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Prediction of Tropospheric Ducting for UHF Signals In Plateau State Using Adaptive Neuro-Fuzzy Inference Systems (ANFIS)

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ABSTRACT

A study on the occurrence of tropospheric ducting for UHF signal in Plateau State using ANFIS had been investigated using the variation of the meteorological data; temperature, pressure, and relative humidity collected from NIMET for Jos, Plateau State Nigeria. The refractivity gradient was calculated using MATLAB as computational software. The conditions of occurrence of path clearance and tropospheric ducting were utilized to checkmate the occurrence of ducting over the period. The data gotten is used to train an ANFIS model, taking 70% of the data for model training, 20% for testing and 10% for validation. The integrity of the ANFIS model was tested using root mean square error (RMSE) and maximum absolute percentage error (MAPE) which confirmed that the model is accurate to 99% considered fit for forecasting. The developed model was able to mimic the tropospheric ducting trend up to a period of 7 years (2019-2025) after successful simulation with an assertion that the rainy months are more prevailed to chances of tropospheric ducting occurrence as higher humidity prevails during this time which has more significance on refractivity gradient. An investigation was carried out on the effect of variation of tropospheric parameters; temperature, pressure and humidity on refractivity gradient using linear regression and Spearman correlation to ascertained the degree of dependence of each parameter and the result showed that refractivity gradient is strongly influenced by relative humidity with a correlation coefficient of -0.9772 as against temperature and pressure having correlation coefficients of -0.2587 and 0.2866 respectively.

Key Words: ANFIS, Meteorological Parameters, Refractivity Gradient, Spear Man, and Tropospheric Ducting.

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1. Introduction

Radio waves traveling through vacuum have little or no external influence. However, when such signals passed through the atmosphere the propagation efficiencies will be determined by atmospheric factors such as temperature, pressure and relative humidity[1], [2] hence, prior knowledge of these components is very important for telecom operators to make the necessary adjustments where possible, to achieved to optimized transmitted power when tropospheric refraction occur. Tropospheric ducting is a unique atmospheric phenomenon that can affect the propagation of electromagnetic waves, including UHF signals. It occurs when the refractive index profile of the lower atmosphere creates a duct-like structure that guides and traps radio waves over long distances. This phenomenon is particularly important in regions such as Plateau State, Nigeria, which is known for its diverse geography and varying weather patterns. Under certain atmospheric conditions, the waves will be trapped in a duct as a result of temperature inversion, which will make the radio range beyond its horizon[3]–[5]. Understanding the behavior of tropospheric ducting is crucial for optimizing the operation of UHF communication systems in Plateau State. By accurately predicting when and where these ducts will occur, engineers and network operators can plan their communication infrastructure more effectively, reducing signal distortions, and improving overall system performance.

The objective of this study is to develop an advanced prediction model based on ANFIS to estimate the occurrence and duration of tropospheric ducting for UHF signals in Plateau State. By analyzing historical data, such as temperature profiles, pressure, and humidity levels, this model will provide valuable insights into the atmospheric conditions that favor tropospheric ducting events. Additionally, the model will allow us to understand the impact of different atmospheric parameters on signal propagation and help optimize communication systems accordingly.

Tropospheric ducting is a well-known phenomenon that has significant implications for the propagation of UHF signals. Over the years, researchers have explored various methods to predict and understand this atmospheric condition. This literature review focuses on previous studies related to the prediction of tropospheric ducting for UHF signals, with a specific emphasis on the use of Adaptive Neuro-Fuzzy Inference Systems (ANFIS) in similar research. This study builds upon previous research on tropospheric ducting prediction, such as the work by [6], which developed an ANFIS model for predicting ducting conditions in the United Kingdom and [7], that utilized machine learning techniques combined with meteorological data to forecast duct occurrence in coastal regions. Research has shown that the path bending of electromagnetic waves were due to the inhomogeneous spatial distribution of the refractive index of air which causes serious multipath fading and noise[5], [8]–[9]. This effect of radio communications often occurs at altitudes up to 2 km [1], [4], [8], [10] so that the refractive index can be considered as a continuous function. The real component of the complex refractive index is responsible for phenomena such as ray bending, reflection, refraction, multipath fading, ducting, beam focusing/de-focusing, and depolarization.

