A High-Capacity Wireless Network by Quad-Sector Cell and Interleaved Channel Assignment [1]

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Abstract

In this paper, we propose an improved sectorization scheme, called Narrow Beam Quad-sector Cell (NBQC) for cellular networks, in which each cell is divided into 4 sectors and each sector is covered by a 60^o antenna. The NBQC structure allows easy implementation of the concept of interleaved channel assignment (ICA), which can take full advantage of antenna directivity. With ICA, the NBQC system can enhance the system performance from several perspectives. First, the NBQC has better coverage performance than the current 3-sector cellular architecture. Second, we demonstrate that in a typical radio environment, the NBQC system can achieve a reuse factor $N = 2$ with the signal-to-interference ratio (SIR) as high as 11 dB in 90 percent of the cell area, which is 3 dB to 5 dB improvement over the existing cellular architectures. Third, as compared to the most advanced 3-sector clover-leaf cell architecture with reuse factor $N = 3$, the NBQC system with ICA can achieve reuse factor $N = 2$ with very slight degradation in SIR performance, thereby still improving system capacity by about 40 percent over a wide range of 90 percentile SIR requirements.

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I INTRODUCTION

Capacity is one of the most important issues in wireless systems. Because of limited available frequency spectrum, current cellular radio systems adopt the concept of frequency reuse to utilize the same frequency repeatedly at different locations. A large frequency reuse distance can enhance the channel quality by reducing low interference, but will decrease the system capacity. One challenge for cell engineering is to optimize the tradeoff among channel quality, system capacity, and the costs of infrastructure and user terminals.

There are two directions to improve the tradeoff between capacity and channel performance. One way is to adopt more sophisticated technologies, such as code division multiple access (CDMA) [1], adaptive antenna arrays [2, 3], and dynamic channel allocations (DCA) [4], etc. These techniques are capable of handling high interference, thereby reducing frequency reuse distance and thus increasing system capacity. They also relieve the burden of frequency planning. However, in addition to increasing the cost of base station equipment and user terminals, these techniques also breed new issues. For example, a CDMA system requires sophisticated power control to achieve high capacity. Adaptive antenna array processing needs to deal with the power consumption issue and the size of user handsets. DCA systems must meet some operational conditions to function effectively [4], e.g., the accuracy of time synchronization among all base stations, and the agility of user terminals' synthesizers, etc.

On the other hand, an economical approach to enhance spectrum efficiency is to develop a better cellular engineering methodology. This approach is economical in the sense that it minimizes the cost of base station equipment, and requires no changes to user terminals at all. Thus a better cellular engineering methodology usually results in equivalent improvements on both downlink and uplink transmissions. Cellular engineering includes three major aspects: 1) optimizing frequency planning to reduce interference, 2) selecting a cell architecture to improve the coverage and interference performance, and 3) choosing better cell site locations to enhance service coverage. The focus of this paper is to find a better methodology for the first two aspects.

Traditional cell planning considers a frequency reuse factor of $N \geq 3$ only to ensure at least a "buffered" cell between co-channel cells, where the reuse factor N is defined as the number of cells sharing the whole frequency spectrum once. Few papers in the area of cellular engineering discuss the system architecture with a low reuse factor $N \leq 2$, except, for example, [5, 6, 7]. In [5], the cellular system can achieve a reuse factor $N = 2$ with good channel quality by using the sector rotation technique and the clover-leaf cellular architecture, whereas the impact of variations of cell site location is unknown. In [6] the cell planning approach can achieve a reuse factor of $N = 2$, at the cost of using six antennas at a cell. In [7], Fong et al. suggest a frequency planning with reuse factor $N = 1$, but only suitable for terminals at fixed locations.

The goal of this paper is to introduce an improved cellular planning methodology such that a high-capacity cellular mobile network with reuse factor $N = 2$ can achieve very good signal-to-interference ratio (SIR) and coverage performance. Furthermore, the proposed high-capacity network can be implemented easily without using expensive and sophisticated transceivers at base stations and does not impose any changes on user terminals at all. To achieve these objectives, we suggest a two-stage cellular planning strategy. First, we select an improved cellular architecture, the narrow-beam quad-sector cell (NBQC), to provide better coverage performance. Secondly, a new frequency planning technique, the interleaved channel assignment

(ICA), is designed specifically for the NBQC architecture to enhance the SIR performance. Unlike most traditional cellular engineering methodologies that treat the selection of cellular architectures and frequency planning as two separate subjects, the proposed methodology exploits the synergy between them. Therefore, in a very cost-effective way, we can improve the system capacity without sacrificing the radio performance.

The narrow-beam quad-sector cell (NBQC) is defined as a sectorization technique, where four 60^o directional antennas serve four sectors per cell, respectively. In [8], it is shown that a cell with four 60^o antennas can optimize the interference performance for CDMA systems. Nevertheless, the performance and potential of this kind of sectorization technique is unknown for TDMA/FDMA systems. In this paper, we investigate the performance of this 4-sector cellular architecture from a frequency reuse perspective and explore a methodology to utilize this improved sectorization technique to achieve an efficient frequency reuse planning.

The interleaved channel assignment (ICA) is a new channel assignment technique originally proposed for a 3-sector cellular system [5]. Although channel assignment techniques have been discussed in cellular radio systems for a long time (see a survey in [9]), the traditional fixed channel assignment is basically the same for both omni-directional cellular systems and sectored cellular systems. Evidently, traditional fixed channel assignment schemes do not take advantage of the antenna directivity provided in sectored systems. ICA exploits the characteristics of directional antennas to further improve spectrum efficiency without sacrificing channel quality. Nevertheless, in a 3-sector cellular system, the use of ICA requires slightly different cell site locations compared to the traditional hexagonal cell layout [5]. As shown in the following, such a requirement is not needed for the proposed 4-sector cellular system.

The remaining parts of this paper are organized as follows. Section 2 describes the sectorization techniques for cellular networks. Section 3 presents the NBQC with the interleaved channel assignment. Section 4 presents the performance results, including coverage and SIR performance. Section 5 gives our conclusion.

