Neural Network Based Optimal Placement of Base Stations in Three Dimensional Plane

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Abstract— **The paper proposes a solution to the problem of optimal placement of base stations, with effective utilization of resources. First, it analyzes the placement of base stations in x-y plane. Then this analysis is extended to 3-dimenional system, by including the z coordinate for representing height. This analysis optimizing these xy coordinate values as well as value of z coordinate, as height also contributes in covering the area of base stations. The Hopfield neural network model is used to find the solution to our problem.. Neural network and all parameters, i.e. x, y and z coordinates are used to maximize the coverage area and to minimize the interference, as optimal placement of base stations refer to these two points. In wireless communication system, the placement of base stations requires work force and costly equipments like GPS etc. resulting in loss of time and money. However, with proposed strategy only a laptop or desktop PC will be required to compute the positions of base stations within very less time. The energy equations are developed for our network which shows that the solution resulting from these equations is stable. The computer simulations and graphs are also included to validate the results.**

***Keywords*— Neural Networks, Interference, Coverage area, Energy equation, Base stations**

I. INTRODUCTION

This Wireless communication has now become an integral part of our life. Over the last few decades, there has been the trend to have efficient communication between any distant points. People have been working on many areas to improve the communication between different points. Channel estimation, spectral efficiency, frequency reuse, sectorization, use of directional antennas etc are the few names of the areas where people have done tremendous efforts and fruitful results are obtained [8-12]. All these areas are very important and efficient communication cannot be established by ignoring one of them but placement of the base stations in a communication system has also vital importance. A lot of attention is paid to the above mentioned areas but comparatively less work is done on the placement of the base stations. Placement of the base stations is a very important entity without which the efficient communication system cannot be possible. If the base stations in any communication system are not placed optimally, the result is the inefficiency of the system since a lot of area will be left uncovered. Placement of the base stations plays an important role in determining the coverage area of the communication system. Base stations should not be placed too close to each other to avoid interference. Secondly, they should not be placed too far from each other to make sure that no uncovered area is left. So the base station placement is a very important factor in communication system and it is necessary to place the base stations optimally. Similarly height of the base stations plays an important role in coverage area. Increasing the height of base station results in increase in coverage area and vice versa [13, 14]. This research work addresses this problem and proposes a solution to this problem. It first optimizes x and y coordinates of the base stations and then extend this work to optimize over their heights.

II. NEURAL NETWORK

Neural network comes from the word neuron. Neurons are the back bone of routing information from the brain to other parts of the body and from other parts of the body to the brain. These neurons work in a massive collective way [1, 2]. They are large in number and have high interconnectivity. The field of neural network evolved with the thought that how human brain is able to work so fast. Given a partial or glimpse of the input, brain can reproduce the all the associated memory in parallel as the output. This led to the evolution of neural networks. There are various categories of neural network and Hopfield neural network is one of them. We have used Hopfield neural network in this research. . It consists of large number of analog processors working collectively. Modern digital computers can perform the numeric computation at very high speed as compared to human brain. But neural network, like human brain, can solve perceptual problems fast and with much ease than the fastest digital computers. Hopfield neutral network is shown in the figure below [3, 4]:

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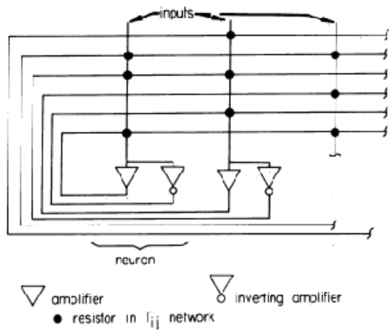

Figure 1. Hopfield Neural Network

Hopfield showed that the neural network converges to the stable solution and the energy equation of such network can be written as:

$$E = -\frac{1}{2}\sum_{i=1}^{n}\sum_{\substack{j=1\\ j\neq i}}^{n} T_{ij}V_iV_j - \sum_{i=1}^{n} V_iI_i \quad (1)$$

Where V_i and V_j are the outputs of i_{th} and j_{th} neuron, I_i is the input to the i_{th} neuron and T_{ij} is the connection strength between i_{th} and j_{th} neuron. We have to put constraints in the energy equation so that these constraints force the solution to a stable point. It is showed in [5] that energy of the above mentioned system always decreases and leads to the stable solution. If we can map our problem to the network described by the above equation we can have a stable solution of our problem.

