Estimation of Secondary Radioclimatic Variables and Its Application to Terrestrial LOS Link Design in South Africa

Peter K. Odedina, Member IEEE and Thomas J. Afullo, Senior Member SAIEE

Abstract—In order to propose a reasonable prediction models for radioclimatic study, a reliable radio propagation data is required. This radio propagation data can be either primary or secondary radio propagation data. The secondary data can be estimated from a relevant primary data. Primary radioclimatic data include temperature, pressure and humidity or water vapour pressure, while secondary radioclimatic data includes, refractivity data such as refractivity gradients, ducting data, geoclimatic factor and also data that incorporate the effect of earth curvature on radiowave propagation such as effective earth radius factor (k-factor). The main concern of this paper is secondary data. We have used 10 years data (1985-1994) from three different regions of South Africa (Durban, Bloemfontein and Cape Town) for terrestrial LOS link design application.

Index Terms—Geoclimatic Factor, Radioclimatology, Refractivity, and k-factor.

I. INTRODUCTION

An appropriate procedure is required for proper planning of terrestrial and earth-space radio links, this is important for assessing the refractivity effects on signals [1]. The propagation of electromagnetic waves around the earth is influenced by the properties of the earth and the atmosphere [2-6]. The earth is an inhomogeneous body whose electromagnetic properties vary considerably as we go from one point to another. Sea water has high conductivity whereas desert sands are dielectric, having virtually zero conductivity but dissipating energy by virtue of polarization [7]. The atmosphere over the earth is a dynamic medium, its properties varying with temperature, pressure and humidity.

According to ITU-R Recommendation P.530 [3], the propagation loss on a terrestrial line-of-sight path relative to free space loss is the sum of different contributions, including the following: attenuation due to atmospheric gases; diffraction fading due to obstruction or partial obstruction of the path; fading due to multipath; and attenuation due to precipitation. Each of these contributions has its own characteristic as a function of frequency, path length and geographical location [7].

Most current predictions of tropospheric propagation effects are made either for the average worst month or the average year. However, the radio-climatological frameworks for such predictions are more than thirty years old for clear-air effects and more than twenty years old for precipitation effects. Moreover, radioclimatological data required to improve on the existing frameworks have been sparse for some regions of the world, including Africa. Radio propagation data for testing prediction techniques based on radioclimatological models have been even scantier. A recent effort by the international community to update the radioclimatological data base for tropospheric propagation predictions has led to an increase in the number of meteorological stations included in the analysis, the introduction of new potential prediction variables, and improved mapping and other presentation procedures (see, for example, Olsen [6]).

Modeling of the primary radioclimatic variable have been dealt with elsewhere [8], this paper therefore focuses on the estimation of the secondary variables in three different regions of South Africa. Also addressed in the paper is the application of these variables to the design of terrestrial line-of-sight links.

II. SECONDARY RADIOClimATIC VARIABLES

The changing nature of the atmosphere causes the refractive index of the troposphere to vary as the height increases from sea level [9] and this consequently has a significant effect on the radio signal. It is important to find the causative agent of these variations. The procedure recommended by the ITU-R for determining these variations are given in [2]. The atmospheric refractive index can be computed from the formula:

\[ n = \sqrt{E_r} = N + 1 \times 10^{-6} \] (1)

\( N \) is the radio refractivity expressed as...
The refractivity gradient is a measure of how the refractive index varies with increasing height. This is given as:

\[
\frac{dN}{dh} = \frac{77.6}{T} \left( P + 4810 \frac{e}{T} \right) - \frac{77.6 P}{T^2} - \frac{746512 e}{T^3} \frac{dT}{dh} + \frac{373256 d e}{T^2} \frac{dh}{dh}
\]

(3)

The effective earth radius factor (k-factor) can be determined as given in [7] by:

\[
k = \frac{1}{1 - \alpha |\rho|} = \frac{1}{1 + \alpha} \frac{d e_r}{dh} \frac{dh}{2}
\]

(4)

Where \( a = 6375 \text{ km} \) is the actual earth radius and \( \rho \) is the radius of curvature of the ray. The relative permittivity of troposphere at height \( h \) is defined by \( e_r \).

The geoclimatic factor which is a measure of the climatic and geographical condition of a terrain is calculated using the following relation [10].

\[ K = 10^{-4.2 - 0.00299 a d N_1} \]

(5)

Where \( K \) = The Geoclimatic Factor

\( d N_1 \) = Point refractivity Gradient in the lowest 65m of the atmosphere not exceeded for 1% of the average year.

The set of equations (1-5) together with the probability distribution plots of Figures (1-2) are used to calculate the secondary radioclimatic variables in three different stations in South Africa. These stations are Durban, Capetown, and Bloemfontein. The values of these variables are presented in Tables 1-3 above.

