

CBWL FOR SECTORIZED CELLULAR COMMUNICATIONS

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Abstract

Channel Borrowing Without Locking (CBWL) is a family of channel assignment schemes for cellular communication systems. They allow real-time borrowing of channels from adjacent cells without the need for channel locking in co-channel cells. In this paper, an analysis of co-channel interference for CBWL schemes in sectorized cellular systems is presented. Two typical configurations are analyzed. One has 120° directional antennas and a reuse factor of 7. The other has 60° directional antennas and a reuse factor of 4. The analysis shows that CBWL can significantly enhance the traffic capacity of sectorized cellular systems at the cost of a slight increase of co-channel interference in comparison with the corresponding sectorized scheme without CBWL.

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1 Introduction

A new channel assignment and sharing method for cellular communication systems has been presented in [1]–[3]. The method is called *channel borrowing without locking* (CBWL). CBWL can increase the traffic capacity of cellular communication systems and accommodate spatially localized communication traffic overloads (or “hot spots”). The method can be adapted to various cellular configurations, but to characterize its efficacy, it is convenient to develop models for “standard” layouts.

In [1]–[2], we considered CBWL schemes for a basic hexagonal layout with base stations (wireless gateways) using omni-directional antennas nominally located at cell centers. In CBWL, as in fixed channel assignment (FCA), channels that are allocated to the system are divided into groups. Each gateway (base station) is allocated a set of channels which are reused at gateways of other cells that are sufficiently distant for the co-channel interference to be tolerable. However, in CBWL, if all channels of the gateway of a cell are occupied when a new call arrives, channel borrowing is employed according to certain rules.

One of the distinguishing features of CBWL is that it does not use channel locking. Using channel locking to limit co-channel interference has been suggested in other channel assignment strategies such as dynamic channel assignment (DCA) and hybrid channel assignment (HCA) [4]. That is, gateways within the required minimum reuse distance from a gateway that borrows a channel cannot use the same channel at the same time. Because of the difficulty in maintaining the reuse distance at the minimum value when channel locking is used, DCA and HCA generally perform less satisfactorily than FCA under high communication traffic loads [5], [6], [7].

In CBWL, a channel can be borrowed only from an adjacent gateway. The borrowed channels are temporarily transferred to the gateway that borrows the channel but are used with limited transmitted power. The power limitation is taken so that the co-channel interference caused by the channel borrowing is not significantly worse than that without channel borrowing. Therefore, *channel locking* is not necessary in CBWL schemes.

Further discussion and comparison of the various channel assignment schemes including FCA, DCA, HCA, Generalized FCA, and Directed Retry is presented in [1]. The reader is referred to [5]–[10] for specific details of the schemes.

Other features of CBWL that enhance system performance include *organization of lending channels*, *channel swapping* and *channel rearrangement*. These features and a detailed description of CBWL are presented in [1]–[3].

In this paper, we consider using CBWL in *sectorized cellular systems*. Sectorized cellular systems use directional antennas and can generally provide greater traffic capacity than non-sectorized layouts [11]–[13]. In sectorized cellular systems, each cell is divided into several sectors. A gateway site is located at the center of each cell. Directional antennas are used at the gateway site in order to provide 360° of coverage. One directional antenna serves as a wireless gateway for one sector of the cell. A group of channels is allocated to each gateway site. Each of these group is further divided into certain number of sub-groups. A sub-group of channels is used by a directional antenna to serve a sector. The sub-group of channels can be reused by other directional antennas that have the same orientation and are sufficiently distant. The sectors that are served by the same sub-group of channels are *co-channel sectors*. We consider that mobile units employ omni-directional antennas.

Two types of sectorized layouts have been frequently discussed.

In 120° antenna cellular systems, three 120° directional antennas are employed at each gateway site to provide coverage, and three rhombus sectors comprise a cell. Figure 1 is an example of 120°

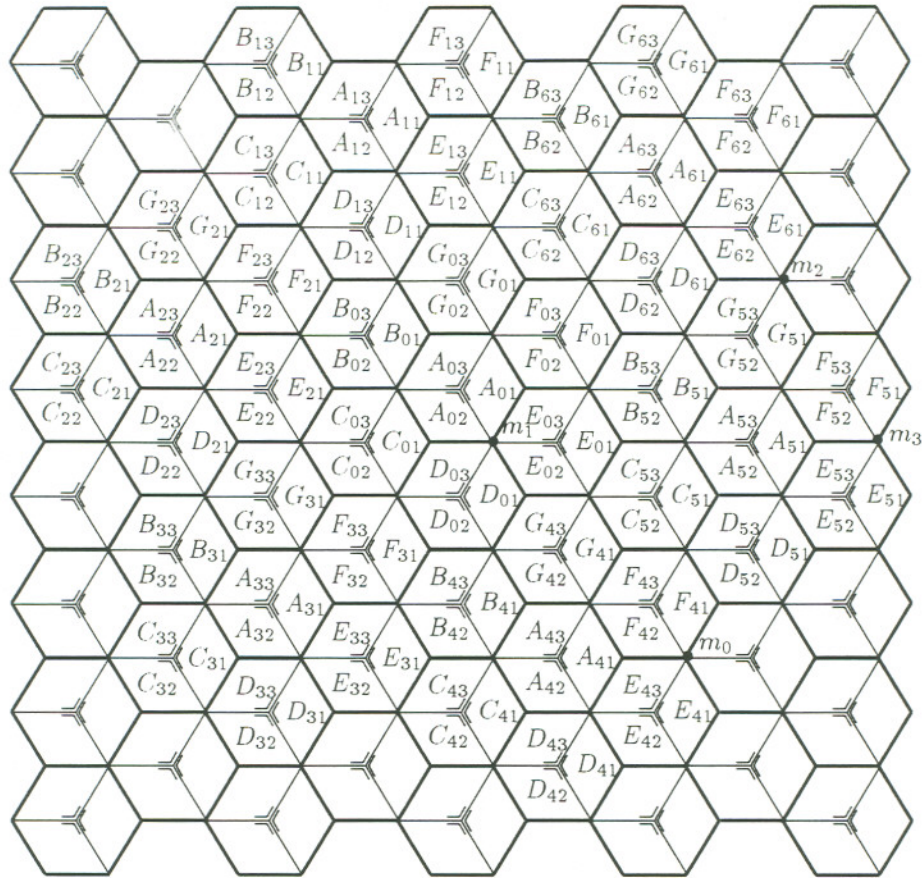


Figure 1: 120° sectorized cellular system with reuse factor of 7

antenna cellular system with a reuse factor of 7. We use A, B, C, D, E, F and G to distinguish seven cells in a cluster. Each sector is labeled by one of seven letters with two subscripts. The first subscript denotes the cluster to which the sector belongs. The second subscript denotes the spatial (angular) orientation of the sector (there are 3 orientations for the layout). Thus, sectors with the same second subscript have the same orientation. Sectors whose labels have the same letter and the same second subscript are co-channel sectors.

In 60° antenna cellular systems, each cell is divided into six triangular sectors. Six 60° directional antennas are employed at each gateway site in order to cover the whole cell. Figure 2 shows an example of a 60° antenna cellular system with a reuse factor of 4. The labeling scheme used is similar to that of Figure 1.

In sectorized CBWL cellular systems, if a sector does not have enough channels to service a call, the sector can borrow a channel from another sector with an idle channel. If the channel is borrowed from a sector whose gateway has the *same orientation* as the given gateway, the reuse distances of the borrowed channel are changed in the neighborhood of the borrowing gateway and co-channel interference between the given sector and some sectors may be increased. On the other hand, if the channel is borrowed from an adjacent sector whose gateway has a different orientation from the given gateway, in the borrowing sector, the borrowed channel will be used in a different orientation from that of its co-channels in other neighboring sectors. Thus the co-channel interference between a sector and its neighbors may be increased due to the *change of orientation*. In addition, the reuse distance of the borrowed channel may also be changed, and this will affect

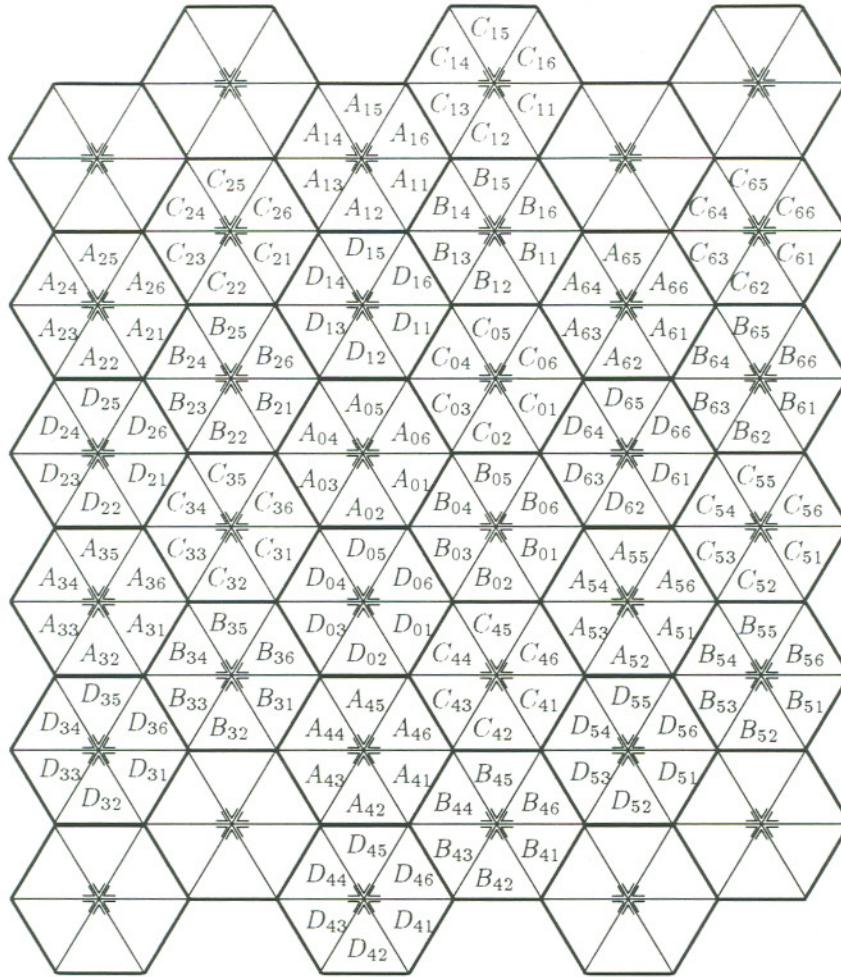


Figure 2: 60° sectorized cellular system with reuse factor of 4

co-channel interference levels. In order to avoid significant increase of co-channel interference (in comparison with no borrowing), in CBWL, the borrowed channels are used with limited power. Therefore, *channel locking* in neighboring co-channel sectors is not necessary.

In Section 2, co-channel interference of CBWL in sectorized cellular systems is analyzed. The numerical results from traffic performance analysis of these layouts are given in Section 3. Details of the interference analyses are presented in the Appendices.

2 Analysis of Co-channel Interference For Sectorized CBWL

In this section, we first consider the signal-to-interference ratio (SIR) of a system using only FCA. The SIR calculation is based on worst-case assumptions. A general formula is derived which can be applied to sectorized cellular system with any reuse factor. Then we calculate the SIR of sectorized CBWL. No corresponding general formula can be found for sectorized CBWL with an arbitrary reuse factor. Two typical sectorized layouts of CBWL are analyzed. One uses 120° directional antennas and a reuse factor of 7. Another uses 60° directional antennas and a reuse factor of 4. We compare the SIR's of CBWL and FCA and find the allowable maximum

layout type	FCA		CBWL			
	forward link	reverse link	on regular channels		on borrowed channels	
			forward link	reverse link	forward link	reverse link
120° antenna no power control	$SIR-A_{FO}$	$SIR-A_{RO}$	$SIR-A_{FN}$	$SIR-A_{RN}$	$SIR-A_{FB}$	$SIR-A_{RB}$
120° antenna with power control	$SIR-B_{FO}$	$SIR-B_{RO}$	$SIR-B_{FN}$	$SIR-B_{RN}$	$SIR-B_{FB}$	$SIR-B_{RB}$
60° antenna no power control	$SIR-C_{FO}$	$SIR-C_{RO}$	$SIR-C_{FN}$	$SIR-C_{RN}$	$SIR-C_{FB}$	$SIR-C_{RB}$
60° antenna with power control	$SIR-D_{FO}$	$SIR-D_{RO}$	$SIR-D_{FN}$	$SIR-D_{RN}$	$SIR-D_{FB}$	$SIR-D_{RB}$

Table 1: Notation system for SIR.

transmitted power on borrowed channels as well as the fraction of service area in which borrowed channels can be used.

The SIR's for the forward links (gateway-to-mobile) and for the reverse links (mobile-to-gateway) are analyzed for the FCA and CBWL schemes. Two cases are discussed. In the first case, power control IS NOT employed. In the second case IT IS.

For convenience, a notation system for SIR's is introduced. We call the layout with 120° antenna, reuse factor of 7 and no power control layout *A*, the layout with 120° antenna, reuse factor of 7 and with power control layout *B*, the layout with 60° antenna, reuse factor of 4 and no power control layout *C* and the layout with 60° antenna, reuse factor of 4 and with power control layout *D*. We use *SIR* to represent SIR of a general layout, and use *SIR-A*, *SIR-B*, *SIR-C* and *SIR-D* to represent SIR of layout *A*, *B*, *C* and *D*, respectively. The notations are used with two subscripts. The first subscript is *F* or *R*. *F* is for SIR on the *forward link* and *R* is for SIR on the *reverse link*. The second subscript is *O*, *N* or *B*. *O* is for SIR of FCA scheme (without borrowing). *N* is for SIR on *normal* channels and *B* is for SIR on *borrowed* channels. The notation system is summarized in Table 1.

For simplicity, the following assumptions are made.

1. All cells (sectors) are the same size. The distance from the center of a cell to a vertex is denoted as *R*.
2. Flat uniform propagation conditions are in effect. Thus, (for a given propagation exponent) the received powers are determined by distances.
3. All gateway antennas have the same height, gain and emit the same maximum transmitted power.
4. All mobile stations use omni-directional antennas and have the same maximum transmitted power.
5. Fading is not included in the model presented here. We calculate SIR as the ratio of median signal power to the sum of median interference powers. Including fading into analysis will

not significantly affect our conclusions. Because both CBWL and FCA are compared on the same basis, protection against fading would require almost the same margin in SIR's in the two systems. Thus one can expect a similar SIR ordering when fading is considered.

6. Only the interference from the first ring of neighboring co-channel sectors is considered.
7. The front-to-back ratio of directional antenna is very large. Thus if a mobile station is outside the "view" angle of a directional antenna, the co-channel interference between the mobile station and the antenna can be neglected.
8. The transmitted power of a directional antenna is uniform within its view angle.

2.1 SIR's for Sectorized FCA

In cellular engineering, the reuse distance D is defined as the distance between the gateways of two nearest co-channel gateways. For systems with hexagonal geometry, the reuse factor (cluster size), N , is related to the reuse shift parameters (i, j) by

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

The integers i and j identify co-channel cells [11]. For convenience we assume that $i \geq j$, $i > 0$ and $j \geq 0$. The reuse distance can be determined from

$$D = \sqrt{3NR} . \quad (2)$$

2.1.1 Power Control

Power control can be used in cellular systems to reduce interference, improve quality and enhance traffic capacity. On the reverse link (mobile-to-base), the objective of power control is to produce a nominal received signal power from each mobile station operating within the cell (or sector) at the gateway's receiver. Regardless of a mobile station's position or propagation loss, each mobile station's signal will be received at the gateway at the same level. On the forward link (base-to-mobile), the purpose of power control is to ensure that the received signal power in each mobile station is suitable for a good communication quality but is not unnecessarily large.

If power control is not employed, a mobile station transmits with *the same power* at any position within a sector. In the worst case, the interfering mobile stations are at *points* that are nearest to the given gateway in co-channel sectors.

If power control is employed, with flat uniform propagation conditions, the transmitted power of a mobile station is determined by the distance between the mobile station and receiving gateway. When a mobile station is at the vertex of a sector, it transmits with its maximum power. In the worst case, the interfering mobile stations in co-channel sectors are at *vertices* that are nearest to the given gateway.

In certain cases, for the gateway of a given sector, the nearest *point* in a co-channel sector is also the nearest *vertex* in the co-channel sector. For example, in Figure 3, the nearest point in A_{41} to the gateway of A_{01} is at m_2 , which is also a vertex of A_{41} . However, in sector A_{51} , the nearest point to the gateway of A_{01} is the gateway of A_{51} and the nearest *vertex* to the gateway of A_{01} is at m_3 . They have different distances to the gateway of A_{01} . Due to the difference, co-channel difference on the *reverse-link* is different for some sectors with and without power control. In the following analysis, we will consider systems with and without power control separately.