III. Mapping of Problem on Neural Network

We need appropriate representation of our problem in neural network. Each neuron represents a base station. V_i = 1 means that base station is present and V_i= 0 means absence of base station. Depending on the outcome of the neuron, the location of base station can be decided. We have to make our energy function in terms of coverage area and interference area. Interference area is the sum of interference areas of all the base stations denoted by I. Covered area is the sum of cell areas minus interference areas of all the base stations. The relation for interference areas of the cells is given by [7]:

$$I = \frac{1}{2}\sum_{i=1}^{n}\sum_{\substack{j=1\\ i\neq j}}^{n} V_iV_jI_{ij} \quad (2)$$

Area covered by the base stations is given by the relation:

$$C = \sum_{i=1}^{n} V_i\left(C_i - \frac{1}{2}\sum_{\substack{j=1\\ i\neq j}}^{n} V_jI_{ij}\right) \quad (3)$$

Now with these interference and covered areas, we develop energy function of the neural network which fulfils all the constraints. We incorporate penalty factors in the energy equation to force our desired result. The constraints can be given as follows:

- The whole area should be covered with all the available base stations. It means that the number of ON neurons should be equal to the number of base stations available.
- Output of the neuron should be 0 or 1. It cannot have in between value.
- The whole cell area should be equal to the covered area i.e. no uncovered area should be present.
- The interference area should be the minimum.

IV. Formulation of Energy Equation

If we take into account all these constraints, then the energy equation can be written as:

$$E = \frac{a}{2}\left(\sum_{i=1}^{n} V_i - N\right)^2 + b\sum_{i=1}^{n} V_i(1 - V_i) + \frac{d}{2}\left(\sum_{i=1}^{n} C_i - \sum_{i=1}^{n} V_iC_i\right)^2 + \frac{f}{2}\sum_{i=1}^{n}\sum_{\substack{j=1\\ i\neq j}}^{n} V_iV_jI_{ij} \quad (4)$$

Where **a**, **b**, **d** and **f** are the penalty terms (constraints). The energy function should have a minimum or ideally zero value to fulfill the constraints and to let the system converge on a stable, optimal solution. It will have zero or minimum value if all the terms in the equation have zero or minimum value. First term of the energy function indicates that the area should be covered with all the available base stations. If it happens, then the first term will become zero otherwise there will be penalty of magnitude **a**. So, naturally **a** should be selected very high to give large penalty Second term of the energy equation is to force the value of base station to either 0 or 1. If it happens, then this term will become zero otherwise it will suffer the penalty of magnitude **b**. Thus the value of **b** should also be large to force the output of neuron to either 0 or 1. Third term of the energy function deals with the coverage area. It states that the cell area should be equal to the coverage area of the base stations. In other words this term states that there should be no uncovered area. If this happens this term will go to zero otherwise there will be a penalty of magnitude **c**. We can have some relaxation in this penalty constant. If we can allow some uncovered area, then the value of this penalty constant can be small but if uncovered area is not allowed then the value of penalty constant should be large. The last term accounts for interference area. This term should be close to zero because we want interference area to be as small as possible. If it is not the case, then there will be a penalty of magnitude **f.** Minimum value of energy function will simply mean that all the constraints are fulfilled and the base stations have been placed optimally. There are different methods for choosing the value of **a**, **b**, **c**, **d** and **f** and are discussed in [20]

V. Formulation of Motion Equation

Motion equation of neural networks involves the derivative of the energy equation. Thus we have following equation:

$$\frac{dU_i}{dt} = -U_i - \frac{\partial E}{\partial V_i} \quad (5)$$

In order to find the new values of U_i's we have to find $\frac{dU}{dt}$ and for this we will have to find $\frac{\partial E}{\partial V_i}$. Taking the partial derivative of the energy equation we have the following equation:

$$\frac{dU_i}{dt} = -U_i - a\left(\sum_{i=1}^{n} V_i - N\right)\frac{\partial}{\partial V_i}\left(\sum_{i=1}^{n} V_i - N\right) - b - d\left(\sum_{i=1}^{n} C_i - \sum_{i=1}^{n} V_iC_i\right)\frac{\partial}{\partial V_i}\left(\sum_{i=1}^{n} V_i - \sum_{i=1}^{n} V_iC_i\right) + f\sum_{\substack{j=1\\ j\neq i}}^{n} V_jI_{ij} \quad (6)$$

