Optimization of Millimeter-Wave Base Station Deployment in 5G Networks

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***Abstract*—** In the fifth-generation (5G) technology for broadband cellular networks, one of the striking problems is the millimeter wave (mmWave) transmission that enables high speed and low latency, also has relatively poor penetration ability and higher deployment cost. Therefore, minimizing the number of base stations (BSs), while satisfying the Quality of Service (QoS) requirement from mobile users, has become a valuable topic in both the academia and the industry. This paper proposes a two-step method to obtain an optimal deployment strategy under a given map.The first step is to apply the Canny Edge Detection and Opening Operation algorithms to detect the edges of actual maps to form a graph; and the second step is to decide the deployment points on the graph based on the Quadtree Traversal Algorithm. The results show that: a coverage ratio close to 100% can be achieved until 1139 BSs are deployed. After adding a constraint that requires the intensity of signals at each point in the map to reach a certain level, the number of BSs required by the optimal deployment was decreased to 497 for a coverage rate of 96.62%. The proposed method significantly decreases the number of BSs deployed.

Keywords—5G, base station, Canny Edge Detection, deployment, Opening Operation, optimization, Quadtree Traversal Algorithm

I. Introduction

Recent years, in order to improve the quality of the mobile communication, technology is constantly being updated. To meet the tremendous demand for high speed of communication, the fifth generation mobile communication technology (5G) has came into sight with its characteristics of high speed, low latency and large scale. However, disadvantage is equally obvious. High speed and low latency cause poor penetration and narrow range of signal which means more base stations (BS) need to be built thus would increase the economic input. Moreover, with the development of cities, the overall arrangement of urban buildings, roads and facilities become more and more complex. This makes the deployment of BS increasingly difficult. How to build as few BSs as possible on the premise of ensuring signal intensity to meet the quality of communication becomes a technical problem what needed to be fixed.

More or less, most of the previous researches are theoretical, i.e., calculating the optimal deployment through a series of algorithms without combining with more realistic urban construction. For example, the simulated annealing algorithm was implemented on the map created by authors [1-5]. Theoretical should be connected with reality. As mentioned in the title, this paper is to find the optimal solution for the deployment of millimeter wave (mmWave) base stations in 5G networks. We considered the solution in two aspects. The first goal is to meet the high quality of consumer use of the network. It is important to ensure that everyone in the target area can receive a dense signal. The second objective is to reduce cost. The goal of this paper is to find the optimized solution for deployment of millimeter wave BS in 5G networks, technically and economically.

II. METHOD

A. Canny Edge Detection

In order to carry out the work smoothly this paper puts forward the following assumptions and concepts: The attenuation of signal with increasing of distance will not be discussed. The radiation range used in the calculation is the actual range of effective; it is assumed that high-speed moving objects, passengers and cargoes will not affect the signal strength; assuming signal overlapping does not enhance the signal. The signals by different BSs will carry their own unique information without interference; assuming signal of BS isn't disturbed by the outside; all BSs have the same model, thus no difference in the signal characteristics. The solution to deployment of BS is mainly divided into two parts: identifying the actual map and extract the target information. Searching all of the required deployment points on the graph according to the Quadtree Traversal Algorithm (Fig. 1 a).

For a image, the frequency is seen as an indicator of the intensity of gray changes which can be interpreted as the gradient of gray in the plane space [6]. Image edge information is mainly concentrated in the high frequency band. Differential operation can find the rate of change of signal, it has the role of strengthening the high frequency components. In space-based operation, sharpening an image is calculating differentiation. Since the signal of the digital image is discrete, differential operation becomes the calculation of the difference or gradient between the discrete points.

Canny Edge Detection is used in this paper since it is considered to be one of the most accurate methods although there are kinds of edge detection operators in image processing, such as Robert Operator and Sobel Operator [7-10]. The algorithm can be summarized into four steps: smooth graph

