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Simulation Analysis of Multi-hop HF Radio

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Abstract. The paper is mainly based on the issue of "radio wave propagation", which is not rare for people on the ship while receiving message. To solve this problem, we focus on the simulation of the propagation based on the electromagnetism knowledge. Then we established precise mathematical model on MATLAB, from which we can calculate the physics value of the simulation. MODEL I: Model for propagation between ionosphere and ocean. According to the electromagnetism knowledge and literature, we simulated the path of radio wave emitted from a certain angle and calculated the total energy loss during this process. After calculation, we found the maximum of reduction is 2.567dB, while the minimum of the reduction is 1.932dB. Also, we simulated the shape of a random ocean wave by interpolation method. Then we calculated the energy leak on a turbulent sea using Monte Carlo Simulating Method. By comparing two results, we can find a converting parameter 7 of 0.6731, to simplify the second model on a wavy sea. MODEL II Model for propagation through mountainous area Based on MODEL I, we established a model to simulate the movement of the radio wave through mountains and found the loss by numerical computation. Deeply, we concluded the relationship between mountain's height, position of the emission point and the receiver. To put the model specially, we assumed that the mountain’s height is 0. In this way, we can find the energy loss through smooth terrain. MODEL III: model for finding the best receiver’s angle. Through the previous models, we set up a model to simulate the total energy received by the ship, and defined a quality of power to describe the amount of received energy. To maximum the energy received by the ship, we used Genetic Algorithm to find the best solution and calculate the best receiver’s angle and the maximum energy for different position of the ship. After this, we can set a threshold which determines the communication area and calculate the travelling time.

Keywords: Radio Wave Propagation, Simulation, Monte Carlo Method, Genetic Algorithm.

1. Introduction

1.1 Problem Background

On high frequencies (HF, defined to be 3 — 30mHz), Radio waves can travel long distances (from one point on the surface of the earth to another distant point on the Earth’s surface) through multiple reflections from the ionosphere and the Earth’s surface. For frequencies below the maximum usable frequency (MUF), HF radio waves from a ground source reflect off the ionosphere back to the earth, where they may reflect again back to the ionosphere, where they may reflect again back to the earth, and so on, travelling further with each successive hop. The frequency above the MUF does not reflect/refract at the ionosphere but passes through the ionosphere into space. MUF varies with season, time and solar conditions. Among other factors, the properties of the reflector not only determine the intensity of the reflected wave but also the integrity and propagation distance of the transmitted signal. This issue will mainly focus on the reflection of HF radio waves on the ocean surface. It has been found empirically that reflections off a turbulent ocean are attenuated more than reflections off a calm ocean. A turbulent ocean is one in which wave heights, shapes, and frequencies change rapidly, and the direction of wave travel may also change. Ocean turbulence will affect the electromagnetic gradient of seawater, changing the local permittivity and permeability of seawater, changing the height and angle of the reflecting surface.

1.2 Restatement

Establish a marine mathematical model of signal reflection. For a 100 — watt HF constant-carrier signal, below the MUF, from a point source on land, determine the strength of the first reflection off a turbulent ocean and compare it with the strength of a first reflection off a calm ocean. If additional reflections (2 through n) occur on a calm sea surface, find out what the maximum number of hops is before the signal's strength drops to an available SNR threshold of 10dB?

Compare the results of the Part I with the high-frequency reflections of rugged terrain and flat terrain?

A ship crossing the ocean will use HF to communicate and receive weather and traffic reports. How does your model adjust to accommodate a shipboard receiver moving on a turbulent ocean? In the same number of paths, the ship's communication signal for how long?

2. Assumptions

Regard the ionosphere as a smooth sphere which is concentric with the Earth.

The distance between the launch point and the ground is negligible.

The medium in the space between the Earth and the ionosphere is uniform, so the dielectric constant has the same value for each point in the area.

