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COVERAGE ENSURING FOR WIRELESS NETWORK SERVICE AREA WITH OBSTACLES

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Service area coverage problem has existed and still remains a fundamental issue in construction of wireless networks. Most of known investigations, concerned with optimal (in sense of ensuring of necessary coverage level at every point in service area) deployment of network nodes, i.e., with optimal network topology, study the problem on the assumption that wireless network service area is free from obstacles, impeding normal propagation of information signals [1-3]. As a result, suggested network topologies become ineffective at presence of obstacles within serviced area. More realistic solution presumes taking into account of obstacles within the serviced area. Possible approaches for placement of wireless network nodes on condition that service area contains obstacles are discussed at present work. Problem is examined from two points of view: as a probabilistic task, as well as a task of computational geometry. The investigation is resulted in some conceptual considerations and practical algorithms for this problem solving.

***Keywords:** wireless networks, coverage, obstacle, service area, Voronoi diagram*

Introduction

Wireless networks (WN) are based on some type of information transmission system that uses electromagnetic waves. One of the fundamental issues, relating to WN, is coverage. In general, coverage is WN property of information delivering to any point of serviced area, and may be considered as a measure of QoS (quality of service) of a wireless network. Among different factors, affecting the wireless network service area (WNSA) coverage level, the most influencing is presence of obstacles, which hamper normal propagation of information radio signals.

All WN types in our investigation are reduced to the following conditional structure. WN nodes are deployed over some area A and are treated as transmitters with transmission radius R_s. All nodes are homogenous. Signals from all nodes form service area of the wireless network. Arbitrary point P within the area A is considered as covered (serviced), if it is inside the coverage zone of one or more nodes. This implies that signal strength from abovementioned node(s) at point P is not lower than some predefined value. Under coverage we'll understand the degree of object servicing at each point P within the area A. Relocation of any node, already arranged within the WNSA, is not permitted. The only legal way for enhancement of WNSA coverage is by arrangement of extra nodes. Known investigations discover possible strategies for deployment of such nodes under the stipulation that serviced area does not contain objects, preventing normal (line of sight) propagation of electromagnetic waves. It is often the case that there are obstacles in the WNSA. It is assumed that we have a priori knowledge about arrangement of these obstacles inside the WNSA. So we must consider the problem of achieving an adequate WNSA coverage in presence of obstacles.

1. Framework

In this section we introduce the basic models used in framework.

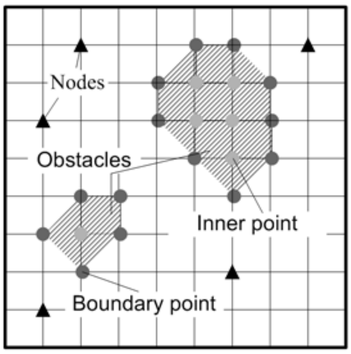
Model of Wireless Network Service Area

Wireless network service area is represented by a two-dimensional grid. The granularity of the grid (distance between consecutive grid points) is adjusted based on the precision of node placement we want, as well as the time and space we can afford for computation. Suppose the dimension of the grid is m x n.

Initial state of the WNSA is described by a m x n matrix T, where each element presents a grid point and can have one of the following states:

- NL (Node Location) – grid point holds a node (transmitter or sensor);
- IO (Inner point of an Obstacle) – inner point of an obstacle:
- BO (Boundary point of an Obstacle) – a point on the perimeter of obstacle;
- FP (Free Point) – a point to be covered.

At description of the WNSA it is supposed that all concerned points are snapped to the grid. Note, that each obstacle must have a unique identifier, i.e. all its inner and boundary points are marked in the matrix T by the same identifier. At construction of T matrix obstacle boundary points may be initially marked as having type BO or as inner points. In the latter case identification of boundary points is pined on special contouring stage. Figure 1 illustrates suggested WNSA model and its description by means of T matrix.



