Modeling and Simulation of Near Space Platform-Land Channel

Deng-yin Zhang
Department of Communication and Information Technology
Nanjing University of Posts and Telecommunications
Nanjing 210003, China
e-mail: zhangdy@njupt.edu.cn

Zhuo-heng Wu
Department of Communication and Information Technology
Nanjing University of Posts and Telecommunications
Nanjing 210003, China
e-mail: forarevercc@hotmail.com

Abstract— **Near space communication has many qualities such as high spectral efficiency, small path loss and low propagation delay. It has both advantages of land wireless communication and satellite communication, which is suitable for Space broadband wireless access. Currently, the studies of near space are abundantly focused on the manufacture and flight on platform. However, the research of specific communication technology is very rare. This paper mainly studied on the communication channel from Near space platforms (NSPS) to Land. Fading and delay spread is selectively analyzed which is caused by multipath. According to WSSUS hypothesis, the stratospheric scattering channel modeled in high dynamic environment with fast fading was structured, and the propagation characteristics are compared with characteristics of satellite-Land channel. It is shown that the proof of near space platform-land (NSP-L) scattering channel model is reasonable, which makes contribution to system performance analysis of NSPS communication.**

Keywords-NSPS; Channel Model; Multipath Fading; Radio Propagation Characteristics

I. INTRODUCTION

With the development of technology of the space communication and the breakthrough of all kinds of key technology, space communication has made great progress. The forthcoming communication network, including satellite network, near space aircraft and terrestrial network, will develop into a space information network incorporated with space, sky and land. Studies on space information network at home and abroad are no longer restricted in satellite, which introduce researches on near space layer based on satellite network [1][2]. Near space layer is a region consisted of communication carriers such as balloon, airship and glider operated in the stratosphere. It is a stable access platform that connects ground stations and satellite. Near Space Platforms (NSPS) are communication facilities flying at altitudes ranging from 20 to 50 km which is relatively static to the earth. Near space communication makes the NSPS as the communication platforms in the stratosphere communicate with control equipments, information interface devices and all kinds of wireless user terminals on the earth, the NSPS and satellites. It constitutes completed, self-contained and integrated space-earth-air comprehensive information mobile communication network system.

Compared with the satellite communication system, the near space communication system has many qualities such as low propagation delay, small free space attenuation, low cost, fast building and high capacity. Besides, it is also beneficial to implement the miniaturization, broadbandization and the asymmetrical duplex wireless access of communication terminals. Compared with the cellular system, the NSPS have a long operating distance, large coverage and small channel fading. It can reduce the cost of information infrastructure and the radioactive pollution of the surrounding base stations [3][4]. Therefore the near space communication is a kind of perspective communication that remedies these defects such as large propagation delay, high power waste and long construction cycle of information propagation of the satellite system.

Currently, most of the studies on NSPS were focused on manufacture and flight of the platform but the researches on communication technology. Nowadays the description of NSPS communication channel is not sufficient. It is hardly seen the researches about signal transmission and information processing technologies of NSPS communication, especially the communication channel of NSPS of the space-based network. In the space-based network, a bit rate of broadband service above 100MHz is designed, which makes communication more sensitive in the propagation environment. This paper focuses on the characteristics of multipath fading of NSPS in the space information network to establish a mathematical model of near space-land communication channel. Compared with the characteristics of satellite-land communication channel in the space information network, the channel model of near space layer-land communication is proved reasonably, which laid the foundation of the researches for the integral capability of the near space communication system.

II. SPACE INFORMATION COMMUNICATION SYSTEM AND PROPAGATION CHARACTERISTICS

Space information network (see Fig. 1) on the base of the space-based, air-based and land-based network makes good use of each layer. It broadens the service coverage and simplifies the means of information exchange. The Space information network has many characteristics of high information capacity, strong real-time ability and so on. Meanwhile, the network

The work was partially supported by Swedish Research Links [No.348-2008-6212], the National Natural Science Foundation of China [61071093], China's Project 863 [2010AA701202], and SRF for ROCS, SEM [NJ209002].

Research presented in this paper was fund by Key Lab of "Broadband Wireless Communication and Sensor Network Technology" (Nanjing University of Posts & Telecommunications), Ministry of Education

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layers cooperate with each other to achieve complementary advantages. On this situation the resource of space-air-land network can be dispatched appropriately, which makes the maximum utilization of network resources happened. Near space communication system is such a mobile communication system that sends NSPS as relay stations or switch centers carried with communication equipments to a fixed place in the stratosphere steadily for a long time. The system can provide all kinds of communication operations such as fixed, mobile, broadband and narrowband. The mobile communication system is consisted of NSPS, land control equipments, interface equipments and all kinds of wireless terminals. The platforms are proposed to fly at altitudes ranging between 17 and 22km above the altitudes of air-line where the average speed of wind is low and the locations of the platforms are relatively easy to decide.

