Characteristic and Simulation of the Near Space Communication Channel

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Abstract: Near space vehicle, the hotspot in the military research currently, has significant strategic value. The paper analyzes the characteristic of the near space communication channel, amends C.Loo's fading channel model based on Doppler Frequency Shift, and gives the expressions for the probability density function, the level crossing rate and the average fading duration of the received signal. The expressions for the fading channel of near space communication in light shadowing, heavy shadowing and overall shadowing are respectively calculated numerically by simulation. The paper has great significance on the development and research for near space vehicles.

Keywords: near space vehicle; channel model; multipath; shadowing; Doppler Frequency Shift

1 Introduction

Near space, the space between the traditional satellites and aircrafts, which is upward the ground 20~100 kilometers. It generally contains stratosphere, mesosphere and some area of ionosphere. Near space vehicles are the vehicles flying in this area, containing stratospheric solar unmanned aerial vehicles, stratospheric airships, floating air balloons and telecontrolled gliding vehicles, etc. By carrying different kinds of loads, they have many military purposes, such as communication, telemetry, intelligence, reconnaissance, surveillance and so on. It was traditionally believed that near space is "a derelict area", where the air is very thin, and most military planes can't aviate, and for satellites the gravity is too large to keep the flight orbit. As a result, there were few vehicles aviating in the area, and human did no systemic and strategic researches into near space all the while. In 2004, John Jumper, the chief of staff in the United States Air Force, realized the enormous potentiality of the near space military platform[3], which has the characteristics of large regional coverage, good mobility and survivability, etc. It can meet the requirement of military communications, and has bright prospects. From then on, many countries all over the world have realized the strategic value of near space gradually, and launch researches into near space vehicles actively. References [1]-[7] are the papers introducing the development of near space vehicles in China and abroad.

The paper analyzes the characteristics of the near space communication channel, amends C.Loo's fading channel model properly, and gives the expressions for the probability density function, the level crossing rate and the average fading duration of the received signal. The probability density function, the level crossing rate and the average fading duration of the received signal for the fading channel of near space communication in light shadowing, heavy shadowing and overall shadowing are respectively calculated numerically by simulation.

2 Characteristic of the Near

This work was supported by the Air Force Equipment Researching Project (KJ06106) and the Natural Science Foundation of Shaanxi Province (2006F22).

Space Communication Channel

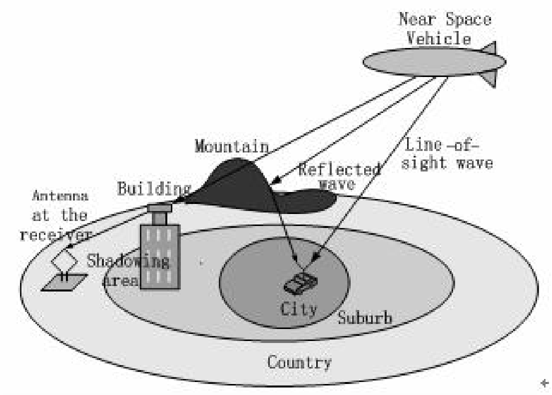

Fig 1 Near Space Communication Channel

The near space communication channel is a time-varying channel, whose characteristic is rather complicated and inclement. There exists not only propagation loss, but multipath effect, shadowing effect and Doppler frequency shift, which all affect the reliability of signal transmission seriously[8], as is showed in Fig 1. In the city zone of its coverage, there exists not only the multipath loss by different transmission paths, but the line-of-sight component, and the envelope of the received signal is Rician distributed. In suburbs and villages, mixed fading of shadowing and multipath affects the near space communication[9]. Multipath fading, shadowing fading and Doppler frequency shift in near space communication will be respectively analyzed following.

(1) Multipath fading

In near space communication, the signal sent from the vehicle to the receiver will be reflected, scattered and diffracted in its transmitting path because of buildings, trees, vegetation, undulating terrain, sea and water surface, which makes the signal at the receiver a compound of many waves from different paths. Because of the different transmitting distance of the waves and its different phases when received, the amplitude of the signal at the receiver undulates dramatically, which causes multipath fading.

(2) Shadowing fading

Electromagnetic waves will be attenuated when they are blocked by buildings, trees, etc in their transmitting paths, which makes the level of the received signal decline. When the signal sent from the near space vehicle passes through the shadowing of different blocks, the level of the signal will be attenuated to varying degrees, making the amplitude of the received signal undulating in a certain range, which causes shadowing fading. If the line-of-sight component is affected by shadowing in transmission, its probability density function is lognormally distributed.

