Channel Alternation and Rotation in Narrow Beam Trisector Cellular Systems

Vincent A. Nguyen, Peng-Jun Wan, Ophir Frieder
Illinois Institute of Technology-Communication Laboratory Research
Computer Science Department-Chicago, Illinois
Email: vnguyen@iit.edu, wan@cs.iit.edu, ophir@ir.iit.edu

ABSTRACT

Two 60^0 Narrow-Beam Trisector Cell (NBTC) frequency reuse plans, 1x(3+1) and 2x(3+1), that employ Channel Alternation and Rotation (CAR) scheme are presented. In CAR, each cell type is allocated one extra channel set that allows network designer to rotate and alternate channels according to nearest front lobe interference avoidant strategy to enhance co-channel interference ratio (C/I) and allow deployment of tighter and non-integer reuse factors thus increase system capacity. For a typical cellular system that requires C/I of 14 dB, 2x(3+1) reuse plan increases system capacity by 12.50% over current frequency reuse plans. For system that requires 9 dB or less, 1x(3+1) reuse plan still provides at least one sector separation interval between co-channel sectors and mobiles that, if employed, can increase system capacity up to 125%. CAR is simple and can be deployed in current trisector cellular systems without any modification to the base station (BS) equipment thus imposing no additional cost.

1. INTRODUCTION

In cellular systems, the entire radio bandwidth is partitioned into frequency channels, allocated, and reused in every group of *N* adjacent cells called reuse cluster. To provide sufficient co-channel interference protection system-wide, frequency channels must be reused at regular equidistant separation intervals called reuse distance. Thus, N is generally restricted within a discrete set of rhombic values, e.g. 3, 4, 7.

Tight frequency reuse or small *N* increases frequency reuse efficiency, which directly determines the system capacity. However, it decreases C/I, which affects Quality Of Service (QOS) since co-channel cells are located much closer together. Conversely, while the cell size is kept constant, large N or long reuse distance interval improves C/I and QOS, however, reduces frequency reuse efficiency. Due to the fast growing demand in mobile services and scarce radio spectrum, cellular network designer must strive to achieve tightest possible frequency reuse whilst maintain adequate interference protection.

Two 60^0 Narrow-Beam Trisector Cell (NBTC) frequency reuse plans, 1x(3+1) and 2x(3+1), that employ CAR scheme are presented. For a typical cellular system that requires C/I of 14 dB, 2x(3+1) reuse plan increases system capacity by 12.50% over the current NBTC and Interleaved NBTC (INBTC) 3x3 reuse plans. For systems that requires 9 dB or less, 1x(3+1) reuse plan is the tightest trisector reuse plan that still maintains at least one sector separation interval between co-channel cells that, if employed, can increase system capacity up to 125% over conventional counterparts and 50% over the tightest available INBTC 2x3 reuse plan.

The remainder of this paper is organized as follows: Section II describes 60^0 directional antenna and current NBTC frequency reuse plans. In section III, we discuss channel assignments and algorithms used in 2x(3+1) and 1x(3+1) reuse plans. In section IV, we analyze the performance of the proposed plans and compare with conventional counterparts based on system capacity and worst C/I. Finally, section V concludes this paper.

2. NARROW BEAM TRI-SECTOR CELLULAR SYSTEMS

Unlike OMNI-directional antenna where energy power radiates equally in all directions, sectorized cellular systems use directional antenna that concentrates energy power in the bore sight direction (at 0^0). This translates into power gain, which is expressed relative to isotropic gain shown in Fig. 1.a, where antenna pattern is associated with a main beam, two side lobes, and a back lobe. Commonly directional antenna is determined by its beam width spanning within $+\theta$ and $-\theta$, where power voltage has reduced to about one half or -3 dB of its maximal strength as illustrated in Fig. 1.b.

Fig. 2 depicts an actual 60^0 antenna's radiation pattern obtained from [8]. With respect to the bore sight, the spanning region within 30^0 and 330^0 defines the 3 dB antenna beam width, also commonly called the front lobe. Based on the received signal strength at the cell boundary, we generally consider interference from the directions between 60^0 to 90^0 and 300^0 to 270^0 as side lobe interferences, and from 90^0 and 270^0, where voltage has dropped below 1% of its maximal strength, to 180^0 as back lobe interference. This antenna radiation pattern will be used to compute C/I in this paper.

Currently most cellular systems employ three 100^0 to 120^0 directional antennae at each base station (BS) [4,5]. In conventional channel assignment, 3 disjoined channel sets are allocated to each cell type, assigned, and repeated uniformly to maintain equidistant separation intervals among co-channels system-wide. This directional reuse scheme is generally called *Nx3* reuse plan. Due to discrete reuse cluster sizes and uniformed channel assignments, conventional tri-sectored cellular system has not taken full advantage of antenna directivities to maximize frequency reuse efficiency.

