Performance of a Microcellular Network in a More Realistic Condition

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ABSTRACT

This paper presents a study on interference in microcellular networks with reuse patterns based on a square grid. The performance of the system is assessed by means of the carrier-to-interference (C/I) ratio for a series of situations such as: the worst case condition, mobiles randomly positioned, and channel activity according to a given traffic intensity. General formulas are presented for all possible reuse patterns, and graphical results are presented for systems with clusters of 5, 8, 9, 10 and 13 microcells. The results show an outstanding improvement in performance when compared to those for the worst case condition presented in previous works of the same authors.

1. INTRODUCTION

With the increase of the number of mobile radio users, and with the concept of a truly personal communication becoming more of a reality, the need for an ample microcellular network to supply this growing demand is indisputable. A microcellular system must provide for a high spectrum efficiency to counterbalance its large cost due to the number of base stations needed, the great effort in positioning these base stations and the strict handoff and control requirements. This spectrum efficiency, or reuse efficiency, is dependent on the interfering environment.

The urban microcellular network comprises short radio paths and small, low-power sites with antennas positioned well below the rooftops of surrounding buildings[1-7]. Radio propagation path in this case occurs in two modes: in a line-of-sight (LOS) mode, with a strong received signal, and in a non-line-of-sight (NLOS) mode, with a much weaker received signal. The asymmetric nature of propagation in the microcellular networks is therefore evident. As a result, the hexagonal cell pattern used for designing macrocellular systems no longer applies, for it assumes isotropic propagation. Different reuse patterns, based on a square grid, have been proposed and analyzed in [1,2].

In [1,2], the performance parameter was the carrier-to-interference (C/I) ratio, analyzed for the interferers positioned for the worst case condition and for the radio channels fully active. The results showed that, even for such a harsh condition, some of the proposed reuse patterns, such as the 5-microcell per cluster, showed a promising performance.

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This paper deepens the investigation on the performance of the several proposed reuse patterns by now considering more realistic conditions. These realistic conditions include, for instance, the interferer to be randomly positioned within the microcell and the channel to be active according to a given traffic intensity. Only the line-of-sight condition of the interferer is considered as contributing to the overall interference computation. The contribution of the obstructed interferers to the overall interference is a subject of a further investigation. Therefore, what is to be shown here may be considered as an upperbound performance, for the given parameters. In contrast, [1,2] may be considered as a lowerbound performance.

2. INSIGHT INTO THE PROBLEM

The performance analysis carried out in this paper considers square grid cellular patterns with their centered base stations positioned every other corner as in [1,2]. This implies that the base stations are collinear and that each microcell covers a square area comprised of four 90°-sector, each sector corresponding to one-half of a block, with the streets running on the diagonals of this square. Figure 1 shows this cellular layout. The horizontal and vertical lines represent the streets, and the diagonal lines represent the microcells' limits. A microcell is highlighted in the figure in order to evidence its location.

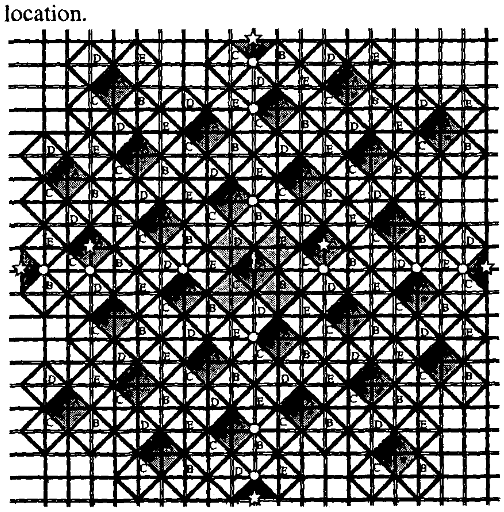

Figure 1: Five-microcell cluster tessellation

The number of microcells per cluster is found to be $N = i^2 + j^2$ [1], leading to clusters accommodating 1, 2, 4, 5, 8, 9, 10, 13, 16, ... microcells. In order to give an insight into how the calculations are performed, we illustrate in Figures 1 and 2 the complete tessellation for clusters containing 5 and 8 cells, in which the highlighted cluster contains the target cell, and the other dark cells correspond to the co-microcells that at a certain time may interfere with the mobile or base station of interest. It is interesting to note that, as far as the microcellular grid is concerned, there is a substantial difference between the situations considered for the performance evaluation of the uplink and downlink. In general, the set of microcells affecting the downlink constitutes a subset of those influencing the uplink. In Figures 1 and 2 the stars indicate the sites contributing to the C/I performance on the downlink, whereas the circles point the worst case location of the mobile affecting the uplink.

