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The spread of radio waves on the calm ocean surface

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Abstract: This paper studies the propagation of radio waves in different environments and the variation of antenna gain caused by sea surface fluctuation. Due to the characteristics of the contact surface, obstacles and other factors, radio waves will have different losses. Based on the geometry of the ocean waves, we simulated surface waves using geometric curves and geometric surfaces. Then, we use the free propagation model and the reflection model to simulate the propagation of radio waves in the background of sea clutter and calculate the maximum hop count of 6.

Keywords: Free space propagation, reflection model, multipath fading model.

1. Introduction

It can be seen from the literature that the loss of radio waves mainly comes from two aspects. One is the loss in the propagation path and the other is the loss of the refraction, scattering and reflection on the contact surface. The electric wave is affected by the interface between the medium and the medium, resulting in phenomena of reflection, scattering, refraction, diffraction and absorption and changing the parameters of the electric wave, such as amplitude, phase, polarization propagation direction and so on.

We first set up a wave model to prepare for calculating the loss. Then we use the free space propagation model to calculate the loss in the path. Since the subject is said to focus on the reflection loss at the sea surface, we assume that the loss in the ionosphere is negligible.

2. Mechanical Analysis

Antenna is set up on the launch point on land to transmit signals and reach the receiving point through multiple reflections from the ionosphere and sea surface. In the calm sea scenario, additional reflections, from 2 to n, occur in the calm sea. The maximum number of times is the number the land-launched signal can reflect on the sea above SNR 10 dB.

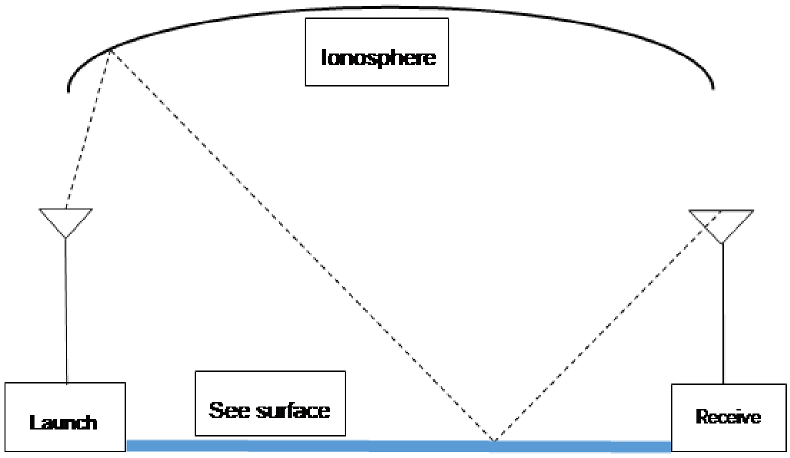

Fig. 1 Radio wave propagation diagram

2.1 Free-space model

2.1.1 definition

Table 1 Definition of sea waves model's variables

signs	definitions
PR(d)	Receiving power
Pt	Emissive power
Gt	Antenna gain
Gr	Receive antenna gain
d	distance
L	Loss factor of system (independent of propagation distance)
λ	wavelength

2.1.2 Analysis

we use the free-space model to calculate the signal loss in air propagation. If the radiation power of an isotropic antenna is PT, the antenna receiving power will be

$$P_R(\mathrm{d}) = \frac{P_T G_T G_R \lambda^2}{(4\pi)^2 d^2 L} \tag{1}$$

Transmitters transmit signals. After the spread of a distance of d meters, power loss due to radiation is known as the path loss. Path loss is defined as the difference between the effective transmit power and receive power:

$$PL(\mathrm{dB}) = 10\lg\frac{P_T}{P_R} = -10\lg\left[\frac{\lambda^2}{(4\pi)^2 d^2}\right] \tag{2}$$

We use matlab to draw the path loss with distance under different frequencies. In the figure, we can see that at different frequencies, the path loss increases logarithmically as the distance increases. The free space path loss is very large.

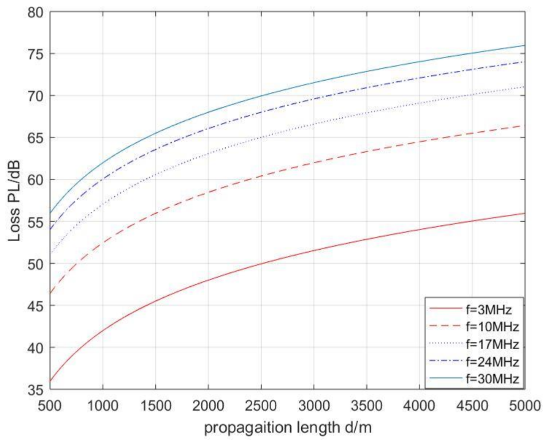

Fig. 2 Path Loss

2.2 Reflection model

The smooth interface of two different media encounters reflections in the radio wave propagation. In wireless communication, the incident wave will reflect at the interface because the atmosphere and the earth are different media. Reflections also produce loss:

$$PL(\mathrm{dB}) = 40\lg \mathrm{d} - (10\lg \mathrm{G}_T + 10\lg \mathrm{G}_R + 20\lg \mathrm{h}_t + 20\lg \mathrm{h}_r) \tag{3}$$

