

Forward Channel Signal-to-Noise Ratio with Microzoning for Narrowband, FDMA Cellular Systems

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Abstract

One of the major design considerations in a cellular mobile radio system is the reduction of co-channel interference. A technique known as microzoning can reduce interference while maintaining system capacity and quality of service. Based on the worst case mobile location at the edge of a microzone, narrowband, frequency-division multiple access cellular systems require seven-cell per cluster architectures in order to maintain a signal-to-noise ratio of 18 dB. This is contrary to the conclusion drawn from previously published work that three-cell per cluster systems are sufficient. A three-cell per cluster architecture can maintain a signal-to-noise ratio of 15 dB.

1 Microzoning

Microzoning is a term used to describe a cellular system where the individual cells have been further divided into smaller zones, usually three. The purpose of microzoning is to reduce co-channel interference in a cellular system. Microzoning is different from cell sectoring, another common technique for reducing co-channel interference, in that the microzone antennas are located at the outer edges of the each microzone and radiate back toward the interior of the cell. Each user's forward and reverse link to the base station is via the microzone that receives the mobile's signal the strongest. Only one microzone transmits to a specific user at a time. Also unlike cell sectoring systems, where specific frequencies are permanently assigned to specific sectors, any frequency can be assigned to any microzone as long as it is not assigned to more than one microzone in the same cell simultaneously. Hence, systems employing microzoning are able to preserve trunking efficiency, thereby keeping the cell capacity equal to that of systems using omnidirectional antennas.

Co-channel interference in cellular systems utilizing frequency-division multiple access (FDMA) has been previously considered in [1]. In [1] microzone co-channel interference is obtained as a function of the ratio of the distance between the center of one microzone in the reference cell and the center of a microzone in the closest co-channel cell to the radius of the microzone, and the worst case

mobile location is considered to be at the center of the reference microzone, one microzone radius away from the desired transmitter. There are two drawbacks to the expression for co-channel interference developed in [1]. First, this technique does not take into account the directional nature of the microzone transmitting antennas. Second, the worst case location is not the center of the microzone but the center of the cell, the farthest point from each microzone transmitter. In this paper, co-channel interference with microzoning is examined and expressions for worst case co-channel interference that take into account the directional nature of the microzone antennas are developed for one-cell, three-cell, and seven-cell per cluster cellular systems.

2 Signal-to-Noise Ratio for Cellular Systems

The generalized expression for the signal-to-noise ratio S/N of the forward link of a FDMA cellular system can be expressed as [2]

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

where 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 mobile in the reference cell. For a FDMA system, the co-channel interference is the power received at the reference mobile from co-channel base stations transmitting on the same frequency channel. Assuming perfect power control at the base stations, we can express received power in terms of distance from transmitter to receiver. 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 path loss exponent for that cell; that is,

$$P_i \propto 1/R_i^{\alpha} \quad (2)$$

where P_i is the average power from the i^{th} cell's base station transmitter received by the reference user, R_i is the distance from the i^{th} base station transmitter to the reference user, and n_i is the path loss exponent from the i^{th} cell to the reference user. Likewise, the power from the reference cell to the desired mobile is inversely proportional to the distance from the appropriate reference cell transmitter to the reference mobile's location, raised to the path loss exponent for the reference cell; that is,

$$P_0 \propto 1/R_0^{n_0} \quad (3)$$

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

$$\frac{P_i}{P_0} = \frac{R_0^{n_0}}{R_i^{n_i}} \quad (4)$$

The evaluation of S/N for an arbitrary location within the reference cell is both difficult and unnecessary. System design must consider the smallest expected S/N ; hence, the evaluation of the worst case S/N is sufficient. For microzoning architectures, co-channel interference is worst at the center of the cell.

