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Testing and Design of Indoor WLAN Using Artificial Intelligence Techniques

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***Abstract*—In this study, the performance of an indoor Wireless Local Area Network (WLAN) which is installed by using traditional methods and cellular design of a WLAN that is to be installed are tested. To implement the test and design, artificial intelligence methods are used. For the WLAN test, Artificial Neural Network (ANN) is used. Access Points (APs) and receiver coordinates are determined as ANN input parameters and optimum Receive Signal Strength (RSS) have been sought. For WLAN design, the Genetic Algorithm (GA) method is used. Wall structures and AP properties are taken into account to obtain optimum Receive Signal Strengths (RSSs). For the analytic solution of the optimum RSS, the indoor setting is divided into cellular areas. Thus, the most suitable locations for APs and the number of APs are determined. As a result, we have tested the performance of a WLAN, which is installed by means of traditional methods. According the experimental results, the indoor WLAN designed with the GA method has provided better performance.**

***Index Terms*—Artificial intelligence, genetic algorithms, artificial neural network, wireless LAN.**

I. INTRODUCTION

Wireless Local Area Networks (WLANs) are one of the network topologies that are identified by the IEEE 802.11x standard enabling mobile devices to access data networks. These devices provide such services through base stations that are called Access Points (APs). APs are particularly used in the extension of WLANs in areas such as university buildings, cafes, and trade centers. The points at which APs are placed indoors determine the coverage area of the WLAN. In this context, the complex structures of the indoor setting influence the coverage areas of the APs [1].

One of the biggest problems in the indoor WLAN design is that APs are unable to provide sufficient RSS in the building. System specialists have determined the coverage area of the WLAN based on whether the mobile device is able to receive an AP signal from a random point in the indoor setting. In cases where trial and error methods are applied, the number of APs to be used in the WLAN increases or sufficient RSS cannot be provided at some points. Due to the complex structures of the buildings, many parameters need to be simultaneously evaluated [1].

In the literature, there are many studies about testing of indoor WLANs and the design of the WLAN which is to be installed soon. In these studies, mathematical models [2] (free space path loss, Keenan motley), heuristic models (Particle Swarm Algorithm [3], Simulated Annealing [4], Genetic Algorithms [5]) and statistical models (one slope model [6], multi-wall model [7]) are defined.

The studies of [8], [9] investigated the signal spread properties of IEEE 802.11 standard in multi-floor buildings with complex geometry. They examined the spread properties of the signal strengths by considering the construction properties such as walls, corridors and windows for multi-floor buildings. The researchers emphasized that the RSS remained too weak at many points of the indoor setting. Therefore an optimum design should be developed. In the study in [10], the number and locations of the APs are determined in the indoor WLAN installations so that WLAN costs (cable length, number of switches etc.) are minimized. However, the complex structures of the indoor setting (doors, windows, type of wall, etc.) and AP properties are not taken into consideration. In the studies of [11], [12], measurements at different points in the building of a WLAN, which is installed by traditional methods in the indoor setting are taken. They attempted to predict the measurement data and the most suitable AP coordinate by using ANN. As the ANN model, Multi-Layer Perceptron and Radial Basis function are used; the ANN model is trained with Levenberg Marquart and Bayesian Algorithms. In order to optimize the locations of the suitable APs in the design of the indoor WLAN, the researchers compared PSO, GA and ACO algorithms. However, it appears that the indoor setting remains insufficient to obtain optimum RSS as it is in a complex structure.

In the current study, the performance of the indoor WLAN, which is installed by traditional methods and the cellular structure of the WLAN that is to be installed soon are tested. ANN is used for the performance test of the existing indoor WLAN. The signal strengths received from two APs in the indoor setting are measured and trained by using the Back Propagation Network (BPN) method. The signal strengths of the APs are tested, the performance test could be performed at many points in the indoor setting and performance results are obtained. The Genetic Algorithm (GA) is used for the design of the indoor WLAN. Wall structures and AP properties are taken into consideration in order to obtain optimum RSS. As a result, we have tested the performance of a WLAN, which is installed by means of traditional methods. According the experimental results, the indoor WLAN that is designed with the GA method has provided better performance.