Although some of these parameters have been adequately studied individually in South Africa and the surrounding countries (for instance, parameters such as k-factor was studied in South Africa by Palmer and Baker[11,13], and in Botswana by Afullo et al [1, 9] while the geoclimatic factor was examined by Dabideen et al[14] and Odedina and Afullo in [10]). They were studied and modeled separately in all cited situations. However in this study, we intend to look at the combined effect of these secondary parameters on radio signal propagation.

### III. Diffraction Fading Application

The main application of the effective earth radius factor (k-factor) in radio link design is to calculate the antenna height requirement and diffraction fading estimate as explained in [15]. A value of \( k \) equals 4/3 for LOS link design calculation, where information about the actual value of \( k \) for that location is not available [3]. But from tables...
(1-3) given above, it is observed that using the k value will not give the required antenna height for LOS link set up in each of the above locations. This may lead to an inadequate link budget. As a result k-factor fading occurrence may be experienced in such design which may subsequently lead to wastage of resources.

The concept of diffraction loss as a function of path clearance around an obstacle is explained by Fresnel zones. The Fresnel zone radius is given as [15]:

\[
r_n = \sqrt{n A \left( \frac{d_1 d_2}{d_1 + d_2} \right)} = 17.3 \sqrt{n \frac{d_1 d_2}{F_{\text{diff}}}}
\]  

(6)

Where \( n \) is an integer, \( \lambda \) is the wavelength of the radio wave at any particular transmitting frequency, \( d_1 \) is the distance from transmitter to any obstruction point and \( d_2 \) is the distance from the obstruction point to the receiver.

If we adopt the knife-edge diffraction model described in [15], then the obstacle may be defined by a single non-dimensional parameter \( v \) given as [15]:

\[
v = \pm \frac{h}{\sqrt{d_1 d_2}} = \pm \frac{h}{r_{ne} \sqrt{2}}
\]  

(7)

Where \( h \) is the obstacle height above (plus sign) or below (minus sign) the direct ray between the transmitter and receiver antennas. \( r_{ne} \) is the first Fresnel radius as defined in equation (6) and \( d \) is the total distance between transmitter and receiver antennas. The following relations therefore hold:

\[
h = \frac{d_1 d_2}{12.75k}
\]  

(8)

And

\[
d = d_1 + d_2
\]  

(9)

Where \( k \) is the k-factor defined earlier in equation (4). The diffraction gain/loss (\( G_d \)) due to the knife-edge obstruction is therefore given as:

\[
G_d (dB) = \begin{cases} 
  0 & v \leq -1 \\
  20 \log(0.5 - 0.62v) & -1 < v < 0 \\
  20 \log(0.5 \exp(-0.95v)) & 0 \leq v < 1 \\
  20 \log \left(0.4 - \sqrt{0.118 - (0.38 - 0.1v)^2}\right) & 1 \leq v < 2.4 \\
  20 \log \left(0.225 \frac{1}{v}\right) & v > 2.4 
\end{cases}
\]  

(10)

A 6.7 km terrestrial LOS link is set up between Howard College campus (HWC) and Westville campus (WSV) of the University of KwaZulu-Natal. The link operating at 19.5GHz design for 60% clearance of the first Fresnel zone radius uses a design k value equals 1.333. If the path profile of the link shown in Fig. 3 is designed such that there is an obstacle on the link path at 4km point, then the diffraction loss on the path can be estimated for the design k value and the true k value for Durban using the procedure explained above. The result from such activity is shown in table 4 below.

<table>
<thead>
<tr>
<th>k values</th>
<th>Obstacle Point</th>
<th>G_d(dB)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.00</td>
<td>h</td>
<td>0.847059</td>
</tr>
<tr>
<td>1.20</td>
<td>0.705882</td>
<td>-30.5806</td>
</tr>
<tr>
<td>1.33</td>
<td>0.636886</td>
<td>-28.9969</td>
</tr>
<tr>
<td>1.40</td>
<td>0.605042</td>
<td>-28.1035</td>
</tr>
<tr>
<td>1.47</td>
<td>0.57623</td>
<td>-27.658</td>
</tr>
</tbody>
</table>

Similar approaches can be employed to estimate the diffraction loss for any link set up in the other stations.

IV. FADE DEPTH APPLICATION

The geoclimatic factor on the other hand finds useful application in fade depth calculation [10]. Unlike the k-factor that has a standard value for link design, the geoclimatic factor has no such value, but is determined by the climatic parameter of the location where link design is required. Hence, there is a great need to estimate the correct value of geoclimatic factor in order to cater for the adequate fade margin necessary for a reliable radio link performance.