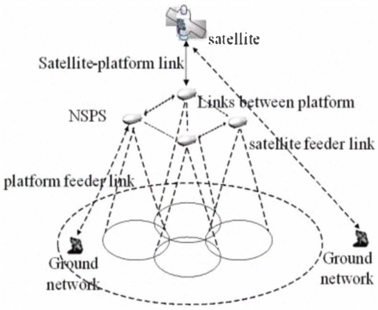

Figure 1. Space information communication system

Compared with satellite communication system, near space communication system has a lot of advantages such as high capacity, high spectral efficiency, low propagation delay, small path loss, easy to maintain and upgrade, rapid to construct and so on. Besides, the NSPS is confined within the national boundary. The sovereignty, proprietary rights and managing rights belong to the homeland [3].

The primary problem of researching the propagation characteristics of near space communication is the propagation loss. Based on the model of generalized scattering theory, the forecast formula of the near space platform stations-land (NSP-L) scatter propagation loss is [5]

$$L = L_F + A_{mu}(f,d) - G(h_{te}) - G(h_{re}) - G_{AREA} \cdot \quad (1)$$

where the L is the median of the path loss(unit dB). L_F is the free space propagation loss. $A_{mu}(f,d)$ is the free space loss median. $G(h_{te})$ is the gain factor of the base station antenna. $G(h_{re})$ is the gain factor of the mobile station. G_{AREA} is environmental enrichment factor.

The signal level of the NSPS changed randomly and it has large scale fading and small scale fading. This paper ignores the large scale fading according to the characteristics of the space information network. The signal is sent to receiver through the straight, reflection, and refraction paths. Because of different distance of propagation paths, each path of the signal received with different arrival time and phase that makes the amplitudes of the received signal sharply changed. That is small scale fading. When the small scale fading occurs, each signal exists random frequency modulate which is caused by the Doppler shift. Meanwhile, multipath propagation causes the time spreading. Main reasons to affect the small scale fading are multipath propagation, velocity of the mobile stations and movement of the object around the propagation environment.

The received scatter signal is the sum of different replicas of the same transmitted signal following different paths that reflected by different scatterers. The distance of different signal echoes are commonly different. It causes multipath of the scatter communication. Multipath propagation of the channel generally extends the propagation time of baseband part which brings about ISI. It will produce frequency selective fading of the signal if the ISI is severe.

The signal is transmitted through the environment that the scatterers are overspreading near the ground receiver. Supposing the length of the i th path is x_i and the reflection coefficient is a_i, the received bandpass signal can be obtained.

$$\begin{aligned} y'(t) &= \sum_i a_i s'(t - \frac{x_i}{c}) = \sum_i a_i \operatorname{Re}\left\{ s(t - \frac{x_i}{c}) \exp\left[j2\pi f_c (t - \frac{x_i}{c}) \right] \right\} \quad (2) \\ &= \operatorname{Re}\left\{ \sum_i a_i s(t - \frac{x_i}{c}) \exp\left[j2\pi (f_c t - \frac{x_i}{\lambda}) \right] \right\} = \operatorname{Re}\left[y(t) e^{j2\pi f_c t} \right] \end{aligned}$$

Where c is the speed of the light. $\lambda = c/f_c$ is the wavelength. The complex envelope of the received signal is the sum of each echo with different fading, phase shift and delay.

$$y(t) = \sum_i a_i e^{-j2\pi \cdot \frac{x_i}{\lambda}} s(t - \frac{x_i}{c}) = \sum_i a_i e^{-j2\pi f_c \tau_i} s(t - \tau_i) \quad (3)$$

Where the delay is $\tau_i = x_i / c$.

III. MODELING NEAR SPACE LAYER-LAND COMMUNICATION CHANNEL

A. Analysis of the channel characteristic

According to the approximate model of the NSP-L channel, the scatterers are overspreading near the ground and the range of the elevation angles of the receivers is between 10 and 90 degrees. When the heights of the scatters and the transmiters are changed in a certain degree, the cumulative distribution functions we gained are basically the same [6]. The power delay profile is obtained by the power fading of different echoes transmitted from transmitter to receiver [7].

$$P(\tau) = \frac{1}{\tau_d (1 - e^{-\tau_{max}/\tau_d})} e^{-\tau/\tau_d}, \quad 0 \le \tau \le \tau_{max} \quad (4)$$

Where the τ is the excess delay (the time difference of scatter channel and LOS channel). τ_{max} is the maximum excess delay. τ_d is the decay rate.

