Evaluation of Radio over Sea Propagation Based ITU-R Recommendation P.1546-5

Han Wang, Wencai Du, and Xing Chen
College of Information Science & Technology, Hainan University, 58 Renmin Ave., Haikou, Hainan 570228, China
Email: hanwang1214@gmail.com; wencai@hainu.edu.cn; waigongjiayou@live.com

Abstract—The propagation prediction research has mainly focused on studying the radio propagation models in urban or rural land areas. In this paper, we extend a method for 950 MHz propagation prediction over sea based ITU-R Recommendation P.1546-5. A gauge of the accuracy of the prediction Free Space model, correction Okumura-Hata model and the P.1546-5 model is presented. The P.1546-5 is evaluated using measurement results which were obtained by utilizing the pilot signal in a commercial GSM network over sea around Haikou, China. The comparison is enabled by using hit rate metrics. Measurement results show that the P.1546-5 model underestimates the field strength about 6 dB on average for Haikou region in South China Sea. However, the P.1546-5 prediction model provides better accuracy prediction of the path loss compared to the Free Space model. We provide proposals to enhance the sea propagation prediction accuracy of ITU-R Recommendation P.1546.

Index Terms—Radio over sea propagation, Propagation prediction, Hit rate metrics, ITU-R P.1546-5, Free space model, Okumura-Hata model

I. INTRODUCTION

Hainan Province is located in the southernmost tip of China, it comprises about 200 square kilometers sea area which is about fifty-seven times its mainland area. Numerous activities in the sea area such as offshore oil exploitation, maritime transportation and marine fishery make the maritime communications more and more important. The current maritime communication models mainly include signal sideband (SSB) short wave radio, VHF radiotelephone, coast cellular mobile communication network and maritime satellite communication network [1]. Maritime VHF radio telephone is mainly used for ship to shore and ship to ship voice communication scenario while the transmission distance should be less than 20 nautical miles. Maritime satellite communication system [2], [3], such as the Inmarsat-F system, Fleet-Broadband maritime data service, is suitable for ocean sea ship communications, but the satellite communication system is relatively costly, the terminal equipment is expensive, accompanied with higher maintenance and update costs and communication fee, the data rate are far from the main user requirements. Consequently, a maritime communication needs to be further developed.

In recent years, there have been a lot of researches in variety models of propagation prediction, well-known propagation models are Longley-Rice model [4], Durkin model and Okumura-Hata model [5]. They are all applicable for the land scenario. Research on radio propagation model over sea mainly utilize parabolic equation method [6], [7], it takes into account phenomena such as reflection, refraction and diffraction. While in line-of-sight propagation, it is usually regarded as free space propagation [8], for non-line-of-sight propagation, the path loss is calculated according to the experience of chart. However, the conclusions of the tradition methods are that none of the evaluated models are comprehensive enough to predict radio propagation over sea. Hence, an accurate prediction model for radio propagation over sea needs to be further studied.

The International Telecommunication Union (ITU) has developed a new Recommendation on the method for point to area predictions for terrestrial services in the frequency rang 30 MHz to 3000 MHz. The latest Recommendation ITU-R P.1546-5 [10] is intended for use on tropospheric radio circuits over land paths, sea paths or mixed land-sea paths up to 1000 km length for effective transmitting antenna heights less than 3000 m. The method is based on interpolation/extrapolation from empirically derived field-strength curves as functions of distance, antenna height, frequency and percentage time.

Currently, the ITU-R P.1546 is increasingly used as a benchmark propagation method to analyze the radio wave propagation. In [11], the Longley-Rice, ITU-R P.1546 and Hata-Davidson propagation models for DVB-T coverage prediction was compared. In [12], a new approach for 1 km urban propagation model of the recommendation ITU-R P.1546 was proposed. The ITU-R P.1546 is also utilized to combine with other model to analyze some special propagation scenario [13]. But the study of ITU-R P.1546 are mainly concentrated on the radio propagation in land scenario.