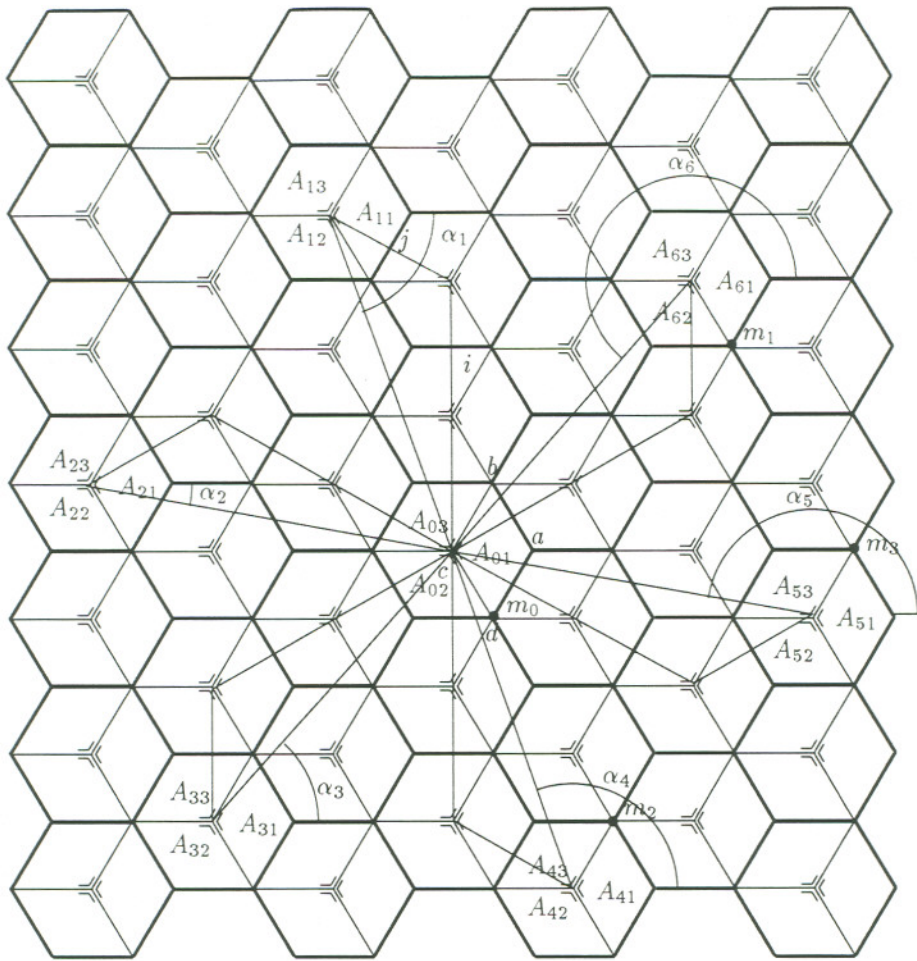


Figure 3: Co-channel sectors of A_{01} in 120° sectorized FCA.

power control	position of interfering source	
	on forward link	on reverse link
no	gateway of co-channel sector	the nearest point in co-channel sector
yes	gateway of co-channel sector	the nearest vertex in co-channel sector

Table 2: The position of interfering source in the worst case in sectorized CBWL.

Because interference on the forward link is from a gateway of a co-channel sector (the position of gateway is fixed for systems with or without power control), co-channel interference on the forward link are the same for systems with or without power control.

The positions of interfering transmitters on both forward link and reverse link for the cases with and without power control are summarized in Table 2.

2.1.2 Layout A, 120° Antenna, No Power Control

forward-link SIR, $SIR-A_{FO}$

In the worst case, the receiving mobile unit is at the sector vertex m_0 (Figure 3). In Appendix A, we determined forward-link SIR of sectorized FCA for any reuse factor. The result is

$$SIR-A_{FO} = \begin{cases} \left[(3N + 1 + 3i)^{-\frac{\gamma}{2}} + (3N + 1 - 3j)^{-\frac{\gamma}{2}} \right]^{-1} & i > j \\ \left[(3N + 1 + 6i)^{-\frac{\gamma}{2}} + (3N + 1 + 3i)^{-\frac{\gamma}{2}} + (3N + 1 - 3i)^{-\frac{\gamma}{2}} \right]^{-1} & i = j \end{cases} \quad (3)$$

where the parameter, γ is a propagation exponent that is heavily influenced by the actual terrain environment. The value of γ usually lies between 3 and 5. For $N = 7(i = 2, j = 1)$ and $\gamma = 4$, we find $SIR-A_{FO} = 247.2(23.9\text{dB})$.

reverse-link SIR, $SIR-A_{RO}$

If power control is not employed, a mobile station transmits the same power at any position of a sector. In the worst case, an interfering mobile station in a co-channel sector is at the position that is closest to the receiving gateway. In Appendix A, we determined $SIR-A_{RO}$, reverse-link SIR no power control for 120° antenna cellular system. The result is

$$SIR-A_{RO} = \begin{cases} \left[(3N)^{-\frac{\gamma}{2}} + (3N + 1 - 3j)^{-\frac{\gamma}{2}} \right]^{-1} & i > j \\ \left[(3N)^{-\frac{\gamma}{2}} + 2(3N + 1 - 3i)^{-\frac{\gamma}{2}} \right]^{-1} & i = j. \end{cases} \quad (4)$$

For $N = 7(i = 2, j = 1)$ and $\gamma = 4$, we find $SIR-A_{RO} = 198.5(23\text{dB})$.

2.1.3 Layout B, 120° Antenna, With Power Control

With power control, in the worst case, the interfering mobile stations are at the nearest vertices of co-channel sectors.

forward-link SIR, $SIR-B_{FO}$

The receiving mobile station is at the vertex, m_0 . The forward-link SIR, $SIR-B_{FO}$ is the same as $SIR-A_{FO}$ in (3).

reverse-link SIR, $SIR-B_{RO}$

In Appendix A, we calculated $SIR-B_{RO}$, the reverse-link SIR *with power control* for 120° antenna cellular system. The result for this case is

$$SIR-B_{RO} = \begin{cases} \left[(3N + 1 + 3j)^{-\frac{\gamma}{2}} + (3N + 1 - 3j)^{-\frac{\gamma}{2}} \right]^{-1} & i > j \\ \left[(3N + 1 + 3j)^{-\frac{\gamma}{2}} + 2(3N + 1 - 3i)^{-\frac{\gamma}{2}} \right]^{-1} & i = j. \end{cases} \quad (5)$$

For $N = 7(i = 2, j = 1)$ and $\gamma = 4$, we find $SIR-B_{RO} = 228.8(23.6\text{dB})$.

2.1.4 Layout C, 60° Antenna, No Power Control

forward-link SIR, $SIR-C_{FO}$

The forward-link SIR for cellular systems with 60° sectors for any reuse factor is determined in Appendix B. It is shown that

$$SIR-C_{FO} = \begin{cases} [3N + 1 + 3(i + j)]^{\frac{\gamma}{2}} & i > j \\ \left\{ (3N + 1 + 3j)^{-\frac{\gamma}{2}} + [(3N + 1 + 3(i + j))]^{-\frac{\gamma}{2}} \right\}^{-1} & i = j. \end{cases} \quad (6)$$

For $N = 4$ ($i = 2, j = 0$) and $\gamma = 4$, $SIR-C_{FO} = 361$ (25.6 dB).

reverse-link SIR, $SIR-C_{RO}$

Also from Appendix B, the reverse-link SIR in this case is

$$SIR-C_{RO} = \begin{cases} (3N)^{\frac{\gamma}{2}} & i > j \\ \frac{1}{2}(3N)^{\frac{\gamma}{2}} & i = j. \end{cases} \quad (7)$$

For $N = 4$ ($i = 2, j = 0$) and $\gamma = 4$, $SIR-C_{FO} = 144$ (21.6 dB).

2.1.5 Layout D, 60° Antenna, With Power Control

forward-link SIR, $SIR-D_{FO}$

The forward-link SIR, $SIR-D_{FO}$ is the same as $SIR-C_{FO}$ in (6).

reverse-link SIR, $SIR-D_{RO}$

In Appendix B, the reverse-link SIR for this case is shown to be

$$SIR-D_{RO} = \begin{cases} (3N + 1 + 3i)^{\frac{\gamma}{2}} & i > j \\ \frac{1}{2}(3N + 1 + 3i)^{\frac{\gamma}{2}} & i = j. \end{cases} \quad (8)$$

For $N = 4$ ($i = 2, j = 0$) and $\gamma = 4$, $SIR-D_{RO} = 361$ (25.6 dB).

2.2 SIR's of Sectorized CBWL

2.2.1 SIR Requirements for sectorized CBWL

In omni-directional antenna cellular systems, a given gateway "sees" interference from all co-channel cells. If a channel is lent by the given gateway to a neighboring gateway, the co-channel reuse distance of the borrowed channel is changed and the co-channel interference is increased in some neighboring co-channel cells. We can reduce the transmitted power on the borrowed channel to let the co-channel interference be the same as that without channel borrowing.

In a *sectorized* cellular system, a given sector interferes only with *some* neighboring co-channel sectors. If a channel is lent from the given sector to an adjacent sector, the channel can become an interference source to some co-channel sectors that are not within the view angle of the owning gateway but are within the view angle of the borrowing gateway. For example, in Figure 1, the gateway of A_{03} does not interfere with mobile stations in A_{53} . However, if A_{01} borrows a channel c_1 from A_{03} , the gateway A_{01} becomes a co-channel interference source to the mobile station in A_{53} that uses channel c_1 . Even if the borrowed channel is used with very low power, the sum of co-channel interference received by the mobile station is still larger than the co-channel interference without borrowing.

Thus, in sectorized CBWL, we cannot always keep SIR the same as that in sectorized FCA. Instead, we will accept some slight degradation of SIR in comparison with FCA. That is

$$\{\text{SIR of CBWL}\} = (1 - d)\{\text{SIR of FCA}\} \quad (9)$$

where d is a small positive value. Under this criterion, we will calculate the maximum transmitted power that can be used on borrowed channels and the fraction of area in a sector in which borrowed channels can be used. If the fraction is sufficiently large, the traffic performance of the system can be increased greatly at the cost of a slight decrease in SIR. Since the SIR of sectorized cellular systems are usually better than SIR of omni-directional cellular system, for small value of d , communication quality may not be significantly degraded.

We note here as well, that in omni-directional antenna CBWL systems, if there is enough SIR margin, we can also accept some slight degradation in SIR to increase the fraction of area in which borrowed channels can be used. Thus, *traffic* performance can be enhanced beyond that considered in [1]–[3], in exchange for reduced (but still satisfactory) signal quality.

2.2.2 Analysis Procedure of Sectorized CBWL

In CBWL, there are two types of channels: regular channels and borrowed channels. Because of the uniform propagation assumptions, the maximum distance between a mobile station using a *regular channel* and its desired gateway is R , (the distance to a vertex of a sector). Since borrowed channels are used with reduced transmitted power, the maximum distance between a mobile station using a *borrowed channel* and its desired gateway is limited to r ($r < R$). In 120° antenna configuration, the area of a sector is equal to $(\sqrt{3}/2)R^2$ and the area in which borrowed channels can be used is $\pi r^2/3$. The *fraction* of area in which borrowed channels can be used, F_b , is about $1.1(r/R)^2$. This relationship is the same as that for the system with 60° antennas. Approximately we can let $F_b = (r/R)^2$. With power control, in the worst case, an interfering mobile station (or gateway) transmits with maximum power. Without power control, the maximum power is used for all cases. We denote the ratio of the maximum power transmitted on a borrowed channel to the maximum power transmitted on a regular channel for the forward-link as P_f . Similarly, the ratio of the maximum power transmitted on a borrowed channel to the maximum power transmitted on a regular channel for the reverse-link is denoted, P_r .

Since SIR_{FO} and SIR_{RO} are not necessarily the same, we can accept different amounts of SIR degradation in each direction. That is

$$\{\text{forward-link SIR of CBWL}\} = (1 - d_1)\{\text{forward-link SIR of FCA}\} \quad (10)$$

$$\{\text{reverse-link SIR of CBWL}\} = (1 - d_2)\{\text{reverse-link SIR of FCA}\} \quad (11)$$

In (10) and (11) d_1 and d_2 are small positive numbers that specify the acceptable degradation on the forward and reverse links, respectively.

To determine the fraction of area in which a user has access to borrowed channels, the procedure is as follows.

1. Calculate the SIR of a *regular* channel on the forward link (considering co-channel interference from borrowed channel), SIR_{AFN} . Similarly, find SIR_{AFB} , the SIR of a borrowed channel on the forward link. The maximum distance *between* a mobile station that uses a borrowed channel *and* the desired gateway [under the forward link SIR requirement given by (10)] is denoted as r_1 . The fraction of service area in which a borrowed channel can be used *under the forward link SIR requirement given by (10)* is denoted as F_{b1} . The quantity of F_{b1} is approximatively equal to $(r_1/R)^2$. Each SIR is a function of P_f and F_{b1} .
2. Since we want the same SIR on regular and borrowed channels in the forward link, we let

$$SIR_{FN} = (1 - d_1)SIR_{FO}$$

and

$$SIR_{FB} = (1 - d_1)SIR_{FO} \quad (12)$$

These two simultaneous equations are solved for P_f and r_1 . Note that d_1 appears as a parameter.

3. Calculate $SIR-A_{RN}$, the SIR of a regular channel on the reverse link (considering co-channel interference from borrowed channel). Also find the SIR of a borrowed channel on the reverse link, $SIR-A_{RB}$. The maximum distance *between* a mobile station that use borrowed channel *and* the desired gateway [under the forward link SIR requirement given by (11)] is denoted as r_2 . The fraction of service area in which a borrowed channel can be used *under the forward link SIR requirement given by (11)* is denoted as F_{b2} . The quantity of F_{b2} is approximatively equal to $(r_2/R)^2$. Each SIR is a function of P_r and F_{b2} .
4. Since we want the same SIR on regular and borrowed channels on the reverse links we require

$$\begin{aligned} SIR_{RN} &= (1 - d_2)SIR_{RO} \\ SIR_{RB} &= (1 - d_2)SIR_{RO} \end{aligned} \quad (13)$$

These two equations are solved simultaneously for P_r and r_2 . The solutions depend on d_2 .

5. The maximum distance *between* a mobile station that can use a borrowed channel *and* the desired gateway is determined by $r = \min(r_1, r_2)$. The fraction of service area in which a user has access to a borrowed channel, F_b can be approximated by $\min(F_{b1}, F_{b2})$.

For sectorized cellular systems, no single formula can be derived for SIR that is valid for any arbitrary reuse factor. We will analyze two typical configurations: 120° antenna with reuse factor of 7; and, 60° antenna with reuse factor of 4.

2.2.3 Layout A, 120° Sectorized CBWL, Reuse Factor of 7, No Power Control

Figure 1 shows the layout. Suppose that A_{01} is a borrowing sector. A_{01} is the same as any other sector. Note that A_{01} is *adjacent* to the sectors A_{02} , A_{03} , G_{02} , D_{03} , E_{02} , E_{03} , F_{02} and F_{03} . None of these sectors has the same orientation as A_{01} . We will consider the SIR's that result from A_{01} borrowing a channel from any of these sectors. Additionally some sectors are in *cells* that are *adjacent* to that of A_{01} and have the *same* orientation as A_{01} . These are B_{01} , C_{01} , D_{01} , E_{01} , F_{01} and G_{01} . The effects of A_{01} borrowing a channel from any of these sectors will be considered as well. Thus there are 14 borrowing possibilities to be considered. We call those sectors that can lend channels to A_{01} , *donor sectors* of A_{01} . Each possibility requires consideration of four SIR's corresponding to channel attributes: regular or borrowed, and forward and reverse. Thus $4 \times 14 = 56$ SIR's are to be considered for this configuration according to the analysis procedure outlined by equations (12)–(13).

Without power control, for the FCA scheme, $SIR-A_{FO} = 247$ (23.9dB) and $SIR-A_{RO} = 198.5$ (23dB). We consider four different criteria: (1) $d_1 = d_2 = .1$, the SIR's of both forward and reverse link will lose .46dB. (2) $d_1 = d_2 = .15$, the SIR's of both forward and reverse link will lose .71dB. Since $SIR-A_{FO}$ is larger than $SIR-A_{RO}$, we can use different degradation factors for forward link and reverse link such that forward-link SIR and reverse-link SIR of CBWL are the same. The last two criteria are: (3) $d_1 = .28$, $d_2 = .1$, both forward-link and reverse-link SIR's are 180 (22.5dB). (4) $d_1 = .317$, $d_2 = .15$, both forward-link and reverse-link SIR's are 169 (22.3dB).

Consider CBWL with A_{01} borrowing a channel from each neighboring sector. We calculate the forward-link and reverse-link SIR's on borrowed channels and on regular channels. The resulting formulas are shown in Table 3. The method of calculation is demonstrated in Appendix C for the case in which A_{01} borrows a channel from E_{01} .