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II. Testing Of WLAN With ANN

The ANN approach is used to predict the RSS at several points in the indoor setting [12]. As is in this study, we have also used the multi-layer ANN (ML-ANN) model to predict of the signal strength in the indoor setting. BPN, which is a supervised learning model, is used in the training of the multi-layer ANN model.

For the multi-point test of the indoor WLAN, the accuracy of the locations of the APs in the WLAN which is installed on the third floor of Suleyman Demirel University Ertokus Bey Classrooms building are tested with ML-ANN. The indoor properties for the performance test of the indoor WLAN are given in Table I.

TABLE I. PROPERTIES OF INDOOR WLAN.

Parameters	Values
Number of APs	3
AP antenna gain (dBi)	3.0
AP transmitter strength (dB)	max. 23dB ETSI (20 dB)
AP Standard	802.11g
Frequency Band (GHz)	2.4
Receiver threshold value (dBm)	-80
AP1(x,y,z)	(14,41,4)
AP2(x,y,z)	(24,28,4)
AP3(x,y,z)	(36,7,4)

The dimensions of the indoor setting are (80 m × 21 m × 5 m). Moreover, there are computer laboratories, special sound insulation inclusive and plasterboard partitioned distance education e-studios, corridors, wooden doors, and brick partitioned wall structures in the indoor setting. Measurements are made by taking the AP properties in Table I into consideration for the multi-point performance test of the indoor WLAN. For the measurements, three Aruba AP-105 series 802.11g standard APs are placed at the points at which the approximate coordinates are shown in Table I. From these APs, the RSS measurements are taken from 443 points in the indoor setting at the range of 1 m–1,5 m between -80 dB and -20 dB. Ralink RT3090 802.11b/g/n Wi-Fi Adapter which is integrated on the HP Mini Notebook is used to take the measurements.

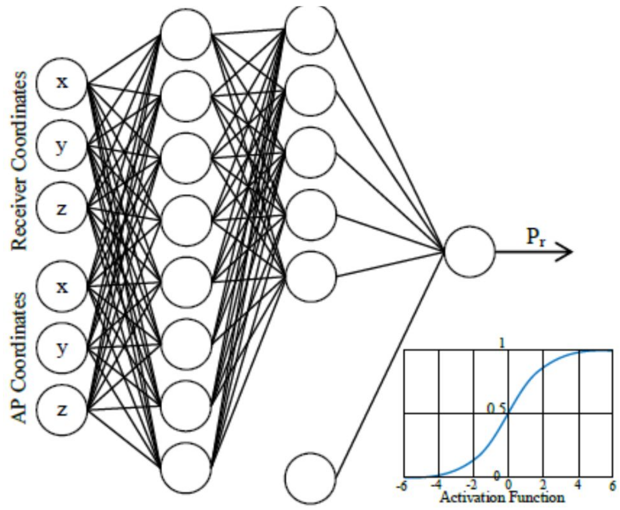

Fig. 1. The ML-ANN structure used in the application.

The distance between the location of AP and the location of the measurement points in the indoor setting is the most important factor to determine the RSS. Therefore, x-y-z coordinates of the signal strengths that are measured through x-y-z coordinates of the AP are determined as the ML-ANN input vector. As shown in Fig. 1, two hidden layers are suggested for the ML-ANN. There are 8 neurons in the first layer and 64 neurons in the second layer. The number of neurons is determined by means of trial and error method. The initial values of the weights are randomly selected at the range of 0 and 1. Sigmoid Function is used at each layer as the activation function. The RSS values that are measured in dB as ANN output layer are normalized. For ANN training, the data that are taken from AP1 and AP3 access points are used and ML-ANN weights are calculated. The BPN training algorithm, the variations of the weights between the neurons are calculated according to (1) until the desired output value is obtained.

$$\Delta w_{ij}(t+1) = -a\frac{\partial E}{\partial w_{ij}(t)} + «\Delta w_{ij}(t). \qquad (1)$$

In (1), a is the learning coefficient, μ is the momentum coefficient and $\Delta w_{ij}(t)$ is the weight change in the previous iteration, a=0.5 and μ=0.1 in this study. On the other hand, in testing the network, the AP2 access point coordinates and the signal strengths at the receiver points of AP2 are used.

