ELECTROMAGNETIC COVERAGE CALCULATION IN GIS

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ABSTRACT:

Wireless communication networks offer subscribers to have free mobility and possibility to access information in any where at any time. Therefore, electromagnetic coverage calculation is important for wireless mobile communication systems, especially in Global System for Mobile communications (GSM) and Wireless Local Area Networks (WLAN). In this study, electromagnetic coverage calculations using neural network algorithm is presented and mobile GIS interrogation System (GIS) is improved with measurements and simulation data to make queries about electromagnetic coverage and electromagnetic pollution. The proposed GIS system realizes mapping and graphical presentation in real time including a Global Positioning System (GPS), a notebook or pocket PC and a GIS software.

1. INTRODUCTION

With the rapid growth of wireless communications, cell sizes are getting smaller and site-specific propagation information is needed for the design of mobile systems. Coverage is simply the distance that a wireless network can transmit data at a given data rate subject to the regulations in its frequency band and the standard under which it operates. Indoor electromagnetic coverage is a primary consideration in the implementation of indoor wireless networks. Especially in the frequency range between 500MHz and 5GHz. Indoor coverage is important for GSM and WLAN networks where the indoor coverage directly impacts the critical capacity and cost. [1, 2]

In this study electric field strength values were measured at the entrance floor of the T Block building in Yıldız Technical University Besiktas Campus and artificial neural network algorithm is used for the coverage prediction.

In computing science technology, Geographic Information System (GIS) is a special interest of fields such as databases, graphics, systems engineering and computational geometry, being not only a challenging application area but also providing foundational questions for these diciplines. The study of GIS has emerged in the last decade as an exciting multi-diciplinary endeavour, spanning such areas as geography, the environmental sciences and computer science. [3]

In this study the proposed GIS ensures propagation environment modelling the number, position and transmitter power of access points, electromagnetic coverage, and the radiation level values.

2. ELECTROMAGNETIC RADIATION

The mechanisms behind electromagnetic wave propagation are diverse, but can generally be attributed to reflection, diffraction and scattering. Most mobile wireless communication systems operate in areas where there is no line of sight path between transmitter and receiver. Due to multiple reflections from various objects, the electromagnetic waves travel along different paths of varying lengths. The interaction between these waves causes multipath fading at a specific location, and the strengths of the waves decrease as the distance between the transmitter and receiver increases.

The power received at distance d can be calculated in terms of power flux density and effective aperture of the receiving antenna. Relation between electric field and received power is given [4]

$$P(d)_{dB} = 10\log\left(\frac{|E(d)|^2 G_r \lambda^2}{480\pi^2}\right) \quad (1)$$

Where Gr is the receiver antenna gain, and $\lambda = c / f_0$ is the wavelength, $c = 3 \cdot 10^8\ m/s$ is the velocity of light and $f_0 = 2.4\ GHz$ is the operating frequency of the wireless transceiver. In this calculation receiver antenna gain is assumed as unity.

3. WIRELESS LOCAL AREA NETWORKS

A wireless LAN (WLAN) is a wireless local area network, allowing users to connect directly to a distribution system without interconnecting wires and cables. WLAN utilizes spread-spectrum technology based on radio waves to enable communication between devices in a limited area, also known as the Basic Service Set (BSS). This gives end-users the mobility to move around within a broad coverage area and still be connected to the network.

The primary reasons of the popularity of wireless LANs are their convenience, cost efficiency, and ease of integration with other networks and network components. [5]

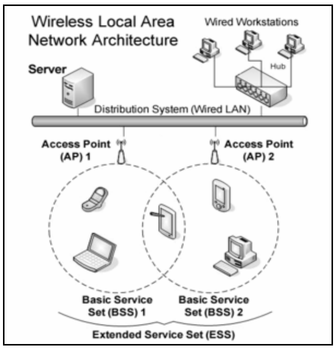

Figure1. A WLAN Architecture using BSS infrastructure

The connections to the end-users in Wireless LANs are established via an air interface and the communication is maintained by an electromagnetic coverage area through WLAN Access Point (AP).

WLANs are mostly implemented on indoor environments and a circular coverage is expected, but the pattern of the coverage area can usually be affected in a destructive or a constructive way. Thus, the coverage area the range and the radiation pattern of a WLAN communication system probably differ from the theoretical prediction approach. [1, 2]

In this study Cisco Aironet 1100 Series Access Point is used for WLAN communication system at entrance floor of T-Block Building in Yıldız Technical University. The indoor Electric Field (V/m) measurements and coverage area analysis were implemented according to these access positions.

