Allocating Channels to a Temporary Base Station

J. N. Portela and M. S. Alencar

Abstract— **This paper presents the allocation of cells of a mobile cellular network as a dynamic ordered order-k multiplicatively weighted Voronoi diagram. The farthest neighbor search is applied to the channel allocation scheme of a temporary base station. Whenever a temporary base station is deployed, its power, antenna height, group of channels and other features are to be configured. The nearest and the farthest point search are applied to the problem of finding the nearest and the farthest base station surrounding the temporary station, in order to identify the group of channels to be allocated. Proximity relations are acquired from the Voronoi diagram and used in solving the problem of allocating channels with a minimum cochannel interference.**

Keywords— **Land mobile radio cellular systems, Prediction methods, Voronoi diagrams.**

I. INTRODUCTION

Temporary base stations (TBS)[1] are deployed in a cellular network when large amounts of people move to a certain area, or when a new cell is to be added to the existing service area [1]. An occasional populational concentration may overload a base station (BS), augmenting unusually the call blocking. To support the traffic of the overloaded BS, a TBS is usually deployed. Proximity between base stations thus becomes the key parameter to determine the cochannel interference and which group of channels should be allocated to the TBS. Neighbor BSs are related to traffic operations as handoff and blocking while the farthest one is related to interference phenomena as outage, frequency reuse and channel allocation. Interference is important to assess the performance of the cellular network, since cells are intended to be intersecting zones with minimum interference. Proximity between them may affect the signal-to-interference ratio (SIR). As the SIR value falls below an accepted threshold, the quality of a link may cause outage [2]. The signal power decreases with distance, thus, the cochannel interference is a function of distance as well as the path loss of the interfering signal.

The channel allocation system must guarantee a minimum SIR value to the TBS. That is, the allocated group of channels should not be used concurrently by neighbor BSs, except by distant ones, outside the reach of the TBS signal. This paper shows a solution to the channel allocation problem by using Voronoi diagrams in searching the nearest and the farthest neighbor BS [3].

II. THE NEAREST AND THE FARTHEST NEIGHBOR SEARCH

The nearest neighbor search is used in communication systems and signal processing in the optimum receiver design, constellation diagrams, bit error probability estimation, pattern recognition and vector quantizing.

The farthest neighbor search is used in scientific and engineering applications to detect the minimum influence of a point in a certain area or similarities in a given data [4].

These methods can be applied to identify the cochannel BS in a cluster, whose interference intensity is inversely related to distance. The inclusion of a TBS in a service area modifies coverage and handoff processing of the surrounding cells. The cells proximity relations are closely related to the cochannel interference and the channel allocation scheme. The farthest neighbor search provides a way to allocate channels to a TBS.

III. THE CELL RADIUS PREDICTION

The cells are not well defined but have fuzzy boundaries because of the statistical fluctuations in radio path losses. However, it is possible to establish a mean boundary using path loss prediction models [5]. These models associate the path loss with distance and makes it possible to predict the cell

J. N. Portela, Centro Federal de Educação Tecnológica do Ceará, Fortaleza, CE, Brasil, phone: +55 83 33101391, E-mail:portela@dee.ufcg.edu.br.
M. S. Alencar, Institute for Advanced Studies in Communications, Department of Electrical Engineering, Universidade Federal de Campina Grande (UFCG), Campina Grande, PB, Brasil, phone: +55 83 33101410, E-mail:malencar@dee.ufcg.edu.br.
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[1]A TBS may be portable or fixed.

radius. When the downlink received power reaches a minimum acceptable value (received power threshold), the mobile receiver blocks the reception and determines a limit to the cell. In an isotropic propagation environment, the maximum path, determined by the receiver blocking, corresponds to the radius of a circle.

