Research on Ka Rough Ocean Surface Channel Modeling Based on Stochastic Processes

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Abstract— It is presented in this paper that a channel modeling technique based on GTD and stochastic bridge, which may boost the usage of low elevation angle Ka or higher frequency satellite down-link radio propagation prediction and estimation. First, it is introduced a random rough ocean surface modeling method under typical ocean states which is the foundation and the first step for electromagnetic simulation of telecommunication channel. Second, a huge data ocean surface reflection, scattering and diffraction based on GTD algorithm are calculated by high performance computer to provide a large number of samples for channel modeling. Third, a multipath channel model is set up to describe the statistical properties of received signal waveform which is modified by rough ocean surface. Last, all the steps are summed up and discussed to show the benefits of the presented modeling technique.

1. INTRODUCTION

Ka-band is generally applied to satellite communication. The radio waves propagation of Ka band has atmospheric attenuation, rain attenuation, atmospheric refractivity, and the loss caused by space change, in addition to the usual reflection, diffraction and scattering, etc.. The propagating process on sea surface is very complex, so, satellite down-link radio propagation prediction and estimation have important significance for maritime communications.

Typical wave propagation channel modeling methods apply experimental modeling method, stochastic modeling method and ray tracing method. Experimental modeling method, conducted by direct measurements and using statistical tools for data fitting and analysis, is not perfectly precise; Stochastic modeling method using statistical methods to analyze the statistical properties of the various parameters of the channel, can capture the channel response instantaneously and low calculation difficulty. But it has a high requirement for experimental environment and conditions. Ray tracing method taking radio waves as rays and using the Maxwell's equations and electromagnetic theory to analyze the channel and calculate the field strength is more accurate. But its calculation is complicated at the same time [1, 2]. Combining the advantages of the latter two methods, stochastic bridge channel modeling regards the electromagnetic wave as rays, and takes multipath propagation paths of rays in the wireless channel as stochastic process samples. The characteristic parameters of stochastic process is determined by the propagation environment [3].

In this paper, the first step is rough ocean surface modeling. Then calculating a huge data of ocean surface reflection, scattering and diffraction based on GTD algorithm by high performance computer to provide a large number of samples for channel modeling. In the end, modeling the the wireless channel on the sea surface.

2. RANDOM OCEAN SURFACE MODELING AND ELECTROMAGNETIC SIMULATION

With the increase in observation data and the development of the theory of the waves, there exist a lot of "experience spectrum", which are in a variety of forms respectively and the flourish logo of the simulation technique of sea wave. The wave spectrum is divided into frequency spectrum and directional spectrum. Frequency spectrum is one of the important statistical properties of the waves, so, the research of frequency spectrum is more widely. We can get wave height and period from the frequency spectrum [4]. Frequency spectrum has a good data foundation, and it is the distribution of wave energy on frequency variation. It is almost experience spectrum by measuring the data.

PM spectrum is fully growth state of the wave spectrum based on wind speed parameter, and it is detailed in the analysis of observational data and simple form. The displacement of sea surface is the the superposition of many waves with different frequency, amplitude and direction. The displacement of sea surface of every point form three-dimensional waves. Use double linear

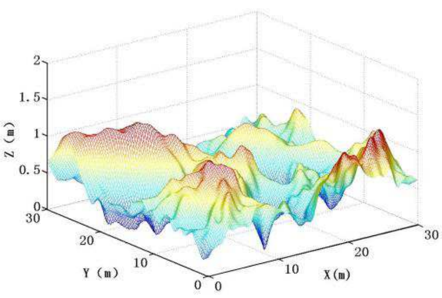

Figure 1: Wave model of level 3.

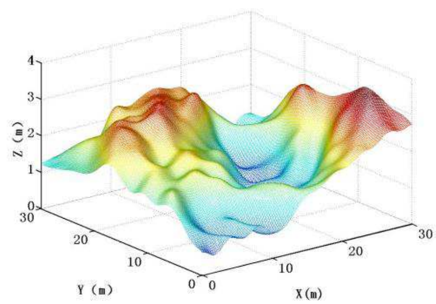

Figure 2: Wave model of level 5.

