New 2D Physical EM Propagation Model Selected

Harry R. Anderson, Ph.D., P.E.
EDX Engineering, Inc.
P.O. Box 1547
Eugene, Oregon 97440
Tel: (541) 345-0019 Fax: (541) 345-8145
e-mail: hra@edx.com

1. Introduction

The IEEE Vehicular Technology Society (VTS) Propagation Committee has been asked by TIA TR8 WG-8.8 Technology Compatibility Committee to contribute to the development and adoption of standard two dimensional (2D) and three dimensional (3D) propagation models for use in mobile wireless system design and frequency coordination. Toward this end, it was decided that comparison testing of different 2D propagation models would be carried out to determine which model offered the best match to existing measurement data contained in the ESSA reports referenced in [1] and [2].

EDX volunteered to conduct this testing and asked participants at the December VTS Propagation Committee meeting to submit alternate models to test. Six alternate models were submitted - two from Motorola and four from EDX. In all, nine different models were tested against the measurements.

This report sets forth the conditions of testing, the statistical results of the testing, and recommendations based on those results.

2. Testing Parameters

2.1 Propagation Models

The following nine propagation models were tested:

1. Free space + Epstein-Peterson diffraction (proposed by EDX)
2. Free space + Edwards-Durkins diffraction (proposed by EDX)
3. Free space + ITU-modified Deygout (proposed by EDX)
4. Hata/Davidson + Epstein-Peterson diffraction (the existing model in the WG8.8 report)
5. Hata/Davidson + Edwards-Durkins diffraction (proposed by Motorola)
6. Hata/Davidson + ITU-modified Deygout (proposed by Motorola)
7. TIREM-EDX (used here as a benchmark)
8. Longley-Rice v.1.2.2 (used here as a benchmark)
9. Anderson 2D v1.00 (proposed by EDX)

For models 1 through 3, the free space model is simply the free space path loss equation with up to 6 dB additional loss if the 0.6 first Fresnel zone is partially obstructed anywhere along the path. This path loss is added to obstruction loss as calculated by the Epstein-Peterson, Edwards-Durkins, or modified Deygout formula. The Epstein-Peterson and Edwards-Durkins algorithms for finding additional loss due to obstructions have previously been presented in documents to WG-8.8. The modified Deygout formulation is described in Document 3J/16-E dated November 1, 1996 submitted to the ITU-R in response to Question 202/3.

For models 4 through 6, a description of the operation of the Hata/Davidson portion of the model can be found in the current WG-8.8 Report. For obstructed paths, loss computed by this method is added to obstacle loss found using the Epstein-Peterson, Edwards-Durkins, or modified Deygout method.

The Longley-Rice model is described in reference [3]. The TIREM model is described in reference [4].

Finally, the Anderson 2D model is currently unpublished. An outline description is provided in Appendix A.

2.1.2 Propagation Model Implementation Issues

For two models - the Edwards-Durkins and the modified Deygout - some arbitrary implementation decisions were required. If was found that with the Edwards-Durkins model that the intersection of the slope lines could sometimes occur at a point before the first obstacle distance or after the last obstacle distance. This particularly occurred if the slope line was flat due to two successive obstacles being the same elevation. For such cases, an arbitrary decision was made to place the "virtual" third obstacle at a location midway between the two end point obstacles with a height equal to the height of the slope line intersection.

For the modified Deygout method, if the parameter v is greater than -0.78 for the principle obstacle, then two secondary profile segments are identified and v values computed for these secondary segments. However, for values of v less than zero, the path still clears the principle obstacle so the dilemma is what obstacle height to use to find v for the secondary paths - the actually height of the principle obstacle or the height of the path as it crosses above the principle obstacle. For the studies done here the former assumption was made.

No implementation ambiguities were found with the other models.

2.2 Terrain Data

As mentioned in the introduction, the models were tested against measurement data for all the paths listed as not "concealed" in the McQuate et. al. Reports Part I, II, and III, and in Part V of the Report authored by Hufford. Both the 30 meter and 3 second terrain elevation databases where used for the testing. Even though the 30 meter data is not available for the entire U.S., for the particular areas where these paths lie, 30 meter data is available for essentially all of it. The only paths that required a mixture of 30 meter and 3 second terrain data are:

R1-50-T4 R1-80-T3
R2-120-T3 R2-50-T5o R2-120-T2 R2-80-T1 R2-80-T4
T4-080-R5 T4-080-R6

However, for comparison purposes, the tests were also done using 3 second data only since this data is complete for the entire U.S. and more accessible to frequency coordination organizations.

Terrain elevation values were found along each test path along the great circle route between the transmitter and receiver. The spacing of the points was set to comply with the current WG-8.0 point spacing criteria of 0.5% of the path length or 0.2 km, whichever is smaller. Within the terrain elevation data grid, linear interpolation among the four surrounding corner points was used to establish the elevation at a given terrain profile point.

