NOVEL METHOD OF VERTICAL REFRACTIVITY PROFILE ESTIMATION USING ANGLE OF ARRIVAL SPECTRA

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ABSTRACT

Refractivity profile variation in lower part of the atmosphere is one of the aspects that influences long-distance terrestrial electromagnetic wave propagation and consequently performance of communication systems. Possibilities of remote sensing of refractivity profiles using field measurement at a receiver site of a terrestrial point-to-point link in terms of angle of arrival (AoA) spectra are discussed here. Models of refractivity profile are introduced to improve the estimation for various refractivity profiles.

INTRODUCTION

The near horizon electromagnetic wave propagation is largely governed by height distribution of refractive index in the atmosphere. One of the effects caused by anomalous refractive index distributions in the atmosphere is trans-horizon wave propagation causing interference effects in point-to-point or point-to-multipoint systems. Knowledge of the profile enables more precise wave propagation modelling and interference analysis. Because of mostly vertical stratification of the troposphere, the vertical refractive index profile has dominant influence on the wave propagation.

Usual methods of the refractive index measurement consisting of measurement of height dependence of temperature, pressure and humidity performed by radiosondes have some drawbacks. The radiosondes do not provide precise results in the lowest altitudes and are usually launched only twice a day. Lately, so called matched-field array processing method was reported [1] that enables the refractive index height dependence estimation based on field measurement at an array of receivers.

The aim of this paper is to asses the possibilities of remote sensing of refractivity using frequencies in millimetre wave band and to compare various refractivity profile models concerning the estimation accuracy.

PROFILE ESTIMATION

At a receiver site of the terrestrial point-to-point link the effects of various refractive index height profiles can be registered in terms of change of received signal strength and in terms of angle of arrival spectrum. Angle of arrival spectrum has the meaning of directions from which the wave arrives at the receiving point of the link and represents angular spectrum of plane waves hitting the aperture of the receiving antenna. The spectrum can be obtained from measured values of amplitude and phase at the elements of vertical antenna array [2]. Fig. 1 shows simulation of propagation under various refractivity profiles computed by parabolic equation/Fourier transform method [3] using Earth flattening transformation, with the frequency of 10 GHz, horizontal polarization and perfectly conducting ground. In Fig. 2, there are corresponding normalized angle of arrival spectra computed from simulation results of amplitude and phase in distance of 30 km and in height range of 30-50 m. It can be seen from the simulated spectra in Fig. 2 that the both gradients in Fig. 1 are distinguishable by this angle-of-arrival spectrum. The principle of the remote sensing refractivity profile estimation is as follows: Field is measured at a receiving antenna array for a given refractivity profile. Propagation simulation is run for various trial refractivity profiles until the computed field fits the measured field. The profile estimation is then given by the corresponding trial solution. This is an optimization problem to which techniques of evolutionary algorithms can be applied. Genetic Algorithms [4] and Self Organising Migration Algorithm (SOMA) [5] are examples of these algorithms.

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The algorithms are probabilistic methods searching the domain of possible solutions. The solutions with better objective function value are preferred in the course of the algorithm and the whole procedure converges to the optimal solution. The objective function used here has a meaning of the distance between the given (measured) angle of arrival spectrum and an angle of arrival spectrum of a trial solution in terms of mean square error. Using normalized angle of arrival spectrum obtained from amplitudes and phases at receiver antenna array, this objective function is close to Bartlett objective function [1] which is obtained directly from amplitudes and phases at the receiver array.

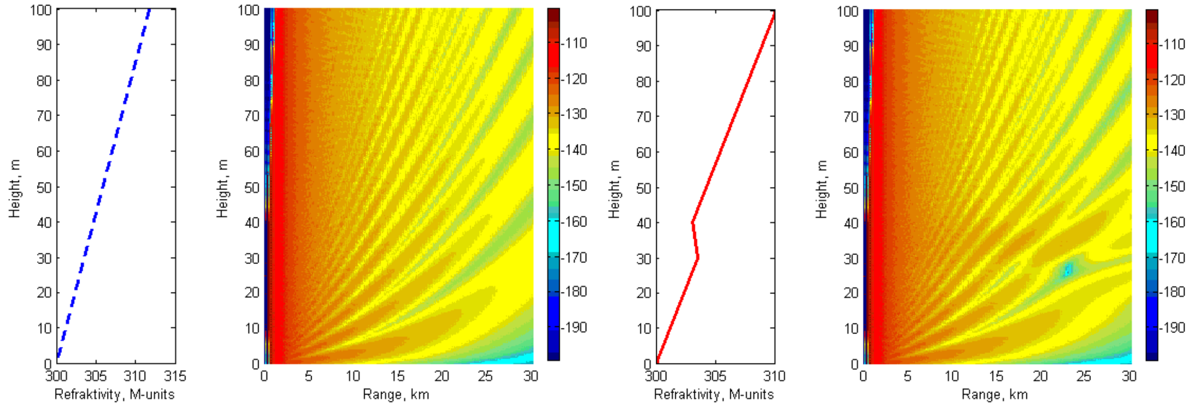


Fig. 1. Propagation simulation for various refractivity profiles, relative received power (dB)

