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T2 ________		F2 ________
T3 ________	Problem Chosen	F3 ________
T4 ________	**A**	F4 ________

2018
MCM/ICM
Summary Sheet

Summary

The communication of high frequency wave on sea is essential in our life but the problem about reflection with several hops for turbulent ocean is not solved.

This paper only considers the basic propagation which includes free-space propagation loss, ionosphere reflection loss, reflection surface loss and extra system loss. For every kind of loss, the specific provements and calculations is described including the provement of reflrction coefficient for vectical and horizantal polarization expecially.

For part I, the situation of one hop is discussed firstly in the paper, which uses different calculation model to express the reflection cofficient for calm ocean and turbulent ocean as well as comparing the differences between the results of simulation. After that, the model and algotithm is come out to calculate the number of hop with assumed parameters.

For part II, according to the characteristic of smooth terrain and rugged terrain, the method to calculating the coefficient is modified while the other models is the same as for part I. Then the difference between four kinds of reflection surface is analyzed by the results of calculation and the relation curve.

For part III, in order to deal with the angle after diffuse reflection, modified Markov process with first-order self-regression model is used in this paper and the relation between SNR and hop, the angle of emission, the frequency as well as power of wave is analyzed detailedly by the results of simulation using modified Markov process with first-order self-regression model. Moreover, the measures to enhance the communication on turbulent ocean is come out and the optimal frequency of wave, the angle of emission are given in the results

Finally, the strengths and weaknesses of these models in this paper is discussed .

Synopsis

High frequencies(HF, defined as 3-30 MHz) radio waves can travel long distance by multiple reflections off the ionoshere and off the earth with sussessive hop. The transmission attenuation of radio wave is an essential problem in engeering when facing different kinds of reflective surface and change of the ionosphere. This paper is focus on the research of characteristics of reflective suface on ocean and terrain with the ionoshere is even distributed and gives the specific analysis and conclusion.

Firstly, there are various factors which influence the attenuation in the transmission process from transmitter to receiver. Considering that the given problem, the basic transmission which includes free-space propagation loss, ionosphere reflection loss, reflection surface loss and extra system loss is analyzed detailedly while the others is ignored. For every kind of loss, the specific provements and calculations is described in the paper including the provement of reflrction coefficient for vectical and horizantal polarization expecially. In fact, the situation on the reflective surface is the most important problem in view of the research topic, and that's why the complex provements of reflective coefficient, Rayleigh criterion and diffuse reflection are analyzed thoroughly in this article.

For the condition on calm ocean and turbulent ocean with one hop, the coeffiecient can be modified with the diffuse reflection factor which is relevant to the characteristics of surface. Generally, the calculation of diffuse reflection factor can be found by real data. In this paper, the calculation functions which denote the character of surface such as soil and sea water is cited from other researches. Conclusion can be drawn that for one hop, the attentuation on turbulent ocean is larger than that on calm ocean from the results of simulation using the previous calculation model and function, which is also estimated empirically to be correct. As for the sussessive hop on the calm ocean, the situation can be taken as specular reflection and thus the angle of emission of each hop will not change. By assuming parameters and contraling the effective distance of radio wave, original angle being changed with effective distance, the maximum hop is 2 which is easily seen from the given curve in the paper.

When dealing with smooth and rugged terrain, the calculation model is almost the same except the modified coefficient function which is also got from the results of other researches. Then by comparing the four kinds of reflective surface using the data from simulation with the same parameters, conclusion is that:
with the increase of frequency,

$$SNR_{rugged\,terrain} \lessapprox SNR_{turbulent\,ocean} \lessapprox SNR_{smooth\,terrain} \lessapprox SNR_{calm\,ocean}$$

when the angle of emission and the power of electromagnetic wave is constant.
with the increase of the angle of emission,

$$SNR_{turbulent\,ocean} \lessapprox SNR_{rugged\,terrain} \lessapprox SNR_{smooth\,terrain} \lessapprox SNR_{calm\,ocean}$$

when the power and frequency of electromagnetic wave is constant.

As for the sussessive hop on turbulent ocean, the angle of elevation will change after each hop. And because of the diffuse reflection is hard to predict, the angle will change randomly. Therefore, the calculation model on calm ocean for n hops is no longer effective for this problem. A new model, modified Markov process with first-order self-regression, is come out in this paper. The angle of elevation after each hop can be got by the last angle combining the transfer probality and random factor in this new model, which can describe the charateristics of turbulent ocean that wave height, shapes, and frequencies change rapidly as well as the direction of wave being changed.

By analyzing the relation between SNR and the original angle of emission, the frequency as well as power of electromagnetic wave respectively through the data of simulation while controling other parameters and varibles, conclusion can be drawn that:

• the larger original angle of transmission is, the more stable electromagnetic wave will be after the same times of diffuse reflection;

• the larger frequency of electromagnetic wave is, the more stable and more strong electromagnetic wave will be;

• the larger frequency of electromagnetic wave is, the more stable and more strong electromagnetic wave will be.

According to relation curve between the SNR and other factors, thers is a optimal problem for increaseing the time to remain in communication, which is $15\,MHz$, $60°$ except the power of electromagnetic wave.

Keywords: **Modified reflection coefficient ; SNR ; Sussessive hop ;**

Modified Markov process ; first-order self-regression

Contents

1 Introduction and assumption

1.1 Introduction

High frequencies(HF, defined as 3-30 MHz) radio waves can travel long distance by multiple reflections off the ionoshere and off the earth with sussessive hop. The transmission attenuation of radio wave is an essential problem in engeering when facing different kinds of reflective surface and change of the ionosphere. This paper is focus on the research of characteristics of reflective suface on ocean and terrain with the ionoshere is even distributed and gives the specific analysis and conclusion.

1.2 Assumptions

In oeder to simply the difficulty of the problem compared with real life, there are several assumptions for the convinient analysis of calculation model.

(a) The earth is considered as a ball
(b) The distribution of ionosphere and stratosphere is even.
(c) The refraction of electromagnetic wave in the stratosphere and the transmit of wave in atmosphere are ignored
(d) The electromagnetic wave is circularly polarized waves.
(e) The height of transmitter and receiver is ignored.
(f) The gains of transmitter and receiver are 1.
(f) The change of ionosphere with seasons, weather, and other factors is ignored.

2 Propagation attenuation calculation model

In the whole transmission process of HF wave from transmitter to receiver, there are all kinds of attenuation reasons which cause the loss of signal strength.

However, considering that this problem focuses on the basic propagation loss[1] in space, the free-space propagation loss ,ionospere absorption loss ,reflecting surface loss and extra systerm loss are taken into account and other factors are ignored in the analysis of propagation attenuation.

$$L_b = L_{fr} + L_i + L_s + L_e \tag{1}$$

where, L_b is the basic transmission loss, L_{bf} is free-space progagation loss, L_i is the ionospere absorption loss, L_s is the reflecting surface loss, L_e is extra extra systerm loss and their unit is dB.