The quantity mostly used to describe the spatial and temporal variability of radio signal propagating in the atmosphere is the refractivity which is measured in N-units which is given by equation (1).

$$N = \frac{77.6}{T}\left(P + \frac{4810e}{T}\right) \quad \ldots (1)$$

Where the water vapor pressure 'e' is related to the relative humidity RH by a relation given in equation (2) and equation (3) as:

$$RH = \frac{100e}{e_S(T)} \quad \ldots(2)$$

$$e = \frac{RH\, e_S(T)}{100} \quad \ldots(3)$$

e_s is the saturated vapor pressure which depends on the temperature according to the empirical formula in equation (4).

$$e_S(T) = a_W \exp\left(\frac{b_W T}{(T + c_W)}\right) \quad \ldots(4)$$

Where a_w= 6.1121 hPa, b_w= 17.502 and c_w= 240.97°C and above ice a_i= 6.1115 hPa, b_i= 22.452 and c_i= 272.55°C[11].

It has been found that the long-term mean dependence of the refractive index upon the height is well expressed by exponential law in equation (5).

$$n(h) = 1 + N \times 10^{-6} \times \exp{-\frac{h}{H}} \quad \ldots(5)$$

Where N: surface refractivity at the Earth's surface

H: scale height (km)

h: height of the Earth's surface above sea level. N and H can be determined statistically for different climates. The global mean of the height profile of refractivity may be defined by [12] as H = 7.35 km.

The reduced form of eq.5 is given by equation (6).

$$N(h) = N \exp{-\frac{h}{H}} \quad \ldots(6)$$

Where h: height of the Earth's surface above sea level (km).

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2. Data Collection and Processing

The daily meteorological data which are the atmospheric pressure, relative humidity and atmospheric temperature were collected from the Nigeria Meteorological Agency (NIMET) for a period of five years (2014 to 2018). The study area under consideration is Jos, Plateau State, Nigeria located on latitude 9°N and longitude 8°E at an altitude of 4232m above sea level. The data was pre-processed, normalized and presented in a rectangular matrix of 30x60 with rows representing the number of days in the month and the columns corresponds with the number of months for the period of five years.

2.1 Computation of Refractivity Gradient

The refractivity gradient was computed as recommended by ITU using eq.6 by checking-in the condition for occurrence of path clearance which is implemented as a MATLAB program file. This program is designed such that a '1' is assigned when ducting condition is met; otherwise '0' will be assigned thereafter, the monthly frequency of ducting over the time is used to train an ANFIS using MATLAB. This data which is arranged in a 30x31 rectangular array was used in the training of an ANFIS where first thirty columns are the input data to the ANFIS while the last column is the output. Table 1 shows how this data can be arranged.

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Table 1: ANFIS Training Data

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The ANFIS training algorithms is shown in Fig. 1.

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Figure 1**:** Implementation of ANFIS flow chart

In the ANFIS training, the GUI window is open by entering the command ‘anfisedit’ in the MATLAB command window which is shown in Fig. 2.

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Figure 2**:** The ANFIS GUI window Editor

The data are divided into three categories with 70% as training data, 20% as testing data and 10% as validation data. As the name suggest, the training data is used to trained the model for 50 epoch using gird portioning with hybrid optimization algorithms .

The training session is shown in Fig. 3

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Figure 3: ANFIS Training Session

Fig. 4 shows the ANFIS structure generated with 30 inputs representing the number of ducting occurring which generated 30 fuzzy rules using the Takagi-Sugeno method with 30 hidden neurons.