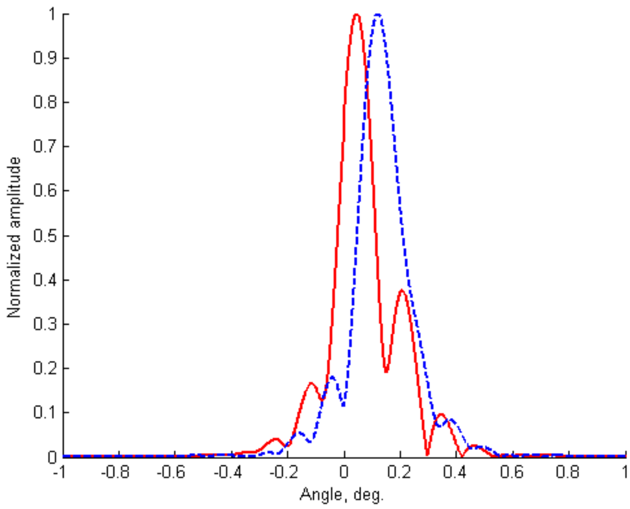


Fig. 2. Angle of arrival spectra computed from 20 m aperture antenna (30 m-50 m)

REFRACTIVITY PROFILE MODEL

To perform the refractivity estimation, refractivity profile model must be chosen first. Fig. 3 shows tri-linear model. This simple model is suitable for rough profile estimation taking account of one ducting layer. Three parameters are to be estimated in this model: lower height of anomalous gradient layer h_{low}, upper height of anomalous gradient layer h_{up} and the gradient of the ducting layer. The gradient outside the ducting layer is considered to be of standard value.
More complicated model can be applied to cope with more sophisticated refractivity profile dependencies to improve estimation accuracy. In [1] empirical orthogonal function model approximating the refractivity gradient is used. The orthogonal functions in the model are derived from measured refractivity profiles. The drawback of this model is that prior knowledge of refractivity profile must be available to obtain the orthogonal function set.

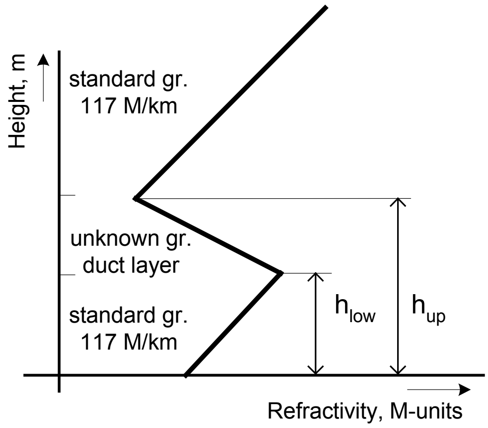


Fig. 3. Tri-linear model

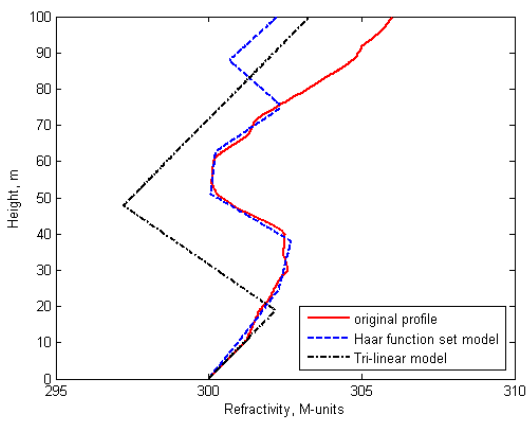
The model used here employs orthogonal functions based on Haar orthogonal function set [6]. The height dependence of the modified refractivity gradient is given by