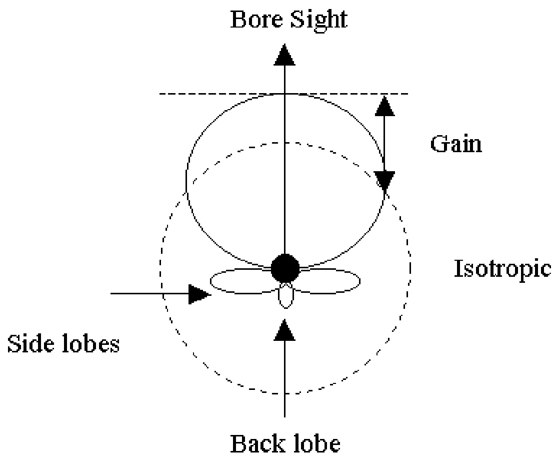


Figure 1: a) Antenna directivity and gain

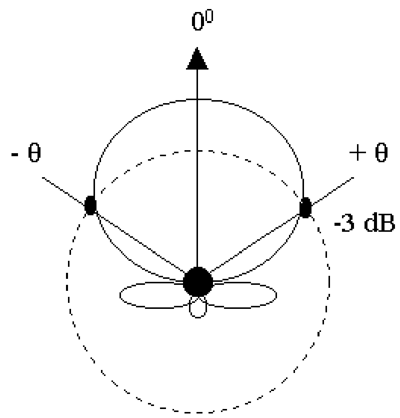


Figure 1: b) 3 dB beam width

NBTC Cellular/PCS System utilizing three 60^0 directional antennae arranged in clover-leaf cell structure shown in Fig. 5b has also been deployed in second generation cellular systems [4,5,6]. To differentiate the two tri-sectored cellular systems, 120^0 directional system has been called Wide-Beam Tri-sector Cell (WBTC) [6]. In comparison with WBTC system, NBTC has shown improvement in coverage and C/I since 60^0 antennas' contour matches closely to the hypothetical hexagonal coverage area.

Fig. 3 depicts conventional NBTC 3x3 reuse plan in which 3 cells, A, B, and C, form a reuse cluster and each channel is assigned once in that particular cluster. Thus, 9 channel sets are allocated to the cluster and reused uniformly in adjacent clusters to provide equidistant separation intervals system-wide. Worst interference scenario is also illustrated, that is when mobile station (MS) is at the fringe of its serving sector, e.g. sector 3, from which front lobe interferers from co-channel sectors are represented in dotted lines and side lobe co-channel interferers are in dashed lines. Back lobe interferences are negligible and neglected.

Group-reuse channel assignment scheme based on NTBC architecture was proposed in [5]. In this scheme, all channel sets are interleaved, grouped into 3 groups, and each group is assigned to sectors that point in a particular direction. Typical group-reuse plan for N=4 is shown in Fig. 4. In this plan, the 3 groups of channels, {1,2,3,4}, {5,6,7,8}, and {9,10,11,12}, are assigned in pairs, e.g. {1,3} and {2,4}, to sectors in adjacent cells that point in a particular direction and repeated pair-wise in adjacent cells with respect to co-channel reuse distance. This channel assignment scheme creates a 16-cell repeat pattern. Within which, each channel set is repeated 4 times, thus N is also the reuse factor, N=4. Results presented in [5] indicates that group-reuse plans N=4 yields C/I about 17.1 dB and N=6 provides 18.6 dB interference protection. However, due to pair-wise channel assignment, group reuse scheme limits N within clusters of 4 and 6 cells. Yet, it too still has not taken full advantage of antenna directivities to maximize frequency reuse efficiency.

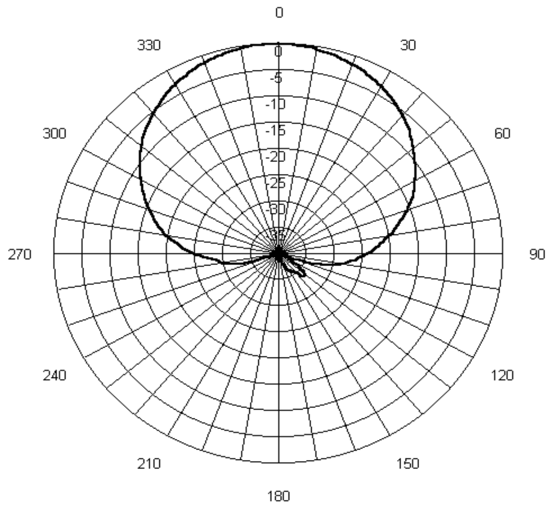


Figure 2: 60 degrees antenna's radiation pattern

Another architecture called Interleaved NBTC (INBTC) was proposed in [3]. INBTC employs cell structure that antennae point in 6 different directions instead of 3 different directions as shown in Fig. 5. INBTC also employs Interleaved Channel Assignment (ICA) scheme that uses N channel sets as common channel sets. The remaining Nx2 non-interleaving channel sets are assigned in pairs to each cell type and rotated in adjacent co-channel cell to avoid front lobe interference. INBTC further improves C/I, thus allows deployment of smaller reuse cluster to enhance frequency reuse efficiency. However, since implementation is limited within INBTC architecture, modifying existing NBTC cell structure and relocating cell sites will carry significant cost.