3. Symbol Description

Table 1. Notations

Symbol	Definition
R	Earth radius
D	The distance between the Earth and the ionosphere
SNR	Signal-to-noise ratio
PS	Signal average power
PN	Noise average power
So	The area of the lunch surface
Po	Transmit signal power
Io	The Energy density of the Transmit signal power

4. Problem Analysis

4.1 Part I

To find the maximum hops of the radio wave, we need to calculate the energy loss in one hop, which has three contributors (the loss through propagation, the loss during the reflection on the ionosphere and the loss during the reflection on the ocean). So, we need to set up a model to find the energy loss in one hop. But this model is not fit to a turbulent ocean, since the wave is moving and the reflection process differs from each other. So, we need to set up a model to simulate the wave, from which we can find the energy loss on a wavy sea. Because we simulate the wave randomly, the value we get is different in various occasions. To solve this problem, we use Monte Carlo method to find the average loss. According to the information listed above, we can find the maximum hops of the radio wave [1].

4.2 Part II

To find the energy loss in a mountainous area, we need to establish a model to simulate the total energy of the wave while it passed the mountain based on PART I. Additionally, it is obvious that some waves bump into the mountains and lose all of the energy. By analyzing the movement of the wave, we can calculate the loss of energy and find the relationship between mountain's height, position of the emission point and the receiver. To put the model specially, we assumed that the mountain height is 0. In this way, we can find the energy loss through smooth terrain.

4.3 Abbreviations and Acronyms

To find the maximum distance to communicate, we need to set a threshold for the received power. To find the threshold, we should definite a variety to assess the energy received by the ship, which can be called the quality of the received power. To maximum the quality, we need find factors which can affect the variety, such as the receiver's angle and the ship's position (2). By the method of Genetic Algorithm, we can find the best receiver angle. In this way, we can find the relationship between the ship's location and the quality, by which we can find the maximum distance for communication.

5. The Models

5.1 Model for Propagation between Ionosphere and Ocean

Suppose the earth is a smooth sphere, and the transmitted signal only occur reflection but not refraction when it reaches the ionosphere. There is a 100-watt HF constant-carrier signal, below the MUF, from a point source on the land. The radio wave propagates outward as a sphere from the launch point. The energy of the unit area in the sphere is decreasing. Suppose that the energy loss come from two aspects:

The energy loss along the propagation path of radio waves [3].

The energy loss that occurs when the radio waves are reflected by the ionosphere and the Earth's surface.

The signal reflection off the calm ocean: Establish a plane rectangular coordinate system, and the Earthafs center is the origin. The Earth's radius is known as 6371km, and the distance between the Earth and the ionosphere is 170km,[4].

so, R = 6371km [5], D = 170km

The coordinate of the i-th reflection in the ionosphere is (xAi, VAi)

The coordinate of the i-th reflection in the Earth is (x^i, VBi)

Note the launch point is (xbo, Vbo),

The radio wave propagation equation is

$$V = \tan Oi - (x - Xi) + Vi \qquad (1)$$

6*(n,i)is the angle with the x-axis when Radio waves reflect *i* times in the ionosphere,(i = 1,2, 3.'..).

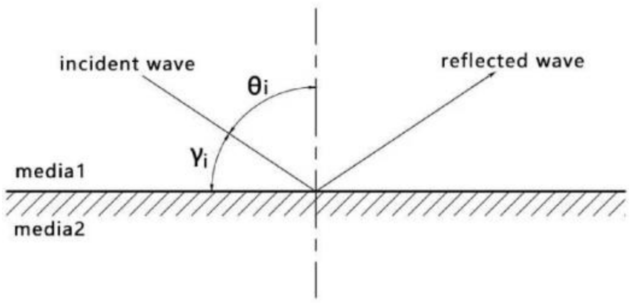

Fig 1. Reflection process

n=1, Radio wave emits to the ionosphere; n = 2, Radio wave emits to the Earth.