FP	NL_1	FP	FP	BO_1	BO_1	FP	NL_2
FP	FP	FP	BO_1	IO_1	IO_1	BO_1	FP
NL_3	FP	FP	BO_1	IO_1	IO_1	BO_1	FP
FP	FP	FP	FP	BO_1	IO_1	BO_1	FP
FP	BO_2	BO_2	FP	FP	BO_1	FP	FP
BO_2	IO_2	BO_2	FP	FP	FP	FP	FP
FP	BO_2	FP	FP	FP	NL_4	FP	FP
NL_5	FP	FP	FP	FP	FP	FP	FP

a *b*

Figure 1. Model of wireless network service area: a – description; b – corresponding T matrix

Model of Node Service Area

Model of electromagnetic wave propagation predicts the received signal power as a function of the transmitter position (s_i) and receiver position (P). For successful receiving of information, signal power must exceed a certain threshold P_{min}. The Friis free space model is an ideal radio propagation model, which predicts the received signal power as a deterministic function of the distance d from the transmitter as

$$P_r(d) = \frac{P_t G_t G_r \lambda^2}{4\pi^2 d^2 L},$$

where P_t is the transmitted power, G_t and G_r are the antenna gains of the transmitter and the receiver respectively. L (L ≥ 1) is the system loss and λ is the system wavelength. It is normal to select $G_t = G_r = 1$ and $L = 1$ for our purposes. Also for our purposes the only sufficient moment is signal depression function depending to distance from node. As far as nature of signal transmission for main frequency ranges used in wireless networks is well studied, this circumstance can be taken into amount when calculating the service radius for corresponding nodes. Since the signal power rapidly decreases as the distance increases, we define a maximum service range R_s as:

$$R_s = \frac{\sqrt{P_t}\lambda}{2\pi}.$$

Model of Coverage

As it has been accepted earlier, WNSA is represented by a m x n grid. Let s be an individual node (transmitter, sensor, etc.) on the serviced field located at grid point (x, y). Each node has servicing range of R_s. For any grid point P at (i, j) we denote the Euclidean distance between s at (x, y) and P at (i, j) as $d_{ij}(x,y) = \sqrt{(x-i)^2 + (y-j)^2}$.

There can be two competent approaches to coverage model: deterministic and probabilistic.

For the deterministic version it is reasonably to assume a binary coverage model that expresses the coverage $c_{ij}(x, y)$ of a grid point at (i, j) by node s at (x, y) as

$$c_{ij}(x,y) = \begin{cases} 1, \text{ if } d_{ij}(x,y) < R_s \\ 0, \text{ otherwise.} \end{cases} \tag{1}$$

In accordance with binary coverage model a point within the service area is considered as covered, if it is within service area of some node, and any point, lying outside the service area of all network nodes, is treated as not covered. Thus, the service range for each node is confined within a circular disk of radius R_s (Figure 2*a*). In a heterogeneous wireless network, service radii of different types of transmitters might vary, but to simplify the analysis of coverage algorithms, we assume that all the nodes are homogeneous and the maximum service radius for all of them is the same, R_s.

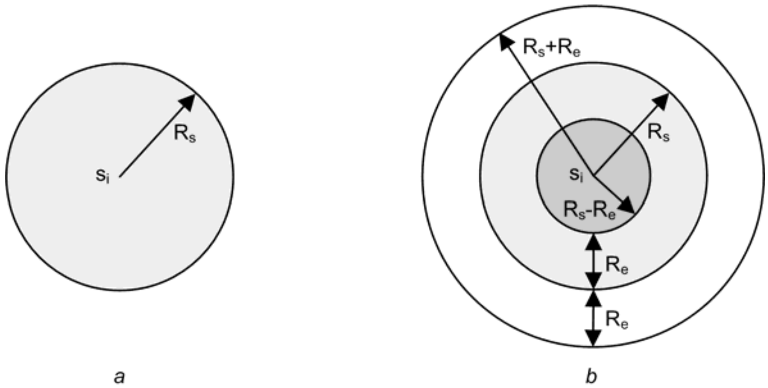


Figure 2. Coverage models: a – binary; b – probabilistic

In reality binary model is imprecise; hence the coverage $c_{ij}(x, y)$ needs to be expressed in probabilistic terms. An evident way to express this uncertainty is by assumption that probability of target servicing by the given node varies exponentially with distance between the target and the node (2).