3 Co-Channel Interference with Microzoning

As mentioned in the last section, the worst case mobile location is the center of the cell, two microzone radii from each microzone transmitter, since the received signal power from the desired signal will be weakest at this point. In [1], the more optimistic mobile placement of one microzone radius from the desired transmitter is used. When microzone antenna positions and orientations are taken into account, it is clear that several microzones in a given cell (one to two per cell, depending on the geometry) will not create interference at the reference mobile due to the directionality of their antenna radiation pattern. As a result, the distances between microzones of co-channel cells that actually contribute to co-channel interference are farther apart than those used in [1]. This, in turn, helps improve the signal-to-interference ratio. In practice, only the first-tier co-channel cells significantly affect $(S/N)_{\text{CCI}}$. The effect on S/N of the second-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.

The difference in the development of the expressions for co-channel interference developed in this paper and those in [1] are illustrated for a one-cell per cluster architecture, shown in Figure 1. Here, cells are represented by circles, while individual microzones are represented by shaded hexagons circumscribed within each cell circle. The microzone transmitters are designated by black semi-circles.

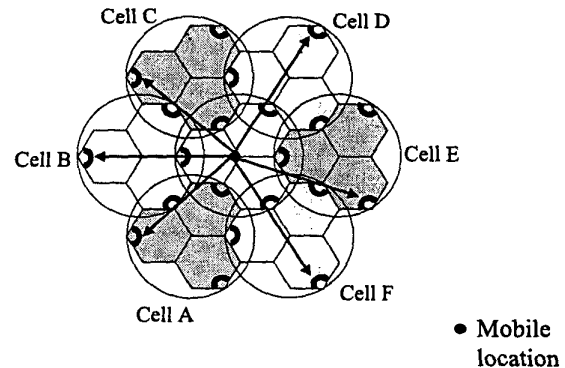


Figure 1: Microzoning for a one-cell per cluster system.

Each microzone transmitter lies on the outer edge of its microzone, and therefore, 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 mobile unit is shown just to the left of the center point of the cell so that it falls under the control of the left-most microzone of the reference, or center, cell. The difference between the results developed in [1] and those developed in this paper can easily be seen by examining the co-channel distance from the reference mobile unit to co-channel cell A. The distance from the mobile unit to the center of the nearest microzone in cell/cluster A is used in [1]. This is the center of the top-most microzone of cell A. However, there are no transmitters located at the centers of the microzones, only at the edges. Additionally, the antenna for the top-most microzone of cell A is radiating away from the reference mobile user, and hence is not a source of interference to the reference mobile. Instead, the left-most and bottom microzones of cell A are the only microzones that generate interference to the mobile user, and therefore, the only microzones that need to be considered for co-channel interference. Since the distance from the reference mobile to the transmitter of both the left-most and bottom microzone of cell A is $\sqrt{19}R_z$, either microzone can be chosen to represent the co-channel interference from this cell. In cells where the distances between potential interfering microzones are different, the shortest microzone distance is chosen since that choice represents the worst case. Only one of the microzones in a particular cell eligible to create interference with the reference mobile need be considered since only one microzone transmitter of a cell is active on a particular frequency at a time in a FDMA system.

Recall that using the technique developed in [1] for a one-cell per cluster architecture results in choosing an ineligible microzone transmitter (the top microzone) in cell A as the microzone contributing to co-channel interference within the reference cell. All other things being equal,

the results obtained taking into account the directionality of the microzone transmitter antennas almost always decrease the co-channel interference from each co-channel cell.

3.1 One-cell per Cluster Microzoning

In a one-cell per cluster architecture, the distances from the reference mobile unit at the center of the reference cell to the transmitters of the worst case (closest) co-channel microzones of each of the co-channel cells, A, B, C, D, E, and F, are $\sqrt{19} R_z$, $5R_z$, $\sqrt{19} R_z$, $5R_z$, $\sqrt{19} R_z$, and $5R_z$, respectively, as seen in Figure 1. The resulting first-tier co-channel interference is given by

$$\left(\frac{S}{I}\right)_{\text{CCI}}^{-1} = (2R_z)^{n_0} \left[(\sqrt{19} R_z)^{-n_A} + (5R_z)^{-n_B} + (\sqrt{19} R_z)^{-n_C} + (5R_z)^{-n_D} + (\sqrt{19} R_z)^{-n_E} + (5R_z)^{-n_F} \right] \quad (5)$$

where R_z is the zone radius and n_A through n_F are the path loss exponents of each of the six first-tier co-channel cells A through F, respectively.