$\frac{dU_i}{dt} = -U_i - a(\sum_{i=1}^{n} V_i - N)(1-0) - b - d(\sum_{i=1}^{n} C_i -$
i=1nViCi0−Ci+fj=1j≠inVjIij

$$\frac{dU_i}{dt} = -U_i - a(\sum_{i=1}^{n} V_i - N) - b + d(\sum_{i=1}^{n} C_i - \sum_{i=1}^{n} V_i C_i) C_i + \sum_{\substack{j=1 \\ j \neq i}}^{n} V_j I_{ij} \tag{7}$$

The above equation is called motion equation of neural networks. New inputs to the neurons can be found out with the help of this equation. If we have old inputs of the neurons U_i's, then the new state of the inputs of the neurons can be found out as follows:

$$U_{i,next} = U_i + delta \times \frac{dU_i}{dt} \tag{8}$$

Where delta is the step size with which the value of $\frac{dU_i}{dt}$ is multiplied to find the new value of the inputs U_i's. Its value is normally taken as 10^{-5}[20]. When these new sets of inputs are received, new set of outputs can be found out using the relation:

$$V_i = \frac{1}{2}\left(1 + \tanh\left(U_i\right)\right) \tag{9}$$

With the above relation we can have the value of the neuron outputs. These values are in real numbers, but we require the output values to be 0 or 1. Output values are computed asynchronously i.e. V_i's are updated after each iteration. After final iteration, we compared each V_i with a threshold value of 0.5 to assign it final value according to following rule:

$$V_i = \begin{cases} 0, & V_i < 0.5 \\ 1, & V_i \geq 0.5 \end{cases}$$

Threshold value of 0.5 means is actually used for unbiased decision between 0 and 1.

Neural network equations will give us the placement of base stations in xy plane given an area and they include terms like covered areas and interference areas. These areas can be calculated from the path loss equation. We choose the simplest case of path loss equation with minimum number of parameters. This equation is given by:

$$P_r(d) = \frac{P_t \lambda^2}{(4\pi)^2 d^2} \tag{10}$$

From this equation coverage distance can be calculated as:

$$d = \sqrt{\frac{P_t \lambda^2}{(4\pi)^2 P_r}} \tag{11}$$

Now this completes the placement of base stations in two dimensions (x-y). If we can determine the height of the base stations, we can cover the third dimension i.e., z dimension. For this purpose height must be included in path loss equation. So (11) is transformed as:

$$P_r(d) = \frac{P_t h_r h_t \lambda^2}{(4\pi)^2 d^2} \tag{12}$$

Where h_t and h_r are heights of transmitter and receivers.

If it is assumed that the effective antenna heights of the receivers (mobile users) is constant and are normalized to 1, then above equation becomes:

$$P_r(d) = \frac{P_t h_t \lambda^2}{(4\pi)^2 d^2} \tag{13}$$

Now the height of base stations can be determined as:

$$h_t = \frac{P_r (4\pi)^2 d^2}{P_t \lambda^2} \tag{14}$$

Now the energy equation also needs to be transformed in order to optimize the heights of the base stations. We specify a set of heights for the base stations and height of a particular base station must be one of the values of that set. New equation which will optimize height of the base stations is given by:

$$E = b \sum_{i=1}^{n} h_i (1 - h_i) + \frac{d}{2}\left(\sum_{i=1}^{n} C_i - \sum_{i=1}^{n} h_i C_i\right)^2 + \frac{f}{2} \sum_{i=1}^{n} \sum_{\substack{j=1 \\ i \neq j}}^{n} h_i h_j I_{ij} \tag{15}$$

First term in equation (4) is omitted because the base stations are already placed in xy plane. Only height needs to be optimized. Since covered area and interference areas are affected by the height of the base stations, they are not omitted from the energy equation. Here h_i represents the output in terms of height. The procedure for the formulation of motion equation will be the same described in previous section.

VI. SIMULATIONS

Simulation of our work consists of series of steps. By following these steps we will achieve the desired results.

- Set up necessary parameters such as transmitted power, received power, number of base stations.
- Initialize the inputs of the neurons, U_i's.
- Find output of the neurons, V_i's according to the initialized U_i's.
- Update U_i's to find the next state of input $U_{i,next}$.
- Find again updated V_i's.
- The final values of V_i's will be the output.

All the procedure necessary for the simulation can be described in a flow chart in Fig. 2.