Fig. 6 depicts an INBTC 3x3 reuse plan, in which each channel pair, namely {1,2}, {3,4}, and {5,6}, are assigned to a particular cell type, and rotated in each adjacent co-channel cell on the same row. The other channel sets, {7,8,9}, are interleaved, used as common channel sets, and assigned sequentially to sectors that point directly toward the co-channel cells on the same

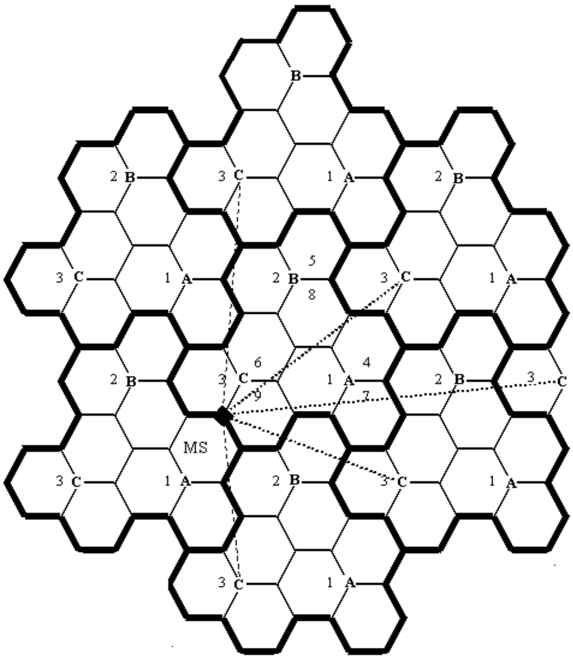


Figure 3: Conventional NBTC 3x3 reuse plan and worst interference scenario

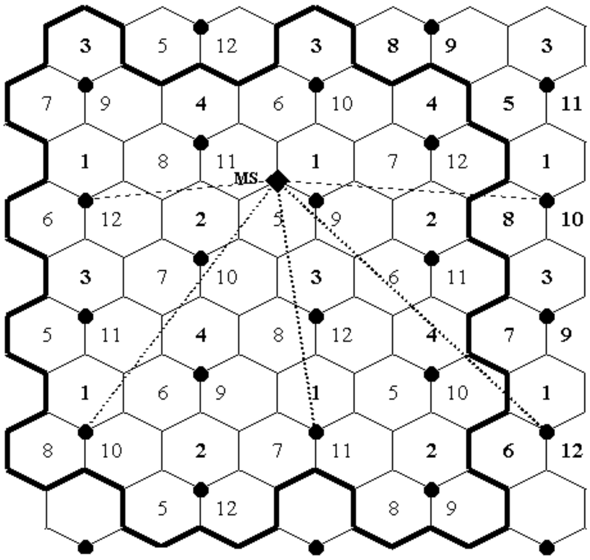
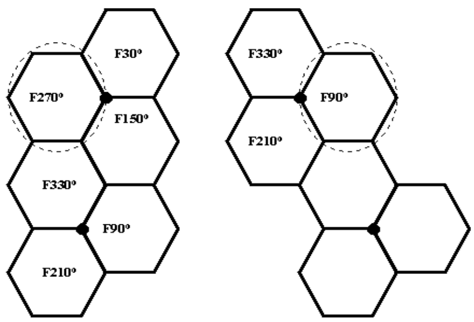