II CELL SECTORIZATION TECHNIQUES

Most current cellular architectures use sectorization techniques to reduce co-channel interference, thereby increasing system capacity. Two important factors influence the effectiveness of sectorization. One is the number of sectors per cell, and the other is the beamwidth of the directional antenna. Intuitively, the more sectors in a cell, the less interference in the system. However, too many sectors at a cell can cause excessive handoffs and increase equipment and operational cost. Therefore, base stations in current cellular systems typically have three to six sectors per cell [6, 10, 11]. Traditional cell architectures usually have antenna beamwidth of Γ degrees equal to the ratio of 360^o over the number of sectors per cell S, that is

$$\Gamma = \frac{360}{S} \ . \tag{1}$$

For example, the wide-beam trisector cell (WBTC) in the first generation cellular mobile system employs three 120^o antennas to cover one cell. A 6-sector cellular system using six 60^o antennas at a cell is also proposed to improve the capacity of the Global System for Mobile communications (GSM) in [6]. Instead of using (1), subsequent cellular architectures determine the cell contour based on antenna radiation patterns, from which antenna beamwidth is then defined. The narrow-beam tri-sector cell (NBTC) in the second generation cellular systems with three 60^o directional antennas and the proposed NBQC with four 60^o antennas per cell fall into this category. Now, let us see how antenna patterns and sector contour fit each other in various designs.

II-A Analytical Signal-Strength Cell Contour

Two major factors determine the signal-strength contour: 1) the path loss, and 2) the antenna radiation pattern. The signal contour with a propagation distance d for a directional antenna with transmitter antenna gain $G_t(\theta)$ and path loss exponent γ can be derived as follows. Consider the two-slope path loss model $PL(d)$ in [12]:

$$PL(d) = \begin{cases} 10\alpha\log\left(\frac{4\pi d}{\lambda}\right) & \text{if } d \leq B \\ 10\alpha\log\left(\frac{4\pi B}{\lambda}\right) + 10\gamma\log\left(\frac{d}{B}\right) & d > B \end{cases} \tag{2}$$

where $B = \frac{4H_tH_r}{\lambda}$ is the breaking point; H_t and H_r are the transmitter and receiver antenna heights, respectively; λ is the wave length; α is the path loss exponent when the propagation distance $d \leq B$, while γ is the path loss exponent when $d > B$. Then, the equal-signal-strength contour with a propagation distance d can be expressed as

$$d = G_t(\theta)^{1/\gamma}\lambda^{(\frac{2\alpha}{\gamma}-1)}K^{1/\gamma} \tag{3}$$

where

$$K = 10^{[P_t + G_r(\theta) - S + (10\gamma - 10\alpha)\log(4H_tH_r)]/10} \tag{4}$$

and S is the received signal strength, P_t is the transmission power, and $G_r(\theta)$ is the receiver antenna gain at the angle of θ.

Commonly used directional antennas in cellular systems have a 3 dB beamwidth of 60^o to 120^o. This paper considers directional antennas with beamwidth of 60^o, 90^o, and 120^o. The radiation patterns for these beamwidths are shown in Fig. 1. Applying the antenna pattern of Fig. 1 into (3), we can obtain the sector contours of the WBTC, NBTC, and the NBQC.

II-B WBTC and NBTC Architectures

The WBTC architecture uses three 100^o - 120^o antennas at each cell site, in which each antenna is designed to cover a diamond-shaped sector, represented by the solid line in Fig. 2. As a result, a WBTC forms a coverage area with the shape of a hexagon. The non-solid or broken lines in Fig. 2 represent the equal-strength signal contour using a 120^o antenna pattern in (3). We observe that the ideal diamond-shaped sector of a WBTC (solid lines) does not match the actual coverage contour of the antenna (broken lines). Therefore, poor coverage occurs in the corners of the hexagon at the common boundary of two sectors.

By contrast, as a newer approach, an NBTC is covered by a base station with three 60^o directional antennas. As shown in Fig. 3, the equal-strength-signal contours (the non-solid lines) match well a hypothetical hexagon sector contour (solid lines). With three such antennas, the coverage contour of an NBTC is therefore like a clover leaf, as shown in Fig. 3. Because of the better match between the cellular contour and the actual cell coverage, the NBTC system performs better than the WBTC system [10]. Although the NBTC eliminates the coverage problem of the WBTC, it can be shown that having 3 directional antennas to serve three sectors per cell does not take full advantage of directional antennas to suppress co-channel interference. As a result, typical cellular networks using WBTC and NBTC require a reuse factor $N \geq 3$ to yield adequate channel quality. Otherwise, in frequency reuse planning with $N = 2$ for the WBTC and NBTC, a strong co-channel interferer always exist in an adjacent cell. To overcome this difficulty and to further enhance system capacity, a new cellular architecture combining the NBQC and ICA is introduced in the next section.

III A NEW ARCHITECTURE BASED ON NBQC AND ICA

III-A NBQC Architecture

We propose to use the narrow-beam quad-sector cell (NBQC) in cellular planning. An NBQC employs four 60^o directional antennas at a base station, each of which is separated by 90^o. The equal-signal-strength contour of an NBQC is illustrated by the the dashed lines as shown in Fig. 4. We find that using a square-shape area can also approximate the coverage area of a 60^o antenna. In the figure, the path loss from point O to point A is about 6 dB larger than that for point O to point B, assuming a path loss exponent of four. However, the antenna gain associated with point A is about 6 dB higher than that for point B according to the radiation pattern of a 60^o antenna in Fig. 1. Consequently, point A has almost the same signal strength as point B. From Fig. 4, we see that the four squares (solid lines) are within the coverage area of the antennas (dashed lines). Therefore, the NBQC, as the NBTC, avoids the coverage problem at the corner of sector boundaries for the WBTC.

Some important features of the NBQC are discussed as follows.

- The NBQC can provide better coverage performance than both the WBTC system and the NBTC system. It is simply because by adding one more antenna per cell, the NBQC system has more diversity gain in selecting the serving sector. As a result, the signal strength of the user in the NBQC system is better than that in the NBTC system. Furthermore, because of higher antenna gain, the NBQC also outperforms the 4-sector cell with four 90^o antennas.

- The NBQC system permits implementation of the concept of the interleaved channel assignment (ICA) easily. ICA has been proven to be a powerful technique to combat interference [5]. However, implementation of ICA in the NBTC system requires offsetting base station locations slightly from those in the original NBTC system. Thus the modified NBTC system in [5] is more suitable when deploying a new system. In contrast, the NBQC system permits implementing ICA without requiring changes on the original cell layout of the NBTC system.

