A MODIFIED DIRECTIONAL FREQUENCY REUSE PLAN BASED ON CHANNEL ALTERNATION AND ROTATION

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ABSTRACT

In previous work, we presented a novel Channel Alternation and Rotation (CAR) scheme that coordinates channel assignment with antenna directivities. In CAR, each cell type is allocated an extra channel set that provides network designer the flexibility to alternate and rotate channels according to nearest front lobe interference avoidant strategy to enhance co-channel interference ratio (C/I). CAR relaxes the constraints assumed in conventional reuse plans to allow deployment of smaller, unconventional reuse cluster sizes based on C/I requirements, thus increases frequency reuse efficiency. In this paper, we present a new reuse plan in which 2 extra channel sets are allocated to each cell type and assigned according to CAR strategy. This reuse plan, referred to as 2x(3+2), increases channel capacity by 20% in comparison with conventional 4x3 reuse plan while still provides signals above the minimum acceptable C/I margin. 2x(3+2) reuse plan is simple and can be implemented without costs.

INTRODUCTION

Unlike Omni-directional antenna which power radiates equally in all directions, directional antennas project main beams power onto front lobe regions, thus side and back lobes interference is reduced. To take advantages of the antenna directivities to enhance C/I, most cellular systems employ three 100^0 to 120^0 directional antennas at each base station (BS) [2][3]. Fig. 1 depicts a typical 3dB beam-width, 120^0 antenna's radiation pattern obtained at [7]. With in which, front lobe region is generally within $\pm 60^0$ from the bore-sight (at azimuth angle 0^0).

In a conventional cellular network, the entire radio frequency is assigned to each reuse cluster of *N* adjacent cells. To provide equidistant separation among co-channel cells, *N* must be a rhombic number determined by the two shift parameters i and j, and expressed as,

$$N = i^2 + ij + j^2 \qquad (1)$$

Thus, N is restricted within a finite set of values e.g. 3, 4, 7. Small *N* or short reuse distance increases frequency reuse efficiency, which directly determines the system capacity, however, decreases C/I, which affects the Quality of Service (QOS). Larger *N* or longer reuse distance increases QOS, however, decreases system capacity.

Furthermore, in tri-sectored cellular system employing fixed channel assignment, 3 unique and disjoined channel sets are assigned once to a tri-sectored cell in the cluster and repeated uniformly in all others. Thus, tri-sectored directional antenna systems are generally denoted as $N * 3$. With those fixed constraints, conventional reuse plans have not taken full advantage of antenna directivities to maximize frequency reuse efficiency. Fig. 2 depicts the conventional 4x3 reuse plan and worse C/I scenario, that is, when MS is at the boundary at $\pm 60^0$ of a serving sector.

Several other researches have been done to enhance C/I and thus increase channel capacity [2][3][4][6]. Although improvement in C/I and channel capacity is realized, all proposed schemes require antennas replacement and or modification to the cell structures. Thus, they are not practical for improving existing 120^0 directional cellular systems, without significant costs.

In previous work [1], we presented CAR reuse scheme in which cell layout is based on *two-tier cell-reuse* structure and each cell type is allocated an extra channel set to give network designer the flexibility to assign channels according to *nearest front lobe interference avoidant* strategy to enhance C/I. CAR relaxes the constraints required in conventional system to allow deployment of reuse cluster sizes based on C/I requirement rather than 3,4,7 as determined by (1). In 2x(3+1), 3x(3+1), 4x(3+1), and 5x(3+1) reuse plans, we obtain reuse factor of 2.6, 4, 5.3, and 6.6 respectively. CAR reuse plan can increase