2.3 Groundcover Data

Using the location of the transmit and receive point, the groundcover code for each was determined from the LULC database using the categories in Table 12 of the current WG-8.8 Report. Most locations had groundcover codes for agriculture or open land resulting in no local clutter correction to the calculated path loss. Some locations were determined to be forest or residential based on the LULC database. However, in the NBS Report a distinction was made between antennas which were "in the open" or "concealed"; i.e. immersed in the local clutter. Only "in the open" paths and measurement results were used here. This would imply that no local clutter loss correction should be used. To be complete, therefore, results for path loss predictions are presented both with and without corrections for local clutter loss based on the groundcover code in the LULC database.

2.4 Antenna Heights

For measurement data from Parts I, II, and III, to match the usual measurement conditions, the transmit antenna height was set at 6.6 meters above the ground elevation as determined from the terrain database. The receive antenna height was set at 2 meters above the ground elevation as determined from the terrain database the corresponding 2 meter receive height measurement data was used where available.

For Part V measurement data, the transmit and receive antenna heights are explicit given for each measurement path. In general, the height of both the transmit and receive antennas was greater than 10 meters above ground, making the results less indicative of mobile operations as compared to Part I, II, and III data. To isolate results for the usual mobile conditions, comparison results for only those paths with 2 meter receive antenna heights were separately calculated.

2.5 Polarizations

The measurement data used here was taken using horizontal polarization. For mobile radio operations, vertical polarization is almost exclusively employed. For free space conditions, of course, there is no difference in propagation between the two polarizations.

For line-of-sight paths with ground reflections, the magnitude and phase of the reflection is affected by conductivity and premittivity of the ground, the angle of incidence and the polarization. For low angles of incidence for ground reflections on most paths, the magnitude and phase of the reflection is comparable for horizontal and vertical polarizations.

For obstructed paths, theoretical knife-edge diffraction is the same for both polarizations. Field results also have generally shown that no significant difference is observed in path loss when comparing horizontal and vertical polarized waves.

Based on this reasoning, it is assumed that the horizontal polarization comparison results presented here as indicative of the model success which will be realized using either vertical or horizontal polarization.

3. Study Results

A statistical summary of the path loss prediction results versus measurements is shown in Tables 1 through 9 on the following pages. Each of the Tables 1 through 9 corresponding to different terrain and ground cover database usage, and different antenna heights, as listed at the top of the each page. Each numbered table is divided into 3 parts - A, B and C corresponding to the overall results, the results for line-of-sight (LOS) paths and the results for non-line-of-sight (NLOS) paths.

The tests were done for all 7 frequencies used in the ESSA measurements ranging from 230 MHz to 9190 MHz of Parts I, II, and III, and from 76 and 8395 MHz for Part V data. If no measurement value was available for a given path, frequency, and antenna height, no model calculations were performed. All the models in the test were capable of predictions over this frequency range except those using Hata/Davidson. The Hata/Davidson formula has an upper frequency limit of 1500 MHz, so it was originally intended that the statistical results only be compiled for the frequencies less than 1500 MHz. However, given the possible application of the methods in the WG8.8 Report to PCS frequencies, it was decided to include 1846 MHz in the statistical comparisons. Frequencies above 2000 MHz were not included in the statistical analysis even though the model calculations were done for these frequencies.

While attempting to use the Part III McQuate data, a difficulty was encountered due to the fact that the coordinates for the common receive site on Table Mountain are not listed anywhere in the McQuate document. Having these exact coordinates are critical to the using Part III data. A call to ITS produced a coordinate pair but upon run the evaluating the Part III paths, several paths where found to be obstructed which is not consistent with the intent of the measurement set. This called into question the accuracy of the coordinates or some other element of the study which could not be resolve before this report was due. As a result, the study result values in Tables 1 through 8 are for all the data except the Part III data. Table 9 is for all Part III data only.

4. Discussion

The models evaluated here fall into two basic categories - physical models such as those with the free space component and the Anderson 2D model, and the hybrid models which combine the Hata/Davidson empirical path loss calculation with an additional algorithm for predicting shadow loss for obstructed paths.

In general, the Hata/Davidson models perform very well for LOS situations which is consistent with the anecdotal evidence from engineers who have successfully used this model for system design. For NLOS cases, these models consistently over-predict path loss with an associated increase in standard deviation. Hybrid models which combine an empirical path loss equation with obstacle-specific losses and local clutter losses are to some extent "double counting" losses due to terrain and clutter. The over-prediction of path loss and the higher standard deviations when compared to the physical models are a manifestation of this double counting.

Conversely, the physical models tend to consistently under-predict path loss, especially in the case of the free space models, even though very good standard deviation figures are often achieved. Physical models also improve with improved descriptions of the propagation environment. The Anderson 2D model is the best overall when standard deviation and mean error are considered.