It is noteworthy that some of the proposed patterns tessellate into staggered configurations with the closer interferers being either completely obstructed or obstructed for most of the time with a LOS interferer appearing many blocks away. It is also worth emphasizing that for clusters with a prime number of constituent cells, as is the case of the 5 cell cluster of Figure 1, the base stations that interfere with the target mobile in the downlink change as the mobile moves along the street.

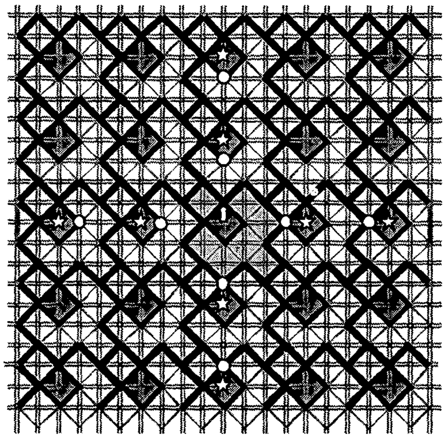

Figure 2: Eight-microcell cluster tessellation

Previous works [1,2] show that for interferers positioned at the worst case condition, the uplink C/I parameter is giver by

$$\frac{C}{I}=\frac{\left[1+(rk)^2\right]^{-1}}{4r^2\sum_{i=1}^{\infty} n_i^{-2}\left[1+(n_i k)^2\right]^{-1}} \qquad (1)$$

where r is the serving base station-to-mobile station distance normalized with respect to the cell radius ($0 < r \leq 1$), k is the ratio between the cell radius and the break point ($k \geq 0$), and n_i=1, 2, 3, ... is the distance between the interferers at the *ith* layer and the target cell site, given in number of units of the cell radius.

In the same way, a C/I ratio can be found for the downlink. However, this ratio depends on the position of the target mobile with respect to its serving base station because, as the mobile moves from the cell center towards the next corner, it acquires a new line-of-sight, and it may find new interfering base stations. Therefore, for the downlink and for the mobile at the vicinity of its serving base station, more specifically, at the intersection of the streets of the station ($r \leq$ normalized distance from the site to the beginning of the street) the *C/I* ratio [1,2] is

$$\frac{C}{I}=\frac{\left[1+(rk)^2\right]^{-1}}{r^2\sum_{i=1}^{\infty}\left\{\begin{array}{l}(n_i+r)^{-2}\left[1+(n_i+r)^2k^2\right]^{-1}+(n_i-r)^{-2}\left[1+(n_i-r)^2k^2\right]^{-1}\\ +2\left(n_i^2+r^2\right)^{-1}\left[1+\left(n_i^2+r^2\right)k^2\right]^{-1}\end{array}\right\}} \qquad (2)$$

Away from the vicinity of the serving base station, which corresponds to most of the path, the *C/I* ratio [1,2] is

$$\frac{C}{I}=\frac{\left[1+(rk)^2\right]^{-1}}{r^2\sum_{i=1}^{\infty}\left\{(n_i+r)^{-2}\left[1+(n_i+r)^2k^2\right]^{-1}+(n_i-r)^{-2}\left[1+(n_i-r)^2k^2\right]^{-1}\right\}} \qquad (3)$$

