ANOMALIES IN THE APPLICATION OF THE MULTIPLE KNIFE-EDGE DIFFRACTION MODEL

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ABSTRACT

Multiple knife-edge diffraction models are commonly used to predict radiowave propagation over irregular terrain. Software application of this method over a region in Western Australia has revealed anomalous behaviour where two nearly identical paths give quite different results, and where adjacent terrain points are selected as separate edges. The implications of these anomalies are discussed in this information paper, and possible solutions are proposed.

INTRODUCTION

Many radio applications require the prediction of propagation loss over long distances or over wide geographic areas. Examples include coverage prediction for broadcasting or cellular mobile systems, link prediction for microwave point-to-point systems, or interference analysis from scattered transmitters to a single receiver. The analysis in this paper arose from the evaluation of potential interference into the Murchison Radio-astronomy Observatory (MRO) site which has been proposed by Australia as the location for the Square Kilometre Array.

For paths at or beyond the radio horizon, diffraction over terrain is a major propagation mechanism. ITU-R Recommendation P.526 [1] provides several diffraction prediction methods, of which the most general is the cascaded knife-edge method. Recommendations ITU-R P.452 [2], for calculating interference between terrestrial systems, and P.1812 [3], for predicting coverage over an area, make use of this method. It is based on the work of Deygout in 1966 [4] as adjusted in 1991 [5], but includes different correction factors and uses at most three edges.

The availability of digital databases has made it possible to use the characteristics of a specific site in point-to-point and point-to-area calculations. The algorithm for selecting edges, calculating the loss at each edge, and combining the results can be implemented in software. However, in automating the process, there is scope for anomalies which would not arise if edges were selected manually by viewing the terrain profile. In his 1991 paper [5], Deygout noted that "As long as one deals with maps and obtains full control of the profile by a glance, … one selects only a few hills… It is a fact, however, that more extensive use of terrain databases can lead to unacceptable evaluation errors."

Recommendations P.526 notes that calculation with different atmospheric parameters can introduce discontinuities in diffraction loss when different terrain points are selected as the principal diffraction edge [1]. The analysis of this paper revealed similar discontinuities with a small change in the location of one end of the path. In the case of atmospheric variability, the median condition can be used as a reference, but for terrain variations there is no obvious reference.

The second effect is that the algorithm may select adjacent terrain points, which are actually part of the same obstruction, as separate edges. The adjacent point adds only a small additional loss, but the method may be ignoring other obstructions which might be more significant. This seems to occur particularly when the principal edge has been chosen "incorrectly" through the mechanism described in the previous paragraph.

MULTIPLE KNIFE-EDGE DIFFRACTION MODEL

The details of the multiple knife-edge diffraction method are given in [1]. A terrain profile is extracted from a digital database; point spacing of 250 metres is typical and is used in the analysis of this paper. The effective earth radius in the calculations is the physical radius (6370 km) multiplied by a *k*-factor which allows for refraction through layers in the atmosphere. The *k*-factor varies with time but a median value of 4/3 is appropriate for initial calculations. At each profile point, a height h is calculated, representing the height of the terrain above a line joining the first and last point of the profile and accounting for earth curvature. Using the same unit for all variables, where h_n is the n^{th} terrain point, d_{ab} is the distance from the first point of the profile to the last point, d_{an} and d_{nb} are the distances from the n^{th} point to the first and last point, respectively, and r_e is the effective earth radius, h is calculated as:

$$h = h_n + [d_{an}\, d_{nb}/2\, r_e] - [(h_a\, d_{nb} + h_b\, d_{an})/d_{ab}] \tag{1}$$

The dimensionless diffraction parameter ν is then calculated for wavelength λ (still in self-consistent units):

$$\nu_n = h\sqrt{2d_{ab}/\lambda d_{an} d_{nb}} \tag{2}$$

The point with the highest value of ν is termed the principal edge, *p*, and the ν value is labelled ν_p. If ν is greater than -0.78, the process is repeated twice, once between the beginning of the path and *p*, and then between *p* and the end of the path. (If ν_p is less than -0.78, diffraction loss is negligible and the calculation can be abandoned.) The points with the largest value of ν on either side of the principal edge are termed "auxiliary edges" with values ν_t and ν_r. (Again, ν values less than -0.78 indicate negligible loss and the point is ignored.) Diffraction is then calculated for the path of length *D* (km) by:

$$L = J(\nu_p) + \{1.0 - \exp(-J(\nu_p)/6)\}\,[\,J(\nu_t) + J(\nu_r) + 10.0 + 0.04D\,] \tag{3}$$

where $J(\nu)$ is approximated (for ν greater than -0.78) by:

$$J(\nu) = 6.9 + 20\log\left(\sqrt{(\nu - 0.1)^2 + 1} + \nu - 0.1\right) \quad \text{dB} \tag{4}$$

ANOMALOUS BEHAVIOUR ON NEARLY IDENTICAL PATHS

To evaluate interference into the MRO site, diffraction loss was calculated using Matlab from points 65 km away in all directions, at frequencies from 100 MHz to 25 GHz. The same effects were found at all frequencies, but the values at 2.3 GHz are used in the example below. Initial calculations took points 0.5 degrees apart, that is, paths with a common centre and endpoints separated by about 560 metres. Discontinuities where the loss changed by 10, 20 or (in one case) 28 dB between adjacent paths occurred in several directions.

Two paths, one at bearing 17.73° (clockwise from North) and one at 17.74°, were selected for closer analysis. The endpoints are about 11 metres apart, significantly less than the resolution of the underlying terrain database. The maximum difference between (interpolated) terrain heights is 186 mm; the average difference is 20 mm.