The differences of absolute signal strength and relative signal strength, the calculation of 4 kinds of basic propagation loss as well as the calculation of usable signal-to-noise ratio(SNR) are in the following analysis

2.1 Relative signal strength and absolute signal strength

The unit of the relative signal strength is dB which only indicate the relative size of different powers. The calculation is given by[2]:

$$L_1 = 10 \lg \frac{P_1}{P_2} \tag{2}$$

where, L_1 is the relative signal strength, P_1 and P_2 are the power of two waves . Taking an example to explain the meaning of the L, if the power of wave α_1 is $100W$ and α_2 is $50W$, then $L_1 = 10 \lg 2 = 3$ dB, which means the stength of α_1 is 3 dB higher than α_2.

The unit of the absolute signal strength is dBm which describles the absolute scalar of power compared with $1mW$. The calculation is given by[2]:

$$L_2 = 10 \lg \frac{P}{1mW} \tag{3}$$

where, L_2 is the absolute signal strength, P is the power of a specific wave. If the power of wave α_1 is $100W$, then $L_2 = 10 \lg 100000 = 50$ dBm.

The relation of relative signal strength and absolute signal strength is as follows:

$$L_1 = L_2' - L_2'' \tag{4}$$

2.2 Free-space progagation loss

As the distance increases, the energy of HF wave diffuses to large sphere in the transmission process, which causes the decline of power flow density,resulting in the free-space progagation loss. And free-space progagation loss is the most important factor for transmisson atteuation.

According to the Frii Free-space Equation, if the electromagnetic is spherical waves, the power of receiver is expressed as[3]:

$$P_r(d) = \frac{P_t G_t G_r \lambda^2}{(4\pi)^2 r^2 L} \tag{5}$$

where, P_t is the power of transmitter, G_t G_r are the antenna gains of transmitter and receiver respectively, λ is the wavelength of electromagnetic wave, r is the efffective transmission distance, L is the factor of the extra sysmtem loss which is irrelevent with the process of transmission.

Further, the loss of free-space transmission is as follows:

$$P_{less} = 10 \lg P_t / P_r = - \lg \frac{G_t G_r \lambda^2}{(4\pi)^2 r^2 L} \tag{6}$$

With $\lambda = c/f$, the final calculation expression after simplification is given by:

$$L_{fr} = 32.44 + 20 \lg f + 20 \lg r \tag{7}$$

where, f is the frequency of electromagnetic wave and unit is MHz, r is the effective transmission path of electromagnetic wave and unit is Km.

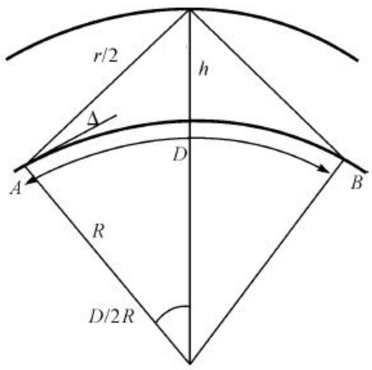

Figure 1: The explaination of one hop[4]

As can be seen in Figure, according to the Cosine theorm and Sine theorem

$$(\frac{r}{2})^2 = R^2 + (R+h)^2 - 2R(R+h)\cos\frac{D}{2R} \tag{8}$$

$$\Delta = \frac{\pi}{2} - \arcsin(\frac{R+h}{r}\sin\frac{D}{2R}) \tag{9}$$

where D is denoted as the length of $\overset{\frown}{AB}$, the below Formula describles the calculation method, Δ is the angle of emission.

$$D = R\arccos c \tag{10}$$

$$c = \sin(LatA)\sin(LatB) + \cos(LatA)\cos(LatB)\cos(LonA - LonB) \tag{11}$$

where, $LatA$ is the lattitude of A, $LonA$ is the longitude of A, $LatB$ is the lattitude of B, $LonB$ is the longitude of B.

2.3 Ionospere absorption loss

when electromagnetic wave transmits cross the ionoshere, the part energy of wave is absopted, causing ionoshere absorption loss which is second important factor for propagation attenuation. The empirical calculation formula is as follows[1].

$$L_i = I\frac{677.2\sec\phi}{(f+f_H)^{1.98} + 10.2} \tag{12}$$

where, f is the frequency of electromagnetic wave, f_H is the magnetic rotation frequency at the height of H, I is absorption coefficient and ϕ is electromagnetic wave incident angle. Generally, f_H can be got by searching the information about the latitude of the receiver and the unit is MHz.

The formulas of I and ϕ are described as follows[1]:

$$I = (1 + 0.0037\bar{R_{12}})(\cos 0.081x)^{1.3} \tag{13}$$

$$\phi = \arcsin(0.985\cos\delta) \tag{14}$$

where, $\bar{R_{12}}$ is 12 months moving average sunspot and x is the top angle of the sun which both of them need to check the related data in geography.The following table[5] is about the 12 months moving average sunspot.

	January	February	March	April	May	June	July	August	September	October	November	December	Average
2009	1.76	1.92	2.19	3.02	3.73	4.29	4.88	5.47	6.15	7.00	8.19	9.75	4.86
2010	11.81	14.56	17.35	19.78	22.69	27.02	32.13	36.83	40.60	43.71	45.97	47.52	30.00
2011	49.11	50.88	52.99	55.52	57.67	58.03	56.58	54.81	53.98	54.37	55.74	57.58	54.77
2012	59.42	61.08	62.60	64.25	67.05	71.47	77.70	85.43	91.71	95.19	98.39	102.39	78.06
2013	104.77	104.74	103.99	102.85	100.25	96.92	94.22	90.98	88.01	86.87	85.09	81.15	94.99
2014	77.99	77.28	76.76	75.93	76.76	77.96	76.48	73.67	71.42	68.82	66.03	64.27	73.61
2015	63.51	62.40	60.90	58.26	53.81	48.94	44.95	41.96	40.05	39.23	38.37	37.18	49.13
2016	35.25	33.35	31.53	31.06	31.05	30.91	31.31	31.22	29.86	28.02	26.83	25.92	30.55
2017	25.01	25.07	25.62	24.93	23.18	21.17	19.07	17.46	16.39	15.57	14.74	14.08	20.19
2018	12.99	10.84	8.28	6.95	6.69	6.52	6.24	6.05	6.26	6.55	6.49	6.00	7.49
2019	5.61	5.65	5.81	7.59	7.59	9.04	10.68	12.19	13.38	14.45	15.55	16.51	10.24

2.4 Reflecting surface loss

Surface can be divided into smooth surface and rough surface according to the roughness degree of reflective surface. On a smooth flat surface, the specular reflection is dominant. On a rough surface, diffuse reflection is dominant. The detailed analysis of smooth surface and rough surface is in the following text.

2.4.1 smooth surface reflection

When the reflection surface is smooth,the oblique incident wave can be divided into 2 circumstances. One is horizontal polarization which means the electric field vector is located in the plane of incidence. And the other is vertical polarization, the electric field vector being perpendicular to the incident surface. Our analysis about these two conditions are as follow.