The investigated Cisco Aironet 1100 Series Access Point is placed at nearly the top center of the corridor and attached to the outside walls of the classrooms. It is at 290 cm high from the floor. The Access Point has the main following features: [5]

- 2.4 GHz IEEE 802.11g Radio Standard
- Configurable output power up to 100 mW
- 10.4 cm wide; 20.5 cm high; 3.8 cm deep physical dimensions
- Integrated 2.2 dBi dipole antennas
- Up to 54 Mbps date rate for range of 27m

4. THE MEASUREMENTS

The measurements were done inside T Block building in Yildiz Technical University Besiktas Campus. In order to produce map and 3 dimensional model of the area, T Block building, surroundings and details inside the building were surveyed by polar survey method. Nikon DTM-330 Electronic Total Station instrument was used in the geodetic measurements. All details of T Block building; classrooms, corridors, stairs, doors, columns, central heating radiators, access points and sample points of which electric field strength determined were surveyed with horizontal and vertical angle and distance readings by Electronic Totalstation. Furthermore, geodetic measurements were done around T block building to determine the topographic land form. 17 benchmark points were installed by referencing 2 GPS survey points and totally 388 detail points were surveyed.

Electric field strength measurements, which are used for analyzing and predicting the electromagnetic coverage area, are performed at the entrance floor of the T-Block building. In sense of symmetrically covering the floor, 217 straight points were chosen. The measurement results at the entrance floor were used in artificial neural networks and interpolation methods. To train the neural networks algorithm as 3 dimensional, the measurements were repeated at 5 different height levels. (50 cm, 100 cm, 140 cm, 215 cm and 290 cm)

Electromagnetic measurements were performed with an EMR-300 radiometer at every single point, the device was fixed at a constant position by using a tripod.

The Radiometer EMR-300 is a versatile system for measuring electromagnetic fields. After setting the measurement system, the device turned on for at least 3 minutes at a given single position and waited for finding the average electric field strength in units of V/m. For every single point the same measurement procedure was repeated.

5. USE OF GEOGHRAPHIC INFORMATION SYSTEMS

Geographic information system (GIS) technology can be used for scientific investigations, resource management, and development planning. A GIS is a computer system capable of capturing, storing, analyzing, and displaying geographically referenced information; that is, data identified according to location. The power of GIS comes from the ability to relate different information in a spatial context and to reach a conclusion about this relationship. Most of the information we have about our world contains a location reference, placing that information at some point on the globe. [6]

ArcGIS is an integrated collection of GIS software products for building a complete GIS. ArcGIS desktop provides a collection of software products that create, edit, import, map, query, analyze, and publish geographic information.

ArcGIS is structured around three main modules: ArcCatalog, ArcMap and ArcScene. These modules are used in the study.

The 3 dimensional points obtained from the area are transferred into ArcMap based on the national coordinate system (ED50) and T Block and surroundings are mapped from these points. A Personal GeoDatabase is performed in ArcCatalog and the applications are stored in that database. Electric field values are related to that points by adding the data to the attribute tables of the system.

Attributes of Measurement Points

NN	X	Y	Z	EMR	Shap
1	416813.177	4547072.981	94.063	0.16	Point
2	416813.514	4547074.145	94.062	0.19	Point
3	416813.851	4547075.309	94.061	0.26	Point
4	416814.189	4547076.473	94.06	0.23	Point
5	416814.526	4547077.637	94.059	0.29	Point
6	416814.863	4547078.802	94.058	0.33	Point

Record: 1 Show: All

Figure2. Attribute table of the points and electromagnetic field strength (EMR)

All the details are determined and transferred into GIS in order to present data about propagation environment. Thus, the proposed system provides to make queries and analysis and utilize the results.

Propagation environment is presented in 3 dimensional form by ArcScene program. T block building is modelled in

AutoCAD and 3ds Max program. AutoCAD is a suite of CAD software products for 2 and 3 dimensional design and drafting and 3ds Max is a full-featured 3D graphics application.

In this study, plans of the building are drawn and extruded with height values by using AutoCAD tools, then rendered by 3ds Max program which creates rich and complex model design visualization. It is saved as VRML format and transferred into ArcScene. In order to transfer the model, it is related with a single point and stored as a symbol and scaled in ArcScene. The land around the T Block building is also modelled by constituting TIN triangular network and contours. The shape of the land surface is shown in Figure 3 and five different height levels of the measurements at the entrance floor are shown in Figure 5 respectively.