- In addition to the advantage of using the same cell sites of the existing systems, the NBQC enables us to use the same antennas in the systems. The extra cost is only for adding one more antenna and associated equipment at the base station in an NBTC and re-orienting the antenna directions.

- As can be seen by comparing Figs. 2 to 4, the NBQC provides more overlapped areas between sectors than the WBTC and NBTC. As a consequence, the NBQC can relax the requirement of completion duration in handoff process. In fact, the additional overlapped area in the NBQC system yields improvements for both inter-cell and intra-cell handoffs.

III-B Interleaved Channel Assignment (ICA)

Following traditional channel assignment approaches, Figure 5 and 6 show the cell layout and assignment for the WBTC ad NBTC system with reuse factor $N = 3$, respectively. By the same approaches, Fig. 7 and 8 depict the respective system with reuse factor of $N = 2$. Notice that antennas for sectors assigned with the identical channel sets are pointing at the same direction. As a result, a strong co-channel interference exist in a neighboring cell, thus significantly degrading the channel quality.

To fully exploit the advantage of the directivity of directional antennas in sectored cellular systems, the interleaved channel assignment (ICA) proposed for a modified NBTC system [5] can be also easily implemented in the NBQC system, as shown in Fig. 9. In this layout, each cell is divided into four sectors and each sector is served by a 60^o antenna. In the ICA scheme, each cell in the same column is assigned with four channels (or channel sets), one for each of its four sectors. To take full advantage of the directivity of sectoral antennas, the channels assigned to the corresponding sectors of adjacent cells in the same column are interleaved. For example, channel 1 and 2 are assigned to the upper-left sectors in the middle column of cells in Fig. 9 in an interleaved fashion; these channels are assigned the upper-right sectors of the cells in the same way. Similarly, channel 3 and 4 are assigned to the lower-left and lower-right sectors in an interleaved pattern in the same cell column. The assignment in this figure allows cells in a neighboring column to use a different set of four channels; thus the assignment yields a frequency reuse factor of 2 (i.e., a channel is reused in every two cells and in every eight sectors).

IV PERFORMANCE RESULTS

IV-A Simulation Assumptions

We use a simulation platform with the following assumptions:

1. We consider only the base-to-mobile (downlink) direction. In most cases, the downlink is the performance-limiting direction [13, 14] and therefore sufficient for our study.

2. In conformity with current practice in FDMA and TDMA systems, we do not consider downlink power control.

3. Each radio link between a user terminal and a base station is modeled by a 2-slope median path loss model, (2), plus shadow fading.

4. The shadow fading components from all base stations to a given user ($\omega_i, i = 0, 1, \ldots, n$) are assumed to be mutually independent. In reality, this may not always be true, since local shadowing for a given user location can affect its paths to all base stations. Some studies have addressed this issue of correlated log-normal fading [15], but the present study does not.

5. We consider at least two tiers of co-channel interferers.

6. For any given channel A, interference from four adjacent channels, two of which are at frequencies higher or lower than that of channel A, are included in the simulation. Specifically, the interference power from the immediately adjacent channel and that next to the latter channel is assumed to be 17 and 52 dB lower than the corresponding cochannel interference, respectively.

Based on these assumptions, our simulation platform has been used to conduct thousands of trials by the following approach:

1. In each trial, 50,000 users are randomly placed in a rectangular coverage area with the cell site layouts under consideration.

2. A cell-wrapping technique is used to avoid edge effects.

3. Site diversity based on received signal strength is adopted to select the serving sector for each user.

4. The SIR population so obtained is then used to compute the SIR cumulative distribution function (CDF).

IV-B Coverage Performance

Using the simulation platform, we also study the user signal level throughout a service area by the approach suggested in [10]. Our aim is to determine which system needs higher transmission power to achieve a specific signal coverage.

To begin, the local mean received power can be written as

$$P_r = C + P_t - 10\gamma\log(d) + G(\theta) + 10\log(\Omega) \ , \tag{5}$$

where Ω is a zero-mean log-normal random variable with standard deviation σ, C is a constant related to antenna height, $G(\theta)$ is the combined gains of the transmitter and receiver antennas in dB, and P_t is the transmitted power. For convenience, we assume that d is in km. The third and fourth terms on the right-hand side of (5) depend on the actual user location, and so we lump them together with the last term as

$$X = -10\gamma\log(d) + G(\theta) + 10\log(\Omega) \ . \tag{6}$$

X can be viewed as a normalized signal strength. In a downlink transmission, X is the ratio of the user received signal power normalized to the base station transmission power in dB. In essence, the higher the value of X, the better the signal strength.

A typical performance requirement is that P_r should fall below some minimum value, P_0, for no more than some percentage, p, of the service area (i.e., p is the specified outage probability). Now let X_p be the numerical value that X falls below at p percent of locations. From (5) and (6), it is then easy to see that the performance requirement is met if

$$P_t \geq P_o - C - X_p \ . \tag{7}$$

Clearly, the larger X_p is, the less transmission power is needed. Thus, by finding the CDF of X for two systems, we can identify the differences in power requirements for specified values of outage probability.

Figure 10 compares the coverage performance of the 3-sector cellular system with that of the 4-sector cellular system in terms of the normalized received signal power, X. Observe that the NBQC (**d** : the 4-sector cell with 60^o antenna) outperforms the others. Interestingly, the NBTC (**b** : the 3-sector cell with 60^0 antenna) is the second best, which is even better than the 4-sector cell with 90^o antenna (**c**). The WBTC (**a**: the 3-sector cell with 120^o antenna) has the worst performance. The NBQC improves the received signal strength in 90 percent of cell area by 2.8dB, 1dB, and 1.5dB when compared to the WBTC, the NBTC, and the 4-sector cell with 90^o antenna, respectively. The performance improvements result from the following reasons. First, the NBQC provides more uniform coverage area and more site diversity gain than the 3-sector cell. Second, the narrower antenna provides higher antenna gain at the angle of zero degree, i.e., $G(0)$. In the cases considered, $G(0) = 10$ dB, 7 dB, and 5 dB, for 60^o, 90^o, and 120^o antennas, respectively. Third, the 60^o antenna can either closely match a square area in the 4-sector cell or a hexagon in the 3-sector cell. From a cellular engineering standpoint, this feature makes the coverage contours of the 60^o antenna easier to tessellate together to provide a complete coverage area than the 90^o and 120^o antennas.

