The Correlation Matrix model of Capacity Analysis in Unmanned Aerial Vehicle MIMO Channel

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Abstract: - The 3D-GBSBCM (Geometrically Based Single Bounce Cylinder Model) channel model is applied in UAV (Unmanned Aerial Vehicle) MIMO communication system which involves direct, reflection and diffuses components. The concise and precise space-time-frequency correlation functions of the UAV channel model are presented. Methods of channel matrix factorization and channel coefficient normalization are applied to deduce the correlation matrix of UAV-MIMO channel. We also use the assumed parameters of correlation matrix to simulate and analyze the influence of antenna distribution on UAV-MIMO channel capacity when the parameters of channel are certain. The simulation results have good reference and application value in the configuration and collocation of antennas in UAV-MIMO system.

Key-Words: - UAV channel, GBSBCM, MIMO Channel Correlation Matrix, Channel Capacity

1 Introduction

With the development of UAV data-link, the demand of data-link in high speed and with large data capacity is increasing. As known that multi-antennas technology can improve the capacity and speed of data link in communication system. Multi-antennas technology was proved to be an effective method approaching high transmission speed in UAV remote control and sensing system. In multi-antenna system, the transmitting speed is determined by the capacity of radio channel [1,2]. So the capacity analysis of MIMO channel is very necessary in application of multi-antennas communication system in UAV.

The traditional aeronautical MIMO channel model mainly involves direct components and scattering ones [3, 4]. And if the transmitter and receiver parts of the system are independence of each other, the Kroneckor correlation model can be used to analyze the aeronautical channel matrix [4-6]. But there are direct or reflection components and some diffuse components in the UAV communication system, and also the transmitters and receivers are interrelated in the UAV MIMO channel. So the aeronautical MIMO channel model cannot reflect the characteristics of UAV-MIMO channel precisely. And the capacity of aeronautical MIMO channel also cannot be directly used in the measurement of UAV-MIMO channel capacity. In paper [10] the 2D-GBSB scattering channel model is proposed and its parameters are analyzed. In papers [11,12] the 3D-GBSBCM scattering channel model is put forward. In paper [13], the gain of channel and MIMO channel correlation coefficient are given out. The Kroneckor correlation model is applied to obtain the scattering channel matrix in [13], and the capacity of GBDBCM (Geometrically Based Double Bounce Cylinder Model) channel is analyzed. But in [5,10-13], the direct and reflection components are neglected, the channel matrix is composed of scattering components or direct and scattering components. So the channel matrix which reflects direct, reflection and scattering components should be adopted to analyze the channel capacity.

In this paper, the downlink of UAV remote sensing channel is investigated and GBSBCM channel model is adopted in the MIMO channel of the UAV according to the communication circumstance between ground and UAV in far field. The simplified representation of direct, reflection and scattering correlation coefficients of MIMO channel are presented. The UAV-MIMO channel matrix is give out as possible to be used directly to analyze the capacity change caused by the distribution of antenna. The antenna of ground station and UAV are both omni-directional and dual-antenna array model, and the analysis involves that this can be extended to any multi-antenna array system.

This paper is organized as follows; Section 2 presents the UAV-MIMO system model and gives out the correlation functions. The theoretic MIMO channel capacity is briefly described in Section 3, The correlated channel matrix representations are described in Section 4, Simulation results with discussions are presented in Section 5, and finally conclusions are drawn in Section 6.

2 UAV-MIMO Channel

In the papers [11,12], it is assumed that the height of scatterers are H_c which is evenly distributed on the circle, and the height of receiving antennas is H_g and the radius of the circle is R. There no scatterers around the UAV when it is flying, and the UAV is far from the ground and has large difference in height, so the direct line-of-sight (LOS), specular (SPE) and diffuse (DIF) paths in the multi-path components should put into consideration. The model of direct and reflection components are shown in Fig.1, the model of

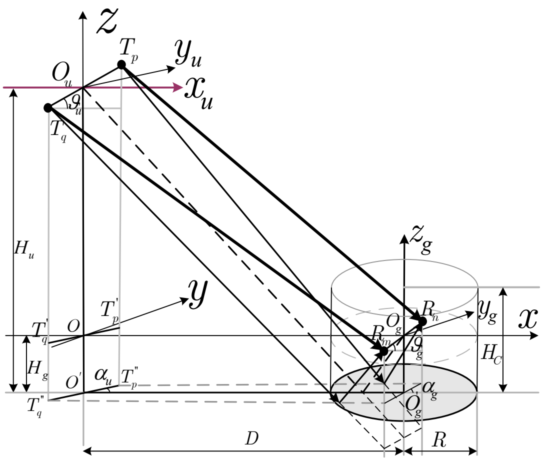


Fig.1 Model of UAV channel with direct and reflection components

scattering components is similar as [11, 12].

Under the condition of WSSUS (wide-sense stationary uncorrelated scattering), we assume that the probability density function of pitch and site angle fits the Von-Mises distribution and belongs to complex parameter model [14, 15]. Then the space-time-frequency correlation functions of line-of-sight in 3D-GBSBCM, the specular and diffuse paths between the transmitters T_p, T_q and receivers R_n, R_m can be simplified as follows:

$$\begin{aligned} &\square^{LOS}_{np,mq}(\Delta t,\Delta f) \\ &= E\left(h_{np,LOS}(t,f)\,h^{*}_{mq,LOS}(t+\Delta t, f+\Delta f)\right) \\ &= e^{jk_0\left(d^{LOS}_{np}-d^{LOS}_{mq}\right)} \times R_{LOS} e^{Jf_{LOS}(\Delta\square\Delta\square)} \end{aligned} \quad (1)$$