Ionospheric equation is

$$x^2 + V^2 = (R + D)^2 \qquad (2)$$

In Figure2, when the wave hops within 3 times, we can render the Earth as a plane, so we can simplify the model of the Earth to a model of a flat plane

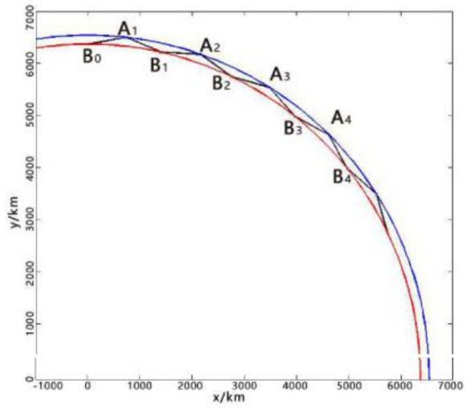

Fig 2. The path of the radio wave's propagation, ($d = 10^{\circ}$)

Due to its symmetry, the equation must be solved. When 9i = 0, the equation has one solution, recorded as: $[xi+i,yi+i]$ When 9i = 0, the equation has two solutions, recorded as: [xi+\, yl^+'i],$[xfh$, y|++\]In these solutions, take the answer closer to the launch point.

The signal reflection off the turbulent ocean: We create a sea-wave model that simulates waves based on the sine function A - sin(^x), where the wavelength can change. The sine function of a periodic image is divided equally into 10 equal parts, a total of 11 points, respectively () And add a random number to xo — xi0 that is subject to a normal distribution (the random variables that xo and xi0 increase are equal). The 11 discrete points obtained are interpolated and fitted to find the derivative of (xi — xg).

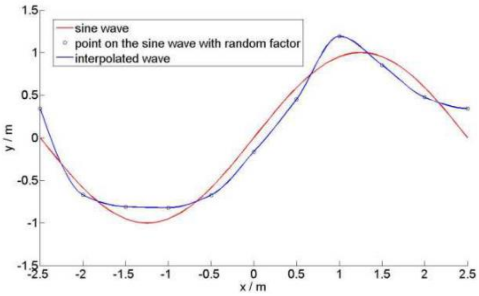

Fig 3. The simulation of a wave

Based on the emission angle and the point from xi to xg chosen by the computer randomly, we calculate the injection angle and the direction to transmit. also, we can find the energy loss during the rejection. The results are shown on Figure5. Besides, the energy is propagate in various directions, which will reduce the energy on a certain path which is simulated in the calm ocean. So, we commute the energy to that certain path by multiply a parameter, converting parameter 7. By simulation, we found 7 = 0.6731.

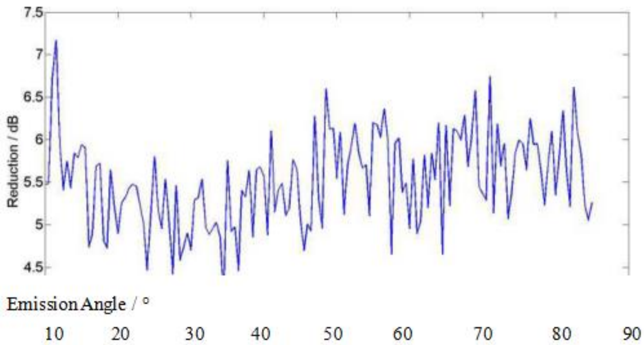

Fig 4. Relationship between emission angle and reduction on turbulent ocean

5.2 Model for Propagation Through Mountainous Area

We use the launch point as the origin to establish the Cartesian coordinate system, and consider the radiations of the radio waves in all directions are uniform and divided into (1/N) degrees. In the process of communication encountered mountain obstacles, if not hit the mountain according to the normal path of transmission, the energy is completely lost.

Finally, the energy of each beam reaching the receiving end is calculated and summed respectively. When the ground is flat, the height of the mountain is considered to be zero, compared with the previous results and the corresponding conclusions are obtained.