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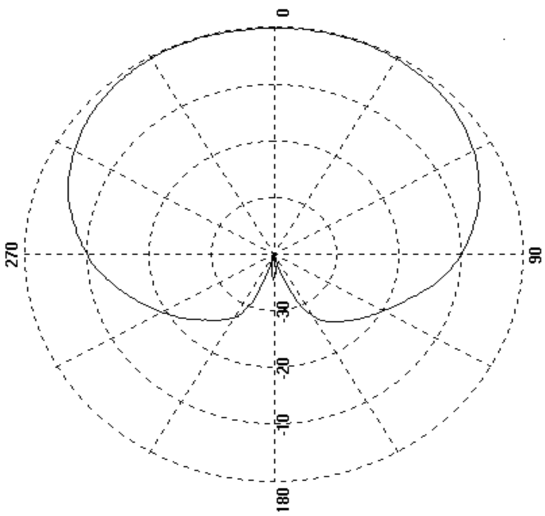

Fig. 1. 120^0 directional antenna pattern

channel capacity up to 31.25% while still maintain C/I margins comparable to targeted conventional N*3 reuse plans. Furthermore, CAR uses existing directional antenna infrastructure, it truly does not impose any cost.

In CAR, each cell only uses 3 of the 4 allocated channel sets, thus the extra *alternate channel* set, if used and carefully planned, can double the capacity any one sector. However, since the total number of channel sets in 3x(3+1) and conventional 4x3 reuse plan are equal, without employing alternate channel, the system capacities of the two schemes remain the same.

In this paper, we present a new reuse plan in which 2 extra channel sets are allocated to each cell type and assigned according to CAR strategy to maximize frequency reuse efficiency. This reuse plan, referred to as 2x(3+2), increases channel capacity by 20% over conventional 4x3 system while still provides signals at and above the minimum acceptable C/I margin.

The remainder of this paper is organized as follows. Section II further describes how directional antenna systems are exploited in CAR, and presents the 2x(3+2) reuse plan. In Section III, we demonstrate the performance advantages of 2x(3+2) over conventional 4x3 and CAR 3x(3+1) reuse plan based on system capacity and worse C/I. Finally, Section IV concludes this paper.

FREQUENCY REUSE PLANNING

A. Conventional 4x3 vs. CAR 3x(3+1) Reuse Plan

In conventional 4x3 reuse plan depicted in Fig. 2, four cells are grouped into a cluster and labeled A, B, C, and D and assigned equidistant to all other co-channel cells. Each cell has 3 sectors and each sector is allocated a unique channel set, which is assigned once in the cluster and repeated uniformly in all others. Thus 3 disjoined channel sets are allocated to each cell type and 12 channel sets are used system-wide, which are typically labeled 1 to 12 and assigned as follows: A = {1,5,9}, B ={2,6,10}, C= {3,7,11}, and D = {4,8,12}. For simplicity, only type A cells are labeled and indexed from the top-left of the cell grid according to interlocking cell structure based on rectangular cell lattice.

In worse interference scenario depicted in Fig. 2, among the six co-channel interferers of channel 1 in cell $A_{4,2}$, $A_{2,4}$ and $A_{6,4}$ are from back lobes, $A_{0,2}$ and $A_{8,2}$ are from side lobes, and $A_{2,0}$, $A_{6,0}$, are from the antennas' front lobes. The other front lobe interferer, $A_{10,0}$, is farther way and has lesser impact on C/I in comparison to $A_{2,0}$ and $A_{6,0}$. Hence, C/I is mainly the result of interference from the