The received power P_r is given by

$$P_r = P_t + G_t + G_r - L, \tag{1}$$

where P_t is the transmission power, G_t and G_r are the antenna gains and L is the predicted path loss. When P_r reaches the received power threshold Z, the signal radio suffers the maximum path loss. As the path loss depends on distance, it is possible to express the distance corresponding to the minimum received power by means of the path loss expression [6]

$$L = a + b\log(d), \tag{2}$$

where a and b are parameters dependent on the path loss prediction model. For example, the COST-Hata model gives the path loss by

$$L = 46.3 + 33.9\log(f) - 13.82\log(h_b) - A(h_m) + (44.9 - 6.55\log(h_b))\log(d), \tag{3}$$

$$A(h_m) = (1.1\log(f) - 0.7)h_m - (1.56\log(f) - 0.8),$$

for medium sized cities and medium trees density, where h_b and h_m are, respectively, the base station and the mobile antenna heights and f is the carrier frequency. By comparing (2) to (3)

$$a = 46.3 + 33.9\log(f) - 13.82\log(h_b) - A(h_m); \tag{4}$$

$$b = 44.9 - 6.55\log(h_b). \tag{5}$$

Inserting (2) in (1)

$$P_r = P_t + G_t + G_r - a - b\log(d). \tag{6}$$

Solving for d, yields

$$d = 10^{\frac{P_t + G_t + G_r - P_r - a}{b}}. \tag{7}$$

As the propagation environment is assumed to be isotropic, for $P_r = Z$, the path loss is omnidirectional and the distance in (7) corresponds to the cell radius

$$r = 10^{\frac{P_t + G_t + G_r - Z - a}{b}}. \tag{8}$$

The cell radius can also be estimated by statistical method in which the signal envelope is considered to follow the Rayleigh, Lognormal and Suzuki distributions [7].

IV. The Mobile Cellular Network as a Dynamic Ordered Order-k Multiplicatively Weighted Voronoi Diagram

The Voronoi diagram is a partition set, generated by site points. This geometric structure assumes the nearest neighbor rule in associating a point, in the $\mathbb{R}^n$ space, to a site point nearest to it. Each resulting partition is named Voronoi region [8].

Let $\mathbf{x}$ be a point in the $\mathbb{R}^n$ space, c_i the i-th site point and V_i the Voronoi region generated by c_i. The association $\mathbf{x} \in V_i$ occurs according to the nearest neighbor rule

$$\text{If } D(\mathbf{x}, c_i) \leq D(\mathbf{x}, c_j),\ \forall j \neq i, \text{ then } \mathbf{x} \in V_i.$$
$$\text{Else } \mathbf{x} \in V_j. \tag{9}$$

The proximity metric D is a function of distance. In a multiplicatively weighted Voronoi diagram, $D = d/w$, where d is the Euclidean distance from $\mathbf{x}$ to c_i and w is the weight of the site point. The nearest neighbor rule is thus defined as

$$\text{If } \frac{d(\mathbf{x}, c_i)}{w_i} \leq \frac{d(\mathbf{x}, c_j)}{w_j}, \forall j \neq i, \text{ then } \mathbf{x} \in V_i.$$
$$\text{Else } \mathbf{x} \in V_j. \tag{10}$$

Consider the proximity model with two adjacent site points (c_1, c_2) illustrated in Figure 1. The distance

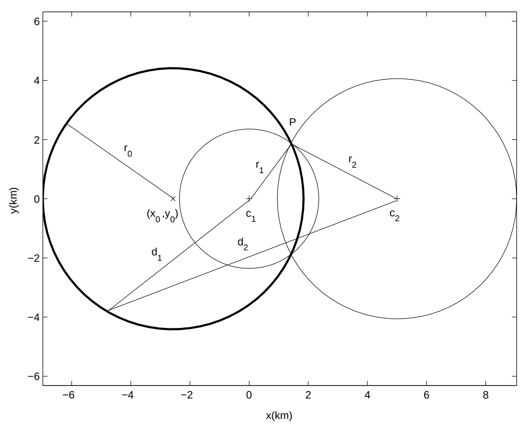

Fig. 1. Two adjacent site points model. The locus of the distance ratio d_1/d_2 corresponds to the circumference of the Apollonius circle, shown in thick line.