There is one more situation of mobile positioning that can experience different interferers. That is the moment in which the mobile reaches the opposite intersection of that of its serving base station, acquiring a new line-of-sight. However, this is not the case for all reuse patterns. This phenomenon only happens for clusters with a prime number of cells, as, for example, in the case of 5 cell clusters illustrated in Figure 1. Hence, for clusters with a prime number of cells and the mobile distant from its serving base station ($1-r \leq$ normalized distance from the site to the beginning of the street) the *C/I* ratio [1,2] is

$$\frac{C}{I}=\frac{\left[1+(rk)^2\right]^{-1}}{r^2\sum_{i=1}^{\infty}\left\{\begin{array}{l}(n_i+r)^{-2}\left[1+(n_i+r)^2k^2\right]^{-1}+(n_i-r)^{-2}\left[1+(n_i-r)^2k^2\right]^{-1}\\ +2\left(n_i^2+r^2\right)^{-1}\left[1+\left(n_i^2+r^2\right)k^2\right]^{-1}\end{array}\right\}} \qquad (4)$$

Finally, to achieve a precise result of the C/I ratio, a general formulation for n_i is defined [3]. For the case of macrocells, which make use of an hexagonal mosaic, the distance from a cell and an interferer co-cell is defined by the number of cells in a cluster and by the cell radius. However, in the case of microcells, as the radiation of the antennas is not the same in all directions, this distance varies with the type of tessellation used. For example, in a pattern that tessellates into a staggered configuration, there is a greater blocking of the co-cells signals than in a pattern that tessellates into a collinear configuration. In such a case, interferers appear at further distances.

The proposed microcellular reuse grid has been exercised over several patterns. In particular, the results to be shown here consider clusters with 5, 8, 9, 10 and 13 microcells. The performance has been evaluated for the mobile subscriber departing from the center of the target cell toward its edge, considering the radius of the microcell as 100 m, a street width of 15 m, the transmitter and receiver antennas heights respectively equal to 4 m and 1.5 m, and an operation frequency of 890 MHz, which lead to $k = 1.405$ [1,2].

3. RANDOMLY POSITIONED MOBILES CASE

This section considers the system operating at full load, but with the mobiles positioned randomly. Assume an uniform probability distribution for the location of a mobile within a cell.

Let i be the number of interferers, i_{LOS} ($0 \le i_{LOS} \le i$) a subset of the interferers that are in a line-of-sight condition, and $i_{NLOS} = i - i_{LOS}$ those that are in an obstructed situation. Let p_{LOS} be the probability of a mobile being in line-of-sight, and $p_{LOS,NLOS}$ be the probability of having i_{LOS} interferers in line-of-sight.

Let $E[C/I|i_{LOS}, i_{NLOS}]$ be the carrier-to-interference ratio estimated in such a case. The overall mean carrier-to-interference ratio is therefore

$$E[C/I] = \sum_{i_{LOS}=0}^{i} E[C/I \mid i_{LOS}, i_{NLOS}] p_{LOS,NLOS} \quad (5)$$

where $p_{LOS,NLOS}$ may be given by (6) or (7), depending on the reuse pattern being used.

$$p_{LOS,NLOS} = \binom{i}{i_{LOS}} p_{LOS}^{i_{LOS}} \cdot p_{NLOS}^{i_{NLOS}} \quad (6)$$

$$p_{LOS,NLOS} = \binom{i^{(1)}}{i_{LOS}^{(1)}} \left(p_{LOS}^{(1)}\right)^{i_{LOS}^{(1)}} \cdot \left(p_{NLOS}^{(1)}\right)^{i_{NLOS}^{(1)}} \times$$
$$\times \binom{i^{(2)}}{i_{LOS}^{(2)}} \left(p_{LOS}^{(2)}\right)^{i_{LOS}^{(2)}} \cdot \left(p_{NLOS}^{(2)}\right)^{i_{NLOS}^{(2)}} \quad (7)$$

$$i^{(1)} + i^{(2)} = i \quad (8)$$

$$i_{LOS}^{(1)} + i_{LOS}^{(2)} = i_{LOS} \quad (9)$$

$$p_{NLOS} = 1 - p_{LOS} \quad (10)$$

There is a unique value for p_{LOS} for clusters with a non-prime number of microcells, as can be observed from the cellular layout. Therefore, Equation (6) is used to evaluate $p_{LOS,NLOS}$ in these cases. On the other hand, for clusters with a prime number of microcells, there is more than one possible value for p_{LOS}. From Figure 1, one can observe that mobile interferers affecting the uplink (circles) from the first two layers are in line-of-sight only when positioned at the corner, whereas mobiles from the third layer are in line-of-sight at any point of a whole street. This is the case for all clusters with a prime number of cells. Therefore, calculations of the performance of the uplink for such cases make use of Equation (7) for the value of $p_{LOS,NLOS}$.