Mountainous or rough terrain: Assuming that the height of the launch point is zero at the ground, the height of the mountain is H, the distance between the launch site and the mountain is x_m, the distance between the mountain, the signal receiving site is x_r and a beam of radio waves is transmitted every (1/N) degrees at the launch site. For the accuracy of N and the model, if you want to improve the accuracy of the model, you can increase the value of N. Create a rectangular coordinate system as shown below:

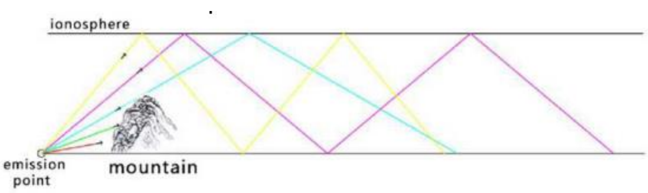

Fig 5. Process of propagation in mountainous area

Radio wave emission equation is:

$$y - yo = \tan 00 - (x - xo)\ y = D \tag{3}$$

The solution is(x^i,yAi)

The radio wave reflection equation is:

$$y - yAi = - \tan 00 - (x - XAi)\ y = o \tag{4}$$

The solution is (xbi,Ybi)

The received energy is calculated according to the following formula:

$$E_r \quad \int_{-\pi}^{\pi} Io - Lids \quad \int_{\pi}^{\pi} Io - (eff)^n - \frac{e^{-aL}}{aL} ds \tag{5}$$

Er —The total energy received between the ionosphere and the ground, the vertical plane where the receiving points are located

I o—Transmit signal energy density

$L\, i$ —A bunch of radio waves energy loss

eff—The attenuation coefficient of the radio wave jumps once

n —The number of radio wave hops

L——Total distance of radio propagation

By simulation and calculation, we get the result shown as Figure6 to Figure8.In Figure6 , when the mountainous height is less than 1.8 km, the power received does not change, since the energy propagate from a higher angle lose too much energy, while the energy propagate from a lower angle cannot convey the energy over the mountain. For the same reason, there have two different tendency in Figure7 and Figure8.

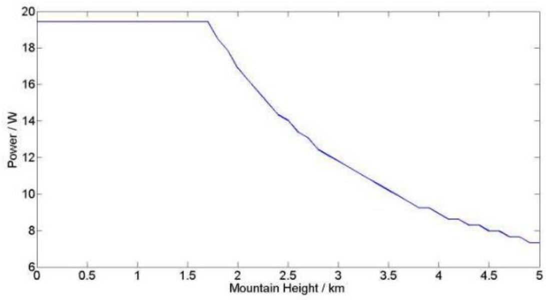

Fig 6. Relationship between mountain s height

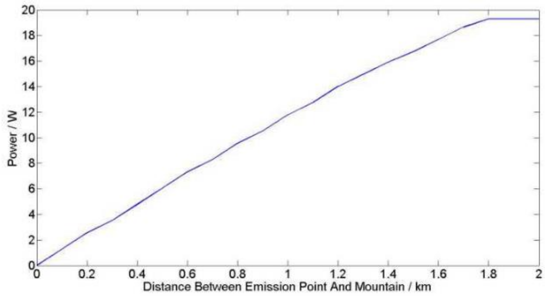

Fig 7. Relationship between emission point s position and power

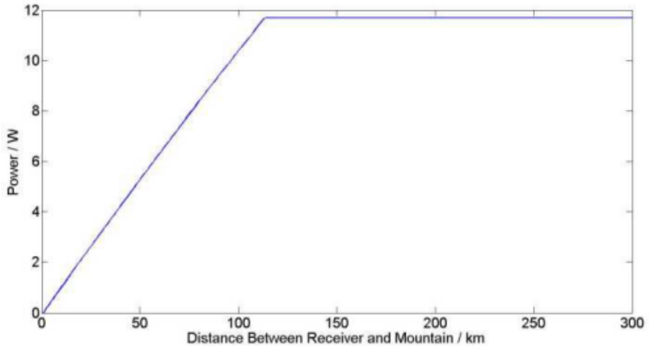

Fig 8. Relationship between receiver's position and power

To put it precisely, we choose some special occasion to calculate, the results listed in Table 2.

Table 2. Simulation results on certain occasion in mountainous area

No.	r_m	$h_m(km)$	Xr (km)	Power(W)
1	1	3	200	11.7914
2	1	2	200	16.8904
3	1	4	200	8.9232
4	0.5	3	200	6.0551
5	0.5	3	200	16.7546
6	1	3	100	10.5167
7	1	3	500	5.4177

Flat terrain:Flat terrain is a special case of a model when the height of the model is zero at the middle of the mountain.