Using Table 3, on forward link, let $SIR_{FN} = SIR_{FB} = (1 - d_1)SIR_{FO}$. We can determine P_f , the ratio of transmitted power on borrowed channels to that on regular channels (for forward

donor sector	forward-link		reverse-link	
	$SIR - A_{FN}$	$SIR - A_{FB}$	$SIR - A_{RN}$	$SIR - A_{RB}$
A_{02}	$\frac{1}{P_f 13^{-\frac{\gamma}{2}} + SIR - A_{FO}^{-1}}$	$\left(\frac{R}{r_1}\right)^\gamma \frac{P_f}{13^{-\frac{\gamma}{2}} + 16^{-\frac{\gamma}{2}}}$	$\frac{1}{P_r 13^{-\frac{\gamma}{2}} + 19^{-\frac{\gamma}{2}}}$	$\left(\frac{R}{r_2}\right)^\gamma \frac{P_r}{13^{-\frac{\gamma}{2}} + 13^{-\frac{\gamma}{2}}}$
A_{03}	$\frac{1}{P_f 25^{-\frac{\gamma}{2}} + SIR - A_{FO}^{-1}}$	$\left(\frac{R}{r_1}\right)^\gamma \frac{P_f}{13^{-\frac{\gamma}{2}} + 16^{-\frac{\gamma}{2}}}$	$\frac{1}{P_r 13^{-\frac{\gamma}{2}} + 21^{-\frac{\gamma}{2}}}$	$\left(\frac{R}{r_2}\right)^\gamma \frac{P_r}{16^{-\frac{\gamma}{2}} + 13^{-\frac{\gamma}{2}}}$
F_{02}	$\frac{1}{P_f 25^{-\frac{\gamma}{2}} + SIR - A_{FO}^{-1}}$	$\left(\frac{R}{r_1}\right)^\gamma \frac{P_f}{25^{-\frac{\gamma}{2}} + 28^{-\frac{\gamma}{2}} + 31^{-\frac{\gamma}{2}}}$	$\frac{1}{P_r 25^{-\frac{\gamma}{2}} + SIR - A_{RO}^{-1}}$	$\left(\frac{R}{r_2}\right)^\gamma \frac{P_r}{16^{-\frac{\gamma}{2}} + 25^{-\frac{\gamma}{2}} + 28^{-\frac{\gamma}{2}}}$
E_{03}	$\frac{1}{P_f 31^{-\frac{\gamma}{2}} + SIR - A_{FO}^{-1}}$	$\left(\frac{R}{r_1}\right)^\gamma \frac{P_f}{16^{-\frac{\gamma}{2}} + 25^{-\frac{\gamma}{2}} + 31^{-\frac{\gamma}{2}}}$	$\frac{1}{P_r 16^{-\frac{\gamma}{2}} + SIR - A_{RO}^{-1}}$	$\left(\frac{R}{r_2}\right)^\gamma \frac{P_r}{19^{-\frac{\gamma}{2}} + 25^{-\frac{\gamma}{2}} + 31^{-\frac{\gamma}{2}}}$
E_{02}	$\frac{1}{P_f 19^{-\frac{\gamma}{2}} + SIR - A_{FO}^{-1}}$	$\left(\frac{R}{r_1}\right)^\gamma \frac{P_f}{7^{-\frac{\gamma}{2}} + 19^{-\frac{\gamma}{2}}}$	$\frac{1}{P_r 7^{-\frac{\gamma}{2}} + 21^{-\frac{\gamma}{2}}}$	$\left(\frac{R}{r_2}\right)^\gamma \frac{P_r}{19^{-\frac{\gamma}{2}} + 28^{-\frac{\gamma}{2}}}$
F_{03}	$\frac{1}{P_f 19^{-\frac{\gamma}{2}} + SIR - A_{FO}^{-1}}$	$P_f 13^{\frac{\gamma}{2}} \left(\frac{R}{r_2}\right)^\gamma$	$\frac{1}{P_r 13^{-\frac{\gamma}{2}} + 19^{-\frac{\gamma}{2}}}$	$\left(\frac{R}{r_2}\right)^\gamma \frac{P_r}{13^{-\frac{\gamma}{2}} + 25^{-\frac{\gamma}{2}} + 31^{-\frac{\gamma}{2}}}$
G_{02}	$\frac{1}{P_f 13^{-\frac{\gamma}{2}} + SIR - A_{FO}^{-1}}$	$\left(\frac{R}{r_1}\right)^\gamma \frac{P_f}{16^{-\frac{\gamma}{2}} + 25^{-\frac{\gamma}{2}} + 31^{-\frac{\gamma}{2}}}$	$\frac{1}{P_r 13^{-\frac{\gamma}{2}} + SIR - A_{RO}^{-1}}$	$\left(\frac{R}{r_2}\right)^\gamma \frac{P_r}{13^{-\frac{\gamma}{2}} + 25^{-\frac{\gamma}{2}}}$
D_{03}	$\frac{1}{P_f 7^{-\frac{\gamma}{2}} + 25^{-\frac{\gamma}{2}} + 31^{-\frac{\gamma}{2}}}$	$\left(\frac{R}{r_1}\right)^\gamma \frac{P_f}{19^{-\frac{\gamma}{2}} + 28^{-\frac{\gamma}{2}}}$	$\frac{1}{P_r 19^{-\frac{\gamma}{2}} + 21^{-\frac{\gamma}{2}}}$	$\left(\frac{R}{r_2}\right)^\gamma \frac{P_r}{7^{-\frac{\gamma}{2}} + 19^{-\frac{\gamma}{2}}}$
B_{01}	$\frac{1}{P_f 13^{-\frac{\gamma}{2}} + 19^{-\frac{\gamma}{2}}}$	$\left(\frac{R}{r_1}\right)^\gamma \frac{P_f}{2 \times 19^{-\frac{\gamma}{2}} + 28^{-\frac{\gamma}{2}}}$	$\frac{1}{P_r 31^{-\frac{\gamma}{2}} + SIR - A_{RO}^{-1}}$	$P_r 9^{\frac{\gamma}{2}} \left(\frac{R}{r_2}\right)^\gamma$
C_{01}	$\frac{1}{P_f 7^{-\frac{\gamma}{2}} + 28^{-\frac{\gamma}{2}}}$	$\left(\frac{R}{r_1}\right)^\gamma \frac{P_f}{21^{-\frac{\gamma}{2}} + 36^{-\frac{\gamma}{2}} + 39^{-\frac{\gamma}{2}}}$	$\frac{1}{P_r 19^{-\frac{\gamma}{2}} + SIR - A_{RO}^{-1}}$	$\left(\frac{R}{r_2}\right)^\gamma \frac{P_r}{7^{-\frac{\gamma}{2}} + 13^{-\frac{\gamma}{2}}}$
D_{01}	$\frac{1}{P_f 13^{-\frac{\gamma}{2}} + 28^{-\frac{\gamma}{2}}}$	$\left(\frac{R}{r_1}\right)^\gamma \frac{P_f}{7^{-\frac{\gamma}{2}} + 28^{-\frac{\gamma}{2}} + 49^{-\frac{\gamma}{2}}}$	$\frac{1}{P_r 7^{-\frac{\gamma}{2}} + SIR - A_{RO}^{-1}}$	$\left(\frac{R}{r_2}\right)^\gamma \frac{P_r}{13^{-\frac{\gamma}{2}} + 28^{-\frac{\gamma}{2}}}$
E_{01}	$\frac{1}{P_f 49^{-\frac{\gamma}{2}} + SIR - A_{FO}^{-1}}$	$p_f \left(\frac{R}{r_1}\right)^\gamma 13^{\frac{\gamma}{2}}$	$\frac{1}{P_r 9^{-\frac{\gamma}{2}} + 19^{-\frac{\gamma}{2}}}$	$\left(\frac{R}{r_2}\right)^\gamma \frac{P_r}{28^{-\frac{\gamma}{2}} + 31^{-\frac{\gamma}{2}} + 39^{-\frac{\gamma}{2}}}$
F_{01}	$\frac{1}{P_f 31^{-\frac{\gamma}{2}} + SIR - A_{FO}^{-1}}$	$\left(\frac{R}{r_1}\right)^\gamma \frac{P_f}{7^{-\frac{\gamma}{2}} + 19^{-\frac{\gamma}{2}}}$	$\frac{1}{P_r 7^{-\frac{\gamma}{2}} + 21^{-\frac{\gamma}{2}}}$	$\left(\frac{R}{r_2}\right)^\gamma \frac{P_r}{19^{-\frac{\gamma}{2}} + 36^{-\frac{\gamma}{2}} + 37^{-\frac{\gamma}{2}}}$
G_{01}	$\frac{1}{P_f 7^{-\frac{\gamma}{2}} + 25^{-\frac{\gamma}{2}} + 31^{-\frac{\gamma}{2}}}$	$\left(\frac{R}{r_1}\right)^\gamma \frac{P_f}{13^{-\frac{\gamma}{2}} + 37^{-\frac{\gamma}{2}}}$	$\frac{1}{P_r 12^{-\frac{\gamma}{2}} + 21^{-\frac{\gamma}{2}}}$	$\left(\frac{R}{r_2}\right)^\gamma \frac{P_r}{7^{-\frac{\gamma}{2}} + 21^{-\frac{\gamma}{2}}}$

Table 3: SIR's of CBWL, 120° sector, no power control.

link). In addition, the fraction of area in which borrowed channels can be used under forward-link requirement, F_{b1} , can be found. Similarly, on the reverse link, let $SIR_{RN} = SIR_{RB} = (1 - d_2)SIR_{RO}$. We can find, P_r , the ratio of transmitted power on borrowed channels to that on regular channels (for reverse link). In addition, the fraction of area in which borrowed channels can be used under reverse-link requirement, F_{b2} , can be found. These results are listed in Table 4 for different value of d_1 and d_2 (In Table 4, data are listed for a propagation loss exponent, $\gamma = 4$).

It is seen in Table tb6-5 that for a given criterion, the F_b 's that result from borrowing channels from different donor sectors are generally different from one another. The F_b 's corresponding to some donor sectors are too small. A_{01} cannot benefit significantly from borrowing channels from these sectors. Thus, we allow A_{01} to borrow channels only from those donor sectors that permit a F_b above a requirement value. Denote the requirement value as p . For a specific criterion, d_1 and d_2 and p , we denote the set of possible donor sectors for A_{01} as $S(d_1, d_2, p)$. That is, for any sector, x , in $S(d_1, d_2, p)$, $F_b(x)$ must be larger than or equal to p .

From [1]-[3], we found that if $p \geq .3$, the system performance can be enhanced significantly. Using $p \geq .3$. It is seen from Table 5 that

$$S(.10, .10, .35) = \{E_{01}(.66), F_{02}(.54), B_{01}(.49), E_{03}(.39), A_{03}(.36), F_{03}(.35)\} \quad (14)$$

donor sector	forward-link								reverse-link			
	$d_1 = .10$		$d_1 = .15$		$d_1 = .28$		$d_1 = .32$		$d_2 = .10$		$d_2 = .15$	
	P_f	F_{b1}	P_f	F_{b1}	P_f	F_{b1}	P_f	F_{b1}	P_r	F_{b2}	P_r	F_{b2}
A_{02}	.08	.20	.12	.24	.26	.39	.32	.44	.48	.48	.53	.52
A_{03}	.28	.36	.45	.47	.96	.74	1.17	.84	.48	.52	.53	.57
F_{02}	.28	.56	.45	.73	.96	1.15	1.17	1.31	.35	.54	.56	.69
E_{03}	.43	.54	.69	.71	1.48	1.12	1.81	1.28	.15	.39	.23	.50
E_{02}	.16	.17	.26	.22	.55	.36	.68	.41	.16	.48	.18	.51
F_{03}	.16	.35	.26	.46	.55	.72	.68	.82	.48	.56	.53	.61
G_{02}	.08	.22	.12	.28	.26	.44	.32	.50	.09	.26	.17	.36
D_{03}	.09	.32	.10	.35	.15	.45	.16	.49	1.20	.54	1.32	.58
B_{01}	.29	.75	.34	.83	.48	1.07	.53	1.17	.54	.49	.85	.64
C_{01}	.16	.44	.17	.47	.21	.57	.23	.61	.20	.20	.32	.26
D_{01}	.54	.33	.59	.36	.73	.42	.79	.46	.03	.14	.04	.17
E_{01}	1.08	.91	1.72	1.17	3.69	1.87	4.51	2.13	.23	.66	.26	.71
F_{01}	.43	.28	.69	.37	1.48	.60	1.81	.68	.16	.46	.18	.50
G_{01}	.09	.24	.10	.28	.14	.35	.16	.37	.48	.35	.53	.37

Table 4: Ratio of transmitted power on borrowed channels (P_f, P_r) and fraction of area that has access to borrowed channel (F_{b1}, F_{b2}) 120° sector, no power control.

donor sector	fraction of area covered by borrowed channels			
	$d_1 = d_2 = .10$	$d_1 = d_2 = .15$	$d_1 = .10, d_2 = .28$	$d_1 = .15, d_2 = .32$
A_{02}	.20	.24	.39	.44
A_{03}	.36	.47	.52	.57
F_{02}	.54	.69	.54	.69
E_{03}	.39	.50	.39	.50
E_{02}	.17	.22	.36	.41
F_{03}	.35	.46	.56	.61
G_{02}	.22	.28	.26	.36
D_{03}	.32	.35	.45	.49
B_{01}	.49	.64	.49	.64
C_{01}	.20	.26	.20	.26
D_{01}	.14	.17	.14	.17
E_{01}	.66	.71	.66	.71
F_{01}	.28	.37	.46	.50
G_{01}	.24	.28	.35	.37

Table 5: Fraction of area covered by borrowed channel, 120° sector, no power control.

$$S(.15, .15, .35) = \{E_{01}(.71), F_{02}(.69), B_{01}(.64), E_{03}(.50), A_{03}(.47), F_{03}(.46), F_{01}(.37), D_{03}(.35)\} \quad (15)$$

$$S(.28, .10, .35) = \{E_{01}(.66), F_{03}(.56), F_{02}(.54), A_{03}(.52), B_{01}(.49), F_{01}(.46), \\ D_{03}(.45), A_{02}(.39), E_{03}(.39), E_{02}(.36), G_{01}(.35), \} \quad (16)$$

$$S(.32, .15, .36) = \{E_{01}(.71), F_{02}(.69), B_{01}(.64), F_{03}(.61), A_{03}(.57), F_{01}(.50), \\ E_{03}(.50), D_{03}(.49), A_{02}(.44), E_{02}(.41), G_{01}(.37), G_{02}(.36)\} \quad (17)$$

In the sets, the value in parentheses are F_b corresponding to the donor sector. The members in a set are arranged in the order of their F_b 's magnitude. If we increase p , we can just truncate the list of sectors. We delete those whose F_b is less than p to find the set for the new (increased) value of p .

We found that there are some "bad" donor sectors. If an $F_b(x)$ is too small under all criteria, sector x is a bad donor sector. The bad donor sectors are C_{01} , D_{01} . "Good" donor sectors corresponds to a large F_b even in the strictest criterion (small d 's). The good sectors in this case are B_{01} , E_{01} , F_{02} , E_{03} , F_{03} and A_{03} .

We note that A_{01} , F_{02} and E_{03} comprise a cell that is covered by three 120° antennas in the corners. Channel borrowing between the three sectors can provide at least two additional advantages. First, we can use space diversity to improve reverse-link SIR (it is usually worse than forward-link SIR). For example, if F_{02} lends a channel to A_{01} , the channel will not be used for users in F_{02} . However, the gateway of F_{02} can still receive the signal from the user in A_{01} that uses the borrowed channel. The received signals from the user at the gateways of F_{02} and of A_{01} comprise diversity signals that can be combined to improve reverse-link SIR. Second, channel borrowing can be used to assist hand-off between the three sectors. Consider that a mobile station that has a call in progress moves from F_{02} to A_{01} . Instead of seeking a free channel of A_{01} for hand-off, the mobile station can still use its original channel (of F_{02}). However, the channel has been borrowed from the gateway of F_{02} to the gateway of A_{01} . Thus, hand-off and channel borrowing are combined smoothly.

Given a SIR criterion (d_1, d_2) and a minimum requirement for $F_b(x)$, p , from above procedure, we can determine a set of donor sectors for every sector. Every gateway keeps a list of its donor sectors. If a gateway needs to borrow channels, it borrows channels from the sectors in the donor list.

To simplify management, we let borrowed channels from all donor sectors in a given set be used within the same service area. The area is determined by the smallest $F_b(x)$ in the set. However, channels that are borrowed from different donor sectors may be used with different transmitted powers to serve the area. When a gateway borrows a channel from an adjacent gateway to serve a mobile station, the gateway will inform the mobile station of the required transmitted power on the borrowed channel. This method is called *power adjustment on borrowed channels*. With *power adjustment* borrowed channels from different sectors are transmitted in different power in order to be used in the *same area* of the borrowing sector. Note that power adjustment is different from power control. Power control adjusts transmitted power on *all channels that are used in a cell* according to the physical propagation condition (position, distance, fading, terrain, etc.) to keep the same received power at desired receiver (without regard to interference to other co-channel sectors). While power adjustment use different transmitted power on *borrowed channels* from different donor sectors to let all borrowed channels cover the same area and to keep interference of borrowed channels to other co-channel sectors at a tolerable level. Power adjustment can be used with or without power control. If power adjustment is used in CBWL, but power control is not, the transmitted power on all channels are classified with different levels. The greatest power is transmitted on regular channels. Different power levels are transmitted on borrowed channels from different donor sectors. For a specific channel, assigned transmitted power is fixed.

If both power control and power adjustment are used in CBWL, regular channels have highest *maximum* transmitted power and different *maximum* transmitted power is assigned to channels borrowed from different donor sectors. Transmitted power on each class of channels can be adjusted according to physical propagation conditions (power control).

Because all borrowed channels are used with the same F_b , the borrowed channels from the sectors in towards the beginning of a donor list causes less interference than those toward the end of the list. In operation, channel borrowing from a donor sector is considered only if all donor sectors that are listed ahead of the sector cannot lend channels to the given sector.

