THE STATISTICAL MODELING OF DUCT CHANNELS AND THE PREDICTION OF RADIO INTERFERENCE THROUGH DUCTING

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ABSTRACT

Radio interference has been occurred in the TRS frequency band at the south coastal area of Korea from 1994, and it turns out that the sources of the interference are base stations signals from Japan, propagated through a duct. To predict the interference level accurately, refractive index profiles around the Korean peninsula were modeled statistically using the measured meteorological data, and wave propagation through a duct channel was calculated using split-step Discrete Mixed Fourier Transform algorithm. Simulation results were compared with the experiment data in 1999, which showed a fairly good agreement.

INTRODUCTION

Ray bending is very closely related with the rate of change of refractivity with height. For convenience, a modified refractive index M is generally used when dealing with superrefractive wave propagation like a ducting and its relation to refractivity n is as follows[1].

$$M = (n-1)\times 10^{6} + 0.157h \tag{1}$$

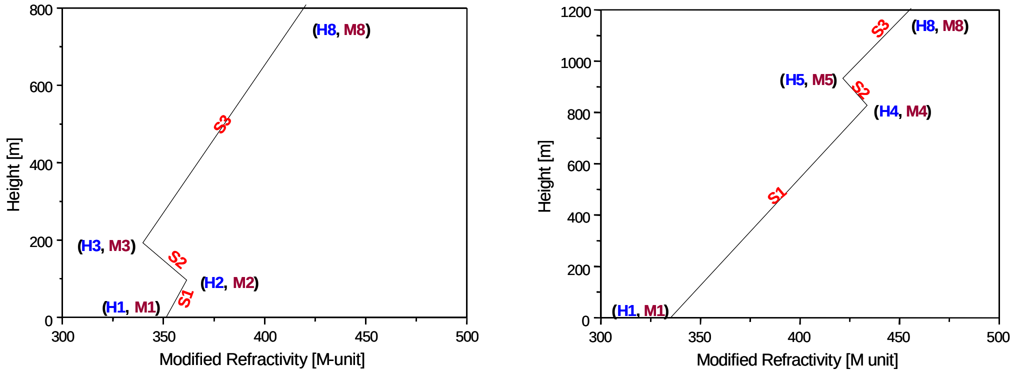
If the gradient of M with height is smaller than 0, trapping layer can be made.

In marine environment there are three distinct types of ducts, namely surface duct, elevated duct, and evaporation duct[2]. It is known that surface duct plays dominant roles in wave propagation along a long over-the-horizon path. The condition for a surface duct to exist is that the M value at the top of the trapping layer is less than the M value at the surface and it is able to support long over-the-horizon propagation ranges at frequencies above 100 MHz.

Parabolic equation derived from the full wave equation can be easily applied to complicated problems involving vertically and horizontally varying refractive index conditions[3]. The parabolic equation can be solved using split-step Fourier algorithm or finite difference method. Since the former has better calculation efficiency, it is used more generally.

STATISTICAL MODELING OF DUCTING CHANNEL

To obtain statistical channel model measured index profiles from the upper-air observation data of Korea Meteorological Administrations, are classified into three cases, namely surface duct, elevated duct and no duct. Surface duct and elevated duct are modeled statistically in three linear regions as shown in Fig. 1, and no duct channel(standard atmosphere) is modeled in only one linear region. Here, parameters H and M represent height and modified refractive index, respectively, and S is the slope parameter. It should be noticed that for surface ducts, for example, H3-H2 was modeled instead of H3 because H3 is always greater than H2. M3 for surface ducts, and (H5, M5) for elevated ducts were modeled similarly.



(a) Surface duct (b) Elevated duct

Fig. 1. Modeling parameters for each duct channel

The χ^2 - test method was used to determine the goodness-of-fit between the assumed probability distribution functions for parameters of ducts and those for the measurement data.

