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Optimum Indoor Signal Coverage of Dense Distributed Receivers via Ray Tracing Coupled with Genetic Algorithm

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Abstract— **In this paper, we propose an optimization method to suitable locating minimum number of transmitter antennas to provide adequately signal coverage in a given indoor environment. This method is based on an integrated realized Ray-Tracing (RT) technique, so-called Ray-Tracing Engine (RTE), and Genetic Algorithm (GA). This integration provides an intelligent system in optimization process. To provide freedom in furniture placement each corner of every room contains a receiver. Therefore, we have a dense map of RSS distribution in propagation environment. According to Simulation results a full coverage using integrated RTE and GA is achieved through suitably locating three transmitters. Furthermore, GA avoids the time consuming process of antenna location finding in an exhaustive search method.**

Keywords- ***ray tracing; genetic algorithm; received signal strenght; wireless communication network***

I. INTRODUCTION

In our society, wireless networks provide various daily services. Mobility is an important task in such networks and therefore they must provide suitable signal coverage in order to use the services in different locations. The suitable signal coverage will be achieved if Received Signal Strength (RSS) in all receivers become higher than a defined threshold. This signal coverage is usually provided at the expense of having more transmitters in the propagation environment. Increasing the number of transmitter increases the overall cost of wireless networks implementation. While, it is very important to reduce the cost of networks. These criteria are the challenges of wireless network designing. Although, a reduced number of transmitters placed in the optimum locations can decrease the overall cost. Therefore, it is important to find optimum locations of transmitters in a reliable and economic way. A traditional solution in determining locations is an exhaustive search through the measurements. Because of time consumption and cost in a complex indoor environment, this method is not a good choice. An alternative could be a reliable numerical site-specific tool that considers all details of propagation environment such as constructed materials and geometrical characteristics, etc., and calculates RSS in any needed location. Therefore, a solution is to use computer based methods. Among them, ray tracing (RT)-based calculation methods, which are used in design of wireless networks [1, 2], are effective techniques. The RT techniques provide the ability of calculating received power and carrying out statistical operations on received signal strength (RSS). The use of RT results in identifying the channel model of a given environment. The channel model describes the behavior of a given environment and provides an appropriate criterion of coverage in the environment. However, exhaustive search through RT techniques still categorized as time consuming procedures. Different optimization algorithms beside RT techniques are usually used to lower the overall processing time of the location finding problem. In this regard, [4, 5] propose several optimization methods. Optimization algorithms have already been used to find the location of transmitter antennas [6, 7]. However, the methods used in [6, 7] have not used a direct link between the method to calculate the received power and the optimization algorithm. In other word, both channel calculations and optimization procedure are not accomplished in same software. The advantage of providing a direct link between optimization algorithm and channel calculations is to reduce the time of extracting information from one software to another. In [8] an integrated method of RT and Genetic Algorithm (GA) to find minimum number of transmitters in optimum locations is presented. The aim is to find minimum number of transmitters in optimum locations so that all receivers achieve RSS higher than a defined threshold. In this optimization procedure, the receivers are located at the center of each room and the transmitters can be chosen only from some fixed locations, which are at the same locations of the receivers. This strategy reduces the accuracy of optimum location finding problem, especially in a complex indoor propagation environment. Furthermore, a denser map of RSS distribution in propagation environment can be achieved with increasing number of receivers. Therefore, there will be more choices for placing furniture in the rooms of indoor propagation environment. An optimization location finding problem is solved in [9]. The Particle Swarm Optimization (PSO) algorithm is used to find the best location of transmitters. Whereas in [9] the receivers are located at the center of each room, the map of RSS distribution in not dense. Thus, the furniture cannot be located in each corner of propagation environment. Moreover, a statistically based optimization algorithm is also proposed in [10] to find the best positions of the transmitters in such network, but do not represent integration between optimizing algorithm and RT. In [10] first, the pattern of antenna, in every probable location of receiver antenna should be determined. So, whereas presented algorithm is fast, determination of antenna pattern in all probable locations is very time consuming. In [11] the best location of a base station by maximizing the lower electric field in two indoor scenarios is determined. To satisfy this aim RT technique associated to a real-coded GA is used. Therefore, no threshold is defined and the aim is not to achieve full coverage. To optimizing location of an antenna in multi input-multi output communication systems in [12] dynamic differential evolution algorithm is used and the aim is to maximize the channel capacity.