(3) Doppler effect

In near space communication, when there is a relative movement between the vehicle and the user terminal, the carrier frequency of the signal at the receiver will shift, which is called Doppler Frequency Shift. Doppler Frequency Shift fm can be calculated by

$$f_m = f_c \times v / c \quad \text{Hz} \qquad (1)$$

Where f_c is the frequency of the carrier, v is the radial relative velocity between objects, and c is the velocity of light.

3 Statistical Model of the Near Space Communication Channel

For mobile satellite model, C.Loo's model [10] assumes that the line-of-sight component rather than the multipath component is affected by shadowing effect, that the amplitude of the line-of-sight component under shadowing is lognormally distributed and the received multipath interference has a Rayleigh distribution, and Doppler Frequency Shift is not calculated. Given the similarity of satellite mobile communication and near space communication, the paper amends C.Loo's model based on Doppler Frequency Shift, analyzed the model of near space communication channel numerically.

(1) Probability distribution function (PDF)

Assume that r is the signal at the receiver,

$$r\exp(j\theta) - z\exp(j\varphi_0) + w\exp(j\varphi) \qquad (2)$$

where the line-of-sight component z is lognormally distributed,

$$p(z)=\frac{1}{\sqrt{2\pi d_0}z}\exp[-\frac{(\ln z-\mu)^2}{2d_0}] \quad (3)$$

where μ and $\sqrt{d_0}$ are the mean and the standard deviation. The multipath component w is Rayleigh distributed, and the phases φ_0 and φ are uniformly distributed between 0 and 2π. If z is temporarily kept constant, then the conditional probability density function of r is simply that of a Rician vector,

$$p(r|z)=\frac{r}{b_0}\exp(-\frac{r^2+z^2}{2b_0})I_0\frac{rz}{b_0} \quad (4)$$

where b_0 represents the average scattered power due to multipath, and I0 is the modified Bessel function of zeroth order. According to reference [10],

$$p(r)=\frac{r}{\sqrt{2\pi d_0}b_0}\bullet \int_0^\infty \frac{1}{z}\exp[-\frac{(\ln z-\mu)^2}{2d_0^2}-\frac{r^2+z^2}{2b_0}]I_0\frac{rz}{b_0}dz \quad (5)$$

So the probability density function of the envelope of the received signal is

$$\begin{aligned}P(r>R)&=\int_R^\infty p(r)dr=1-\int_0^R p(r)dr\\&=1-\frac{1}{\sqrt{2\pi d_0}b_0}\bullet\\&\int_0^R dr\int_0^\infty\frac{r}{z}\exp[-\frac{(\ln z-\mu)^2}{2d_0^2}-\frac{r^2+z^2}{2b_0}]I_0\frac{rz}{b_0}dz\end{aligned} \quad (6)$$

(2) Level crossing rate (LCR)

Level crossing rate and average fading duration, which reflect the changing rate of the state of the channel, are second-order statistics of channel model. Level crossing rate N_R is defined as the expected rate at which the envelope crosses a specified signal level R,

$$N_R=\int_0^\infty \dot{r}p(R,\dot{r})d\dot{r} \quad (7)$$

where $\dot{r}$ is the time derivative of r and $p(R,\dot{r})$ is the joint probability density function of $\dot{r}$ and r at r=R.

According to reference [10], the expression of LCR is

$$N_R=\frac{\sqrt{1-\rho^2}}{\sqrt{2\pi}}\frac{b\sqrt{b+2\rho\sqrt{bd}+d}}{b(1-\rho^2)+4\rho\sqrt{bd}}p(r) \quad (8)$$

where $\sqrt{b}$ and $\sqrt{d}$ are respectively the square variance of the changing rate of the envelope of the received signal in multipath fading and shadowing fading. Assume that the fading spectrum due to shadowing and multipath is symmetrical and Gaussian, that is

$$b=b_0(2\pi f_m)^2,\, d_2=d_0(2\pi f_m)^2 \quad (9)$$

So,

$$\begin{aligned}N_R&=\sqrt{2\pi}\sqrt{1-\rho^2}f_m b_0\frac{\sqrt{b_0+2\rho\sqrt{b_0d_0}+d_0}}{b_0(1-\rho^2)+4\rho\sqrt{b_0d_0}}p(r)\\&=\sqrt{\frac{1-\rho^2}{d_0}}\frac{\sqrt{b_0+2\rho\sqrt{b_0d_0}+d_0}}{b_0(1-\rho^2)+4\rho\sqrt{b_0d_0}}f_m\bullet\\&\int_0^\infty\frac{r}{z}\exp[-\frac{(\ln z-\mu)^2}{2d_0^2}-\frac{r^2+z^2}{2b_0}]I_0(\frac{rz}{b_0})dz\end{aligned} \quad (10)$$

(3) Average fading duration (AFD)

Average fading duration t_N is defined as the average time at which the level of the received signal is lower than a certain level.