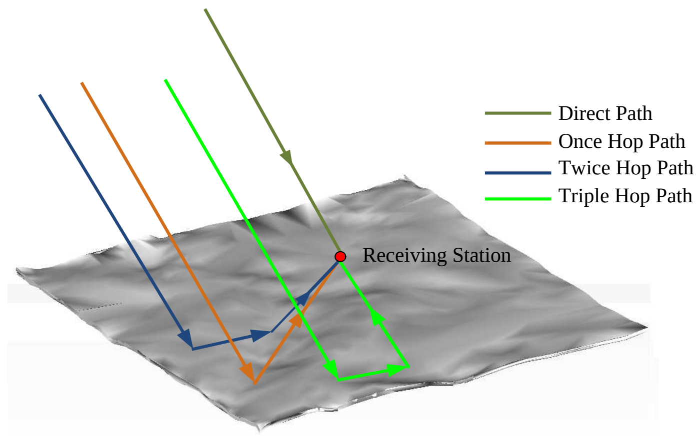

Figure 3: The scenario of ray path tracing.

superposition method to build PM spectrum wave model. The sea level is divided by the wind speed of rough sea surface [5, 6]. We take wave model of level 3 and 5 for example. As shown in Figure 1 and Figure 2, the sea level is higher, the sea level rough degree is bigger, and the waves rolled more violently.

As to the Ka band, the size of the rough surface is much greater than the wavelength, so rough sea belongs to the electrically large targets [7]. For electromagnetic simulation, at first, the waves model is built; Then put it in the electromagnetic simulation software to divide PO grid; At last, electromagnetic simulation model is generated. The scenario of ray path tracing is as shown in Figure 3. Direct path represents there is no obstacle between the launch and receiving station; Hop path includes reflection propagation and diffraction propagation.

For receiving station, its energy is contributed by a variety of rays. Because after hopping 3 times on the sea surface, the rays' energy have been very little, we just consider of direct rays and the rays that hop not more than 3 times. According to the electromagnetic simulation, we can obtain propagation characteristics of wireless channel and rays' path length, delay time and power at the receiver.

3. STOCHASTIC BRIDGE CHANNEL MODELING

The really propagation path of electromagnetic wave on the sea surface is uncertain. In mobile communications field, taking the multipath as a sample of random bridge process has been widely used [8–10]. Stochastic bridge is defined as followed: if the stochastic process $\{Y(t, \omega)\}$ meets the condition $\forall_0 \leq t \leq T$, and

$$Y_{0,r_0}^{T,r_1}(t, \omega) = r_0 + X(t, \omega) - \frac{t}{T}\left[X(T, \omega) - r_1 + r_0\right] \tag{1}$$

where, $Y_{0,w}^{T,w}(0, \omega) = r_0$, $Y_{0,w}^{T,w}(T, \omega) = r_1$, r_0 is the start point, and r_1 is the end point. Stochastic process $X(t, \omega)$ can be described by a stochastic differential equation. According to the different stochastic bridge variance and the number of paths, we can generate different samples of radio path. The parameter of the stochastic bridge is determined by the simulation of the electromagnetic.

We can get digital features of random variables on the basis of electromagnetic simulation based on GTD. Then, path length of random rays can be calculated. At last, We can obtain the time delay of the multipath component further. Under the condition of omni-directional antennas, assume that the direct signal $a_0 = 1$, multipath component amplitude (normalized) is as followed:

$$|a_{ij}| = \left(\frac{z_{ij}}{z_0}\right)^{-n/2} 10^{\frac{-1}{20}\left[\sum\limits_{k=0}^{i} L_{ijk} + L_{ij}\right]} \tag{2}$$