IV-C Co-Channel Interference Performance

Assuming that base station antennas for all sectors transmit at the same power, the SIR for a given user can be expressed as

$$\frac{S}{I} = \left[\sum_{i=1}^{n} \left(\frac{G_i(\theta_i)}{G(\theta_0)} \right) \left(\frac{d_i}{d_0} \right)^{-\gamma} \left(\frac{\Omega_i}{\Omega_0} \right) \right]^{-1} , \tag{8}$$

where Ω is the shadow fading variable ($10\log(\Omega)$ is a Gaussian random variate with zero mean and standard deviation σ), the subscript 0 corresponds to the desired signal, and $i = 1, \ldots, n$ are the subscripts for the n active interferers.

We adopt the total co-channel interference probability as a performance criterion. The total co-channel interference probability is given by

$$P(S/I < \mathrm{SIR_{req}}) = \sum_{i=1}^{n} P(S/I < \mathrm{SIR_{req}} \mid i) \begin{pmatrix} n \\ i \end{pmatrix} \rho_c^i (1 - \rho_c)^{n-i} , \tag{9}$$

where S is the desired signal power, I the total interference power, and $\mathrm{SIR_{req}}$ is the required SIR to maintain a successful communication link, n is the total number of interferers, and ρ_c is the probability of an interferer being active (i.e., transmitting). $P(S/I < \mathrm{SIR_{req}} \mid i)$ is the outage probability conditional on the i active interferers.

Consider a reuse factor $N = 2$ under a full traffic load condition (i.e., each base station antenna transmits all the time). We compare the SIR performance of the NBQC using the interleaved channel assignment with that for the NBTC and the WBTC. Figure 11 presents the cumulative distributive functions (CDF) of the SIR of the 3-sector cell and 4-sector cell with 60^o, 90^o, and 120^o antenna. We have three observations. First, the 4-sector cell performs better than the 3-sector ones. The NBQC with the ICA improves the 90 percentile SIR by 3 dB and 5 dB over the NBTC and WBTC, respectively. Second, the NBQC (with the 60^o antenna) outperforms 4-sector cells with the 90^o antenna. Third, even with reuse factor $N = 2$, the 90 percentile SIR of the NBQC with ICA reaches 11 dB, beyond the SIR requirement of GSM. The results confirm that the interleaved channel assignment for the NBQC is an effective technique to reduce co-channel interference by exploiting the directivity of sector antennas, thereby increasing spectrum efficiency.

As expected, when the traffic load is less than 100% (i.e., $\rho_c < 1$), the interference power is reduced, thus improving SIR performance. Figure 12 shows how the 90 percentile SIR is improved by reducing traffic load. Of course, network capacity is decreased by lowering the carried load, which is a tradeoff to be determined by cellular engineers. Observe that the performance of the NBQC with $N = 2$ significantly exceeds that of the NBTC and WBTC with $N = 2$, and is slightly below the NBTC with $N = 3$. Such improvement is due to the fact that the NBQC and ICA exploit the directional antennas in suppressing interference effectively.

IV-D Spectrum Efficiency

In this section, we compare capacity of the proposed NBQC system with that of other sectored cellular systems. Consider a system with the total number of channels N_t, the reuse factor N, the number of sectors per cell S, the blocking probability requirement P_B, and the SIR requirement SIR_{req}. The capacity for each cell in the system is limited by the blocking or SIR requirement. In fact, the cell capacity is the minimum of that determined by considering blocking and interference requirement alone. That is,

$$\text{Cell capacity (Erlang)} \quad = \quad \min\{\frac{N_t \mathrm{A_o}}{N}, \quad SE_B\} \tag{10}$$

where A_o is the capacity per channel while meeting the SIR requirement and E_B is the Erlang capacity for each sector to satisfy the blocking requirement. To obtain A_o, the probability of an interferer being active in (9) can be interpreted as the carried load per channel, while satisfying the SIR percentile requirement. Based on this, we have

$$A_o = \frac{\rho_c}{1 - P_B} \quad . \tag{11}$$

Since each cell is allocated with $\frac{N_t}{N}$ channels, the cell capacity under the interference consideration is $(\frac{N_t}{N})A_o$. To find E_B, we recognize that E_B depends on the number of channels allocated to each sector $\frac{N_t}{NS}$ and the specified P_B. To be precise, the Erlang-B formula yields

$$P_B = \frac{E_B^{N_t/NS}}{(N_t/NS)!} \left(\sum_{k=0}^{N_t/NS} \frac{E_B^k}{k!} \right)^{-1} \quad . \tag{12}$$

For fixed $\frac{N_t}{NS}$, P_B is a monotonically increasing function of E_B. Thus, for a given P_B, E_B can be solved from (12). Thus, the Erlang capacity per cell for meeting the blocking requirement P_B is given by SE_B.

Our numerical experience reveals that if N_t is large (e.g., on the order of hundreds) and P_B is not high (e.g., up to a few percent), A_o becomes a limiting factor for the cell capacity in (10). Otherwise, SE_B is the dominating factor in determining the cell capacity due to trunking efficiency.

In this study, we consider a system with $N_t = 300$ and $P_B = 0.01$. Figure 13 shows the cell capacity as functions of the 90 percentile SIR requirement for various cellular designs. It is important to note that because of the effectiveness of NBQC and ICA, the NBQC with $N = 2$ provides a significant increase in capacity per cell over the NBTC with $N = 3$. Figure 14 expresses such capacity improvement in percentage. These results reveal that over a wide range of requirement for the 90 percentile SIR, the NBQC and ICA design provides at least 35% increase in capacity over other cellular designs.