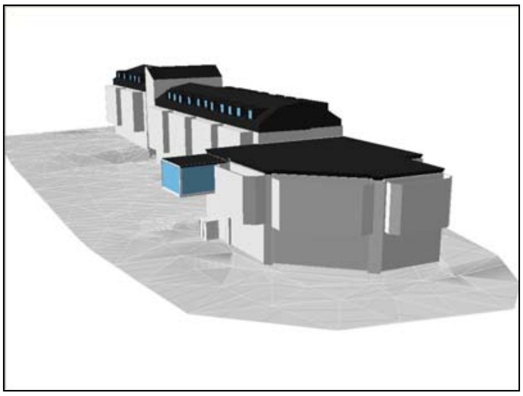

Figure 3. T Block building and the land

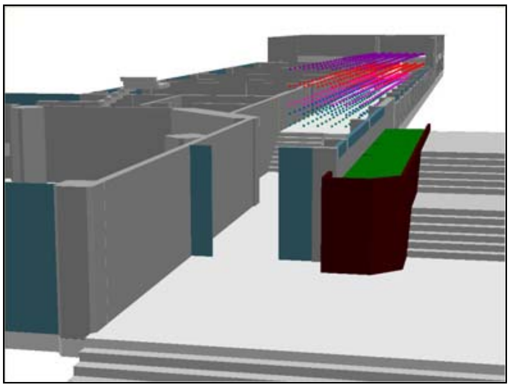

Figure4. Measurement points along the corridor at 5 different height levels

Interpolation is an important feature of a Geographic Information System; it is the procedure to estimate values at unknown locations within the area covered by existing observations. Inverse Distance Weighted (IDW), Spline and Kriging methods can be used to create interpolated surfaces through the user interface of ArcScene. Each interpolation method makes assumptions to show how to determine the estimated values.

In this study, various measurements show that there are instantaneous changes in the electric field values depending on the propagation environment. As a result of the non-linear variation, Kriging method is chosen due to its geostatistical evaluation for interpolating.

Kriging method assumes that the distance or direction between sample points reflects a spatial correlation that can be used to explain variation in the surface. Kriging is a multi-step process; it includes exploratory statistical analyze of the data, variogram modeling, creating the surface, and optionally, exploring a variance surface.

IDW and Spline are referred to as deterministic interpolation methods because they are directly based on the surrounding measured values or on specified mathematical formulas that determine the smoothness of the resulting surface. A second family of interpolation methods consist of geostatistical methods such as kriging, which are based on statistical models that include autocorrelation (the statistical relationship among the measured points). Because of this, not only do these techniques have the capability of producing a prediction surface, but they can also provide some measure of the certainty or accuracy of the predictions. [7]

The measurement points are separately interpolated for 5 different height level by Kriging method. Because those traditional interpolation functions mainly deal with 2 dimensional GIS dataset.

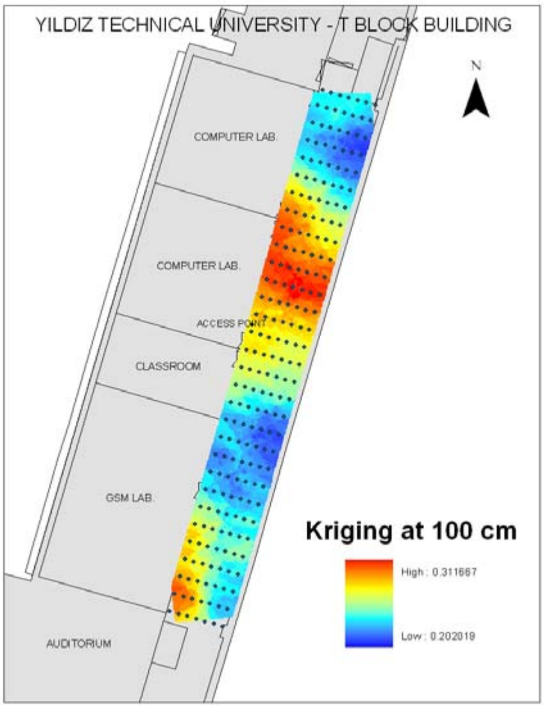

Figure 5. Kriging interpolation surface of the electric field strength values at 100 cm height level

