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

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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 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 and the correction Okumura-Hata 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 refection, 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 3000MHz. 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 1000km 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

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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_2 is 10 m. Where the receiving antenna is adjacent to sea for $h_2 \geq 10$ m, the correction should be calculated using equation

$$\text{Correction} = K_{h2} \log\left(\frac{h_2}{R'}\right) \text{ dB} \tag{1}$$

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:

$$D_{06} = \frac{D_f \bullet D_h}{D_f + D_h} \tag{2}$$

where $D_f = 0.0000389 f h_1 h_2$, $D_h = 4.1\left(\sqrt{h_1} + \sqrt{h_2}\right)$, 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:

$$\text{Correction} = 0 \text{ dB} \quad \text{for } d \leq d_{h2} \tag{3}$$

For $d_{h2} < d < d_{10}$,

$$\text{Correction} = C_{10} \frac{\log\left(d/d_{h2}\right)}{\log\left(d_{10}/d_{h2}\right)} \text{ dB} \tag{4}$$

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 $D_{06}\left(f, h_1, 10\right)$, 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 $D_{06}\left(f, h_1, h_2\right)$. 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.

$$Correction = 20\log\left[\frac{d}{d_{slope}}\right] \text{ dB} \tag{5}$$

where d is the horizontal distance and d_{slope} is the slope distance.

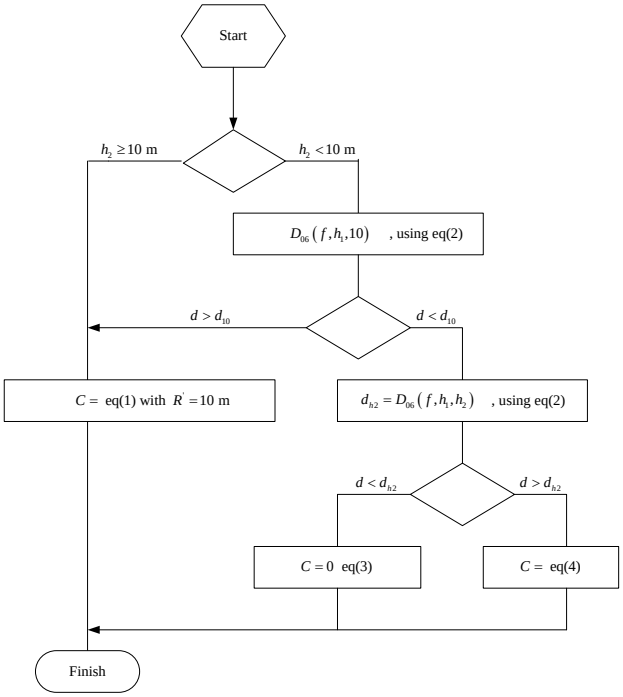

Fig. 1. Flowchart for receiver antenna height correction

$$d_{slope} = \sqrt{d^2 + 10^{-6}\left[\left(h_a + h_{tter}\right) - \left(h_2 + h_{rter}\right)\right]^2} \quad (6)$$

where h_a is the antenna height above ground, h_{tter} and h_{rter} are the terrain heights in meters above sea level at the transmitter and receiving terminals respectively. Although the correction given by equation (5) is very small except for short paths and high values of h_1, it is recommended that it is used in all cases to avoid making an arbitrary decision as to precision.

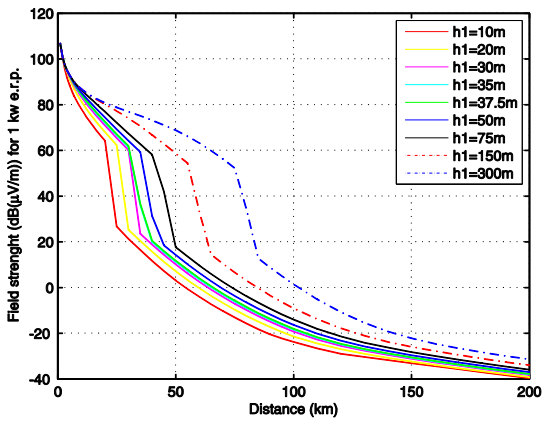

Fig. 2. P.1546-5 propagation curves for different transmitting antenna heights h_1, frequency of 950 MHZ, warm sea paths, 50% of time and locations and receiving antenna height h_2 equals 5 m.