If the i th path of the signal with excess delay τ_i has an amplitude A_i, then the rms delay spread σ_τ caused by multipath is

$$\sigma_\tau = \sqrt{(\overline{\tau^2} - (\overline{\tau})^2)}\,. \quad (5)$$

Where:

$$\bar{\tau} = \frac{\sum_n A_i^2 \tau_i}{\sum_n A_i} = \frac{\sum_n P(\tau_i)\tau_i}{\sum_n P(\tau_i)}, \overline{\tau^2} = \frac{\sum_n A_i^2 \tau_i^2}{\sum_n A_i^2} = \frac{\sum_n P(\tau_i)\tau_i^2}{\sum_n P(\tau_i)}. \quad (6)$$

In a digital communication system, if the rms delay spread is larger than symbol period, the different echoes of the signal will arrive at different symbol period cause the ISI. So the channel we discussed previously is called frequency-selective channel. Assume that $\tau_{\max}$=15us and τ_d=1us. The rms delay spread of NSP-L channel σ , equals to 42ns, according to the power delay profile.

If the correlation function of frequency is 0.9, the coherent bandwidth of the channel can evaluated as

$$B_c = \frac{1}{50\sigma_\tau} = 476.19 \text{ KHz} \cdot \quad (7)$$

The relative motion of the transmitter and the receiver in the space information network causes the frequency shift of the received signal which is called Doppler shift (see Fig. 2). The Doppler shift makes the spectrum of the transmitted signal expanded at the receiver, which causes the frequency diffuse of the fading process. Then the time-selective fading of the signal are formed.

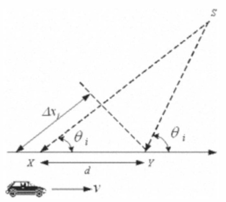

Figure 2. Doppler shift schematic diagram

The speed of ground user is v_u=50km/h. The speed of NSPS is v_p=150km/h and the carrier frequency is f=2GHz. The maximum Doppler shift f_{max} can then be obtained.

$$f_{\max} = f_{d,p} + f_{d,u} = (v_p + v_u) f / \lambda = 370.4 \quad \text{Hz} \quad (8)$$

Coherence time of the channel is

$$T_c = \frac{9}{16\pi f_{\max}} = 0.483 \text{ ms} \cdot \quad (9)$$

The results above indicate that the time spread can be ignored because of the low delay spread of the NSP-L channel, but the Doppler effect can not be ignored since frequency diffusion caused by the movement of the platform and the user is severe.

B. Channel mathematical modeling

Multipath scattering model is the continuum of the multipath component, which is usually used to describe the scatter channel [8][9]. The linear time-varying (LTV) system with complex low-pass equivalent response $\tilde{c}(\tau, t)$ is often applied in channel modeling. To establish a mathematical model for the time-varying channel, the $\tilde{c}(\tau, t)$ is assumed as a Wide Sense Stationary (WSS) stochastic process with a parameter *t*. Supposing the attenuation and the phase shift of each echo with different delay is uncorrelated, the multipath channel can be called Uncorrelated Scattering(US) channel.

$$\mathrm{R}_{\tilde{c}\tilde{c}}(\tau, \alpha) = E\{\tilde{c}^*(\tau, t)\tilde{c}(\tau, t+\alpha)\} \quad (10)$$

Wide Sense Stationary Uncorrelated Scatter (WSSUS) channel model is a common model about time-varying multipath channel of scatter communication. The second order statistics is completely determined by the scatter function which can be expressed as

$$S(\tau, \lambda) = F\{(R_{\tilde{c}c}(\tau, \alpha))\} = \int_{\infty}^{\infty} R_{\tilde{c}\tilde{c}}(\tau, \alpha) \exp(-j2\pi\lambda\alpha) d\alpha \cdot \quad (11)$$

The function $\mathrm{S}(\tau, \lambda)$ has two independent variables such as time variation (delay) and frequency variation (Doppler shift). It makes use of delay and Doppler shift as a measurement of output of the average power of the channel. Assuming the NSP-L channel as a WSSUS channel, a Tap-Delay-Line (TDL) model can be obtained to simulate the NSP-L channel (see Fig.3).