Duct parameters were modeled using normal, log-normal, exponential and gamma distributions, and the results showed a fairly good fit. The detailed results of statistical duct-channel modeling are omitted in this paper due to the limited space.

SPLIT-STEP DISCERTE MIXED FOURIER TRANSFORM ALGORITHM

Various operator approximations have been used to obtain parabolic equation from Maxwell's wave equation. In this paper the following wide-angle propagator is used.

$$\frac{\partial u}{\partial x} = i\sqrt{k^2 + \frac{\partial^2}{\partial z^2}}u + ik(n-2)u \tag{2}$$

Here x and z are the horizontal (range) and vertical (altitude) coordinates, and k is the free-space wave number.

When representing propagation over the boundary, not perfect conductor, following impedance boundary condition should be satisfied :

$$\frac{\partial u}{\partial z}(x,0) + \alpha u(x,0) = 0\,, \quad \alpha = ik\sin\theta\left[\frac{1-R}{1+R}\right], \tag{3}$$

where R is reflection coefficient and θ is the grazing angle measured from a local surface tangent. The following mixed Fourier transform pair allows the parabolic equation to incorporate a surface impedance into split-step solutions of the parabolic equation[4].

$$F(p) = \int_0^\infty f(z)\left[\alpha\sin(pz) - p\cos(pz)\right]dz$$

$$f(z) = Ke^{-\alpha z} + \frac{2}{\pi}\int_0^\infty F(p)\,\frac{\alpha\sin(pz) - p\cos(pz)}{\alpha^2 + p^2}\,dp$$

$$K = \begin{Bmatrix} 2\alpha\int_0^\infty f(z)e^{-\alpha z} & ;\mathrm{Re}(\alpha) > 0 \\ 0 & ;\ \mathrm{Re}(\alpha) \le 0 \end{Bmatrix} \tag{4}$$

Now, equation (2) can be implemented using the split-step algorithm :

$$u(x+\delta x, z) = e^{i(\frac{k}{2})(q-1)dx} \left\{ F_s^{-1}\left[\frac{\alpha}{\alpha^2 + p^2} e^{i\delta x\left(\sqrt{x-p^2}-k\right)} U(x,p) \right] \right.$$

$$\left. - F_c^{-1}\left[\frac{\alpha}{\alpha^2 + p^2} e^{i\delta x(\sqrt{x^2-p^2}-k)} U(x,p) \right] + e^{i\delta x(\sqrt{x^2-\alpha^2}-k)} e^{-\alpha z} K(x) \right\}, \qquad (5)$$

where

$$U(x,p) = \alpha F_s\left[e^{(ik/2)(q-1)\delta x} u(x,z)\right] - pF_c\left[e^{(ik/2)(q-1)\delta x} u(x,z)\right], \; q = \sqrt{n^2 + \frac{2z}{a_e}}. \qquad (6)$$

To take into account the effects of surface roughness, we applied the Miller-Brown model and Phillips spectrum model.

$$R_r = R_s e^{-\xi} J_0(i\xi), \; \xi = 8\left(\frac{\pi h}{\lambda}\sin\theta\right)^2 \qquad (7)$$