In a similar manner, if the reference mobile position is taken to be the center of its microzone as in [1] and transmitter directionality is considered, the first-tier co-channel interference is given by

$$\left(\frac{S}{I}\right)_{\text{CCI}}^{-1} = R_z^{n_0} \left[(\sqrt{13} R_z)^{-n_A} + (4R_z)^{-n_B} + (\sqrt{13} R_z)^{-n_C} + (\sqrt{31} R_z)^{-n_D} + (\sqrt{28} R_z)^{-n_E} + (\sqrt{31} R_z)^{-n_F} \right] \quad (6)$$

which generally is much smaller than is obtained using the analysis developed in [1].

3.2 Three-Cell per Cluster Microzoning

The architecture and co-channel distances for a three-cell per cluster microzoning system are shown in Figure 2. In the three-cell per cluster system, the clusters are designated as clusters O, A, B, C, D, E, and F which appear as the first letter of the cell labels. Every cluster has three cells, which are represented by circles and designated as cells one through three. They appear as the last number of the cell labels. All cells designated with the same number use the same set of frequencies, and hence, are co-channel interferers with each other.

In Figure 2, the mobile unit is shown just to the right of the center of cell one of the reference cluster, falling under the control of the right-most microzone of cell O2. The distances from the reference mobile unit to the appropriate microzone transmitters of co-channel interfering

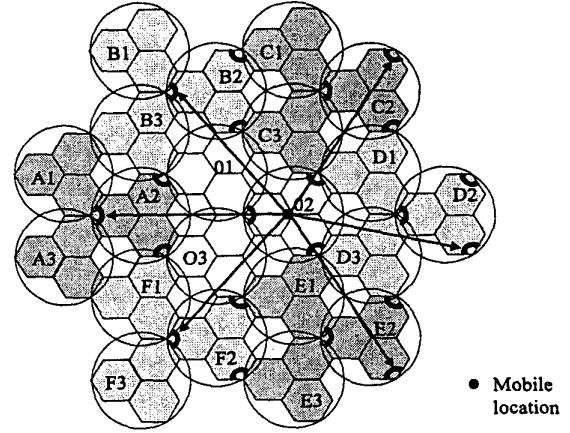


Figure 2: Microzoning for a three-cell per cluster system.

cells A2, C2, and E2 are equal with a value of $8R_z$. The distances to B2, D2, and F2 are equal with a value of $\sqrt{52} R_z$. Consequently, the first-tier co-channel interference for this architecture is given by

$$\left(\frac{S}{I}\right)_{\text{CCI}}^{-1} = (2R_z)^{n_0} \left[(8R_z)^{-n_A} + (\sqrt{52} R_z)^{-n_B} + (8R_z)^{-n_C} + (\sqrt{52} R_z)^{-n_D} + (8R_z)^{-n_E} + (\sqrt{52} R_z)^{-n_F} \right] \quad (7)$$

In a similar manner, if the reference mobile position is taken to be the center of its microzone as in [1] and transmitter directionality is considered, the first-tier co-channel interference is given by

$$\left(\frac{S}{I}\right)_{\text{CCI}}^{-1} = R_z^{n_0} \left[(7R_z)^{-n_A} + (\sqrt{43} R_z)^{-n_B} + (\sqrt{73} R_z)^{-n_C} + (\sqrt{67} R_z)^{-n_D} + (\sqrt{73} R_z)^{-n_E} + (\sqrt{43} R_z)^{-n_F} \right] \quad (8)$$

As in the one-cell per cluster case, this generally is much smaller than is obtained using the analysis developed in [1].