2.2.4 Layout B, 120° Sectorized CBWL, Reuse Factor of 7, With Power Control

For the FCA scheme with power control, we find that $SIR-B_{FO} = 247$ (23.9dB) and $SIR-B_{RO} = 229$ (23.6dB). Consider some different criterion: (1) $d_1 = d_2 = .1$, both forward-link and reverse-link SIR's have a loss of 0.46dB. (2) $d_1 = d_2 = 0.2$, both forward-link and reverse-link SIR's have a loss of 0.97dB. The last two criteria give the same value of forward-link and reverse-link SIR's for CBWL. (3) $d_1 = 0.17$, $d_2 = 0.1$. Both forward-link and reverse-link SIR's are 206 (23.1dB). (4) $d_1 = 0.26$, $d_2 = 0.2$. Both forward-link and reverse-link SIR's are 183 (22.6dB).

Proceeding as before (for the case of no power control), we will find the forward-link and reverse-link SIR's on both borrowed channels and regular channels. For this purpose, we consider A_{01} borrowing channels from each neighboring sector. These results are shown in Table 6. Only the entries indicated by an asterisk (*) are different from Table 3. The differences are due to different positions of the mobile station in co-channel sectors. With power control, in the worst case, an interfering mobile station will be at the nearest vertex of a sector (it transmits the maximum power there). Without power control, the mobile station transmits the same power throughout all the sector. In the worst case, its position in the sector is as close as possible to the receiving gateway. For $\gamma = 4$, Table 7 lists, P_f , the ratio of transmitted power of forward link on borrowed channels to that on regular channels; F_{b1} , the fraction of area that has access to borrowed channels on forward link; P_r , the ratio of transmitted power of reverse link on borrowed channels to that on regular channels; F_{b2} , the fraction of area that has access to borrowed channels on reverse link; These results are listed for different value of d_1 and d_2 . F_b 's of all donor sectors under four criteria are given in Table 8. The "bad" sectors are D_{01} and C_{01} . The "good" sectors in this case are B_{01} , E_{01} , F_{02} , E_{03} , F_{03} , D_{03} and A_{03} .

Using $p \geq .3$. It is seen from Table 8 that

$$S(.10, .10, .33) = \{E_{01}(.77), F_{02}(.62), B_{01}(.47), F_{02}(.47), A_{03}(.36), F_{03}(.35), E_{03}(.33)\} \quad (18)$$

$$S(.20, .20, .30) = \{E_{01}(.93), B_{01}(.92), F_{02}(.74), F_{03}(.54), E_{03}(.53), A_{03}(.53), F_{01}(.46), D_{03}(.39), G_{02}(.33), G_{01}(.3), A_{02}(.3)\} \quad (19)$$

$$S(.17, .10, .30) = \{E_{01}(.77), B_{01}(.62), F_{02}(.47), F_{03}(.45), A_{03}(.41), F_{01}(.40), D_{03}(.36), G_{01}(.3)\} \quad (20)$$

$$S(.26, .20, .33) = \{B_{01}(.98), E_{01}(.93), F_{02}(.74), F_{03}(.54), A_{03}(.53), E_{03}(.53), F_{01}(.51), D_{03}(.44), A_{02}(.36), G_{02}(.35), E_{02}(.35), G_{01}(.33)\} \quad (21)$$

There is a sufficient number of donor sectors for CBWL with 120° sectors to allow enhanced system traffic performance.

donor sector	forward-link		reverse-link	
	$SIR - B_{FN}$	$SIR - B_{FB}$	$SIR - B_{RN}$	$SIR - B_{RB}$
A_{02}	$\frac{1}{P_f 13^{-\frac{\gamma}{2}} + SIR - B_{FO}^{-1}}$	$\left(\frac{R}{r_1}\right)^\gamma \frac{P_f}{13^{-\frac{\gamma}{2}} + 16^{-\frac{\gamma}{2}}}$	$\frac{1}{P_r 13^{-\frac{\gamma}{2}} + 19^{-\frac{\gamma}{2}}}$	$\left(\frac{R}{r_2}\right)^\gamma \frac{P_r}{13^{-\frac{\gamma}{2}} + 13^{-\frac{\gamma}{2}}}$
A_{03}	$\frac{1}{P_f 25^{-\frac{\gamma}{2}} + SIR - B_{FO}^{-1}}$	$\left(\frac{R}{r_1}\right)^\gamma \frac{P_f}{13^{-\frac{\gamma}{2}} + 16^{-\frac{\gamma}{2}}}$	$\frac{1}{P_r 13^{-\frac{\gamma}{2}} + 21^{-\frac{\gamma}{2}}}$	$\left(\frac{R}{r_2}\right)^\gamma \frac{P_r}{16^{-\frac{\gamma}{2}} + 13^{-\frac{\gamma}{2}}}$
F_{02}	$\frac{1}{P_f 25^{-\frac{\gamma}{2}} + SIR - B_{FO}^{-1}}$	$\left(\frac{R}{r_1}\right)^\gamma \frac{P_f}{25^{-\frac{\gamma}{2}} + 28^{-\frac{\gamma}{2}} + 31^{-\frac{\gamma}{2}}}$	$\frac{1}{P_r 25^{-\frac{\gamma}{2}} + SIR - B_{RO}^{-1}}$	$\left(\frac{R}{r_2}\right)^\gamma \frac{P_r}{16^{-\frac{\gamma}{2}} + 25^{-\frac{\gamma}{2}} + 28^{-\frac{\gamma}{2}}}$
E_{03}	$\frac{1}{P_f 31^{-\frac{\gamma}{2}} + SIR - B_{FO}^{-1}}$	$\left(\frac{R}{r_1}\right)^\gamma \frac{P_f}{16^{-\frac{\gamma}{2}} + 25^{-\frac{\gamma}{2}} + 31^{-\frac{\gamma}{2}}}$	$\frac{1}{P_r 16^{-\frac{\gamma}{2}} + SIR - B_{RO}^{-1}}$	$\left(\frac{R}{r_2}\right)^\gamma \frac{P_r}{19^{-\frac{\gamma}{2}} + 25^{-\frac{\gamma}{2}} + 31^{-\frac{\gamma}{2}}}$
E_{02}	$\frac{1}{P_f 19^{-\frac{\gamma}{2}} + SIR - B_{FO}^{-1}}$	$\left(\frac{R}{r_1}\right)^\gamma \frac{P_f}{7^{-\frac{\gamma}{2}} + 19^{-\frac{\gamma}{2}}}$	$\frac{1}{P_r 7^{-\frac{\gamma}{2}} + 21^{-\frac{\gamma}{2}}}$	$\left(\frac{R}{r_2}\right)^\gamma \frac{P_r}{19^{-\frac{\gamma}{2}} + 28^{-\frac{\gamma}{2}}}$
F_{03}	$\frac{1}{P_f 19^{-\frac{\gamma}{2}} + SIR - B_{FO}^{-1}}$	$P_f 13^{\frac{\gamma}{2}} \left(\frac{R}{r_2}\right)^\gamma$	$\frac{1}{P_r 13^{-\frac{\gamma}{2}} + 19^{-\frac{\gamma}{2}}}$	$\left(\frac{R}{r_2}\right)^\gamma \frac{P_r}{13^{-\frac{\gamma}{2}} + 25^{-\frac{\gamma}{2}} + 31^{-\frac{\gamma}{2}}}$
G_{02}	$\frac{1}{P_f 13^{-\frac{\gamma}{2}} + SIR - B_{FO}^{-1}}$	$\left(\frac{R}{r_1}\right)^\gamma \frac{P_f}{16^{-\frac{\gamma}{2}} + 25^{-\frac{\gamma}{2}} + 31^{-\frac{\gamma}{2}}}$	$\frac{1}{P_r 13^{-\frac{\gamma}{2}} + SIR - B_{RO}^{-1}}$	$\left(\frac{R}{r_2}\right)^\gamma \frac{P_r}{13^{-\frac{\gamma}{2}} + 25^{-\frac{\gamma}{2}}}$
D_{03}	$\frac{1}{P_f 7^{-\frac{\gamma}{2}} + 25^{-\frac{\gamma}{2}} + 31^{-\frac{\gamma}{2}}}$	$\left(\frac{R}{r_1}\right)^\gamma \frac{P_f}{19^{-\frac{\gamma}{2}} + 28^{-\frac{\gamma}{2}}}$	$\frac{1}{P_r 19^{-\frac{\gamma}{2}} + 21^{-\frac{\gamma}{2}}}$	$\left(\frac{R}{r_2}\right)^\gamma \frac{P_r}{7^{-\frac{\gamma}{2}} + 19^{-\frac{\gamma}{2}}}$
B_{01}	$\frac{1}{P_f 13^{-\frac{\gamma}{2}} + 19^{-\frac{\gamma}{2}}}$	$\left(\frac{R}{r_1}\right)^\gamma \frac{P_f}{2 \times 19^{-\frac{\gamma}{2}} + 28^{-\frac{\gamma}{2}}}$	$\frac{1}{P_r 31^{-\frac{\gamma}{2}} + SIR - B_{RO}^{-1}}$	$P_r 13^{\frac{\gamma}{2}} \left(\frac{R}{r_2}\right)^\gamma *$
C_{01}	$\frac{1}{P_f 7^{-\frac{\gamma}{2}} + 28^{-\frac{\gamma}{2}}}$	$\left(\frac{R}{r_1}\right)^\gamma \frac{P_f}{21^{-\frac{\gamma}{2}} + 36^{-\frac{\gamma}{2}} + 39^{-\frac{\gamma}{2}}}$	$\frac{1}{P_r 19^{-\frac{\gamma}{2}} + SIR - B_{RO}^{-1}}$	$\left(\frac{R}{r_2}\right)^\gamma \frac{P_r}{7^{-\frac{\gamma}{2}} + 13^{-\frac{\gamma}{2}}}$
D_{01}	$\frac{1}{P_f 13^{-\frac{\gamma}{2}} + 28^{-\frac{\gamma}{2}}}$	$\left(\frac{R}{r_1}\right)^\gamma \frac{P_f}{7^{-\frac{\gamma}{2}} + 28^{-\frac{\gamma}{2}} + 49^{-\frac{\gamma}{2}}}$	$\frac{1}{P_r 7^{-\frac{\gamma}{2}} + SIR - B_{RO}^{-1}}$	$\left(\frac{R}{r_2}\right)^\gamma \frac{P_r}{13^{-\frac{\gamma}{2}} + 28^{-\frac{\gamma}{2}}}$
E_{01}	$\frac{1}{P_f 49^{-\frac{\gamma}{2}} + SIR - B_{FO}^{-1}}$	$p_f \left(\frac{R}{r_1}\right)^\gamma 13^{\frac{\gamma}{2}}$	$\frac{1}{P_r 13^{-\frac{\gamma}{2}} + 19^{-\frac{\gamma}{2}}} *$	$\left(\frac{R}{r_2}\right)^\gamma \frac{P_r}{28^{-\frac{\gamma}{2}} + 31^{-\frac{\gamma}{2}} + 43^{-\frac{\gamma}{2}}} *$
F_{01}	$\frac{1}{P_f 31^{-\frac{\gamma}{2}} + SIR - B_{FO}^{-1}}$	$\left(\frac{R}{r_1}\right)^\gamma \frac{P_f}{7^{-\frac{\gamma}{2}} + 19^{-\frac{\gamma}{2}}}$	$\frac{1}{P_r 7^{-\frac{\gamma}{2}} + 25^{-\frac{\gamma}{2}}}$	$\left(\frac{R}{r_2}\right)^\gamma \frac{P_r}{19^{-\frac{\gamma}{2}} + 37^{-\frac{\gamma}{2}} + 43^{-\frac{\gamma}{2}}} *$
G_{01}	$\frac{1}{P_f 7^{-\frac{\gamma}{2}} + 25^{-\frac{\gamma}{2}} + 31^{-\frac{\gamma}{2}}}$	$\left(\frac{R}{r_1}\right)^\gamma \frac{P_f}{13^{-\frac{\gamma}{2}} + 37^{-\frac{\gamma}{2}}}$	$\frac{1}{P_r 13^{-\frac{\gamma}{2}} + 21^{-\frac{\gamma}{2}}} *$	$\left(\frac{R}{r_2}\right)^\gamma \frac{P_r}{7^{-\frac{\gamma}{2}} + 25^{-\frac{\gamma}{2}}} *$

Table 6: SIR's of CBWL, 120° sector, with power control.

2.2.5 Layout C, 60° Sectorized CBWL, Reuse Factor of 4, No Power Control

Figure 2 depicts a cellular layout with 60° sectors. Let A_{01} be a borrowing sector. The possible donor sectors of A_{01} are its adjacent sectors: A_{02} , A_{06} , A_{03} , A_{05} , D_{05} , C_{03} , C_{02} , D_{06} , B_{03} , B_{05} and B_{04} . The sectors, C_{31} , D_{11} , C_{01} , D_{01} , B_{01} , B_{21} are in adjacent cells and have the same orientation as A_{01} . The possibility of borrowing channels from these sectors will also be considered. The above sectors have different orientations and positions. Each sector must be studied individually.

Without power control (layout C), for FCA scheme, $SIR - C_{FO} = 361$ (25.6dB) and $SIR - C_{RO} = 144$ (21.6dB). $SIR - C_{RO}$ is much less than $SIR - C_{FO}$ (difference of 4dB). We cannot degrade $SIR - C_{RO}$ too much. Four criteria are considered: (1) $d_1 = d_2 = .1$, both forward-link and reverse-link SIR's have 0.46dB of loss. (2) $d_1 = d_2 = 0.15$, both forward-link and reverse-link SIR's have 0.71dB of loss. The last two criteria have a larger d_1 than d_2 . (3) $d_1 = 0.3$, $d_2 = 0.1$, the SIR's for forward-link and reverse-link have 1.5dB and 0.5dB of loss respectively. (4) $d_1 = 0.5$, $d_2 = 0.15$. the SIR's for forward-link and reverse link have 3dB and 0.7dB of loss respectively.

Table 9 lists the forward-link and reverse-link SIR's on both borrowed and regular channels, with A_{01} borrowing channels from each neighboring sector. Table 10 lists P_f , F_{b1} , P_r , and F_{b2} . These results are listed for different criteria (d_1 , d_2). F_b of all donor sectors under four criteria are given in Table 11. We limit the maximum value of F_b as 1.00. The "bad" sectors are A_{03} , A_{05} ,

donor sector	forward-link								reverse-link			
	$d_1 = .10$		$d_1 = .17$		$d_1 = .2$		$d_1 = .260$		$d_2 = .10$		$d_2 = .2$	
	P_f	F_{b1}	P_f	F_{b1}	P_f	F_{b1}	P_f	F_{b1}	P_r	F_{b2}	P_r	F_{b2}
A_{02}	.08	.20	.14	.26	.17	.30	.24	.36	.35	.37	.46	.46
A_{03}	.28	.36	.51	.50	.63	.57	.89	.71	.35	.41	.46	.53
F_{02}	.28	.56	.51	.78	.63	.88	.89	1.11	.30	.47	.68	.74
E_{03}	.43	.54	.78	.76	.97	.87	1.37	1.07	.12	.33	.28	.53
E_{02}	.16	.17	.29	.24	.37	.28	.51	.35	.13	.39	.16	.46
F_{03}	.16	.35	.29	.49	.37	.56	.51	.69	.35	.45	.45	.54
G_{02}	.08	.22	.14	.30	.17	.33	.24	.42	.08	.22	.17	.35
D_{03}	.09	.32	.11	.36	.12	.39	.14	.44	.93	.45	1.15	.52
B_{01}	.29	.75	.35	.86	.39	.92	.46	1.04	.47	.62	1.05	.98
C_{01}	.16	.44	.18	.48	.19	.50	.21	.56	.18	.17	.39	.28
D_{01}	.54	.33	.61	.36	.64	.39	.71	.42	.02	.14	.05	.20
E_{01}	1.08	.91	1.95	1.26	2.43	1.44	3.42	1.85	.35	.77	.45	.93
F_{01}	.43	.28	.78	.40	.97	.46	1.37	.57	.16	.44	.19	.51
G_{01}	.09	.24	.11	.28	.12	.30	.14	.33	.44	.32	.54	.36

Table 7: Ratio of transmitted power on borrowed channels (P_f, P_r) and fraction of area that has access to borrowed channel (F_{b1}, F_{b2}) 120° sector, with power control.

donor sector	fraction of area covered by borrowed channels			
	$d_1 = d_2 = .10$	$d_1 = d_2 = .2$	$d_1 = .10, d_2 = .17$	$d_1 = .20, d_2 = .26$
A_{02}	.20	.30	.26	.36
A_{03}	.36	.53	.41	.53
F_{02}	.47	.74	.47	.74
E_{03}	.33	.53	.33	.53
E_{02}	.17	.28	.24	.35
F_{03}	.35	.54	.45	.54
G_{02}	.22	.33	.22	.35
D_{03}	.32	.39	.36	.44
B_{01}	.62	.92	.62	.98
C_{01}	.17	.28	.17	.28
D_{01}	.14	.20	.14	.20
E_{01}	.77	.93	.77	.93
F_{01}	.28	.46	.40	.51
G_{01}	.24	.30	.28	.33

Table 8: Fraction of area covered by borrowed channel, 120° sector, with power control.