Using the standard procedure as detailed in [3,10], the percentage of time that fade depth \( A \) (dB) is exceeded can be estimated. Similar links can be simulated for the three locations using different propagation parameters as follows:

- From the antenna heights, calculate the magnitude of the path inclination \( |\epsilon_p| \) (in milliradians) using:

\[
|\epsilon_p| = \frac{|h_r - h_c|}{d}
\]  

(11)

Where \( d \) is the path length (km), \( h_r \) is the altitude (m) of the received antenna, and \( h_c \) is the altitude of the transmit antenna.

- For an initial planning link design application, calculate the percentage of time \( p_w \) that fade depth \( A \) (dB) is exceeded in the average worst month from:

\[
p_w = K d^3 \left(1 + 1.03f \right)^{-1.2} \times 10^{0.033 f - 0.001 h_l - A / 10}
\]  

(12)

Here \( f \) is the frequency (GHz), \( h_l \) is the altitude of the lower antenna (i.e. the smaller of \( h_h \) and \( h_l \)), and \( K \) is the geoclimatic factor as obtained in the previous section.

Fade depth is defined as the ratio, usually expressed in decibels of a reference signal power to the signal power during a fade. In order to determine the quantities given in equations (11) and (12), a 6.7-km link is simulated for Durban, Capetown and Bloemfontein. The path parameters used for the Durban, Capetown and Bloemfontein links are as follows:
Durban:
\[ f = 19.5 \text{GHz}, h_e = 20 \text{m}, h_r = 24 \text{m}, d = 6.7 \text{km} \]

Capetown:
\[ f = 23 \text{GHz}, h_e = 60 \text{m}, h_r = 88 \text{m}, d = 6.7 \text{km} \]

Bloemfontein:
\[ f = 11 \text{GHz}, h_e = 25 \text{m}, h_r = 30 \text{m}, d = 6.7 \text{km} \]

Using the link parameters and the procedures explained above, the percentage of time that fade depth A was exceeded was calculated for Durban, Capetown and Bloemfontein. The result is shown in Table 5.

<table>
<thead>
<tr>
<th>Location</th>
<th>Geoclimatic Factor</th>
<th>% of time Fade Depth A is exceeded</th>
</tr>
</thead>
<tbody>
<tr>
<td>Durban</td>
<td>0.0000967</td>
<td>0.007</td>
</tr>
<tr>
<td>Capetown</td>
<td>0.00009515</td>
<td>0.002</td>
</tr>
<tr>
<td>Bloemf.</td>
<td>0.00011774</td>
<td>0.004</td>
</tr>
</tbody>
</table>

V. CONCLUSION

The secondary variables necessary for radioclimatological modeling was estimated for three different stations in South Africa. These stations were: Durban, Capetown and Bloemfontein. The two main secondary variables determined in the paper were; the effective earth radius factor (k-factor) and the geoclimatic factor.

Ten years radiosonde data between 1985-1994 was used for the calculation. The application of these two variables to line-of-sight link design was discussed in the paper. While a standard value of k equal 4/3 could be used for link design in regions where there was no measured data, geoclimatic factor variable, on the other hand, had no standard value, and therefore, had to be locally determined.

The application above has shown that using a true k value for Durban, would require the link designer to plan for a signal loss margin of as much as 27dB. Using a wrong k value for instance, would require signal loss planning as much as 30dB.

The effect of using the correct geoclimatic factor value was also examined, although the link parameters chosen in the above simulation showed that the percentage of time that fade depth A(10dB), A(25dB) and A(40dB) were exceeded in the average worst months for the locations were insignificantly small (See Table 5). This does not necessarily suggest that geoclimatic factor variable was not important to link design. Rather it suggests that the arbitrarily chosen link parameters were responsible for this insignificant percentage time exceedances for the tested fade depths.

Although there are other variables such as terrain variables, surface roughness variables, and duct occurrence probability, these variables were not the focus of this paper but the authors hope to discuss it in future presentations.

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REFERENCES


Peter K. Odedina holds a B.Sc. degree in Physics (Electronics Specialization) from the Federal University of Technology Akure (FUTA), Nigeria and an M.Sc. in Electrical Engineering from the University of KwaZulu-Natal Durban, South Africa. He is currently pursuing a PhD degree in Electronics Engineering at the same University. He has been an IEEE member for four years.

Thomas J. Afullo holds a B.Sc (Hons) in Electrical Engineering from University of Nairobi, Kenya, an MSEE from the West Virginia University, USA, a License in Technology and a PhD in Electrical Engineering from the Vrije Universiteit Brussel (VUB), Belgium. He has held various positions in the industry and the university for more than 25 years. He is currently an Associate Professor, Dept. of Electrical Engineering, University of KwaZulu-Natal, Durban, South Africa.

Fig. 1. Plot of Probability Distribution of k for Jan-Dec(1985-1994)
Fig. 2. Plot of Cumulative Distribution of $dN_1$ for Jan-Dec(1985-1994)

Fig. 3. Path Profile Diagram for HWC – WSV Terrestrial LOS Link [16]