The results to be shown here consider clusters of 5, 8, 9, 10 and 13 cells. The probability p_{LOS} is different for each tessellation, because in some cases there are co-microcells that have a whole street in line-of-sight, and others that just have corners in line-of-sight. In cases in which the co-microcell has a whole street in line-of-sight, we considered the interfering mobile as positioned at the center of its microcell.

The calculations of C/I presented here take into account an infinite number of interferers. These interferers are divided into two groups: those belonging to the layers closer to the target cell and those belonging to the other layers. For practical purposes, only the former will be given random positioning properties, whereas the latter will be positioned for the worst case condition. It has been found [3] that only the first six layers may contribute with some significant influence in the overall calculation. Therefore, in the calculation that follow we consider the interferes within the first six layers to be randomly distributed and the remaining ones (up to 600 layers) positioned for the worst case condition. These remaining interferers are considered to be in the worst case position and always active.

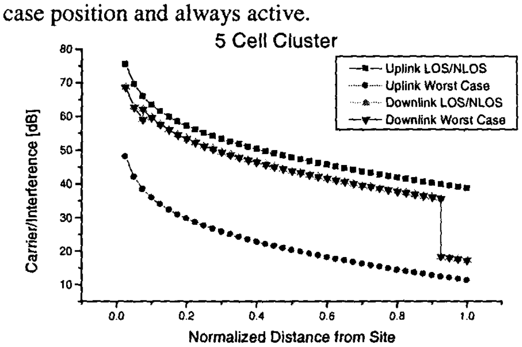

Figure 3 – C/I as a function of normalized distance for the uplink and downlink for a 5 cell cluster, for the randomly positioned mobiles case

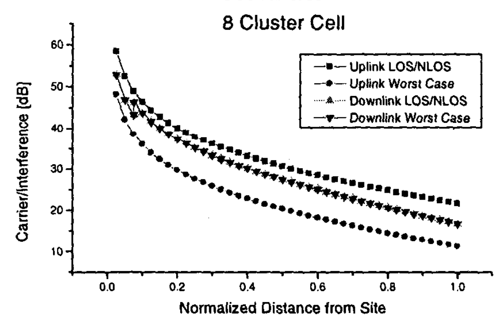

Figure 4 – C/I as a function of normalized distance for the uplink and downlink for an 8 cell cluster, for the randomly positioned mobiles case

Results for all sections of these paper were obtained for clusters with 5, 8, 9, 10 and 13 microcells.

Figures 3 and 4 show the performances for the uplink and the downlink as a function of the normalized distance to the base station considering the random positioning of the mobiles and also the worst case condition for an infinite number of interferers for purposes of comparison, for clusters with 5 and 8 microcells respectively.

The plots show an outstanding increase in performance in the uplink as compared to the worst case condition.

The behavior of the performance for 9 and 10 cell clusters is very similar to that of the 8 cell cluster, and behavior in performance of the 13 cell cluster is very similar to that of the 5 cell cluster. It is worth noting that this increase is enhanced for the case of the 5 cell cluster and the 13 cell cluster. The reason for this phenomenon is that, in these cases, most of the co-microcells only have their corners in line-of-sight, whereas the co-microcells in the other cases studied are collinear to the target cell and therefore have a whole street in line-of-sight. The performance for the downlink has been unaltered as expected, for the interferers in this case are the base stations of the co-microcells, and these have fixed positions.

4. CHANNEL ACTIVITY CASE

This section considers the interferer positioned for the worst case, but with channel occupancy depending on the traffic intensity. A reasoning similar to that of the previous section has been used here. In such a case

$$E[C/I] = \sum_{i_{ACT}=0}^{i} E[C/I \mid i_{ACT}, i_{NACT}]\, p_{ACT,NACT} \quad (11)$$

where,

$$p_{ACT,NACT} = \binom{i}{i_{ACT}} p_{ACT}^{i_{ACT}} \cdot (1-p_{ACT})^{i-i_{ACT}} \quad (12)$$

$$p_{ACT} = \frac{A(1-B)}{N} \quad (13)$$

i is the total number of interferers, i_{ACT} is the number of active interferers, i_{NACT} is the number of not active interferers, p_{ACT} is the probability of a mobile being active, $p_{ACT,NACT}$ is the probability of having i_{ACT} active interferers, A is the traffic of the system, B is the grade of service and N is the number of channels in a microcell.