$$c_{ij}(x,y) = e^{-\alpha d_{ij}(x,y)} \tag{2}$$

This model characterizes coverage confidence level of the point from node *s*. The parameter α can be used to model the rate at which coverage probability diminishes with distance. Clearly, the coverage probability is 1 if the target location and node location coincide. Alternatively, we can also use another probabilistic node coverage model (Figure 2*b*).

Let us define a quantity R_e ($R_e < R_s$) thus, that coverage probability for an object, distant from the node at a distance that is less than or equal to ($R_s – R_e$) is 1, and at distance greater than or equal to ($R_s + R_e$) is 0. In the interval (($R_s – R_e$), ($R_s + R_e$)), there is a certain probability *p*, that an object will be serviced by the node. The quantity R_e is a measure of uncertainty in object servicing. The model is given in equation (3).

$$c_{ij}(x,y) = \begin{cases} 1, & \text{if } R_s - R_e \ge d_{ij}(x,y) \\ e^{-\lambda\alpha^{\beta}}, & \text{if } R_s - R_e < d_{ij}(x,y) < R_s - R_e \\ 0, & \text{if } R_s + R_e \ge d_{ij}(x,y) \end{cases}, \tag{3}$$

where R_e ($R_e < R_s$) is a measure of the uncertainty in object servicing, $\alpha = d_{ij}(x,y) - (R_s - R_e)$, and parameters λ and β are that measure coverage probability when a target is at distance greater than R_e but within a distance from the node. This probabilistic coverage model reflects the servicing behavior of devices such as infrared and ultrasound sensor.

We’ll also introduce the concept of joint coverage of a grid point as follows:

$$c_{ij}^{c}(S) = 1 - \prod_{k=1}^{N}(1 - c_{ij}(x_k y_k)), \tag{4}$$

where $S = \{s_l, l = 1, 2, \ldots, N\}$ is the set of all nodes within the wireless network service area. The joint coverage characterizes coverage probability when at estimation of signal strength are summed signals, received from all nodes. Note that at presence of obstacles $c_{ij}(x, y)$ in expressions (1-3) value of $c_{ij}(x, y)$ is zeroed, if straight line segment between node at (x, y) and point at (i, j) intersects any obstacle.

Model of Obstacle

Wireless systems encompass a wide range of information transmission mechanisms, including cordless phones, paging systems, cell phones, satellite communication systems, maritime-mobile systems, industrial and medical monitoring systems, infrared (IR) remote controls, and so on. These systems have unique operating frequency bands. Frequencies for wireless networks narrow to UHF or typically in the range of 900 MHz to 3 GHz. Usage of these frequencies require a clear line of sight (LoS) between the transmitter and target. Presence of obstacles may cause so called "blocked" or "dark" areas or zones. Blocked area encloses all points which can not be covered by given node due presence of obstacles (Figure 3).

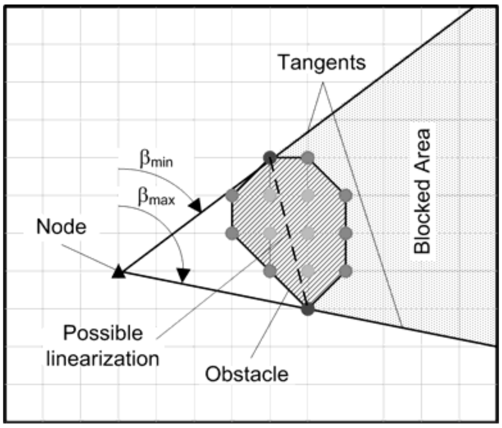


Figure 3. Example to illustrate the concept of blocked area

Obstacles within the WNSA are represented by compact sets of grid points, and might have any shape. We'll model obstacles as convex polygons, snapped to grid. It means that all vertexes coincide with some grid point. For simplification of geometric calculations it is accepted that neighbouring vertexes of the obstacle belong to the same grid cell.