3.3 Seven-Cell per Cluster Microzoning

The architecture and co-channel distances for a seven-cell per cluster microzoning system are shown in Figure 3. In the seven-cell per cluster system, the clusters are designated as clusters O, A, B, C, D, E, and F which appear as the first letter of the cell labels. Every cluster has seven

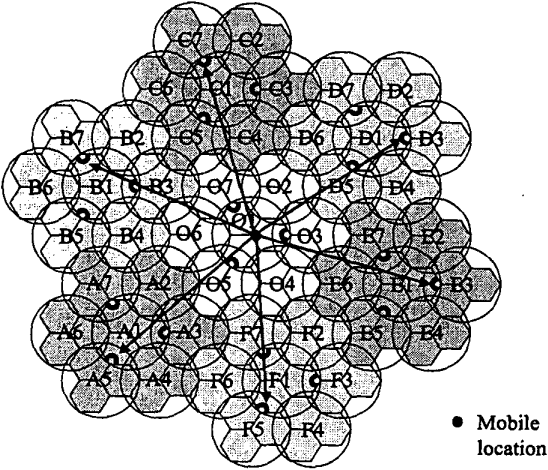


Figure 3: Microzoning for a seven-cell per cluster system.

cells, which are represented by circles and designated as cells one through seven. They appear as the last number of the cell labels. All cells designated with the same number use the same set of frequencies, and hence, are co-channel interferers with each other.

In Figure 3, the mobile unit is shown just to the right of the center of cell one of the reference cluster, falling under the control of the right-most microzone of cell O1. The distances from the reference mobile unit to the appropriate microzone transmitters of co-channel interfering cells A1, C1, and E1 are equal with a value of $\sqrt{97} R_z$. The distances to B1 and F1 are equal with a value of $\sqrt{91} R_z$. Finally, the distance to D1 is $\sqrt{73} R_z$. Consequently, the first-tier co-channel interference for this architecture is given by

$$\left(\frac{S}{I}\right)_{\text{CCI}}^{-1} = (2R_z)^{n_0} \left[(\sqrt{97} R_z)^{-n_A} + (\sqrt{91} R_z)^{-n_B} + (\sqrt{97} R_z)^{-n_C} + (\sqrt{73} R_z)^{-n_D} + (\sqrt{97} R_z)^{-n_E} + (\sqrt{91} R_z)^{-n_F} \right] \quad (9)$$

In a similar manner, if the reference mobile position is taken to be the center of its microzone as in [1] and transmitter directionality is considered, the first-tier co-channel interference is given by

$$\left(\frac{S}{I}\right)_{\text{CCI}}^{-1} = R_z^{n_0} \left[(\sqrt{112} R_z)^{-n_A} + (\sqrt{109} R_z)^{-n_B} + (\sqrt{103} R_z)^{-n_C} + (\sqrt{64} R_z)^{-n_D} \right]$$

$$+ (\sqrt{79} R_z)^{-n_E} + (\sqrt{91} R_z)^{-n_F} \quad (10)$$

As in the one-cell per cluster and three-cell per cluster cases, this generally is much smaller than is obtained using the analysis developed in [1].

4 Results

Because of the greater distance between the mobile user and the desired microzone transmitter for the worst case mobile location at the microzone edge, we generally expect the worst case signal-to-noise ratio to be smaller than that predicted by the method discussed in [1]. At the same time, the method discussed in [1] is overly pessimistic in accounting for co-channel interference, which when properly accounted for tends to increase S/N . As a result, the S/N at the center of the microzone as derived in this paper is larger than that predicted in [1]. For reasonable path loss propagation exponents, the S/N at the microzone center as predicted by [1] is overly pessimistic, in some instances by a significant factor. For the mobile location at the microzone edge, the improvement in S/N obtained by properly accounting for co-channel interference is generally more than offset by the decrease in received signal power for multi-cell per cluster architectures. For three-cell per cluster and seven-cell per cluster systems and for reasonable path loss propagation exponents, the S/N at the worst case location is less than that obtained using the method in [1], again in some instances by a significant amount. This is not the case for one-cell per cluster systems.