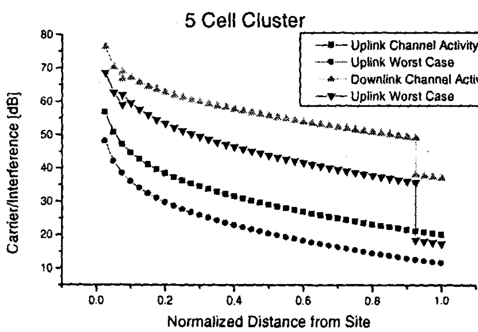

Figure 5 – C/I as a function of normalized distance for the uplink and downlink for a 5 cell cluster, for the channel activity case

The calculations of the C/I ratio for this system have been carried out by considering 8 channels per microcell and grade of service of 2%. An infinite microcell system was considered. The interferers from the first 6 layers were made to vary their channel activity. The other interferers were considered to be in the worst case position and always active. The other parameters are the same as those used for Section 3. Figures 6 and 7 show the performances for the uplink and the downlink as a function of the normalized distance to the base station considering the varying channel activity of the interferers and also the worst case condition for an infinite number of interferers for purposes of comparison, for clusters with 5 and 8 microcells respectively.

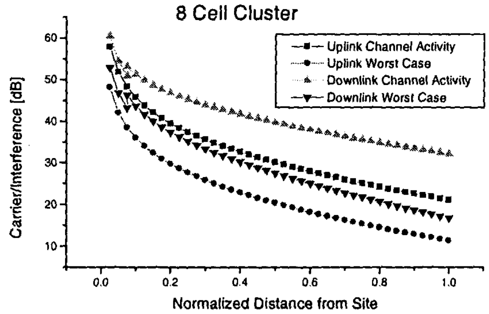

Figure 6 – C/I as a function of normalized distance for the uplink and downlink for a 8 cell cluster, for the channel activity case

In this case, the plots show an increase in performance in downlink as well as in the uplink as compared to the worst case condition. The increase for the uplink was greater than in the randomly positioned mobiles case for cluster with 8, 9, and 10 microcells, and was smaller for clusters with 5 and 13 microcells. This fact is due to the great difference in value for the p_{LOS}, as explained in Section 3. The increase in performance as compared to the worst case was practically the same for the uplink and downlink for all reuse patterns studied. Special attention should be paid to the enhancement in efficiency at the corner opposed to the serving base station for the cases of clusters with a prime number of cells (Figures 6). Those points showed a poor C/I ratio for the worst case, and now, considering a much more realistic situation, the relation has much more apprizing values.

5. RANDOMLY POSITIONED MOBILES AND CHANNEL ACTIVITY CASE

Finally, we combine the two considerations made in Sections 3 and 4, that is, we consider the interferers to have varying position and channel activity according to a given traffic. A reasoning similar to the previous section has been used here. In such a case

$$E[C/I] = \sum_{i_{ACT\&LOS}=0}^{i} E[C/I \mid i_{ACT\&LOS}]\, p_{ACT\&LOS} \quad (14)$$

where,

$$p_{ACT,NACT} = \binom{i}{i_{ACT\&LOS}} (p_{LOS}\times p_{ACT})^{i_{ACT\&LOS}} (1-p_{LOS}\times p_{ACT})^{i-i_{ACT\&LOS}} \quad (15)$$

or

$$p_{ACT\&LOS} = \binom{i^{(1)}}{i^{(1)}_{ACT\&LOS}} \left(p^{(1)}_{LOS}\times p_{ACT}\right)^{i^{(1)}_{ACT\&LOS}} \cdot \left(1-p^{(1)}_{LOS}\times p_{ACT}\right)^{i^{(1)}-i^{(1)}_{ACT\&LOS}} \times$$