Figure 4: 4x3 group reuse plan and worst interference scenario



a) INBTC b) NBTC

Fig. 5. Antenna directions shown as functions of degrees

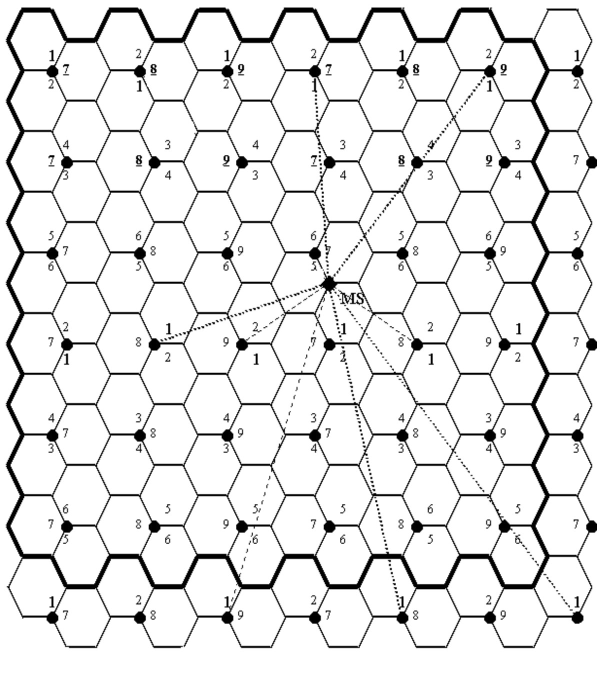


Figure 6: INBTC 3x3 reuse plan and worst interference scenario

row, and to sectors in adjacent cells that point in the opposite direction, shown in underlined. Due to channel rotation and interleaving assignment, the repeat pattern has expanded to 36 cells; however, since Nx3 channel sets are used and each channel set is repeated equally in the repeat pattern, the reuse factor remains equal N. Worst interference scenario is also illustrated, where MS is located at the edge and served by sector 1.

3. Channel Alternation and Rotation

3.1 Introduction

In current tri-sectored cellular systems, each cell type has 3 disjoined channel sets uniformly assigned throughout the system. This results in *N*3* channel sets system-wide and each channel is used once in a reuse cluster of *N* cells or equally in the reuse pattern; thus N is also the reuse factor. In CAR, each cell type is allocated one or more extra channel sets used for *channel alternation* that results in $3+x$ channel sets per cell type and $N(3+x)$ sets system-wide. Thus, CAR scheme can be generalized and labeled $N(k+x)$, where k is the number of sectors in a cell and x is the number of alternate channel sets. The extra channel sets, called *alternate channels*, allow cellular network designer to coordinate channel assignment with antenna directivities by rotating and alternating channels when strong front lobe interference from nearest co-channel is present to enhance C/I and allow deployment of smaller N, thus increase frequency reuse efficiency. CAR can be deployed in any cell structure without any modification to BS equipment, thus it carries no extra cost.

3.2 2x(3+1) Reuse Plan

In this reuse plan, we employ 2-cell reuse cluster and allocate one alternate channel set to each cell type.

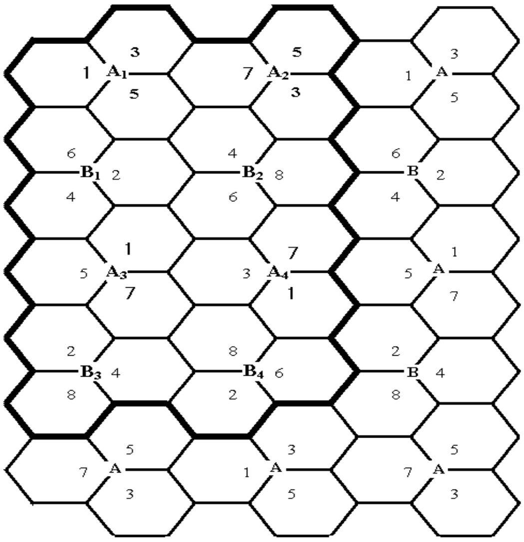


Figure 7: CAR 2x(3+1) reuse plan using INBTC structure

Thus, there are 2 cell types, namely A and B, and each cell type has 3+1 = 4 channel sets, that results in 8 channel sets system-wide which are allocated as follows: A={1,3,5,7}, and B={2,3,6,8}. Based on CAR, we assign channels as follows:

1. Label a rectangular tile comprising Nx4 adjacent cells as shown in Fig. 7.
2. From the 4 channel sets allocated to each particular cell type, label 2 channels Alternating Pair (AP) and the other 2 channels Rotating Pair (RP).
3. Determine the direct front lobe interfering sector (sector that points directly toward its adjacent co-channel cell). Assign an AP channel to that sector. Assign RP channels to the two remaining sectors.
4. Move to the next column-adjacent co-channel cell, rotate RP channels and alternate AP channel.
5. Reverse RP and AP channels. Thus, AP channels become RP channels and vice versa.
6. Move to the next co-channel row, Assign an AP channel and RP channels to the first cell on the row avoiding strong front lobe interference to and from nearest co-channel cells.
7. Move to the next column-adjacent co-channel cell, rotate RP channels and alternate AP channel.
8. Repeat from step 2 for type B cell.
9. Replicate the tile for system-wide implementation.