D_{31} , and C_{31} . The “good” sectors in this case are B_{21} , C_{02} , D_{06} and B_{01} . For $p \geq .3$. It is seen

donor sector	forward-link		reverse-link	
	$SIR - C_{FN}$	$SIR - C_{FB}$	$SIR - C_{RN}$	$SIR - C_{RB}$
A_{02}, A_{06}	$\frac{1}{P_f 13^{-\frac{\gamma}{2}} + SIR - C_{FO}^{-1}}$	$P_f (13 \frac{R}{r_1})^\gamma$	$P_r^{-1} SIR - C_{RO}$	$P_r (\frac{R}{r_2})^\gamma SIR - C_{RO}$
A_{03}, A_{05}	$\frac{1}{P_f 7^{-\frac{\gamma}{2}} + SIR - C_{FO}^{-1}}$	$P_f (7 \frac{R}{r_1})^\gamma$	$P_r^{-1} 7^{\frac{\gamma}{2}}$	$P_r (7 \frac{R}{r_2})^\gamma$
C_{31}, D_{11}	$P_f^{-1} 13^{\frac{\gamma}{2}}$	$(\frac{R}{r_1})^\gamma \frac{P_f}{13^{-\frac{\gamma}{2}} + 31^{-\frac{\gamma}{2}}}$	$\frac{1}{P_r 9^{-\frac{\gamma}{2}} + SIR - C_{RO}^{-1}}$	$(\frac{R}{r_2})^\gamma \frac{P_r}{9^{-\frac{\gamma}{2}} + 21^{-\frac{\gamma}{2}}}$
D_{01}, C_{01}	$\frac{1}{P_f 13^{-\frac{\gamma}{2}} + SIR - C_{FO}^{-1}}$	$(\frac{R}{r_1})^\gamma \frac{P_f}{13^{-\frac{\gamma}{2}} + 31^{-\frac{\gamma}{2}}}$	$P_r^{-1} 9^{\frac{\gamma}{2}}$	$(\frac{R}{r_2})^\gamma \frac{P_r}{9^{-\frac{\gamma}{2}} + 21^{-\frac{\gamma}{2}}}$
B_{01}	$\frac{1}{P_f 43^{-\frac{\gamma}{2}} + SIR - C_{FO}^{-1}}$	$P_f (7 \frac{R}{r_1})^\gamma$	$P_r^{-1} 3^{\frac{\gamma}{2}}$	$P_r (27 \frac{R}{r_2})^\gamma$
B_{21}	$P_f^{-1} 7^{\frac{\gamma}{2}}$	$P_f 37^{\frac{\gamma}{2}} (\frac{R}{r_2})^\gamma$	$P_r^{-1} 27^{\frac{\gamma}{2}}$	$P_r (3 \frac{R}{r_2})^\gamma$
D_{05}, C_{03}	$\frac{1}{P_f 13^{-\frac{\gamma}{2}} + SIR - C_{FO}^{-1}}$	$P_f (19 \frac{R}{r_1})^\gamma$	$P_r^{-1} 19^{\frac{\gamma}{2}}$	$P_r (13 \frac{R}{r_2})^\gamma$
D_{06}, C_{02}	$\frac{1}{P_f 19^{-\frac{\gamma}{2}} + SIR - C_{FO}^{-1}}$	$P_f (19 \frac{R}{r_1})^\gamma$	$P_r^{-1} 19^{\frac{\gamma}{2}}$	$P_r (19 \frac{R}{r_2})^\gamma$
B_{03}, B_{05}	$\frac{1}{P_f 19^{-\frac{\gamma}{2}} + SIR - C_{FO}^{-1}}$	$P_f (13 \frac{R}{r_1})^\gamma$	$P_r^{-1} 13^{\frac{\gamma}{2}}$	$P_r (19 \frac{R}{r_2})^\gamma$
B_{04}	$\frac{1}{P_f 19^{-\frac{\gamma}{2}} + SIR - C_{FO}^{-1}}$	$P_f (19 \frac{R}{r_1})^\gamma$	$\frac{1}{P_r 43^{-\frac{\gamma}{2}} + SIR - C_{RO}^{-1}}$	$P_r (19 \frac{R}{r_2})^\gamma$

Table 9: SIR's of CBWL, 60° sector, no power control.

donor sector	forward-link								reverse-link			
	$d_1 = .10$		$d_1 = .15$		$d_1 = .30$		$d_1 = .50$		$d_2 = .10$		$d_2 = .15$	
	P_f	F_{b1}	P_f	F_{b1}	P_f	F_{b1}	P_f	F_{b1}	P_r	F_{b2}	P_r	F_{b2}
A_{02}, A_{06}	.05	.17	.08	.22	.20	.36	.47	.66	1.11	1.11	1.18	1.17
A_{03}, A_{05}	.02	.00	.02	.00	.06	.10	.14	.20	.38	.37	.40	.40
C_{31}, D_{11}	.52	.48	.55	.51	.67	.62	.94	.87	.06	.17	.10	.24
D_{01}, C_{01}	.05	.14	.08	.20	.20	.33	.47	.61	.63	.57	.66	.61
B_{01}	.57	.30	.90	.37	2.19	.66	5.12	1.18	.06	.62	.07	.66
B_{21}	.15	.80	.16	.84	.19	1.02	.27	1.44	5.63	.62	5.96	.66
D_{05}, C_{03}	.05	.24	.08	.32	.20	.54	.47	.97	2.79	1.91	2.94	2.02
D_{06}, C_{02}	.11	.35	.18	.46	.43	.78	1.00	1.41	2.79	2.79	2.94	2.94
B_{03}, B_{05}	.11	.24	.18	.32	.43	.54	1.00	.97	1.30	1.91	1.38	2.02
B_{04}	.11	.35	.18	.46	.43	.78	1.00	1.41	2.79	2.79	2.94	2.94

Table 10: Ratio of transmitted power on borrowed channels (P_f , P_r) and fraction of area that has access to borrowed channel (F_{b1} , F_{b2}) 60° sector, no power control.

from Table 11 that

$$S(.10, .10, .30) = \{B_{21}(.62), C_{02}(.35), D_{06}(.35), B_{01}(.3)\} \quad (22)$$

$$S(.15, .15, .32) = \{B_{21}(.66), B_{04}(.46), C_{02}(.46), D_{06}(.46), B_{01}(.37), C_{03}(.32), D_{05}(.32), B_{03}(.32), B_{05}(.32)\} \quad (23)$$

$$S(.30, .10, .33) = \{B_{04}(.78), C_{02}(.78), D_{06}(.78), B_{01}(.62), B_{21}(.62), C_{03}(.54), D_{05}(.54), B_{03}(.54), B_{05}(.54)\}, A_{02}(.36), A_{06}(.36), D_{01}(.33), C_{01}(.33)\} \quad (24)$$

donor sector	fraction of area covered by borrowed channels			
	$d_1 = d_2 = .10$	$d_1 = d_2 = .15$	$d_1 = .10, d_2 = .30$	$d_1 = .15, d_2 = .50$
A_{02}, A_{06}	.17	.22	.36	.66
A_{03}, A_{05}	.00	.00	.10	.20
C_{31}, D_{11}	.17	.24	.17	.24
D_{01}, C_{01}	.14	.20	.33	.61
B_{01}	.30	.37	.62	.66
B_{21}	.62	.66	.62	.66
D_{05}, C_{03}	.24	.32	.54	.97
C_{02}, D_{06}	.35	.46	.78	1.00
B_{03}, B_{05}	.24	.32	.54	.97
B_{04}	.35	.46	.78	1.00

Table 11: Fraction of area covered by borrowed channel, 60° sector, no power control.

$$S(.50, .15, .61) = \{B_{04}(1.0), C_{02}(1.0), D_{06}(1.0), C_{03}(.97), D_{05}(.97), B_{03}(.97), B_{05}(.97), B_{01}(.66), B_{21}(.66), A_{02}(.66), A_{06}(.66), D_{01}(.61), C_{01}(.61)\} \quad (25)$$

There is a sufficient number of donor sectors for CBWL with 60° sectors (no power control) to allow enhanced system traffic performance.

2.2.6 Layout D , 60° Sectorized CBWL, Reuse Factor of 4, With Power Control

For layout D of FCA, $SIR-D_{FO} = SIR-D_{RO} = 361$ (25.6dB). $SIR-D_{RO}$ is the same as $SIR-D_{FO}$. Because $SIR-D_{FO}$ and $SIR-D_{RO}$ are large, we can afford larger degradation of SIR than other cases. Three criteria are considered: (1) $d_1 = d_2 = .1$, both forward-link and reverse-link SIR's have 0.46dB of loss. (2) $d_1 = d_2 = 0.3$, both forward-link and reverse-link SIR's have 1.6dB of loss. (3) $d_1 = d_2 = 0.5$, both forward-link and reverse-link SIR's have 3dB of loss (but SIR's are still large enough).

Table 12 lists the forward-link and reverse-link SIR's on both borrowed channels and regular channels, with A_{01} borrowing channels from each neighboring sector. Only the entries indicated by an asterisk (*) are different from Table 9. Table 13 lists P_f , F_{b1} , P_r and F_{b2} . F_b of all donor sectors under three criteria are given in Table 14. We limit the maximum value of F_b to 1.00. The "bad" sectors are A_{03} , A_{05} . The "good" sectors in this case are B_{21} , B_{04} , C_{02} , D_{06} and B_{01} .

For $p \geq .3$. It is seen from Table 14 that

$$S(.1, .1, .3) = \{B_{21}(.8), B_{04}(.35), C_{02}(.35), D_{06}(.35), B_{01}(.3)\} \quad (26)$$

$$S(.3, .3, .3) = \{B_{21}(1.), B_{04}(.78), C_{02}(.78), D_{06}(.78), B_{01}(.66), C_{03}(.54), D_{05}(.54), B_{03}(.54), B_{05}(.54), A_{02}(.36), A_{06}(.36), D_{01}(.33), C_{01}(.33), C_{31}(.3), D_{11}(.3)\} \quad (27)$$

$$S(.5, .5, .6) = \{B_{04}(1.), B_{01}(1.), B_{21}(1.), C_{02}(1.), D_{06}(1.), C_{03}(.97), D_{05}(.97), B_{03}(.97), B_{05}(.97), A_{02}(.66), A_{06}(.66), D_{01}(.61), C_{01}(.61), C_{31}(.6), D_{11}(.6)\} \quad (28)$$

donor sector	forward-link		reverse-link	
	$SIR - D_{FN}$	$SIR - D_{FB}$	$SIR - D_{RN}$	$SIR - D_{RB}$
A_{02}, A_{06}	$\frac{1}{P_f 13^{-\frac{\gamma}{2}} + SIR - D_{F0}^{-1}}$	$P_f (13 \frac{R}{r_1})^\gamma$	$P_r^{-1} 13^{\frac{\gamma}{2}} *$	$P_r (13 \frac{R}{r_2})^\gamma *$
A_{03}, A_{05}	$\frac{1}{P_f 7^{-\frac{\gamma}{2}} + SIR - D_{F0}^{-1}}$	$P_f (7 \frac{R}{r_1})^\gamma$	$P_r^{-1} 7^{\frac{\gamma}{2}}$	$P_r (7 \frac{R}{r_2})^\gamma$
C_{31}, D_{11}	$P_f^{-1} 13^{\frac{\gamma}{2}}$	$(\frac{R}{r_1})^\gamma \frac{P_f}{13^{-\frac{\gamma}{2}} + 31^{-\frac{\gamma}{2}}}$	$\frac{1}{P_r 9^{-\frac{\gamma}{2}} + SIR - D_{R0}^{-1}}$	$(\frac{R}{r_2})^\gamma \frac{P_r}{9^{-\frac{\gamma}{2}} + 21^{-\frac{\gamma}{2}}}$
D_{01}, C_{01}	$\frac{1}{P_f 13^{-\frac{\gamma}{2}} + SIR - D_{F0}^{-1}}$	$(\frac{R}{r_1})^\gamma \frac{P_f}{13^{-\frac{\gamma}{2}} + 31^{-\frac{\gamma}{2}}}$	$P_r^{-1} 13^{\frac{\gamma}{2}} *$	$(\frac{R}{r_2})^\gamma \frac{P_r}{13^{-\frac{\gamma}{2}} + 28^{-\frac{\gamma}{2}} *$
B_{01}	$\frac{1}{P_f 43^{-\frac{\gamma}{2}} + SIR - D_{F0}^{-1}}$	$P_f (7 \frac{R}{r_1})^\gamma$	$P_r^{-1} 7^{\frac{\gamma}{2}} *$	$P_r (37 \frac{R}{r_2})^\gamma *$
B_{21}	$P_f^{-1} 7^{\frac{\gamma}{2}}$	$P_f 37^{\frac{\gamma}{2}} (\frac{R}{r_2})^\gamma$	$P_r^{-1} 37^{\frac{\gamma}{2}} *$	$P_r (7 \frac{R}{r_2})^\gamma *$
D_{05}, C_{03}	$\frac{1}{P_f 13^{-\frac{\gamma}{2}} + SIR - D_{F0}^{-1}}$	$P_f (19 \frac{R}{r_1})^\gamma$	$P_r^{-1} 19^{\frac{\gamma}{2}}$	$P_r (13 \frac{R}{r_2})^\gamma$
D_{06}, C_{02}	$\frac{1}{P_f 19^{-\frac{\gamma}{2}} + SIR - D_{F0}^{-1}}$	$P_f (19 \frac{R}{r_1})^\gamma$	$P_r^{-1} 19^{\frac{\gamma}{2}}$	$P_r (19 \frac{R}{r_2})^\gamma$
B_{03}, B_{05}	$\frac{1}{P_f 19^{-\frac{\gamma}{2}} + SIR - D_{F0}^{-1}}$	$P_f (13 \frac{R}{r_1})^\gamma$	$P_r^{-1} 13^{\frac{\gamma}{2}}$	$P_r (19 \frac{R}{r_2})^\gamma$
B_{04}	$\frac{1}{P_f 19^{-\frac{\gamma}{2}} + SIR - D_{F0}^{-1}}$	$P_f (19 \frac{R}{r_1})^\gamma$	$\frac{1}{P_r 43^{-\frac{\gamma}{2}} + SIR - D_{R0}^{-1}}$	$P_r (19 \frac{R}{r_2})^\gamma$

Table 12: SIR's of CBWL, 60° sector, with power control.

donor sector	forward-link						reverse-link					
	$d_1 = .10$		$d_1 = .30$		$d_1 = .50$		$d_2 = .10$		$d_2 = .30$		$d_2 = .50$	
	P_f	F_{b1}	P_f	F_{b1}	P_f	F_{b1}	P_f	F_{b1}	P_r	F_{b2}	P_r	F_{b2}
A_{02}, A_{06}	.05	.17	.20	.36	.47	.66	.52	.52	.67	.67	.94	.94
A_{03}, A_{05}	.02	.00	.06	.10	.14	.20	.15	.14	.19	.20	.27	.26
C_{31}, D_{11}	.52	.48	.67	.62	.94	.87	.05	.14	.20	.30	.47	.60
D_{01}, C_{01}	.05	.14	.20	.33	.47	.61	.52	.47	.67	.61	.94	.85
B_{01}	.57	.30	2.19	.66	5.12	1.18	.15	.80	.19	1.02	.27	1.44
B_{21}	.15	.80	.19	1.02	.27	1.44	4.21	.80	5.42	1.02	7.58	1.44
D_{05}, C_{03}	.05	.24	.20	.54	.47	.97	1.11	.76	1.43	.98	2.00	1.37
D_{06}, C_{02}	.11	.35	.43	.78	1.00	1.41	1.11	1.11	1.43	1.43	2.00	2.00
B_{03}, B_{05}	.11	.24	.43	.54	1.00	.97	.52	.76	.67	.98	.94	1.37
B_{04}	.11	.35	.43	.78	1.00	1.41	1.11	1.11	1.43	1.43	2.00	2.00

Table 13: Ratio of transmitted power on borrowed channels (P_f , P_r) and fraction of area that has access to borrowed channel (F_{b1} , F_{b2}) 60° antenna, with power control.

There is a sufficient number of donor sectors for CBWL with 60° sectors (with power control) to allow enhanced system traffic performance.

3 Traffic Performance of Sectorized CBWL

Assume that the system has a total of 420 channels (each channel includes a forward-link and a reverse-link). With 120° sectors and reuse factor of 7, each sector has 20 channels. With 60° sectors

donor sector	fraction of area covered by borrowed channels		
	$d_1 = d_2 = .10$	$d_1 = d_2 = .30$	$d_1 = d_2 = .50$
A_{02}, A_{06}	.17	.36	.66
A_{03}, A_{05}	.00	.10	.20
C_{31}, D_{11}	.14	.30	.60
D_{01}, C_{01}	.14	.33	.61
B_{01}	.30	.66	1.00
B_{21}	.80	1.00	1.00
D_{05}, C_{03}	.24	.54	.97
C_{02}, D_{06}	.35	.78	1.00
B_{03}, B_{05}	.24	.54	.97
B_{04}	.35	.78	1.00

Table 14: Fraction of area covered by borrowed channel, 60° sector, with power control.