The models involving the modified Deygout formulation were the worst performers. Careful attention was paid to the implementation of this model to insure that it was constructed as described in the reference. That fact that it over-predicts path loss can to some extent be attributed to the low rolling terrain for most of the study paths. The Deygout model apparently is more successful on paths with distinct, isolated obstacles where the notion of "principle" and "secondary" obstacles may have some meaning. Also, the modified Deygout model has a built attenuation of approximately 7.3 dB to adjust the mean loss to best match a measurement set developed in Great Britain. In general, adding fixed path loss factors of this type is a very poor modeling strategy. Consider, for example, two paths. One has a v value of just greater than -0.78, and the other has a v value of just less than -0.78. The paths are essentially identical and should therefore have nearly identical path losses, yet the one with v just greater than -0.78 will invoke the modified Deygout algorithm with its 7.3 dB loss irrespective of any other path characteristics. Having this artificial discontinuity in path loss is physically implausible. Because of its demonstrated poor performance with the test data, and the fundamentally unsound construction of the algorithm, the models using the modified Deygout algorithm for shadow loss are regarded here as not acceptable.

Frequency range: 30.0 MHz to 2000.0 MHz
Terrain: 30 meter + 3 sec data
Groundcover: no groundcover data

TABLE 1A
Total number of points: 1392

MODELS TESTED	Errors: Ave:	S.D.:	Worst:
Free space/E-P	-8.9 dB	12.1 dB	-66.1 dB
Free space/E-D	-10.6 dB	12.0 dB	-66.1 dB
Free space/Deygout	8.7 dB	17.1 dB	71.3 dB
Hata-Dav./E-P	3.9 dB	15.1 dB	88.6 dB
Hata-Dav./E-D	2.2 dB	13.6 dB	87.9 dB
Hata-Dav./Deygout	23.9 dB	21.8 dB	108.9 dB
TIREM-EDX	-9.4 dB	15.0 dB	-63.6 dB
Longley-Rice v.1.2.2	-3.1 dB	11.4 dB	72.9 dB
Anderson 2D	-5.7 dB	10.8 dB	-63.2 dB

TABLE 1B
Total number of points: 567

MODELS TESTED	Errors: Ave:	S.D.:	Worst:
Free space/E-P	-4.8 dB	12.1 dB	-66.1 dB
Free space/E-D	-4.8 dB	12.1 dB	-66.1 dB
Free space/Deygout	2.2 dB	13.1 dB	-55.8 dB
Hata-Dav./E-P	-4.6 dB	10.6 dB	-63.2 dB
Hata-Dav./E-D	-4.6 dB	10.6 dB	-63.2 dB
Hata-Dav./Deygout	8.1 dB	14.5 dB	-53.5 dB
TIREM-EDX	.7 dB	13.0 dB	-63.6 dB
Longley-Rice v.1.2.2	-6.3 dB	10.5 dB	-68.1 dB
Anderson 2D	-7.3 dB	10.7 dB	-63.2 dB

TABLE 1C
Total number of NLOS points: 825

MODELS TESTED	Errors: Ave:	S.D.:	Worst:
Free space/E-P	-11.8 dB	11.2 dB	-49.7 dB
Free space/E-D	-14.6 dB	10.3 dB	-49.7 dB
Free space/Deygout	13.2 dB	18.0 dB	71.3 dB
Hata-Dav./E-P	9.8 dB	14.9 dB	88.6 dB
Hata-Dav./E-D	7.0 dB	13.4 dB	87.9 dB
Hata-Dav./Deygout	34.8 dB	19.1 dB	108.9 dB
TIREM-EDX	-16.3 dB	12.0 dB	-49.7 dB
Longley-Rice v.1.2.2	-.8 dB	11.4 dB	72.9 dB
Anderson 2D	-4.6 dB	10.8 dB	51.7 dB

Frequency range: 30.0 MHz to 2000.0 MHz
Terrain: 3 sec data only
Groundcover: no groundcover data

TABLE 2A
Total number of points: 1392

MODELS TESTED	Errors: Ave:	S.D.:	Worst:
Free space/E-P	-5.2 dB	16.5 dB	-61.6 dB
Free space/E-D	-9.8 dB	13.5 dB	-61.6 dB
Free space/Deygout	10.9 dB	18.3 dB	70.1 dB
Hata-Dav./E-P	9.3 dB	19.3 dB	77.2 dB
Hata-Dav./E-D	4.8 dB	14.4 dB	85.2 dB
Hata-Dav./Deygout	27.3 dB	21.9 dB	114.2 dB
TIREM-EDX	-10.2 dB	15.3 dB	-61.6 dB
Longley-Rice v.1.2.2	-1.0 dB	12.0 dB	62.2 dB
Anderson 2D	-2.6 dB	13.7 dB	-58.5 dB

TABLE 2B
Total number of LOS points: 432

MODELS TESTED	Errors: Ave:	S.D.:	Worst:
Free space/E-P	-3.8 dB	12.2 dB	-59.7 dB
Free space/E-D	-3.8 dB	12.2 dB	-59.7 dB
Free space/Deygout	2.7 dB	12.4 dB	-49.8 dB
Hata-Dav./E-P	-3.3 dB	10.0 dB	-46.5 dB
Hata-Dav./E-D	-3.3 dB	10.0 dB	-46.5 dB
Hata-Dav./Deygout	9.0 dB	13.9 dB	48.8 dB
TIREM-EDX	.4 dB	12.1 dB	-55.2 dB
Longley-Rice v.1.2.2	-4.3 dB	10.6 dB	-49.8 dB
Anderson 2D	-6.2 dB	10.5 dB	-58.5 dB