ratio $w_{12} = d_1/d_2$ is constant along the circumference shown in thick line, whose radius r_0 and center $\langle x_0, y_0\rangle$ are given by

$$r_0 = \left|\frac{d_{12}w_{12}}{(w_{12})^2 - 1}\right|; \tag{11}$$

$$x_0 = \frac{(w_{12})^2 x_2 - x_1}{(w_{12})^2 - 1}; \tag{12}$$

$$y_0 = \frac{(w_{12})^2 y_2 - y_1}{(w_{12})^2 - 1}, \tag{13}$$

where $\langle x_i, y_i\rangle$ is the site points location and d_{12} is the distance $\overline{c_1c_2}$. The circumferences with radii r_1 and r_2 intersect at point P and gives

$$\frac{d_1}{d_2} = \frac{r_1}{r_2}. \tag{14}$$

Expressing (14) as

$$\frac{d_1}{r_1} = \frac{d_2}{r_2}, \tag{15}$$

yields the definition of the nearest neighbor rule in (10). If the site points represent base stations, the weights in (15) correspond to the cells radii

$$w_i = r_i \tag{16}$$

and the distance ratio is

$$w_{ij} = \frac{r_i}{r_j}. \tag{17}$$

The proximity relations between cells are represented by the multiplicatively weighted Voronoi diagram, since the link mobile-BS is established according on a proximity rule expressed as a function of the received power. A BS works as a site point determining a Voronoi region by means of its radio signal. Figure 2 shows the edges between two BSs in terms of the distance ratio.

A. The order-k Voronoi diagram

Let $C = \{c_1, ..., c_N\}, |C| = N$, be the site points set, X a subset of $C, |X| = k, \overline{X} = C - X$. The order-$k$ Voronoi region is defined as

$$V(X) = \{\mathbf{x} : D(\mathbf{x}, c_i) \leq D(\mathbf{x}, c_j), \forall c_i \in X, \forall c_j \in \overline{X}\}, \tag{18}$$

where $\mathbf{x}$ is a point in $\mathbb{R}^n$, D is a function of distance, $k \in \mathbb{Z}^+$ and $k \in [1, N-1]$.

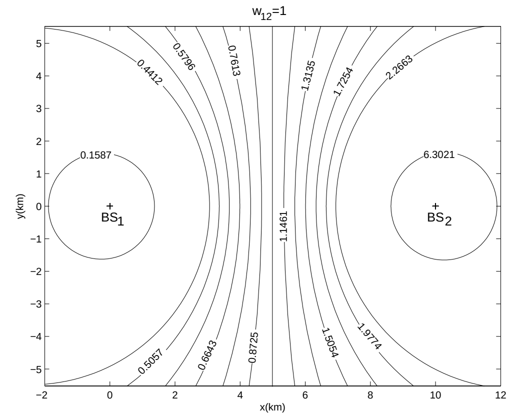

Fig. 2. Edges of two adjacent BSs in terms of the distance ratio ($w_{12} = r_1/r_2$).

The order-k diagram is obtained from the order-$(k-1)$ diagram according to the following procedure [9]:
1. Remove a site point c_i obtaining new edges for the $N-1$ site points diagram. The effect of removing c_i is the elimination of the edges determined by c_i and the extension of the neighbor edges to the interior of V_i;
2. Place the previous removed site point c_i back into its location and remove another site point;
3. Repeat for all the site points.

B. The ordered order-k Voronoi diagram

The ordered order-k multiplicatively weighted Voronoi diagram is an order-k diagram where the proximity relations are ordered in sequence of proximity. It is obtained from the superposition of the order-$k, k-1, ..., 1$ diagrams [10]. A Voronoi region, depicted as $O(X), X = \{i, j, ..., q\}$, is the locus of all the points closest to the site point c_i. If c_i is removed, the site point c_j becomes the closest to O and c_q is the farthest one. The edges $E(i, j)$ of the diagram define the Voronoi regions. Each edge is a bisector, it divides the plane into half-planes $\pi_i^{(\xi)}, \pi_j^{(\xi)}$, where ξ indicates the order of the edge. Each Voronoi region O is the intersection of the half-planes

$$O(X) = \bigcap_{n\in X, \xi\in[1,k]} \pi_n^{(\xi)}, \tag{19}$$

For instance, see the region

$$O(3, 2, 1) = \pi_3^{(1)} \cap \pi_2^{(2)} \cap \pi_1^{(3)}$$

illustrated in Figure 3.

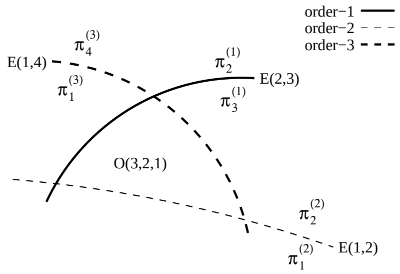

Fig. 3. Limits of an ordered order-3 Voronoi region in the plane.