$$M_G(h) = M_m(h) + \sum_{n=1}^{N} a_n f_n(h) \tag{1}$$

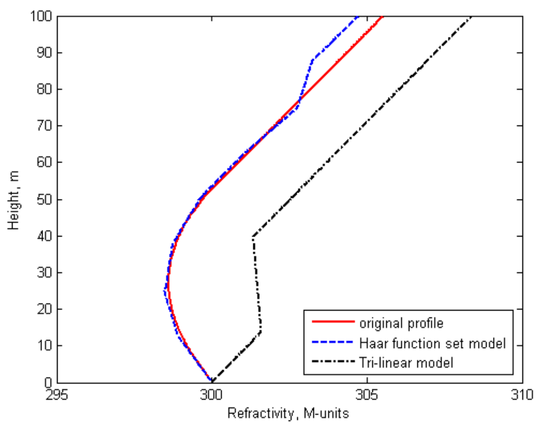
where M_G (h) is refractivity gradient height dependence, M_m (h) is mean value of the refractivity gradient and a_n are the coefficients of the corresponding orthogonal functions f_n. The remote sensing method using electromagnetic wave propagation simulation can only provide the estimation of refractivity gradient allowing the value of M (0) to be chosen arbitrarily.

RESULTS

To find out a suitability of the refractivity models mentioned above a random refractivity test profile was created and corresponding received field values were obtained to simulate the measured field. This field distribution was computed using parabolic equation simulation results corresponding to two receiving arrays extending from 20 to 35 and from 50 to 65 m to expand the scanned range of heights. Distance between transmitter and receiver is 30 km, frequency is 10 GHz, height of the transmitter is 25 m. Using simulated angle of arrival spectrum SOMA algorithm was run to find the best approximation of the original test profile. Fig. 4(a) shows a random test profile based on a surface duct profile and its estimation using tri-linear and Haar orthogonal function models and AoA-based objective function. It can be seen that the estimation using Haar orthogonal function set gives far more accurate estimation in this case. In Fig. 4(b) there is a test profile based on evaporation duct profile and its estimation. As in the previous situation the Haar orthogonal function set model gives better estimation comparing to tri-linear model.



(a)



(b)

Fig. 4. Test profile and estimations using Haar orthogonal function set (8 basis functions) and tri-linear model

Fig.5 shows several random test profiles and their estimation using Haar orthogonal function set model with 8 basis functions. Estimations using AoA-based objective function and Bartlett objective function are shown. As in the previous case two antenna arrays are considered extending from 20 to 35 and from 50 to 65 m.

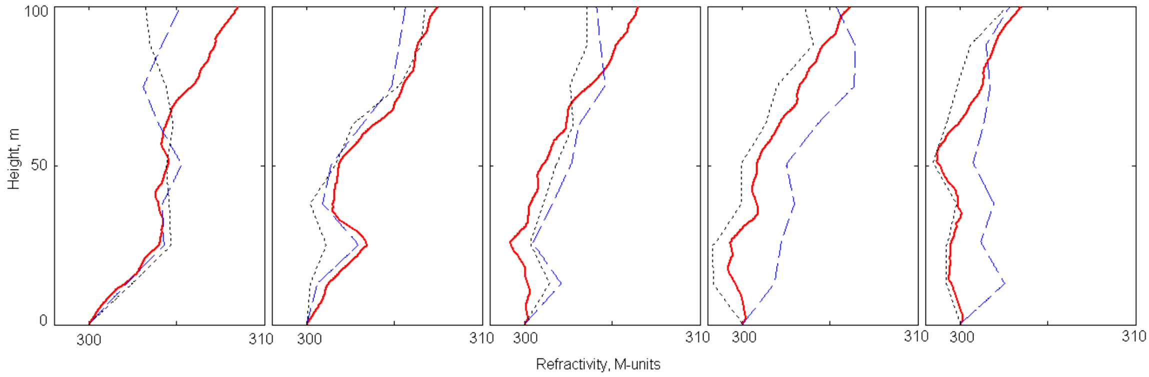


Fig. 5. Estimation comparison, test profile (red solid line), estimation based on Haar function set model with 8 basis functions using AoA based objective function (blue dashed) and Bartlett objective function (black dotted)

CONCLUSION

Principles of remote sensing of refractivity profile using field amplitude/phase measurements were shown. It was shown that reasonable estimation results can be expected for millimetre frequency band using antennas of several meters aperture. Refractivity model based on Haar orthogonal function set was introduced. Comparisons of estimation accuracy performance of the Haar orthogonal function set model and tri-linear model were carried out. The results show a good performance of the Haar orthogonal function set model for various types of unknown refractivity profiles. Estimations were performed using AoA-based and Bartlett objective functions to show their estimation performance.

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