GEOMETRICAL COMPUTATION OF CELL COVERAGE AREAS IN PLANNING OF OUTDOOR URBAN MICROCELLULAR SYSTEMS

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1.Introduction

In the recent development of mobile telecommunication systems, the microcellular architecture is one of the most promising technique to cope with the current explosive growth of the mobile network subscribers. Especially in urban area, deployment of the low power and low height cell site (CS) antenna systems enables the reduction of the cell coverage size, which will enhance the spatial utilization of limited frequency resources.

From the network planning point of view, however, there arise some bothering problems in the development of practical urban outdoor microcellular networks. Different from the conventional macro cell systems, transmitting antennas are generally located at lower height relative to the surrounding high-rise buildings. Enclosed in the canyon of high-rise buildings, the radio signal from one of the transmitting antennas propagates along the street and then the cell coverage may be confined along streets, which result in the cell coverage shape like " fish bone", considerably different from the quasi-circular shape generally assumed in the traditional macro cell networks. Furthermore, due to the reduced cell coverage size, enormous number of CSs should be installed so that the network provides the wide and seamless service coverage in the area of interest. For the effective design of this kind of urban microcellular systems, the network planners have to pay a great deal for the evaluation of the complicated cell coverage area for all of the CSs before starting the commercial services.

Various kinds of radio propagation models have been proposed so far which describe the propagation characteristics under the urban complicated microcellular environment. Thanks to these models, the radio propagation phenomena in microcellular environment is becoming to be clarified. At present, some effective methodologies are expected for the practical use of these models to serve as the easy and simple assistance of practical network planning under the complicated urban built-up environment.

The recent progress in the area of geographical information systems (GIS) enables us to utilize some digital building data which have acceptable accuracy. In addition, some kinds of computational geometry approaches, that have been mainly developed in the area of computer graphics, are available for general purposes in these days supported by the higher performance of recent computer systems. Integrating such digital building data and the techniques of the computer geometrical analysis, this paper introduces the comprehensive and effective approach for the purpose of the complicated initial planning of the urban outdoor microcellular networks. Our approach can provide the network planners with a versatile methodology for the evaluation of the non homogeneous cell coverage shape strongly affected by the surrounding ground constructions in urban microcellular environment.

2.Computer Geometrical Approach for Cell Coverage Evaluation

2.1 Objective and Assumptions

The objective of our approach is mainly for the evaluation of the shape of cell coverage in urban microcellular environment. Detail evaluation of field strength at a specific point in the cell coverage is out of scope in this paper, but only the shape of each cell coverage is evaluated from the geometrical information of buildings and quite simple propagation models. At the first stage of the microcellular network planning, rough estimation of the cell coverage is more required rather than the detail radio analysis in the area of interest, because such cell coverage estimation is highly required to assess the investment of equipment and to decide the antenna site selection policies.

The microcellular systems deploying the low height antenna sites are considered in this paper. Enclosed in the canyon of the surrounding buildings higher than the antenna sites, the radio signal in microcellular environments is assumed to propagate mainly along the streets. In the case of higher antenna site relative to the surrounding buildings, some statistical approaches may be more suitable rather than the geometrical analysis presented in this paper.

2.2 Geometrical Computation for Cell Coverage Areas

In evaluating the cell coverage in case of sufficiently low height transmitting antenna, the radio paths guided by streets are dominant compared with the effect of the paths over the roof-tops of buildings. The contribution of the latter paths may be negligibly small due to the multiple diffraction loss at the edges of building roof-tops. Then the height of all the buildings can be assumed to be infinity, therefore the information of the building height is no longer required and only the two dimensional geometrical analysis is enough for our analysis.

In this case, the most significant factor in estimating the cell coverage is the visibility between the CS and the location of mobile personal station (PS) terminal. The radio propagation characteristics may much differ between the Line-of-Site (LOS) and non Line-of-Site (NLOS) regions. So we first have to specify the LOS and NLOS regions and to evaluate the cell coverage separately for each region.

An algorithm to find " visibility polygon" is used for the purpose of identifying the LOS region of a CS. The " visibility polygon" problem is defined as follows : " given a point p and a group of disjointed polygons as obstacles on a plane, find an area which is visible from p" . Considering the two dimensional geometrical data of buildings as the polygons, two dimensional plane-sweep techniques are used for finding visibility polygon of the given CS location[1]. The order of the calculation time of this algorithm is $O(n\log n)$ with respect to the number of vertices of all polygons n and it will be suitable for the practical large scale problems.