where, Z_{ij} is the path length, and i stands for hopping i times, j stands for the j-th multipath component; Z_0 is the length of direct wave; For free space $n = 2$; L_{ijk} include reflection loss and diffraction loss, when the ij-th multipath component occurs the k times hop; L_{ij} is the atmospheric absorption loss of the ij-th multipath component. According to the above analysis, expression of channel impulse response is:

$$h(t,\tau) = \sum_{i=0}^{N} \sum_{j=1}^{Mi} p_{ij} \left|a_{ij}\right| \delta\left(\tau - \tau_{ij}(t)\right) \tag{3}$$

where P_{ij} represents the phase delay, $P_{ij} = \exp(j2\pi Z_{ij}/\lambda)$, j is the imaginary number; λ is wavelength of radio wave, τ_{ij} is the time delay of the multipath component.

4. SIMULATED ANALYSIS

The electromagnetic simulation conditions is as followed: The incident wave is a plane wave and the vertical polarization; The radial direction is the connecting line of radiation sources and observation point. Source location is set at the elevation direction of 5 degrees, and the height of it is 40 km above the sea surface; The receiving station is 10 m above the sea surface; The incident wave frequency is 30 GHz; The electromagnetism emulational sea is level 1, level 3, and level 5. Through the many times electromagnetic simulation for every sea condition, the mean value of number of hop rays corresponding to different sea condition is shown as followed.

There almost have no rays that thought once, twice and triple reflection can reach the receiver. As shown in Table 1, Most of the arrival rays is once diffraction. When the sea is flat, there almost is no once reflection plus once diffraction rays. Because the reflection loss is much smaller diffraction loss, even if the number of once reflection plus once diffraction rays is less than once diffraction rays, the once reflection plus once diffraction rays have big disturbance on direct path as once diffraction rays.

We assume the amplitude of direct signal is 1. Direct signal is only under the influence of path loss, and its actual amplitude is $3.9866 * 10^{-10}$. Figures 4–6 show the the impulse response of all the multipath components except the direct signal. The time delay in Figures 4–6 is relative time delay that relative to direct path. The channel impulse response of multipath components that are through reflection to arrive at the receiver have random amplitude and relative delay. As shown in Figures 4–6, we can see that multipath components have the large disturbance on direct path. With the increase of time delay, the amplitude of multipath components decrease, and with the increase of the sea level, that is to say the fluctuation of sea level is more severe, the number of components increase, the time delay is longer.

In order to validate the established model, calculate the ratio of channel input signal and output signal, then compare with RCS value that exist in literature of electromagnetic scattering characteristics of sea surface. The stochastic bridge simulation results is basically the same with the conclusions of the existing literature. So, we can draw a conclusion that stochastic bridge model can describe the channel characteristic of sea surface scattering environment.

Table 1: The mean value of number of hop rays corresponding to different sea condition.

Sea condition	The mean value of number of hop rays			
	Once reflection plus once diffraction	Once diffraction	Twice diffraction	Triple diffraction
Level 1	1	316	27	57
Level 3	68	305	49	63
Level 5	47	229	37	29

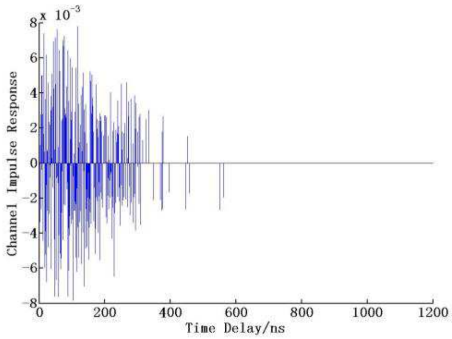

Figure 4: Channel impulse response of primary wave.