This research work concentrates on finding the suitable location of minimum number of transmitter antennas to provide a good coverage using a developed integrated RT and optimization scheme. First, the channel parameters are calculated by the RT technique for a deterministic propagation environment. Second, the data provided by the RT technique is given to an optimization algorithm. We use GA, which is frequently used in electromagnetic optimization problems [13-15], as the optimization algorithm. Third, several parameters, such as the location, number or type of transmitter antennas, are determined to satisfy a given criterion using the optimization algorithm. It is quite difficult to provide a link between the software calculating RSS, and the optimization algorithm. To provide a direct link between the RT method and the optimization algorithm, we write a code in Matlab, named ray-tracing engine (RTE). This engine is based on two-dimensional (2D) RT calculations and calculates the RSS in arbitrary points. According to this engine, the transmitter position can be chosen from any location of the simulated environment. Furthermore, to achieve more choices for placing furniture in the rooms of indoor propagation environment four receivers in every corner of each room are located. Using RTE, the optimum coverage can be provided with no concern about facing with the complexity of empirical models. To evaluate the performance of the proposed method in terms of time consuming and calculation complexity, it is performed for WiFi based wireless network in a sample indoor propagation environment. We show that the best signal coverage can be provided with a minimum number of transmitters.

The rest of the paper is organized as follows. In Section II, we describe RTE in details for a sample environment. Section III presents the proposed fitness function used for the transmitter location finding problem. The developed GA, specifically designed for the optimization problem in this study, is explained in the same section. We perform this designed GA to find the best locations of the transmitters in Section IV. In this section optimum place of transmitters will determine. Finally, Section V states the conclusion.

II. RAY TRACING ENGINE

RT schemes are powerful numerical simulation tools to represent the propagation channel. These methods are site-specific and good alternative for the measurement procedures. In RT techniques, electromagnetic waves are basically considered as rays. These computational electromagnetic methods are classified as high frequency schemes which are developed based on Geometrical Optic (GO) [16] and Geometrical Theory of Diffraction (GTD) [16]. Although the accurate results can be drawn using three dimensional (3D) modeling of the environment in RT calculations, it is shown that 2D RT modeling not only significantly reduces the computational complexity but also reveals adequate performance against 3D one [17]. There exist several commercial RT softwares such as Radiowave Propagation Simulator (RPS) [18] which have shown good performance in numerical simulation propagation channels. However, there is no direct access to their engines to link with the written codes for optimization techniques like GA. Hence, in order to solve an optimization problem as defined in this paper we have to design an integrated RT scheme and optimization method.

In this section, we propose a developed RT algorithm performed on a sample environment which is the school of Electrical and Computer Engineering in the University of Sistan and Baluchestan. A 3D map of this indoor environment is shown in Fig. 1.

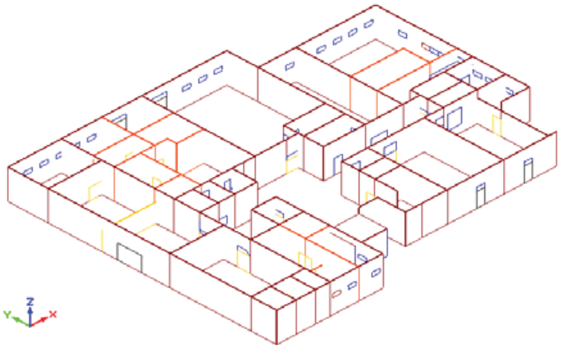


Figure. 1. A 3D plane of the indoor environment used in this study.

