Engineering Science and Technology, an International Journal xxx (2018) xxx–xxx

HOSTED BY

ELSEVIER

Contents lists available at ScienceDirect

Engineering Science and Technology, an International Journal

journal homepage: www.elsevier.com/locate/jestch

Full Length Article

Path loss predictions for multi-transmitter radio propagation in VHF bands using Adaptive Neuro-Fuzzy Inference System

Nazmat T. Surajudeen-Bakinde [a], Nasir Faruk [b], Segun I. Popoola [c,*], Muhammed A. Salman [a], Abdulkarim A. Oloyede [b], Lukman A Olawoyin [b], Carlos T. Calafate [d]

[a] Department of Electrical and Electronics Engineering, University of Ilorin, Nigeria
[b] Department of Telecommunication Science, University of Ilorin, Ilorin, Nigeria
[c] Department of Electrical and Information Engineering, Covenant University, Ota, Nigeria
[d] Department of Computer Engineering, Technical University of Valencia (UPV), Valencia, Spain

ARTICLE INFO

Article history:
Received 19 February 2018
Revised 25 April 2018
Accepted 21 May 2018
Available online xxxx

Keywords:
Path loss models
Adaptive Neuro-Fuzzy Inference System
Neural network
Radio wave propagation

ABSTRACT

Path loss prediction is an important process in radio network planning and optimization because it helps to understand the behaviour of radio waves in a specified propagation environment. Although several models are currently available for path loss predictions, the adoption of these models requires a trade-off between simplicity and accuracy. In this paper, a new path loss prediction model is developed based on an Adaptive Neuro-Fuzzy Inference System (ANFIS) for multi-transmitter radio propagation scenarios and applicable to the Very High Frequency (VHF) bands. Field measurements are performed along three driving routes used for testing within the urban environment in Ilorin, Kwara State, Nigeria, to obtain the strength values of radio signals received from three different transmitters. The transmitters propagate radio wave signals at 89.3 MHz, 103.5 MHz, and 203.25 MHz, respectively. A simple five-layer optimized ANFIS network structure is trained based on the back-propagation gradient descent algorithm so that given values of input variables (distance and frequency) are correctly mapped to corresponding path loss values. The adoption of the Pi membership function ensures better stability and faster convergence at minimum epoch. The developed ANFIS-based path loss model produced a low prediction error with Root Mean Square Error (RMSE), Standard Deviation Error (SDE), and correlation coefficient (R) values of 4.45 dB, 4.47 dB, and 0.92 respectively. When the ANFIS-based model was deployed for path loss predictions in a different but similar propagation scenario, it demonstrated a good generalization ability with RMSE, SDE, and R values of 4.46 dB, 4.49 dB, and 0.91, respectively. In conclusion, the proposed ANFIS-based path loss model offers desirable advantages in terms of simplicity, high prediction accuracy, and good generalization ability, all of them critical features for radio coverage estimation and interference feasibility studies during multi-transmitter radio network planning in the VHF bands.

1. Introduction

Propagation models, which can be empirical, semi-empirical or deterministic, are used in predicting the strength of a radio wave signal received at a given distance relative to the position of the base station transmitter. Path loss prediction models are used by radio network engineers to estimate the coverage area of a given transmitter. Empirical path loss models are widely used because they require less computational efforts. Also, detailed information about the physical and geometrical structures of the propagation environment are not required in the use of empirical path loss models. However, these models are not as accurate as deterministic models, especially when they are used in another environment that differs from the one where measurements were originally taken [1].

In previous works [2–8], the prediction accuracy of various empirical models have been investigated. These studies covered both urban and rural propagation environments in Nigeria. The results of the comparative analyses showed that empirical models are liable to high prediction errors. Although, research findings reported in [9–11] showed that some of the models with high performance can be tuned to minimize their prediction error and improve their prediction accuracy. However, the calibrated path loss models eventually become site-specific.

* Corresponding author.
E-mail addresses: segun.popoola@stu.edu.ng, segun.popoola@covenantuniversity.edu.ng (S.I. Popoola).

Peer review under responsibility of Karabuk University.

https://doi.org/10.1016/j.jestch.2018.05.013
2215-0986/© 2018 Karabuk University. Publishing services by Elsevier B.V.

Please cite this article in press as: N.T. Surajudeen-Bakinde et al., Path loss predictions for multi-transmitter radio propagation in VHF bands using Adaptive Neuro-Fuzzy Inference System, Eng. Sci. Tech., Int. J. (2018), https://doi.org/10.1016/j.jestch.2018.05.013

On the other hand, deterministic models are formulated based on theories and principles of physics, which are complex to implement and computationally expensive. Also, the prediction accuracy of deterministic path loss models is usually influenced by the accuracy and resolution of digital terrain model and topographical (or land use) database. In addition, it is sometimes necessary to fine-tune the path loss model even when a full and accurate database is available. This is done to guarantee model prediction accuracy [12].