$$\begin{aligned}t_N&=\frac{1}{N_R}\int_0^R p(r)dr\\&=\frac{[b_0(1-\rho^2)+4\rho\sqrt{b_0d_0}]}{b_0\sqrt{2\pi(1-\rho^2)(b_0+2\rho\sqrt{b_0+d_0}+d_0)}f_m}\bullet\\&\frac{\int_0^\infty dr\int_0^\infty\frac{r}{z}\exp[-\frac{(\ln z-\mu)^2}{2d_0^2}-\frac{r^2+z^2}{2b_0}]I_0(\frac{rz}{b_0})dz}{\int_0^\infty\frac{r}{z}\exp[-\frac{(\ln z-\mu)^2}{2d_0^2}-\frac{r^2+z^2}{2b_0}]I_0(\frac{rz}{b_0})dz}\end{aligned} \quad (11)$$

4 Simulation Results

Tab1[10] shows the typical parameters in infrequent light shadowing, frequent heavy shadowing and the combined results of light and heavy shadowing. For the fading channel model of near space communication, formulas (6), (10) and (11) are simulated by MATLAB, showed in Fig 2, 3, and 4. In the figures, the long dashed line represents the case of infrequent light shadowing (wide area in city and sparse tree-covering area in country), the dotted line represents the case of frequent heavy shadowing (building-shading area in city and dense tree-covering area in country), and the real line the case of the combined results of light and heavy shadowing (area in suburb where building and tree are distributed unevenly). When calculating LCR and AFD, $\rho=0.5$; the velocity of vehicles v=38m/s, namely f_m=6016.66Hz.

Tab 1 Model Parameters [10]

Conditions	Standard Deviation ($10\lg\sqrt{d_0}$)	Mean ($10\lg\mu$)	Multipath Power ($10\lg b_0$)
Infrequent light shadowing	0.5	0.5	-8.0
Frequent heavy shadowing	3.5	-17.0	-12.0
Overall results	1.0	-3.0	-6.0

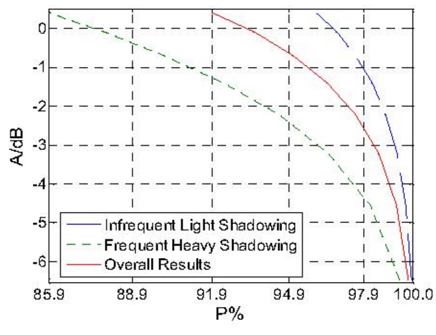

Fig 2 PDF in Different Fading Cases

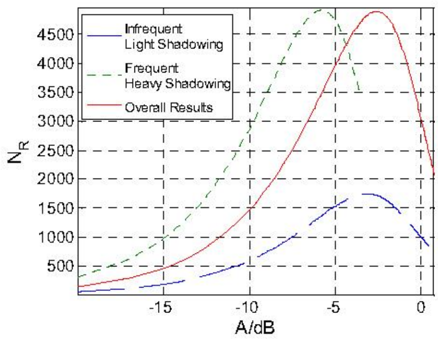

Fig 3 LCR in Different Fading Cases

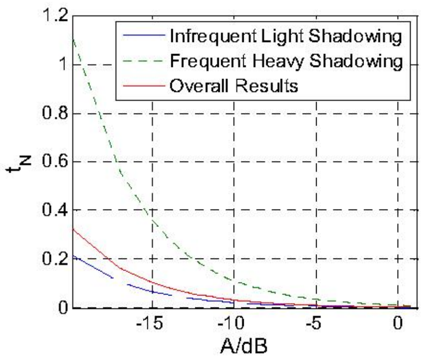

Fig 4 AFD in Different Fading Cases

From the figures, it can be seen that in near space multipath and shadowing fading communication, the probability that the envelope of the received signal suffers shallow fading is much deeper than deep fading; PDF decreases with the increase of the amplitude of the received signal, and its value in infrequent light shadowing is higher than it in frequent heavy shadowing; LCR has a maximum value, which in infrequent light shadowing is less than it in frequent heavy shadowing; AFD decreases with the increase of the amplitude of the received signal, and its value in frequent heavy shadowing is higher than it in infrequent light shadowing.

5 Conclusion

The paper amends C.Loo's model based on Doppler Frequency Shift. A model for near space communication channel is described, the expressions for PDF, LCR and AFD are obtained, and PDF, LCR and AFD of the envelope of the received signal in infrequent light shadowing, frequent heavy shadowing and the combined results of light and heavy shadowing are simulated by numerical calculation. It also shows the changing rule for the envelope of the received signal in near space communication. The conclusion in this paper can be helpful to the design and research for near space vehicles to a certain extent.

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