NOVEL REUSE PATTERNS FOR MICROCELLULAR NETWORKS

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Abstract

This paper proposes novel reuse patterns for microcellular network based on a square grid. An initial carrier-to-interference ratio assessment for these patterns considers the mobiles positioned at the worst case condition and the system operating at a full load. Among the possible reuse patterns (1, 2, 4, 5, 8, 9, 10, 13, ...microcells per cluster) the performance analysis investigates systems with clusters of 5, 8, 9, and 10 microcells. The results show a substantial difference in performance for the up and downlinks, with the former performing less satisfactorily than the latter and with this difference diminishing as the size of the cluster increases. Both the 10- and the 9-microcell clusters exhibit an outstanding performance and, if appropriately explored, a remarkable trade-off between capacity and interference may be encountered in the 5-microcell cluster.

1. INTRODUCTION

The expansion and the evolution of the wireless network shall be supported by an ample microcellular structure, not only to satisfy the high traffic demand in the dense urban regions but also to provide for the services requiring low mobility.

The microcellular network concept is rather different from that of the macrocellular one, widely employed in both analog and digital cellular systems. In particular, the macrocellular network makes use of a hexagonal cell array with reuse pattern being established with the supposition that reuse distances are isotropic and that a cluster is constituted by a contiguous group of cells. In theory, the high-power sites combined with base station antennas being positioned well above the rooftops provide for a propagation symmetry, in which case, for system planning purposes, the hexagonal coverage grid has proven appropriate.

In microcellular systems, with low-power sites and antennas mounted at the street level (below the rooftops), the supposed propagation symmetry of the macrocellular network no longer applies and the hexagonal cell pattern does not make sense. The "microscopic" structure of the environment (e.g., street orientation, width of the streets, layout of the buildings, among others) constitutes a decisive element influencing the system performance.

The ubiquitous coverage of a service area based on a microcellular network will have to make use of an exceedingly greater number of base stations as compared with that of the macrocellular systems. Therefore, among the important factors to be accounted for in the microcellular system planning (cost of the site, size of the service area, etc.) the per-subscriber cost is determinant. This cost is intimately related with how efficiently the radio resources are re-utilized in a given service area. The reuse efficiency depends on the interfering environment of the network and on the ability of the involved technology to cope with the interfering sources.

The studies of interference in the macrocellular systems is greatly eased by the intrinsic symmetry of the problem. In the microcellular case, the inherent asymmetry due to the microscopic structures involved implies an additional complication. In such a case, the interference is dependent not only on the distance between transmitter and receiver but also, and mainly, on the line-of-sight (LOS) condition of the radio path. For instance, assuming base stations located at street intersections, mobiles on streets running radially from the base station may experience an interference pattern changing along the street as they depart from the vicinity of their serving base station, where the desired signal is strong and the relevant interfering signals are obstructed by buildings (non LOS - NLOS), and approach new intersections, where they may have a LOS condition not only to their serving base station but also to the interfering ones. The interfering situation will then follow a completely distinct pattern on the perpendicular streets. Again the asymmetry of the problem is stressed by the traffic distribution, which is more likely to comply with an uneven configuration as the main streets will certainly accommodate more mobile users than the secondary ones.

The aim of this paper is to propose different reuse patterns for microcellular systems and to investigate the system performance with the application of these patterns. The performance will be initially assessed by means of the carrier-to-interference (C/I) ratio for the mobiles positioned at the worst case condition and the system operating at a full load. The other conditions (mobiles positioned at random and for a given channel activity) with the respective outage probabilities, which correspond to a more realistic situation, are currently under investigation. The objective here is to give an insight into the potential of the proposed patterns.

This work has been motivated by the need for capacity expansion experienced by TELESP CELULAR, in the metropolitan area of the city of São Paulo, Brazil. With more than half a million subscribers and over 300 cells, the system has been going through an explosion of demand for wireless services. Among other solutions to this problem, the massive use of microcells within the dense urban region is currently under investigation [1].

2. MICROCELLULAR REUSE PATTERNS

A number of field measurements and previous works [2-7] suggest that an urban microcell service area can be reasonably well-approximated by a square diamond. Assuming a square cellular grid, as in Figure 1, where R is the cell radius and $\sqrt{2}R$ [8] is the unit in the respective set of coordinates, the distance D between the centers of the cells is given by $D^2 = i^2 + j^2$, where $i = u_2 - u_1$ and $j = v_2 - v_1$ range over the integers. Considering that reuse distances are isotropic and that a cluster is a contiguous group of cells, the format of the clusters must be of a square type, whose area is given by D^2. Given that the area of the cell equals $2R^2$, then the number N of cells per cluster is found to be $N = i^2 + j^2$, leading to clusters accommodating 1, 2, 4, 5, 8, 9, 10, 13, 16, ...cells.