In this paper, we focus on the prediction over sea propagation. We extend the ITU-R P.1546-5 as a radio over sea propagation model. Propagation measurement results are compared with the prediction based propagation model Recommendation ITU-R P.1546-5. Some conventional empirical models, such as the Free Space model, correction Okumura-Hata model and the P.1546-5 model are evaluated using measurement results which were obtained by utilizing the pilot signal in a commercial GSM network over sea around Haikou, China. The comparison is enabled by using hit rate metrics. Measurement results show that the P.1546-5 model underestimates the field strength about 6 dB on average for Haikou region in South China Sea. However, the P.1546-5 prediction model provides better accuracy prediction of the path loss compared to the Free Space model. We provide proposals to enhance the sea propagation prediction accuracy of ITU-R Recommendation P.1546.
Space model and the Okumura-Hata model, are used as path loss prediction benchmark. Hit rate metrics are introduced to complement conventional first order statistics.

The rest of this paper is organized as follows: Section 2 describes the Recommendation ITU-R P.1564-5 and its two main correction factors. Measurement procedure and analysis methods are given in Section 3. The evaluation of prediction models and measurements are presented in Section 4. Finally, the conclusion and a discussion for the future work are presented in Section 5.

II. RECOMMENDATION ITU-R P.1546-5

The ITU-R P.1546 model provides a set of curves and tables of field strength as a function of frequency (100 MHz, 600 MHz, and 2 GHz), distance (1 km to 1000 km), transmitting antenna height (10 m to 1200 m), time variability (50%, 10%, and 1%), location variability (1% to 99%), and path type (land, cold sea, warm sea, and mixed paths), at the height of the receiving antenna being equal to the representative height of ground cover. It has mentioned that if families of curves exist for regions with different climates which experience substantially different prevailing radio propagation conditions, accurate characterization of radio propagation in these regions may be attained using the methods found in this Recommendation. There are some correction factors in the Recommendation, including correction for transmitting antenna height, interpolation of field strength as a function of distance and frequency, correction for receiving antenna height, cluttered transmitter correction, terrain clearance angle correction, correction due to tropospheric scattering, etc.

In this paper, we study on the prediction of radio over sea propagation, especially considering interpolation and extrapolation of field strength as a function of distance and frequency, correction of receiving antenna heights, correction based on tropospheric scattering. Compared with version P.1546-4 [9], the latest version P.1546-5 which has addition correction for antenna height difference is also considered in this paper. The two main correction factors [10] of P.1546-5 shown in the following are implemented to extend a sea propagation model.

A. Correction for Receiving Antenna Height \( h_2 \)

For the sea path, the concept of transmitting antenna \( h_1 \) is that it represents the physical height of the antenna above the surface of the sea. The Recommendation gives correction for the situation “adjacent to sea” where the receiving antenna is either over sea, or is immediately adjacent to the sea with no significant obstruction in the direction of the transmitting station. For sea paths the notional value of \( h_1 \) is 10 m. Where the receiving antenna is adjacent to sea for \( h_2 \geq 10 \) m, the correction should be calculated using equation

\[
\text{Correction} = K_{h2} \log \left( \frac{h_2}{R} \right) \text{ dB}
\]

where \( R = 10 \) m , \( K_{h2} = 3.2 + 6.2 \log(f) \) , \( f \) is the frequency (MHz).

When the receiving antenna is adjacent to sea for \( h_2 < 10 \) m, an alternative method should be used, based upon the path lengths at which 0.6 of the first Fresnel zone is just clear of obstruction by the sea surface. For a given frequency and antenna heights \( h_1 \) and \( h_2 \), the path length which just achieves a clearance of 0.6 of the first Fresnel zone over a smooth curved earth is given approximately by:

\[
D_{06} = \frac{D_fD_h}{D_f + D_h} \quad \text{(2)}
\]

where \( D_f = 0.0000389fh_1h_2 \) , \( D_h = 4.1\left(\sqrt{h_1} + \sqrt{h_2}\right) \) . \( f \) is frequency, \( h_1 \) and \( h_2 \) are antenna heights above smooth earth (m).

If the transmission distance is equal to or greater than \( d_{10} \), the correction should be calculated using equation (1) with \( R = 10 \) m . If the transmission distance is less than \( d_{10} \), then the correction should be calculated as:

\[
\text{Correction} = 0 \text{ dB} \quad \text{for} \quad d \leq d_{h2} \quad \text{(3)}
\]

For \( d_{h2} < d < d_{10} \),

\[
\text{Correction} = C_{10} \frac{\log(d/d_{h2})}{\log(d_{10}/d_{h2})} \text{ dB} \quad \text{(4)}
\]

here \( d_{10} \) is distance at which the path just has 0.6 Fresnel clearance for \( h_2 = 10 \) m given in equation (2) calculated as \( D_{06}(f,h_2,10) \) , \( C_{10} \) is correction for the required value of \( h_2 \) at distance \( d_{10} \) using equation (1) with \( R = 10 \) m , \( d_{h2} \) is distance at which the path has 0.6 Fresnel clearance for the required value of \( h_2 \) given in equation (2) calculated as \( D_{06}(f,h_1,h_2) \) . The recommendation is not valid for receiving antenna heights less than 3 m when adjacent to sea. In this paper, the receiving antenna we utilized is more than 3 m above the horizontal.