In this simulation we are assuming 10×10 area to be covered. This means that there are 100 neurons whose values determine the presence or absence of the base stations. The values of U_i's are initiated with random numbers less than 5000. The initialization of U_i's with these values has better convergence properties as discussed in [20]. V_i's are found out using (9). Then next states of U_i's are determined using (8) and then again the output is determined using (9). This iterative process continues until neural network converges to optimized solution. The output shown optimizes the area to be covered. But this area is in two dimensions. To go in three dimensions, we have to include height in our work. The procedure described above is repeated again to optimize the value of height. The height of the base stations can be selected from one of the possible values from the set {5, 10, 15, 20, 25, 30, 35, 40, 45, 50}. When all the steps described above are followed we obtain following output.

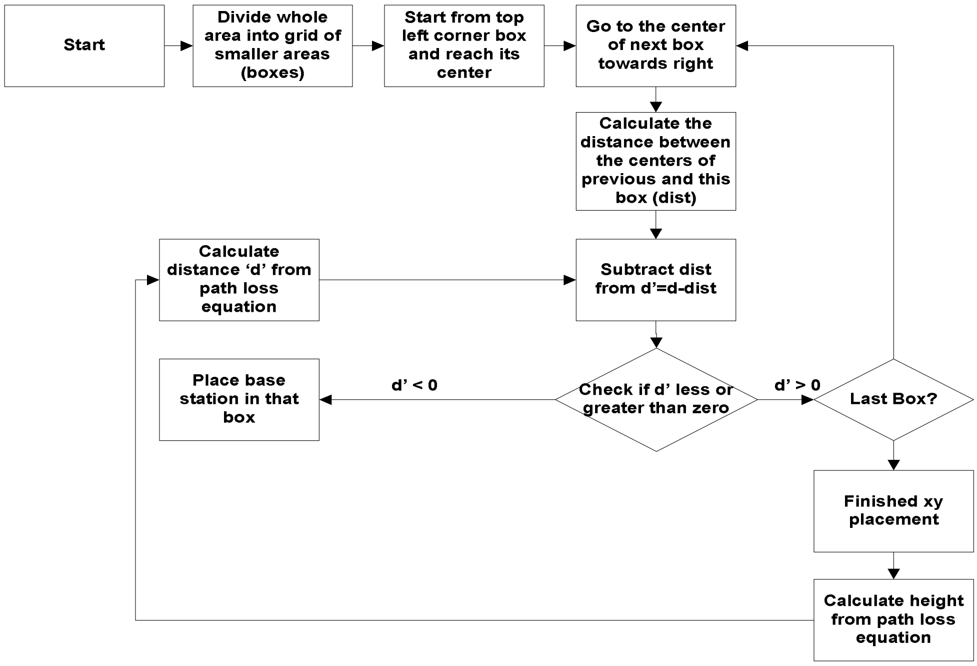

Figure 1. Flow chart for carrying out simulations

$$V_i = \begin{bmatrix} 0\,0\,0\,0\,0\,0\,0\,0\,0\,0 \\ 0\,0\,0\,0\,0\,0\,1\,0\,0\,0 \\ 0\,0\,0\,0\,0\,0\,0\,0\,0\,1 \\ 0\,1\,0\,0\,0\,0\,0\,0\,0\,0 \\ 0\,0\,0\,0\,0\,0\,0\,0\,0\,0 \\ 0\,0\,0\,0\,0\,1\,0\,0\,0\,0 \\ 0\,0\,0\,0\,0\,0\,0\,0\,0\,0 \\ 0\,0\,0\,0\,1\,0\,0\,0\,0\,0 \\ 0\,0\,0\,0\,0\,0\,0\,0\,0\,0 \\ 0\,0\,0\,0\,0\,0\,0\,1\,0\,0 \end{bmatrix}$$

$$h = [010\,0\,0\,0\,1\,0\,0\,1\,0]$$

The presence and absence of a base station is shown by 1 and 0 in the matrix V_i respectively. Vector h determines which value of height is chosen from the set described above for the base stations. This completes the placing of base stations in three dimensional plane. Matrix V_i accounts for area and vector h for height covering all the three dimensions. The procedure can be extended to as large a grid as one needs to

VII. CONCLUSIONS

Placement of base stations is very important in cellular communication. Coverage area, interference and other important parameters depend upon the placement of these base stations. If the base stations are placed optimally, these parameters can be made optimal. Thus placing the base stations optimally is very important factor in cellular communication system. Neural network tool can be used for optimization. By using neural network we always lead to stable solution. Our neural network based research work provides a mechanism to place these base stations automatically and optimally.

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