Where,

$$d^{LOS}_{np} = \sqrt{\begin{aligned}&\left(\left(H_{\square}+\frac{\delta_{pq}}{2}\sin\vartheta_{\square}\right)-\left(H_g+\frac{\delta_{nm}}{2}\sin\vartheta_g\right)\right)^2\\ &+\left(D-\frac{\delta_{pq}}{2}\cos\vartheta_{\square}\cos\alpha_{\square}+\frac{\delta_{nm}}{2}\cos\vartheta_g\cos\alpha_g\right)^2\end{aligned}} \quad (2)$$

and

$$d^{LOS}_{mq} = \sqrt{\begin{aligned}&\left(\left(H_{\square}-\frac{\delta_{pq}}{2}\sin\vartheta_{\square}\right)-\left(H_g-\frac{\delta_{nm}}{2}\sin\vartheta_g\right)\right)^2\\ &+\left(D+\frac{\delta_{pq}}{2}\square\square\square\vartheta_{\square}\square\square\square\alpha_{\square}-\frac{\delta_{nm}}{2}\cos\vartheta_g\cos\alpha_g\right)^2\end{aligned}} \quad (3)$$

$$\begin{aligned} &R^{\square\square\square}_{np,mq}(\Delta t,\Delta f) \\ &= E\left(h_{np,\square\square\square}(t,f)\,h^{*}_{mq,\square\square\square}(t+\Delta t, f+\Delta f)\right) \\ &= e^{jk_0\left\{d^{SPE}_{np}-d^{SPE}_{mq}\right\}} \times R_{SPE} e^{\square f_{SPE}(\Delta\square\Delta\square)} \end{aligned} \quad (4)$$

Where,

$$d^{SPE}_{np} = \sqrt{\begin{aligned}&\left(\left(\square_{\square}+\frac{\delta_{pq}}{2}\sin\vartheta_{\square}\right)+\left(\square_g+\frac{\delta_{nm}}{2}\sin\vartheta_g\right)\right)^2\\ &+\left(D-\frac{\delta_{pq}}{2}\cos\vartheta_{\square}\cos\alpha_{\square}+\frac{\delta_{nm}}{2}\cos\vartheta_g\cos\alpha_g\right)^2\end{aligned}} \quad (5)$$

and

$$d^{SPE}_{mq} = \sqrt{\begin{aligned}&\left(\left(\square_{\square}-\frac{\delta_{pq}}{2}\sin\vartheta_{\square}\right)+\left(\square_g-\frac{\delta_{nm}}{2}\square\sin\vartheta_g\right)\right)^2\\ &+\left(D+\frac{\delta_{pq}}{2}\cos\vartheta_{\square}\cos\alpha_{\square}-\frac{\delta_{nm}}{2}\cos\vartheta_g\cos\alpha_g\right)^2\end{aligned}} \quad (6)$$

$$R_{np,mq}^{DIF}\left(\Delta t,\Delta f\right)$$

$$= R_{DIF} e^{\square f_{DIF}(\Delta\square,\Delta\square)} \times e^{\square 2\pi k_0\left(\cos\vartheta_u \cos\alpha_u - \Delta_1 \sin\vartheta_u\right)/\sqrt{1+\Delta_1^2}}$$

$$\times I_0\left(\sqrt{x^2+y^2}\right) \times R\left(\square,\square\right)\Big/ I_0\left(k\right) \quad (7)$$

Where,

$$x = jk_0\delta_{nm}\cos\vartheta_g\cos\alpha_g + k\cos\theta_{g0} + f_x\left(\Delta t,\Delta f\right) \quad (8)$$

$$\square = jk_0(\delta_{\square\square}\cos\vartheta_g\sin\alpha_g + \delta_{\square\square}\cos\vartheta_u\sin\alpha_u\Delta_{xy}\Big/\sqrt{1+\Delta_1^2}) + k\sin\theta_{g0} + f_y(\Delta t,\Delta f) \quad (9)$$

$$\Delta_{xy} = R/D, \Delta_1 = \left(H_U - H_G - Rtg\varphi_{G,l}\right)\Big/D \quad (10)$$

$$R(m,n) = \int_{-\varphi_g^{\square\square\square}}^{\varphi_g^{\square\square\square}} \square^{\square\square_0\delta_{\square\square}\varphi_g\square\square\square\vartheta_g} f\left(\varphi_g\right)d\varphi_g \quad (11)$$

$$\varphi_g^{\square\square\square} = arctg(H_g / R) \quad (12)$$

$$\varphi_g^{\square\square\square} = arctg(H_c - H_g / R) \quad (13)$$

where, λ represents wavelength; $k_0 = 2\pi / \lambda$ represents wave number in free-space; k represents the angle spread factor in the Von-Mises distribution; $f(\varphi_g)$ is represented to the complex parameter model; $\vartheta_\square$ and $\alpha_\square$ denotes the pitch and azimuth angle of transmitter respectively; $\vartheta_\square$ and $\alpha_\square$ are the pitch and site angles in receiving antenna; φ_u and θ_u are the pitch and azimuth angles of the scattering components which is from the UAV to ground; φ_g and θ_g are the pitch and azimuth angles of scattering components which are received on the ground; θ_{g0} is the average of the azimuth angle θ_g; δ_{pq} and δ_{nm} are the distance between the transmitting and receiving antenna; H_u represents the height of UAV and D represents the horizontal distance of UAV and which is satisfied with the following type.

$$D \gg H_v \gg R \gg H_c \gg H_g \gg Max\left(\delta_{pq},\delta_{nm}\right) \quad (14)$$

R_{LOS} , R_{SPE} and R_{DIF} represent the correlation functions amplitude of line-of-sight, specular and diffuse paths respectively; $f_{LOS}(\Delta t,\Delta f)$, $f_{SPE}(\Delta t,\Delta f)$, $f_{DIF}(\Delta t,\Delta f)$, $f_x(\Delta t,\Delta f)$ and $f_y(\Delta t,\Delta f)$ are the functions variables of which are Δt and Δf , and which are also satisfied with the following type (15).

$$f_{LOS}(0,0) = f_{SPE}(0,0) = f_{DIF}(0,0) = f_x(0,0) = f_y(0,0) = 0 \quad (15)$$

3 MIMO Channel Capacity

If the channel parameters in the transmitter part is unknown and the channel coefficients are constant, as well as the MIMO system has n_T transmitting antennas and n_R receiving antennas, then its capacity can be expressed as follows [16-18].

$$C = \log_2\left[\det(I_{n_R} + \frac{\rho}{n_T}HH^*)\right](bit/s/Hz) \quad (16)$$

where, ρ is the receiving SNR, H is the channel correlation matrix of $n_T \times n_R$, H^* is the conjugate transpose of H .