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Figure 4: The ANFIS Structure

The mean square error (RMSE) and the maximum percentage error (MAPE) after successful training, testing and validation is determined using equation (7) and equation (8)

$$R.M.S.E = \sqrt{\frac{\sum_{i=1}^{n}\left(\text{Predicted value} - \text{Actual value}\right)^2}{n}} \quad \text{--- (7)}$$

$$MAPE = \frac{100}{n}\sum_{i=1}^{n}\left\|\frac{(\text{Predicted value} - \text{Actual value})}{\text{Actual Value}}\right\| \quad \text{---(8)}$$

3. Results and Discussion

The daily variations of the refractivity gradient from 2014 –to- 2018 (five years) is shown in Fig. 5 a-e

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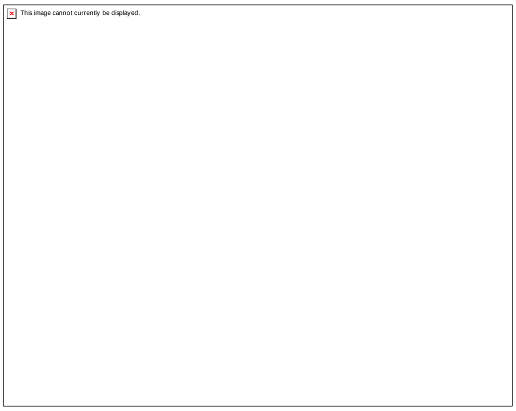

Figure 5a**:** Profile for the year 2014

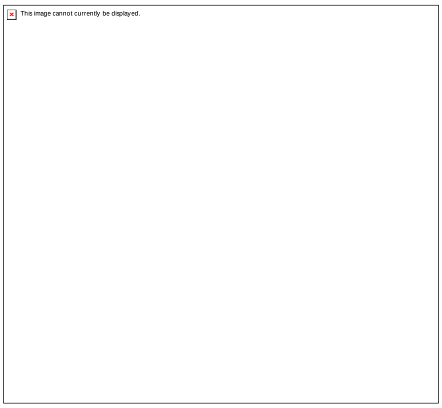

Figure 5b: Profile for the year 2015

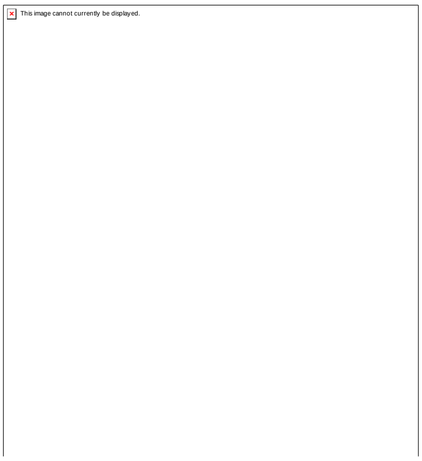

Figure 5c**:** Profile for the year 2016

Figure 5d: Profile for the year 2017

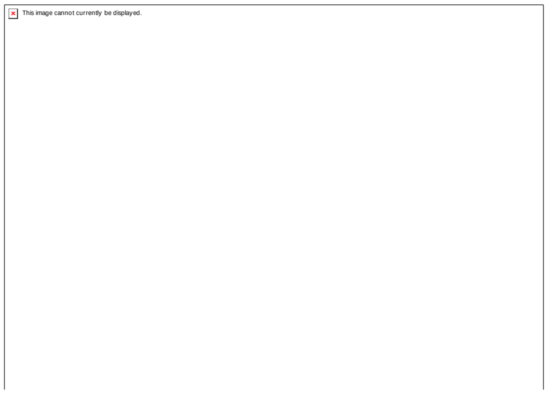

Figure 5e**:** Profile for the year 2018

The slope of the refractivity gradient is lower between April to October with August having the least refractivity gradient for all the twelve months of the year which is because the peak humidity is experienced during this month characterized by high saturated vapor pressure and low average temperature. This is expected because the onset rainy season in Plateau State is in April and ends in October and is characterized by high relative humidity as the saturated vapor pressure is high. The dry and sunny months (dry seasons) which commenced from November to March, have a high refractivity gradient which is ascribed to the fact that the humidity is low therefore, the vapor pressure is too depressed [4], [5], [13], [14]. Thus, from the plot of the refractivity gradient one can intuitively say that there are higher chances of radio waves traveling beyond the horizon during wet seasons and lower chances of long-range radio horizon in the dry seasons for UHF signals, therefore one could conclude that ducting occurrence is seasonal dependence as stated by [15] and also in that of [16].