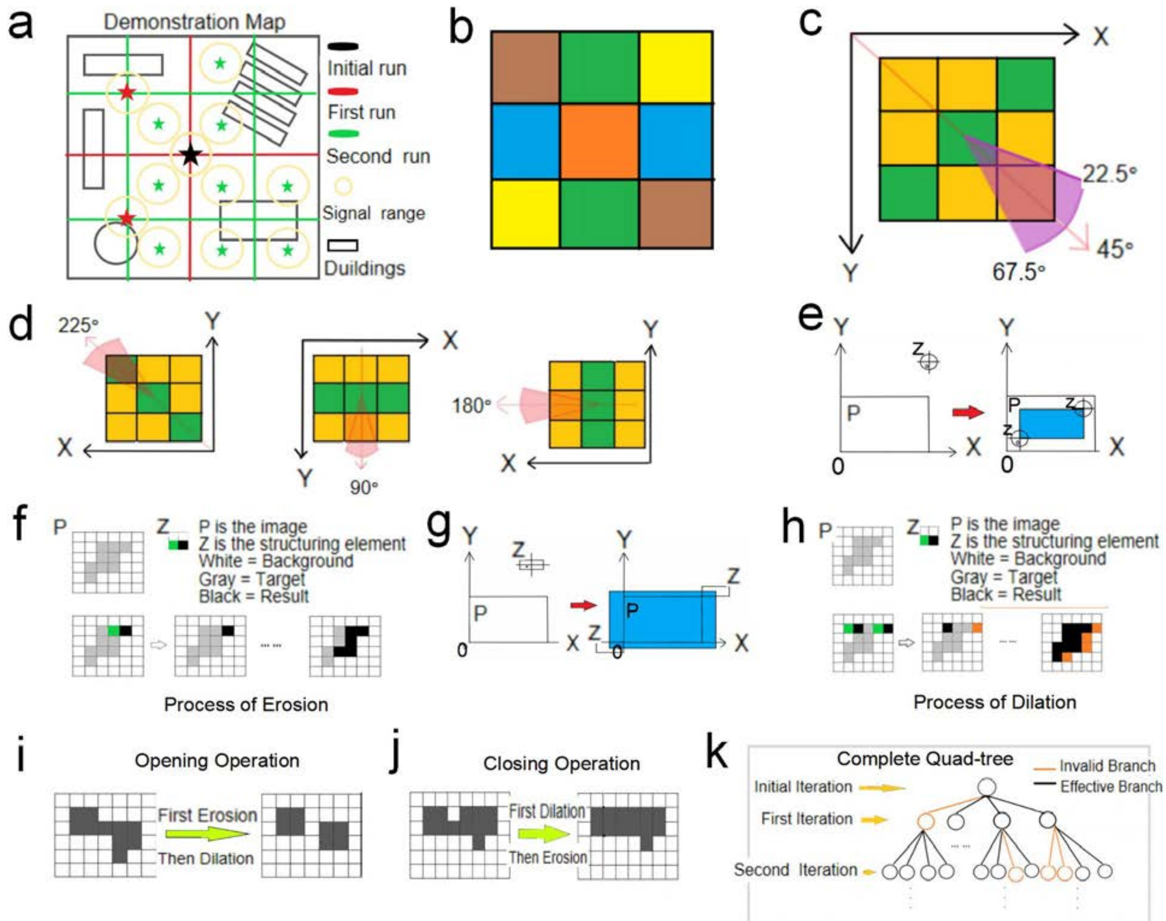

Fig. 1. Concept image of model construction

gradients and directions, non-maximum suppression and detect and connect the edges.

Smoothing graph: the first step is to get an actual graph from the map then gray the image and get a pre-processed initial image. Subsequently Gaussian Filter is used to the gray-scaled image. Image Gaussian filtering can be realized directly by a two-dimensional Gaussian Kernel convolution [11].

Gradients and directions: the second is to calculate the magnitude and direction of the gradient at each point in the image and the standard Sobel Edge Detector was used.

Non-maximum suppression: after calculating the magnitude and direction of the gradients, we can start the edge detection. The primary operation of this step is to compare the gradient in front of and behind it along the gradient direction. For a gray pixel, there are only four edges possible. For the point in the centre, it only has north-to-south, east-to-west and two diagonal directions (Fig. 1 b). The process of the four directions was shown in Figure 1 c and d. Through this step, a primary edge gets.

Detect and connect the edges: general edge detection algorithms use a threshold to filter out minor gradients raised by noise or color changes while reserving large gradients [8, 10]. Canny algorithm uses double thresholds, that is, a high threshold and a low threshold to distinguish edge pixels. Canny edge detection algorithm was used to complete the operation on the image.

B. Opening Operation

After the initial extraction of the boundaries, the mathematical morphological image processing methods were used to further process the boundaries. This method can be divided into two operations: opening operation and closing operation. The key factor that distinguishes the two operations is the different order of erosion and dilation operations [12-15].

The principle of erosion is to find a specific structural element *Z* and let *Z* shift *a* in the processing object to get *Za*. Provided that *Za* is contained in *P*, all *a* points meeting the above conditions are preserved, and the set of *a* is called the consequence of *P* being eroded by *Z*. The concept and process of erosion were illustrated in Figure 1 e and f.