Appling the algorithm described above on INBTC system, we obtain 2x(3+1) reuse plan depicted Fig. 7. Since each cell is assigned only 3 out of 4 allocated channel sets, there are $\binom{4}{3}$=4 unique patterns per cell type. Type A cell consists of patterns A_1={1,3,5}, A_2={3,5,7}, A_3={1,5,7}, and A_4={1,3,7}, and type B cell consists of patterns B_1={2,4,6}, B_2={4,6,8}, B_3={2,6,8}, and B_4={2,4,8}.

The repeating pattern for 2x(3+1) reuse plan consisting of 8 cells is shown in Fig. 7. In the first row, RP channels 3 and 5 in cell A_1 radiate toward A_2; however, since channels 3 and 5 in A_2 have been rotated, interference is significantly reduced, as they become side lobe interferers. AP channel 7 in cell A_2 points directly toward A_1, however only AP channel 1 is used in A_1, nearest front lobe interference is avoided. In adjacent co-channel row, AP channels become RP channels and vice versa, thus channels 3 and 5 become AP channels and 1 and 7 become RP channels, which are then assigned avoiding direct and nearest front lobe interference. Hence, in A_3, channel 1 is assigned to the sector pointing toward A_2, which does not contain channel 1. Also channel 1 in cell A_1 points in a different direction, thus interference is minimized. These channels are then systematically rotated and alternated in subsequent co-channel cell. Thus, the impact of nearest front lobe interference is avoided.

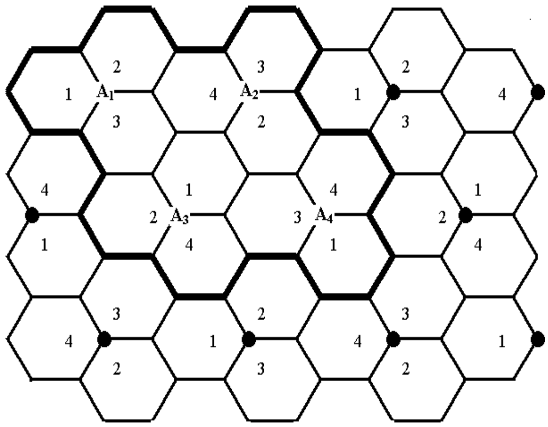


Figure 8. CAR 1x(3+1) reuse plan using NBTC structure

3.3 1x(3+1) Reuse Plan

In 1x(3+1) reuse plan, there is only one cell type; thus 4 channel sets are allocated system-wide, namely {1,2,3,4}. Appling previously described CAR algorithm on a 4-cell tile, since 1x(3+1)=4, we obtain repeat pattern comprising A_1={1,2,3}, A_2={4,3,2}, A_3={2,1,4}, and A_4={3,4,1} depicted in Fig. 8.

Similar to 2x(3+1), on the first row, RP channels 2 and 3 in cell A_1 radiate toward A_2; however, since they have been rotated, interference is significantly reduced. AP channel 4 in cell A_2 points directly toward A_1, but only AP channel 1 is used in A_1, nearest front lobe interference is avoided. On adjacent row, channels 1 and 4 become RP channels and 2 and 3 become AP channels, which are assigned to each sector with respect to nearest front lobe interference avoidant strategy. Thus from A_3, channel 1 points to A_2, which does not contain channel 1 and channel 1 in A_1 is on its side lobe, hence avoiding nearest front lobe interference. These channels are then systematically rotated and alternated in subsequent column-adjacent co-channel cell. On the other hand, all adjacent sectors that point directly to A_3 are assigned channel 3, which is not being used in the observed cell, therefore nearest front lobe interference is avoided. The nearest co-channels are thus coming from second tier co-channel sites at reuse distance $3\frac{\sqrt{3}}{2}R$. Hence, at least one sector separation between co-channel mobiles is maintained.