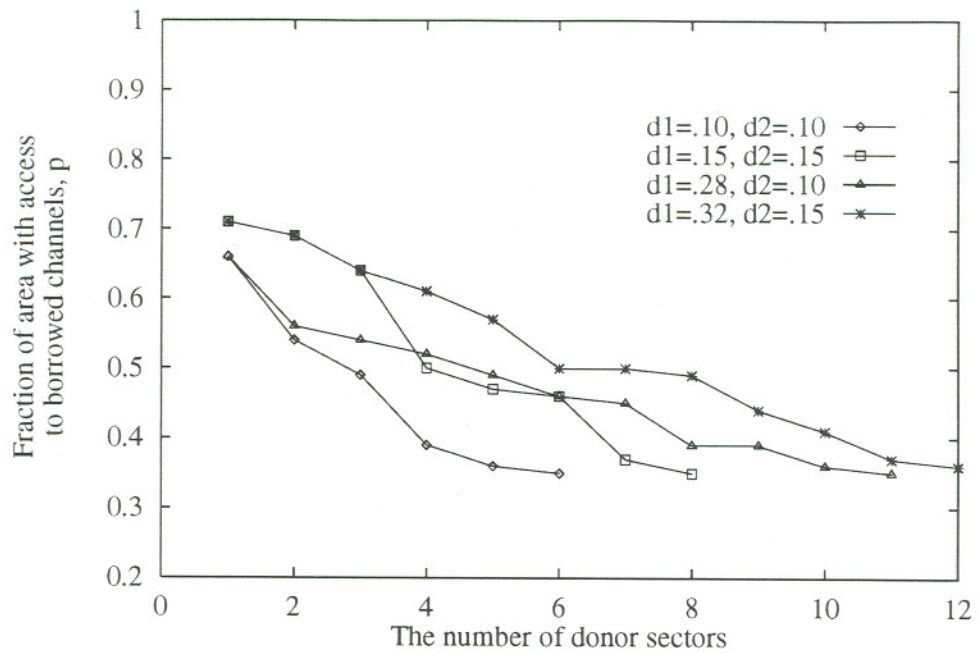
and reuse factor of 4, each sector has $\lfloor 420/24 \rfloor = 17$ channels. In this section, we are going to show some numerical results about the capacity performance of CBWL for above two configurations under different co-channel interference criteria. The analytical approach is described in [1]–[3].

From last section, we know that in sectorized CBWL, each donor sector may have different F_b . Given a SIR criterion and p , minimum requirement for F_b , a donor-sector set can be determined for each sector. The larger p is, the smaller the size of the donor sector set is. Assume that borrowed channels from every sector in a donor-sector set are used with the same F_b . The F_b is equal to p —the smallest F_b in the set. Increasing p allows more new call arrivals to use borrowed channels, thus increases the traffic capacity. But with a large p , the number of sectors in the donor-sector set must be reduced. With fewer donor sectors, the number of channels can be borrowed by the given sector is reduced. Thus the increase of traffic capacity is limited. The two parameters, p and the number of donor sectors, must be overall balanced.

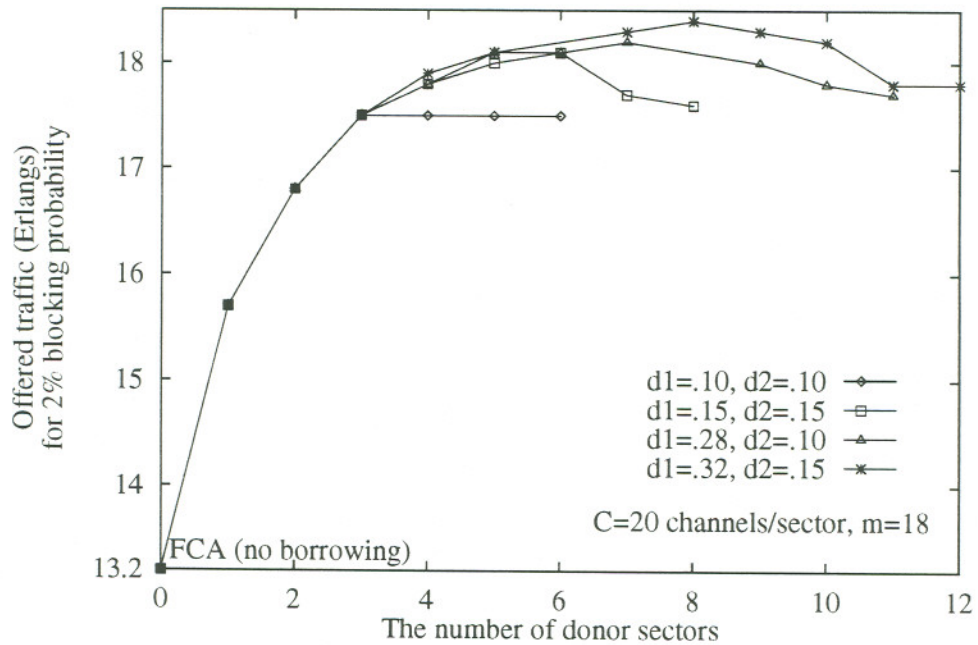
Figure 4(a) shows the relationship of p and the size of donor-sector set for each criterion of the system. Figure 4(b) shows the offered traffic that the 120° sectorized CBWL/CR (no power control) can accommodate under the requirement of 2% of blocking probability, for different size of donor-sector sets that are determined by four SIR criteria. When the size of donor-sector set is zero, no channel can be borrowed. That point gives the offered traffic that the same configuration in FCA can accommodate. The similar plots for 120° sectorized CBWL with power control, 60° sectorized CBWL without and with power control are shown in Figure 5, Figure 6 and Figure 7, respectively.

From these figures, we can find the optimum size of donor-sector set and p for a given SIR criterion. It is seen that when p is greater than 0.5, system traffic performance is not sensitive to the quantity of p , and when the number of donor sectors is more than six, the performance is not sensitive to the number of donor sectors. In general, with a p that is between 0.4–0.5 and the number of donor sectors that is between 3–6, the traffic performance is significantly enhanced.

With a 2% of blocking probability, a cell (three sectors) of 120° sectorized FCA with total of 420 channels can accommodate about 39.6 Erlangs of offered traffic (13.2 Erlangs/sector). While in 120° sectorized CBWL/CR, the load in a cell can be increased to at least 52.5 Erlangs. The traffic capacity is increased about 33%. The traffic capacity of a cell (with six sectors)

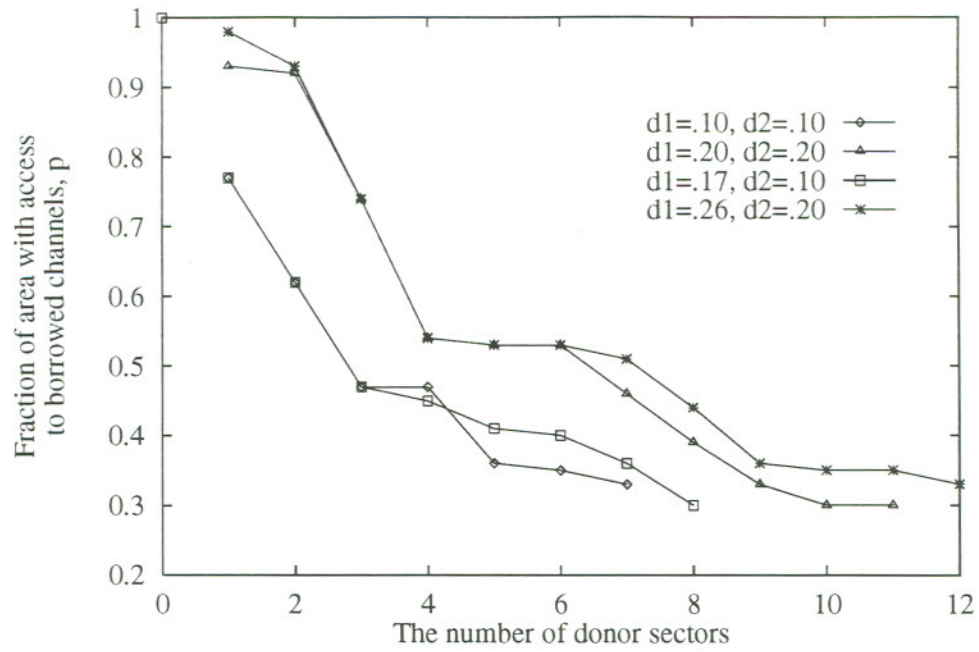


(a) The fraction of area with access to borrowed channels, p , v.s. the number of donor sectors.

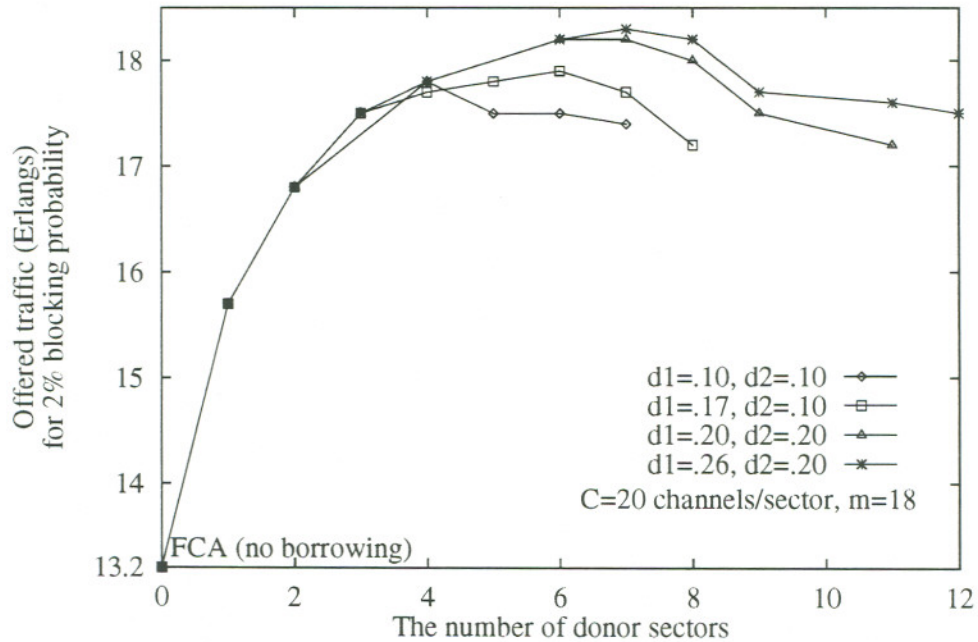


(b) Load capacity v.s. the number of donor sectors.

Figure 4: Capacity of 120° sectorized CBWL/CR (no power control).

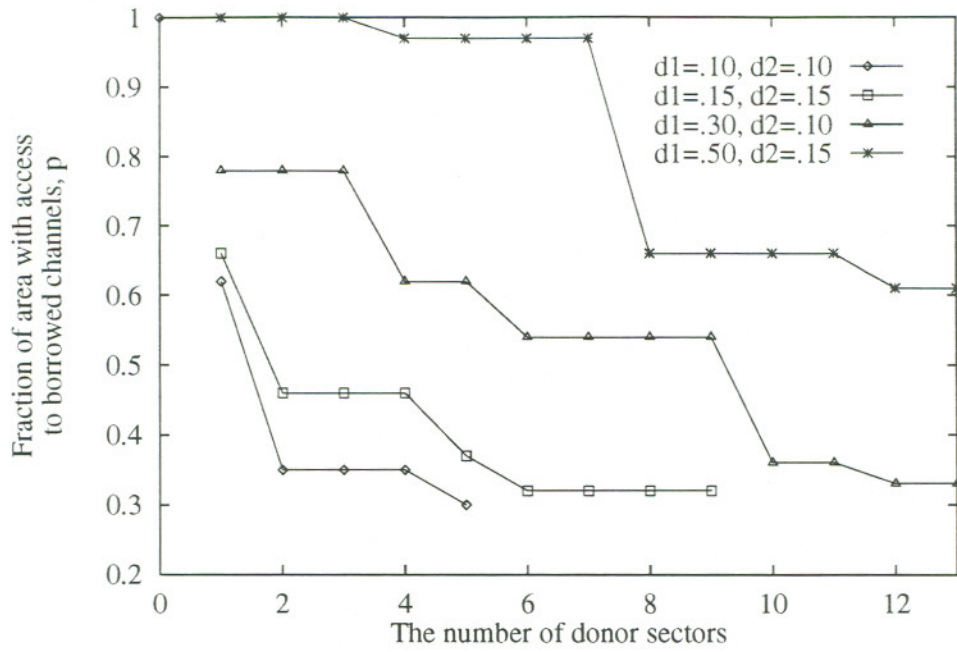


(a) The fraction of area with access to borrowed channels, p , v.s. the number of donor sectors.

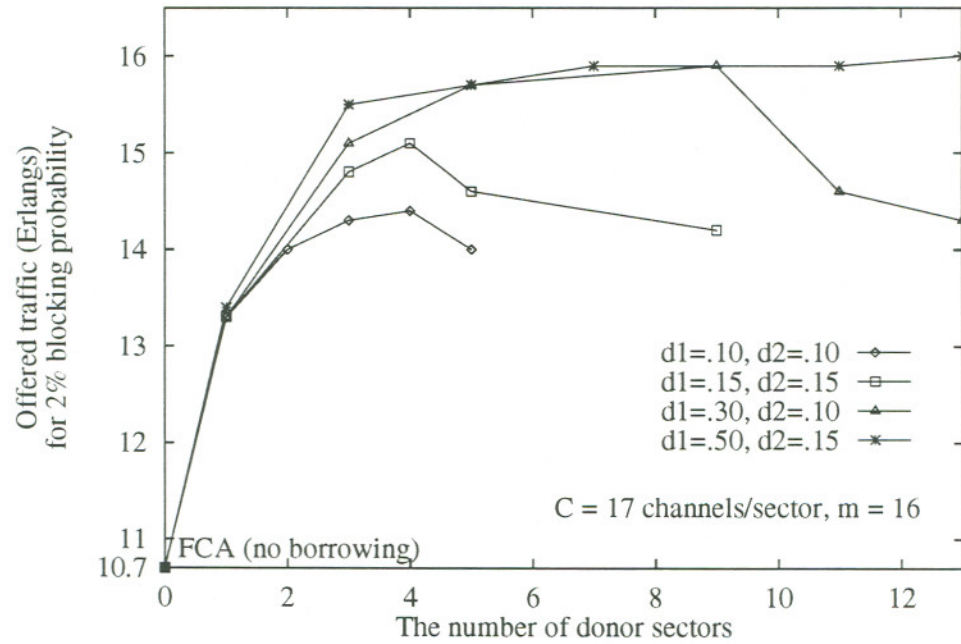


(b) Load capacity v.s. the number of donor sectors.

Figure 5: Capacity of 120° sectorized CBWL/CR (with power control).

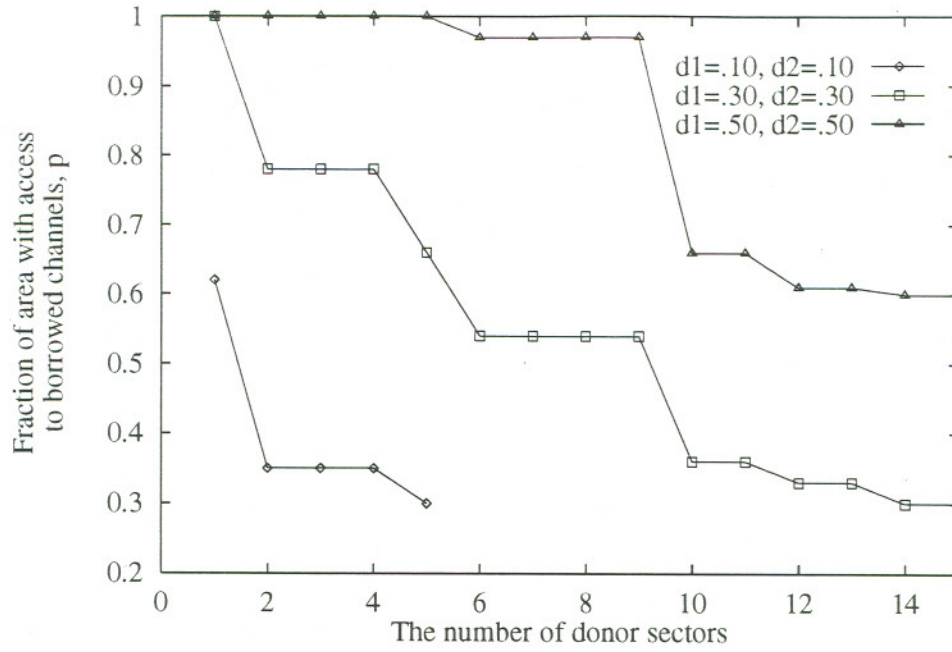


(a) The fraction of area with access to borrowed channels, p , v.s. the number of donor sectors.