V CONCLUSION

In this paper, we have proposed an improved sectorization scheme, called Narrow Beam Quad-Cell (NBQC) for cellular networks, in which each cell is divided into 4 sectors and each sector is covered by a 60^o antenna. The NBQC structure enables easy implementation of the concept of interleaved channel assignment (ICA) to take full advantage of antenna directivity. With ICA, the NBQC system can enhance system performance from several perspectives. First, the NBQC system with ICA significantly improves the system capacity and quality of radio links. We demonstrate that in a typical radio environment, the NBQC system can achieve a reuse factor $N = 2$ with the 90 percentile of SIR equal to 11 dB. Comparing this to the Global System for Mobile Telecommunications (GSM), which requires $N = 4$ to achieve the SIR requirement of 9 dB, our proposed system thus improves the system capacity by a factor of two. Second, the proposed NBQC system can also improve the converge performance. Third, as compared to the most advanced 3-sector clover-leaf cell architecture with reuse factor $N = 3$, the NBQC system with ICA yields at least 35% increase in network capacity over a wide range of 90 percentile SIR requirements.

The proposed improved sectorization technique and the ICA scheme can further enhance the system capacity and channel quality if suitable power control or signal processing techniques can be adopted. Furthermore, we plan to continue this study in a number of areas. First, besides for the reuse factor of $N = 2$, the ICA with NBQC should be generalized for other reuse factors. Second, it will be desirable to quantify the performance impact to the NBQC/ICA scheme of imperfect cell site locations.

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References

[1] W. C. Y. Lee, "Overview of cellular CDMA," *IEEE Transactions on Vehicular Technology*, vol. 40, pp. 291–302, May 1991.

[2] J. H. Winters, "Smart antennas for wireless systems," *IEEE Personal Communications*, vol. 5, pp. 23–27, Feb. 1998.

[3] V. K. Gard and L. Huntington, "Application of adaptive array antenna to a TDMA cellular/PCS system," *IEEE Communications Magazine*, pp. 148–152, Oct. 1997.

[4] J. C. I. Chuang, "Performance issues and algorithms for dynamic channel assignment," *IEEE Journal on Selected Areas in Communication*, vol. 11, pp. 955–963, Aug. 1993.

[5] L.-C. Wang, "A new cellular architecture based on an interleaved cluster concept," *Proceedings of IEEE International Conference on Universal personal Communications*, pp. 281–285, 1998; and to appear in *IEEE Trans. on Vehicular Technology.*

[6] J. Xiang, "A novel two site frequency reuse plan," in *IEEE Vehicular Technology Conference*, pp. 441–1369, 1996.

[7] T. K. Fong, P. S. Henry, K. K. Leung, X. Qiu, and N. K. Shankaranarayanan, "Radio resource allocation in fixed broadband wireless networks," *IEEE Transactions on Communications*, vol. 46, no. 6, pp. 806–818, 1998.

[8] T. W. Wong and V. K. Prabhu, "Optimum sectorization for CDMA 1900 base stations," in *IEEE Vehicular Technology Conference*, pp. 1177–1181, 1997.

[9] I. Katzela and M. Naghshineh, "Channel assignment schemes for cellular mobile telecommunication systems: a comprehensive survey," *IEEE Personal Communications*, vol. 3, no. 3, pp. 10–31, 1996.

[10] L.-C. Wang, K. C. Chawla, and L. J. Greenstein, "Performance studies of narrow beam trisector cellular systems," *International Journal of Wireless Information Networks*, vol. 5, no. 2, pp. 89–102, 1998.

[11] G. K. Chan, "Effects of sectorization on the spectrum efficiency of cellular radio systems," *IEEE Transactions on Vehicular Technology*, vol. 41, pp. 217–225, Aug. 1992.

[12] V. Erceg, S. Ghassemzadel, M. Taylor, D. Li, and D. L. Schilling, "Urban/suburban out-of-sight propagation modeling," *IEEE Communications Magazine*, pp. 56–61, June 1992.

[13] M. V. Clark, V. Erceg, and L. J. Greenstein, "Reuse efficiency in urban microcellular networks," in *IEEE Vehicular Technology Conference*, pp. 421–425, 1996.

[14] R. Rudokas and T. Benz, "Is it time to rethink frequency reuse formulas?," *Telephony*, vol. 232, pp. 68–74, Mar. 1997.

[15] S. Ariyavisitakul, T. E. Darcie, L. J. Greenstein, M. P. Phillips, and N. K. Shankaranarayanan, "Performance of simulcast wireless techniques for personal communication systems," *IEEE Journal on Selected Areas in Communication*, vol. 14, pp. 632–643, May 1996.

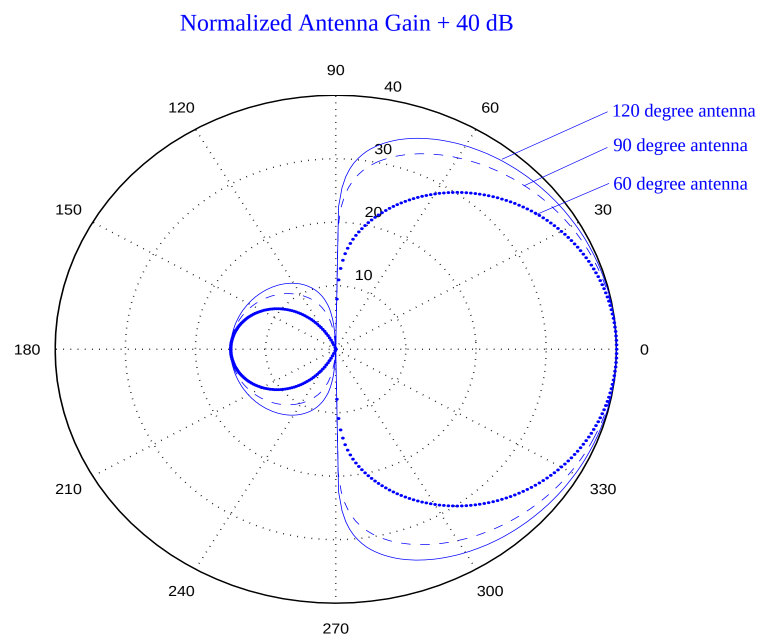

Figure 1: Radiation patters for the 60^o, 90^o, and 120^o directional antenna.