TABLE 2C
Total number of NLOS points: 960

MODELS TESTED	Errors: Ave:	S.D.:	Worst:
Free space/E-P	-5.9 dB	18.1 dB	-61.6 dB
Free space/E-D	-12.5 dB	13.1 dB	-61.6 dB
Free space/Deygout	14.6 dB	19.4 dB	70.1 dB
Hata-Dav./E-P	15.0 dB	19.8 dB	77.2 dB
Hata-Dav./E-D	8.4 dB	14.6 dB	85.2 dB
Hata-Dav./Deygout	35.5 dB	19.7 dB	114.2 dB
TIREM-EDX	-15.0 dB	14.2 dB	-61.6 dB
Longley-Rice v.1.2.2	.5 dB	12.2 dB	62.2 dB
Anderson 2D	-1.0 dB	14.6 dB	-55.7 dB

Frequency range: 30.0 MHz to 2000.0 MHz
Terrain: 30 meter + 3 sec data
Groundcover: no groundcover data
RX height: 2 meter RX height data only

TABLE 3A
Total number of points: 361

MODELS TESTED	Errors: Ave:	S.D.:	Worst:
Free space/E-P	-10.2 dB	14.7 dB	-66.1 dB
Free space/E-D	-12.3 dB	13.4 dB	-66.1 dB
Free space/Deygout	15.6 dB	23.5 dB	71.3 dB
Hata-Dav./E-P	8.2 dB	21.7 dB	88.6 dB
Hata-Dav./E-D	6.1 dB	20.8 dB	87.9 dB
Hata-Dav./Deygout	35.3 dB	29.2 dB	108.9 dB
TIREM-EDX	-11.0 dB	14.6 dB	-63.6 dB
Longley-Rice v.1.2.2	-1.5 dB	16.8 dB	72.9 dB
Anderson 2D	-6.8 dB	14.1 dB	-63.2 dB

TABLE 3B
Total number of LOS points: 110

MODELS TESTED	Errors: Ave:	S.D.:	Worst:
Free space/E-P	-10.9 dB	14.1 dB	-66.1 dB
Free space/E-D	-10.9 dB	14.1 dB	-66.1 dB
Free space/Deygout	-.7 dB	16.8 dB	-55.8 dB
Hata-Dav./E-P	-3.8 dB	17.9 dB	-63.2 dB
Hata-Dav./E-D	-3.8 dB	17.9 dB	-63.2 dB
Hata-Dav./Deygout	10.6 dB	21.1 dB	-53.5 dB
TIREM-EDX	-6.5 dB	15.1 dB	-63.6 dB
Longley-Rice v.1.2.2	-10.1 dB	13.9 dB	-68.1 dB
Anderson 2D	-10.6 dB	14.3 dB	-63.2 dB

TABLE 3C
Total number of NLOS points: 251

MODELS TESTED	Errors: Ave:	S.D.:	Worst:
Free space/E-P	-9.9 dB	14.9 dB	-49.7 dB
Free space/E-D	-12.9 dB	13.0 dB	-49.7 dB
Free space/Deygout	22.8 dB	22.5 dB	71.3 dB
Hata-Dav./E-P	13.4 dB	21.1 dB	88.6 dB
Hata-Dav./E-D	10.4 dB	20.5 dB	87.9 dB
Hata-Dav./Deygout	46.1 dB	25.5 dB	108.9 dB
TIREM-EDX	-13.1 dB	14.0 dB	-49.7 dB
Longley-Rice v.1.2.2	2.2 dB	16.6 dB	72.9 dB
Anderson 2D	-5.0 dB	13.7 dB	51.7 dB

Frequency range: 30.0 MHz to 2000.0 MHz
Terrain: 3 sec data only
Groundcover: no groundcover data
RX height: 2 meter RX height data only

TABLE 4A
Total number of points: 361

MODELS TESTED	Errors: Ave:	S.D.:	Worst:
Free space/E-P	-13.6 dB	15.5 dB	-61.6 dB
Free space/E-D	-15.0 dB	15.2 dB	-61.6 dB
Free space/Deygout	10.9 dB	25.4 dB	70.1 dB
Hata-Dav./E-P	5.4 dB	22.9 dB	77.2 dB
Hata-Dav./E-D	4.0 dB	22.1 dB	85.2 dB
Hata-Dav./Deygout	30.6 dB	31.7 dB	114.2 dB
TIREM-EDX	-14.4 dB	16.1 dB	-61.6 dB
Longley-Rice v.1.2.2	-4.4 dB	16.7 dB	62.2 dB
Anderson 2D	-8.6 dB	15.3 dB	-58.5 dB