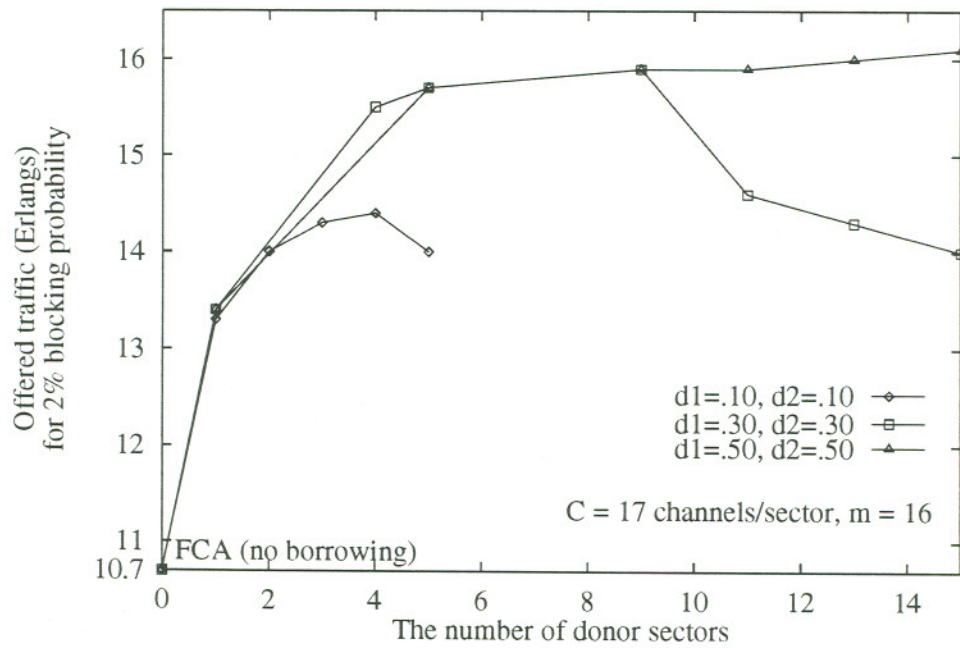


(b) Load capacity v.s. the number of donor sectors.

Figure 6: Capacity of 60° sectorized CBWL/CR (no power control).



(a) The fraction of area with access to borrowed channels, p , v.s. the number of donor sectors.



(b) Load capacity v.s. the number of donor sectors.

Figure 7: Capacity of 60° sectorized CBWL/CR (no power control).

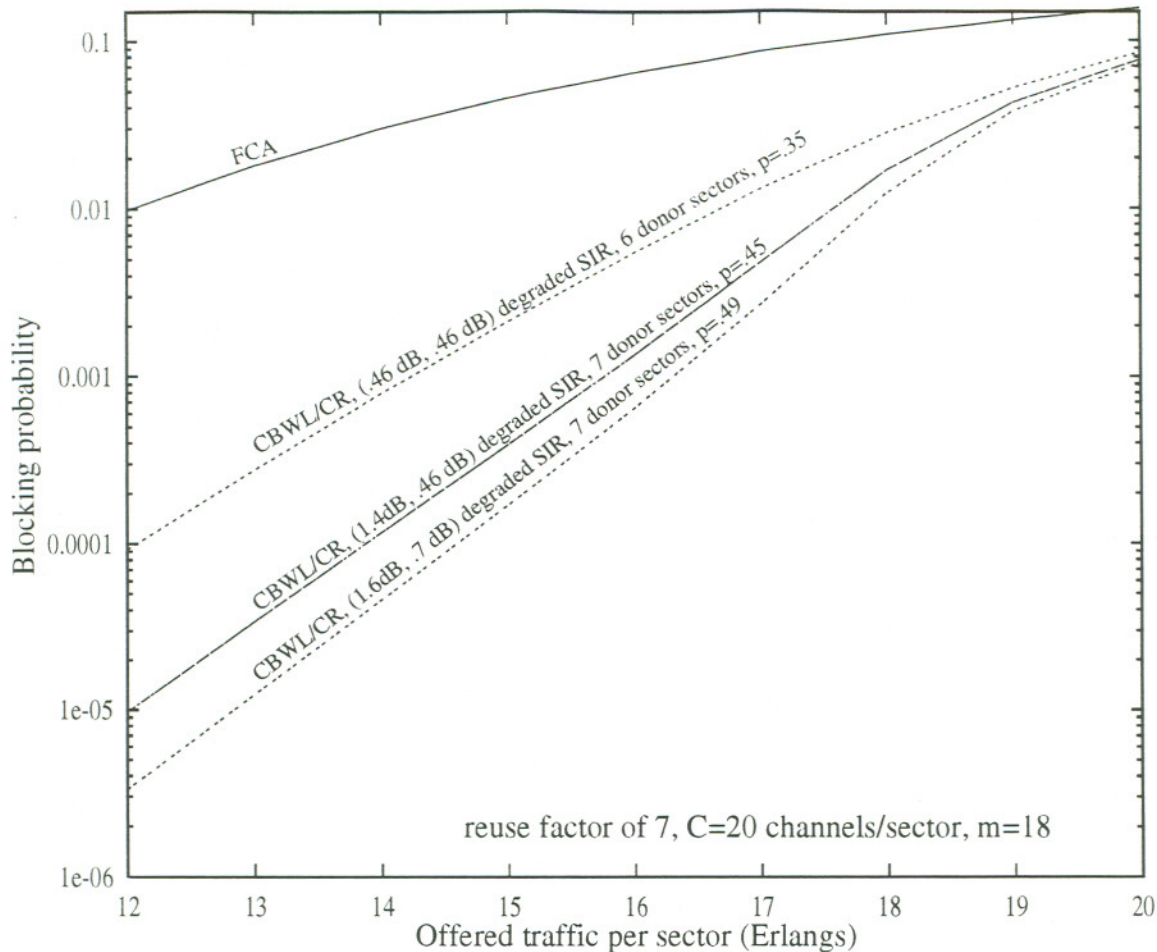


Figure 8: Blocking probabilities of 3-sector CBWL/CR, no power control.

of 60° sectorized FCA with total 420 channels is about 64 Erlangs (10.7 Erlangs/sector). Its counterpart of CBWL/CR can accommodate at least 86 Erlangs of load in a cell. The traffic capacity is increased about 35%.

Figure 8 shows the blocking probabilities against offered traffic per sector for 120° sectorized CBWL, no power control. The curves are plotted for the optimum size of donor-sector set of each SIR criteria. The blocking probabilities of FCA are also plotted for comparison. It is seen that sectorized CBWL/CR can significantly improve the blocking probability. Note that the differences between blocking probabilities of different SIR criteria are not significant.

Figure 9 is a similar diagram for 60° sectorized CBWL/CR scheme with power control. Its performance is better than 120° sectorized CBWL/CR.

4 Conclusion

We have shown that in sectorized cellular system, Channel Borrowing Without locking can be used to enhance the capacity of cellular system. With CBWL, co-channel interference is increased. However, with borrowing channels from some selected neighboring sectors and reducing the transmitted power on borrowed channels, we can minimize the increase of co-channel interference and degradation of SIR. At the cost of slight degradation in SIR, in comparison with no borrowing,

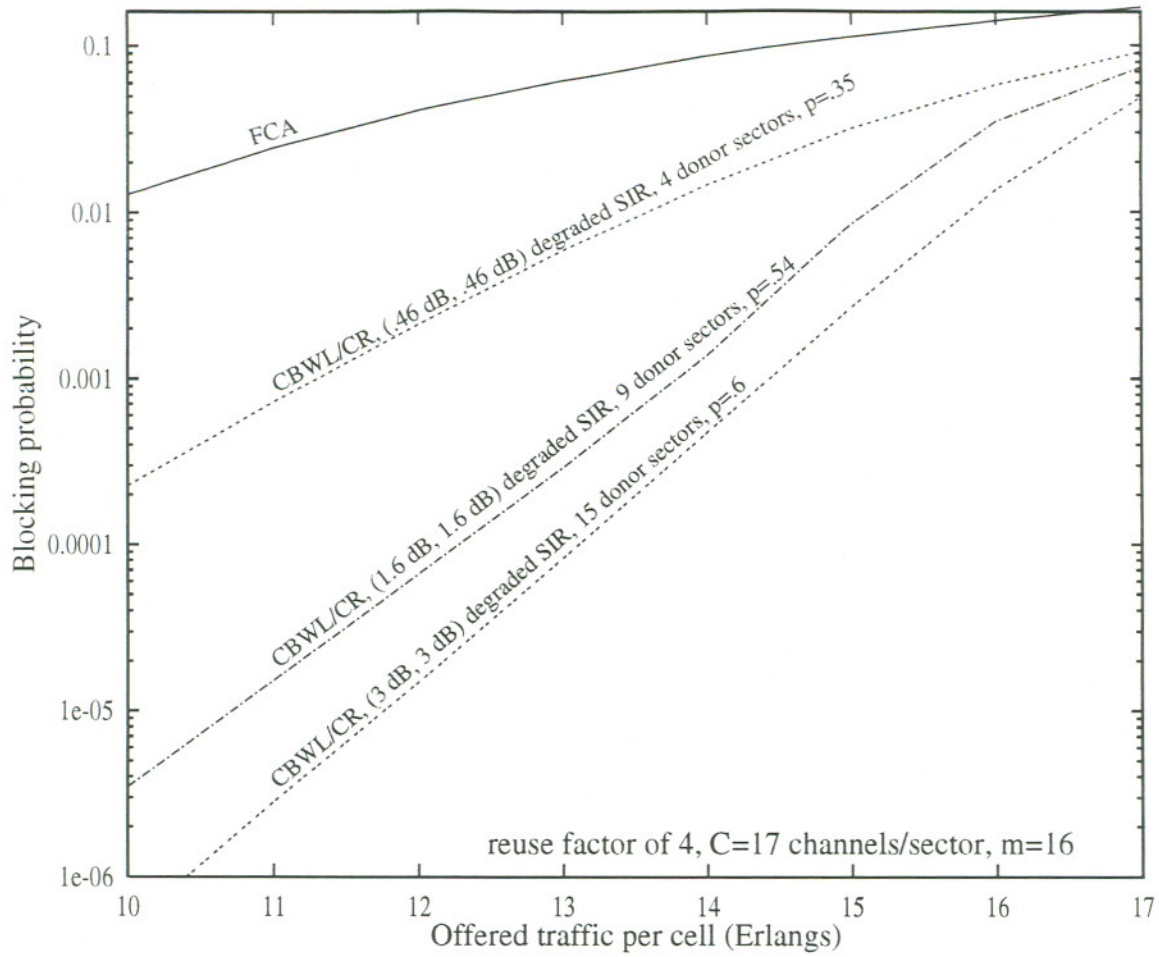


Figure 9: Blocking probabilities of 6-sector CBWL/CR, with power control.

channel capacity can be significantly enhanced with simple channel control management.

Appendix

A Calculation of SIR for FCA, 120° Antenna Configuration

A.1 Determination of Interfering Sectors

With 120° antenna, a given sector is interfered by only 2 or 3 sectors among the first ring of co-channel sectors. The interfering co-channel sectors can be determined for any reuse factor by following ways. In Figure 3, we use A_i , $i = 1, \dots, 6$ to label six first ring co-channel cells of A_0 . The label system of sectors is the same as Figure 1. A_{01} is an interfered sector. Denote the angle between the horizontal line and the line that connects the centers of A_0 and A_i as α_i . From simple trigonometry, we find

$$\alpha_1 = -\arctan \frac{2i+j}{\sqrt{3}j} = -\alpha. \quad (\text{A.1})$$

Since $i \geq j$, $\alpha \geq 60^\circ$. If $i = j$, $\alpha = 60^\circ$. If $i > j$, $\alpha > 60^\circ$. Thus, $\alpha_1 \leq -60^\circ$.

The line that connects the centers of A_0 and A_i ($i = 2, \dots, 6$) can be got by turning the line that connects the centers of A_0 and A_1 with $(i-1)60^\circ$, counterclockwise. Therefore,

$$\alpha_i = (i-1)60^\circ - \alpha, \quad i = 1, 2, \dots, 6. \quad (\text{A.2})$$

In Figure 3, from point a of sector A_{01} , we draw two lines that are extended from the sides ab and ad respectively. If a co-channel sector of A_{01} is in the region on the left of the two lines, the gateway of the sector can interfere the mobile stations in A_{01} . We called the co-channel sectors as *forward-link interfering sectors* of A_{01} . By observation, we can find that the cells that contain forward-link interfering sector must have the property of $-60^\circ \leq \alpha_i \leq 60^\circ$. From point c of sector A_{01} , we draw two lines that extended from the sides cb and cd respectively. If a co-channel sector of A_{01} is in the region on the right of the two lines, mobile stations in the sector will interfere the gateway of A_{01} . We called the co-channel sectors as *reverse-link interfering sectors* of A_{01} . By observation, we can find that the cells that contain reverse-link interfering sector must have the property of $120^\circ \leq \alpha_i \leq 240^\circ$.

Using these two properties, we can determine interfering sectors of A_{01} for any reuse factor. Two cases can be considered separately.

Case 1: $i = j$ In this case, from (A.1), $\alpha = 60^\circ$. Thus,

$$\alpha_1 = -60^\circ, \alpha_2 = 0^\circ, \alpha_3 = 60^\circ, \alpha_4 = 120^\circ, \alpha_5 = 180^\circ, \alpha_6 = 240^\circ. \quad (\text{A.3})$$

Then, A_{11} , A_{21} and A_{31} are forward-link interfering sectors of A_{01} . A_{41} , A_{51} and A_{61} are reverse-link interfering sectors of A_{01} .

Case 2: $i > j$ In this case, from (A.1), $\alpha > 60^\circ$. Thus,

$$\begin{aligned} -90^\circ \leq \alpha_1 < -60^\circ, & \quad -30^\circ \leq \alpha_2 < 0^\circ, & \quad 30^\circ \leq \alpha_3 < 60^\circ, \\ 90^\circ \leq \alpha_4 < 120^\circ, & \quad 150^\circ \leq \alpha_5 < 180^\circ, & \quad 210^\circ \leq \alpha_6 < 240^\circ. \end{aligned} \quad (\text{A.4})$$

Then, A_{21} and A_{31} are forward-link interfering sectors of A_{01} . A_{51} and A_{61} are reverse-link interfering sectors of A_{01} . Note, if $i > j$, the number of interfering sectors is reduced by one.

A.2 Calculation of SIR for FCA

With flat, uniform propagation, SIR is determined by the distance between receiver and transmitter and the distance between receiver and interferers. To calculate these distances, we use a coordinate system with its origin at the center of A_0 . Denote the coordinates of center of A_i as (x_i, y_i) ($i = 0, 1, \dots, 6$). Thus $(x_0, y_0) = (0, 0)$. Given reuse factor $N = i^2 + ij + j^2$, other (x_i, y_i) can also be determined. From Figure 3, we can find

$$\begin{aligned}
x_1 &= -j\sqrt{3}R \sin 60^\circ = -1.5jR \\
y_1 &= \sqrt{3}R(i + j \cos 60^\circ) = \sqrt{3}R(i + .5j) \\
x_2 &= -\sqrt{3}R(i \sin 60^\circ + j \cos 30^\circ) = -1.5R(i + j) \\
y_2 &= \sqrt{3}R(i \cos 60^\circ - j \sin 30^\circ) = .5\sqrt{3}R(i - j) \\
x_3 &= -i\sqrt{3}R \cos 30^\circ = -1.5iR \\
y_3 &= -\sqrt{3}R(i \sin 30^\circ + j) = -\sqrt{3}R(.5i + j) \\
x_4 &= j\sqrt{3}R \sin 60^\circ = 1.5jR \\
y_4 &= -\sqrt{3}R(i + j \cos 60^\circ) = -\sqrt{3}R(i + .5j) \\
x_5 &= \sqrt{3}R(i \sin 60^\circ + j \cos 30^\circ) = 1.5R(i + j) \\
y_5 &= -\sqrt{3}R(i \cos 60^\circ - j \sin 30^\circ) = -.5\sqrt{3}R(i - j) \\
x_6 &= i\sqrt{3}R \cos 30^\circ = 1.5iR \\
y_6 &= \sqrt{3}R(i \sin 30^\circ + j) = \sqrt{3}R(.5i + j) .
\end{aligned} \tag{A.5}$$

A.2.1 Layout A: 120° Sectorized FCA, No Power Control

Forward-link SIR: $SIR-A_{FO}$

If $i > j$, The interferers are the gateways of A_{21} and A_{31} . If $i = j$, The interferers are the gateways of A_{11} , A_{21} and A_{31} . In the worst case, the interfered mobile station in A_{01} is at m_0 (Figure 3). The coordinates of m_0 is $(.5R, -.5\sqrt{3}R)$. The distance between m_0 and the gateway of A_{01} is R . The distances between m_0 and the gateway of A_{11} , A_{21} and A_{31} are

$$\begin{aligned}
D(m_0, A_{11}) &= \sqrt{(x_1 - .5R)^2 + (y_1 + .5\sqrt{3}R)^2} = \sqrt{3N + 1 + 6jR} \\
D(m_0, A_{21}) &= \sqrt{(x_2 - .5R)^2 + (y_2 + .5\sqrt{3}R)^2} = \sqrt{3N + 1 + 3iR} \\
D(m_0, A_{31}) &= \sqrt{(x_3 - .5R)^2 + (y_3 + .5\sqrt{3}R)^2} = \sqrt{3N + 1 - 3jR} .
\end{aligned} \tag{A.6}$$

where A_{i1} means the position of gateway of A_{i1} . The antennas of all gateways are of equal height, gain and transmitted power. According to the reciprocity theorem of radio propagation, the received signal-to-interference ratio at the desired mobile receiver can be expressed as

$$SIR-A_{FO} = \begin{cases} \left[(3N + 1 + 3i)^{-\frac{\gamma}{2}} + (3N + 1 - 3j)^{-\frac{\gamma}{2}} \right]^{-1} & i > j \\ \left[(3N + 1 + 6i)^{-\frac{\gamma}{2}} + (3N + 1 + 3i)^{-\frac{\gamma}{2}} + (3N + 1 - 3i)^{-\frac{\gamma}{2}} \right]^{-1} & i = j \end{cases} \tag{A.7}$$

where γ is a propagation exponent [14] determined by actual terrain environment; γ usually lies between three and five.

