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A new model for indoor propagation prediction using genetic algorithm

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Abstract: In this study, a new, simple and accurate computation of the received signal strength (RSS) level for indoor environment is performed. The genetic algorithm (GA) approach is used for prediction of the RSS. The proposed model is formed on the knowledge of measurements without requiring any detail of the environment. The model provides a time efficient method to estimate RSS dynamically at any location in the test environment. The accuracy of the measurement results and the genetic algorithm approach are presented for three distinct transmitters located at different positions.
Keywords: indoor radio communication, propagation, genetic algorithm
Classification: Electromagnetic theory

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1 Introduction

Signal strength estimation for indoor wireless communications has been exploited in many applications including coverage analysis and localization. In the literature, several localization systems have been proposed to utilize the distance measurement function [1]. Distance measurement function measures the distance between a receiver and a transmitter. The Received Signal Strength (RSS) exploits either theoretical or empirical calculations for mapping the signal strength measurements to distance. However, radio signals are subject to reflections, diffractions and scattering in obscured environments. These result in the multipath effect and time variance of the observation, hence performance decrease in the estimation. It is desirable to develop accurate and time efficient methods that interactively predict RSS at a specific location. Statistical modeling approaches such as maximum likelihood and Kalman Filter methods [1] are incorporated for improving the performance. Generally, a radio signal propagation model is assumed first, and then statistical approaches are used to estimate the model parameters.

It is well-known that in recent studies, genetic algorithms have been increasingly used to optimize the operational characteristics of various microstrip components and antennas and to estimate the radar cross section of objects [2]. In this study, a GA is used to predict RSS at the measurement locations in the environment. A medium scale obscured indoor environment is focused on. The aim is to develop an accurate model for estimating the RSS level. In contrast to the models encountered in the literature, the proposed model relies on the knowledge of measurements without requiring much detail such as the interior arrangement of the building, properties of the transmitter or the receiver. The remainder sections of this paper are organized as follows: Section 2 presents the background information; Section 3 describes the GA model for predicting RSS level. Section 4 presents the measurement procedure and some numerical results are given in Section 5. The paper is finalized with conclusions section.

2 Background information

RSS is location dependent as it is affected by factors such as attenuation due to the distance from the transmitter and existing obstacles. Buildings represent a complex environment of very large dimensions compared to wavelength. Reflection, diffraction and scattering of radio waves by structures inside a building result in the transmitted signal to reach the receiver through more than one path. There are several approaches to indoor propagation prediction. In one approach, electromagnetic theory is applied using ray-tracing techniques. In this method, propagation predictions can be applied without performing propagation measurements first. However, computation

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times on personal computers can be long, and then, the predictions cannot be obtained interactively or with algorithms for estimating user locations. The ray tracing requires a detailed description of the building and the locations of all obstacles, as well. In the alternative approach, power law models are used to estimate path loss based on measurements. The prediction results can be computed quickly, but it relies on the specifics of the structures and gives not accurate results for indoor environments with obstacle [3].

3 Proposed model

In this part a brief description of the GA used in the proposed model is presented, and its application on prediction of RSS level is described. In this work, the tournament selection is used as a selection strategy since it is the most effective strategy for many applications. In this selection, a subpopulation of N individuals is randomly selected from the population. The individuals of this subpopulation compete on the basis of their fitness and, therefore, one having the highest fitness value wins the tournament and becomes the selected individual. All of the subpopulation members are then reinserted into the general population and the process is repeated.

In the analysis, measurement results of RSS level are used to determine the parameters of the fitness function. Fitness function can be expressed as a functional representation of the RSS level. The electromagnetic field may be represented by means of diffracted and ray-optical fields [4]. The field at an observation point is given by the sum of direct, reflected, transmitted and scattered ray fields. The scattered field comprises a combination of diffracted and multiple rays such as double reflected, reflected-transmitted, reflected-diffracted, and transmitted-reflected. It can be seen from the equations listed in [4] and [5] that all the ray fields are a function of the distance including some additional parameters. Accordingly, in this study, a proper fitness function for the genetic algorithm is postulated in the following form,

$$f_{fit} = f_d + f_r + f_t + f_s \tag{1}$$

where, f_d, f_r, f_t and f_s represent direct, reflected, transmitted and scattered rays, respectively. The terms for direct (f_d), reflected (f_r) and transmitted (f_t) rays can be expressed as

$$f_{d,r,t} = (X_{1,d,r,t} + jX_{2,d,r,t})d\, e^{(X_{3,d,r,t}+jX_{4,d,r,t})d} \tag{2}$$

separately. The term for scattered (f_s) ray is chosen in similar form

$$f_s = \frac{X_{1s} + jX_{2s}}{d^{X_{3s}}} e^{(X_{4s}+jX_{5s})d}. \tag{3}$$

GA is used to obtain the estimates for X's, to match the measurement data as a function of the distance d between the receiver and the transmitter. By considering the indoor environment in which the measurements are taken, some of the rays which has no significant effect on the numerical results can be neglected to simplify fitness function. In the analysis, a Fortran version of