Obstacles with arc or curve boundaries are approximated by polygons. Obstacle of arbitrary form by means of triangulation can be decomposed into few convex ones [4]. We assume that a grid point P at (i, j) can be covered by node S at (x, y) if it is within a distance $d_{ij} = \sqrt{(x-i)^2 + (y-j)^2} \le R_s$ and line of sight $\overline{PS}$ exists with the existence of obstacles, i.e. the line segment $\overline{PS}$ does not intersect any obstacle inside the WNSA.

2. Solution of Main Geometric Tasks

Strategies, suggested in this work, assume some geometric tasks to be solved prior or during realization of the strategies. Among these geometric tasks, first of all, following ones must be mentioned:

- contouring of obstacles;
- revelation of line segment and convex polygon intersection;
- exposure of "dark" zones, caused by obstacles.

This section is dedicated to consideration of listed tasks and most suitable ways for their solution.

Contouring of Obstacles

As it has been accepted earlier, obstacles within the WNSA are presented by convex figures. At contouring of obstacles we must define all its boundary points (vertexes). In the simplest case it can be done at forming of matrix T, by marking of all points, lying on the perimeter of obstacle, as having type BO. Otherwise we must solve the planar convex hull problem: for given set of points, forming the obstacle, find ones, lying on perimeter of convex polygon, representing the obstacle.

Computing of a convex hull is one of the sophisticated geometry algorithms. There are many variations of it. The most popular algorithms are the "Graham scan" and the "divide-and-conquer" algorithms. Both are O(n log n) time algorithms, but the Graham has a low runtime constant in 2D and runs very fast there. Table 1 contains a list of some well-known 2D hull algorithms (n – number of points in input set; h – number of vertices on the output hull).

Table 1. 2D hull algorithms

Algorithm	Speed	Algorithm	Speed
Graham Scan	$O(n \log n)$	Brute Force	$O(n^4)$
Divide-and-Conquer	$O(n \log n)$	Gift Wrapping	$O(nh)$
Monotone Chain	$O(n \log n)$	Jarvis March	$O(nh)$
Incremental	$O(n \log n)$	QuickHull	$O(nh)$
Marriage-before-Conquest	$O(n \log n)$		

Revelation of Line Segment and Convex Polygon Intersection

An arbitrary point within the WNSA may be covered by a node, located within the same area, only if the straight line segment, connecting the point and the node, is not blocked by an obstacle. Geometrically such blocking appears in presence of two points of intersection between the line segment, connecting examined point with a node, and boundary of the convex polygon, representing the obstacle. Formally, checking of line of sight blocking can be reduced to elementary geometric problem: whether or not two given line segments intersect. First segment represents straight line, connecting node with the examined point. As a second segment we must in turn take edges of convex polygon, which are line segments, connecting pairs of neighbouring vertices. If after examination of all edges intersections take place twice, then the obstacle blocks the straight line between the node and the point.

The straightforward way to solve line segment intersection problem is to find the intersection point of the lines defined by the line segments and then check whether this intersection point falls between the endpoints of both of the segment. As well the procedure must be implemented for all examined points, all nodes and all obstacles within the WNSA, it is desirable to have more effective algorithm in sense of minimization of computational load.