The height and angle at which reflections are reflected in calm waters and turbulent waters are different. And because of changes in salinity, there is also a small range of sea water conductivity and permittivity. We ignore the secondary factors, consider the height and angle of the impact on the reflection intensity.

$$h_{r(calm\_sea)} = h_t + 10\sin(40\,\mathrm{d} \times \alpha \times \mathrm{rand}()) \tag{4}$$

$$PL_{(calm\_sea)}(\mathrm{dB}) = 40\lg \mathrm{d} - (20\lg h_t + 20\lg h_{r(calm\_sea)}) \tag{5}$$

$$h_{r(turbulent\_sea)} = h_t + a^{\alpha \sin 40d} \tag{6}$$

$$PL_{(turbulent\_sea)} = 40\lg d - (20\lg h_t + 20\lg h_{r(turbulent\_sea)}) \tag{7}$$

We can see the difference between the first reflection intensity in the calm sea area and the turbulent sea area, the reflection in calm sea area is more stable, and the turbulence area shows a regular fluctuation. (PS/PN)i,(PS/PN)o are the input and output signal power and noise power ratio.

SNR is defined as:

$$N_F = 10\lg\left[\frac{(P_S / P_N)_i}{(P_S / P_N)_o}\right] \tag{8}$$

Based on the definition of the reflection loss and the SNR of the calm sea before, we calculated that the number of multi-hops on a calm sea surface was 6 times.

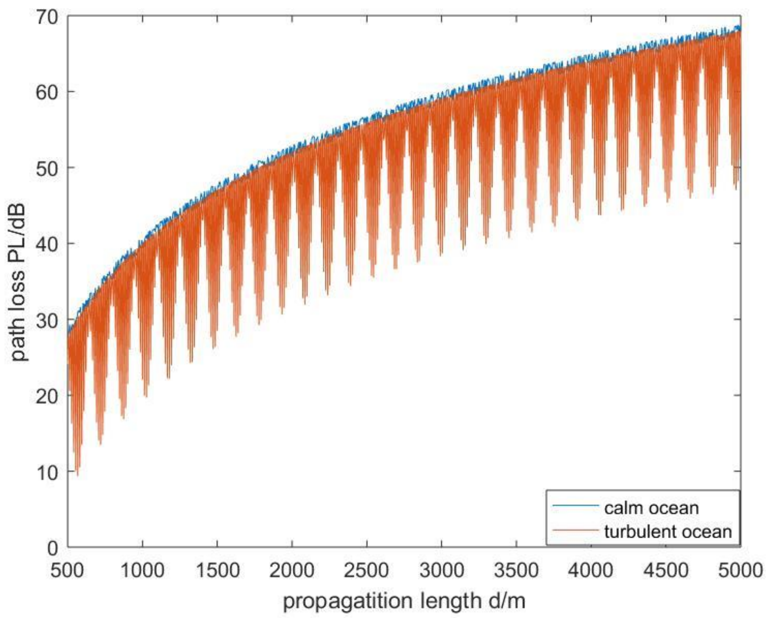

Fig.3 The reflaction loss of calm sea and turbulent

2.3 Multipath fading model

It can be learned in the wireless multipath signal, the signal impulse response can be expressed as:

$$h[k,n]=\sum_{l=0}^{L-1}h_l[n]\cdot\delta[k-\tau_l[n]] \tag{9}$$

$$\delta[k]=\begin{cases}0, & k\neq 0\\ 1, & k=0\end{cases} \tag{10}$$

$$k=0,1,2\ldots K-1, K\geq \max_l\{\tau_l\}\ n=0,1,2\ldots N-1\ l=0,1,2\ldots L-1$$

Considering the time-varying characteristics of noise and signal, the actual measurement results of the signal are:

$$r[k,n]=\sum_{m=0}^{M-1}h[k-m,n]\cdot g[m]+u[k,n] \tag{11}$$

represents the actual received signal after the unit pulse is transmitted through the filter, the signal and the receive filter in the nth sampling, and is a binary function of k and n. g[m] is the equivalent representation of the transmit and receive filters, is the order of the filter. denotes the complex Gaussian white noise introduced at the kth sampling point in the nth sample. For the fixed reference sample n, the n-th sampling process analysis, for reception waveform, can be simplified as the following formula:

$$r[k] = \sum_{m=0}^{M-1} h[k-m] \cdot g[m] + u[k] \quad (12)$$

The convolution process is converted to a product in the form of a matrix, can be obtained:

$$r^{(n)} = H^{(n)} \cdot G + \mu^{(n)} \quad (13)$$

It can be determined using the least squares method to the actual channel impulse response:

$$H^{(n)} = r^{(n)} \cdot G^{+} \quad (14)$$

$$G^{+} = (G^{H} G + I_{K})^{-1} \cdot G^{H} \quad (15)$$

G^{+} is the pseudo-inverse of the filter matrix, G^H is the order unit matrix.

3. Conclusion

Ignoring the loss of radio waves reflected by the ionosphere, we calculate a maximum hops of 6. The reflection in calm sea area is more stable, and the turbulence area shows a regular fluctuation. By the same token, comparing the propagation distance of radio waves between smooth terrain and rough terrain, the former propagates more distance.

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