When the channel coefficients are stochastic, Eq. (16) represents instantaneous channel capacity. Then, the channel capacity can be taken as an ergodic process and the channel coefficients can be obtained through the averaging method.

When the channel coefficients of transmitter are known, if we apply the waterflooding principle and distribute different transmitting power to different antennas, then the capacity of channel can be expressed as [17,18].

$$\overline{C} = E_H(C) \quad (17)$$

$$C = \sum_{i=1}^{r}\log_2(1+\rho\lambda_i p_i^+) \quad (18)$$

Among them, λ_i denotes one of the r positive eigenvalues of HH^* ; r represents the rank of channel matrix.

$$x^+ = \max\{x,0\} \quad (19)$$

$$p_i^+ = (\mu - 1/\rho\lambda_i)^+ \quad (20)$$

$$\mu = 1/L\ln 2 \quad (21)$$

where, L is the Lagrange constant in the condition of $\sum_{i=1}^{r} p_i^+ = 1$.

4 UAV MIMO Channel Correlation Matrix

According to Eqs. (10)-(12), channel correlation matrix H is very important in the analysis of the UAV-MIMO channel capacity. Because the UAV channel coefficient $h_{n_T,n_R}(t,\tau)$ is a random variable, so the average of channel correlation matrix is necessary to analyze the average channel capacity. If we take the whole characterization of UAV communication system into consideration, and apply the methods of channel matrix analysis and channel coefficient normalization, the correlation matrix of UAV-MIMO channel can be deduced.

4.1 Factorization of Channel Correlation Matrix

The UAV-MIMO channel correlation matrix H can be decomposed as follows:

$$H = \eta_{LOS}H_{LOS} + \eta_{SPE}H_{SPE} + \eta_{DIF}H_{DIF} \tag{22}$$

where, η_{LOS} , η_{SPE} and η_{DIF} represent respectively the proportion factor of direct, reflection and scattering components of the receiving power, they can be written as (23).

$$\begin{cases} \eta_{\square\square\square} = \sqrt{\dfrac{k_{\square\square\square\square}}{1 + k_{\square\square\square\square} + k_{\square\square\square\square}\Gamma^2}} \\ \eta_{\square\square\square} = \Gamma\sqrt{\dfrac{k_{\square\square\square\square}}{1 + k_{\square\square\square\square} + k_{\square\square\square\square}\Gamma^2}} \\ \eta_{\square\square\square} = \sqrt{\dfrac{1}{1 + \square_{\square\square\square\square} + \square_{\square\square\square\square}\Gamma^2}} \end{cases} \tag{23}$$

In the previous expressions, $\Gamma \in [-1,1]$ represents the specular reflection coefficient which is the ratio between the incident wave and the reflected wave, $K_{Rice} \in [0,+\infty)$ represents the Rice factor which is the ratio between the direct and the scattering component. In Equation (22), H_{LOS} , H_{SPE} and H_{DIF} are the correlation matrix of direct, reflection and scattering components. If $n_R = n_T = 2$, H_{LOS} can be expressed as follows:

$$H_{LOS} = E\left\{\begin{bmatrix} h_{11,LOS}(\square,\tau) & h_{12,LOS}(\square,\tau) \\ h_{21,LOS}(\square,\tau) & h_{22,LOS}(\square,\tau) \end{bmatrix}\right\} \tag{24}$$

The expression of H_{SPE} and H_{DIF} is similar as H_{LOS}, but the channel coefficients are consists of the reflection coefficient and the scattering coefficient.

4.2 Normalization of Channel Coefficient

Through the normalization method of the channel coefficient the corresponding channel correlation matrix can be obtained. Firstly, we take $h_{11,LOS}(\square,\tau)$ as standard and $h_{11,LOS}(\square,\tau) = 1$. Then, $h_{12,LOS}(\square,\tau)$, $h_{21,LOS}(\square,\tau)$ and $h_{22,LOS}(\square,\tau)$ are divided by $h_{11,LOS}(\square,\tau)$, which can keep the relativity between each channel. Finally, the channel correlation matrix can be obtained starting from Equations (1)-(3) as follows:

$$\begin{aligned} &H_{LOS} \\ &= E\left\{\begin{bmatrix} 1 & \dfrac{h_{12,LOS}(\square,\tau)}{h_{11,LOS}(\square,\tau)} \\ \dfrac{h_{21,LOS}(\square,\tau)}{h_{11,LOS}(\square,\tau)} & \dfrac{h_{22,LOS}(\square,\tau)}{h_{11,LOS}(\square,\tau)} \end{bmatrix}\right\} \\ &= \begin{bmatrix} 1 & \dfrac{\square_{12,11}^{\square\square\square}(0,0)}{\mathrm{Re}\{\square_{12,11}^{\square\square\square}(0,0)\}} \\ \dfrac{\square_{21,11}^{\square\square\square}(0,0)}{\mathrm{Re}\{\square_{21,11}^{\square\square\square}(0,0)\}} & \dfrac{\square_{22,11}^{\square\square\square}(0,0)}{\mathrm{Re}\{\square_{22,11}^{\square\square\square}(0,0)\}} \end{bmatrix} \end{aligned} \tag{25}$$