Taking into account that all objects (nodes, obstacles), as well as all examined points, coincide with grid points, we propose fast algorithm for intersection problem. As a basis, for building line segment from the node to a point to be covered, it uses the Bresenham's algorithm, (a well known method for choosing cells in a grid to represent lines) with one sufficient modification. With the standard Bresenham's algorithm line is formed as a sequence of elementary movements between points belonging to the same grid cell. Depending on of formed line direction, regular endpoint will be grid cell vertex, which relative to preceding point of Bresenham's line takes up horizontally, vertically or diagonally. In the case of diagonal point, constructed line can cross edge of convex polygon between its vertexes. The heart of suggested modification is in replacement of stepwise approximation of diagonal movement by sequence of two movements: horizontal and vertical, i.e. in insertion of extra line point. Due to this modification intersection between constructed line and convex polygon is possible only at vertexes of the convex polygon. Figure 4 illustrates described modification of Bresenham's algorithm.

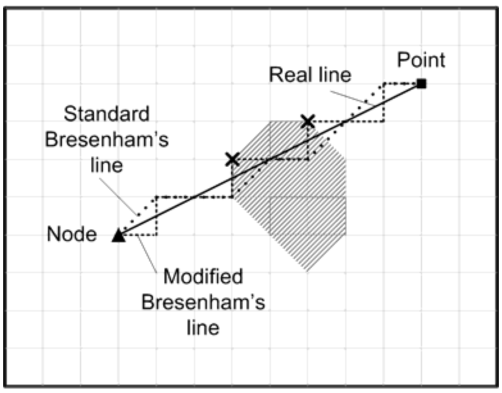


Figure 4. Example to illustrate modified Bresenham's algorithm

Due to suggested modification revelation of line segment and convex polygon intersection is reduced to simple procedure of comparing of current line point coordinates, got in accordance with modified Bresenham's, with coordinates of all points within matrix *T*, having *BO* type, i.e. with coordinates of obstacles' boundary vertexes.

Exposure of "Dark" Zones Caused by Obstacles

Some covering strategies come from assumption that extra nodes, first of all, must ensure coverage of those WNSA fields, which are blocked by obstacles, or so called "dark" zones. It arise a problem of discovering of such zones.

The obvious solution may be described as follows. Each grid points, except containing nodes or belonging to obstacles, is checked either this point is blocked by an obstacle. It can be done with the help of previous algorithm. The inspection must be done relative to all obstacles. If after this procedure the examined point remains blocked, it means that this point belongs to a "dark" zone. As a next step the Next step clusterization of "dark" points must be done by separation of compact groups of adjacent "dark" points. Each group represents one "dark" zone within the WNSA.