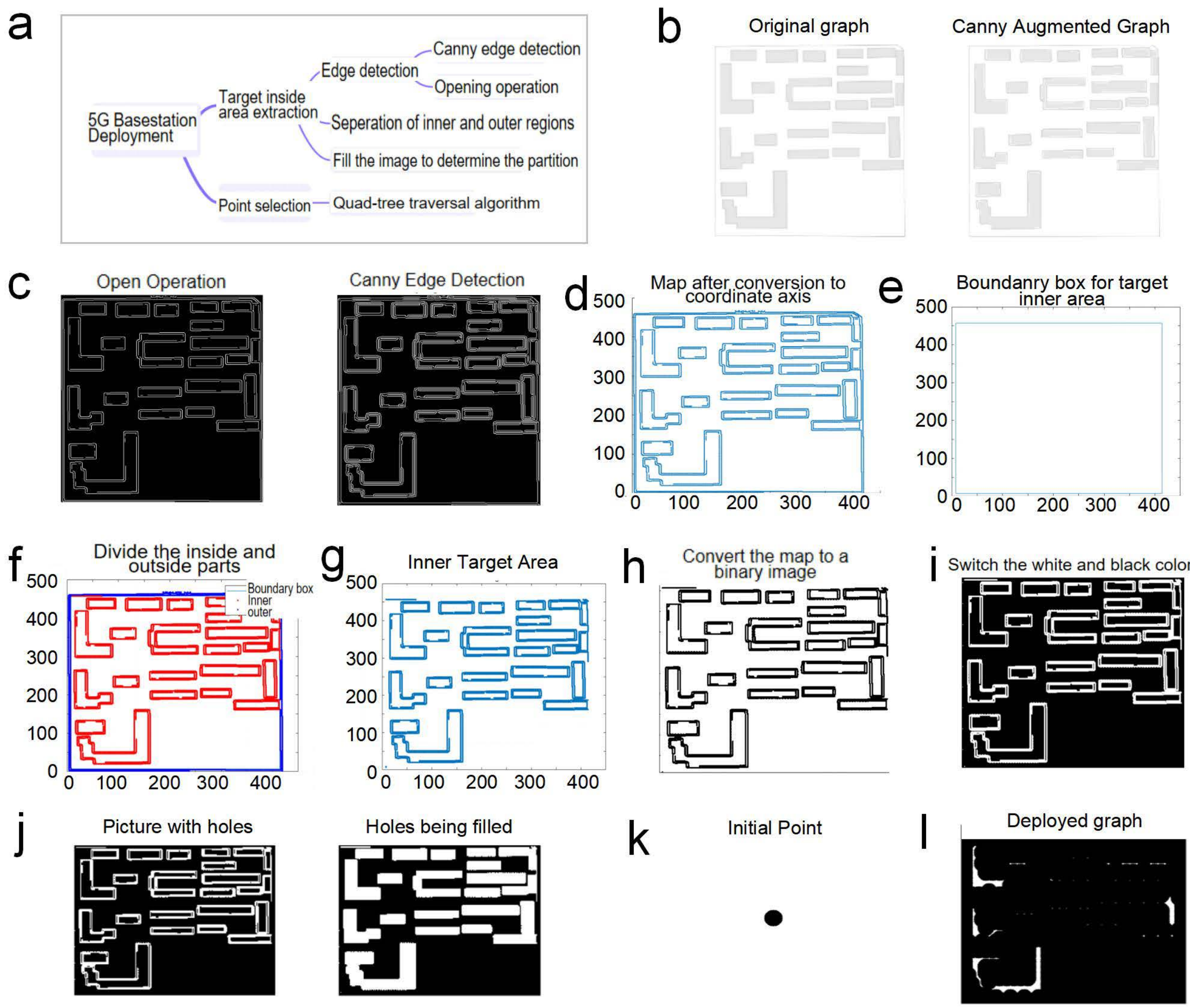

Fig. 2. Operation process

Dilation is to find a specific structural element *Z* and let *Z* shift *a* in the processing object to get *Za*. If *P* is touched by *Za*, all *a* points meeting the above conditions are saved, and the set of *a* is called the result of *P* being dilated by *Z*. The concept and process of dilation were illustrated in Figure 1 g and h.

Opening is to first apply erosion and then dilation. The result was shown in Figure 1 i. Opening operation can remove small isolated points, burrs and bridges, but the overall position and shape is unchanged. Opening is a filter based on geometric operation. Different sizes of structural elements will lead to different filtering effects. The selection of different structural elements leads to different segmentation, that is, different features are extracted.