$$\times \binom{i^{(2)}}{i^{(2)}_{ACT\&LOS}} \left(p^{(2)}_{LOS}\times p_{ACT}\right)^{i^{(2)}_{ACT\&LOS}} \cdot \left(1-p^{(2)}_{LOS}\times p_{ACT}\right)^{i^{(2)}_{ACT\&LOS}} \quad (16)$$

$$i^{(1)} + i^{(2)} = i \quad (17)$$

$$i^{(1)}_{ACT\&LOS} + i^{(2)}_{ACT\&LOS} = i_{ACT\&LOS} \quad (18)$$

i is the total number of interferers, $i_{ACT\&LOS}$ is the number of interferers that are active and in line-of-sight, and $p_{ACT,NACT}$ is the probability of having $i_{ACT\&LOS}$ interferers active and in line-of-sight.

Similarly as was implemented in Section 3, Equation (16) is used to evaluate $p_{ACT\&LOS}$ for the C/I ratio of the uplink of clusters with a prime number of cells, whereas Equation (15) is used for all other cases.

The calculations of the C/I ratio for this system were made considering the same parameters used in Sections 3 and 4. Figures 7 and 8 show the performances for the uplink and the downlink as a function of the normalized distance to the base station considering the varying channel activity and varying position of the interferers and also the worst case condition for an infinite number of interferers for purposes of comparison, for clusters with 5 and 8 microcells respectively.

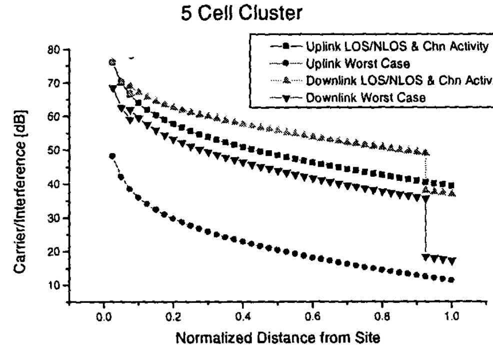

Figure 7 – C/I as a function of normalized distance for the uplink and downlink for a 5 cell cluster, for the randomly positioned mobiles and channel activity case

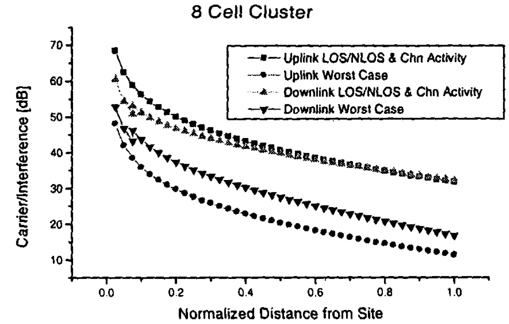

Figure 8 – C/I as a function of normalized distance for the uplink and downlink for a 8 cell cluster, for the randomly positioned mobiles and channel activity case

The plots for this case show the best performance of the uplink for all situations considered in this work. The results of the downlink are the same as those obtained in Section 5, as expected, for the interferers in this case are the base stations of the co-cells, and these have fixed position.

6. CONCLUSIONS

This paper presented a study on the interference in microcellular network with reuse patterns based on a square grid. Results were analyzed for clusters with 5, 8, 9, 10 and 13 microcells. The performance parameter used was the carrier-to-interference (C/I) ratio, and all the results obtained were compared with those for inteferers positioned in the worst case condition and for the radio channels fully active. The latter results mentioned were obtained and analyzed in [1,2]. This paper considered more realistic conditions. These include the interferer randomly positioned within the microcell and the channel activity according to a given traffic intensity. Only the line-of-sight condition of the interferers was considered as contributing to the overall interference calculation.

The results showed a remarkable performance for all reuse patterns studied when subject to the considerations mentioned above. The carrier-to-interference ratio, in all cases, showed a much higher value than those presented priviously. Therefore, these new results may be considered an upperbound performance for the given parameters, while those presented in [1,2] may be considered as a lowerbound performance.

Because the obstructed signals attenuate much more drastically then those in line-of-sight condition, it is expected that in a real situation the performance would be closer to the upperbound than to the lowerbound curves.

7. REFERENCES

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