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a GA including niching and elitism described by Carroll [6] is used. Among the many variations of crossover, the uniform crossover is chosen for this problem. The uniform crossover is preferable to a single point crossover, as it is found that GA convergence is faster with the former.

4 Research method

In this study, a Radio Frequency Identification System (RFID) is used in order to demonstrate the validity of the new model for indoor propagation prediction using GA. The environment considered in this work is a laboratory in the scale of (6.8, 19.5, 2.9)m. The area includes obstacles, which cause scattering and reflection of radio waves. Obstacles are walls, windows, wooden tables with 73 cm height and steel shelves (180 × 60 × 192 cm), etc. One side of the room is covered with windows and the room walls are made of concrete blocks while the room ceiling is made of concrete with 2 cm plaster and floor of concrete with 4 cm chipboard. Measured data include recordings of RSS indicator (RSSI) levels from the three transmitters. RSSI measurements are carried out with the use of an active RFID tag and reader, and 3 transmitter-beacons. Each of the three transmitters (TX1, TX2 and TX3) is located at distant locations of the subject environment as in Fig. 1, on the walls (TX1, TX3) and at the ceiling (TX2).

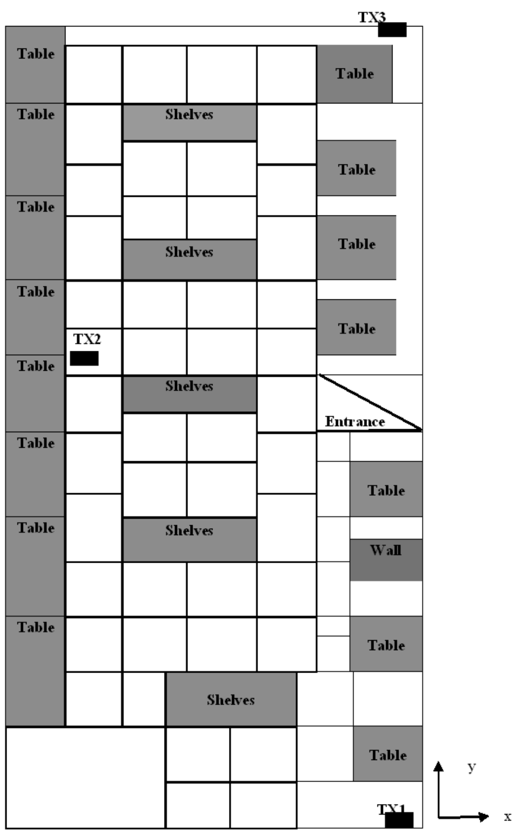

Fig. 1. Indoor environment and positioning of transmitters. The coordinates of TX1, TX2 and TX3 are (5.75, 0, 2.35)m, (1.2, 10.5, 2.9)m and (5.75, 19.5, 2.35)m, respectively.

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Each transmitter transmits RF signals at UHF band, with distinct frequencies (433.056 MHz, 433.344 MHz and 433.680 MHz) and with −10 dBm. The tag is carried by the subject at 105 cm height from the floor, and it collects signal strengths from the three transmitters as the subject moves around the environment. The RSSI sensed by the tag is transferred to a computer via RFID reader by use of proprietary data collection software, and is processed by the computer. RSSI values are directly proportional to the RSS levels; hence they possess a correspondence to the distance between the tag and the transmitter.

5 Results

The GA approach based predictions are compared to the measurements in indoor environment. As a first step, the indoor environment shown in Fig. 1 is divided into 120 cm × 120 cm square grids. For each grid, we recorded 52 measurements (RSSI values) from each transmitter at the corners and at the center of the grid, and when the tag's embedded small-sized spiral dipole antenna is facing different orientations. A helical antenna is attached to each transmitter. In this environment, the contribution of direct, reflected and scattered rays are severe and they reach the receiver. Since metallic furniture is the most dominant reflector in the room and wooden table height is lower than the receiver height, transmitted field is neglected [7]. Then, the fitness function is postulated to have the following form:

$$f_{fit}=(X_1+jX_2)d\,e^{(X_3+jX_4)d}+\frac{X_5+jX_6}{d^{X_9}}e^{(X_7+jX_8)d}+(X_{10}+jX_{11})d\,e^{(X_{12}+jX_{13})d} \quad (4)$$

The mean of the measured RSSI values as a function of distance d for each transmitter is exploited to obtain the estimates of $X_1 - X_{13}$ in Eq. (4). The distance d is the separation between the transmitters and the tag, computed as a straight line in three dimensions. It is observed that there is no significant difference when median operator is replaced by mean.