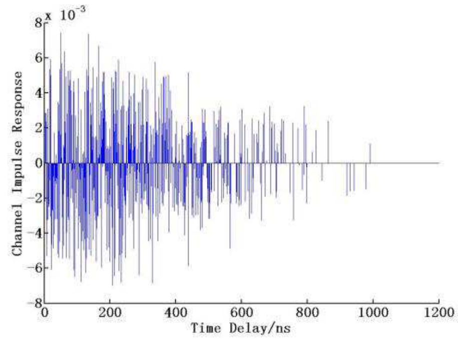

Figure 5: Channel impulse response of three stage wave.

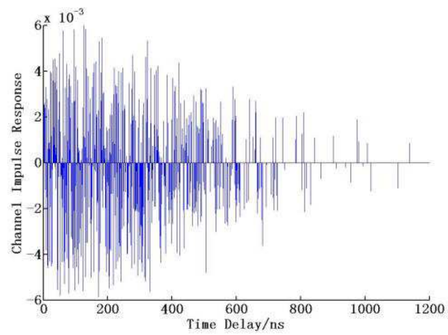

Figure 6: Channel impulse response of five level wave.

5. CONCLUSION

In this paper, we present a channel modeling technique based on GTD and stochastic bridge. At first, random rough ocean surface modeling present the displacement of sea surface under various wind speeds, and provide the basic for electromagnetic simulation of telecommunication channel. Then, electromagnetic simulation based on GTD algorithm present a huge data ocean surface reflection, scattering and diffraction, which determine the numerical characteristics of stochastic bridge and act as the samples for channel modeling. At last, a multipath channel model based on stochastic bridge provide the channel impulse response under typical ocean states. We can see clearly that the channel modeling technique we present do without a high requirement for experimental environment and conditions, and its calculation is less complicated compared with ray tracing method.

The simulations reveal that the established channel model can reflect the essential properties of radio waves propagation channel on the sea surface, and also can be verified its correctness. We can obtain the output signal based on the convolution of impulse response and the input signal, which may boost the usage of low elevation angle Ka or higher frequency satellite down-link radio propagation prediction and estimation.

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REFERENCES

1. Bullington, K., "Radio propagation at frequencies above 30 Megacycles," *Proceedings of the IRE — Waves and Electrons Section*, Vol. 10, 1222, 1946,.
2. Richads, J. A., *Radio Wave Propagation: An Introduction for the Non-specialist*, 6–10, Springer, 2008.

3. Hu, L. and H. Zhu, "Bounded brownian bridge model for UWB indoor multipath channel," *IEEE Int. Symp. on Microwave, Antenna, Propagation and EMC Technol. for Wireless Commun. Proc.*, 1406–1409, Beijing, China, Aug. 2005.
4. Mouche, A. A., B. Chapron, and N. Reul, "A simplified asymptotic theory for ocean surface electromagnetic wave scattering," *Waves in Random and Complex Media*, Vol. 17, No. 3, 321–341, 2007.
5. Kuga, Y. and P. Phu, "Experimental studies of millimeter-wave scattering in discrete random media and from rough surface," *Progress In Eletromagnetics Reseach*, Vol. 14, No. 1, 37–88, 1996.
6. Elfouhaily, T., B. Chapron, K. Katsaros, et al., "A unified directional spectrum for long and short wind-driven waves," *J. Geophys. Res.*, Vol. 102, 15781–15796, 1997.
7. Huang, H., D. Wang, and F. Liu, "Modeling of Ka-band mobile satellite channel and ber performance analysis," *Journal of University of Science and Technology of China*, Vol. 35, No. 3, 346–353, 2005.
8. Hu, L. Q., *Stochastic Modeling and Applications for Radio Wave Propagation,* Huazhong University of Science and Technology Press, 2011.
9. Primak, S., V. Kontorovitch, and V. Lyandres, *Stochastic Methods and Their Applications to Communications: Stochastic Differential Equations Approach*, John Wiley & Sons, Inc., NY, 2004.
10. Molisch, A. F., A. Kuchar, J. Laurila, et al., "Geometry-based directional model for mobile radio channels-principles and implementation," *European Transactions on Telecommunications*, Vol. 14, No. 4, 351–359, 2003.