This research is performed for a WiFi wireless network and therefore the frequency is set to 2.4 GHz. Hence, we must only consider that the scatters whose size are bigger than 25cm, i.e. twice a wavelength, in the environment modeling [19].

We develop the RT method with Matlab codes which are based on 2D RT calculations.

The RTE is based on ray-shooting, also called ray-launching strategy [20]. To develop this engine, we first construct the propagation environment with the associated materials at the operating frequency. Moreover, we are able to design communication links for the modeled wireless network in RTE with several types of antennas and their orientations. Now, we determine the locations of the transmitter and the receiver, which have their associated antenna types. Then, the ray-shooting procedure is developed on the constructed environment. Although all the propagation mechanisms such as free space propagation, reflection, penetration, diffraction, etc must be considered in a ray-shooting algorithm, in practice some propagation phenomena, like the diffraction, have less effect in final results and add computational complexity [21]. Hence, in the developed RTE we only consider free space propagation, reflection and penetration. The free space propagation is calculated based on the Friis' formula in which the received power is given by [22]:

$$p_r(dB)=p_t(dB)-32.5-20.\log_{10}\left(f\left(GHz\right)\right)-20.\log_{10}\left(D\left(m\right)\right)... \\ +G_t(dB)+G_r(\mathrm{dB}) \tag{1}$$

Where p_t, f, D, G_t and G_r are the transmit power, the operating frequency, the distance between the transmitter and the receiver, the transmitter gain and the receiver gain, respectively. Moreover, the reflection mechanism considered in our RTE is based on the reflection coefficient [23]:

$$\overline{R}=\frac{1-\exp\left(-j2\delta\right)}{1-R_i^{\,2}\exp\left(-j2\delta\right)}R_i \qquad \text{for } \ i\in\left\{s,p\right\} \tag{2}$$

Where $\delta=\left(2\pi d/\lambda\right)\sqrt{n^2-\sin^2\theta}$ in which d, λ, θ and n are respectively the material thickness, the wavelength in free space, the angle of incident and the complex refractive index of reflecting materials. Moreover, the R_s and R_p denote the Fresnel's reflection coefficients for the interface between air and a dielectric material when the electric field is perpendicular and parallel to the plane of incident, respectively. We define the plane of incident as the plane including the wave propagation direction and the normal to the reflecting surface. The R_s and R_p coefficients are given by [23]:

$$R_s=\frac{\cos\theta-\sqrt{n^2-\sin^2\theta}}{\cos\theta+\sqrt{n^2-\sin^2\theta}} \tag{3}$$

$$R_p=\frac{n^2\cos\theta-\sqrt{n^2-\sin^2\theta}}{n^2\cos\theta+\sqrt{n^2-\sin^2\theta}} \tag{4}$$

Finally, the penetration mechanism is calculated based on the formula given by [23]:

$$\overline{T}=\frac{\left(1-R_i^{\,2}\right)\exp\{-j\left(\delta-k_0d\right)\}}{1-R_i^{\,2}\exp(-j2\delta)} \qquad \text{for } \ i\in\{s,p\} \tag{5}$$

where $k_0 = 2\pi/\lambda$ is the free space propagation constant.

According to the ray-launching algorithm with the above mentioned properties, we are able to find the channel impulse response, which is calculated as follows [24]:

$$h(\tau)=\sum_{i=0}^{M}\sqrt{p_i}\,e^{j\theta_i}.\delta(\tau-\tau_i) \tag{6}$$

where P_i, θ_i and τ_i are the power, the phase and the delay of the ith received ray, respectively. Now, we can calculate RSS using the following formula:

$$RSS=\left|\sum_{i=0}^{M}\sqrt{p_i}\,e^{j\theta_i}.e^{j2\pi f\tau_i}\right|^2 \tag{7}$$

Now, to find the signal coverage map in a given environment for an arbitrary transmitter location we move the receiver all around of the environment and find RSS for each receiver location. In most practical wireless systems, an accessible coverage level is defined where below this threshold no communication link can be placed. Herein, we choose this threshold based on 802.11b WiFi receiver sensitivity, which is -76dBm [25].