moreover ,

$$\begin{aligned} &\frac{R_{22,11}^{\square\square\square}(0,0)}{\mathrm{Re}\{R_{22,11}^{\square\square\square}(0,0)\}} \\ &= e^{jk_0\left(\sqrt{\left(\left(H_\square+\frac{\delta_{pq}}{2}\sin\vartheta_\square\right)-\left(\square_g+\frac{\delta_{nm}}{2}\sin\vartheta_g\right)\right)^2+\left(D-\frac{\delta_{pq}}{2}\cos\vartheta_\square\cos\alpha_\square+\frac{\delta_{nm}}{2}\cos\vartheta_g\cos\alpha_g\right)^2} -\sqrt{\left(\left(\square_\square-\frac{\delta_{pq}}{2}\sin\vartheta_\square\right)-\left(\square_g-\frac{\delta_{nm}}{2}\sin\vartheta_g\right)\right)^2+\left(D+\frac{\delta_{pq}}{2}\square\square\square\vartheta_\square\square\square\square\alpha_\square-\frac{\delta_{nm}}{2}\cos\vartheta_g\cos\alpha_g\right)^2}\right)} \end{aligned} \tag{26}$$

In Equation (26), $R_{12,11}^{\square\square\square}(0,0)$ and $R_{21,11}^{\square\square\square}(0,0)$ are the channel correlation function when $\delta_{pq} = 0$ and $\delta_{nm} = 0$. Similarly, the method can be adopted to calculate H_{SPE} and H_{DIF} . Where:

$$\begin{aligned} &\frac{R_{22,11}^{\square\square\square}(0,0)}{\mathrm{Re}\{R_{22,11}^{\square\square\square}(0,0)\}} \\ &= e^{jk_0\left(\sqrt{\left(\left(H_\square+\frac{\delta_{pq}}{2}\sin\vartheta_\square\right)-\left(\square_g+\frac{\delta_{nm}}{2}\sin\vartheta_g\right)\right)^2+\left(D-\frac{\delta_{pq}}{2}\cos\vartheta_\square\cos\alpha_\square+\frac{\delta_{nm}}{2}\cos\vartheta_g\cos\alpha_g\right)^2} -\sqrt{\left(\left(\square_\square-\frac{\delta_{pq}}{2}\sin\vartheta_\square\right)-\left(\square_g-\frac{\delta_{nm}}{2}\sin\vartheta_g\right)\right)^2+\left(D+\frac{\delta_{pq}}{2}\square\square\square\vartheta_\square\square\square\square\alpha_\square-\frac{\delta_{nm}}{2}\cos\vartheta_g\cos\alpha_g\right)^2}\right)} \end{aligned} \tag{27}$$

$$\frac{R_{22,11}^{\square\square\square}(0,0)}{\mathrm{Re}\{R_{22,11}^{\square\square\square}(0,0)\}} = e^{jk_0\left\{\sqrt{\left(\left(\square_{\square}+\frac{\delta_{pq}}{2}\sin\vartheta_{\square}\right)+\left(\square_g+\frac{\delta_{nm}}{2}\sin\vartheta_g\right)\right)^2+\left(D-\frac{\delta_{pq}}{2}\cos\vartheta_{\square}\cos\alpha_{\square}+\frac{\delta_{nm}}{2}\cos\vartheta_g\cos\alpha_g\right)^2} - \sqrt{\left(\left(\square_{\square}-\frac{\delta_{pq}}{2}\sin\vartheta_{\square}\right)+\left(\square_g-\frac{\delta_{nm}}{2}\square\sin\vartheta_g\right)\right)^2+\left(D+\frac{\delta_{pq}}{2}\cos\vartheta_{\square}\cos\alpha_{\square}-\frac{\delta_{nm}}{2}\cos\vartheta_g\cos\alpha_g\right)^2}\right\}} \tag{28}$$

If we replace H_{LOS}, H_{SPE}, H_{DIF} and Equation (23) into the Equation (22), the UAV-MIMO channel correlation matrix H can be obtained. Then the average channel capacity can be analyzed if we consider H in Equation (17), and then the communication channel at the transmitter part can be known. We can also analyze the average channel capacity in the same way.

5 The Simulation of UAV-MIMO Channel Capacity

According to the method above, the influence of antenna distance between transmitter and receiver on UAV-MIMO capacity can be simulated by the software of Matlab. We take the working environment of UAV into consideration and assume the parameters as follows:

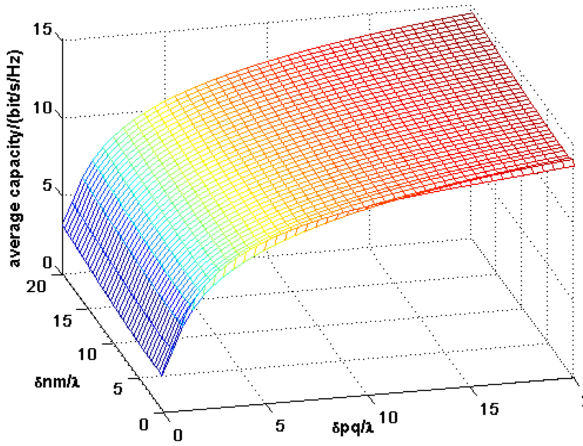
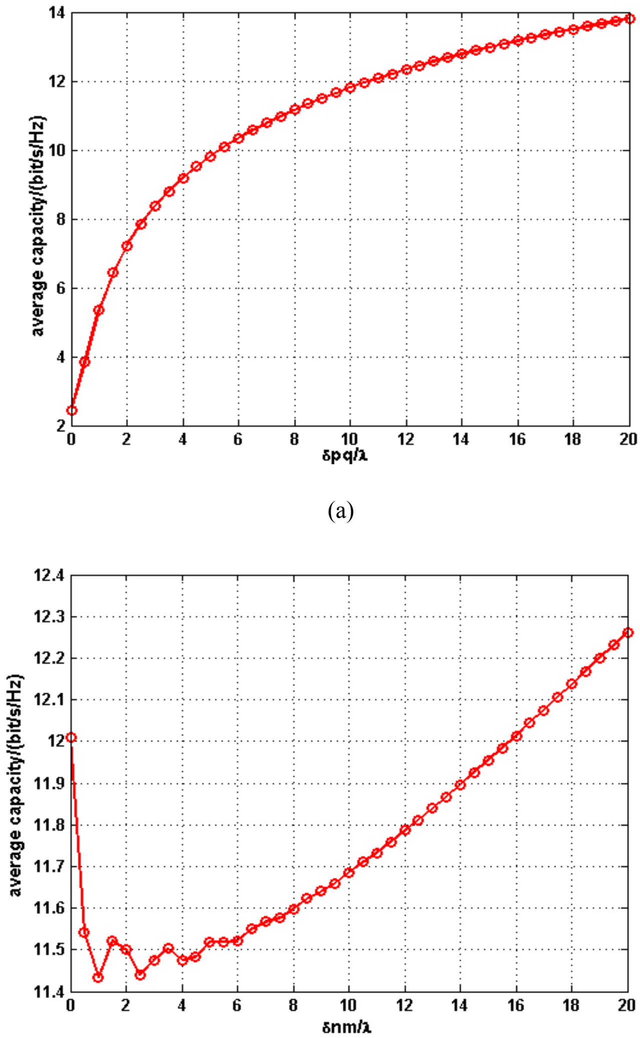


Fig.2 Relationship of antenna distance and channel average capacity when the channel of transmitter is unknown



(a)

(b)

Fig.3 (a) Relationship of transmitter's antenna distance and channel average capacity when the channel of transmitter is unknown $\delta_{\square\square}=10\lambda$

(b) Relationship of Receiver's Antenna Distance and Channel Average Capacity When the Channel of Transmitter is unknown $\delta_{\square\square}=10\lambda$

$D=60Km$, $H_{\square}=2Km$, $H_{\square}=5m$, $H_{\square}=300m$, $R=3Km$, $\theta_{g0}=\pi/8$, $\vartheta_{\square}=\alpha_{\square}=\vartheta_{\square}=\alpha_{\square}=\pi/4$, $K_{Rice}=4dB$, $\Gamma=-1$, $k=0$.

When the channel parameters are unknown in the transmitter part, we assume $SNR=20dB$. The three-dimension relationship between the antenna distance of transmitter and receiver with UAV-MIMO average capacity is shown in Fig.2. If $\delta_{\square\square}=10\lambda$, the impact between distances of transmitting antenna and average capacity is shown in Fig.3(a). When $\delta_{\square\square} = 10\lambda$, the impact between antenna distance of receiver and average capacity is shown in Fig. 3(b). Fig. 3 shows that the average capacity of the channel is increased linearly when $\delta_{\square\square} < 10\lambda$. But the average capacity grows slowly with the increase of antenna distance while $\delta_{\square\square} \geq 10\lambda$. So we can set the antenna distance of transmitter with $\delta_{\square\square} = 10\lambda$, with the consideration of the UAV space. Fig. 3 indicates that the largest distance from antenna and the greatest the capacity of the channel. So we can adopt the method of increasing the antenna intervals of receiver to add capacity of the channel.

When the parameters of the channel are unknown at the transmitter part, if $\delta_{\square\square} = 10\lambda$, the SNR relationships of transmitter's antenna distance and channel average capacity are shown in Fig.4, It

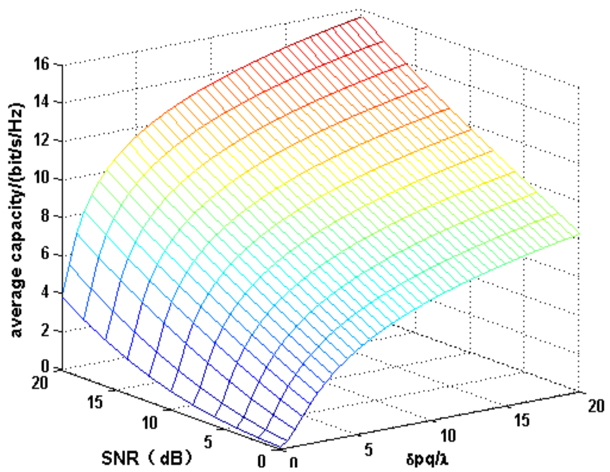


Fig.4 Relationship between transmitter's antenna distance, SNR and channel average capacity

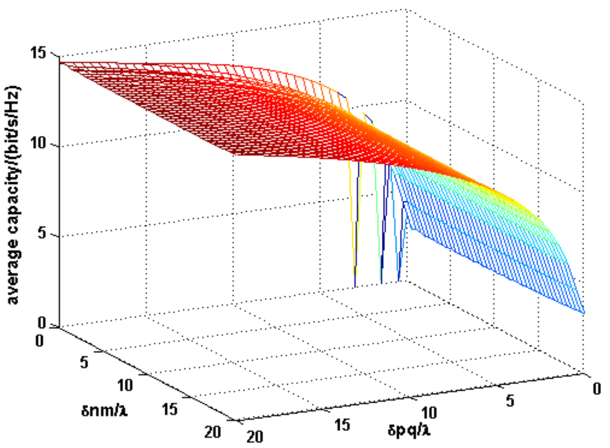
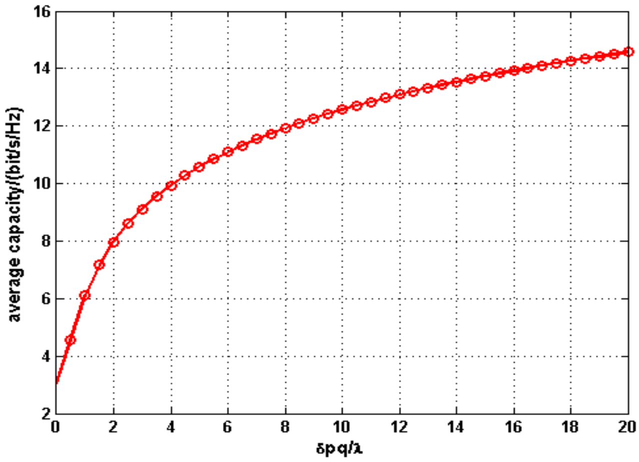