Reverse-link SIR: $SIR-A_{RO}$

If power control is not employed, a mobile station transmits with the same power at any position in a sector. In the worst case, the interfering mobile station in a co-channel sector is at

the nearest position to the gateway of A_{01} . In A_{61} , the position is $m_1(x_6 + .5R, y_6 - .5\sqrt{3}R)$. In A_{51} , the position is the gateway of A_{51} (Figure 3). If $i = j$, another interfering mobile station $m_2(x_4 + .5R, y_4 + .5\sqrt{3}R)$ in A_{41} must be included. Their distances to the gateway of A_{01} are

$$\begin{aligned} D(m_1, A_{01}) &= \sqrt{(x_6 + .5R)^2 + (y_6 - .5\sqrt{3}R)^2} = \sqrt{3N + 1 - 3j}R \\ D(A_{51}, A_{01}) &= \sqrt{x_5^2 + y_5^2} = \sqrt{3N}R \\ D(m_2, A_{01}) &= \sqrt{(x_4 + .5R)^2 + (y_4 + .5\sqrt{3}R)^2} = \sqrt{3N + 1 - 3i}R \end{aligned} \quad (\text{A.8})$$

In the worst case, the desired mobile station is at a vertex of A_{01} . The distance from the mobile station to the gateway of A_{01} is R . The reverse-link SIR no power control is

$$SIR-A_{RO} = \begin{cases} \frac{1}{(3N)^{-\frac{\gamma}{2}} + (3N+1-3j)^{-\frac{\gamma}{2}}} & i > j, \\ \frac{1}{(3N)^{-\frac{\gamma}{2}} + 2(3N+1-3j)^{-\frac{\gamma}{2}}} & i = j. \end{cases} \quad (\text{A.9})$$

A.2.2 Layout B: 120° Sectorized FCA, with Power Control

Forward-link SIR: $SIR-B_{FO}$

$SIR-B_{FO}$ is the same as $SIR-A_{FO}$ in (A.7).

Reverse-link SIR: $SIR-B_{RO}$

With power control, the transmitted power of a mobile station can be adjusted such that in desired gateway the received power from all mobile stations in this sector are the same. When a mobile station is at the vertex of a sector, it transmits with its maximum power and causes the strongest interference to its co-channel sectors. Thus in the worst case, the interfering mobile stations are at the nearest *vertex* in co-channel sectors. In A_{51} , in the worst case, the interfering mobile is at $m_3(x_5 + .5R, y_5 + .5\sqrt{3}R)$ (Figure 3). In other co-channel sectors, the worst position of interfering mobile station is the same as that no power control. The distance between m_3 and the gateway of A_{01} is

$$D(m_3, A_{01}) = \sqrt{(x_5 + .5R)^2 + (y_5 + .5\sqrt{3}R)^2} = \sqrt{3N + 1 + 3j}R. \quad (\text{A.10})$$

The SIR in reverse link with power control is

$$SIR-B_{RO} = \begin{cases} \frac{1}{(3N+1+3j)^{-\frac{\gamma}{2}} + (3N+1-3j)^{-\frac{\gamma}{2}}} & i > j, \\ \frac{1}{(3N+1+3j)^{-\frac{\gamma}{2}} + 2(3N+1-3j)^{-\frac{\gamma}{2}}} & i = j. \end{cases} \quad (\text{A.11})$$

B Calculation of SIR for FCA, 60° Antenna Configuration

B.1 Determination of Interfering Sectors

Using similar analysis to 120° system, we can find the two rules to determine forward-link and reverse-link interfering sectors of 60° antenna configuration.

Rule 1: The cells that contain forward-link interfering sectors of A_{01} must have the property of $-60^\circ \leq \alpha_i \leq 0^\circ$.

Rule 2: The cells that contain reverse-link interfering sectors of A_{01} must have the property of $120^\circ \leq \alpha_i \leq 180^\circ$.

Using the two rules, we can determine interfering sectors of A_{01} (Figure 10).

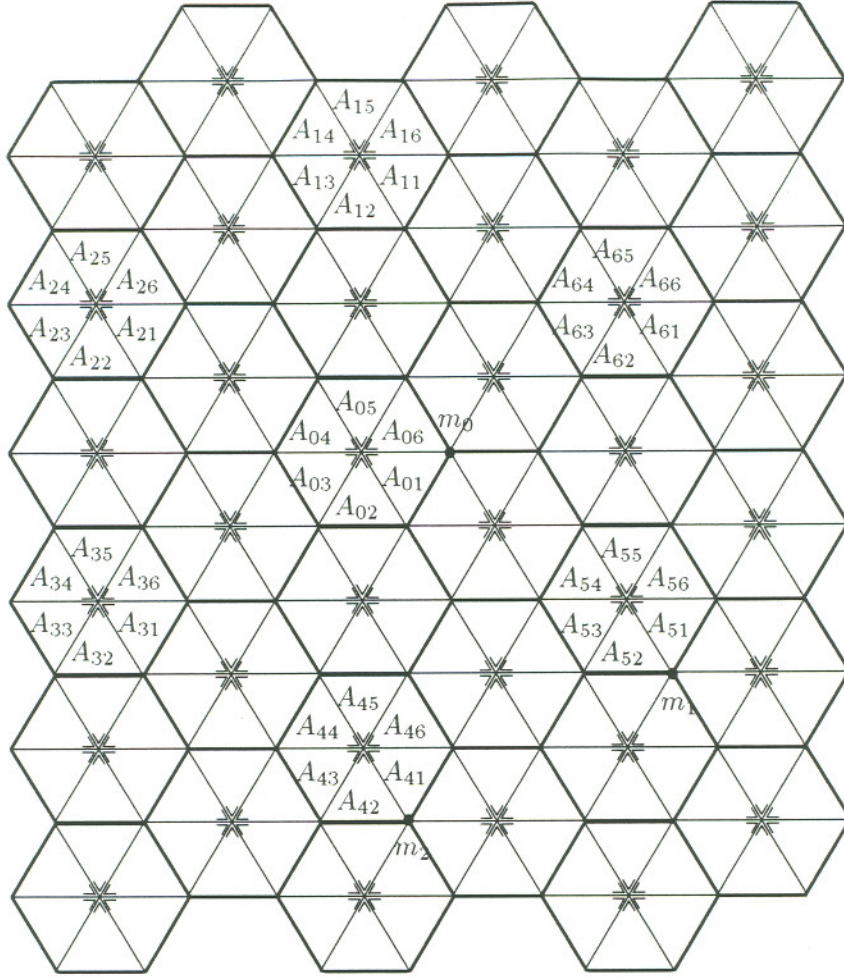


Figure 10: Co-channel sectors of A_{01} in 60° sectorized cellular system with reuse factor of 4.

Case 1, $i = j$

From (A.3), we find that the forward-link interfering sectors of A_{01} are A_{11} and A_{21} , the reverse-link interfering sectors of A_{01} are A_{41} and A_{51} .

Case 2, $i > j$

From (A.4), we find that the forward-link interfering sector of A_{01} is A_{21} , the reverse-link interfering sector of A_{01} is A_{51} .

B.2 Calculation of SIR for FCA

B.2.1 Layout C: 60° sectorized FCA, No Power Control

Forward-link SIR: $SIR-C_{FO}$

Interference are from the gateways of A_{21} . If $i = j$, the gateway of A_{11} is another interference. In the worst case, the interfered mobile station in A_{01} is at $m_0(R, 0)$. The distance between transmitter and receiver is R . The distances between m_0 and the gateway of A_{11} and A_{21} are

$$D(m_0, A_{11}) = \sqrt{(x_1 - R)^2 + y_1^2} = \sqrt{3N + 1 + 3j}R$$

$$D(m_0, A_{21}) = \sqrt{(x_2 - R)^2 + y_2^2} = \sqrt{3N + 1 + 3(i + j)}R \quad (\text{B.1})$$

The forward-link SIR is

$$SIR-C_{FO} = \begin{cases} [3N + 1 + 3(i + j)]^{\frac{\gamma}{2}} & i > j \\ \left\{ (3N + 1 + 3j)^{-\frac{\gamma}{2}} + [(3N + 1 + 3(i + j))]^{-\frac{\gamma}{2}} \right\}^{-1} & i = j. \end{cases} \quad (\text{B.2})$$

Reverse-link SIR: $SIR-C_{RO}$

Without power control, in the worst case, the interfering mobile station in a co-channel sector is at the nearest position to the gateway of A_{01} . The position is at the gateway of A_{51} (Figure 10). If $i = j$, an additional interfering mobile station at the gateway of A_{41} must be included. Their distances to the gateway of A_{01} are

$$\begin{aligned} D(A_{51}, A_{01}) &= \sqrt{x_5^2 + y_5^2} = \sqrt{3N}R \\ D(A_{41}, A_{01}) &= \sqrt{x_4^2 + y_4^2} = \sqrt{3N}R. \end{aligned} \quad (\text{B.3})$$

The reverse-link SIR no power control is

$$SIR-C_{RO} = \begin{cases} (3N)^{\frac{\gamma}{2}} & i > j, \\ \frac{1}{2}(3N)^{\frac{\gamma}{2}} & i = j. \end{cases} \quad (\text{B.4})$$

B.2.2 Layout D: 60° Sectorized FCA, with Power Control

Forward-link SIR: $SIR-D_{FO}$

$SIR-D_{FO}$ is the same as $SIR-C_{FO}$ in (B.2).

Reverse-link SIR: $SIR-D_{RO}$

With power control, in the worst case, the interfering mobile stations are at the nearest *vertex* in co-channel sectors. In A_{51} , the position is $m_1(x_5 + .5R, y_5 - .5\sqrt{3}R)$ (Figure 10). In A_{41} , the position is $m_2(x_4 + R, y_4)$. The distances between m_1, m_2 and the gateway of A_{01} are

$$\begin{aligned} D(m_1, A_{01}) &= \sqrt{(x_5 + .5R)^2 + (y_5 - .5\sqrt{3}R)^2} = \sqrt{3N + 1 + 3i}R \\ D(m_2, A_{01}) &= \sqrt{(x_4 + R)^2 + y_4^2} = \sqrt{3N + 1 + 3j}R. \end{aligned} \quad (\text{B.5})$$

The reverse-link SIR with power control is

$$SIR-D_{RO} = \begin{cases} (3N + 1 + 3i)^{\frac{\gamma}{2}} & i > j, \\ \frac{1}{2}(3N + 1 + 3i)^{\frac{\gamma}{2}} & i = j. \end{cases} \quad (\text{B.6})$$

C Calculation of SIR in Sectorized CBWL

In sectorized CBWL, when a gateway borrows channels from its different donor sectors, the SIR's may be different. Here we only consider an example that the given gateway borrows a channel from a specific sector. We use the example to describe the method to calculate SIR of sectorized CBWL.

We consider the 120° sectorized CBWL system in Figure 1. The borrowing sector is A_{01} . A_{01} borrows a channel from E_{01} . Without power control, gateway and mobile stations always transmit with their maximum power. With power control, in the worst case, mobile stations and

gateways transmit with their maximum power. In this paper, since we only consider SIR's in the worst case, we use maximum transmitted power in our analysis. We denote the maximum power transmitted on the borrowed channel for the forward link as P_{FB} , the maximum power transmitted on the borrowed channel for the reverse link as P_{RB} , the maximum power transmitted on a regular channel for the forward link as P_{FN} and the maximum power transmitted on a regular channel for reverse link as P_{RN} . For CBWL, we have to distinguish four types of SIR's: (1) SIR of reverse link on borrowed channel, SIR_{RB} . (2) SIR of forward link on borrowed channels, SIR_{FB} . (3) SIR of reverse link on regular channels, SIR_{RN} . (4) SIR of forward link on regular channels, SIR_{FN} . On the forward link, SIR's are the same with or without power control. On the reverse link, in the worst case, with power control, interfering mobile station is at the closest vertex of co-channel sector and no power control, the interfering mobile station is at the closest point. Thus, on the reverse link, SIR's will be analyzed separately for cases with and without control. The SIR's are calculated below. The reader is referred to Figure 1.

C.1 Layout A: 120° Sectorized CBWL, No Power Control

C.1.1 Forward-Link SIR on Regular Channels: $SIR-A_{FN}$

When A_{01} borrows a channel from E_{01} , the transmission on the borrowed channel will interfere with the co-channel users in E_{41} , E_{51} and E_{61} . Because the reuse distances of the borrowed channel from A_{01} to E_{51} and E_{61} are longer than the ordinary reuse distance, the co-interference to mobile stations in E_{51} and E_{61} is reduced. However, with the channel being borrowed from E_{01} to A_{01} , the gateway of A_{01} becomes an *additional* interferer to the co-channel user in E_{41} . Therefore, the co-channel user in E_{41} is the most severely interfered. If the co-channel user is at m_0 , it receives the ordinary co-channel interference of FCA (see Appendix A) plus an additional interference from A_{01} . The distance from m_0 to the gateway of A_{01} is $7R$. Thus,

$$SIR-A_{FN} = \frac{P_{FN}R^{-\gamma}}{(P_{FB}49^{-\frac{\gamma}{2}} + P_{FN}SIR-A_{FO}^{-1})R^{-\gamma}} = \frac{1}{P_f49^{-\frac{\gamma}{2}} + SIR-A_{FO}^{-1}} \quad (C.1)$$

where $P_f = P_{FB}/P_{FN}$ is the ratio of the transmitted power on borrowed channel to the transmitted power on regular channel in forward link.

C.1.2 Forward-Link SIR on Borrowed Channel: $SIR-A_{FB}$

The mobile station that uses borrowed channel in A_{01} is only interfered by the gateway of E_{21} (the number of interferers is reduced). In the worst case, the mobile station is close to m_1 . The distance from m_1 to the gateway of E_{21} is *about* $\sqrt{13}R$. The distance between the mobile station to the gateway of A_{01} is r_1 . Thus,

$$SIR-A_{FB} = \frac{P_{FB}r_1^{-\gamma}}{P_{FN}(\sqrt{13}R)^{-\gamma}} = P_f\left(\frac{R}{r_1}\right)^{\gamma}13^{-\frac{\gamma}{2}}. \quad (C.2)$$

C.1.3 Reverse-Link SIR on Regular Channel: $SIR-A_{RN}$

The mobile station that uses the borrowed channel in A_{01} interferes with the gateway of E_{21} . Without power control, in the worst case, the mobile station is at the gateway of A_{01} . The distance

between the gateways of A_{01} and E_{21} is $3R$. Another co-channel interferer to the gateway of E_{21} is co-channel user in E_{11} (regular channel). The distance between them is $\sqrt{19}R$. Thus,

$$SIR-A_{RN} = \frac{P_{RN}R^{-\gamma}}{(P_{RB}9^{-\frac{\gamma}{2}} + P_{RN}19^{-\frac{\gamma}{2}})R^{-\gamma}} = \frac{1}{P_r 9^{-\frac{\gamma}{2}} + 19^{-\frac{\gamma}{2}}} \quad (C.3)$$

where $P_r = P_{RB}/P_{RN}$ is the ratio of the transmitted power on borrowed channel to the transmitted power on regular channel in reverse link.

C.1.4 Reverse-Link SIR on Borrowed Channels: $SIR-A_{RB}$

On the borrowed channel, the gateway of A_{01} is interfered by co-channel users in E_{41} , E_{51} and E_{61} . In the worst case, these co-channel users are at m_0 in E_{41} , the gateway of E_{51} and m_2 in E_{61} , respectively. Their distances to the gateway of A_{01} are $\sqrt{31}R$, $\sqrt{39}R$ and $\sqrt{28}R$. The distance between the desired user in A_{01} to the gateway of A_{01} is r_2 .

$$SIR-A_{RB} = \frac{P_{RB}r_2^{-\gamma}}{P_{RN}(28^{-\frac{\gamma}{2}} + 31^{-\frac{\gamma}{2}} + 39^{-\frac{\gamma}{2}})R^{-\gamma}} = \left(\frac{R}{r_2}\right)^{\gamma} \frac{P_r}{28^{-\frac{\gamma}{2}} + 31^{-\frac{\gamma}{2}} + 39^{-\frac{\gamma}{2}}} \quad (C.4)$$

C.2 Layout B: 120° Sectorized CBWL, with Power Control

On the forward link, $SIR-B_{FN}$ and $SIR-B_{FB}$ are the same as $SIR-A_{FN}$ and $SIR-A_{FB}$ in layout A.

C.2.1 Reverse-Link SIR on Regular Channel: $SIR-B_{RN}$

With power control, in the worst case, the interfering mobile station in A_{01} is at m_1 . The distance between m_1 and the gateway of E_{21} is $\sqrt{13}R$. Thus, equation (C.3) becomes

$$SIR-B_{RN} = \frac{1}{P_r 13^{-\frac{\gamma}{2}} + 19^{-\frac{\gamma}{2}}} \quad (C.5)$$

C.2.2 Reverse-Link SIR on Borrowed Channels: $SIR-B_{RB}$

With power control, in the worst case, in E_{51} , the interfering mobile station is not at the gateway, but at m_3 . The distance between the mobile station to the gateway of A_{01} is $\sqrt{43}R$. The other two interfering mobile stations are not changed. Thus,

$$SIR-B_{RB} = \left(\frac{R}{r_2}\right)^{\gamma} \frac{P_r}{28^{-\frac{\gamma}{2}} + 31^{-\frac{\gamma}{2}} + 39^{-\frac{\gamma}{2}}} \quad (C.6)$$

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