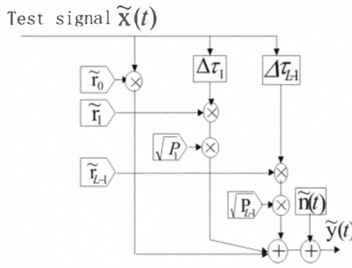

Figure 3. TDL model of NSP-L channel

Where the $\tilde{x}(t)$ is the complex of the input signal and each of the taps represents a path (the number of the tap is finite). The NSP-L communication channel has a light of sight (LOS) propagation path whose excess delay is $\tau_0 = 0$. The excess delay τ_i of the other propagation path obeys $[0, \tau_m]$ uniform distribution. The tap gain $\tilde{r}(t)$, obtained as the product of the White Gaussian Process passing through the FIR filter, is time-varying. The bandwidth of the FIR filter is the maximum Doppler shift. The power spectrum density of each tap $\sqrt{P_i}$ is evaluated by Doppler spectrum using power delay profile. The received signal is the sum of each echoes of signal and the white Gaussian noise.

$$y(t) = \sum_{i=0}^{N} \sqrt{P_i} \tilde{r}_i(t) \tilde{x}(t - \frac{i\tau_m}{N}) + \tilde{n}(t) \quad (12)$$

Where:
$$\tilde{r}_i(t) = \sum_{k=0}^{N} c_k(t) s_i(t - \frac{k\tau_m}{n}) \quad (13)$$

IV. SIMULATION AND RESULT ANALYSIS

The wireless channel between a base station on the near space layer and a land mobile user is simulated by matlab tool. The performance of the NSP-L channel discussed above will be compared with the performance of the channel of the LEO satellite.

As the approximate model of the NSP-L wireless channel has been shown, the scatterers are overspreading near the ground and the range of elevation angles of the receivers is between 10 and 90 degrees. When the heights of the scatters and the transmitters are changed in a certain degree, the cumulative distribution functions we gained are basically the same. Then it is possible to evaluate the signal power with a certain excess delay. Supposing the number of tap is N=8 and $\Delta\tau$ =20ns, the normalized power delay profile of the NSP-L channel we obtained will be discrete (see Fig.4).

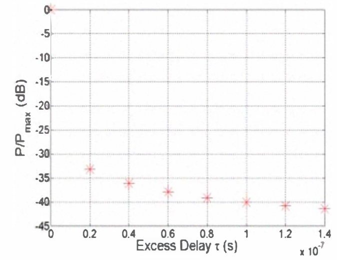

Figure 4. Normalized Power Delay Profile(discrete form)

As a simulation example, we consider a 2-PSK modulated signal at a carrier frequency of 2 GHz. The platform is assumed to have a speed of 150 Km/h (41.67m/s), while the speed of the user is 50 Km/h (13.89 m/s). From the simulation, the maximum Doppler spread $f_{\max}$ is calculated as 370.4 Hz and the coherence time T_c is calculated as 0.483ms. In calculations leading to the power delay profile, we obtain the rms delay spread σ_τ =42ns and the coherence bandwidth B_c =476.19 KHz.

The NSP-L channel is tested with a bit rate of 0.25 Mb/s, 1 Mb/s and 4 Mb/s. The test symbol number is 200000 and the simulation result is shown in Fig.5 (a).

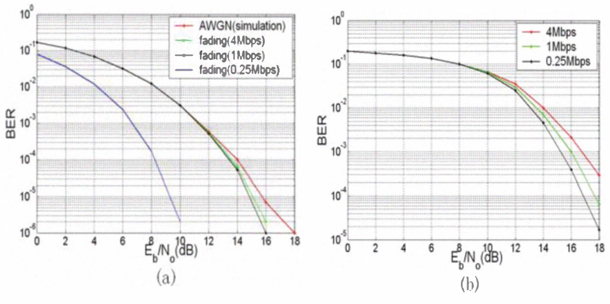

Figure 5. Simulation of NSP-L and LEO satellite channel

The LEO satellite communication channel has many qualities such as large propagation loss and large Doppler shift, time-varying and fading. As a large number of tests about satellite channel have been application abroad, the order of magnitude of multipath delay of the LEO satellite communication system in the city is obtained as 100 ns. The LEO satellite channel is tested with a bit rate of 0.25 Mb/s, 1 Mb/s and 4 Mb/s and the simulation result is shown in Fig.5 (b).

Fig.5 (a) and Fig.5 (b) depict that the bit error rate (BER) of the NSP-L channel is smaller than the BER of the LEO satellite channel and also is the delay. The parameters of the simulation of LEO satellite channel are given. The channel has 5 paths and the delay of each path is 0.1, 0.2, 0.3, 0.4, 0.5 μs . The power of each path is 0.588, 0.247, 0.106, 0.041, 0.018.

V. CONCLUSION

In this paper, characteristics of link loss, Doppler effect and delay spread of the NSP communication system are analyzed. The characteristics of the NSP-L scatter channel are described under the circumstances of fast fading of the near space network. The simulation of the channel is derived. Comparison of BER between the NSP-L and the satellite channel validates the rationality of the NSP-L scatter channel model and the advantages of the near space communication. Compared with the satellite communications, near space communications have a lot of advantages of low propagation loss, low propagation delay, small BER with same signal to noise ratio (SNR) and so on.

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