This gives spatial information to plan frequency reuse and channel allocation, since cochannel interference is a function of proximity.

V. Allocating Channels to a Temporary Base Station

An example of the method to allocate temporary channels is described below. The data of the BSs is given in Table I, the Voronoi edges are described in Table II. Four groups of channels are assigned to the BSs: $BS_1 \rightarrow$ group A, $BS_2 \rightarrow$ group B, $BS_3 \rightarrow$ group C and $BS_4 \rightarrow$ group D. The data of TBS is: antenna height=5.7 m, gain=6 dB, power=36 dBm. The TBS cell radius predicted by Equation (8) is 1.2 km. The carrier frequency is 1800 MHz, the mobile antenna gain is assumed to be 3 dB, the mobile antenna height 3 m, the received power threshold -100 dBm. The COST-Hata model is adopted to predict the path loss.

The algorithm for the Voronoi diagram construction in $\mathbb{R}^2$ is now summarized. The input data is: the order of the diagram k, BS locations $\langle x_i, y_i \rangle$ and cells radii r_i. The output is the collection of circular arcs $E(i,j)$ described by the center coordinates $\langle x_0, y_0 \rangle$ and radius r_0.

INPUT: $k, \langle x_i, y_i \rangle, r_i$.
OUTPUT: $E(i,j) \equiv (\langle x_0, y_0 \rangle, r_0)$.
Step 1. Initialization: order$= 1$.
Step 2. Compute $E(i,j)$, taking BSs pairwise, using Equations (11), (12) and (13).
Step 3. Determine the intersections of bisectors.
Step 4. IF order$= k$, EXIT.
Step 5. ELSE order$\rightarrow$order$+1$. Extend bisectors to reach an end point. GO TO 4.
% An end point is an intersection between edges. The outer edges have no end point and must be truncated.

Figure 4 shows the resulting ordered order-3 Voronoi diagram. The regions are depicted as $O(i,j,p)$. This means that the region O is nearest to BS_i and farthest to BS_q such that $q \notin \{i,j,p\}$. Figure 4 shows arbitrary locations marked as $\lambda, \varphi, \beta, \Phi$ and Δ, where a TBS is to be located. The group of channel allocated to TBS is taken from the farthest BS as shown in Table III.

The λ-location case is shown as an example in Figure 5, where E(2,λ) is a closed arc, thus it generates no order-k ($k > 1$) edges, because higher order edges are extensions of the lower ones. The same case occurs for Φ-location. At locations β and φ, the edges of BS_2 and BS_3 are simultaneously modified and new order-k Voronoi regions are generated. The case of β-location is shown in Figure 6 where the regions $O(\beta,1)$ and $O(\beta,3)$ are the overlapping area between cells of BS_2, BS_3 and β-TBS. The Δ-location, similarly to the β case, modifies the edges between BS_1 and BS_3 but does not alter the remaining edges.

TABLE I

BASE STATION DATA.

BS	1	2	3	4
Channels	A	B	C	D
Location	⟨1,1⟩	⟨3,10⟩	⟨5,6⟩	⟨9,12⟩
Power (dBm)	40	40	34	43
Antenna Height (m)	41.56	50.89	73.55	48.86
Cell Radius (km)	4.0	3.6	3.2	4.8
COST-Hata parameters	a_1=129.8 b_1=34.3	a_2=128.7 b_2=33.7	a_3=126.5 b_3=32.7	a_4=128.9 b_4=33.8

TABLE II

VORONOI EDGES DATA AND DISTANCE RATIO.

	Center	Radius (km)	Distance ratio
E(1,2)	⟨-7.5,-37.6⟩	43.869	0.9
E(1,3)	⟨20,24.8⟩	27.131	1.12
E(1,4)	⟨-9.3,-13.1⟩	23.318	0.75
E(2,3)	⟨8.6,-1.1⟩	9.962	1.24
E(2,4)	⟨-10.6,5.5⟩	17.205	0.833
E(3,4)	⟨1.8,1.2⟩	8.655	0.666

VI. Conclusions

The ordered order-k multiplicatively weighted Voronoi diagram represents the coverage of the cells as a space tessellation. It provides proximity relations useful in searching the farthest BS from a given area, in order to allocate channels to a TBS. It is an efficient tool for space and proximity