(a). vertical polarization

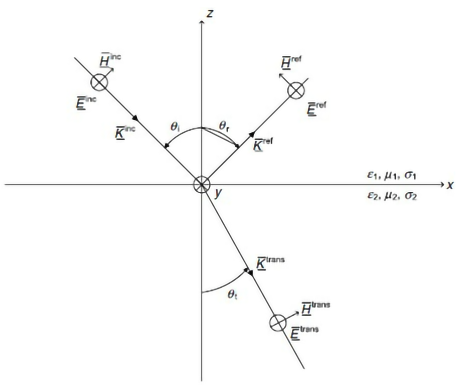

Figure 2: vertical polarization

The incident, reflected and transmitted wave vector in the coordinate system when the polarization is vectical are denoted as

$$k^{inc} = \hat{x}k_x^{inc} - \hat{z}k_z^{inc} = \omega\sqrt{u_1\varepsilon_1^e}(\hat{x}\sin\theta_i - \hat{z}\cos\theta_i) \tag{15}$$

$$k^{ref} = \hat{x}k_x^{ref} + \hat{z}k_z^{ref} = \omega\sqrt{u_1\varepsilon_1^e}(\hat{x}\sin\theta_r + \hat{z}\cos\theta_r) \tag{16}$$

$$k^{trans} = \hat{x}k_x^{trans} - \hat{z}k_z^{trans} = \omega\sqrt{u_2\varepsilon_2^e}(\hat{x}\sin\theta_t - \hat{z}\cos\theta_t) \tag{17}$$

In the meantime, the incident, reflected and transmitted wave electric fields are expressed as

$$E^{inc} = \hat{y}E_{0,\perp}e^{-jk_{inc}*\Gamma} \tag{18}$$

$$E^{ref} = \hat{y}\Gamma_\perp E_{0,\perp}e^{-jk_{ref}*\Gamma} \tag{19}$$

$$E^{trans} = \hat{y}T_\perp E_{0,\perp}e^{-jk_{trans}*\Gamma} \tag{20}$$

The total electric field in both media is denoted repectively as

$$E_1 = E^{inc} + E^{ref} \tag{21}$$

$$E_2 = E^{trans} \tag{22}$$

By the relation

$$H = \frac{1}{\omega\varepsilon}k \times E \tag{23}$$

Therefore, H^{inc}, H^{inc} and H^{trans} can be expressed respectively as

$$H^{inc} = \frac{\hat{x}k_z^{inc} + \hat{z}k_x^{inc}}{\omega u_1}E_{0,\perp}e^{-jk_{inc}*\Gamma} \tag{24}$$

$$H^{ref} = \frac{-\hat{x}k_z^{inc} + \hat{z}k_x^{inc}}{\omega u_1}\Gamma_\perp E_{0,\perp}e^{-jk_{ref}*\Gamma} \tag{25}$$

$$H^{trans} = \frac{\hat{x}k_z^{trans} + \hat{z}k_x^{inc}}{\omega u_2}T_\perp E_{0,\perp}e^{-jk_{trans}*\Gamma} \tag{26}$$

The total magnetic field in both media is denoted repectively as

$$H_1 = H^{inc} + H^{ref} \tag{27}$$

$$H_2 = H^{trans} \tag{28}$$

Then applying the boundry condition at $z = 0$, equations are as follows

$$1 + \Gamma_\perp = T_\perp \tag{29}$$

$$(1 - \Gamma_\perp)\frac{k_z^{inc}}{\omega u_1} = T_\perp\frac{k_z^{trans}}{\omega u_2} \tag{30}$$

By solving above equations, the vetical polarization reflection coefficient can be got finally.

$$\Gamma_\perp = \frac{u_2k_z^{inc} - u_1k_z^{trans}}{u_2k_z^{inc} + u_1k_z^{trans}} \tag{31}$$

$$T_\perp = \frac{2u_2k_z^{inc}}{u_2k_z^{inc} + u_1k_z^{trans}} \tag{32}$$

(b). horizontal polarization

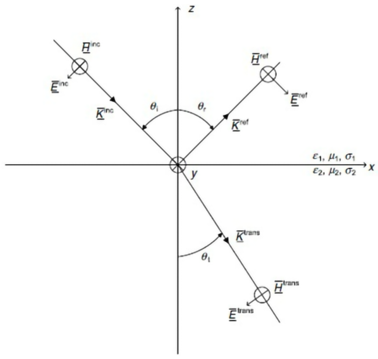

Figure 3: horizantal polarization

$H_{||}^{inc}$, $H_{||}^{inc}$ and $H_{||}^{trans}$ in the coordinate system when the polarization is horizantal can be expressed as

$$H_{||}^{inc} = \hat{y}\frac{E_{0,||}}{\eta_1}e^{-jk_{inc}*\Gamma} \tag{33}$$

$$H_{||}^{ref} = \hat{y}\frac{\Gamma_{||}E_{0,||}}{\eta_1}e^{-jk_{ref}*\Gamma} \tag{34}$$

$$H_{||}^{trans} = \hat{y}\frac{T_{||}E_{0,||}}{\eta_2}e^{-jk_{trans}*\Gamma} \tag{35}$$

The total magnetic field in both media is denoted repectively as

$$H_1 = H_{||}^{inc} + H_{||}^{ref} \tag{36}$$

$$H_2 = H_{||}^{trans} \tag{37}$$

By the relation

$$E = -\frac{1}{\omega\varepsilon}k \times H \tag{38}$$

Therefore, E^{inc}, E^{inc} and E^{trans} in the coordinate system can be expressed as

$$E^{inc} = \frac{-\hat{x}k_z^{inc} - \hat{z}k_x^{inc}}{k_1}E_{0,||}e^{-jk_{inc}*\Gamma} \tag{39}$$

$$E^{ref} = \frac{\hat{x}k_z^{inc} - \hat{z}k_x^{inc}}{k_1}\Gamma_{||}E_{0,||}e^{-jk_{ref}*\Gamma} \tag{40}$$

$$E^{trans} = \frac{-\hat{x}k_z^{trans} - \hat{z}k_x^{inc}}{k_2}T_{||}E_{0,||}e^{-jk_{trans}*\Gamma} \tag{41}$$

The total electric field in both media is denoted repectively as

$$E_1 = E^{inc} + E^{ref} \tag{42}$$

$$E_2 = E^{trans} \tag{43}$$

Applying the boundry condition at $z = 0$, equations are as follows.

$$1 + \Gamma_{||} = T_{||}\frac{\eta_1}{\eta_2} \tag{44}$$

$$(1 - \Gamma_{||})\frac{k_z^{inc}}{k_1} = T_{||}\frac{k_z^{trans}}{k_2} \tag{45}$$

By solving the above equations, the horizatal polarization reflection coefficient can be got finally.

$$\Gamma_{||} = \frac{\varepsilon_2^e k_z^{inc} - \varepsilon_1^e k_z^{trans}}{\varepsilon_2^e k_z^{inc} + \varepsilon_1^e k_z^{trans}} \tag{46}$$

$$T_{||} = \frac{2\varepsilon_2^e k_z^{inc}\eta_2}{(\varepsilon_2^e k_z^{inc} + \varepsilon_1^e k_z^{trans})\eta_1} \tag{47}$$