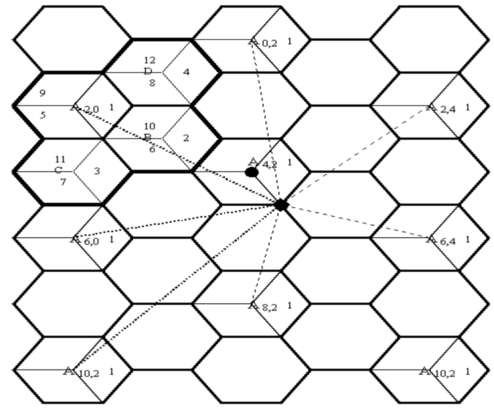

Fig. 2. 4x3 reuse plan and worse interference

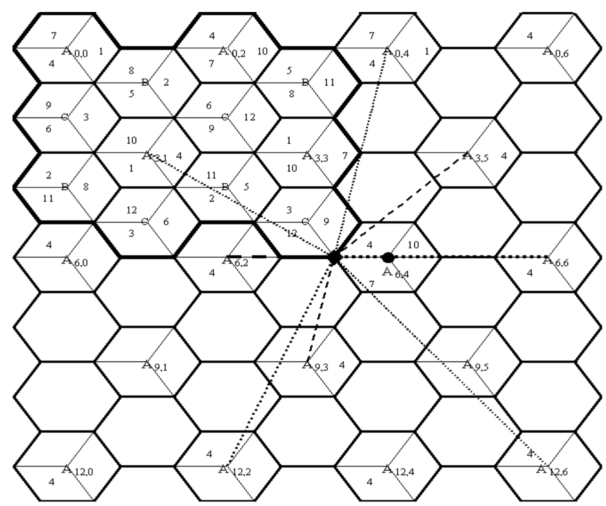

Fig. 3. 3x(3+1) reuse plan and worse interference

two nearest front lobes interferers, specifically $A_{2,0}$ and $A_{6,0.}$

Unlike conventional tri-sectored antenna systems, in CAR, each cell type is allocated an extra channel set used for *channel alternation* that results in *k+1* sets per cell type and $N(k+1)$ sets system-wide. Thus, in 3x(3+1) reuse plan depicted in Fig. 3, a total of 12 channel sets are used and assigned as follows: A = {1,4,7,10}, B = {2,5,8,11}, and C = {3,6,9,12}. Since each cell is assigned only 3 of the 4 allocated sets, there are $\binom{4}{3}$ = 4 unique patterns per cell type, e.g., A_1 = {1,4,7}, A_2 = {1,4,10}, A_3 = {1,7,10}, and A_4 = {4,7,10}. Therefore, the 3x(3+1) reuse plan consists of repeating patterns of 12 cells and each channel is used 3 times in the pattern, as illustrated in Fig 3.

Consider cell $A_{0,0}$ on the top left corner, channel 1 (sector 1) points directly toward its nearest column-adjacent co-channel cell $A_{0,2}$, since channel 1 is replaced by channel 10, front lobe interference is avoided. Channel 10 is then alternated by channel 1 in the next column-adjacent co-channel cell $A_{0,4}$. Thus, 1 and 10 become alternating channel pairs. Furthermore, channel 4 and 7 are also rotated in each nearest column-adjacent co-channel cell, interference is greatly reduced, as they become side lobe interferers instead. Also notice that in subsequent row-adjacent co-channel cells, alternating channel pairs become rotating channel pairs and vice versa. Thus, although channel 10 from the row-adjacent co-channel cell, $A_{3,1}$, points directly toward cell $A_{0,0}$, however, channel 10 is not used in $A_{0,0}$, there is no interference. Due to channel rotation, channel 1 becomes back lobe interferer; therefore, interference is negligible. Other adjacent co-channels are assigned likewise. Since front lobe interference from nearest co-channel cells is avoided, interference is mainly from antennas' side and back lobes that are either reduced or negligible, and from antennas' front lobes from second tier co-channels that are farther away. Thus CAR schemes allow co-channels to be assigned closer in comparison with their counterparts.

In worse interference scenario, also depicted in Fig. 3, when MS is at the boundary of sector 4 in cell $A_{6.4}$, among the six co-channel cells, due to channel alternation, $A_{3,3}$ and $A_{9,5}$ do not contains channel 4, thus there is no interference; since channel 4 in $A_{6,2}$ and $A_{6,6}$ are rotated, they become back lobe and side lobe interferers; similarly $A_{3,5}$ and $A_{9,3}$ also become back and side lobe interferers. All front lobe interferers, $A_{0,4}$, $A_{3,1,}$ $A_{12,2}$, and $A_{12,6}$ are from second tier co-channel cells which are farther away.