The results provided by RTE will be compared with those given by RPS, which is a reliable RT software. Thus, the results of signal coverage, in terms of RSS, provided by these two engines are compared. The comparison results are presented in the rest of paper in term of error function (T_e).

III. GENETIC ALGORITHM

GA has been successfully used in many electromagnetic optimization problems [13-15]. It contains of three main parts: genetic representation, fitness function, and genetic operators. As an iterative optimization procedure it starts with a population of potential solutions which are randomly selected. In this population, each solution is called a *gene*. Then, we reprocess this population so that the solutions gradually move toward their global optimum values. The population reprocessing is using the genetic rules, or operators, such as selection, crossover and mutation [26].

In this study, we propose a developed GA in order to find the best locations of the transmitters for a suitable signal coverage in a RAKE receiver network. For a 2D representation of the indoor environment, each transmitter location is shown with two parameters, x_0 and y_0, which are along x and y axes and can get any values. Hence, in this optimization problem the gene has the structure shown in Fig. 2.

x_0	y_0

Figure. 2. Gene structure.

The fitness function in the developed GA, as a minimizing algorithm, is the number of receivers with RSS less threshold to number of all receivers. Finally, the crossover and mutation rates are herein considered 0.6 and 0.07, respectively, in order to make the algorithm efficient in terms of processing speed, and avoid any local minimum. We will consider 30 genes in every population in our GA. Fig. 3 demonstrates the algorithm flowchart. In this flowchart, the stop conditions happen with either the following three cases:

1: The algorithm iterations exceed a predefined value which is hearing 30 iterations.

2: The fitness function value is remained unchanged after a certain number of iterations.

3: All the receivers have the calculated RSS above the threshold.

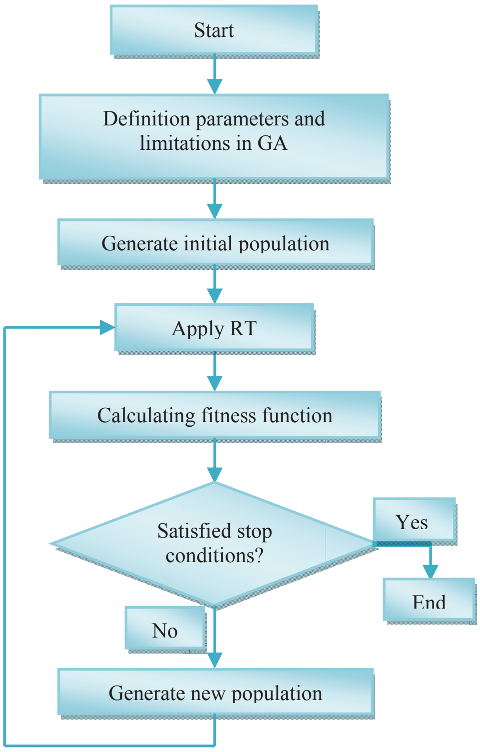


Figure. 3. Flowchart of Genetic algorithm.

IV. NUMERICAL RESULTS

Considering minimum number of transmitter antennas, the optimization problem is to find suitable location of transmitters to achieve acceptable RSS in all receivers. First, the propagation environment, the department of electrical and communication of University of Sistan and Baluchestan, and its properties should be introduced. The propagation environment is a 42.41m by 33.9m one-floor building. There are two types of walls, brick walls and prefabricated ones. The permittivity constant for brick walls $\square_{r1}$ = 3.686 - j 0.4 and for prefabricated walls $\square_{r2}$ = 0.75 – j 0.14. The thickness of all walls and frequency are set to 10 cm and 2.4 GHz, respectively. All of these parameters are adjustable. In free space propagation, according to Friis' formula at 2.4GHz the path loss will be 61dB for 12m distance from transmitter. This distance is defined as the threshold distance between transmitters. Therefore, in optimization process the distance between transmitters will be checked to be more than this threshold. This intelligent selection of genes in GA reduces the time of optimization process.