6. ARTIFICIAL NEURAL NETWORKS

Neural network is mathematical models of human cognition, which can be trained to perform a specific task based on available experiential knowledge. The model is typically composed of three parts: input, one or many hidden layers, and an output layer. Hidden and output neuron layers include the combination of weights, biases and transfer functions.(Figure-6) The weights are connections between neurons while the transfer functions are linear or non-linear algebraic functions. When a pattern is presented to the network, weights and biases are adjusted so that a particular output is obtained. Neural networks provide a learning rule for modifying their weights and biases. Once a neural network is trained to a satisfactory level, it can be used as novel data. Training techniques can either be supervised or unsupervised. Supervised training methods are adapted for interpolation problem. [8]

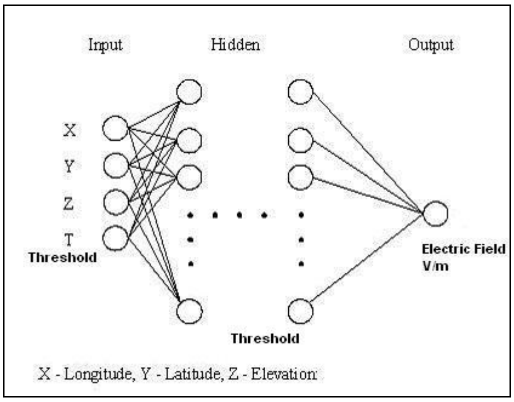

Figure 6. Typical Neural Network Model

In this project, Back-propagation (BP) algorithm is used. As the algorithm's name implies, the errors (and therefore the learning) propagate backwards from the output nodes to the inner nodes. So technically speaking, back-propagation is used to calculate the gradient of the error of the network with respect to the network's modifiable weights. This gradient is almost always then used in a simple stochastic gradient descent algorithm to find weights that minimize the error.

Design and Implementation

In this study; an artificial neural network (ANN), which is composed of one input layer with (k=3) neurons representing x-y-z coordinates, one hidden layer with (j=15) neurons and (m=1) output layer with a single neuron representing the Electric Field Intensity Value (V/m), is used. Besides, threshold matrice is applied through the hidden and output layers. Back Propagation training algorithm is implemented on the feed-forward network. The x-y-z coordinates are used as input data and they are reduced by replacing a point to the origin (0-0-0 values) of the coordinate system in order to mean the transfer function. Then the other measurement points are referenced to that point.

The transfer function applied to both hidden and output layers is a non-linear Sigmoid Function shown below

$$f(net) = \frac{1}{1+e^{-net}} \tag{2}$$

$$Net = \sum_{k=1}^{n} A_{kj} C_k \tag{3}$$

where A_{kj} and C_k are matrices of weights and outputs respectively.

1085 measurement points are separated into two groups as training data (672 points) and test data (413 points) respectively. Firstly, neural network is trained by the input of 672 points and Back – Propagation calculation performed for every training point in order to distribute the errors to weights, after 200 iterations, found the final updated weight matrice.

The optimized weight matrice applied between hidden and output layers is found as:

$$A_{jm}{}^{ih}(t) = A_{jm}{}^{ih}(t-1) + \Delta A_{jm}{}^{ih}(t) \tag{4}$$

$$\Delta A_{jm}{}^{ih}(t) = \lambda \delta_m C_j{}^{h} + \alpha \Delta A_{jm}{}^{ih}(t-1) \tag{5}$$

$$\delta_m = f'(net) E_m \tag{6}$$

where t represents the number of iterations.

and the weight matrice applied between input and hidden layers is found as applying the same procedure mentioned above by shifting the nodes through the input layer of the ANN including the derivation of δ_j term:

$$\delta_j = f'(net) \sum_m \delta_m A^{ih}{}_{jm} \tag{7}$$

413 input points are tested by the updated network with optimized weight matrices and the average error and accuracy of the neural network is calculated.

$$E_m = B_m - C_m \tag{8}$$

where E_m = error for m*th* process (V/m)
B_m = target result; electric field measurements
C_m =Output of the network

$$\text{Expected Accuracy} = \left(1 - \frac{\sum |E|}{n}\right) * 100 \tag{9}$$

where E = error
n = number of the test data

Average Error is 0.1305 and Expected Accuracy is almost 87 percent and the error result is accepted for interpolation of electric field intensity values and coverage prediction. In order to determine the best network topology, points chosen for input data, the number of neurons at hidden layer, iterations, learning and momentum rate are changed by various combinations until obtaining an acceptable accuracy.