Fig. 2 displays the mean of the measured RSSI values and the values predicted by Eq. (4) for a single transmitter (TX2). As it is seen in Fig. 2, actual measurements and f_{fit} agree quite well with each other. Measurement and GA results are also compared for other transmitters (TX1 and TX3). Standard deviations of the predictions for each transmitter located in the laboratory are presented in Table I.

The standard deviation in error for the proposed GA model are 2,43; 2,61 and 4,07 for TX1, TX2 and TX3 respectively while that for the conventional power law models given by [8] are 3,57; 3,15 and 5,12. When statistics of the comparisons in accuracy between the measurements and predictions by the GA model and the conventional power law model are considered, the new GA model fits the data within 10% error for 94% of all measurements for TX1, within 10% error for 93,5% of all measurements for TX2 and error in the range of 10% error occurred at 57% of all measurements for TX3 while the conventional power law model fits the data within 10% error for 70%, 77%, 43% of all measurements for TX1, TX2 and TX3, respectively.

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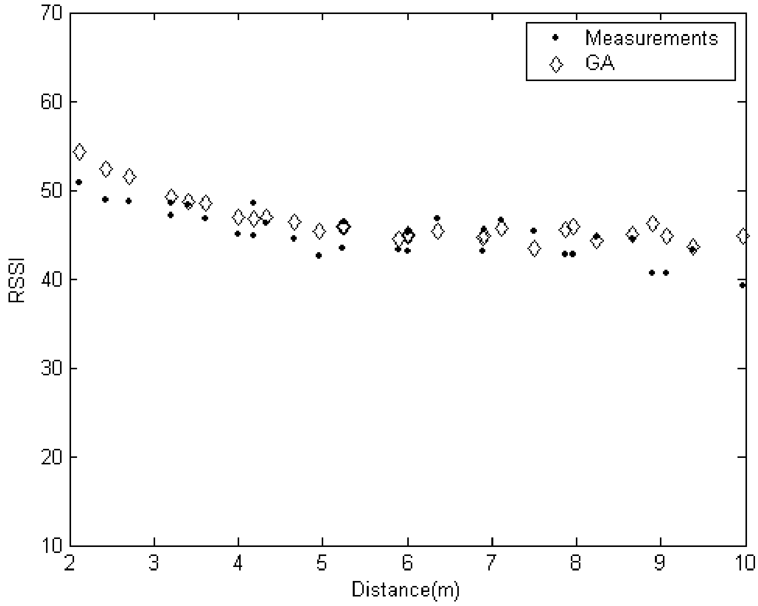

Fig. 2. RSSI level as a function of for TX2.

Table I. Standard deviation in error between the measurements and predictions by the GA and conventional power law models.

Model	TX1	TX2	TX3
GA	2,43	2,61	4,07
Conventional Power Law [8]	3,57	3,15	5,12

When all ray components of Eq. (1) are considered for this environment, a small improvement is observed only in specific distance. However, the difference in standard deviations is very low. From these analyses it is clear that, transmitted ray has no significant effect for this special case. It is seen that accuracy of this new GA model is better than conventional power law model for all transmitters. It should be noted that the components of fitness function must be recalculated when the transmitter location is changed or any of the transmitters is replaced with another with different properties at the same location.

6 Conclusion

In this study, a new GA model for RSSI as a function of the distance between the transmitter and the receiver has been developed. The model in this paper is used to predict RSSI at the measurement locations for an obscured indoor area, which are received from three distinct transmitters located at different locations in a specific environment. On the other hand, all of the rays may have significant contribution to the propagation feature in environments such as a transmitter and receiver may be located on different rooms or floors, as well as office environments with panel systems made of dielectric and metallic hybrid materials. As this model is proposed for any environment, in the future studies, it needs to be verified in other environments, as well. The pro-

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posed model relies on only the knowledge of the measurement results without requiring the detail of the obstacle, building properties and the transmitter and receiver's power and frequency. Besides, it is straightforward to apply and is computationally very efficient. The results of this study show that, the new GA model has better accuracy than the conventional power law model for all tested transmitters.

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