TABLE 4B
Total number of LOS points: 84

MODELS TESTED	Errors: Ave:	S.D.:	Worst:
Free space/E-P	-9.5 dB	13.7 dB	-59.7 dB
Free space/E-D	-9.5 dB	13.7 dB	-59.7 dB
Free space/Deygout	-2.1 dB	15.9 dB	-49.8 dB
Hata-Dav./E-P	-1.8 dB	16.6 dB	-46.5 dB
Hata-Dav./E-D	-1.8 dB	16.6 dB	-46.5 dB
Hata-Dav./Deygout	8.8 dB	20.7 dB	48.8 dB
TIREM-EDX	-4.6 dB	14.4 dB	-55.2 dB
Longley-Rice v.1.2.2	-8.8 dB	12.9 dB	-49.8 dB
Anderson 2D	-8.8 dB	13.7 dB	-58.5 dB

TABLE 4C
Total number of NLOS points: 277

MODELS TESTED	Errors: Ave:	S.D.:	Worst:
Free space/E-P	-14.8 dB	15.8 dB	-61.6 dB
Free space/E-D	-16.7 dB	15.3 dB	-61.6 dB
Free space/Deygout	14.8 dB	26.5 dB	70.1 dB
Hata-Dav./E-P	7.6 dB	24.1 dB	77.2 dB
Hata-Dav./E-D	5.8 dB	23.2 dB	85.2 dB
Hata-Dav./Deygout	37.3 dB	31.5 dB	114.2 dB
TIREM-EDX	-17.4 dB	15.4 dB	-61.6 dB
Longley-Rice v.1.2.2	-3.1 dB	17.5 dB	62.2 dB
Anderson 2D	-8.6 dB	15.8 dB	-55.7 dB

Frequency range: 30.0 MHz to 2000.0 MHz
Terrain: 30 meter + 3 sec data
Groundcover: groundcover data used

TABLE 5A
Total number of points: 1392

MODELS TESTED	Errors: Ave:	S.D.:	Worst:
Free space/E-P	-6.1 dB	12.4 dB	-54.4 dB
Free space/E-D	-7.8 dB	12.4 dB	-54.4 dB
Free space/Deygout	11.6 dB	17.6 dB	79.8 dB
Hata-Dav./E-P	6.7 dB	14.9 dB	88.6 dB
Hata-Dav./E-D	5.1 dB	13.4 dB	87.9 dB
Hata-Dav./Deygout	26.7 dB	21.9 dB	108.9 dB
TIREM-EDX	-6.6 dB	15.3 dB	-51.9 dB
Longley-Rice v.1.2.2	-.2 dB	11.7 dB	72.9 dB
Anderson 2D	-2.9 dB	11.2 dB	51.7 dB

TABLE 5B
Total number of LOS points: 567

MODELS TESTED	Errors: Ave:	S.D.:	Worst:
Free space/E-P	-1.6 dB	11.8 dB	-54.4 dB
Free space/E-D	-1.6 dB	11.8 dB	-54.4 dB
Free space/Deygout	5.4 dB	12.8 dB	47.1 dB
Hata-Dav./E-P	-1.5 dB	10.5 dB	-51.5 dB
Hata-Dav./E-D	-1.5 dB	10.5 dB	-51.5 dB
Hata-Dav./Deygout	11.3 dB	14.1 dB	48.2 dB
TIREM-EDX	3.8 dB	12.5 dB	-51.9 dB
Longley-Rice v.1.2.2	-3.2 dB	10.3 dB	-56.4 dB
Anderson 2D	-4.1 dB	10.9 dB	-51.5 dB

TABLE 5C
Total number of NLOS points: 825

MODELS TESTED	Errors: Ave:	S.D.:	Worst:
Free space/E-P	-9.2 dB	11.8 dB	-49.7 dB
Free space/E-D	-12.0 dB	10.9 dB	-49.7 dB
Free space/Deygout	15.8 dB	19.2 dB	79.8 dB
Hata-Dav./E-P	12.4 dB	14.8 dB	88.6 dB
Hata-Dav./E-D	9.5 dB	13.3 dB	87.9 dB
Hata-Dav./Deygout	37.4 dB	19.9 dB	108.9 dB
TIREM-EDX	-13.7 dB	12.7 dB	-49.7 dB
Longley-Rice v.1.2.2	1.8 dB	12.2 dB	72.9 dB
Anderson 2D	-2.0 dB	11.2 dB	51.7 dB

Frequency range: 30.0 MHz to 2000.0 MHz
Terrain: 3 sec data only
Groundcover: groundcover data used

TABLE 6A
Total number of points: 1392

MODELS TESTED	Errors: Ave:	S.D.:	Worst:
Free space/E-P	-2.4 dB	16.7 dB	64.0 dB
Free space/E-D	-7.0 dB	13.8 dB	-59.7 dB
Free space/Deygout	13.8 dB	18.7 dB	77.6 dB
Hata-Dav./E-P	12.1 dB	19.0 dB	77.2 dB
Hata-Dav./E-D	7.6 dB	14.1 dB	85.2 dB
Hata-Dav./Deygout	30.1 dB	21.7 dB	114.2 dB
TIREM-EDX	-7.4 dB	15.6 dB	-56.5 dB
Longley-Rice v.1.2.2	1.8 dB	12.1 dB	62.2 dB
Anderson 2D	.2 dB	13.9 dB	-58.5 dB