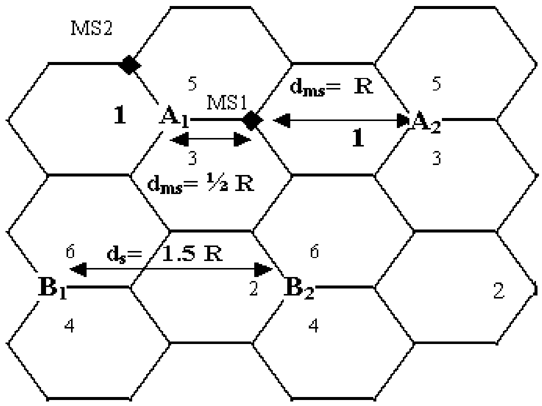


Figure 9. Separation intervals in NBTC 2x3 reuse plan

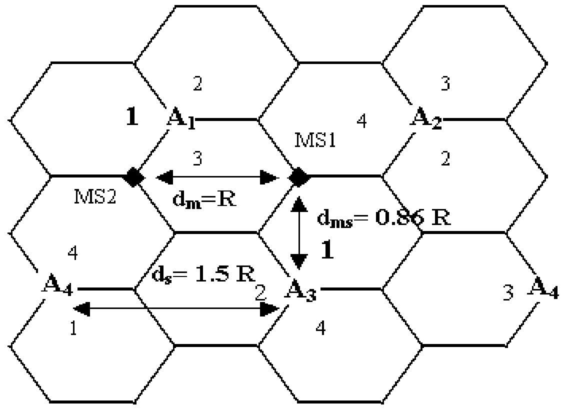


Figure 10. Separation intervals in CAR 1x(3+1) reuse plan

4. PERFORMANCE EVALUATION

4.1 Reuse Separation Intervals

In order to provide at least one sector separation interval among mobile users between co-channel sectors, in tri-sectored cellular systems require reuse cluster N=3. At N=2, the separation interval between co-sites is $d_s = 1.5R$, however, in worse case, the separation interval from mobile to the nearest co-channel site is reduced to $d_{ms} = \frac{1}{2}R$. This correlation is illustrated in Fig. 9. Mobile user (MS1) communicates with cell A_2 using channel 1 from distance $d_{ms} = R$ at its maximal power with respect to the cell size, while its nearest co-channel A_1 is located at only distance $d_{ms} = \frac{1}{2}R$. With the same distance, MS2 also communicates with cell A_1 on channel 1, at normal antenna gain less than 10% of its maximal strength. Therefore, MS1 would cause significant interference to A_1 and MS2. Furthermore, at distance $d_{ms} = \frac{1}{2}R$, back lobe interference on the down link direction from cell A_1 to MS1 is still significant. Thus, reuse cluster N=2 is not practical in conventional channel assignment.

At N=1, the proposed 1x(3+1) reuse plan still maintains a minimum separation interval $d_s = 1.5R$ between co-channel sectors. In worst case, when MS1 is at distance $d_{ms} = \frac{\sqrt{3}}{2}R$ from its serving cell A_3, CAR 1x(3+1) still provides a separation interval $d_m = R$ to MS2 in the nearest co-channel sector and a comparable distance to the nearest co-channel cell A_1, while the distance from MS2 to its serving A_1 is only at distance $d_{ms} = \frac{1}{2}R$. Fig. 10 illustrates these correlations. On this note, we observe that CAR 1x(3+1) is tightest possible reuse plan proposed that still allows at least 1 sector separation between mobiles in any two co-channel sectors while current system requires N=3 and INBTC requires at least N=2, yet, it is only applicable to specific architecture.

4.2 Reuse Factor

In current tri-sectorized channel assignment schemes, Nx3 channel sets are used and each channel is assigned once or equally in the repeat pattern, thus N is also the reuse factor. In CAR 2x(3+1) and 1x(3+1), each cell type has 4 channel sets and each channel set is reused 3 times in repeating patterns of 4N cells. Thus, the reuse factor for CAR reuse plan can be generalized as:

$$N = \frac{s}{j * k} \tag{1}$$

where *s* is the number of sectors in the repeating pattern, *j* is the number of times each channel set is reused, and *k* is the number of sectors in a cell. Applying (1), we obtain reuse factors 2.66 and 1.33 for 2x(3+1) and 1x(3+1) reuse plans, respectively.

4.3 C/I and Channel Capacity

To analyze the performance of the proposed reuse plans, we assume that cell sizes are equal and transmit at the same power. We neglect shadow fading factor and consider only downlink direction (BS to mobile) since it is the performance limiting direction [3][5]. Thus, worst C/I for users located at the fringe of a serving cell is expressed as,

$$\frac{C}{I} = 10\log\left[\frac{G(\theta_0)\,D_0^{-\lambda}}{\sum_{i=1}^{n} G(\theta_i)\,D_i^{-\lambda}}\right] \tag{2}$$

where subscript 0 refers to the user services. Thus, with respect to the cell radius, D_0 is the distance from MS to the serving BS, and D_i is the distance from MS to i^{th} co-channel BS; n represents the number of co-channel interferers, λ is the path loss exponent set to 4. $G(\theta_0)$ and $G(\theta_i)$ are antenna gains of MS from the serving BS and i^{th} co-channel BS at angle θ_i from the bore-sight, respectively, and expressed in decibels as,