For the sea path, the above correction for receiver antenna height can be summarized by the flowchart shown in Fig. 1.

A correction is also required to take account of the difference in height between the two antennas.

\[
\text{Correction} = 20\log \left( \frac{d}{d_{\text{slope}}} \right) \text{ dB} \quad \text{(5)}
\]

where \( d \) is the horizontal distance and \( d_{\text{slope}} \) is the slope distance.
seen that as distance increase field strength decrease. Higher values of \( h_1 \) can obtain higher field strength, lower values of \( h_1 \) curves are more sensitive to the change of distance.

### B. Correction Based on Tropospheric Scattering

For sea paths, the influence of scattering to the transmission is very significant. Taking account of tropospheric scattering, we calculate the path scattering angle in degrees \( \theta_s \), using

\[
\theta_s = \frac{180d}{\pi ka}
\]

(7)

where \( d \) is the path length (km), \( a = 6370 \text{ km} \), radius of the earth, \( k = \frac{4}{3} \), effective earth radius factor for median refractivity conditions. Here, we ignore the effect of diffraction in the sea level. Terrain clearance angle correction which is given by the Recommendation is appropriate for land path. In this paper, we consider the terrain clearance angle correction is zero.

Calculate the field strength predicted for tropospheric scattering, \( E_s \), using

\[
E_s = 24.4 - 20\log(d) - 10\theta_s + 0.15N_0 + G_t
\]

(8)

where \( L_f = 5\log(f) - 2.5[\log(f) - 3.3] \) is the frequency-dependent loss; \( N_0 = 325 \) , median surface refractivity, N-units, typical of temperate climates; \( G_t = 10.1(-\log(0.02))^{0.7} \), time-dependent enhancement; \( d \) is path length; \( f \) is required frequency.

The Recommendation gives an equivalent basic transmission loss. The basic transmission loss equivalent to a given field strength is given by:

\[
L_b = 139.3 - E + 20\log f \text{ dB}
\]

(9)

where \( L_b \) is basic transmission loss, \( E \) is field strength for 1 kW e.r.p, \( f \) is frequency (MHz).

### III. MEASUREMENT PROCEDURE AND ANALYSIS METHODS

In order to acquire the path loss over sea propagation measurement data, a investigation team was sent by College of Information Science & Technology, Hainan University, to conduct radio wave spectrum measurement and radio wave path loss measurement in the range of Hainan region in South China Sea. Fig.3 shows the survey boat at maximum speed of 5 m/s.

Radio wave propagation measurement was performed using a signal scanner made by Agilent Technologies Inc, machine module is N9342C. The scanner is controlled by a laptop personal computer and includes a global positioning system (GPS) receiver and an Omni-
directional antenna. During the measurement, the receiving antenna was placed on a boat at a height of approximately 5 m above horizontal. Table I shows the main parameters of the scanner.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Values</th>
<th>Parameters</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Impedance</td>
<td>50</td>
<td>Gate Delay</td>
<td>0.000018</td>
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<tr>
<td>Number of Points</td>
<td>461</td>
<td>Gate Length</td>
<td>0.000084</td>
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<tr>
<td>Sweep Time(s)</td>
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<td>Burst Level</td>
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<tr>
<td>Attenuation</td>
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<td>Timer Period</td>
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<tr>
<td>Trigger Delay</td>
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<td>Timer Offset</td>
<td>0</td>
</tr>
</tbody>
</table>

The measurement was started at nearby Haikou sea in Nov. 2014. Fig. 4 is the measurement path profile. The transmitting pilot power, antenna height, and antenna gain of the BSs were provided by China Mobile Hainan branch. The measurement data originating from the two BSs with Omni-directional antenna in nearby Haikou sea and Wenchang sea were analyzed and used for evaluating the P.1546-5.