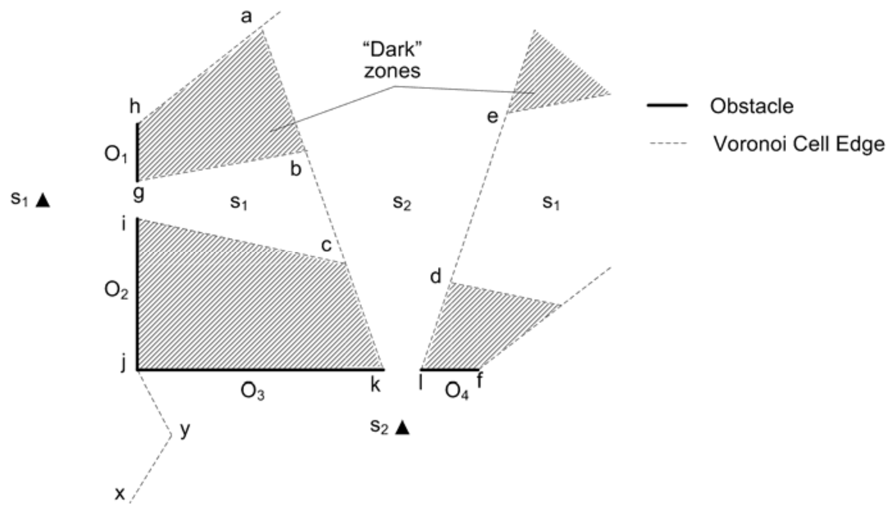


Figure 5. CW-Voronoi diagram of nodes and obstacles

Instead, for our purposes we suggest other leverage, based on building of constrained and weighted Voronoi diagram (CW-Voronoi diagram) [5]. As an example, consider Figure 5. which shows the CW-Voronoi diagram where s_1, s_2 are two nodes and O_1, O_2, O_3, O_4 are 4 line obstacles. The field areas are dark regions which cannot be covered by either of the two nodes s_1, s_2. The remaining cells of the CW-Voronoi diagram are labelled by the nodes to which they are closest. Note that a Voronoi cell of a point (a node in our case) may consist of several disjoint subcells (as it is shown on Figure 5 for s_1 and s_2). The vertex set of this CW-Voronoi diagram consists of (a) the set of obstacle endpoints, (b) the intersection of bisectors between nodes and (c) the intersection of extended visibility lines from nodes passing through the obstacle endpoints. Every Voronoi edge is a section of the bisector of two nodes (e.g., (x, y) in Figure 5), or a visibility line determined by a node and an endpoint of an obstacle (e.g., (g, b) in Figure 5), or a section of an obstacle (g, h) in Figure 5).

As well as obstacles in this algorithm are presented by line segments, while we describe obstacles as convex polygons, the last ones must be replaced by corresponding linear segments. As a linear equivalent we can take line segment connecting tangent points – those. As tangent points are taken convex polygon vertexes, for which lines, connecting vertex with given node, has the minimal and the maximal slope among all vertexes (Figure 3).

3. Coverage Ensuring Strategies at Presence of Obstacles

Coverage problem at presence of obstacles comes to ensuring of coverage of all grid points within the area *A* (except the obstacles itself), despite of negative influence of obstacles. For areas with no obstacles this problem was adequately investigated and a number of ways for its solving were offered. All are based on placing of extra nodes, and vary in the algorithms of selection of the best locations for these nodes. All things considered it expedient to extend these solutions on WNSA with obstacles. However it is possible after elimination of all problems caused by the obstacles. Taking into account aforesaid, a generalized coverage ensuring strategy for WNSA of obstacles may include two phases. Deployment of additional nodes at first phase must guarantee coverage of those grid points, which may be under influence of obstacles. After elimination of problems, concerned with obstacles, the second phase can be started. Its goal is coverage ensuring for those WNSA points, which remain uncovered after the first phase. Most of known algorithms for coverage with no obstacles can be used at this phase, but with one restriction: inner points of obstacles are not examined as an object of coverage and also can not be used as locations for additional nodes. In this work we talk over possible ways for realization of both abovementioned strategies. Note, that for some strategies the preliminary phase may be omitted. Obstacles are taken into account as a part of common procedure.

Elimination of problems caused by obstacles

During this phase of general coverage insuring procedure we must assure coverage for those grid points, which are under influence of obstacles, i.e. points whose line of sight with any existing node is blocked by obstacles. Two approaches for solving of this problem may be proposed.

In accordance with the first approach, denoted as *obstacle perimeter covering* (OPC), extra nodes must, first of all, completely cover all boundary points of each obstacle within the WNSA.

The second approach is based on determination of “dark” zones, stipulated by blocking of lines of sight between the examined grid points and nodes, already located in the WNSA. Next we must locate additional nodes, which cover found “dark” zones. This approach we’ll denote *dark zone covering* (DZC).

4. Offered Deterministic Strategies

The node deployment problem does pose much challenge. We’ll single out two prevailing approaches for coverage insuring at presence of obstacles. The first one in respect to sensor networks is described in [6, 7]. Here, first of all, additional nodes are deployed to eliminate the coverage holes near the obstacles. It can be easily solved by sequential node placing in belt-like manner along the boundaries of the region and obstacles. Second approach presupposes exposing of all “dark” zones within the WNSA, blocked by obstacles, which must be covered first. At the second phase of both approaches coverage of points which remain uncovered is ensured.