(c). the reflection coefficient of the surface

If the reflection surface is non-magnetic media, then $u_1 = u_2$. Considering the relationship in the coordinate system

$$k_z^{inc} = \omega\sqrt{u_1\varepsilon_1^e}\cos\theta_i \tag{48}$$

$$k_z^{trans} = \omega\sqrt{u_2\varepsilon_2^e - u_1\varepsilon_1^e\sin^2\theta_i} \tag{49}$$

The reflection coefficients of vertical and horizontal polarization on the smooth surface are expressed as follows.

$$\Gamma_{\perp} = \frac{\cos\theta_i - \sqrt{\varepsilon_2^e/\varepsilon_1^e - \sin^2\theta_i}}{\cos\theta_i + \sqrt{\varepsilon_2^e/\varepsilon_1^e - \sin^2\theta_i}} \tag{50}$$

$$\Gamma_{||} = \frac{\varepsilon_2^e/\varepsilon_1^e\cos\theta_i - \sqrt{\varepsilon_2^e/\varepsilon_1^e - \sin^2\theta_i}}{\varepsilon_2^e/\varepsilon_1^e\cos\theta_i + \sqrt{\varepsilon_2^e/\varepsilon_1^e - \sin^2\theta_i}} \tag{51}$$

Because of the assumption that incident electromagnetic wave is the circularly polarized wave, the scalars of vertical and horizontal polarization are equal. Therefore, the fomula of reflection coefficient is as follows.

$$\rho_0 = \frac{|\Gamma_{\perp}|^2 + |\Gamma_{||}|^2}{2} \tag{52}$$

where ρ_0 is the reflection coefficient of smooth surface.

Then, the reflection loss on the smooth surface is described in Formula and unit is dB.

$$L_s = -10\lg\rho_0 \tag{53}$$

2.4.2 Rayleigh Criterion

Actually, there is no absolutely smooth surface in reality. In order to judge the relative flatness of the surface, Rayleigh came out a criterion. As can be seen in Figure 4, there is a beam of parallel electromagnetic casting to the rugged ground. Ray ① reflects at the

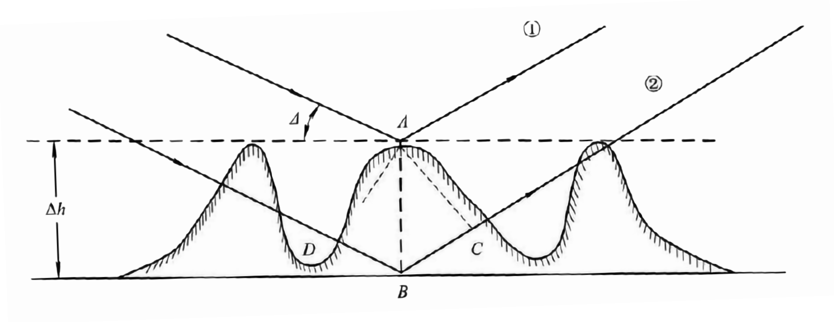

Figure 4: The reflection on rough surface

point A and Ray ② reflects at the point B. Because of the different propagation path of the two rays, there is a phase difference when they arrive at the receiving point, which are described respectively as follows.

$$\Delta r = 2\Delta h \sin\Delta \tag{54}$$

$$\Delta\psi = \frac{2\pi}{\lambda}\Delta r = 4\pi\Delta h\frac{\sin\Delta}{\lambda} \tag{55}$$

where, λ is the wavelength, h is the undulating wave height difference, Δr is the path difference, $\Delta\psi$ is the phase differencea and generally the reflection surface is thought to be smooth if $\Delta\psi \leq \pi/2$ which corresponds the below inequality[6] as well as Rayleigh Criterion.

$$\Delta h_{max} \leq \frac{\lambda}{8\sin\Delta} \tag{56}$$

When the undulating wave height difference satisfies Rayleigh Criterion ,it is generally considered the surface is smooth and produces specular reflection only.

2.4.3 rough surface reflection

When the surface is so rough that Rayleigh Criterion can not be met, the power reflected to antenna from is mainly contributed by diffuse reflection.

For the rough surface, equvilent coefficient reflection is difined as[7]

$$\rho_r = \epsilon\nu\gamma\rho_0 \tag{57}$$

where, ϵ is the diffusion factor, ν is reduction factor, γ is the antenna directional suppression factor. Generally, ρ_r is calculated by empirical function according to the specific surface and the roughness.

Then, the reflection loss on the rugged surface is as follows and unit is dB.

$$L_s = -10\lg\rho_r \tag{58}$$

2.5 Extra system loss

Extra system loss includes offset absorption, additional loss in the ionospere E, polarization loss and so on. It's almost a function of time in a day which can be searched in the following table[1].

2.6 Signal-to-noise ratio

In the classical calculation model, the electric field at the receiver can be calculated by:

$$E_t = 137.2 + 20\lg f + 10\lg P + G_t - L_b \tag{59}$$

where, the unit of E_t is dB, f is the frequency of electromagnetic waves and unit is MHz, P is the transmit power of transmitter and unit is kW, G_t is antenna radiation direction gain and unit is dB, L_b is the propagation loss of waves and unit is dB.

Atmosperic noise is the main noise sourse for the transmission of electromagnetic waves on the sae. The electric field of atmosperic noise can be calculated by:

$$E_n = F_a + 10\lg B + 20\lg f - 96.8 \tag{60}$$

where, the unit of E_n is dB, F_a is the effective coefficient of atmospheric radio noise and unit is dB, B is the effective noise bandwidth of receiver and unit is Hz, f is the frequency of electromagnetic waves and unit is MHz.

According to the Formular, the calculation of signal-to-noise ratio for electromagnetic waves on the sea is as follows:

$$SNR_t = 202.56 + 10\lg P_t - 20\lg f - 20\lg r - 10\lg B - L_i - L_e - F_a \tag{61}$$

3 Analysis and Simulation of Part I

This section is divided into three parts which are analysis of one hop and analysis of n hops on calm ocean in the following article.

