Figures 3 and 4, respectively; however, the propagation path loss exponents for all the cells are now taken to be four. From a comparison of Figures 3 and 5 and Figures 4 and 6, we can see that microzoning is much more sensitive to the propagation path loss exponent than the other architectures. In all cases, the higher path loss exponent actually improves  $S/N$ ; but at  $E_b/N_0=25$  dB, for example, microzoning shows an improvement of approximately 3.5 dB with a propagation path loss of four as compared to one of three, while the sectoring and omnidirectional systems show only about 0.5 to 1.0 dB of improvement. Since all propagation path loss exponents are assumed to be equal, the penalty for having a higher propagation path loss exponent in the reference cell is outweighed by the fact that all of the interfering cells also have a higher propagation path loss exponent. This results in more attenuation of the transmissions from the co-channel cells, and hence, lowers co-channel interference. The improvement in  $S/N$  obtained with cdma2000 systems without carrier stealing is similar to that obtained for smaller propagation path loss exponents. The  $S/N$  for microzoning, 120° sectoring, and 60° sectoring improves

by about 2.5 dB, 3 dB, and 9 dB, respectively.

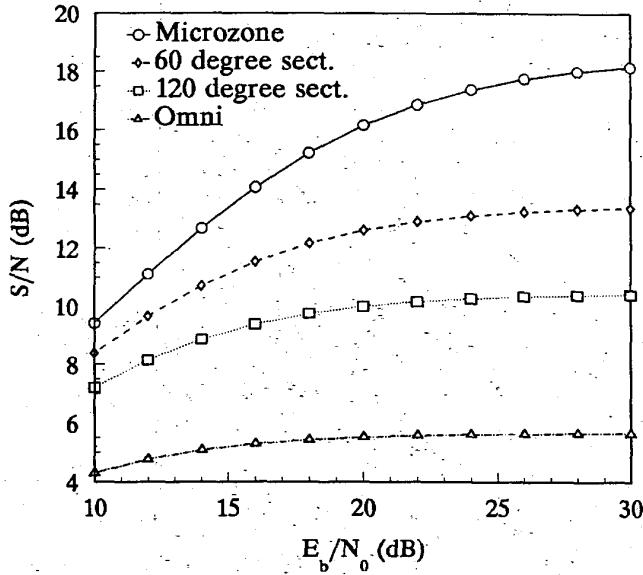


Figure 5: Comparison of CDMA architectures with a processing gain of 128, 24 users per cell, and propagation path loss exponents equal to four.

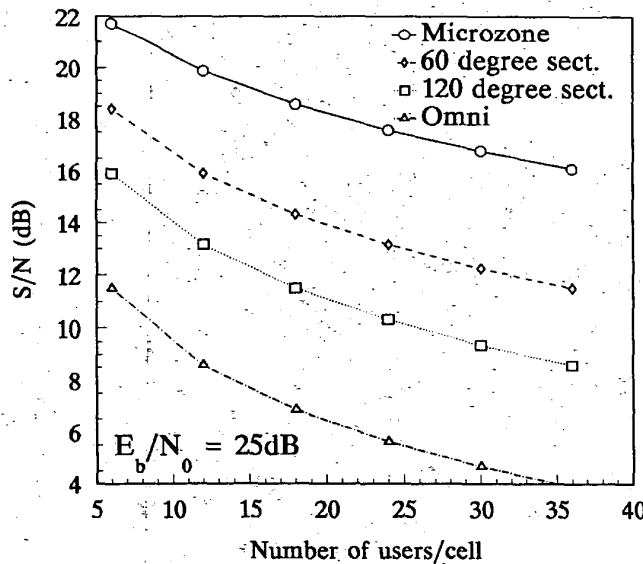


Figure 6: Comparison of CDMA architectures with a processing gain of 128 and propagation path loss exponents equal to four.

## 7 Conclusion

For wideband CDMA systems such as W-CDMA and cdma2000 with carrier stealing, co-channel interference is significantly reduced by the implementation of microzoning, although sectoring also reduces co-channel interference as compared to an omnidirectional system. The disadvantage of microzoning is that intra-cell interference is no longer ideally zero on the forward channel, as it is with sectoring and omnidirectional architectures. If the intra-cell interference can be reduced or eliminated, then microzoning architectures will be much more advantageous than other architectures since there is no reduction in trunking efficiency as there is with sectoring architectures.

For wideband CDMA systems such as cdma2000 without carrier stealing, co-channel interference is reduced by both microzoning and 60° sectoring architectures even more than in the case of W-CDMA and cdma2000 with carrier stealing. In this case, since forward channel intra-cell interference remains ideally zero, the significant reduction of co-channel interference by microzoning makes microzoning clearly superior to omnidirectional architectures. Furthermore, this is a strong argument in favor of cdma2000 without carrier stealing over W-CDMA and cdma2000 with carrier stealing. Even more significant reductions in co-channel interference are possible in this case with 60° sectoring, but the loss of trunking efficiency makes this alternative less attractive.

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