$$h = 0.0051 V_w \qquad (8)$$

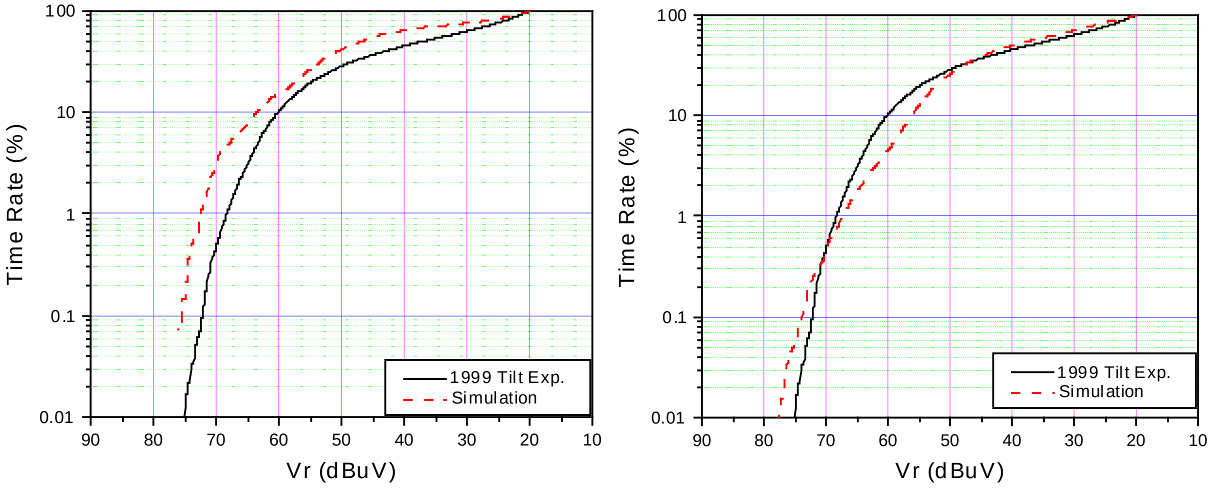
Here R_s is the reflection coefficient of a smooth surface and h and V_w represents the rms height of rough surface respectively and a wind speed respectively. The effects of terrain was also taken into account using the piece-wise linear terrain method[5]. In this method terrain is represented as a sequence of linear segments.

RESULTS OF THE SIMULATION

Refractive index profiles were randomly generated for Pohang and Baengnyeongdo using the previously mentioned statistical models and the occurrence rate given in Table 1 was used. As the noise level was 10 ~ 20 $dB\mu V$ in the experiment, only the signal over 20 $dB\mu V$ was considered. In our simulation, we assumed 818 MHz, vertical polarization, and 10 m/s of wind speed. Dielectric constant and conductivity of sea is ε_r = 80, σ = 4 S/m. Transmitter was assumed to have a gaussian beam pattern with the half power beam width of 4 degrees. The height of transmitter and receiver are 80 m and 298 m, respectively, and the distance between the transmitter(Kyusyu, Japan) and the receiver(Pusan, Korea) is 250 km.

Table 1. Occurrence rate of ducts in Pohang and Baengnyeongdo

	Surface duct	Elevated duct	No duct
Pohang	0.8 %	41.3 %	57.9 %
Baengnyeongdo	11.9 %	45.2 %	42.9 %



(a) Pohang (b) Baengnyeongdo

Fig. 2. Comparison of time rate characteristics between simulation result and Tilt Experiment

Fig. 2 shows time rate characteristics of the open-terminal voltage at receiving antenna from antenna-tilt experiment and simulation. Simulation results for Pohang at the time rate of 10 %, 1 %, and 0.1 % are 65.225, 72.675, and 76.123 $dB\mu V$ and the corresponding experiment data are 60.225, 68.475, and 72.375 $dB\mu V$, which shows that the differences are less than 5 $dB\mu V$. Fig. 2 (b) shows simulation results for Baengnyeongdo duct model, which shows better agreement than Pohang. It is because Baengnyeongdo is located in west sea of Korea and their refractive index profiles are closer to actual index profiles in marine environment than those of Pohang which is located in southeast costal area of Korea.

CONCLUSIONS

In this paper, refractive index profiles of the atmosphere are modeled on statistical basis using the upper-air observation data measured at Pohang and Baengnyeongdo Meteorological Observatory, and wave propagation through a ducting channel was modeled using Discrete Mixed Fourier Transform algorithm. Modeling results for interference were compared with experiment data between Korea and Japan.

Simulation results show a fairly good agreement, indicating that refractive index profiles on sea are closer to real situation than those of coastal area. Currently, we are thus trying to develop more accurate statistical duct-channel model, by collecting long-term meteorological data and taking into account the variation of refractive index profiles along the path.

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