3.1 Analysis of one hop

3.1.1 calm ocean surface analysis

Specular Reflection is dominant when the ocean is calm, therefore the reflection coefficient of smooth surface can be used in this condition. According to the Formula, the coefficients of vertical and horizontal polarization after equivalent change, $\sin^2\theta_i + \cos^2\theta_i = 1$, can be expressed respectively as:

$$\Gamma_\perp = \frac{\varepsilon \sin\theta_i - \sqrt{\varepsilon - \cos^2\theta_i}}{\varepsilon \sin\theta_i + \sqrt{\varepsilon - \cos^2\theta_i}} \tag{62}$$

Table 1: Extra system loss with the time

The local time of transmitter	extra system loss (dB)
22-04	18
04-10	16.6
10-16	15.4
16-22	16.6

$$\Gamma_{||} = \frac{\sin\theta_i - \sqrt{\varepsilon - \cos^2\theta_i}}{\sin\theta_i + \sqrt{\varepsilon - \cos^2\theta_i}} \tag{63}$$

where, ε is the complex permittivity. The specific caculation expressions of ε for calm water are as follows[6]:

$$\varepsilon = \varepsilon' - i\varepsilon'' \tag{64}$$

$$\varepsilon' = \varepsilon_{ir} + \frac{\varepsilon_s - \varepsilon_{ir}}{1 + (2\pi f\tau)^2} \tag{65}$$

$$\varepsilon'' = \frac{2\pi f\tau(\varepsilon_s - \varepsilon_{ir})}{1 + (2\pi f\tau)^2} + \frac{\sigma_s}{2\pi f\varepsilon_0} \tag{66}$$

where, f is the frequency of electromagetic wave, ε_0 is the permittivity of free space and $\varepsilon_0 = 8.854 \times 10^{-12}F/m$, ε_{ir} is the sea water dielectric permittivity and $\varepsilon_{ir} = 4.9$, τ is the relaxation time of sea water, σ_s and ε_s are the ionic conductivity and the static permittivity of the ocean, respectively.

3.1.2 simulated calculation on calm ocean

Comsidering the problem ignores a lot of information, some relevent parameters are given by the Internet and some are based on The details for one hop(from the transmitter to the sea surface for the first time) are as follows.

In calculation process of the reflection loss of calm ocean for the 100-watt wave, the freuency f is taken as $30MHz$, $\varepsilon = 70$ and $sigma_s = 5$, then the reflection coefficient of calm surface $\rho_0 = 0.9091$, therefore the reflection loss L_c is $0.8281dB$.

As for the calculation process of ionoshere absorption loss, the frequency of electromagnetic waves f is taken as $30MHz$, the magnetic rotation frequency at the height of $210Km$ is taken as $1.4MHz$, 12 months moving average sunspot $\bar{R_{12}}$ is 749 and the top angle of the sun x is $43.8948°$, then the ionosphere absorption loss L_i is $2.5232dB$ by Formular.

When calculating the free-space transmission loss, the frequency f is taken as $30MHz$, the distance D between A and B is taken as $2000Km$, then the angle Δ is $7.1505°$ and effective transmission length r is $2073.6Km$ for one hop by Formular, therefore the free-space transmission loss L_{fr} is $128.3269dB$.

The extra system loss L_e is taken as $16.6dB$ by Figure .

After the above calculation, the basic propogation attenuation L_b is $148.2782dB$, absolute strength of wave and SNR at the receiver is $-98.278dBm$, $23.721dB$ respectively while F_a is taken as 30 and F_h is $1.4MHz$.

Figure 5 shows the relation curve between the SNR and the angle of emission Δ in the condtion that the frequency of wave is $10MHz$ for one hop, $20MHz$ and $30MHz$ repectively. As can be seen in this fugure, the higher frequency is, the larger SNR will be when the angle Δ is small. However, the oppisite conclusion will be drawn when the angle gets larger. And this phenomenon meets the empirical data in our life .

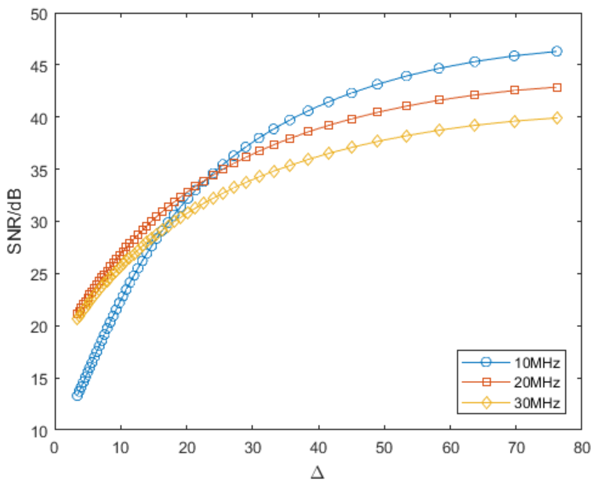

Figure 5: the relation curve between the SNR and Δ

3.1.3 turbulent ocean surface analysis

When the ocean is turbulent, the diffuse reflection is dominant and the calculation method has to make some change which is in the following formula.

$$\rho_r = \rho_0 \rho_d \tag{67}$$

where, ρ_0 is the reflection coefficient of smooth srface, ρ_d is diffuse reflection factor which is the function of angle Δ and mean square wave height σ_h and the length of electromagnetic wave λ. The approximation of diffuse reflection factor are got through research[8]:

$$\rho_d = \frac{1}{\sqrt{3.2g - 2 + \sqrt{(3.2g)^2 - 7g + 9}}} \tag{68}$$

where,

$$g = 0.5(4\pi\sigma_h \lambda sin\Delta)^2 \tag{69}$$

$$\sigma_h = 0.0051v^2 \tag{70}$$

where, v is the power of wind and formular is given by the unit is m/s. The induction of Formula 68 is from Rayleigh criterion and relevant theory.

3.1.4 simulated calculation on turbulent surface

The ionoshere absorption loss, free-space transmission loss and The extra system loss is almost the same as the section 4.1.2.The only difference is the calculation of the reflection loss

In calculation process of the reflection loss of turbulent ocean for the 100-watt wave, the freuency f is taken as $30MHz$, v is taken as $12.25m/s$, ρ_d is 0.5732, then the reflection coefficient of turbulent surface $\rho_0 = 0.5291$, therefore the reflection loss L_c is $5.6656dB$.

After the above calculation, the basic propogation attenuation L_b is $153.1117dB$, absolute strength of wave and SNR at the receiver is $-103.1117dBm$, $18.888dB$ respectively while F_a is taken as 30 and F_h is $1.4MHz$.

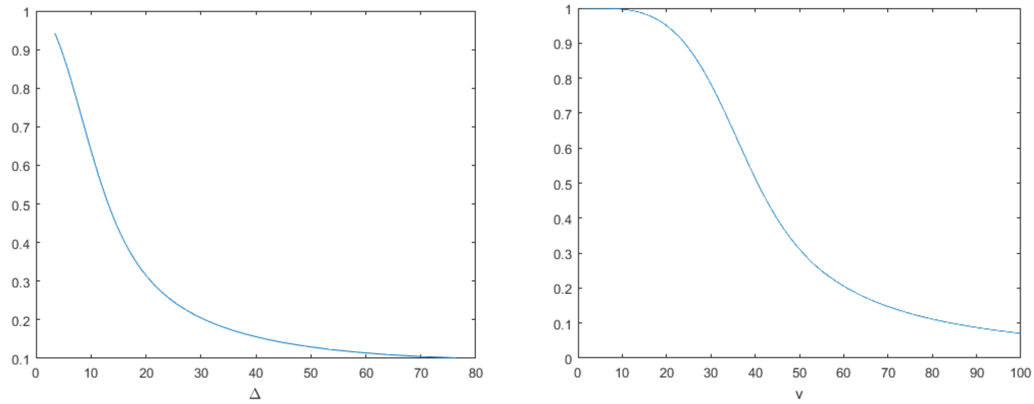

Figure 6: the relation curve of ρ_d and Δ (left), ρ_d and v (right)

Figure 6(left) shows the change of the diffuse reflection factor with the angle of elevation Δ in the condition of turbulent ocean when the effective transmission distance D is $2000Km$ for one hop. In this figure, with the angle increases, the diffuse reflection factor decreases rapidly at first but decreases slowly when the angle gets larger.