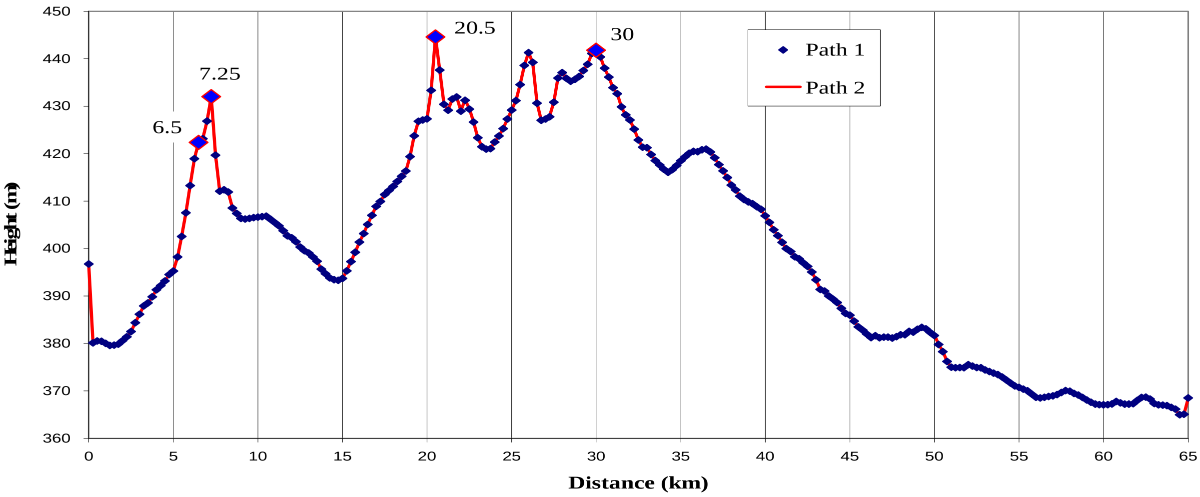

Figure 1: Adjacent path profiles (adjusted for median Earth radius)

A visual inspection of the profiles in Figure 1 would suggest that the three main obstacles are the peaks at 7.25 km, 20.5 km and 30 km. In Matlab, on path 2 those three edges are indeed selected. On path 1, however, the ν value at 7.25 km is very slightly more than that at 20.5 km , shifting the principal edge. The left-hand auxiliary edge is then found at 6.5 km but is too low (ν = -0.9) to contribute to the diffraction loss. The 30 km point is again chosen as the right-hand side auxiliary, and contributes nearly 4 dB more loss than it did on path 2, due to the distance dependence in (2). The diffraction calculations for the two paths are summarised in Table 1. In total, the tiny difference in ν at the two distances on the two paths leads to a difference of 10 dB in predicted loss. The same edge "jumping" occurs at all frequencies. At 100 MHz the discontinuity is 3 dB, while at 1 GHz the difference is 7 dB.

Table 1. Diffraction values for the two paths (calculated at 2.3 GHz)

	ν at 7.25	ν at 20.5	Principal edge	$J(\nu_p)$	Auxiliary edge *t*	$J(\nu_t)$	Auxiliary edge *r*	$J(\nu_r)$	total loss
Path 1	**1.8739**	1.8705	7.25 km	19 dB	6.5 km	0 dB	30 km	15 dB	45 dB
Path 2	1.8761	**1.8774**	20.5 km	19 dB	7.25 km	14 dB	30 km	11 dB	55 dB

ADJACENT TERRAIN POINTS AS SEPARATE EDGES

A second anomaly occurs when there are two distinct obstructions on one side of the principal edge but nothing of interest on the other side. One of the two obvious obstructions is selected as one auxiliary edge, and, typically, the point adjacent to the principal edge is selected as the other. As above, this often occurs when two points have close ν values. The adjacent point contributes much less to the overall loss than the second obstruction on the other side of the principal edge would – it may not contribute at all. The small additional loss is based on the higher loss from a rounded obstacle compared to a knife-edge, but the missed separate obstacle can lead to an underestimation of the total loss.

A visual profile inspection would select the principal edge and the other two obstructions. A slightly different terrain profile (as on an adjacent path) may find those three points. This also leads to discontinuity between similar paths.

POSSIBLE SOLUTIONS

In light of Jacques Deygout's comments in [5], it is tempting to suggest that path profiles be inspected visually to choose the principal and auxiliary edges! However, for wide-area calculations, this is clearly impractical.

One solution is to compare the maximum and second-largest value of ν when searching for the principal edge. If they are close, the calculation should be carried out twice with these two points as the principal edge. The contribution of the auxiliary edges found in the two cases should be compared. On path 1 in the example above, this would have found that using the point at 20.5 km as the principal edge gives two significant auxiliary edges rather than just one. In the case of adjacent points being chosen in preference to separate obstacles, this would also find a more realistic solution. In all cases, the middle of the three edges would be considered the principal edge for the purposes of calculating (3). It is not obvious, however, how close the two largest ν values should be to trigger this comparison.

A second solution is find further auxiliary edges by continuing to break the path into segments between the start, the edges and the end, looking for the maximum ν value on each segment until the maximum is less than -0.78. This would, in theory, find all significant edges; it would also be likely to choose more "adjacent points". In calculating the total loss, equation (3) would need to be modified to account for the additional edges and the empirical correction values of $10 + 0.04D$ in (3) may no longer be appropriate.

CONCLUSIONS

This paper represents a work in progress. Anomalous behaviour of a widely used prediction method has been identified which may lead to significant underprediction of loss in some situations. Two possible solutions have been suggested but need to be clarified and tested, preferably against measurement results. The authors welcome further discussion.

REFERENCES

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