III. Design of WLAN with Genetic Algorithm

The Genetic Algorithm (GA) is an artificial intelligence technique that aims to arrange the self-learning and self-deciding systems by using accidental research methods in light of the heuristic approach principles [13]. In this study, the locations, number and coverage areas of the APs that will be used in a WLAN to be established in the indoor setting with a complex structure were optimized by using the GA.

In Fig. 2, the structure of the chromosomes in the initial population and the gene structure of a chromosome are shown. Here, the coordinates of APs, cells, walls at the x-y coordinate axes and wall types are determined as chromosome encoding. Wall properties (brick wall, concrete wall, drywall, metallic obstacle, etc…), doors and windows are the parameters of the complex structure in the indoor architectural coordinate plane and these bring several restrictions to obtain effective signal strength for the WLAN which is to be designed.

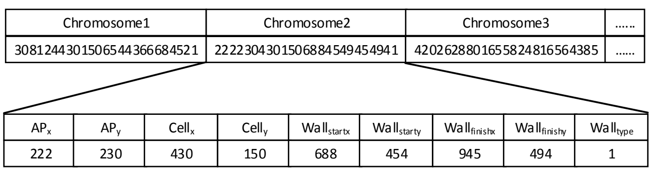

Fig. 2. Chromosome Structured of GA.

TABLE II. LOSS OF SIGNAL STRENGTH BY BUILDING MATERIALS.

Building Materials	Loss (dB)
Unpainted Glass, Wooden Door, Tile Block Wall, Plaster	2 - 4
Brick Wall, Marble, Wire Mesh or Metal, Painted Glass	5 – 8
Concrete Wall, Paper, Ceramic, Bulletproof Glass	10 – 15
Metal, Silvered mirror, etc…	> 15

These parameters need to be evaluated to determine the effective signal strength in the indoor WLAN. This is because these parameters lead to the weakening of the signal strength. Table II shows the signal strength losses of the signal that transits from the building materials based on the building materials.

The transmission standard, antenna gain, antenna type and transmission strength of the AP which would be used in the installation of the indoor WLAN are determined and randomly placed in the architectural plan. Following this process, the architectural plan is divided into 3570 cells each of which is 1.2 m^2 to create receiver points. Subsequently, the signal strengths of the AP signal in these cells are obtained. In the study [12], 140 receiver points are determined for an AP in an indoor setting. On the other hand, in the current study, the number of receiver points is increased for a more effective signal measurement of the indoor setting. The GA has revealed the signal strength of the cells at these receiver points in the indoor setting.

The compatibility function of each chromosome is calculated based on (3) in order to obtain the RSS of each of the cells in the indoor WLAN:

$$d(AP_i, c_j) = \sqrt{\left(\left|x_{AP_i} - x_{c_j}\right|\right)^2 + \left(\left|y_{AP_i} - y_{c_j}\right|\right)^2}, \quad (2)$$

$$Fi = P_{AP} - \left[\left(20\log f + 20\log\frac{d(AP_i, c_j)}{1000}\right) + \sum wall\,effect\right], \quad (3)$$

where $d(AP_i, c_j)$ is the distance between the AP and the cell and it is given in (2). In the compatibility function which is determined in (3), (Fi), P_{AP} is the signal transmission strength of an AP. The coverage area of the AP is proportional to its transmission strength. The coverage area of the AP in the gap is associated with frequency (f) and distance ($d(AP_i, c_j)$).