Figure 6(right) shows the relation curve of the diffuse reflection factor and the power of wind. The slope of this curve changes differently along with the increase of wind, which is very special.

3.1.5 comparsion between calm and turbulent ocean

From the data got from section 4.1.2 and 4.1.4 for one hop, the absolute strength of reflection wave about the calm and turbulent ocean is $-98.278dBm$ and $-103.1117dBm$ respectively, which tells that that disturb of the poor teparature will decrease about $5dB$ when the frequency of wave is 30MHz.

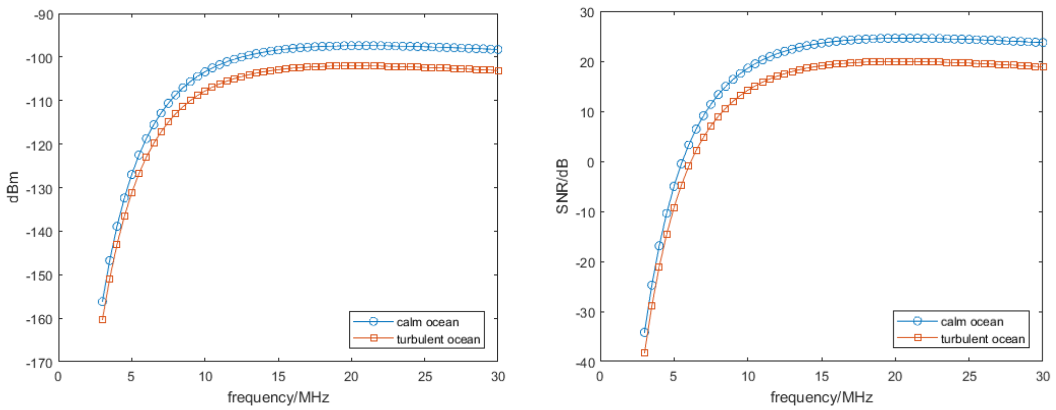

Figure 7: the relation curve of L_2 and f (left), SNR and f (right)

Figure 7(left) shows the change of the absolute strength of wave with different frequency in the condition of calm and turbulent ocean when the effective transmission distance D is $2000Km$ for one hop. In this figure, with the frequency in increases, the absolute strength of wave increases rapidly at first and almost becomes a constant finally. Moverover, the absolute on turbulent ocean is always lower than calm ocean.

Figure 7(right) shows the relation curve of SNR and the frequency of waves, the same conclusion as the figure can be drawn.

3.2 Analysis of n hops on calm ocean

For the situation that the electromagnetic wave takes n hop on a calm ocean, the method is by contralling the number of D and to find the limit.The all parameters of simulation is as same as section 4.1.2 and results are in the following article.

The max number of n is 11 while the SNR of 12 hops is smaller than 10 dB. And For 11 hops, the reflection loss L_c is $2.5049dB$ and the ionosphere absorption loss L_i is $6.4208dB$. When calculating the free-space transmission loss, the angle Δ is $68.8386°$ and effective transmission length r is $5047.3929Km$, therefore the free-space transmission loss L_{fr} is $136.0538dB$.

From above data, the basic propogation attenuation L_b is $161.5795dB$, absolute strength of wave and SNR at the receiver is $-111.5795dBm$, $10.4202dB$ respectively.

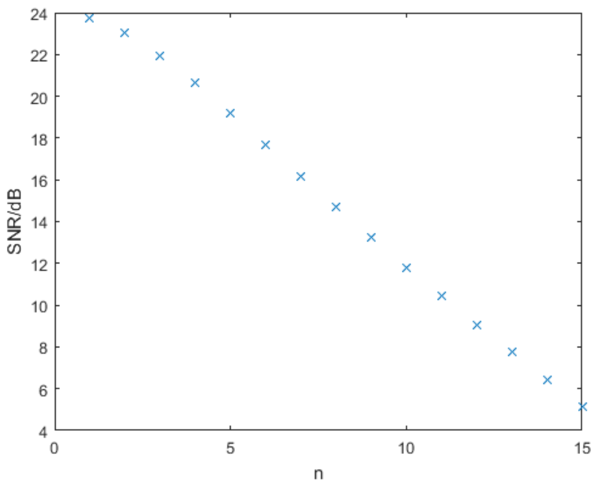

Figure 8: the relation curve of SNR and n

Figure 8 shows the change of the SNR with different n hops when the effective transmission distance D is $2000Km$. In this figure, the threshold of n for maintaining a usable signal-to-noise ratio can be seen easily. Moreover, conclusion can be drawn that when D is a constant, the SNR at the receiver is almost a linear function of n.

4 Analysis and Simulation of Part II

4.1 Analysis of smooth and rugged terrain

(a). smooth terrain

On the condition that the terrain is smooth, the baisc parameters are the same as the parameters in section 4.1.2 except the permittvity is 15 and ionic conductivity is 0.033.By calculation, the reflection loss L_s is $2.9361dB$, the ionosphere absorption loss L_i is $2.5232dB$,the free-space transmission loss L_{fr} is $128.3269dB$ and the extra system loss L_e is $16.6dB$.

After the above calculation, the basic propogation attenuation L_b is $148.2782dB$, the SNR at the receiver is $21.6135dB$.

(b). rugged terrain

If the terrain is rugged, there are many models to describe the diffuse reflection coefficient. Ament's moedl uses random variable subjected the Gaussian distribution to express calculation facator for ups and downs of rugged terrain[9].

$$\rho_d = e^{-8(\pi \sigma_h sin \Delta \lambda)^2} \tag{71}$$

where, σ_h is the standard deviation of roughness of rugged terrain.

The all results of calculation on a rugged terrain are the same as the smooth terrain except that L_r is $9.6879dB$ and the SNR at the receiver is $14.8617dB$.

