A Modeling Method of Sea Surface Radio Channels based on EM Simulation

Changhao LI[1], Kaijie JIANG[2], Tao JIANG[3]

[1]College of Information and Communication Engineering,
Harbin Engineering University (Harbin 150001, China)
E-mail:lichanghao@hrbeu.edu.cn

[2]College of Information and Communication Engineering,
Harbin Engineering University (Harbin 150001, China)
E-mail:jiangkaijie@hrbeu.edu.cn

[3]Professor, College of Information and Communication Engineering,
Harbin Engineering University (Harbin 150001, China)
E-mail:jiangtao@hrbeu.edu.cn

With the development of marine resources and the expansion of marine transportation, marine wireless communication systems occupy an increasingly important position. A series of important progresses have been made in sea surface wireless communication following recent years of random rough sea surface radio wave propagation characteristics and experimental research.. In order to obtain a modeling technical solution suitable for microwave sea surface multi-path propagation, this paper introduces the stochastic bridge into the field of sea surface microwave channel modeling. It provided the sea surface electromagnetic model of different microwave frequency bands under typical sea conditions and obtained a large amount of simulation data. Then according to the stochastic bridge model, parameters in channel modeling are calculated based on those data. To verify the effectiveness of the stochastic bridge model for sea surface channel, the relationship between the model and the experimental model was analyzed.

Key Words : *sea surface****,*** *channel, stochastic bridge, electromagnetic simulation, stochastic rays*

1. INTRODUCTION

Usually, traditional radio channel modeling methods can be divided into two categories: one is the statistical model, which summarizes the statistical characteristics of the transmission environment[1], the other is the deterministic ray tracking model, which uses the rays transmitted from various propagation “nodes” in the scene to the receiver for direct calculation, obtain the amplitude and phase characteristics of the received signal. Compared with statistical models, deterministic models are accurate in modeling and can reliably predict system characteristics, but the calculations are complex, the statistical model can capture the instantaneous change of the channel response and the calculation difficulty is low, but the experimental conditions are very demanding.

At present, a new method to integrate the merits of the two modeling methods above has become a research hotspot in radio system channel modeling[2]. This paper intends to introduce the stochastic bridge process theory into the field of channel modeling on the sea surface, obtain the impulse response mathematical model which describes the stochastic multiple reflections of the channel, and provide support for the analysis of the sea surface channel characteristics.

2. BASIC WAVE THEORY

The electromagnetic wave propagation model and its related calculation play a key role in constructing the multi-path transmission model of the sea surface channel[3]. Most of the stochastic sea surface generation methods are based on the wave power spectrum model, among which the common method is based on the linear theory.

Geometric modeling of linear sea surface is realized by sea spectrum, so it is very important to select the appropriate model. For sea surface with low wind speed, P-M spectrum in simplified form has good reliability which is one of the reasons to use P-M spectrum in simulation of random radio waves[4].

The power spectral density of P-M spectrum can be expressed as

$$W_1(K)=\frac{\alpha}{4K^3}e^{-\frac{\beta g^2}{k^2U^4}} \tag{1a}$$

where α is coefficient, $\alpha=8.1\times10^{-3}$; $\beta=0.74$; g is gravitational acceleration, $g=9.81\text{m/s}^2$; K is the geometric spatial beam of the ocean surface wave; U is the average wind speed at 19.5 meters above sea level.

If stochastic bridge process satisfies $\forall 0\le t\le T$ its definition is

$$\left\{Y(t,\omega)\,|\,Y(0,\omega)=r_0,Y(T,\omega)=r_1,r_0,r_1\in R,0\le t\le T\right\} \tag{1b}$$

then $Y(t,\omega)$ satisfies the $Y(0,\omega)=r_0$, $Y(T,\omega)=r_1$. If $X(t,\omega)$ in the above formula is Brownian motion, then $Y(t,\omega)$ is Brownian bridge process[5].

Multi-path in wireless channel is regarded as a sample of random process in many research fields. In the process of electromagnetic wave propagation, there will be a large number of objects to scatter the signal, and considering the shape of these objects is irregular or the surface is not smooth, the signal propagation path will be more complex. In general, the spatial coordinates of the reflection points on the propagation path of the signal can be used to approximate the propagation path of the signal in the wireless channel. But in fact it is impossible to determine the true propagation path of a ray, so these propagation paths can be equivalent to a random process.