The selection of the most suitable chromosomes in the population is the process of selection of the chromosomes that will be transferred to the next population from the existing population. This process enables the transfer of the good chromosomes with the determined compatibility values to the next generation. The bad chromosomes whose compatibility value is below the -80dB threshold value in the elimination of bad chromosomes have not been transferred to the next generation. The simplest and most useful selection mechanism to perform this selection is the Roulette Wheel Selection [13].

A chromosome is transferred to the next generations by changing the original chromosome structure through crossover and mutation operators [13]. In the current study, single point crossover is used between the chromosome pairs in the population to provide chromosome diversity in the next generations and the crossover rate (P_c) of 0,6 (60 %) is determined. The mutation operator is applied in the case that chromosome diversity could not be provided in the next generations. The aim of this operator is achieved through the variation of the genes in the chromosomes in which diversity decreases. Here, chromosomes are mutated at a rate of (P_m) 0,01 (1 %).

IV. Test And Design Results

The cellular test and design of the WLAN is installed on the third floor of Suleyman Demirel University Ertokus Bey Classrooms building which has a complex geometric structure. A software tool is developed for test and design of the WLAN by using C#.NET programming language.

For the indoor WLAN test, the RSSs at the receiver points measured from AP1 and AP3 base stations are used as training data in the ML-ANN training. Measurements for the training data are taken from 1,2 meter height at approximately one meter range from the AP1 and AP3 base stations. The comparison between the ML-ANN training and AP1 and AP3 measurement RSS is demonstrated in Fig. 3. ML-ANN training is achieved with a success rate of 98 %.

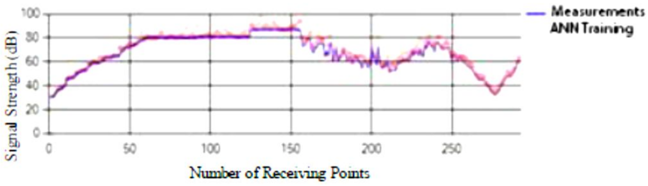

Fig. 3. Comparison of AP1 and AP3 Measurement RSS and Training Data for ML-ANN.

The RSSs measured from the receiver points for AP2 in the indoor WLAN and the ML-ANN test results are compared and shown in Fig. 4. Thus, the compatibility of the location of the AP2 base station in the Indoor WLAN is evaluated. Accordingly, the signal strengths measured from the receiver points for AP2 and the ML-ANN test results are demonstrated to be within a sufficient range. Therefore, the AP2 location of the indoor WLAN proves to be suitable and the recommended ML-ANN model proves to be successful.

Fig. 4. Comparison of AP2 measurement RSS and Test Data for ML-ANN.

In an indoor setting with a complex structure, a cellular partition is made and the design of the WLAN is implemented by utilizing the GA method. As it is seen in Fig. 5, the architectural structure is shown by taking the construction properties (doors, windows, walls) into consideration in the building with a complex structure with (80 m × 21 m × 5 m) dimensions. To create the initial population, random APs are placed in the cells in the indoor setting. The number of the cells in the indoor setting and the number of randomly assigned APs produced the global optimum of the GA. As it is shown in Fig. 5, four APs are found to provide the best coverage area. Based on the GA optimization results that can be seen in Fig. 5, the light colors indicate the locations where WLAN signal strength is sufficient, and the dark colors indicate the locations where WLAN signal strength decreased. The RSSs in the cells inside the indoor architectural structure are between -10 dB and -65 dB. Since the RSSs are greater than the threshold value, it is shown that effective data communication is obtained between the mobile devices and APs. The fitness function curve for candidate AP locations is shown in Fig. 6. It is presented that optimum AP locations are determined after 200 iterations and it is proved to provide optimum AP placement in the GA search space.