4.2 Comparision between terrain and ocean surface

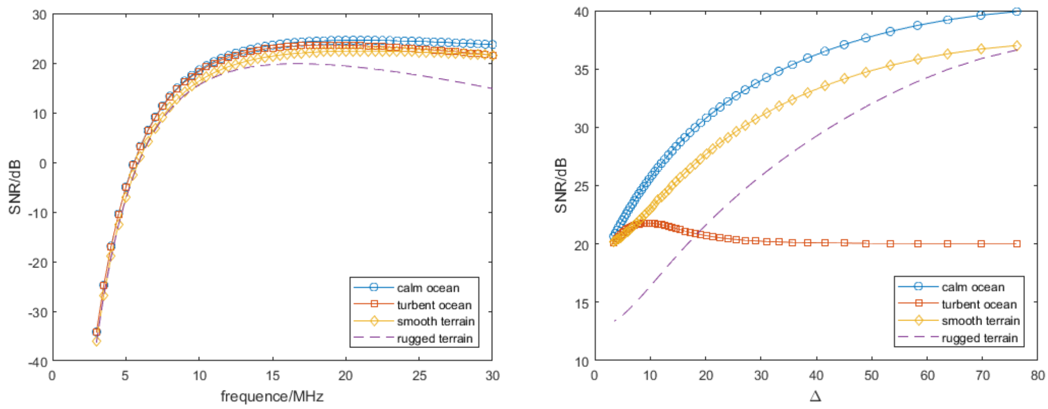

Figure 9: the relation curve of SNR and f (left), SNR and Δ (right)

Figure 9(left) shows the change of SNR with different frequency by comparing four different reflection surface when the effective transmission distance D is $2000Km$ and angle the emission is constant for one hop. In this figure, the relation between these four surface is as follows.

$$SNR_{rugged\,terrain} \le SNR_{turbulent\,ocean} \le SNR_{smooth\,terrain} \le SNR_{calm\,ocean} \tag{72}$$

Figure 9(right) shows relation curve between SNR and angle of emission Δ by comparing the four kinds of surface when the frequency of wave f is $30MHz$ for one hop. In this figure, with the frequency in increases, the SNR increases rapidly at first while increases slowly finally except for turbulent ocean. The SNR of turbulent ocean is almost a constant when Δ larger than $30°$.

5 Analysis and Simulation of Part III

When considering the calculation of SNR on turbulent ocean for n hops, the angle Δ_2 will change after each hop. And because of the diffuse reflection is hard to predict, the angle Δ_2 will change randomly. Therefore, the calculation model on calm ocean for n hops is no longer effective for this problem. A new model, first-order self-regression Markov process, is used in the following article.

5.1 Modified Markov process with first-order self-regression model

If a time series X_t meets the following the formula:

$$P(X_{t+1} = j|X_0 = i_0, X_1 = i_1 \cdots X_t = i_t) = P(X_{t+1} = j|X_t = i_t) \tag{73}$$

where P is the change probablity, then the X_t is called a Markov chain generated by Markov process, which means that the probable status of X at time t is only related to the previous status at time $t-1$.

If a time series Y_t meets the following the formular:

$$Y_{t+1} = \zeta Y_t + \Psi \tag{74}$$

where, ζ is self-regression coefficient, Ψ is a random variable subjected the Standard Normal Distribution $N(0, 1)$. Then Y_t is called a classic first-order self-regression series. accoording the theory of econometrics, the series Y_t is stabe if and only if $|\zeta| \leq 1$..

The thought of calculating of modified Markov process with first-order self-regression model is that the angle of elevation after each hop can be got by the last angle combining the transfer probality and random factor in this new model, which can describle the charateristics of turbulent ocean that wave height, shapes, and frequencies change rapidly as well as the direction of wave being changed.

5.2 Methods to calculating the communication time

Presuming that $\Delta_0 = 10°$ and the $\zeta = 0.9021$ by the estimation from data, the SNR with 300 times simulation after 2 hops and 3 hops for wave of $30MHz$ frequency is in the following figure respectively using the new model in section 6.1

As can be seen in Figure 10, the average SNR is $11-13\,dB$ approximately after 2 hops for 100-watt electromagnetic wave of $30\,MHz$ while it becomes about $4.5-5.5\,dB$ after 3 hops. Therefore, the max hops is 2 for a usable SNR and the effective distance is about $3200-3800\,Km$ using the above given parameters.

In order to solve the time for remaining in communication, there are some assumption that parameters and calculated results are as above, the direction of ship is away from the transmitter and the communication can be remained only when SNR is usable. Then the calculation is given by

$$T = D_{usable}/w \tag{75}$$

where, w is the speed of the ship on turbulent ocean and unit is Km/h. Taking an example, if the speed is $30\,Km$,then the time for remaining in communication is about $100-130\,hours$.

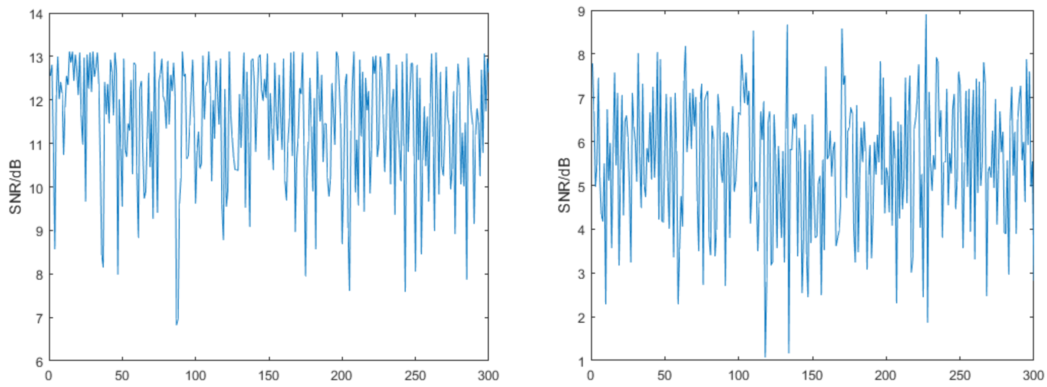

Figure 10: the relation curve of SNR of 2 hops (left), SNR and 3 hops (right)

5.3 Improvement for communication on turbulent ocean

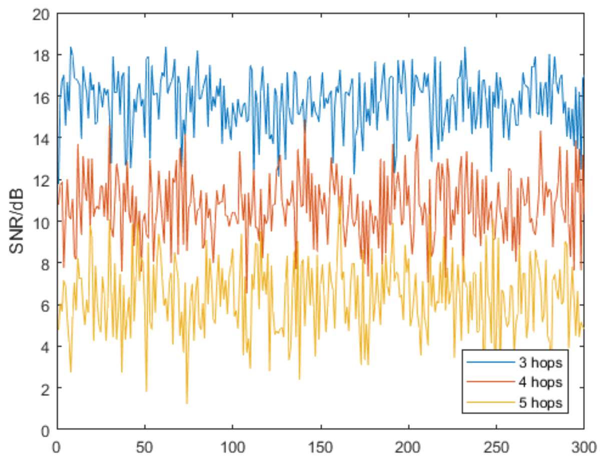

Figure 11: the relation curve of SNR of 3 hops, 4 hops and 5 hops

Figure 11 shows the SNR with 300 times simulation of 3 hops, 4 hops and 5 hops respectively for $1000-watt$ wave of 30 MHz with the parameter $\Delta_0 = 10°$. In this figure,

$$SNR_{3hops} \lnsim SNR_{4hops} \lnsim SNR_{5hops}$$

Moreover,

$$Fluctuation_{3hops} \lnsim Fluctuation_{4hops} \lnsim Fluctuation_{5hops}$$

Conclusion can be drawn that the larger hop is, the fluction of SNR will be in modified Markov process with first-order self-regression model, which is easily understood empirically because of the joint seveal times random diffuse reflection influence.