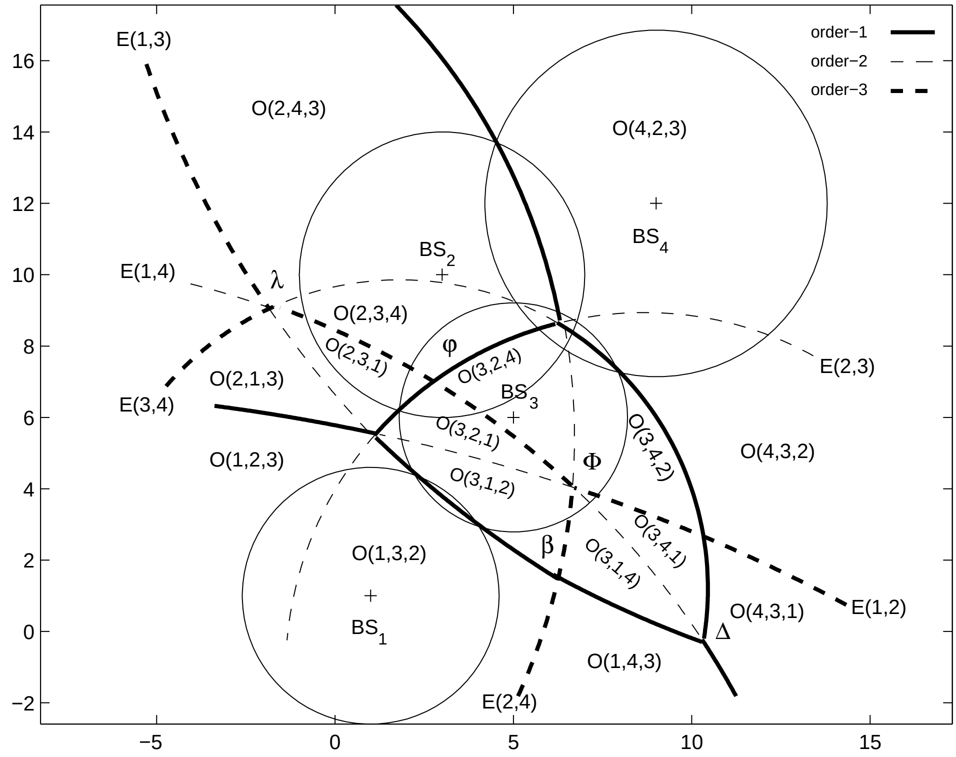

Fig. 4. A cluster of four cells represented by an ordered order-3 multiplicatively weighted Voronoi diagram. Each Voronoi region is defined by three circular arcs as shown in Figure 3. Temporary BSs are arbitrarily located at $\lambda, \varphi, \beta, \Phi$ and Δ.

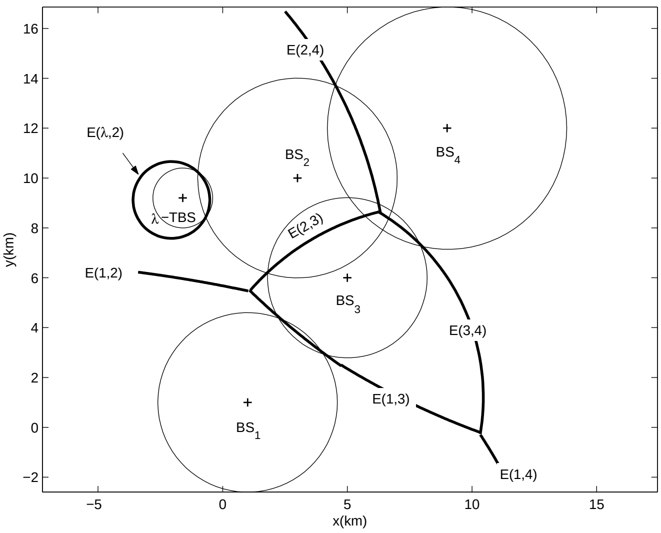

Fig. 5. A TBS deployed at λ-location modifies the coverage of BS_2 only. The order-1 edge $E(\lambda, 2)$ is a closed arc, it can not extend to generate an edge of order higher than 1.