In this paper, the first order statistics and hit rate metrics have been used to evaluate the measurement results.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Values</th>
<th>Parameters</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean error (dB)</td>
<td>5.754</td>
<td>Standard deviation of error (dB)</td>
<td>2.268</td>
</tr>
<tr>
<td>Standard deviation</td>
<td>2.268</td>
<td>Correlation coefficient</td>
<td>0.907</td>
</tr>
</tbody>
</table>

The first order statistics summary in Table II shows that the P.1546-5 has the smallest mean error and standard deviation of error in the three models. However, the Free Space model and Okumura-Hata model yield a slightly better correlation coefficient than the P.1546-5 model. For further analysis of the accuracy of the three models can be obtained by hit rate metrics.

B. Hit Rate Metrics

First order statistics are not always comprehensive to reflect the accuracy of prediction models. Assume a set of prediction path loss that closely match measurement results for most of the range, but which are subject to an error in the predicted or measured locations, then the calculate of mean of error and standard deviation of error will be large, although the model is accurate for the prediction of the overall number of locations. Hence, Hit rate metrics were proposed by Owadally, Montiel, and Saunders [15] to complement conventional first order statistics. The measured data, \( m_i \), and predicted data, \( p_i \), are compared to the path loss threshold, \( L_T \). If the
magnitude of any measured path loss is less than or equal to the magnitude of the path loss threshold, then define that the measurement result is in ‘coverage’. Otherwise, the measurement result is in ‘outage’. The same applies for the set of predicted path loss data. This can be expressed as a function as below:

\[ U(x) = \begin{cases} 1 & \text{if } x \leq L_T \\ 0 & \text{otherwise} \end{cases} \] (14)

where \( x = p_i \) or \( m_i \). Refer to [15], for a given path loss threshold, there are four kinds of hit rate metrics, they are Total Hit Rate (THR), Availability Hit Rate (AHR), Outage Hit Rate (OHR) and Coverage Area Accuracy (CAA).

The THR gives a direct indication of the quality of a model, for it directly evaluate how often the predictions correctly predict the coverage state of any given location, and can be calculated as:

\[
\text{THR}(L_T) = \frac{\sum_{i} U(m_i) \cdot U(p_i)}{N_T} + \frac{\sum_{i} \bar{U}(m_i) \cdot \bar{U}(p_i)}{N_T} \times 100
\] (15)

where \( \bar{U} \) is the complement of \( U \), \( N_T \) is the total number of points compared.

The AHR is the ratio of the number of locations where both measurements and predictions are in a ‘coverage’ situation. The AHR is defined as

\[
\text{AHR}(L_T) = \frac{\sum_{i} U(m_i) \cdot U(p_i)}{\sum_{i} U(p_i)} \times 100
\] (16)

The OHR is the ratio of the number of locations where both measurements and predictions are in an ‘outage’ situation relative to the number of predicted outage locations. The OHR is given by

\[
\text{OHR}(L_T) = \frac{\sum_{i} \bar{U}(m_i) \cdot \bar{U}(p_i)}{\sum_{i} \bar{U}(p_i)} \times 100
\] (17)

The CAA can also evaluate the accuracy of the model, contrast with the THR, the specific location of coverage is less important than the overall area served. It is given by

\[
\text{CAA}(L_T) = 100 - \left( \frac{\sum_{i} U(m_i) \cdot U(p_i)}{N_T} - \frac{\sum_{i} U(p_i)}{N_T} \right) \times 100
\] (18)

IV. EVALUATION BY MEASUREMENTS AND PREDICTIONS

In this paper, the Free Space model and the correction Okumura-Hata model [2] are used to compare with correction P.1546-5. Here, the Free Space field strength for 1 kW e.r.p is given by:

\[
E_f = 106.9 - 20\log(d)
\] (19)

The correction Okumura-Hata prediction of the field strength is given by:

\[
E = 69.82 - 6.16\log(f) + 13.82\log(H_1) + a(H_2) - (44.9 - 6.55\log(H_1))(\log d)^b
\] (20)

where \( H_1 = 35 \text{ m}, H_2 = 5 \text{ m}, f = 950 \text{ MHz}, b = 1 \). Fig. 3 shows the measurements and predictions path loss curves versus transmitting distance.

