Project	IEEE P802.16 Broadband Wireless Access Working Group
Title	Comparison of Propagation Models
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Re:	In response to a request at the Montreal meeting for a comparision of rain models and inputs or comments to: IEEE 802.16.2 Topical Outline for "Recommended Coexistence Practices for Broadband Wireless Access Systems"
Abstract	There are differences between the two most popular models, ITU terrestrial model and Crane model. Crane has produced three models; the Crane Global model, Crane two-component model, and revised Crane two-component model that produce slightly different estimates of the long term mean fade probability. The Crane models tend to produce higher attenuation than the ITU model. But the uncertainty of either of these models or alternatively the short-term expectation of fade is quite large. Uncertainty stems from variations from year-to-year and location-to-location. The complexity of each model is also discussed.
Purpose	By describing the various rain propagation models and comparing results from the models, an input to section 5 of the outline can be generated.
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Comparison of Fade Models for LMDS

William Myers

I. Introduction

Variability is inherent in the estimation of path fading because empirical equations have been derived from a few measurement points around the world over limited time periods.
Rain attenuation, which is the dominant fading mechanism for millimeter wave paths, is based on nature, which can vary from location-to-location and from year-to-year.

There are differences between the two most popular models, ITU [1] terrestrial model and Crane [2-4] models, that produced slightly different estimates of the long term mean fade probability. But the uncertainty of either model or alternatively the short-term expectation of fade is quite large. The uncertainty, as measured by the estimated attenuation standard deviation, is greater than 30% and tends to overshadow arguments about the accuracy of the means. The uncertainty stems from variations from year-to-year and location-to-location. Location-to-location within a rain zone has an estimated attenuation standard deviation of 19% [5]. Also, worst month predictions predict much higher fade depths than the basic annual predictions.

An underestimate of the required margin to compensate for a given probability of rain outage results in a system that does not meet link availability requirements. If availability guarantees are accepted in system contracts, cost incentives may have to be paid for underdesigning a system. Overestimations of the required margin results in overdesign of systems which results in unnecessary system costs.

Crane has evolved his model from the Crane Global model to the Two-Component model, and the Revised Two-Component model. In most cases, the Crane models predict higher rain attenuation than the ITU model.

This paper compares prediction methods for rain attenuation and the associated variability. In low rainfall areas, clear air fading mechanisms could effect the availability of a link and are also briefly described.

II. Fading Mechanisms

Clear air fading occurs from three mechanisms. The refractive index gradient of the atmosphere near the earth's surface (0 - 100 meters) varies over time and can cause decoupling of the beam. If the antenna beam is too narrow, the link can be lost when this condition is severe. If the antenna beam is too wide, surface multipath can occur. Another effect is scintillation fading due to turbulent irregularities in the atmosphere. From a cursory calculation based on ITU-R P.530 [1] equations, clear air fading can prevent an availability of 99.999% for a path of 5 km and 28 dB link margin without any rain. These calculations are location dependent and make use of the refractive index data in ITU-R P.453 [6].

At millimeter wave, rain fading is the most dominant factor. Attenuation occurs due to absorption and scattering in rain. Fading due to rain attenuation is described empirically from link tests and point rainfall data. Location variation is based on selected point rainfall data and radar reflectivity data accumulated around the world. Because raindrops are oblate rather than spherical, attenuation tends to be greater for horizontally polarized signals than for vertical polarized signals.

The ITU has recommended a calculation method for terrestrial systems, ITU-R P.530, and for space to earth links, ITU-R P.618 [7]. These models take into account a distance reduction factor to account for the cellular nature of storms and have improved since the original CCIR version.

The “Crane” models, after Robert K. Crane, are popular for space-earth links but also have terrestrial models. There are 3 versions of the Crane models. The Global Crane model was developed in 1980. In 1982 the 2-component Crane model was developed that used a path-integrated technique. A volume cell contribution and a debris contribution for a path were computed separately and added to provide a link calculation. As a refinement of the 2-component model, the revised two-component model was introduced in 1989 which includes spatial correlation and statistical variations of rain within a cell. All of these are included in Crane’s book.