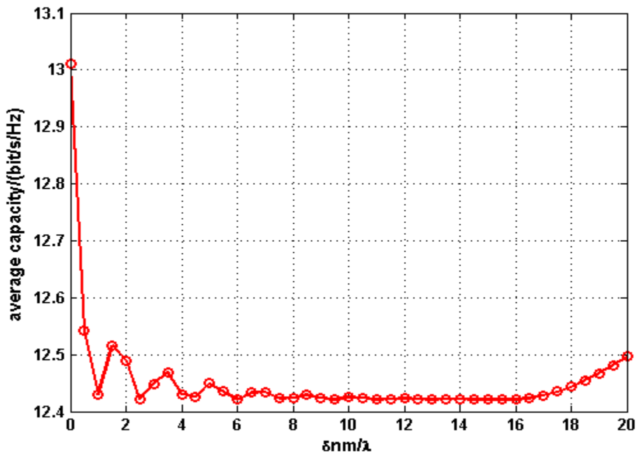
Fig.5 Relationship of antenna distance and channel average capacity when the channel parameters of transmitter are known

is obvious that average capacity can be improved with the increase of transmitter's antenna distance.

When the channel parameters are known at the transmitter, if $\delta_{\square\square} = 10\lambda$,the three-dimensional relationships among the antenna distance of transmitter and receiver with UAV-MIMO average capacity are shown in Fig.5. When $\delta_{\square\square} = 10\lambda$, the relationships between antenna distance of transmitter and average capacity are shown in Fig. 6(a). If $\delta_{\square\square} = 10\lambda$, the influence between antennas distance of receiver and average capacity are presented in Fig. 6(b). By Comparing with the



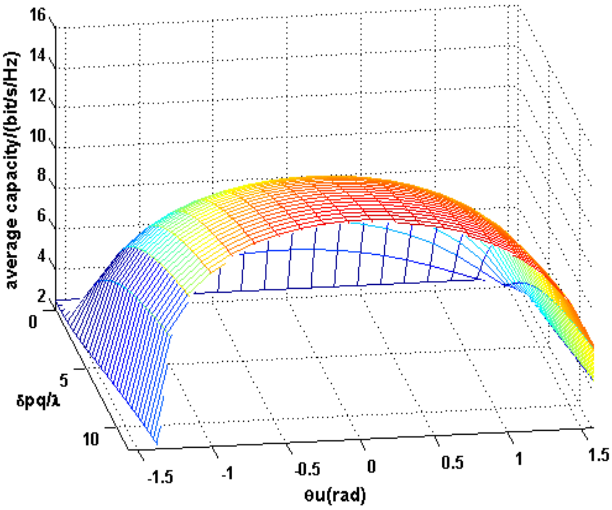
(a)



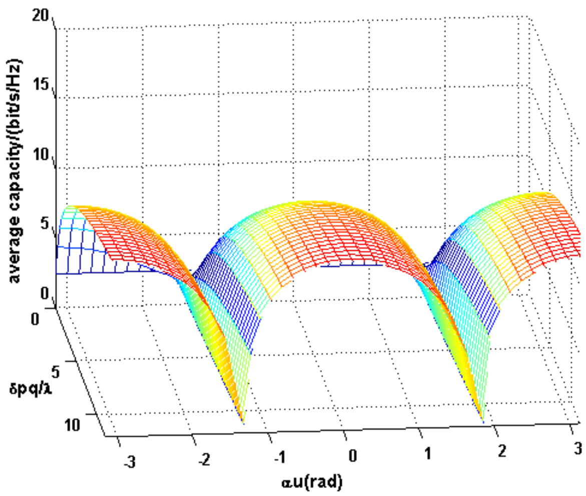
(b)

Fig.6 (a) Relationship of transmitter's antenna distance and channel average capacity, when the channel of transmitter is known and $\delta_{\square\square} = 10\lambda$

(b) Relationship of receiver's antenna distance and channel average capacity when the channel of transmitter is known and $\delta_{\square\square}=10\lambda$,



(a)

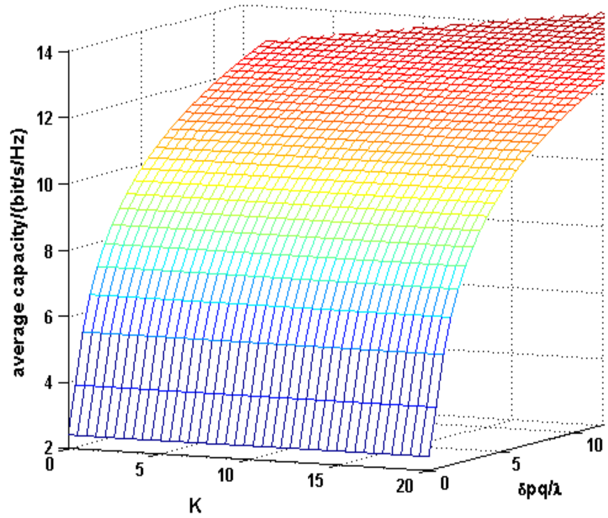


(b)