TABLE 6B
Total number of LOS points: 432

MODELS TESTED	Errors: Ave:	S.D.:	Worst:
Free space/E-P	-.6 dB	12.2 dB	-59.7 dB
Free space/E-D	-.6 dB	12.2 dB	-59.7 dB
Free space/Deygout	5.9 dB	12.0 dB	-49.4 dB
Hata-Dav./E-P	-.1 dB	9.9 dB	-42.1 dB
Hata-Dav./E-D	-.1 dB	9.9 dB	-42.1 dB
Hata-Dav./Deygout	12.2 dB	13.2 dB	48.8 dB
TIREM-EDX	3.6 dB	11.9 dB	-55.2 dB
Longley-Rice v.1.2.2	-1.1 dB	10.5 dB	-45.9 dB
Anderson 2D	-3.0 dB	10.9 dB	-58.5 dB

TABLE 6C
Total number of NLOS points: 960

MODELS TESTED	Errors: Ave:	S.D.:	Worst:
Free space/E-P	-3.2 dB	18.3 dB	64.0 dB
Free space/E-D	-9.9 dB	13.5 dB	-56.5 dB
Free space/Deygout	17.3 dB	20.0 dB	77.6 dB
Hata-Dav./E-P	17.6 dB	19.6 dB	77.2 dB
Hata-Dav./E-D	11.0 dB	14.4 dB	85.2 dB
Hata-Dav./Deygout	38.2 dB	19.9 dB	114.2 dB
TIREM-EDX	-12.4 dB	14.5 dB	-56.5 dB
Longley-Rice v.1.2.2	3.1 dB	12.6 dB	62.2 dB
Anderson 2D	1.7 dB	14.8 dB	-49.9 dB

Frequency range: 30.0 MHz to 2000.0 MHz
Terrain: 30 meter + 3 sec data
Groundcover: groundcover data used
RX height: 2 meter RX height data only

TABLE 7A
Total number of points: 361

MODELS TESTED	Errors: Ave:	S.D.:	Worst:
Free space/E-P	-7.0 dB	14.6 dB	-54.4 dB
Free space/E-D	-9.1 dB	13.4 dB	-54.4 dB
Free space/Deygout	18.8 dB	24.5 dB	79.8 dB
Hata-Dav./E-P	11.3 dB	20.6 dB	88.6 dB
Hata-Dav./E-D	9.2 dB	19.7 dB	87.9 dB
Hata-Dav./Deygout	38.4 dB	29.2 dB	108.9 dB
TIREM-EDX	-7.9 dB	14.7 dB	-51.9 dB
Longley-Rice v.1.2.2	1.7 dB	17.0 dB	72.9 dB
Anderson 2D	-3.6 dB	14.1 dB	51.7 dB

TABLE 7B
Total number of LOS points: 110

MODELS TESTED	Errors: Ave:	S.D.:	Worst:
Free space/E-P	-7.4 dB	13.4 dB	-54.4 dB
Free space/E-D	-7.4 dB	13.4 dB	-54.4 dB
Free space/Deygout	2.8 dB	15.7 dB	-44.1 dB
Hata-Dav./E-P	-.2 dB	17.1 dB	-51.5 dB
Hata-Dav./E-D	-.2 dB	17.1 dB	-51.5 dB
Hata-Dav./Deygout	14.1 dB	19.9 dB	48.2 dB
TIREM-EDX	-2.9 dB	14.2 dB	-51.9 dB
Longley-Rice v.1.2.2	-6.6 dB	13.2 dB	-56.4 dB
Anderson 2D	-7.1 dB	13.9 dB	-51.5 dB

TABLE 7C
Total number of NLOS points: 251

MODELS TESTED	Errors: Ave:	S.D.:	Worst:
Free space/E-P	-6.9 dB	15.1 dB	-49.7 dB
Free space/E-D	-9.9 dB	13.4 dB	-49.7 dB
Free space/Deygout	25.8 dB	24.4 dB	79.8 dB
Hata-Dav./E-P	16.4 dB	19.9 dB	88.6 dB
Hata-Dav./E-D	13.4 dB	19.4 dB	87.9 dB
Hata-Dav./Deygout	49.1 dB	26.1 dB	108.9 dB
TIREM-EDX	-10.0 dB	14.4 dB	-49.7 dB
Longley-Rice v.1.2.2	5.3 dB	17.3 dB	72.9 dB
Anderson 2D	-2.0 dB	14.0 dB	51.7 dB

Frequency range: 30.0 MHz to 2000.0 MHz
Terrain: 3 sec data only
Groundcover: groundcover data used
RX height: 2 meter RX height data only

TABLE 8A
Total number of points: 361

MODELS TESTED	Errors: Ave:	S.D.:	Worst:
Free space/E-P	-10.4 dB	15.6 dB	-59.7 dB
Free space/E-D	-11.8 dB	15.3 dB	-59.7 dB
Free space/Deygout	14.1 dB	26.0 dB	77.6 dB
Hata-Dav./E-P	8.6 dB	22.1 dB	77.2 dB
Hata-Dav./E-D	7.2 dB	21.2 dB	85.2 dB
Hata-Dav./Deygout	33.8 dB	31.4 dB	114.2 dB
TIREM-EDX	-11.3 dB	16.1 dB	-56.5 dB
Longley-Rice v.1.2.2	-1.2 dB	16.8 dB	62.2 dB
Anderson 2D	-5.4 dB	15.5 dB	-58.5 dB