5.3 Marine Radio Wave Reception Model

Given the angle of the receiving antenna, the location of the ship, simulates the radio wave propagation process. As the figure shows below:

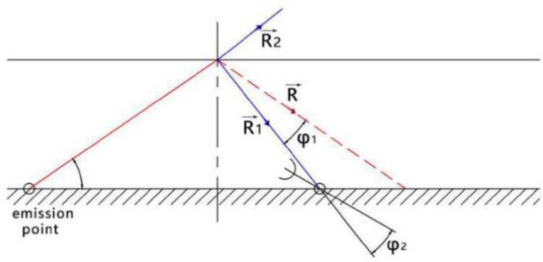

Fig 9. Simulates the Radio Wave Propagation Process

In the figure, Xi is the abscissa of the i-th radio wave reflected by the ionosphere; x_{CUrV} is the current position of the ship.

If xi > $Xcurp$, the paper believes the antenna cannot receive the radio signal.

Else $Xi < Xcurp < Xi+i$, the radio wave ~n emitted from point Xi is vector-decomposed into Ri and R2. Where Ri and antenna in the same direction, that the antenna to absorb the best energy.

When j < i, the part of the energy is neglected because the radio wave emitted from point Xj has more energy loss when it propagates to the antenna.

This article defines maritime radio wave reception quality as:

$$dQ = effi - eff^{n-i} - \cos \hat{}i - \hat{}2\ ds$$
$$effi - eff^{n-i} - \cos \hat{}i - \hat{}2\ ds \qquad (6)$$

$$(\hat{}i = \frac{\pi}{2} - 0 - \arctan \frac{x_{curp} - Xi}{i-J}$$
$$\hat{}2 = \frac{\pi}{2}n - 0r - \arctan \frac{J\ x_{curp} - x_i}{i-J} \qquad (7)$$

$effi$—Radio wave attenuation coefficient in the ionosphere $0r$—Antenna receiving angle ($0r <$ 90o)

^i—The angle between ~R and R

^2—The angle between Receive antenna and R

The Value of $Xcurp$ find a series of Q's and get the maximum value of Q. The result is shown below:

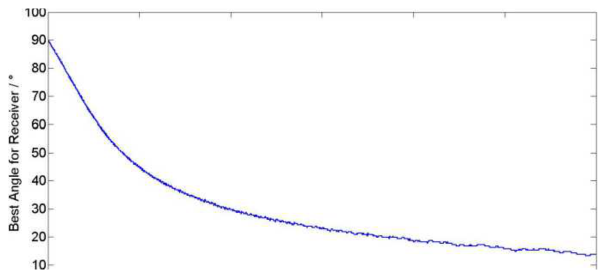

Fig 10. Relationship between location and best angle for receiver

According to the above equation, $Xcurp$,0 and Q have a functional relationship.

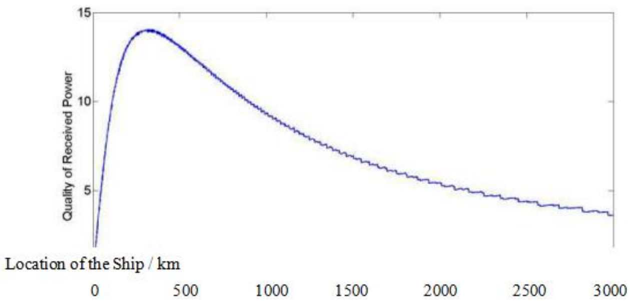

Fig 11. Relationship between location and quality of power

6. The Models

Genetic Algorithm is a kind of optimization algorithm based on Darwinars natural selection principle. It shows its efficiency for most of the problems, especially some complex nonlinear problems that cannot solved by traditional searching methods, since it uses abstract concept of genetic material (DNA) to describe macro concept. We wrote a program to simulate the development of a community including the elimination, reproduction and variation. After thousands of generations, the community converges and becomes steady [9].