Fig. 2 shows one set of curves that is applicable for sea paths and with a frequency equal to 950 MHz. A rigorous interpolation/extrapolation procedure is given to allow consistent prediction for any input values within the specified range. The frequency f , transmitting antenna h_1 and receiving antenna height h_2 are corrected. It is 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 θ_s, using

$$\theta_s = \frac{180d}{\pi ka} \quad (7)$$

where d is the path length (km), $a = 6370$ 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 angel correction is zero.

Calculate the field strength predicted for tropospheric scattering, E_{ts}, using

$$E_{ts} = 24.4 - 20\log(d) - 10\theta_s - L_f + 0.15N_0 + G_t \quad (8)$$

where $L_f = 5\log(f) - 2.5\left[\log(f) - 3.3\right]$ is the frequency-dependent loss; $N_0 = 325$, median surface refractivity, N-units, typical of temperate climates; $G_t = 10.1\left(-\log(0.02t)\right)^{0.7}$, 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:

$$L_b = 139.3 - E + 20\log f \text{ dB} \quad (9)$$

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.

Fig. 3. Survey boat

TABLE I: MAIN PARAMETERS OF THE SCANNER

Parameters	Values	Parameters	Values
Impedance	50	Gate Delay	0.000018
Number of Points	461	Gate Length	0.000084
Sweep Time(s)	0.092527	Burst Level	-20
Attenuation	0	Timer Period	0.001
Trigger Delay	0.000006	Timer Offset	0

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.

Fig. 4. The measurement path profile from Google Earth

A. First Order Statistics

Mean of the error, standard deviation of the error and the correction coefficient between the measurements and predictions are expressed in the conventional first order statistics. The mean of error is defined as the difference between the predicted values, p_i and the measured values, m_i on a logarithmic [dB] scale. The prediction error is expressed as

$$\varepsilon_i = p_i - m_i,\ i = 1, 2, ..., N \tag{10}$$

where N is the number of sample. Hence, the mean of error is given as

$$\bar{\varepsilon} = \frac{1}{N}\sum_{i=1}^{N}\varepsilon_i \tag{11}$$

The standard deviation can reflect the dispersion degree of data, it is a significant index to evaluate the accuracy of predictions. It can be calculated as

$$\sigma = \sqrt{\frac{\sum_{i=1}^{N}\left(\varepsilon_i - \bar{\varepsilon}\right)^2}{N-1}} \tag{12}$$

The correlation coefficient gives a measure of the degree of linear relationship between two random variables and is calculated as [14]

$$r_e = \frac{\sum_{i}^{N}\left(m_i - \bar{m}\right)\left(p_i - \bar{p}\right)}{\sqrt{\sum_{i}^{N}\left(m_i - \bar{m}\right)^2 \sum_{i}^{N}\left(p_i - \bar{p}\right)^2}} \tag{13}$$

where $\bar{m}$ and $\bar{p}$ are the means of the measured and predicted values, respectively.

TABLE II: FIRST ORDER STATISTICS FOR PREDICTION MODELS

First order statistics	P.1546-5	Free space	Okumra-Hata
Mean error (dB)	5.754	8.645	17.925
Standard deviation of error (dB)	2.268	4.084	4.799
Correlation coefficient	0.907	0.897	0.894

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:

$$U(x)=\begin{matrix}1 & |x\le L_T| \\ 0 & \text{others}\end{matrix} \tag{14}$$

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:

$$THR(L_T)=\left[\frac{\sum_i U(m_i)\cdot U(p_i)}{N_T}+\frac{\sum_i \bar{U}(m_i)\cdot \bar{U}(p_i)}{N_T}\right] \tag{15}$$

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

$$AHR(L_T)=\frac{\sum_i U(m_i)\cdot U(p_i)}{\sum_i U(p_i)}\times 100 \tag{16}$$

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

$$OHR(L_T)=\frac{\sum_i \bar{U}(m_i)\cdot \bar{U}(p_i)}{\sum_i \bar{U}(p_i)}\times 100 \tag{17}$$

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

$$CAA(L_T)=100-\left|\frac{\sum_i U(m_i)}{N_T}-\frac{\sum_i U(p_i)}{N_T}\right|\times 100 \tag{18}$$

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 :

$$E_{fs}=106.9-20\log(d) \tag{19}$$

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

$$E=69.82-6.16\log(f)+13.82\log H_1+ a(H_2)-(44.9-6.55\log H_1)(\log d)^b \tag{20}$$

where $H_1=35$ m, $H_2=5$ m, $f=950$ MHz, $b=1$. Fig. 3 shows the measurements and predictions path loss curves versus transmitting distance.