Coverage Results

The Neural Network is finally formed with the optimized weight matrices and these matrices are set to the feed-forward network. After setting the final neural network, the WLAN coverage is analyzed for 100 cm altitude level which represents the usual height of a WLAN receiver. The coordinate values (x-y-z) defining the 100cm level are applied to the input nodes of the network and the predicted Electric Field strength values are given by the output node. The corresponding outputs of the input coordinate values are firstly converted to the units of received power (dB), and then they are sketched as a contour diagram (Figure-7) representing the cross-section radiation pattern of the WLAN AP.

The predicted coverage figure shows a linear propagation varying between -64.6 dB and -68.6 dB power values. In several attempts, it was noticed that various types of WLAN adapters could access to the system even below the -70 dB threshold. Thus, in a range of 27m, the radiating WLAN AP can almost cover the whole corridor to satisfy up to a 54 Mbps communication with a IEEE 802.11g compliant WLAN Adapter [9]. However, actual throughput may vary based upon numerous environmental factors and the efficient communication data rate can not be achieved for low power level points as shown in the figure 7. Moreover, this electromagnetic coverage does not lead to an electromagnetic pollution due to the low power levels. [10]

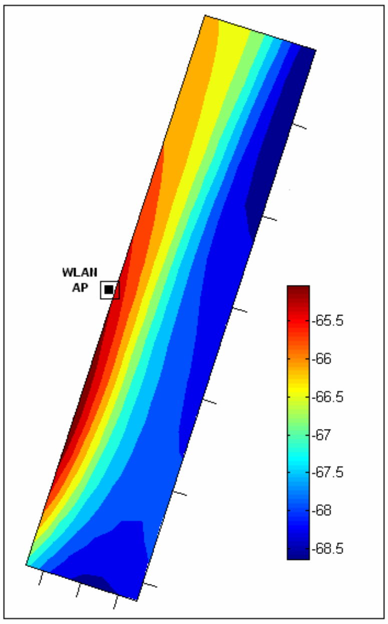

Figure 7. ANN Prediction of Received Power (dB) Values at 100 cm Height Level

Comparison of ANN Prediction and Kriging Interpolation Method

The electromagnetic coverage in the propagation environment now can be modelled by both ANN Prediction and Kriging Interpolation Method. To compare these approaches, 10 coordinate values are set as the inputs of each model. Half of the coordinates are selected randomly. The Comparison is given Table 1.
Both of the models have the similar error values. ANN prediction uses a Back-progation algorithm, updating itself by optimizing the weight matrices to enable a three-dimensional (3D) query. On the other hand, Kriging can only do a 2D interpolation to predict the coverage.

7. CONCLUSION

In this study 3D electromagnetic coverage and electromagnetic pollution modelling with Artificial Neural Network (ANN) using Back Propagation Algorithm is realized and modelled in GIS environment. Algorithms for coverage prediction are investigated. The comparison of the algorithm results are shown. Additionally a Geographic Information System (GIS) providing 3D propagation environment modelling the number, position and transmitter power of access points, electromagnetic coverage, the radiation level values, is proposed. As a result the proposed GIS system with ANN prediction help a telecom RF designer to make queries about the current electromagnetic coverage and pollution analysis in a given propagation environment and helps to determine the communication signal quality.

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Table1. Comparison of ANN and Kriging Interpolation method.

	INPUT			OUTPUT			ERROR		
Point No	**X (m)**	**Y (m)**	**Z (m)**	**ANN (V/m)**	**KRIGING (V/m)**	**TARGET (V/m)**	**ANN (V/m)**	**KRIGING (V/m)**	**ANN-POWER (dB)**
Random 1	416814,487	4547073,162	94,2	0,2049	-	-	-	-	-68,5843
Random 2	416817,061	4547082,573	94,8	0,2697	-	-	-	-	-66,2003
Random 3	416818,87	4547091,062	95,1	0,3347	-	-	-	-	-64,325
Random 4	416819,488	4547093,249	95,32	0,3352	-	-	-	-	-64,3106
Random 5	416822,636	4547096,216	93,47	0,2148	-	-	-	-	-68,1747
41	416816,794	4547083,289	93,663	0,2864	0,3122	0,3	0,0136	-0,0122	-65,6777
302	416821,761	4547098,254	94,163	0,2648	0,3032	0,28	0,0152	-0,0232	-66,3599
440	416814,863	4547078,802	94,563	0,3113	0,2741	0,33	0,0187	0,0559	-64,9542
851	416821,054	4547087,103	95,313	0,1764	0,2017	0,19	0,0136	-0,0117	-69,889
1050	416824,856	4547102,405	96,063	0,2085	0,2409	0,22	0,0115	-0,0209	-68,4343