2.3 Building Data Consideration

Cell coverage evaluation in our approach requires some two dimensional geometrical data which represent the shape of the buildings in the area of interest. For the computer geometrical processing described in the previous subsection, these building data must be in a vectorised format, that is, the shape of each buildings is represented by polyline segments which correspond to the building walls. Thanks to the remarkable progress in the GIS field, such kinds of vectorised building data are available for some major cities from commercial or public services.

For the area where such data are not provided, however, it is still possible to obtain the vectorised building data through scanning and digitizing the paper map using a high definition scanning system and some computer aided design (CAD) tools. For example, 1/10000 scale topographical paper maps and a 600 dpi scanner can produce the vectorised building data with acceptable accuracy when applied for our purpose in a practical amount of work.

2.4 Radio Propagation Pathloss Models

To evaluate the coverage area of each CS, appropriate propagation pathloss models are necessary for both LOS and NLOS regions. These models are expected to be as simple as possible so far as they successfully represent the microcellular pathloss characteristics. In our approach, the propagation pathloss is simply represented by a function of distance between the CS and PS measured along the streets as shown in Fig. 1. According to this figure, we can categorize the area of interest in 3 regions.

Region 1 in Fig. 1 corresponds to the LOS region of the cell site. The dual-slope log-linear function is commonly used to describe the pathloss characteristics[2]. Slope indices of 2 before breakpoint and 4 beyond breakpoint are employed in our approach, which are verified in large literature. The pathloss-distance function in this case is represented as follows,

$$L_{LOS}(d) = L_b + \begin{cases} 20 \cdot \log(d / D_b) & , d \le D_b \\ 40 \cdot \log(d / D_b) & , d > D_b \end{cases} \quad (1)$$

where, d is the distance between the CS and the PS, D_b is the breakpoint distance, and L_b represents the pathloss at the breakpoint.

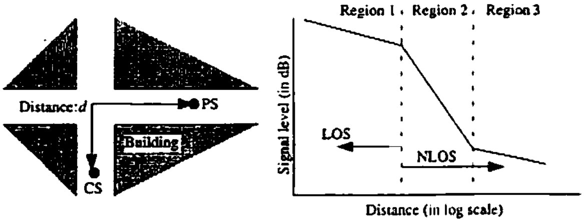

Fig. 1 Pathloss Model in Microcellular Environment

In NLOS region, the signal strength at PS rapidly falls for a short distance after turning around the corner (Region 2) and in further area the signal level slowly decreases as the distance increases (Region 3)[3,4]. The sharp falling of signal level in Region 2 is in the order of 20 to 30 dB. In most case of the practical microcellular network design, the signal threshold level at the PS lies in this region and the propagation characteristics in region 3 will much less contribute to coverage area evaluation. For our purpose, therefore, pathloss characteristics in region 2 is much more significant than in region 3. In our approach coverage area evaluation in Region 3 is omitted for this reason. Also the area which is unreachable through only one diffraction from the CS is out of consideration because of the large pathloss through multiple diffraction. NLOS coverage evaluation is performed for the region which is reachable from the CS through only one diffraction.

Fig. 2 represents the pathloss curve dependency on the interval between the CS and the turning corner in Region 2. As depicted in this figure, the pathloss slope is roughly approximated by log-linear function, and its slope index increases as the interval between CS and turning corner increases.

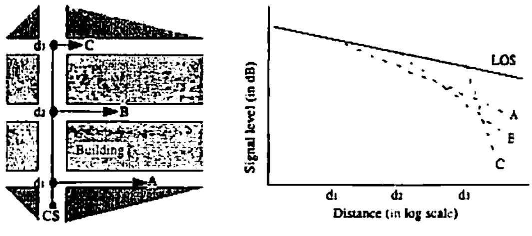

Fig. 2 Pathloss Characteristics in NLOS region

From this qualitative characteristics, we --modeled the pathloss characteristics in Region 2 as the following function (2).

$$L_{NLOS}(d) = L_{LOS}(d_1) + n_{NLOS}(d_1)\cdot\log(d/d_1) \quad (2)$$

where d_1 represents the interval between the CS and the turning corner, d represents the distance between the CS and the PS measured along the LOS/NLOS streets. The function $n(d_1)$ describes the pathloss slope index in Region 2 and has been defined based on the field measurements conducted during the trial of personal handyphone system (PHS) services.