To eliminate species, we use an elimination function /i to describe the possibility to be eliminated.

$$/i = Q3 \tag{8}$$

To assess species, we use an adaption function /2 to describe the possibility to be lived.

$$/2 = j \times \max\{Q3\} - Q3 \tag{9}$$

The program's flowchart is shown as Figure12, while the development of the community is shown as Figure 13.

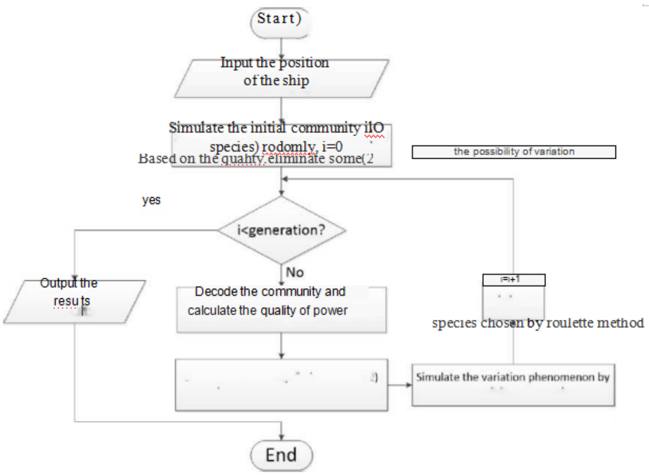

Fig 12. Flowchart of Genetic Algorithm

From Figure13, we can find that the stability of the community is weak, since the average of received power's quality is waving. As the time pass, the community converges, although some waves occur. But the decrease does not last for a long time, which means the community has a better stability. At the end of the simulation, the community will evolve to the best. If we set the threshold of 5, the ship can travel as far as 2166 km. To put it differently, if the ship travels at a speed of 90 knot, it can keep in touch within 23.4162 hours.

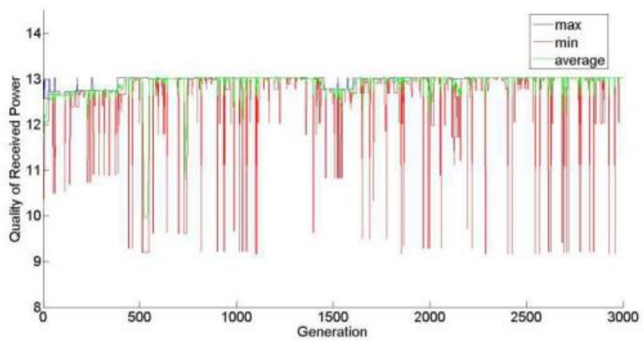

Fig 13. Characteristic values of each generation

7. Strengths and Weaknesses

7.1 Strengths

We use Monte Carlo Simulation, which can decrease the program running time.

The result of optimization using genetic algorithm can increase the accuracy of the optimized result.

We use discrete variety to replace successive variety which can reduce amount of calculation.

7.2 Weaknesses

Monte Carlo methods generally require more calculation steps N, resulting in less computational efficiency.

Genetic algorithm convergence in a slow speed if the community is too large, as a result, we need to take longer time facing lower accuracy problems.

Genetic algorithm may converge too fast, if the community is too small, so we cannot find the global best solution.

8. Conclusion

Based on the electromagnetic knowledge and literature, we set up a model to simulate the radio wave propagating in the space between the ionosphere and the Earth. We simulate the actual path of the radio wave and find that the earth can be rendered as a plane in this problem. Also, we assumed:

Regard the ionosphere as a smooth sphere which is concentric with the Earth.

The distance between the launch point and the ground is negligible.

The medium in the space between the Earth and the ionosphere is uniform, so the dielectric constant has the same value for each point in the area.

Acknowledgments

The preferred spelling of the word “acknowledgment” in America is without an “e” after the “g”. Avoid the stilted expression “one of us (R. B. G.) thanks ...”. Instead, try “R. B. G. thanks...”. Put sponsor acknowledgments in the unnumbered footnote on the first page.

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