TABLE 8B
Total number of LOS points: 84

MODELS TESTED	Errors: Ave:	S.D.:	Worst:
Free space/E-P	-7.4 dB	13.6 dB	-59.7 dB
Free space/E-D	-7.4 dB	13.6 dB	-59.7 dB
Free space/Deygout	.0 dB	15.2 dB	-49.4 dB
Hata-Dav./E-P	.3 dB	15.5 dB	-42.1 dB
Hata-Dav./E-D	.3 dB	15.5 dB	-42.1 dB
Hata-Dav./Deygout	10.9 dB	19.0 dB	48.8 dB
TIREM-EDX	-2.5 dB	14.0 dB	-55.2 dB
Longley-Rice v.1.2.2	-6.7 dB	12.6 dB	-45.9 dB
Anderson 2D	-6.7 dB	13.8 dB	-58.5 dB

TABLE 8C
Total number of NLOS points: 277

MODELS TESTED	Errors: Ave:	S.D.:	Worst:
Free space/E-P	-11.3 dB	16.1 dB	-56.5 dB
Free space/E-D	-13.1 dB	15.6 dB	-56.5 dB
Free space/Deygout	18.4 dB	27.1 dB	77.6 dB
Hata-Dav./E-P	11.1 dB	23.1 dB	77.2 dB
Hata-Dav./E-D	9.3 dB	22.2 dB	85.2 dB
Hata-Dav./Deygout	40.8 dB	31.2 dB	114.2 dB
TIREM-EDX	-13.9 dB	15.8 dB	-56.5 dB
Longley-Rice v.1.2.2	.4 dB	17.6 dB	62.2 dB
Anderson 2D	-5.1 dB	16.0 dB	-49.9 dB

Frequency range: 30.0 MHz to 2000.0 MHz
Terrain: 30 meter + 3 sec data
Groundcover: no groundcover data

TABLE 9A
Total number of points: 242

MODELS TESTED	Errors: Ave:	S.D.:	Worst:
Free space/E-P	-2.7 dB	10.2 dB	47.2 dB
Free space/E-D	-2.8 dB	10.2 dB	47.2 dB
Free space/Deygout	2.5 dB	15.2 dB	88.7 dB
Hata-Dav./E-P	21.1 dB	18.3 dB	85.3 dB
Hata-Dav./E-D	21.1 dB	18.2 dB	85.3 dB
Hata-Dav./Deygout	27.4 dB	23.7 dB	126.7 dB
TIREM-EDX	-.5 dB	10.6 dB	47.2 dB
Longley-Rice v.1.2.2	-.7 dB	13.5 dB	79.3 dB
Anderson 2D	.8 dB	10.9 dB	50.8 dB

TABLE 9B
Total number of LOS points: 182

MODELS TESTED	Errors: Ave:	S.D.:	Worst:
Free space/E-P	-3.6 dB	8.8 dB	-33.2 dB
Free space/E-D	-3.6 dB	8.8 dB	-33.2 dB
Free space/Deygout	-1.3 dB	9.9 dB	-34.2 dB
Hata-Dav./E-P	17.4 dB	16.9 dB	58.8 dB
Hata-Dav./E-D	17.4 dB	16.9 dB	58.8 dB
Hata-Dav./Deygout	21.1 dB	19.5 dB	61.9 dB
TIREM-EDX	-.6 dB	9.4 dB	-32.2 dB
Longley-Rice v.1.2.2	-3.9 dB	9.0 dB	-34.2 dB
Anderson 2D	-1.1 dB	9.1 dB	-34.2 dB

TABLE 9C
Total number of NLOS points: 60

MODELS TESTED	Errors: Ave:	S.D.:	Worst:
Free space/E-P	-.1 dB	13.5 dB	47.2 dB
Free space/E-D	-.3 dB	13.6 dB	47.2 dB
Free space/Deygout	13.8 dB	21.6 dB	88.7 dB
Hata-Dav./E-P	32.4 dB	17.6 dB	85.3 dB
Hata-Dav./E-D	32.3 dB	17.5 dB	85.3 dB
Hata-Dav./Deygout	46.4 dB	25.5 dB	126.7 dB
TIREM-EDX	-.4 dB	13.6 dB	47.2 dB
Longley-Rice v.1.2.2	9.0 dB	19.0 dB	79.3 dB
Anderson 2D	6.5 dB	13.5 dB	50.8 dB

Note: Table 9 values were developed using McQuate Part III data only.

5. Recommendations

The propagation models for land mobile frequency coordination in the U.S. need to serve two purposes. For shared channel use, the objective is usually to seek a frequency which is the "least occupied". Determining the "least occupied" frequency can be done in a number of ways including accessing simple desired-to-undesired contour overlap as is currently done with certain types of broadcast allocations. The contour distances can be determined using a simple and fast propagation model which provides monotonically-decreasing signal level values as a function of distance and thereby a unique contour location in any given direction. Determining the extent of contour overlap is thus a straightforward process. For this purpose, the Hata/Davidson model (without any obstacle loss component) is the best currently available choice. The analysis done here shows that it generally provides good predictions for LOS situations, and the model itself is simple to implement.