Closing has the inverse order of erosion and dilation compared to the Opening, which can fill small holes and close small cracks, while the overall position and shape remains unchanged (Fig. 1 j). It was to filter the image by filling the concave angle of the image. Similar to the Opening, different sizes of structural elements will lead to different filtering effective results.

In order to reduce unnecessary burrs and edge, this paper used opening operation. In MATLAB, the 'spur' command was used to remove small branches, make edges simple and clear, and remove some invalid boundaries raised by errors caused by image colors.

C. Quadtree Traversal Algorithm

The Quadtree Traversal Algorithm was used when BSs were deployed. Quadtree or quaternion, is widely used in image processing, spatial data index, fast collision in 2D, storage coefficient data and other problems[16-19]. This paper will use the thought of graph traversal and apply the tree traversal to solve the deployment of BS (Fig. 1 k). The traversal algorithm is to visit each node in the tree (graph) in turn searching along a specific search route [20].

Specifically, it can be expanded as followings: in the initial state of 0 coverage, all nodes suitable for BS construction are found and deployed by constructing a complete quadtree structure until the current state becomes the state of final target of reaching a certain coverage.

D. Model Construction

Our model consists of two parts. The first is image edge recognition and processing, Canny Edge Recognition and Opening Operation were used. The second is the BS point determination, Quadtree Traversal Search Algorithm was used. The mind map was illustrated in Figure 2 a. The specific steps were operated as target inside area extraction and point selection. In target inside area extraction, programs of edge detection (ED), separation of inner and outer region (SIOR), fill the image to determine the partition (FIDP) were operated.

ED: the map selected in this article is from the open source website: Open Street Map. First we used Canny Algorithm to augment our map primarily. From the augmented graph the edges of buildings were more significant compared to the original graph (Fig. 2 b). Then the Opening Operation was applied to further strengthen the information in the graph. At the same time the graph was transferred into a binary image. In this graph, some edges are single-lined and some edges are closely next to the boundary of the map, which will be deleted in later steps. Also, there were breakpoints alone the edges which might trigger problem to later operations. Then Canny Edge Detection was used to enhance the graph by connecting and doubling each edge (Fig. 2 c). This step helps the edges to be more reliable for not being afraid to be canceled even when it is right next to the boundary. Knowing that the exact point axis was needed in the deployment, each pixel was assigned a coordinate. To locate each point better on the graph, we converse it on to a coordinate axis (Fig. 2 d).

SIOR: after extracting the edges from the original graph, 'max' and 'min' operations were used to find the extreme of the boundaries. The map is approximately to a rectangular, only need to create a smaller rectangular as the constrain boundary to define the regions. After analyzing the data of graph boundaries, 5 steps were took inward on the left , right and lower boundaries. Since there are disturbance on the top boundaries, 10 steps were took inward. So the constraint boundary box is shown in Figure 2 e. This rectangular box was put into the original coordinate axis, using red to indicate inner region and blue for the outer (Fig. 2 f). From the result graph we can conclude that the boundary box works well. Next, the outer region and the boundary box were deleted. Only inner region is left (Fig. 2 g). At this point, goal of capturing edges of the requirement area is completed. Then, add information to each point to deploy BSs depending on the point information.

FIDP: a binary graph in reverse was generated in this step. The graphology should contain two messages: available or not available. The easiest and fastest way of getting such a graph is to convert it into a binary graph. Each point on a binary graph has a logical value, either 0 or 1. This information is the key to detect whether the point is available or not (Fig. 2 h). Then we switch the two colors in this image. In Matlab, there is a command to fill in the holes on the graph, but the graph must be a binary graph with black background. After switching, white indicates the edges (Fig. 2 i). After filling the holes, white areas indicate the areas which can not be selected to build BS and black indicate areas available (Fig. 2 j). In the computer language, the points in white have a logical meaning of false (value 0) and points in blackness have the logical meaning of true (value 1). Each of these points also has its own coordinates. At this point, extraction of inner region of the target is completed.

Quadtree Transversal Algorithm was used to select points. First, the central point was found and assign it as the initial point and load the coordinates (Fig. 2 k). Testing the status of this point. If the logical value equals to 1, then a BS was deployed. Then make the area within the specified radius of the center of the circle unavailable. Second, with the initial point as the center, the map was divided into four regions, upper left, lower left, upper right and lower right, and the center point of each region is determined. Repeat the first step. Third, each subsequent iteration will repeat the operation in second step based on all points generated in the previous iteration as the center, until the coverage of the whole map reaches the preset standard (Fig 2. l). Note that each point used to locate the center point for the next iteration is all possible points, independent of the point where the BS was built.