Obstacle Perimeter Covering

Coverage of boundary points of all obstacles can serve as a sufficient condition for posterior (during the second phase of coverage insuring procedure) overall coverage. As distinct from area coverage this coverage form is known as boundary coverage.

Perimeter covering can be can be realized by sequential placing of extra nodes along the boundaries of the obstacles. Nodes are placed at vertexes of convex polygons, presenting the obstacle, as it is shown on Figure.6.

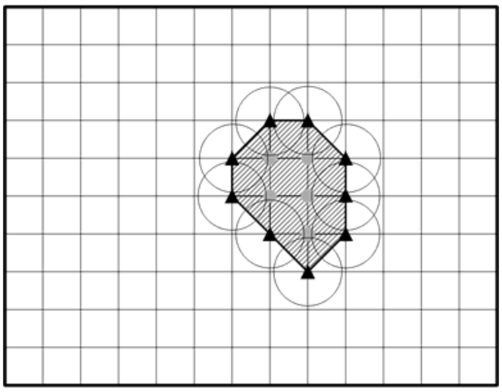


Figure 3. Example to illustrate obstacle perimeter covering

Covering of “Dark” Zones

An objective of the DZC procedure is to ensure that every point of “dark” areas within the WNSA is covered and no such zones remain. As it follows from the nature of blocked zones, they represent convex polygons. Reasoning from this thesis, following procedure is suggested.

Step 1. For current configuration of wireless network nodes find all "dark" zones within the WNSA.

Step 2. If no such zones were found, than terminate.

Step 3. Delineate each "dark" zone by calculating of convex hull.

Step 4. For each convex polygon, representing a "dark" zone, define its centroid (centre of gravity).

Step 5. Find "dark" zone, having the greatest Euclidian distance between its vertexes and centroid.

Step 6. Place extra node at gride point, nearest to the centroid of the "dark" zone, fount in Step 6, and return to Step 2.

The circumscribed procedure eliminates problems, caused by obstacles within the WNSA, and can serve as first phase in the solution common problem of WNSA coverage.

Coverage Ensuring After Elimination of Obstacles Influence

For those WNSA points, which remained uncovered after elimination of problems, stipulated by obstacles, three strategies [1] are suggested: Worst Coverage Point (WCP), Worst Coverage Domain (WCD) and the Farthest Voronoi Vertex (FVV).

The base of the WCP strategy is that the worst coverage has a point most remote from the nearest to it network node. This point is taken as the best place for placement of additional node.

WCP algorithm can be described by the following steps:

Step 1. Cover wireless network service area A by a grid of $m \times n$ square cells. Each point P ($i \times$ m, j $\times$ n) in the area corresponds to square cell corner. Describe area A by matrix T.

Step 2. For each point, which after the first phase of covering strategy has type FP, find the nearest node from all nodes already placed in the area A.

Step 3. Calculate the Euclidean distance between each mentioned point and its nearest node.

Step 4. Find the point with maximal distance from the nearest to it node.

Step 5. Compare this distance with node service radius R_s. If the distance is less or equal to R_s, then the procedure is completed.

Step 6. Place an additional node on the position, corresponding to maximal distance and return to Step 2.

The WCD approach to determining a candidate point is to compute the cumulative coverage over each square domain, for several overlapping such domains in the terrain. This is based on the observation that adding a new node affects its nearby area, not just the point where it is placed. The WCD algorithm consists of the following steps:

Steps 1-5. are the same as the WCP algorithm.

Step 6. Divide the area around the worst coverage point (WCP) into N_G partial overlapping square domains (step of overlapping is equal to cell size c) as follows:

Step 6.1. Each domain has side $g = \sqrt{2}R_s$ and encloses the WCP. Thus each point of the domain can be serviced from the centre of this domain.

Step 6.2. Number of data points in a domain $P_G = \left(\frac{g}{c} + 1\right)^2$

Step 6.3. No domain can cross the bounds of area A. Such domains are excluded from further considerations.