2.5 Coverage Area Evaluation

Once the geometrical computation, the two dimensional building data and the propagation pathloss models are all integrated as described in the above subsections, the cell coverage area is evaluated by the following procedure for a CS. Let L_{th} be the threshold pathloss level at PS. L_{th} can be determined by CS transmitting power, antenna gain, receiver sensitivity, and so force.

i) Calculate the visible polygon of the CS antenna location.

ii) Calculate the LOS coverage distance d_{LOS} using L_{th} and equation (1).

iii) Trim the visible polygon so that the distance from CS and the edge of the polygon will be d_{LOS}. The resultant polygon will be the LOS coverage area.

iv) For the edges of the LOS coverage polygon, which are not blocked by the building walls, define a fictitious origin point on the edge.

v) Using L_{th}, the distance d_1 between the CS and the fictitious origin point, and equation (2), calculate the NLOS coverage distance d_{NLOS}.

vi) Calculate the visible polygon of the origin point and trim with the distance d_{NLOS} like procedure ii). The resultant polygon corresponds to the NLOS coverage area.

Fig. 3 shows the concept of this procedure.

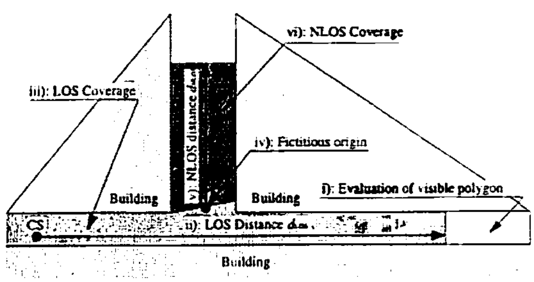

Fig. 3 Coverage evaluation procedure

3.Software Implementation

For the practical application of our approach, we have developed the CS planning (CSPLAN) support software. Based on the techniques presented in the previous section 2, the software realizes the following functions which are quite beneficial for the practical design of microcellular networks.

- Estimation of the LOS/NLOS cell coverage area for more than thousands of CSs
- Color graphical display of CS coverage areas as well as the building and other background topographical information
- CS data management using common spread sheet software
- Production of large scale CS maps using a color plotter system
- Comprehensive operation through the graphical user interface

The system is implemented on the commonly used SUN workstation running Solaris operating system and X window system with MOTIF user interface.

Fig. 4 depicts an example display of CSPLAN software. A number of buildings are represented by light gray polygons in this figure around the Tokyo station area. The black point at the center of the building map shows the CS whose coverage area is evaluated as an example. The cell coverage area is successfully calculated for LOS region, which is represented by the cross-shape gray area around the CS, and for NLOS region, which is shown as dark gray polygons, respectively. The computation time in this coverage area evaluation is approximately 20 seconds.

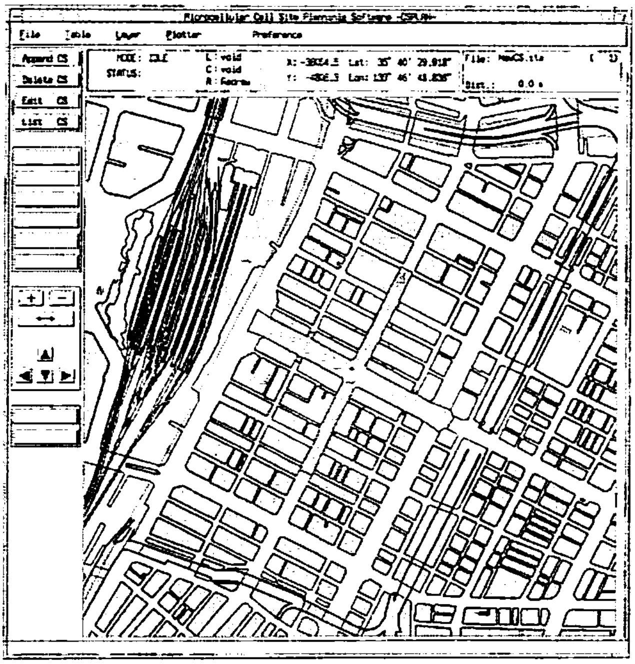

Fig. 4 Calculation example of CSPLAN

4.Concluding Remarks

A methodology for the practical use of urban radio propagation characteristics and models is introduced in this paper aiming at the application for the design of practical microcellular networks. Focusing on the geometrical properties of urban microcellular environments such as two dimensional building shape or CS location, our approach will realize effective utilization of urban microcellular radio propagation models and provide a powerful assistance for the time-consuming cell coverage evaluation procedure on the initial phase of microcellular networks. Our approach has successfully been implemented as a software product which will run on a commonly used engineering workstation.

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