![Fig. 5. The measurement and predictions path loss curves versus transmitting distance.](image)

From Fig. 5, it can be seen that the Okumura-Hata model provides overall higher path loss prediction than Free Space model and P.1546-5. The P.1546-5 gives the approximate path loss values to measurement data. Within 2 km transmission, the three path loss curves are very close. The measurement data show that the path loss values, in the transmission range of 10 km, have relatively large fluctuation.

![Fig. 6. Models comparison using Total Hit Rate (THR) metric](image)

Fig. 6 and Fig. 7 show the THR curve and CAA curve, respectively. In Fig. 6 and 7 the THR and CAA provide further insight into demonstrating that the P.1546-5 is more accurate than the Free Space model and Okumura-Hata model. A high THR means that there is a good match between the predictions and the measurements. Fig 6 shows that in a band of the path loss threshold, between...
120 dB to 180 dB, the P.1546-5 outperforms the other two models. While in a band of 90 dB to 120 dB, the three models have similar prediction accuracy. The CAA gives a concept of the number of locations at which the predictions lie on the same side of the path loss threshold as the measurements. As shown in Fig. 7, in the band of 110 dB to 180 dB, the P.1546-5 does better than the other two models.

The AHR and OHR metrics correspond with standard deviation of the error. If the standard deviation of the error and the mean error are low, the prediction and measurement curves are expected to be very close to each other and to have a similar shape. Fig. 8 and Fig. 9 show the AHR and OHR respectively, we can see that the P.1546-5 have a higher OHR but lower AHR. From the analysis data, there are a set of locations where predictions differ significantly from the measurements. Hence this causes the predictions and measurements to be different sides of the path loss threshold. This is why results in Fig. 8 and Fig. 9.

V. CONCLUSION

In this paper, we extend a correction ITU-R recommendation P.1546-5 for radio over sea propagation. The correction P.1546-5 is compared with two traditional models and evaluated using measurements that were obtained by utilizing a commercial GSM mobile network. The measurements were carried out in Nov. 2014 from nearby Haikou sea to Wenchang sea, China. Four hit rate metrics were used to evaluate the accuracy of the three models. It has been shown that P.1546-5 provides better overall prediction of the path loss compared to the Free Space model and the Okumura-Hata model. Hit rate metrics give a complementary ways to analyze the accuracy of the models.

Although a method to predict the field strength for sea paths has been provided in Recommendation ITU-R P.1546 since 2007, additional works are still needed to complete the model that can be wildly applied for various ocean scenarios. In this paper, the effect of diffraction is ignored, and there is no terrain clearance angel correction for sea paths in the Recommendation ITU-R P.1546. To develop reliable correction models, the effect of diffraction from obstacles on the sea should be considered, a lot of measurements from different types of terrain should be obtained and analyzed in future work.

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REFERENCES


Han Wang was born in Jiangxi Province, China, in 1986. He received the B.S. degree in electrical engineering from Hubei University of Nationalities, China, in 2009 and the M.S. degree in information and communication system from Hainan University, Haikou, China, in 2013. He has worked in China Mobile Jiangxi branch as a network engineer for one year. Now, he is pursuing the Ph.D. degree with the Department of College of Information Science & Technology in Hainan University. His research interests include maritime communication and information theory.

Wencai Du received the Bachelor of Science degree from the Peking University, Beijing, China, in 1978. He received the two M.S. degree from the Hohai University, Nanjing, China, in 1986, and from ITC, Enschede, The Netherlands, in1996. He received the Ph.D. degree at University of South Australian, in 2000. He conducted postdoctoral research at Technion-Israel Institute of Technology (ITI), Israel, from March, 2001-March 2002. His research interests span the areas of computer science and communication engineering. He is especially interested in the computer networking, service computing, e-service and maritime communication. Dr. Du has authored or co-authored 18 books and more than 80 scientific publications. Dr. Du has served on the technical and executive committees of several major conferences and workshops. He was the Conference Chair to IEEE/ACIS ICIS 2011, Conference Co-Chair to SNPD 2010, London, Conference Chair to IEEE/ACIS to SERA 2009, and Program Chair to SNPD 2009, Daegu, Korea.

Xing Chen was born in Hainan Province, China, in 1991. She received her B.S. degree in communication engineering from Nanjing University of Science and Technology, China, in 2013. Now, She is a master student, major in information and communication engineering in Hainan University. Her research interest is the marine white spectrum occupancy analysis.