The multi-path channel stochastic bridge process modeling method is to combine the transmitter and receiver as the start and end of the stochastic bridge process, The *i-th* reflection point of the multi-path component is denoted as $P_i(x,y,z)$, it is a random variable. The path identified by each P_i value can be treated as a sample generated by the stochastic bridge process[6]. In practice, for a single ray, the result of this method will be different from the actual situation. Since there are many multi-path components that can be resolved in a channel, there are hundreds of multi-path components that can be resolved in a general channel, and the distribution of these multi-path components is non-overlapping and scattered. From a statistical point of view, the analysis of multiple paths of signal propagation as samples generated by a stochastic bridge process is consistent with the theory. In the study of multi-path propagation channel, the points at the transmitting antenna and the receiving antenna are taken as the starting point and end point of the stochastic bridge, then the path of the multi-path component in the channel can be processed as the stochastic bridge process. Fig.1 shows a sample of a stochastic bridge in three-dimensional space with a low number of jumps.

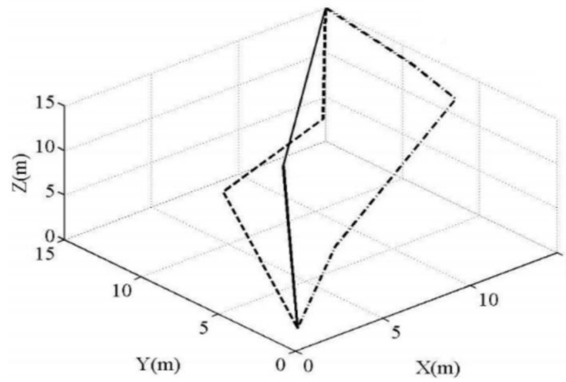

Fig.1 Sample of stochastic bridge process with low hops

3.CHANNEL MODELING METHOD

Brown-bridge stochastic modeling combines the characteristics of ray tracing method and statistical model. The amplitude can be determined by the path length of the random ray, and then the impulse response of the random multi-reflection model can be obtained to establish the channel model.

Take the distance of the Brown bridge sample in the L-dimensional space as a variable and denoted as Z_i ,which represents the length of the propagation path. The expression defining Z_i is as follows:

$$Z_i=\sqrt{\sum_{k=0}^{i}\left\{\sum_{l=1}^{L}\left[Y_l\left(t_{k+1},\omega\right)-Y_l\left(t_k,\omega\right)\right]^2\right\}} \tag{2a}$$

where $Y(t_k,\omega)$ is the time series sample generated by Brownian bridge process. The time delay τ_{ij} of the *j-th* multi-path component with the serial of reflections *i* can be expressed as

$$\tau_{ij} = \left(z_{ij} - z_{01}\right)/c \quad (2b)$$

where Z_{ij} is the track length of the *ij-th* multi-path component, c is the electromagnetic wave propagation speed.

Different distance samples of radio wave propagation can be obtained according to different stochastic bridge variance and number. In this paper, digital features of stochastic bridge can be obtained by the following method: first of all to establish sea condition the surface geometry of the linear and nonlinear model, and then according to the propagation environment of electromagnetic simulation for many times, and then extract the statistical characteristics of random ray time-varying environment, the mathematical expressions of samples of stochastic bridge of random ray space is used to determine the electromagnetic wave propagation path length, so as to determine the time delay distribution.

Based on the two-dimensional electromagnetic calculation model of rough sea surface, the information of the random effective rays is analyzed, and the statistical distribution of the relative time delay of the random rays is obtained, and then the variances corresponding to different jump times of the stochastic bridge process are fitted.

Under the condition of an omnidirectional antenna, the amplitude of the *j-th* multi-path component undergoing *i* reflections in the channel is expressed as

$$\left|a_{ij}\right| = \left(z_{ij}/z_0\right)^{-\frac{n}{2}} 10^{\frac{\left(\sum_{k=0}^{i} L_{ijk} + L_a + L_r\right)}{-20}} \quad (2c)$$

where i is the serial of reflections when a certain multi-path component propagates, j is the *j-th* multi-path in the case of i reflections, k is the reflection of the *ij-th* multi-path component, n is the path loss index, L_a is the atmospheric absorption loss, L_r is rain and fog loss, which is related to rainfall intensity, L_{ijk} is the reflection loss when the *ij-th* multi-path component and obstacles are reflected at the *k-th* time. To calculate the reflection loss, the reflection coefficient of the electromagnetic wave on the sea surface should be calculated first. Specular reflection occurs when radio waves incident from the atmosphere into the sea at a wavelength much smaller than that of ocean waves. Reflection coefficient determines the intensity of the electric field of the reflected wave, which is related to the incident angle and polarization mode of the wave as well as the dielectric constant of the sea water.