III. Attenuation Comparison of Methods

Calculation by the ITU model is straightforward by scaling the .01% rain rate and by using an effective path length reduction factor to account for the cellular nature of heavy rainfall. Mean cumulative distributions of rainfall zones are defined geographically in ITU-R 837 [8].

The Crane rainfall zones are defined differently than the ITU zones with more defined zones in the US than the ITU zones.

The following comparison of predicted attenuation is provided for places where the ITU and Crane zones overlap. ITU zone M does not correspond to a Crane zone very well and is not included in the comparison. Crane D2 and E are irregular through M, with Crane E extending from Florida to Northern Alabama and up to South Carolina. Listed in the table are attenuation values for the same locations using the ITU zone for ITU calculations and the corresponding Crane zone for Crane calculations. All of the Crane models predict a larger attenuation than the ITU model, however this difference is also about the same as the difference between various Crane models.

Table 1 Rain Attenuation Comparison at 99.99% Availability for 3 km Path

ITU Zone/Crane Zone	Units	E/F	D/C	K/D2	N/E
Rain Rate ITU/Crane	mm/hr	22/22	19/29	42/47	95/91
ITU-R 530	dB	10.8	14.3	22.3	39.2
Crane Global	dB	13.2	17.2	25.7	45.9
Crane 2-component	dB	13.6	18.4	28.8	52.0
Crane revised T-C	dB	12.4	20.0	26.9	51.3

It is interesting that ITU zone D is Northern California with less rainfall and E is Southern California with more rainfall. The corresponding Crane zones are C for Northern California and F for Southern California that predict just the opposite intensity.

Table 2 shows a comparison of attenuation for the same location (ITU K and Crane D2) at different availability values for a 3 km path.

Table 2 Attenuation exceeded (1- Avail)% of the time Comparison for Different Link Availabilities

	Units	99.999%	99.99%	99.9%
ITU-R 530	dB	47.8	22.3	8.5
Crane Global	dB	55.3	25.7	9.4
Crane 2-component	dB	75.7	28.8	9.3
Crane revised T-C	dB	68.7	26.9	9.0

Data presented by Yamada [9] compares the results of the earlier CCIR model with the Crane Global and two-component models along with models by Morita [10], Lin [11] and others. The Crane and other models were believed to overestimate the attenuation compared to the CCIR model. Yamada used 124 data sites and proposed changes to the CCIR model that are represented in the present ITU model. After improvement to the CCIR method, errors in the mean attenuation were less than 20% at availabilities of 99.9% or better.

Rain loss for ITU rain zones is shown in Figure 1 for path lengths up to 5 km and for an availability of 0.9999. Capabilities are shown in dotted lines for an example QPSK system with EIRP density values of the US FCC EIRP limit, Canadian limit, and a typical system having 0 dBW/MHz EIRP. An EIRP density of 0 dBW/MHz is within today's technology and provides fade margin from 20 – 30 dB. With a subscriber antenna gain of 35 dBi, this would support links up to 5 km in some rain zones.