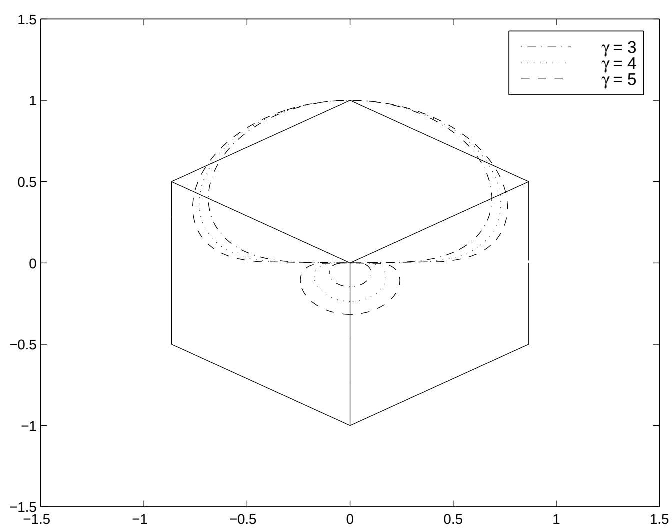

Figure 2: Coverage area of a base station comprising three 120 degree directional antennas, a wide-beam tri-sector cell (WBTC), where solid lines represent hypothetical sector contours, non-solid lines analytical sector contours, and γ is the path loss exponent.

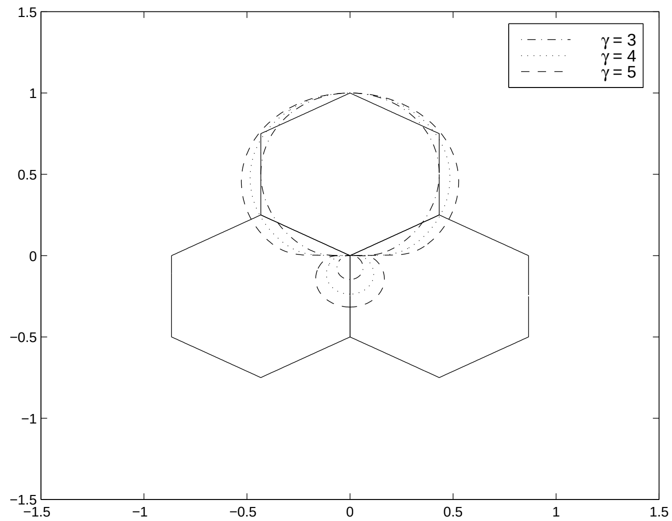

Figure 3: Coverage area of a base station comprising three 60 degree directional antennas, a narrow-beam tri-sector cell (NBTC), where solid lines represent hypothetical sector contours, non-solid lines analytical sector contours, and γ is the path loss exponent.

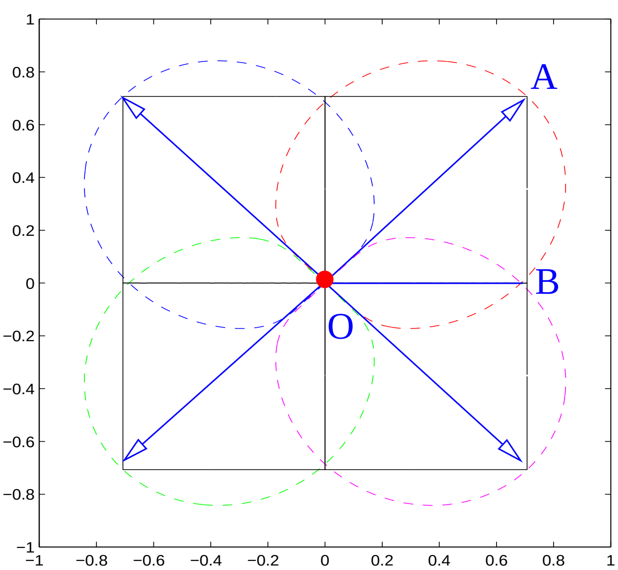

Figure 4: Coverage area of a base station comprising three 60 degree directional antennas, a narrow-beam quad-sector cell (NBQC), where solid lines represent hypothetical sector contours, non-solid lines analytical sector contours.

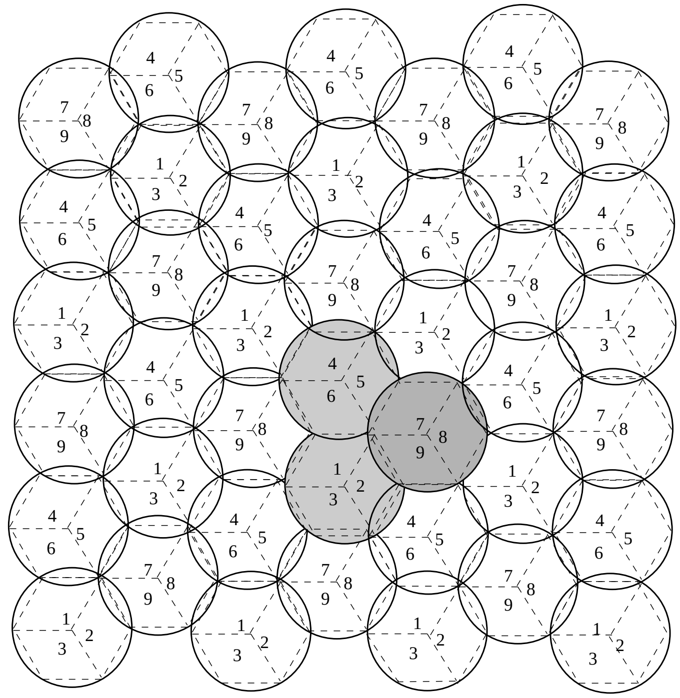

Figure 5: A WBTC system with reuse factor $N = 3$.