Path loss predictions in rural areas were carried out successfully by Stocker and Landstorfer in [13], wherein an adaptive learning was used to develop a planning tool for mobile radio communication systems. In [14], a theoretical model and a neural network model were combined in the application of feed-forward Artificial Neural Network (ANN) for path loss predictions in an outdoor environment. The results obtained were compared to the prediction outputs of COST 231-Walfisch-Ikegami path loss model. In another related work by Eichie et al. [15], data were collected from selected rural and suburban areas of Minna, Niger State, Nigeria, and the measurement data were used in training ANN path loss model. The developed ANN-based path loss model was found to be better than Hata, Egli, COST 231, and Ericsson path loss models. Atmospheric parameters were used as inputs in developing two new models in [16]. It was observed that the developed model had an acceptable accuracy when compared to the measured values. In [17], the strengths of IS-95 pilot signal of a commercial Code Division Multiple Access (CDMA) mobile network was measured in a rural part of Western Australia, and the propagation measurements were used to train an ANN for path loss predictions. The proposed model, when compared to the ITU-R P.1546 and Okumura-Hata models, was found to be more efficient. In a related work, Neškovi'c et al. [18] proposed a prediction model based on feed forward neural networks for the mobile phone environment. The results obtained showed that the model is fast, accurate and reliable.

Benmus et al. [19] took measurements in Tripoli, Libya, and applied an ANN model to predict path loss in the Ultra-High Frequency (UHF) band. The results of the model, after evaluation and comparison, were found to be more accurate than the Hata model. In another research effort [20], very similar to the work done in this paper, an ANFIS-based path loss model was developed by training the network with field measurement data that were taken at 900 MHz in Harbiye, Province of Turkey, to predict path loss values at varying distances. There was a 15% increase in prediction accuracy for the ANFIS-based path loss model when its prediction outputs were compared to those of Bertoni-Walfisch path loss model. Angeles and Dadios [21] found Neural Network (NN) model to be the most efficient for path loss predictions in digital TV macro cells in the UHF band, when a comparative analysis was done in reference to the Free Space Loss (FSL) and Egli models. The prediction accuracy and generalization ability of ANN and Extreme Learning Machine (ELM) algorithms were investigated in [22,23].

Different Artificial Intelligence (AI) models have also been used to achieve high accuracy and better computational efficiency in path loss predictions [24,25]. Gupta and Sharma [26] employed the Fuzzy Logic (FL) model to predict path loss as a function of the path loss exponent in the fringe areas of the suburban region of Clementown and Dehradun. Path loss predictions using heuristic algorithms in urban macro cellular environments were done in [27]. To the best of our knowledge, the depth of the work done with respect to the application of ANFIS to path loss predictions in the Very High Frequency (VHF) bands is still very limited. The effectiveness of the NF model needs to be tested in view of the terrain peculiarities of the environment under investigation. Also, previous works in the literature that employed the ANFIS technique for path loss modeling only considered single transmitter propagation scenarios. In short, the capability of the ANFIS technique to model path loss predictions in urban environments at VHF bands has not been widely investigated for the multi-transmitter propagation use case in the context of tropical geographic terrains such as in Nigeria. Meanwhile, there seems to be a continuous growth in the deployment of wireless systems which operate in the VHF band. Hence, the need for this present study.

In this paper, a new path loss prediction model is developed for multiple transmitter radio propagation scenarios in VHF band using ANFIS. Field measurements are performed along three drive test survey routes within an urban environment in Ilorin, Kwara State, Nigeria, to obtain the strength values of radio signals received from three base station transmitters. The transmitters propagate radio wave signals at 89.3 MHz, 103.5 MHz, and 203.25 MHz, respectively. The Received Signal Strength (RSS) data obtained are calibrated to corresponding path loss values. A simple five-layer optimized ANFIS network structure is trained based on the back-propagation gradient descent algorithm such that given values of input variables (distance and frequency) are correctly mapped to corresponding path loss values. The complete dataset that contained all data instances of separation distance between transmitter and receiver, frequency of transmission, and path loss, is randomly divided into 75% training data subset, and 25% testing data subset. Measurement data obtained from propagation scenarios in the training data subset are used for model development and validation. The developed model is tested with measurement data that were collected from different but similar propagation scenarios within the urban environment. Model complexity and prediction accuracy are optimized using least square error approach. The ability of different membership functions (generalized, triangular, trapezoidal, Gaussian, and pi) to ensure good stability and fast convergence at minimum epoch were experimentally investigated. The prediction accuracy and generalization ability of the proposed ANFIS-based path loss model are evaluated based on the Mean Absolute Error (MAE), Mean Square Error (MSE), Root Mean Square Error (RMSE), Standard Deviation Error (SDE), and correlation coefficient (R), relative to the path loss values in training and testing data subsets, respectively. Finally, the prediction outputs of the developed ANFIS-based path loss model are compared with four popular empirical path loss models (Hata, COST 231, Egli, and ECC-33) to determine the optimal model for radio coverage estimation and interference feasibility studies during multi-transmitter radio network planning in the VHF bands.

2. Materials and methods

This section is divided into two parts: the first part describes the measurement procedure, and the second part explains the adaptive NF approach to path loss modelling in the VHF band.

2.1. Measurement campaign procedure

Field measurements were performed along three drive test survey routes within an urban environment in Ilorin, Kwara State, Nigeria (Longitude 4°36′25″E, Latitude 8°25′55″N), to obtain the strength values of radio signals received from three base station transmitters. The transmitters of the Nigerian Television Authority (NTA) Ilorin, UNILORIN FM, and Harmony FM propagate radio wave signals at 89.3 MHz, 103.5 MHz, and 203.25 MHz, respectively. Radio signals transmitted were received by a dedicated Agilent spectrum analyzer mode N9342C and the measured data were carefully logged. The receiver was properly positioned in a vehicle driven at an average speed of 40 km/hr to minimize Doppler Effects [28–30]. The spectrum analyzer has a Displayed Average Noise Level (DANL) of −164 dBm/Hz, being able to detect even very weak