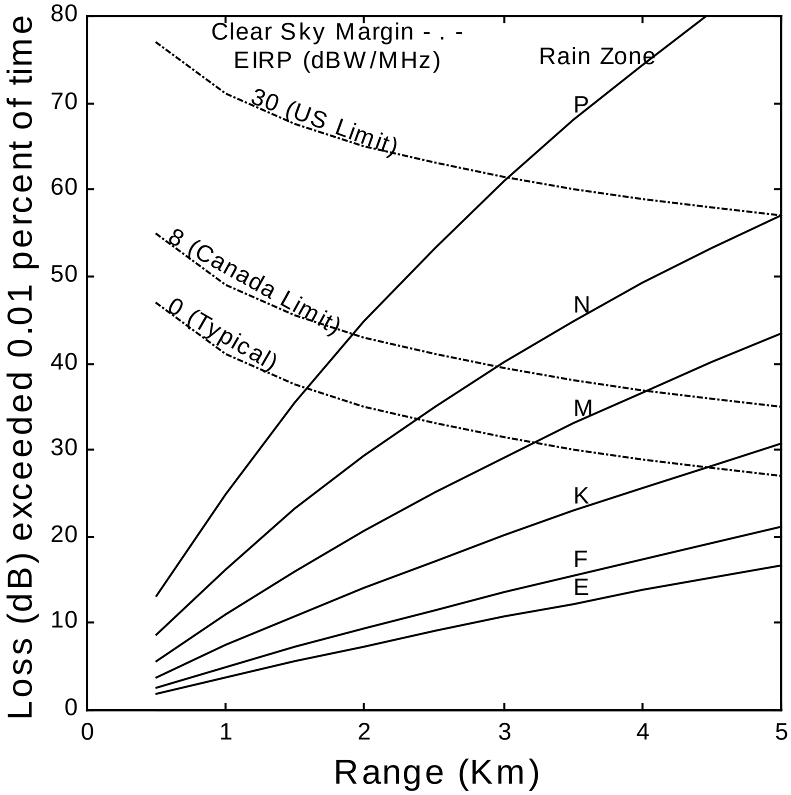

Figure 1 Rain Loss for ITU Rain Zones at 0.9999 Availability

(or 0.01% Un-availability)

IV Variability in Results

Year to year and location to location variations occur from the predicted mean attenuation. Both Crane and Yamada have calculated the standard deviation of the predictions. Yamada found attenuation standard deviation as high as 64% and Crane as high as 48% in the sample cases studied. Crane determined that the distribution of deviations was lognormal and presents a model for variability in terms of risk. Standard deviation of the natural logarithm of rain-rate, S_m, was obtained as follows:

Year-to-year, $S_m = 0.21$
Location-to-location, $S_m = 0.17$
Combined year-to-year and location-to-location, $S_m = 0.28$

The year-to-year standard deviation corresponds to 23% in dB and the combined standard deviation corresponds to 32% in dB. A risk model [12] is presented by Crane to estimate the attenuation for any year over a selected number of years using the variability standard deviation.

V Complexity of Models

For prediction of rain fade attenuation using the ITU 530 standard, rain rate at the 0.01% exceeded level for the zone of interest is required, frequency, path length, frequency, and attenuation factors from ITU-R 838 [13]. Other percentages are calculated using only the 0.01% value. The ITU model consists of simple equations and know for ease of use.

The Crane Global model requires solution of about 8 equations to obtain the path-averaged rain rate and a piecewise representation of the path profile by exponential functions.

The initial two-component Crane model first computes the volume cell contribution from the path integrated rain rate produced by a volume cell and the debris contribution based on the length scale for the debris path. About 10 equations are involved.

For the revised two-component Crane model, spacial correlation functions are included and an integral equation for the debris path. It also includes a prediction for satellite path diversity. Because of the complexity of the two-component models, attenuations in the above tables were obtained from the program disk included with the book.

VI Summary

In 1987, Yamada compared eight different models including 2 CCIR models using radiometer measurements and satellite measurements. His conclusion was that the CCIR model for mean attenuation was the most accurate overall. The Crane two-component model was very close to experimental results for probabilities around 0.1 to 1%. Although 124 test data points were used in Yamada's evaluation, however most were for about 1-year duration. Crane makes similar comparisons from other data and concludes that his model is more accurate.

I recommend that ITU 530 model should be used for terrestial links. The model is simple to compute, and it is not clear that one model is more accurate than the other particularly at high rain rates. ITU 530 is an ITU recommendation that is the consensus among a group of international experts on the best method to estimate fade events.

References

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