For systems with Protected Service Areas (PSA), and other situations requiring accurate path loss predictions in both LOS and NLOS circumstances, the Anderson 2D model is the recommended model. The results in Tables 1 through 9 show that it more frequently produces the lowest mean and standard deviation of errors that any of the other models tested. Also, because it is a physical model, it is readily extended to the Anderson 3D case which is conceptually described in the current WG-8.8 Report. As a ray-based physical model, it can also be extended to explicitly consider reflection and diffraction from buildings yielding a seamless and self-consistent model construction from the long-range wide area case to the short range microcell case. It thus represents part of the framework of a powerful general purpose approach to propagation modeling.

It is recommended that the WG-8.8 document language be amended to describe both the Hata/Davidson model (without obstacle loss) and the Anderson 2D model, with appropriate direction on which model is to be employed for different frequency coordination objectives.

6. References

[1] McQuate, P.L. et. al. "Tabulations of Propagation Data over Irregular Terrain in the 230 to 9200 MHz Frequency Range, Parts I, II and III", ESSA Technical Report ERL 65-ITS-58, Institute of Telecommunication Sciences, Boulder, Colorado, March 1968.

[2] Hufford, G.A.. et. al. "Tabulations of Propagation Data over Irregular Terrain in the 75- to 8400 MHz Frequency Range, Parts V: Virginia", NTIA Report 91-282, December 1991. (NTIS access number PB92-137413.

[3] Hufford, G.A., Longley, A.G., and Kisseck, W.A. "A Guide to the Use of the ITS Irregular Terrain Model in the Area Prediction Mode", NTIA Report 82-100. 1982. (NTIS access number PB 82-217977)

[4] "Microcomputer Spectrum Analysis Models (MSAM)," NTIA, 1990. (NTIS access number PB 91-100669)

Appendix A

Outline of the Anderson 2D Model

The Anderson 2D model is a basic physical model which uses traditional ray techniques to calculate path loss. Like most models, for a given transmitter-receiver pair, it first determine if the path is line-of-sight (LOS) or non-line-of-sight (NLOS). Based on this determination, one of two calculation branches is used as described below.

Line-of-Sight Paths

For line-of-sight paths including those just to the point of a grazing obstruction, the path loss is determined using the base free space path loss equations with the addition of two additional loss factors. First, the path is evaluated to determine if any sub-path terrain feature impinges on the 0.6 first Fresnel zone. If any do, the one which most greatly obstructs the Fresnel zone is considered to cause additional path loss. The additional path loss ranges from 0 to 6 dB as a linear function based on the extent of the 0.6 first Fresnel zone which is obstructed. A 6 dB loss is thus introduced just at grazing which provides a smooth attenuation transition to paths which are just slightly obstructed.

For LOS cases, an explicit consideration of a ground reflection is also included. The ground reflection point is found by evaluating the angle of incidence from the transmitter and receiver to each point on the intervening terrain profile. Where the angles are equal, or at the two adjacent profile points where the angle to the transmitter and receiver cross (the former becomes smaller than the latter), the section of the profile where the reflection point exist is determined. Linear interpolation based on the angles of incidence is then used to exactly establish the reflection point location on this profile segment. Once established, tradition specular reflection coefficients are calculated and the amplitude and phase on the ground reflection vectorially added to the direct ray. The contribution of the reflection can cause the net signal at the receiver to be greater or less than the free space signal level. Practical limits on the path loss change due the reflection are set at 25 dB (additional loss due to phase cancellation) and -6 dB (less loss due to in-phase addition of the reflection). Explicit consideration of the reflection in this way for flat or smooth earth paths is quite accurate. Note that depending on the path geometry, a reflection contribution may not necessarily exist (in reality) or be found by the model.

Obstructed Paths

For obstructed paths, the diffraction attenuation is computed using the Epstein-Peterson approach extended to multiple knife edges, where the obstacles are basically established at the points where a "stretched string" between the transmitter and the receiver would touch the terrain profile. This is modified somewhat to deal with "false plateaus" anomalies in the terrain database. When the geometry finds obstacles at successive points along a terrain profile, the model replaces the successive string of obstacles with two knife edge obstacles, one at the beginning and one at the end of the succession. The heights of these knife edges are set at the heights of the first and last points in the succession, respectively, which are often the same for the false plateau anomaly. This double knife edge construction will also be invoked for real plateaus of other flat smooth sections of the profile if they happen to represent an obstacle along the path between the transmitter and the receiver.

In addition to the diffraction loss, the terrain profile between the transmitter and the first obstacle and the last obstacle and receiver are evaluated to determine if there are any sub-path obstacles which impinge on the 0.6 first Fresnel zone for either path segment. If such obstacles exists, an additional loss of 0 to 6 dB is included in each case using the same approach described for the Line-of-Sight section above. ❖