Figure 12 shows the SNR with 300 times simulation of 2 hops for $100 - watt$ wave of 30 MHz with the parameter $\Delta_0 = 30°$, $\Delta_0 = 60°$ repectively. In this figure,

$$SNR_{60°} \approx SNR_{30°}$$

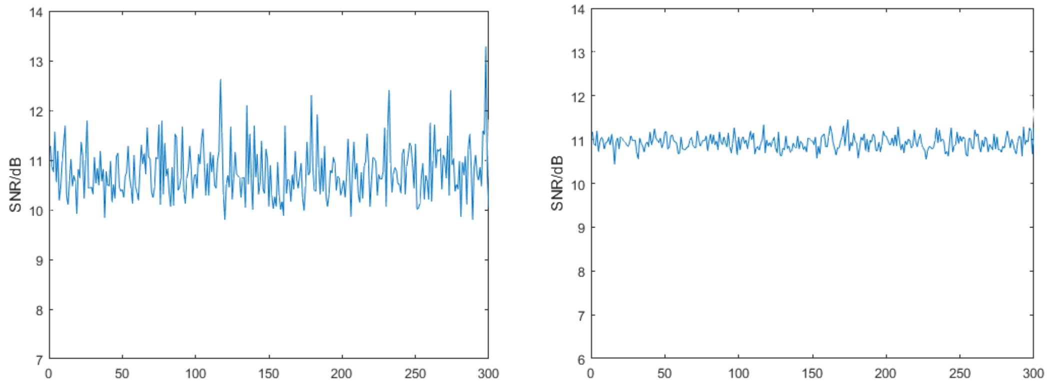

Figure 12: the relation curve of SNR of 30° (left), SNR of 60° (right)

However,

$$Fluctuation_{60^\circ} \lnsim Fluctustion_{30^\circ}$$

which means the larger original angle of emission is, the more stable electromagnetic wave will be after the same times of diffuse reflection on the condition that other parameters are totally the same.

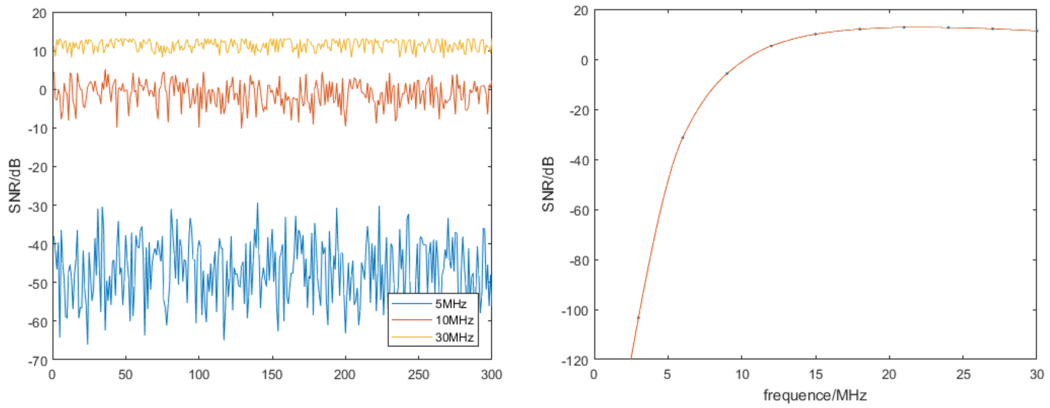

Figure 13: the relation curve of SNR of f (left), SNR and f (right)

Figure 13(left) shows the SNR with 300 times simulation of 2 hops with the parameter $\Delta_0 = 30^\circ$ for $100 - watt$ wave of $5\,MHz$, $10\,MHz$ and $30\,MHz$ respectively. As can be seen,

$$SNR_{5MHz} \lnsim SNR_{10MHz} \lnsim SNR_{30MHz}$$

Moreover,

$$Fluctuation_{30MHz} \lnsim Fluctuation_{10MHz} \lnsim Fluctuation_{5MHz}$$

which means the larger frequency of electromagnetic wave is, the more stable and more strong electromagnetic wave will be after the same times of diffuse reflection.

by the above analysis, measures which can improve the time in remaining communication on turbulent ocean are as follows.

measure 1 Increase the original angle of emission.
measure 2 Increase the power of electromagnetic wave.
measure 3 Increase the frequency of electromagnetic wave.

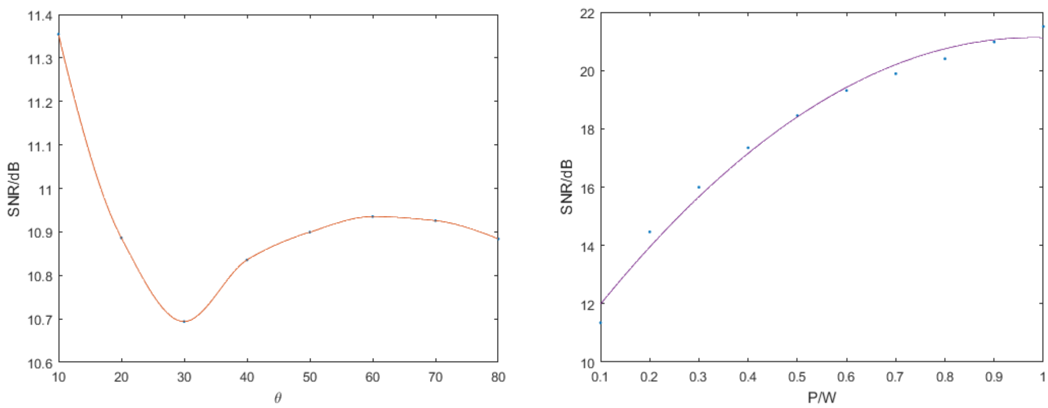

Figure 14: the relation curve of SNR of Δ (left), SNR and $watt$ (right)

Figure 13(right), 14(left) and 14(right) show the SNR with 300 times simulation of with different frequency, angle of emission and power of electromagnetic wave respectively. As can be seen in these 3 figure, thers is a optimal problem for increaseing the time to remain in communication, which is 15 MHz,60° except the power of electromagnetic wave. Geneally, the larger power of wave is, the more stable SNR will be.

6 Strength and weaknesses

strength

• The specific provement and calculation of four kinds of loss is described in the analysis.

• This paper takes different calculation model for different situation and the results is reasonable.

• For the turbulent ocean on the condition n hops, the first-order self-regression Markov process is innovate and can describle the approximate real situation.

• This paper analysis all kinds of curve that SNR with different parameters and draw specific conclusions

• The optimum frequency, angle of emission, and power of wave to enhance the communication are given in the paper.

weaknesses

• These calculation models ignores the loss in stratosphere and the transmit of electromagnetic wave in the ionoshere which will cause errors.

• The parameters of simulation is constant which is not meets the condition in real life.

• There is no real data to prove the results of simulation and the accuracy of first-order self-regression Markov process model.

7 References

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