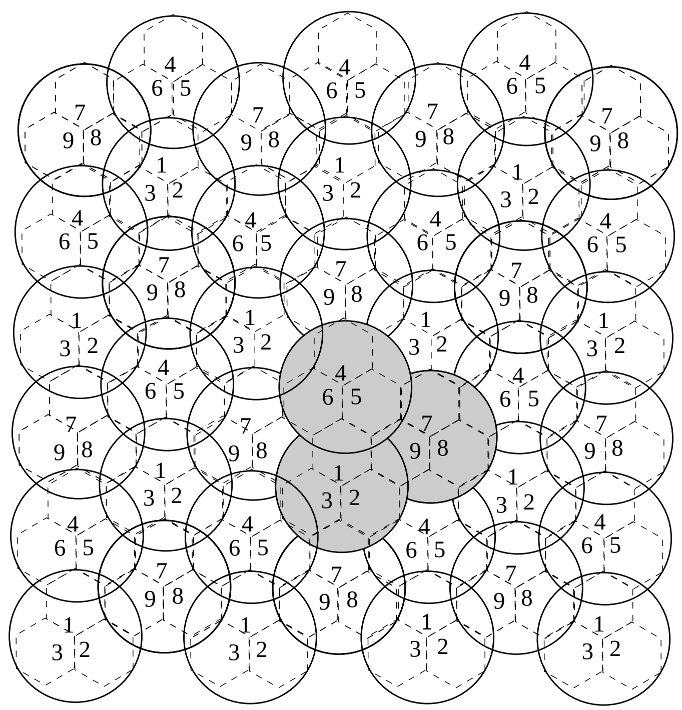

Figure 6: An NBTC system with reuse factor$N = 3$.

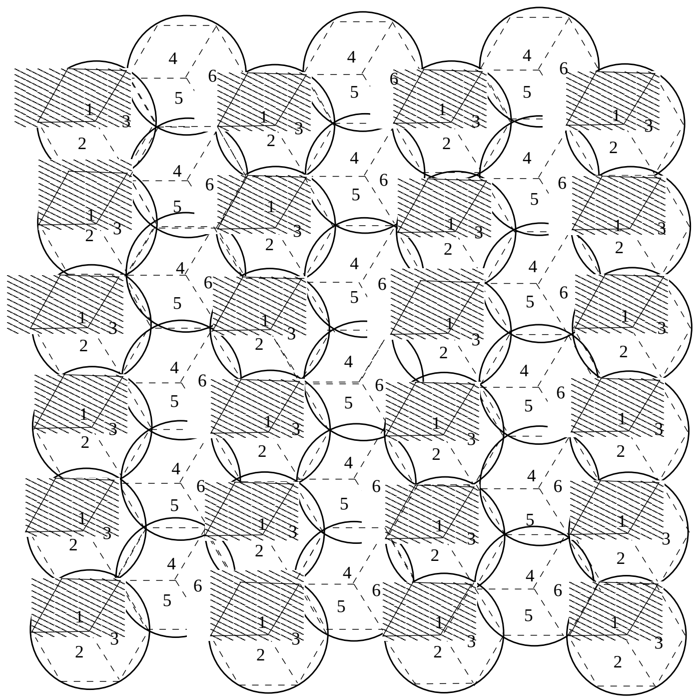

Figure 7: A WBTC system with reuse factor $N = 2$.

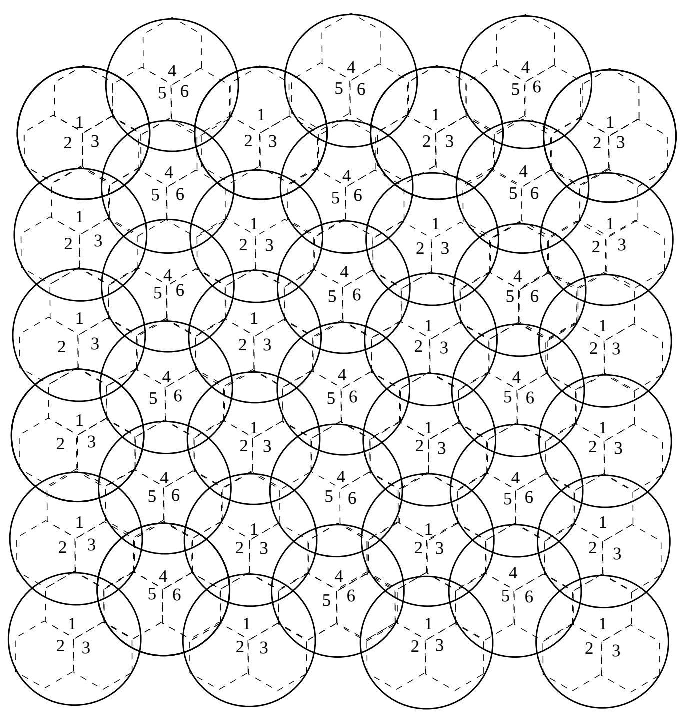

Figure 8: An NBTC system with reuse factor $N = 2$.

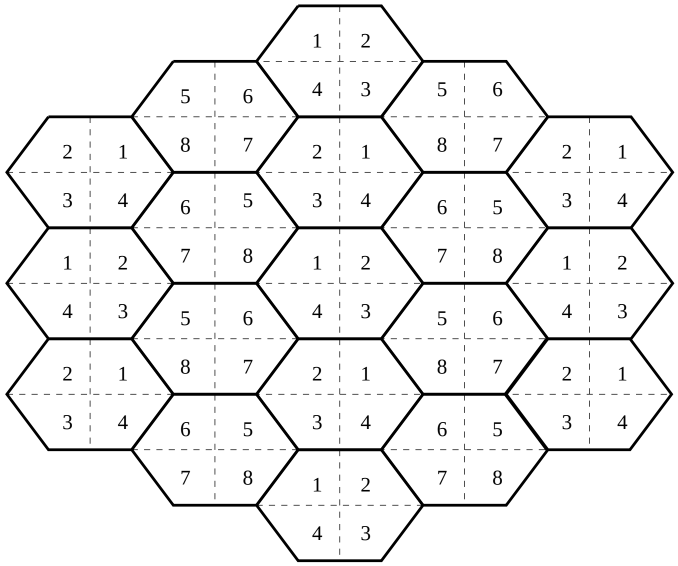

Figure 9: A 4-sector cell layout and interleaved channel assignment with $N = 2$.