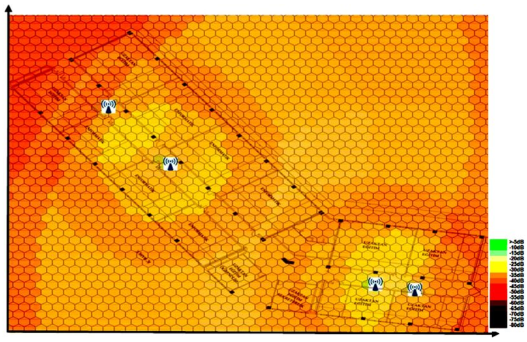

Fig. 5. Coverage map of GA optimization result.

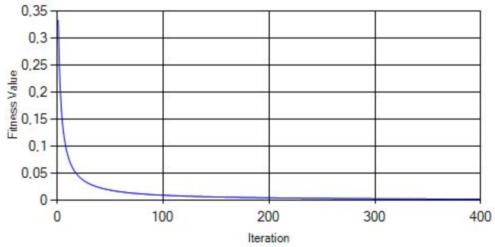

Fig. 6. Fitness change of iteration.

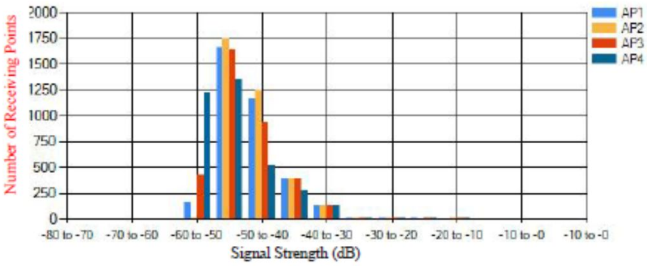

Fig. 7. Number of RSS measured in the test field.

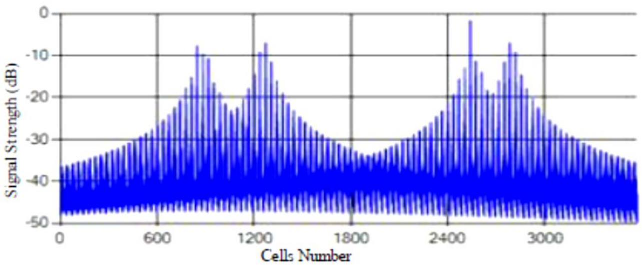

Fig. 8. Signal strengths in the cells of the indoor setting.

In Fig. 7, the number of RSSs of the APs is shown based on the best AP placement optimized by the GA inside 3570 cells in the indoor setting. It shows that RSSs are between -10dB and -65 dB based on the APs that provide the best placement in the environment where WLAN design is made. Thus, the RSSs are at a range where the mobile devices can perform uninterrupted data communication with the APs whose locations are determined in the indoor setting. In Fig. 8, the distributions of the RSSs inside the cellular indoor WLAN are shown. Based on this graphic, it is shown that the cells with RSSs below -50 dB are out of the indoor setting, and the cells with RSSs beyond -50 dB are inside the indoor setting. It is shown that the APs that are placed in the cells inside the indoor setting provided sufficient signal strength and are distributed to the indoor setting in the most optimum location and number.

V. CONCLUSIONS

The multi-point performance test and cellular design of the indoor WLAN are performed by employing artificial intelligence techniques. For the performance test, ML-ANN is trained through the BPN method and the WLAN performance test is achieved with high success rate by comparing the test results with the RSS that are measured from the receiver points. The GA that is used in the design of the network and the cells that contain RSSs inside the indoor are investigated by means of GA and their optimum AP locations and number are determined. We proved that our indoor WLAN design using GA has provided better performance than the traditional methods. Additionally, the mobile devices performed uninterrupted data communication with the APs whose locations were determined in the indoor setting. The defined models are presented to serve as a usable means to increase the performance of the WLANs and a good means for wireless network planning in particular. In the studies to be implemented in the future, other heuristic optimization algorithms are considered as a target study in the determination of the locations and number of the APs in the cellular WLAN designs for indoor setting with complex geometry.

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