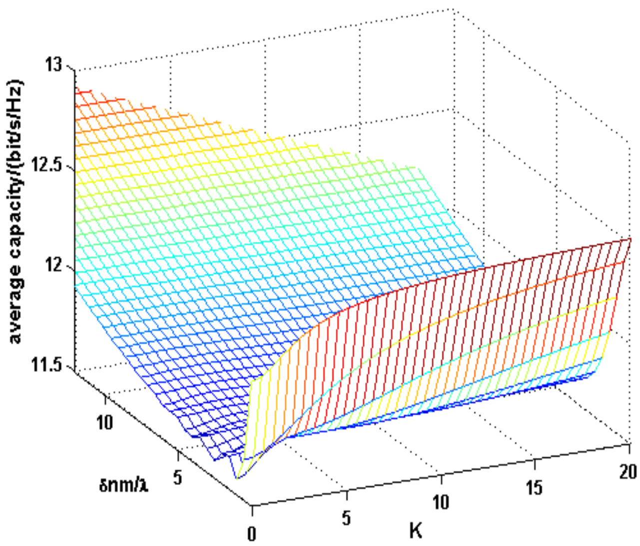
Fig.7 (a) Pitch angle effect of UAV antennas placement on the average capacity
(b) Azimuth angle effect of UAV antennas placement on the average capacity

unknown channel of transmitter, the average capacity will be increased when the channel is known at the transmitter part of the system. In this case, the average capacity is increased slowly when $\delta_{\square\square}\geq 8\lambda$, and the effect of receiver's antenna distance on the average capacity is not obvious.

In addition, the pitch and azimuth angle of the antennas arrangement also have a great influence on the average capacity of the UAV channel. When $SNR=20dB$, $\delta_{\square\square}=10\lambda$, the effect of pitch and azimuth angle of UAV antennas on the average capacity are presented in Fig.7, which show that the average capacity is symmetrical when the pitch angle is among $[-\pi/2 \quad \pi/2]$. If the absolute value of the UAV pitch angle is larger, the average capacity of the channel will be smaller. So the arrangement of UAV antennas should be horizontal along the x axis as shown in Fig.1, and smaller antennas distance will lead to larger average capacity.



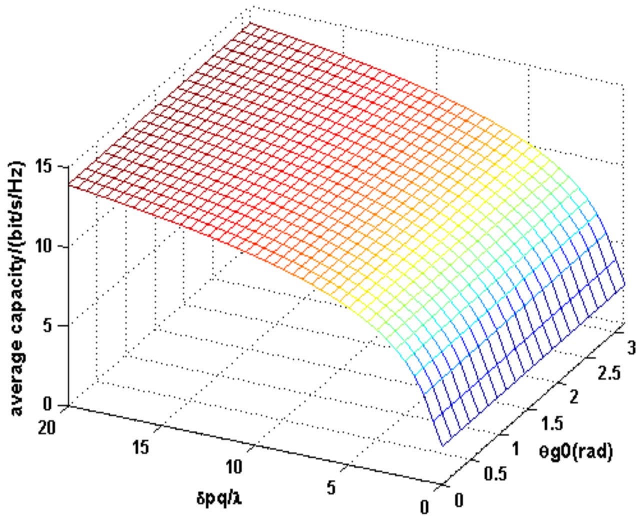
(a)



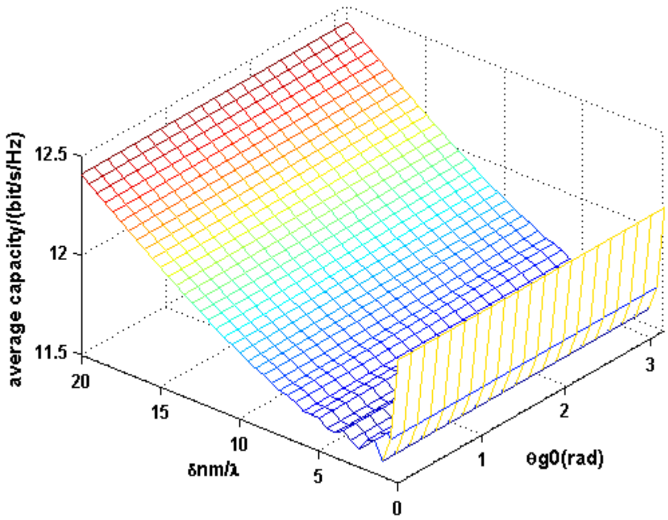
(b)

Fig.8 (a) Effect of the angle spread factor on the average capacity when $\delta_{\square\square}=10\lambda$
(b) Effect of the angle spread factor on the average capacity when $\delta_{\square\square}=10\lambda$

The influence of the angle spread factor on the average capacity of the channel is shown in Fig.8 when $SNR=20dB$ .The different angle spread factors also have an effect on the average capacity. With the increase of angle spread factor, the average capacity is also increased, and the average capacity of receiver is more sensitive than that of the transmitter. Effects of the average of the azimuth angle on the average capacity when $\delta_{\square\square} = 10\lambda$ and $\delta_{\square\square} = 10\lambda$ are given out in Fig.9, the average of azimuth angle has little effect on the average capacity.