B. CAR 2x(3+2) Reuse Plan

Since TDMA system such as IS-136 requires 14 dB, to further enhance frequency reuse efficiency from 4x3 reuse plan, in this paper, we present a reuse plan in which the number of cell type is reduced to 2 and the number of alternate channels is increased to 2 to a total of 5 channel sets per cell type and 10 channel sets system-wide. This scheme results in a novel reuse plan referred to as 2x(3+2). Based on channel separation factor N, the channel allocations are as follows: A = {1,3,5,7,9}, and B = {2,4,6,8,10}.

C. CAR 2x(3+2) Algorithm

To simplify 2x(3+2) channel assignment algorithm, we again employ a rectangular cell-lattice $I_{[j,k]}$ indexed according to interlocking rows and columns starting from the top left of the grid, e.g. j =0,k=0.

1. Divide the available channels into 10 channel sets and allocate to each cell-type as illustrated in Table I.
2. Start from the left column of cell-type I; For I = A to B
   a) Label 5 channel sets allocated to type I cell as {C_1, C_2, C_3, C_4, C_5}
   b) Assign the first 3 channels to each sector of the first cell of type I counter-clockwise starting from bottom to side and top sector, which are denoted $f210^0$, $f90^0$, and $f330^0$ based on antenna's direction shown in Fig. 4, respectively.
   c) For each remaining type I cells in the same column
      - Advance to next adjoined co-channel cell.
      - Assign previous (channel previously used in) $f90^0$ to current $f210^0$ and previous $f330^0$ to current $f90^0$.
      - If current $f90^0$ is C5 then assign C_1 to $f330^0$, else assign the next channel in sequence.
   d) For each subsequent column of type I cells
      - Move to first cell on the top of the column.
      - Assign previous column adjacent $f330^0$ to current $f210^0$
      - If current $f210^0$ is C5 then assign C_1 to $f90^0$, else assign the subsequent channel to $f90^0$.
      - If current $f90^0$ is C5 then assign C_1 to $f330^0$, else assign the next channel to $f330^0$
      - Repeat step c.

Applying the above algorithm, we obtain 2x(3+2) reuse plan depicted in Fig. 5. This reuse plan consists of repeating patterns of 10 cells which are as follows: A_1 = {1,3,5}, A_2 = {3,5,7}, A_3 = {5,7,9}, A_4 = {7,9,1}, and A_5 = {9,1,3} and B_1 = {2,4,6}, B_2 = {4,6,8}, B_3 = {6,8,10}, B_4 = {8,10,2}, and B_5 = {10,2,4}. Table 1 summarizes the

Cell Type / Reuse Plan	A	B	C	D
4x3	1,5,9	2,6,9	3,7,11	4,8,12
3x(3+1)	1,4,7,10	2,5,8,11	3,6,9,12	
Pattern1	1,4,7	2,5,8	3,6,9	
Pattern2	1,4,10	2,5,11	3,6,12	
Pattern3	1,7,10	2,8,11	3,9,12	
Pattern4	4,7,10	5,8,11	6,9,12	
2x(3+2)	1,3,5,7,9	2,4,6,8,10		
Pattern1	1,3,5	2,4,6		
Pattern2	1,3,9	2,4,10		
Pattern3	1,7,9	2,8,10		
Pattern4	3,5,7	4,6,8		
Pattern5	5,7,9	6,8,10		

Table 1. Channel allocation

channel allocation and assignment of the three schemes discussed above for comparisons.

Note that in 2x(3+2), the same channel sets are repeated in adjoined co-channel cells; however, since they all point at different directions, a back lobe co-channel separation equal *R* is obtained and thus interference is minimal. Yet, to further minimize interference, we suggest using directional antennas with high front-to-back ratio to maximally suppress side and back lobe radiation.