III. INITIAL RUNNING AND OPTIMIZATION

Running model on a 397*504 graph with unit set to 10 initially, the radiation step is 20 (200 m in practice). When the iteration was set to the end with coverage of more than 98% without considering the overlapping, the radiation rate was observed 72.6% after deploying 265 BSs. Afterwards, with the increase of BS numbers, the growth of radiation rate slows down. The turning point reached with deployment of 1139 BSs and gradually approached to 100% (Fig. 3 a). The result indicates less room left for deployment as iteration move on. However, signal overlapping seriously.

To optimize the model, one constraint (λ) was added. The *Increasing* was calculated ahead.

$$Increasing = \lambda\ (signal\ area/total\ area) \tag{1}$$

Where, the '*signal area*' is one complete signal area of one BS, and λ is the parameter of efficiency. The constraint expressed as [(*testradiation* − *lastradiation*) ≥ *Increasing*]. When $\lambda = 0.25$, it means that the increasing area of one new deployment need to be larger than a quarter of one complete signal area, thus the deployment was effective and deployment will be applied. The optimized result was deploying 549 BSs with the radiation rate of 96.8%. When $\lambda = 0.33$, the final radiation rate was observed 96.8% with 567 BSs (Fig. 3 b). Similar to the case of $\lambda = 0.33$, the first smoothing begins at point 391 and the second smoothing begins at point 551. The final radiation rates are sensitive to values of λ.

If we take the value of λ to be adjusted from 0 to 1 with increment of 0.1, i.e. λ = 0.1, 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8 and 0.9, the number of BS needed = 584, 551, 559, 529, 547, 559, 582, 538, 497 and 512, respectively; its coverage rate = 96.8%, 96.9%, 96.3%, 97.0%, 96.7%, 97.0%, 96.6%, 96.4%, 96.6% and 96.4%, respectively. The performance shows: the highest

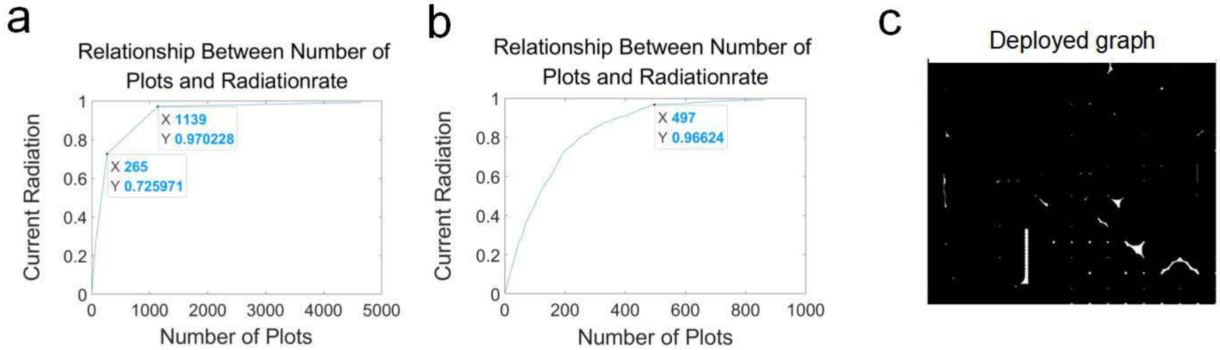

Fig. 3. Initial running and optimization

coverage rate of 97.0% was observed at $\lambda = 0.4$ with 529 BSs. The optimized BS deployment plan was to build 497 BSs with the cover rate of 96.6%, $\lambda = 0.9$. Adopting this plan, the economic benefit and technical effect are the best.

IV. CONCLUSION

To conclude, this article used two models to solve the problem of 5G millimeter wave base station deployment. One model is about image processing, using the algorithm of Canny Edge Detection and Opening Operation. The other model used the concept of Quadtree Transversal Algorithm to find all appropriate possible plots for deployment. The optimal coverage rate of 96.6% was observed with 497 BSs, $\lambda = 0.9$.

For prospect, if the data of the relationship between cost and deployment can be obtained, the influential indicators and corresponding influential coefficients shall be found. Also, our model can be significantly improved further by taking considerations of aspects related to signal strength, signal overlapping, building height and building blocks attenuation.

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