$$G(\theta_i) = 10^{G(\theta_i)_{dB}/10} \tag{3}$$

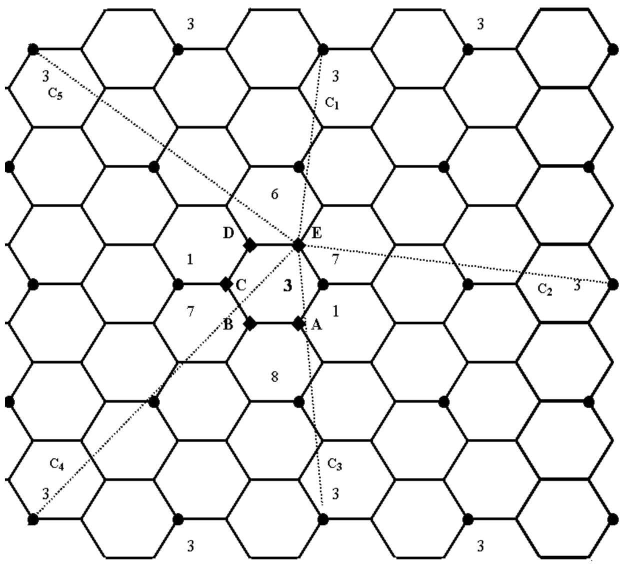


Figure 11: Mobile at worst interference locations (A,B,C,D,E) in 2x(3+1) reuse plan

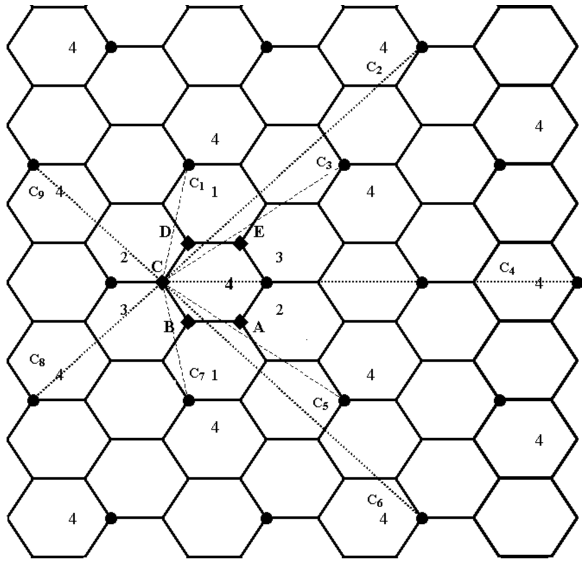


Figure 12: Mobile at worst interference locations (A,B,C,D,E) in 1x(3+1) reuse plan

Applying (2), (3), and 60^0 GSM antenna's radiation pattern obtained from [8] and depicted in Fig. 2, we calculate C/I for all worst interference scenarios in 2x(3+1) and 1x(3+1) depicted in Fig. 11 and 12, respectively, where mobile locations are shown in bolded square dots and denoted A to E. Worst C/I in each reuse plan is illustrated in Table 1 and 2, while Table 3 and 4 summarize worst C/I of all locations, within which F^i is the function of degrees indicating antenna directions. Observe that in 2x(3+1), we employ INBTC architecture, thus there are 6 main directions, namely sectors F30^0, F90^0, F150^0, F210^0, F270^0, and F330^0, while in 1x(3+1) we use NBTC structure, within which, the 3 main beam directions are F30^0, F150^0, and F270^0.

In 2x(3+1), we observe that worst interference locations occur in sectors F90^0 and F270^0. Fig. 11 represents one of the two worse sectors. Among the worst locations at the cell boundary labeled A…E in sector F270^0 (channel 3), user A and E are provided with 14.4 dB protection level, which is slightly above the threshold required in TDMA systems such as IS-136. At the same locations, user A also receives signals from sectors F150^0 (channel 1) and F330^0 (channel 8), while user E receives signals from sectors F30^0 (channel 7) and F210^0 (channel 6), which provide 21.9, 23.1, 20.5, and 21 dB, respectively. Summary provided in Table III shows C/I and available signals of the remaining user locations. Note that all sectors, except F270^0 and F90^0, provide C/I at and above 20 dB, thus to improve QOS in those worst sectors, network designer can easily control power, e.g. down-tilting antennae in other sectors, to minimize their interferences and achieve higher QOS if desired.

To provide 14 dB C/I margin, WBTC 4x3 reuse plan requires 12 channel sets and INBTC and NBTC 3x3 reuse plans require 9 channel sets, which typically provide 15.7 dB, 16.9 dB, and 18.8 dB, respectively. CAR 2x(3+1) only uses 8 channel sets, thus channel

Table 1
Worst C/I in 2x(3+1) reuse plan

Co-Channel Site	D_i	θ_i	$G(\theta_i)_{dB}$	$G(\theta_i)(D_i)^{-\lambda}$
C_0	0.5	60^0	-12.1	9.87E-01
C_1	2.2	37^0	-4.7	1.50E-02
C_2	3.3	8^0	-0.2	8.26E-03
C_3	3.0	325^0	-4.0	4.65E-03
C_4	4.1	12^0	-0.5	3.18E-03
C_5	3.5	338^0	-1.6	4.61E-03
C/I				14.4 dB