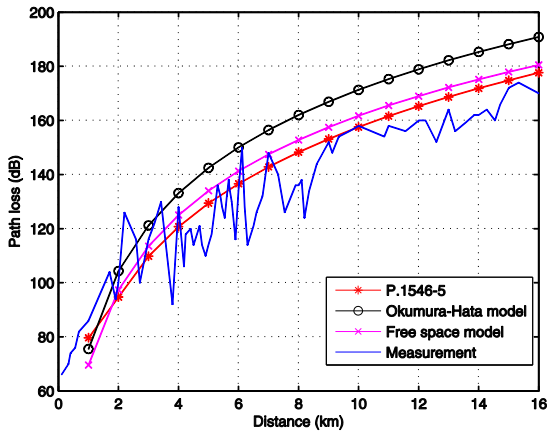

Fig. 5. The measurement and predictions path loss curves versus transmitting distance. The prediction model parameters are $f=950$ MHz, $h_1=35$ m, $h_2=5$ m .

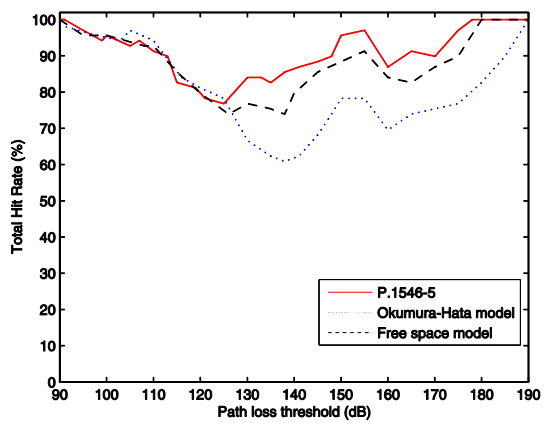

Fig. 6. Models comparison using Total Hit Rate (THR) metric

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 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.

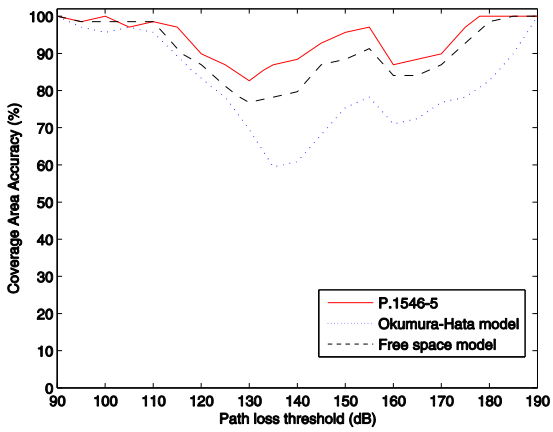

Fig. 7. Models comparison using Coverage Area Accuracy (CAA) metric.

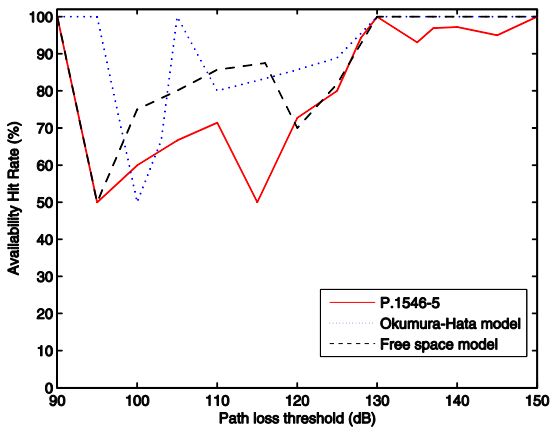

Fig. 8. Models comparison using Availability Hit Rate (AHR) metric

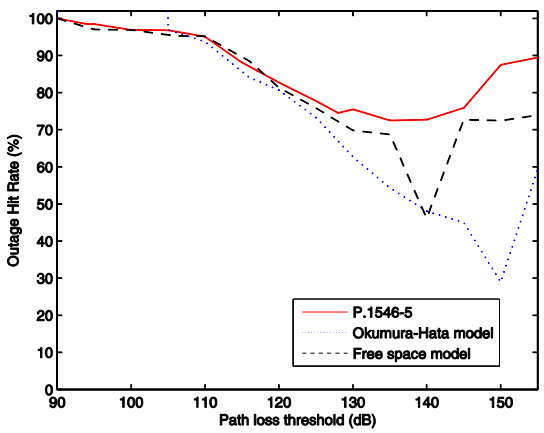

Fig. 9. Models comparison using Outage Hit Rate (OHR) metric

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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