The layout of the cells within the cluster to be proposed here is attained having as principal targets *symmetry* and *compactness*. Figure 2 shows some of the suggested repeat patterns. The tessellation over the entire plane is then achieved by replicating the cluster in an isotropic manner. In other words, if the chosen reuse pattern is such that $i = p$ and $j = q$ then, for the reference cell located at the coordinates (0, 0) the four corresponding equidistant cocells are positioned at (p, q), $(-q, p)$, $(-p, -q)$, and $(q, -p)$. Figure 2 illustrates this for the case $i = 1$ and $j = 2$ ($N = 5$). It is noteworthy that some of the proposed patterns tessellate into staggered configurations with the closer interferers being either completed obstructed or obstructed for most the time with a LOS interferer appearing many blocks away. In our calculations, however, we shall consider the worst case condition.

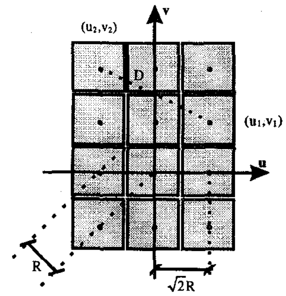


Figure 1: Square cell geometry

3. PERFORMANCE ANALYSIS MODEL

The performance analysis to be carried out here will initially consider a square cellular pattern with base stations positioned at every other intersection of the streets. This means that base stations are collinear and that each microcell covers a square area comprised of four 90°-sectors, each sector corresponding to one-half of a block, with the streets running on the diagonals of this square.

Concerning the radio coverage aspects it has been observed [2-7] that the LOS and the NLOS modes of

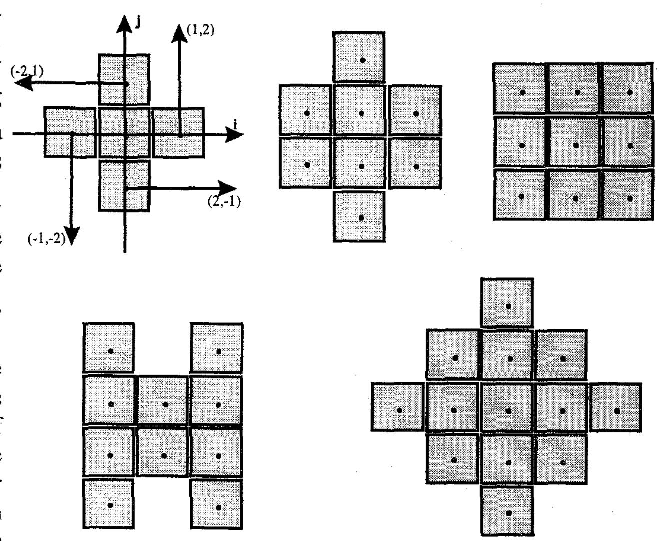


Figure 2: Some possible reuse patterns (N= 5, 8, 9, 10, 13 microcells per cluster)