To check RSS in rooms shown in Fig. 4, four receivers in every corner of each room is placed. In big rooms the number of receivers may be increased. In this study, 178 isotropic receiver antennas have been incorporated in the building. The rectangles in Fig. 4 demonstrate the place of receivers.

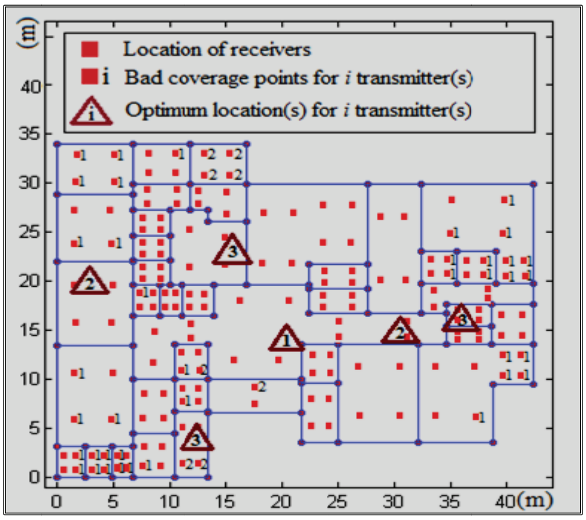


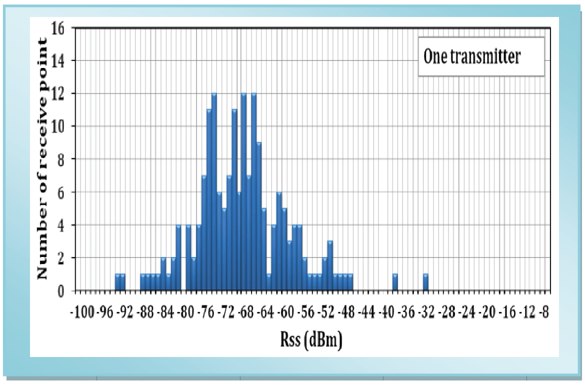
Figure. 4. Receivers and optimum place of transmitters

The location of transmitters should be defined in such a way that the RSS in each receiver is greater than a threshold. As dipole antenna is frequently used in wireless communication [27, 28], this type of antenna is selected as the transmitter antenna. First, we consider only one transmitter antenna. To find the best position of the transmitter, a GA having 30 genes is run for 30 times. Finally, the crossover and mutation rates are respectively considered 0.6 and 0.05. The best place of this antenna is shown in Fig. 4. In this case, the RSS is less than the threshold in 39 receivers. Also these receivers are specified in Fig. 4. As a result, this procedure has to be repeated for two transmitters. The best place of these transmitter antennas are shown in Fig. 4. Again, the minimum RSS required is not satisfied for 8 receivers. Therefore, the procedure is repeated for three transmitters. Fig. 4 shows the best place of these transmitters. In this case, simulation results show that the threshold condition on RSS is satisfied for all receivers. The results of antenna placement are represented in Table 1.