PERFORMANCE EVALUATION

In 2x(3+2), each channel is used 3 times in the repeating pattern, thus the actual reuse factor for 2x(3+2) reuse plan labeled N_{car} generalized in [1] as,

$$N_{car} = \frac{N(k+x)}{j} \qquad (2)$$

where j is the number of times the same channel set is repeated in the pattern. Thus the reuse factor for 2x(3+2) is 3.3 in comparison with reuse factor N=4 in 4x3 and 3x(3+1).

To determine its performance, worse interference scenario is assumed. Thus C/I for user located at the fringe of a sector is considered and provided in [1] as,

$$\frac{C}{I} = 10\log\frac{G(\theta_0)}{\sum_{i=1}^{n} G(\theta_i)\left(\frac{D_i}{R}\right)^{-y}} \qquad (3)$$

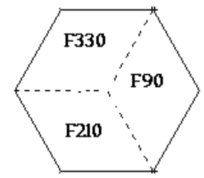

Fig. 4. Sector Orientations

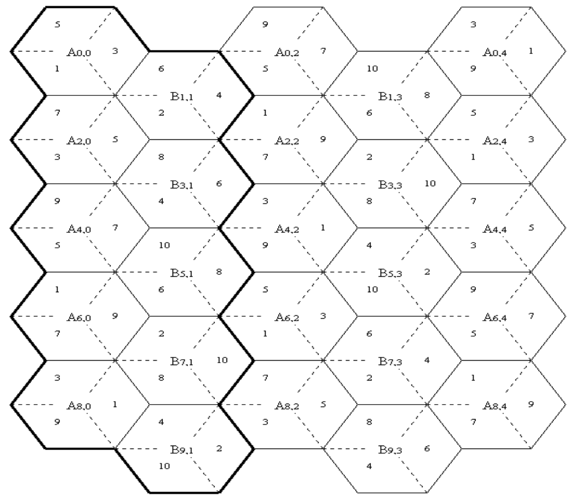

Fig. 5. Channel assignment and reuse cluster in 2x(3+2)

where R is the radius of the cell and also the distance from MS to the serving BS, normalized to 1; D_i is the distance from MS to i^{th} co-channel BS; n is the number of co-channel interferers, and γ is the path loss exponent set equal to 4; $G(\theta_0)$ and $G(\theta_i)$ are antenna gains by MS from the serving BS and from i^{th} co-channel BS at angle θ_i with respect to antenna bore-sight (at 0^0) respectively, and expressed in decibels as,

$$G(\theta_i) = 10^{G(\theta_i)_{dB}/10} \qquad (4)$$

In our analysis, we include all co-channel interferers from adjacent co-channel cells and all second and third tier front lobe and side lobe interferers that interference may be significant, generally when D_i < 7R and $\theta_i<90^0$. However, we exclude and assume no shadowing effect. On the other hand, we also omit antenna down tilting factor, which can increase C/I by several dB. In conventional plans where channels are assigned uniformly system-wide, thus, worse interference is theoretically the same for all sectors and corners. However, in 2x(3+2), due to channel rotation and channel assignment, which are based on antenna directions, some corners and sectors

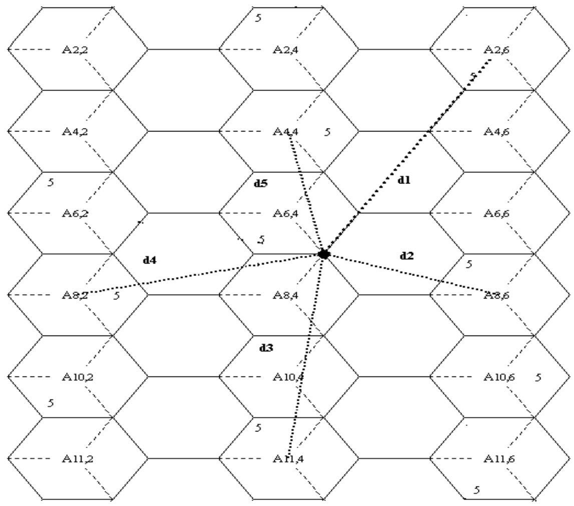

Fig. 6a: Worse C/I in F210^0 (channel 5).