3.1 Effects of the Meteorological Parameters on Refractivity Gradient

To study the dependence of the refractivity gradient on temperature, pressure, and humidity a scatter diagram and the equation of the line of best fit for each scattered plot is paramount. Fig. 6-8 shows the variation.

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Figure 6**:** Refractivity Gradient against Relative Humidity

Figure 7**:** Refractivity Gradient against Temperature

Figure 8**:** Refractivity Gradient against Pressure

Based on the scatter diagram, the least square regression model of the parameters are: Refractivity gradient = -2.5628H – 4.5134, Refractivity gradient = -5.3356T + 12.5447, Refractivity gradient = -5.5141P + 329.8954 where H= relative humidity, T= temperature, and P=pressure. From these model equations, it is obvious that the relative humidity greatly affects the refractivity gradient as it has the steepest which conforms with what was reported by[11], [17], [18]. To further determined the degree of dependence of the refractivity gradient on the meteorological parameters, the correlation coefficient for each parameter was obtained using the spearman rank correlation coefficient and the values obtained were -0.9772 for humidity, -0.2857 for temperature, and -0.2866 for pressure respectively, which shows that there is strong dependence between refractivity gradient and relative humidity whereas temperature and pressure shows no significant effect on the refractivity gradient which is in compliance with what was reported by[1], [5], [11], [19], [20].

3.2 Prediction of Tropospheric Ducting

Fig. 9 shows the number of times tropospheric ducting has occurred based on the data collected from NIMET whereas Fig. 10-11 shows the chances of occurrence of tropospheric for a period of 7 years.

Figure 9: Ducting Profile (2014-2018)

From Fig. 10 ducting occurrences are more prevalent during the raining season as seen from the refractivity gradient computation thus, showing a seasonal dependence as obtained by [15].

Figure 10: Predicted Ducting Profile (2019-2021)

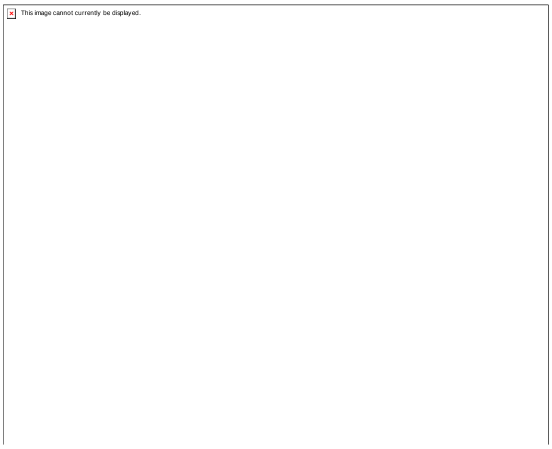

Figure 11: Predicted Ducting (2022-2025)

Fig.10, with the prediction of the number of ducts having a maximum value of 22 to 26 from July to November for the years 2019 to 2021 and a minimum value of 0 to 8 from January to April of the years under it. And this also shows seasonal dependence on the number of ducting occurrences. Similarly, Fig. 11 shows similar behavior only that the number of ducting occurrences is smaller than that of Fig. 10.

4. Conclusion

The spatial variation of the refractivity gradient was used to determine possibilities of occurrence of tropospheric ducting using an ANFIS model which is trained using 70% training data, 20% as testing data and 10% validation data and it has been demonstrated that the model is capable of predicting the number of times of occurrence of tropospheric ducting for a period of 7 years.

5. Authors Contribution

The major contribution of this research is by incorporating ANFIS into the prediction of tropospheric ducting, to enhance the accuracy and reliability of predictions for UHF signals in Plateau State, providing valuable insights for network planners, operators, and stakeholders in the telecommunications industry. The results of this research will also help to optimizing the design and deployment of UHF communication systems, improving communication reliability and efficiency in Plateau State.

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