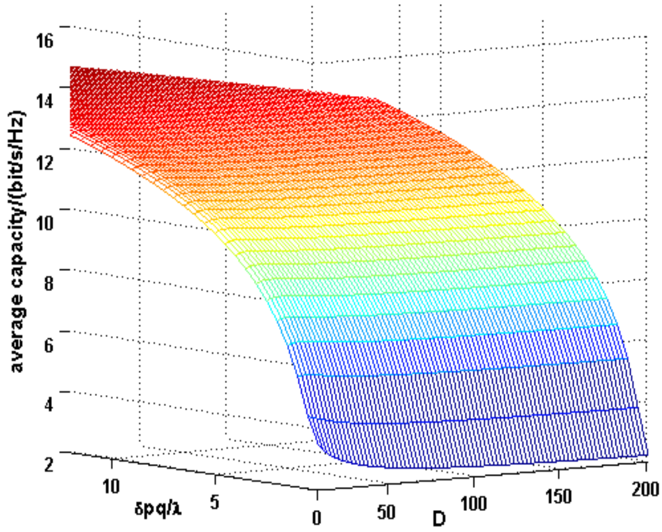


(a)

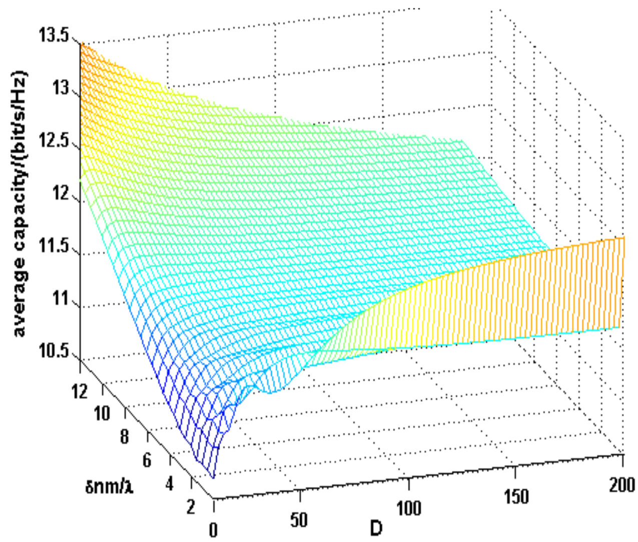


(b)

Fig.9 (a) Effect of the average of the azimuth angle spread on the average capacity when $\delta_{\square\square} = 10\lambda$
(b) Effect of the average of the azimuth angle spread on the average capacity when $\delta_{\square\square} = 10\lambda$



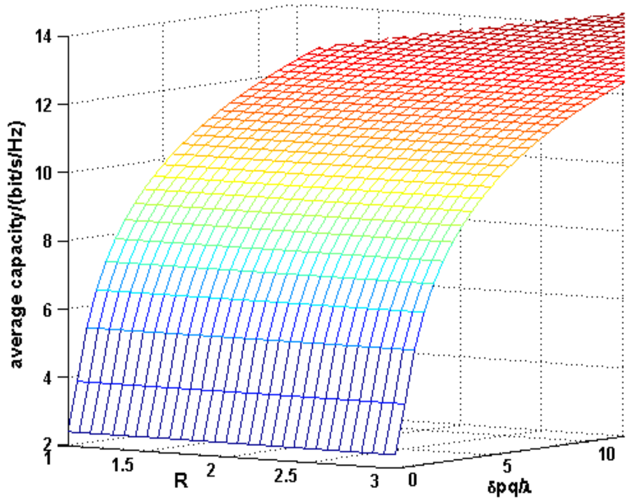
(a)



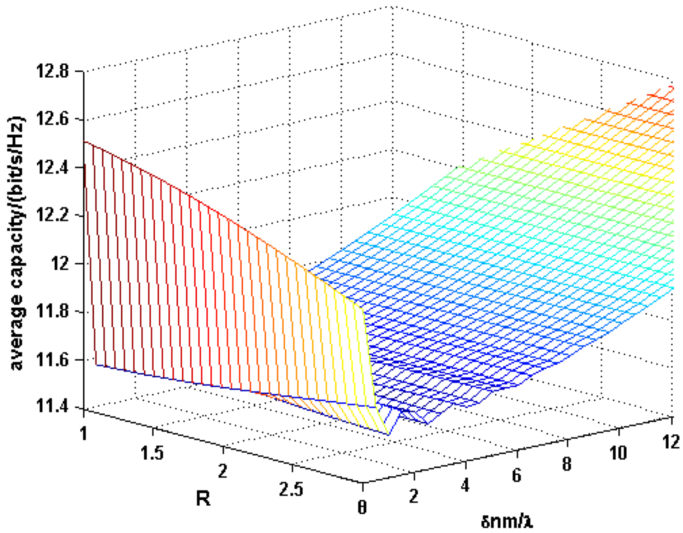
(b)

Fig.10 (a) Effect of UAV horizontal distance on the average capacity when $\delta_{\square\square} = 10\lambda$
(b) Effect of UAV horizontal distance on the average capacity when $\delta_{\square\square} = 10\lambda$

Similarly, if we assume that $SNR = 20dB$, the effects of horizontal distance on the average capacity are shown in Fig.10. The horizontal distance has a great effect on the average capacity when $\delta_{\square\square}$ is a variation and $\delta_{\square\square} = 10\lambda$, but it has little effect on the average capacity when $\delta_{\square\square}$ is a variation and $\delta_{\square\square} = 10\lambda$. Fig.11 shows the effect of scattering radius on the average capacity when $\delta_{\square\square} = 10\lambda$ and $\delta_{\square\square} = 10\lambda$. When the antennas distance is a constant, larger scattering radius involves greater capacity. If the test and measurement circumstance is open and void, the larger scattering radius, the weaker spatial multi-path resolving power, and the stronger average capacity.



(a)



(b)

Fig.11 (a) Effect of scattering radius on the average capacity when $\delta_{pq} = 10\lambda$
(b) Effect of scattering radius on the average capacity when $\delta_{nm} = 10\lambda$

6 Conclusion

This paper presents the simplified space-time-frequency correlation coefficient of UAV-MIMO based on the GBSBCM channel model. According to the demand of MIMO capacity, we put forward the method of channel correlation matrix factorization and channel coefficient normalization to obtain channel correlation matrix of UAV-MIMO. Then we analyze the influence of the antenna distance of transmitter and receiver on UAV-MIMO capacity. It can be found that the rational allocation of antenna distance can play an important role in improving the UAV MIMO capacity.

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