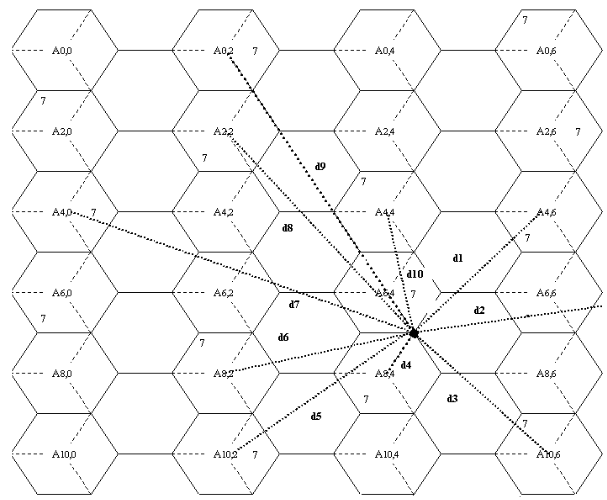

Fig. 6b: Worse C/I in adjoined F90^0 (channel 7).

	D_i / R	θ_i	$G(\theta_i)_{dB}$	$G(\theta_i)(D_i / R)^{-y}$
d_0	1	300	-2.9	0.5129
d_1	5.00	0	-0	0.0016
d_2	2.65	319.1	-1.1	0.0158
d_3	4.36	36.59	-.0.8	0.0023
d_4	3.61	346.1	-0.1	0.0058
d_5	2.65	79.11	-6.7	0.0044
C/I				12.34 dB

Table 2. Worse C/I in 2x(3+2) reuse plan (sector f210)

within the cell are different. Therefore, we compute C/I for both corners of each sector.

Assume that the user is at the cell border of sector 5 in cell $A_{6,4}$, among 8 neighboring co-channel cells, only one of the two adjoined co-channel cells, $A_{4,4}$ contains set 5, but it points away at angle *f90^0*, thus it either becomes side or back lobe interferer. $A_{8,2}$ and $A_{8,6}$ are the only first tier front lobe interferers, which have the strongest impact on C/I. All others do not contain 5, hence cause no interference, or point to other directions, thus have minimal interference. Two other front lobe interferers are from second tier co-channels; however, due to small N, they too generate considerable interference. Fig 6a represents the worse interference scenario where user is at the boundary corner in sector *f210^0* (channel 5), since it is closer to the strongest interferer $A_{8,6}$ and $A_{8,2.}$

At the same location, the given user can also be served by adjoined sector *f90^0* (channel 7). Front this sector, both adjoined co-channel cells $A_{4,4}$ and $A_{8,4}$ contains 7; however, they point at different directions, therefore interference is minimal. The two strongest interferers are from $A_{4,6}$ and $A_{10,6.}$ Fig 6b depicts the interference of this

d	D_i / R	θ_i	$G(\theta_i)_{dB}$	$G(\theta_i)(D_i / R)^{-y}$
d_0	1	60	-3.0	0.501
d_1	3.61	13.9	-0.1	0.006
d_2	5.58	291.1	-4.5	4E-04
d_3	3.61	346.1	-0.1	0.006
d_4	1.00	180	-29.0	0.001
d_5	4.39	323.4	-0.8	0.002
d_6	3.61	106.1	-12.0	4E-04
d_7	7.00	21.79	-0.2	4E-04
d_8	5.57	291.1	-4.5	4E-04
d_9	7.00	60	-3.0	2E-04
d_{10}	2.65	199.1	-26.0	5E-05
C/I				14.72 dB

Table 3. Worse C/I in adjoined sector (f90)

adjoined sector. In addition, at that given corner location, the user also receives 4 other signals from neighboring cells. Starting in clockwise direction, they are channels 10, 6, 9, and 1.