It can be known from the time delay and amplitude of the multi-path component, the time domain model of the multi-path channel is expressed as follows

$$h(t) = \sum_{l=0}^{N}\sum_{k=0}^{M} a_{k,l} \exp\left(j\varphi_{k,l}\right)\delta\left(t - T_l - \tau_{k,l}\right) \quad (2d)$$

where N is the total number of clusters of the signal, M is the total number of multi-paths, $\alpha_{k,l}$ is the signal amplitude, $\phi_{k,l}$ is the signal phase, T_l is the arrival delay of the *l-th* cluster signal, $\tau_{k,l}$ is the time delay relative to the *l-th* cluster signal.

4.SIMULATION RESULTS

The stochastic bridge random modeling method is used for the channel model, and the simulation parameters selected are as follows: the salinity of sea water is 35%, the temperature is $13°C$, the sea state is level 4, the incident wave is a plane wave, the incident angle is $2°$, the direct radio wave propagation distance is 10 km, and the height of the receiving antenna is 10 m.

The radio wave propagation characteristics on the random sea surface are the result of the interaction between the incident wave and the rough surface. Different sea level and the wind direction over the sea surface will affect the roughness of the sea surface, and then affect the information of the reflection and diffraction rays on the sea surface.

The wind speed is determined according to the table of sea conditions, and the wave characteristics are changed through frequency spectrum and angle number to set the simulation area of sea surface, through calculation, a local wave model can be obtained, as shown in Fig.2.

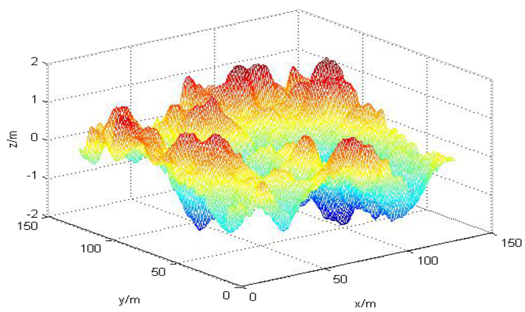

Fig.2 Model of waves under four sea conditions

Simplify and optimize the electromagnetic model of the ocean wave model, and perform electromagnetic simulation.

Take the multi-path reflection of radio waves in typical sea conditions as a sample of stochastic bridges. The direct path only needs to consider the propagation loss in free space, while for multi-path transmission, the reflection loss needs to be considered in addition to the space propagation loss. Fig.3 shows the power delay profile for multiple reflection paths. The delay in the figure is the delay of the diffraction path relative to the direct signal.

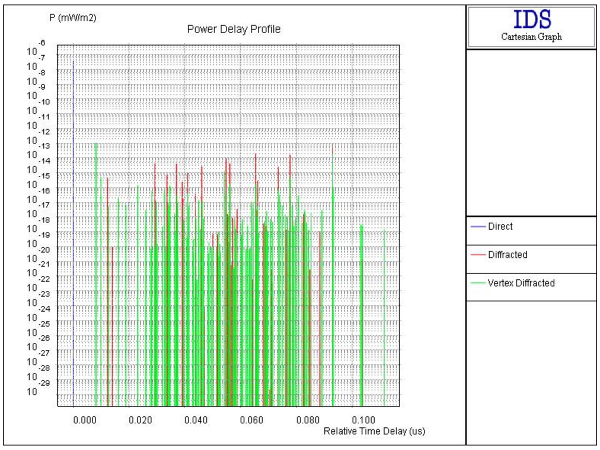

Fig.3 The power delay profile

Calculate the ratio of the channel input signal to the output signal field, and compare it with the RCS value in the electromagnetic scattering characteristics of the sea surface and the external field test results in the existing literature. The incident wave frequency is 12GHz. The scattering coefficient calculated by stochastic bridge channel modeling is -6.5dB, and the external field test result is -5dB, It shows that the stochastic bridge model can describe the channel characteristics of the sea surface scattering environment.

5.CONCLUSIONS

In this paper, the stochastic bridge process theory is introduced into the modeling field of sea surface microwave channel. The multi-path propagation trajectory of electromagnetic wave in channel is regarded as the sample of the random process, and the wave propagation characteristics in sea surface channel are studied. Experimental results show that the established channel model can more accurately reflect the nature of the channel characteristics and can effectively perform the simulation of the receiving waveform. It proved that it method of modeling two-dimensional surface microwave channel is feasible by using stochastic bridge theory, even in complex electromagnetic environment. It is an effective means of theory and technology for ship electronic equipment receiving waveform modeling and simulation.

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