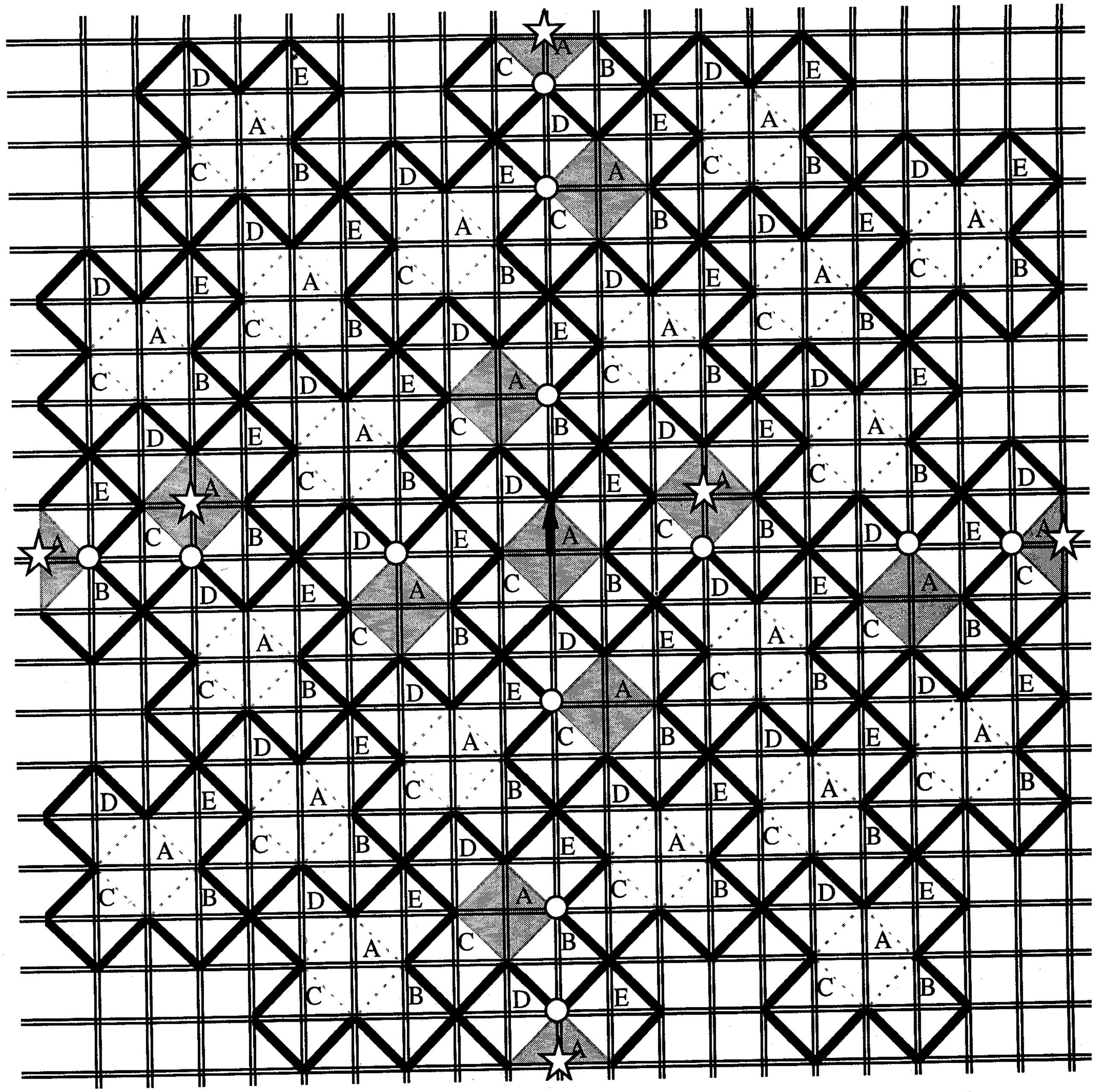


Figure 3: Five-microcell cluster tessellation

propagation are very distinct from each other. The respective propagation losses at a distance d from the base station and for a wavelength λ, transmitting antenna height h_t, and a receiving antenna height h_r are then given by

$$L_{LOS} = \frac{K_{LOS}}{d^2}\left[1+\left(\frac{d}{d_B}\right)^2\right]^{-1} \quad (1)$$

$$L_{NLOS} = \frac{K_{NLOS}}{d^{\alpha}} \quad (2)$$

where $K_{LOS} = \left(\lambda/4\pi\right)^2$, $d_B = 4h_t h_r / \lambda$ is the breakpoint distance, K_{NLOS} = 0.16 for 900 MHz and 0.0015 for 2 GHz, and α = 4.3 for 900 MHz and 3.8 GHz [7].

Defining r as the serving base station-to-mobile station distance normalized with respect to the cell radius ($0 < r \leq 1$) and k as the ratio between the cell radius and the breakpoint distance ($k \geq 0$), it is possible to show that, for the interferers positioned at the worst case condition, the uplink C/I parameter is given by

$$\frac{C}{I} = \frac{\left[1+(rk)^2\right]^{-1}}{4r^2 \sum_{i=1}^{\infty} n_i^{-2}\left[1+(n_i k)^2\right]^{-1}} \tag{3}$$

where n_i = 1, 2, 3, ... is the distance between the interferers at the ith tier and the target cell site, given in number of units of the cell radius. In the same way, for the downlink and for the mobile at the vicinity of its serving base station ($r \leq$ normalized distance from the site to the beginning of the street) the C/I ratio is

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

Away from the vicinity of the serving base station, which corresponds to most of the path, the C/I ratio is

$$\frac{C}{I} = \frac{\left[1+(rk)^2\right]^{-1}}{r^2 \sum_{i=1}^{\infty} \left\{ (n_i+r)^{-2}\left[1+(n_i+r)^2k^2\right]^{-1} + (n_i-r)^{-2}\left[1+(n_i-r)^2k^2\right]^{-1} \right\}} \tag{5}$$

These formulas have been thoroughly exercised and manipulated and a number of interesting results obtained. Without loss of generality they can be reduced to closed-form solutions with the error between the exact and the approximate formulas falling within an acceptable range (less than 0.4 dB) [1]. These, however, shall be explored in a future publication.