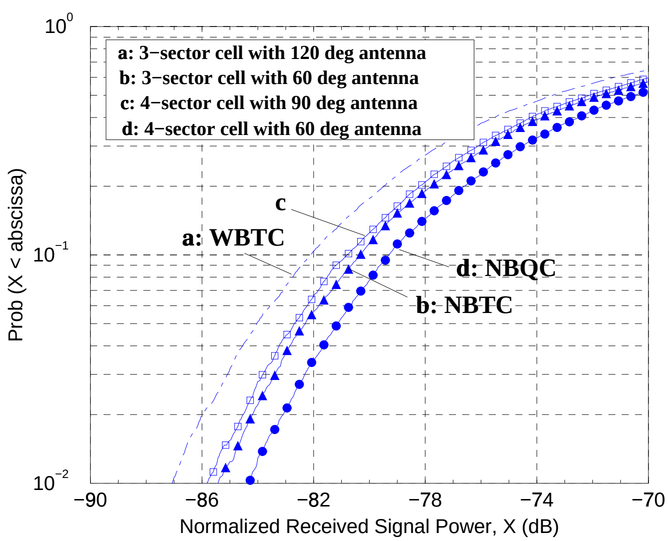

Figure 10: Coverage performance comparison of the 3-sector cellular system and the 4-sector cellular system with 3 dB beamwidth equal to 60^o, 90^o, and 120^o in terms of the normalized received power X, where $\sigma = 8$ dB; $\gamma = 4$; reuse factor $N = 2$.

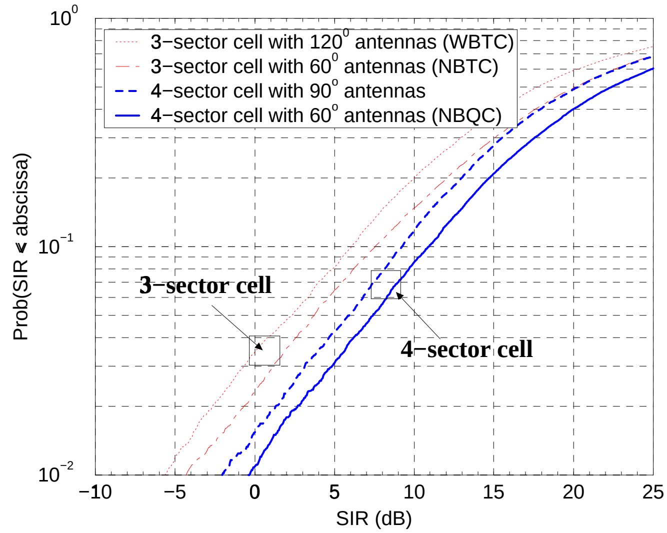

Figure 11: SIR performance comparison of the 3-sector cellular system and the 4-sector cellular system with full traffic load and 3 dB beamwidth equal to 60^o, 90^o, and 120^o, where $\sigma = 8$ dB; $\gamma = 4$; reuse factor $N = 2$.

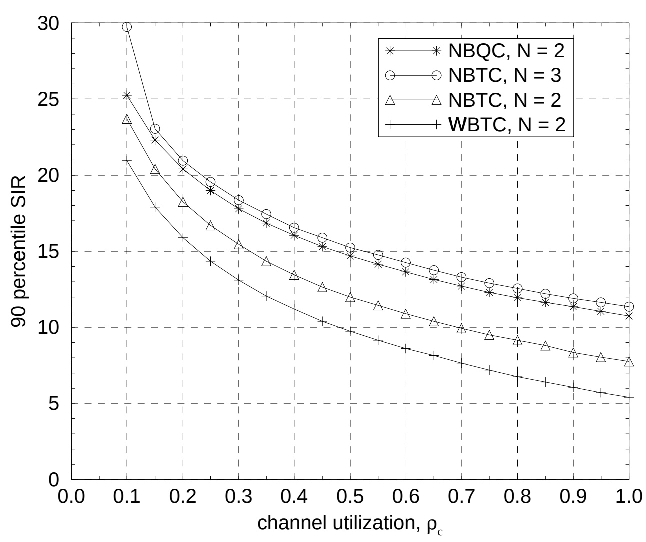

Figure 12: Performance of 90 percentile SIR versus channel utilization, ρ_c.

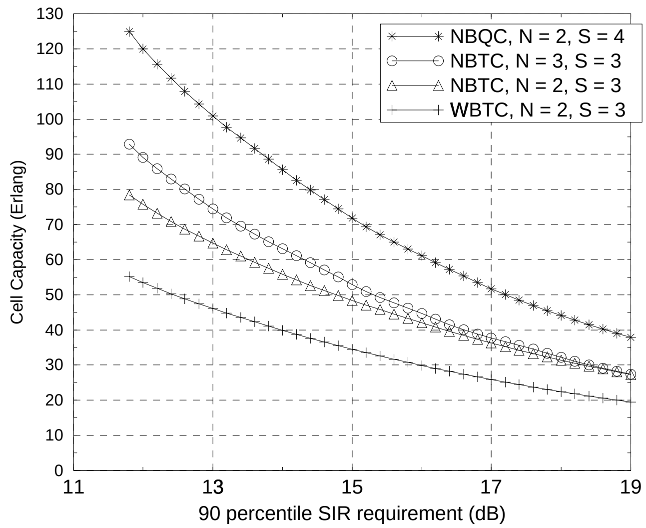

Figure 13: Cell capacity versus SIR requirement for $N_t = 300$.

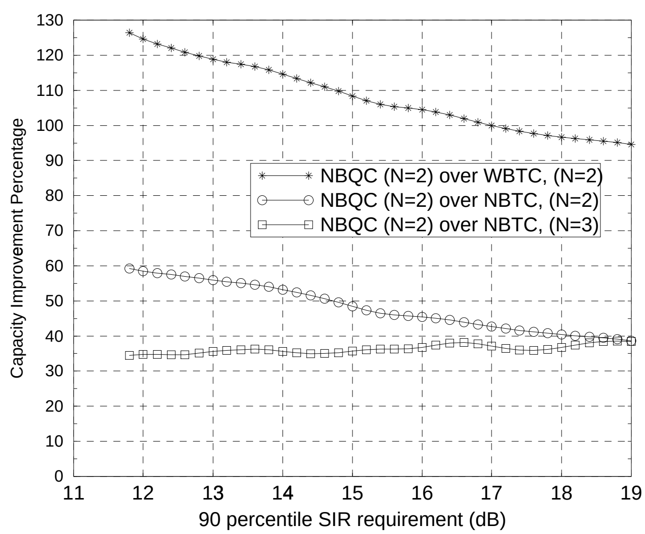

Figure 14: Capacity improvement of NBQC with reuse factor $N = 2$ over the NBTC with $N = 3$, NBTC with $N = 2$, and WBTC with $N = 2$.