Using (3), (4), and 120^0 directional antenna pattern depicted in Fig. 1, we obtained C/I for each scenario described. Table 2 and 3 illustrate the calculations of the worse interference scenario depicted in Fig. 6a and its adjoined sector shown in Fig. 6b.

In worse scenario depicted in Fig. 6a, 2x(3+2) reuse plan only provides 12.3 dB, which is below the C/I threshold for QOS in TDMA systems such as IS-136. However, unlike conventional plan where C/I below the minimum is unacceptable, since all sectors provide about the same C/I protection level, in 2x(3+2), C/I is varied from side to side and sector to sector. Also in practice, MS always monitors the signals and selects the strongest available one to operate within. In which case, the adjoined sector (channel 7) and two other overlapping sectors (channel 10 and 1)

Sector	5	7	10	6	9	1
C/I (dB)	12.3	14.7	14.6	12.9	13.5	14.7

Table 4. Worse C/I and signal availability in 2x(3+1)

Reuse Plan	Reuse Factor	Capacity Per Cell	Increment
4x3	4	25.00%	
3x(3+1)	4	25.00%	
2x(3+2)	3.3	30.00%	20.00%

Table 5. Channel capacity

provide 14.6 and 14.7 dB, which are above the 14 dB requirement. Similarly, for example, if the user is served by sector 6 in which worse C/I is at 12.9 dB, there are adjoined sector (channel 10) and two overlapping sectors (channel 7 and 1) that provide C/I above 14 dB. Thus for any corner location which C/I falls below the acceptable margin, there is an adjoined sector and two other overlapping sectors that provide C/I above the 14 dB which MS can select from. The availability of signals and worse C/I are summarized in Table 4.

Due to reduction in reuse factor, some tradeoff in QOS is unavoidable. Thus, antenna down tilting is necessary to reduce interference and increase C/I. Also load balancing within each cell can be used to fully maximize its gain since some sectors must assume additional load. Note that if the MS moves farther away from the edge or further inside the cell, signal strength will increase accordingly.

Since 2x(3+2) reuse plan only requires reuse factor of 3.3 or 10 channel sets system-wide, in comparison with conventional 4x3 and CAR 3(3+1) reuse plan whereas 12 channels are used, 2x(3+2) increases channel capacity by 20%. These comparisons are illustrated in Table 5.

CONCLUSION

Since interference from antenna back lobe is negligible and interference from the side lobe is significantly reduced, CAR scheme was proposed to take full advantage of antenna directivities to enhance C/I and increase channel capacity. In CAR, each cell type is allocated an ex an extra channel set, which provides network designer the flexibility to is used to strategically *rotate* and *alternate* channels to minimize the effects of and to avoid front lobe interference to and from the nearest co-channels.

Since reducing the separation between co-channel cells hence reduces C/I protection level, conventional reuse plan tighter than 4x3 is not practical for TDMA systems that require C/I of 14 dB [2][6]. In this paper, we presented a high capacity directional reuse plan referred to as 2x(3+2) in which 2 alternate channels are used for channel rotation and alternation.

Performance analysis shows that 2x(3+2) reuse plan can increase channel capacity by 20% in comparison with conventional 4x3 reuse plan, due mainly to smaller reuse factor of 3.3 vs. 4, respectively. Yet, 2x(3+2) still provides signals with acceptable C/I protection level.

Given a scenario where improvement in channel capacity for system that require 14 dB is desired, 2x(3+2) is a viable candidate since conventional 3x3 reuse plan cannot be deployed due to low C/I. However, due to reduction in reuse factor, some tradeoff in QOS is unavoidable, particularly in the corner regions and if significant shadow fading is present. Thus, antenna down tilting and load balancing within each cell may also be necessary to fully maximize its gains.

CAR 2x(3+2) reuse plan is simple to switch from 4x3 tri-sectored directional antenna systems. Since modification to system infrastructure is not required, it does not imposing any costs.

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