Step 7. For each domain from Step 6 calculate the cumulative distance over this domain.

Step 8. Add a new node at the centre of a domain with the maximal cumulative distance and return to Step 2.

The third strategy, called Farthest Voronoi Strategy (FVV), is based on the properties of Voronoi diagram.

The FVV algorithm can be described as follows:

Step 1. For all nodes within the area A build the Voronoi diagram.

Step 2. Calculate the Euclidean distance between each vertex point of Voronoi diagram and its nearest node.

Step 4. Find the vertex point with maximal distance from the nearest to it node.

Step 5. Compare this maximal value and the node service radius R_s value. If it is less or equal to R_s then the procedure is completed.

Step 6. Place an additional node on the position, corresponding to farthest Voronoi vertex and return to Step 1.

5. Offered Probabalistic Strategy

As it was stated earlier, level of coverage for grid point P at (i, j) by node s at (x, y) is estimated by value $c_{ij}(x, y)$, characterizing coverage probability at this point. A point is treated as covered if at least one of c_{ij}, got from all N nodes within area A, exceeds given threshold. In the case under study we must suggest strategy for placing of extra nodes with overall goal to reach given coverage probability for all grid points, except ones occupied by nodes and obstacles.

Node placing algorithm uses a greedy heuristic to determine the best placement for one node at a time. The algorithm is iterative, and it place one node in the serviced area during each iteration, and may be described in such steps.

Step 1. Cover area A by a grid of $m \times n$ square cells.

Step 2. Describe this grid by matrix T, where each element has a certain type. Points, containing nodes, are marked as having type NL_k (k – node serial number, k = 1..N). All points, covered by obstacles, must have type IO_l, where l represents index of obstacle. Rest points are marked as FP-type points.

Step 3. Define points, lying on the boundary of obstacles. Their type must be changed from IO_l to BO_l. It can be done right away at Step 2 or by contouring procedure.

Step 4. For each grid point of FP type at (i, j), define vector $C_{ij}=\{c_{ij}(x_1, y_1), c_{ij}(x_2, y_2),\ldots c_{ij}(x_N, y_N)\}$, where elements are coverage probabilities, provided by N nodes, located within the WNSA. These probabilities are calculated in accordance with equation (3). At calculating of $c_{ij}(x_k, y_k)$ check, whether LoS for (i, j) and (x_k, y_k) intersects obstacles. In this case $c_{ij}(x_k, y_k) = 0$.

Step 5. For each C_{ij} calculate representative coverage probability c_{ij} as c_{ij} = max $\{c_{ij}(x_1, y_1), c_{ij}(x_2, y_2),\ldots c_{ij}(x_N, y_N)\}$. In the case of joint coverage value c_{ij} is calculated as $c_{ij} = 1 - \prod_{k=1}^{N}(1 - c_{ij}(x_k y_k))$.

Step 6. Among all FP-type points find one with minimal value of c_{ij} . If this value exceeds prescribed threshold terminate the procedure.

Step 7. Place extra node at a point, having minimal c_{ij}. Increment number of nodes by one ($N := N + 1$). Change the type of new node location in the T matrix to NL_N with new N as an index.

Step 8. Return to Step 4. Note at this step we must only enlarge each vector C_{ij} by adding of one element, stipulated by new node.

Conclusions

Coverage of wireless network service area becomes more complicated in presence of different obstacles, breaking line of sight between nodes (transmitters or sensors) and target points. Possible ways for solving of this problem are presented. Though the subject of investigation is discussed conceptually, there are proposed some suitable deterministic and probabilistic strategies for WNSA covering, as well as computationally effective geometric algorithms for realization of these strategies. Experimental results (omitted in view of their tentative nature) showed competence of proposed strategies and algorithms. Estimation of advantages and disadvantages of suggested approaches require more careful simulation and will be subject of subsequent work.

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