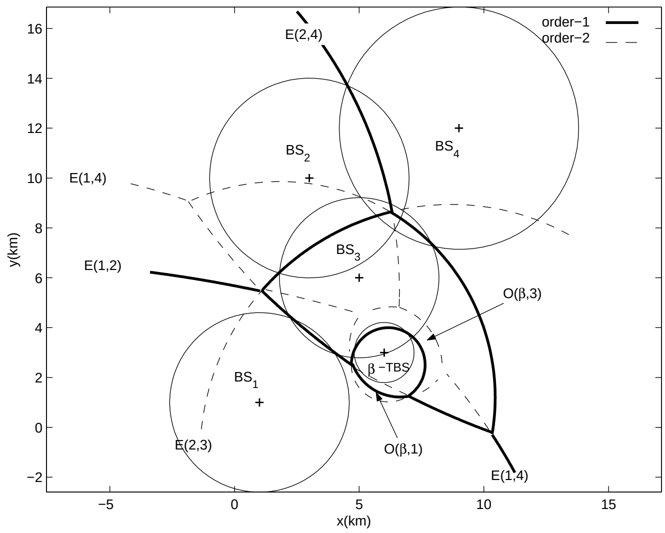

Fig. 6. A TBS deployed at β-location modifies the coverage of BS_1 and BS_3. Order-2 edges of Voronoi regions are generated. The coverage of BS_2 and BS_4 are not altered.

TABLE III

TBS LOCATION AND ITS VORONOI REGIONS. NEAREST AND FARTHEST BS, ALLOCATED GROUP OF CHANNELS CORRESPONDING TO THE FARTHEST BS.

TBS location	Voronoi region	Nearest BS	Farthest BS	Group of Channels
λ	O(2,4,3)	BS_2	BS_1	A
φ	O(2,3,4)	BS_2	BS_1	A
β	O(3,1,2)	BS_3	BS_4	D
Φ	O(3,4,2)	BS_3	BS_1	A
Δ	O(4,3,1)	BS_4	BS_2	B

relations analysis. The space information on the proximity between cells can be used in planning traffic operations as handoff, frequency reuse and channel allocation.

REFERENCES

[1] A. M. Monk and L. B. Milstein, "A CDMA cellular system in a mobile base station environment", *IEEE Global Telecommunications Conference*, GLOBECOM'93, vol.4, pp. 65 - 69, 29 Nov.-2 Dec. 1993.

[2] J. N. Portela and M. S. Alencar, "Outage contour using a Voronoi diagram", *Proceedings of the IEEE Wireless Communication and Networking Conference*, WCNC'04, Atlanta, GA, 21-26 Mar. 2004.

[3] M. I. Shamos and D. Hoey, "Closest-point problems", *Proceedings of the Annual IEEE Foundations of Computer Science*, pp. 151-162, Oct. 1975.

[4] M. Kobayasi, "Classification of color combinations based on distance between color distributions", *Proceedings of the International Conference on Image Processing*, ICIP 99, vol. 3, pp. 70 - 74, 24-28 Oct. 1999.

[5] M. Hata, "Propagation loss prediction models for land mobile communications", *International Conference on Microwave and Millimeter Wave Technology Proceedings*, ICMMT'98, 1998.

[6] J. N. Portela and M. S. Alencar, "The mobile cellular network as a set of Voronoi diagrams", *XXI Simpósio Brasileiro de Telecomunicações*, SBrT'2004, 6-9 Set. 2004, Belém, Brasil.

[7] M. D. Yacoub, "Cell designing principles" in *The mobile communications handbook*, CRC press, 1st edition, chapter 19, pp. 319-332, 1996.

[8] F. Aurenhammer, "Voronoi Diagrams – A Survey of a fundamental geometric data structure", *ACM Computing Surveys*, vol. 23, pp. 345 – 405, 1991.

[9] D.-T. Lee, "On k-nearest neighbor Voronoi diagrams in the plane", *IEEE Transactions on Computers*, vol. C-31, no. 6, pp. 478 – 487, Jun. 1982.

[10] M. Held and R. B. Williamson, "Creating electrical distribution boundaries using computational geometry", *IEEE Transactions on Power Systems*, vol. 19, issue 3, pp. 1342 – 1347, Aug. 2004.