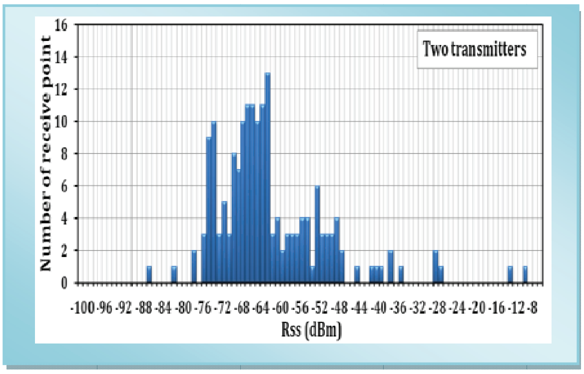
TABLE I. RESULTS OF THE OPTIMIZATION PROCESS

Number of transmitters	Position of transmitters	Number of receivers with RSS less than threshold
One	(20.41, 14.60)	39
Two	(2.55, 20.37) (30.93, 15.64)	8
Three	(12.99, 3.89) (16.77, 23.59) (35.02, 16.19)	None

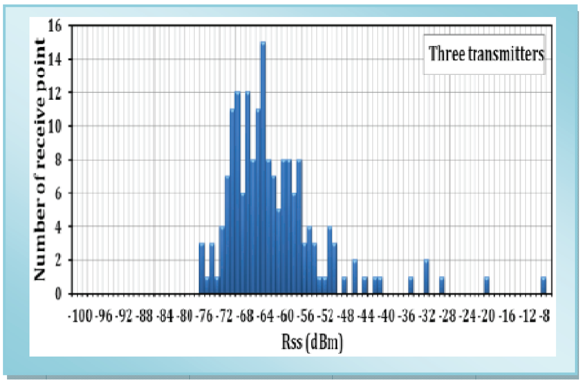
In order to study the quality of coverage, we plot a histogram of the coverage for the 178 available receive points. In fact, we aim to statistically study RSS for these receive points when different number of transmitters exists in the propagation environment. Fig. 5 shows this histogram. According to this figure, by adding more transmitters to the propagation environment the number of receive points with lower RSS are reduced. This improvement is remarkable when two transmitters are used instead of one. However, the improvement rate decreases when we add more transmitters. Hence, if we relax the RSS threshold and give more weight to the network overall cost, two transmitters in the network could be enough for reasonable signal coverage.



(a)



(b)



(c)

Figure. 5. RSS Histogram for: (a) one transmitter, (b) two transmitters, (c) three transmitters.

The above results can be verified by RPS.We apply the obtained results to RPS and then compare the signal coverage in terms of the RSS. The comparison results are shown in Table 2 with the error function T_e which is defined as follows:

$$T_e = \frac{1}{K}\sum_{i=1}^{K} R_e^{(i)} \qquad (11)$$

where K is total number of receivers and

$$R_e^{i} = 2\frac{P_{RPS}^{(i)} - P_{RTE}^{(i)}}{P_{RPS}^{(i)} + P_{RTE}^{(i)}} \qquad (12)$$

In (12), $P_{RPS}^{(i)}$ and $P_{RTE}^{(i)}$ are the power of the ith receive point calculated by the RPS software and our developed RTE, respectively.

TABLE II. COMPARISON OF SIGNAL COVERAGE IN RTE AND RPS

Number of transmitters	T_e (%)
One	3.38
Two	3.65
Three	3.62

In future, we can apply the optimization process in more complicated propagation environment (with considering human and furniture in building). Furthermore, we can increase the accuracy of simulations with a 3D RT. In order to approach to real propagation, the effect of roughness of obstacles can be considered. Moreover, other optimization algorithms such as PSO may be compared with GA to select the best algorithm in time and accuracy.

V. CONCLUSION

To achieve good propagation coverage in a given indoor environment through suitably locating minimum number of transmitters, an optimization-based technique was proposed in this paper. A software engine, named RTE, was developed in Matlab to calculate the electromagnetic field in several points of the environment. Appropriate location of transmitters was determined using GA. According to the simulation results, a full coverage was achieved through suitably placing three transmitters.

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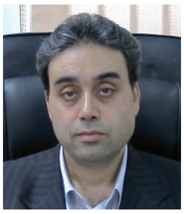

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