4. AN APPLICATION EXAMPLE

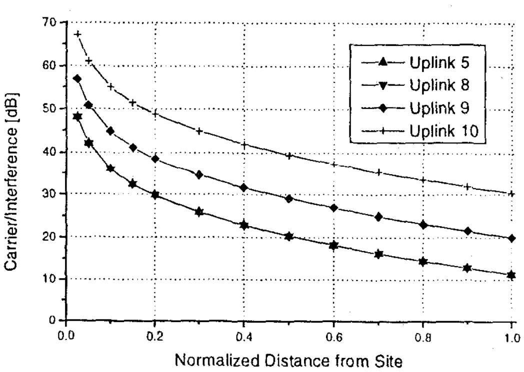
The proposed microcellular reuse grid has been exercised over several patterns. In particular, the results to be shown here consider clusters with 5, 8, 9, and 10 microcells.

In order to give an insight into how the calculations have been performed we illustrate, in Figure 3, the complete tessellation for the 5-microcell cluster. The performance has been evaluated having the central microcell as the target cell, and for the mobile subscriber departing from the center toward its edge, as shown by the arrow in the respective cell. Figure 3 also shows, in gray, the co-microcells that at a certain time will interfere with the wanted mobile in a LOS condition. 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 Figure 3, 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.

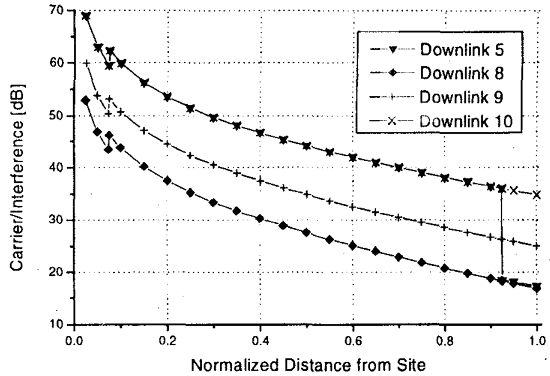
5. RESULTS

In the results to be shown here we consider 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.

Figures 4a and 4b show respectively the downlink and uplink performances for the cases of 5-, 8-, 9-, and 10-microcell clusters as a function of the normalized distance. In general, the bigger the cluster the better the carrier-to-interference ratio, as expected. However, the 5-microcell cluster has a notably outstanding behavior, with its C/I coinciding with that of the 8-microcell cluster for the uplink (lower curve in Figure 4a) and with that of the 10-microcell cluster for the downlink for most of the extension of the path (upper curve in Figure 4b), with the separation of the curves in the latter occurring at the edge of the microcell, where two new interferers appear in a LOS condition.



(a)



(b)

Figure 4: Carrier-to-interference ratio as a function of normalized distance; a) for the uplink; b) for the downlink

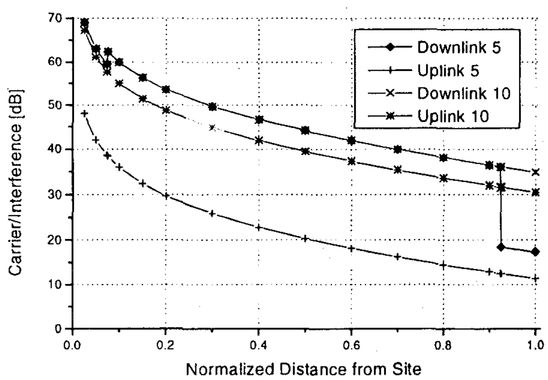


Figure 5: Carrier-to-interference ratio as a function of normalized distance for up and downlinks compared.

6. CONCLUSIONS

This paper has proposed novel reuse patterns for microcellular network based on a square grid. An initial assessment of these patterns has been carried out by means of the carrier-to-interference ratio for the mobiles positioned at the worst case condition and the system operating at a full load. The other conditions (mobiles positioned at random and for a given channel activity) with the respective outage probabilities, which correspond to a more realistic situation, are currently under investigation. The objective here is to give an insight into the potential of the proposed patterns. Among the possible reuse patterns (1, 2, 4, 5, 8, 9, 10. 13, 16 ... microcells per cluster) the performance analysis has considered systems with clusters of 5, 8, 9, and 10 microcells. The results show a substantial difference in performance for the up and downlinks, with the former performing less satisfactorily than the latter and with this difference diminishing as the size of the cluster increases. It has been observed that both the 10- and the 9-microcell cluster present an outstanding performance and that, if appropriately explored, a remarkable trade-off between capacity and interference may be encountered in the 5-microcell cluster. It is noteworthy that, for the geometry explored here, the worst case condition occurs with probability of $(3\times10^{-5})^i$ [1], where i is the number of interfering tiers considered. Therefore, by taking into account the random distribution of the users and the channel occupancy the mean *C/I* ratio will be certainly notably higher [1] than what has been shown in this paper.

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