As an example, numerical results are presented for one-cell per cluster, three-cell per cluster, and seven-cell per cluster systems in Tables 1, 2, and 3, respectively, with $E_b/N_0 = 15, 20, 25,$ and 30 dB. We assume that $n_A = n_B = n_C = n_D = n_E = n_F = 4$. When the path loss propagation exponents are all equal, the computed S/N is independent of the absolute value of the microzone radius R_z . As can be seen from Table 1, for $E_b/N_0 = 25$ dB the predicted S/N at the worst case location is approximately 2.5 dB greater than that predicted by the technique discussed in [1], while the predicted S/N at the microzone center is significantly greater. Because a one-cell per cluster system is the most geographically compact architecture in terms of the distance to the co-channel cells, the improvement due to better accuracy in measuring distance to the actual interfering transmitter's location has the greatest effect in this case. The additional distance that results from the difference in directionality and transmitter placement between the analysis in this paper and that in [1] produces a significant decrease, percentage-wise, of co-channel interference. In the one-cell per cluster architecture, the advantage is great enough to overcome the disadvantage of having a true worst case mobile location.

Realistically, the S/N necessary for an FDMA cellular system cannot be obtained with a one-cell per cluster

Table 1: Signal-to-noise ratio for one-cell per cluster systems.

E_b/N_0 (dB)	15	20	25	30
Worst case location	6.2	6.6	6.7	6.8
Microzone center	12.9	15.4	16.5	17.0
[1]	4.0	4.2	4.3	4.3

Table 2: Signal-to-noise ratio for three-cell per cluster systems.

E_b/N_0 (dB)	15	20	25	30
Worst case location	12.1	14.0	14.9	15.2
Microzone center	14.7	19.2	22.8	25.1
[1]	13.9	17.2	19.1	19.9

architecture. Comparing Tables 2 and 3, we see that a frequency-reuse pattern of seven is generally required to maintain a satisfactory S/N of about 18 dB at the worst case mobile location. We also note that, using the method developed in [1], we would conclude that a three-cell per cluster architecture would be satisfactory. For a three-cell per cluster system, at $E_b/N_0 = 25$ dB the method developed in [1] predicts $S/N = 19.1$ dB, while the actual worst case $S/N = 14.9$ dB. For a seven-cell per cluster system, at $E_b/N_0 = 25$ dB the method developed in [1] predicts $S/N = 22.4$ dB, while the actual worst case $S/N = 18.2$ dB.

Although the worst-case S/N obtained with microzoning is not as high as that obtained with other co-channel interference reduction methods, such as sectoring, microzoning yields higher signal-to-noise ratios than systems with omnidirectional antennas. Additionally, unlike sectoring, microzoning has the collateral benefits of preservation of trunking efficiency, thereby allowing for greater user capacity and soft hand-off. Finally, there is no additional overhead associated with frequency assignment planning within the sectors of each cell as there is with sectoring schemes [2].

Table 3: Signal-to-noise ratio for seven-cell per cluster systems.

E_b/N_0 (dB)	15	20	25	30
Worst case location	13.6	16.6	18.2	18.9
Microzone center	14.9	19.7	24.0	27.5
[1]	14.7	19.0	22.4	24.5

5 Conclusion

The worst case signal-to-noise ratio for a narrowband, frequency-division multiple access cellular system with microzoning developed in this paper is more accurate than that obtained with the method developed in [1]. Except for one-cell per cluster systems, the worst case S/N developed in this paper is lower than that predicted previously. Nevertheless, microzoning still results in a considerable improvement in S/N as compared to omnidirectional architectures while maintaining system capacity and soft hand-off capability. Based on the worst case mobile location at the edge of a microzone, narrowband, frequency-division multiple access cellular systems require seven-cell per cluster architectures in order to maintain a worst case signal-to-noise ratio of 18 dB. If a worst case signal-to-noise ratio of 15 dB is acceptable, then a three-cell per cluster architecture can be employed.

References

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