Table 2
Worst C/I in 1x(3+1) reuse plan

Co-Channel Site	D_i	θ_i	$G(\theta_i)_{dB}$	$G(\theta_i)(D_i)^{-\lambda}$
C_0	1	0^0	-0	1.00E+00
C_1	1.32	161^0	-44.4	1.17E-05
C_2	3.61	314^0	-6.9	1.21E-03
C_3	2.18	84^0	-21.9	2.86E-04
C_4	4	0^0	-0	3.91E-03
C_5	2.18	277^0	-20.82	3.67E-04
C_6	3.61	46^0	-7.1	1.15E-03
C_7	1.32	199^0	-38.4	4.70E-05
C_8	1.8	14^0	-0.7	8.06E-02
C_9	1.8	346^0	-0.7	8.06E-02
C/I				7.7 dB

capacity is increased by 50% over WBTC 4x3 reuse plan and 12.5% over INBTC and NBTC 3x3 reuse plans. These comparisons are summarized in Table 4.

Table 5 shows worst C/I and signal availability in 1x(3+1) reuse plan. Shown in Fig. 12, user C (in sector 4) experiences the worst interference, mainly due to strong front lobe interference from co-channels C_8 and C_9. At this location, 1x(3+1) reuse plan only provides C/I at 7.7 dB, which is below the 9 dB acceptable threshold in GSM system. However, user C also receives two QOS signals coming from sectors F30^0

Table 3
Worst C/I in 2x(3+1) reuse plan

User	Signal availability and antenna directions shown as functions of degrees					
	$F30^0$	$F90^0$	$F150^0$	$F210^0$	$F270^0$	$F330^0$
A			21.9		14.4	23.1
B			21.0		15.3	22.0
C	22.0		20.5		15.2	
D	23.1			22.0	15.3	
E	20.5			21.0	14.4	

Table 4
Worst C/I in 1x(3+1) reuse plan

User	Signal availability and antenna directions shown as functions of degrees		
	$F30^0$	$F150^0$	$F270^0$
A	7.7	13.0	13.0
B	9.5	9.5	9.5
C	13.0	13.0	7.7
D	9.5	9.5	9.5
E	13.0	7.7	13.0

Table 5
Channel capacity based on 14 dB requirement

Reuse Plan	Reuse Factor	Capacity Per Sector	Increment
WBTC 4x3	4	8.33%	
NBTC 3x3	3	11.11%	33.33%
INBTC 3x3	3	11.11%	33.33%
CAR 2x(3+1)	2.66	12.50%	50.00%

Table 6
Channel capacity based on 9 dB requirement

Reuse Plan	Reuse Factor	Capacity Per Sector	Increment
WBTC 3x3	3	11.11%	
NBTC 3x3	3	11.11%	
INBTC 2x3	2	16.67%	50.00%
CAR 1x(3+1)	1.33	25.00%	125.00%

(channel 2) and $F150^0$ (channel 3) that provide C/I of 13 dB from which user C can use to transmit, if C/I-based site diversity is implemented. The remaining locations are above 9 dB requirements and shown in Table V.

Due to tight frequency reuse, for environments with significant variations such as unequal cell sizes and shadow fading, advance interference suppression techniques such as antenna beam forming, frequency hopping, and filtering are required to improve QOS. Yet, for 9 dB requirement or less, 1x(3+1) reuse plan is a viable solution to enhance channel capacity, that if employed, can increase channel capacity by 125% over WBTC and NBTC 3x3 reuse plans and 50% over INBTC 2x3 reuse plan.

5. Conclusion

In this paper, we present two high capacity, tight frequency reuse plans namely CAR 2x(3+1) and 1x(3+1) that improve channel capacity in tri-sectored cellular systems employing NBTC and INBTC structures. CAR provides wireless network designer the flexibility to alternate and rotate channels to avoid front lobe interference. It allows deployment of smaller and non-integer reuse factors based on C/I requirements.

In the proposed scheme, we achieve reuse factors N=1.33 and N=2.66. At N=2.66 and based on 14 dB requirement, 2x(3+1) reuse plan increases channel capacity by 50% over WBTC system, and 12.5% over NBTC and INBTC systems. Two-cell reuse cluster is not practical in traditional NBTC insufficient reuse separation. INBTC 2x3 provides a possible solution for improving frequency reuse, however, it is restricted within particular cell structure. CAR 1x(3+1), with only 1-cell reuse, still provides at least one sector separation between co-channel mobiles and 1.5R between co-channel sectors. With advance techniques in filtering, antenna engineering, e.g. multi-beam or smart antenna and among others that can further reduce co-channel interference, 1x(3+1) is a viable solution for improving channel capacity in future wireless system.

CAR is simple and can be deployed in any tri-sectored cellular systems without modification to BS equipment. Thus, it truly does not impose any additional cost.

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