On Capacity Performance of 2×2 Satellite-earth Link at 30 GHz in Rain Environment

Jing Yang, Xiaowei Xue, and Shuhong Gong
School of Physics Optoelectronic Engineering, Xidian University, China

Abstract— Give the equivalent model of STBC, VBLAST sche mes for analyzing their channel capacity. The channel capacity performances of SISO, 2×2 STBC and 2×2 VBLAST schemes in 20 mm/h rain environment are simulated and discussed based on an assumed 2×2 satellite-earth link at 30 GHz in circular polarization as an example.

1. INTRODUCTION

In comparison with traditional Single-Input Single-Output (SISO) communication technology, MIMO communication technology shows great advantages, such as higher transmission rate, spectrum utilization ratio and power efficiency. Therefore, MIMO communication technology represents a breakthrough in the modern communication field [1–3].

Many reports about MIMO communication have been focused on the frequencies below 10 GHz [1]. In contrast, the research on the MIMO communication above 10 GHz, such as Ku and Ka bands or higher frequencies, is still in its infancy, although the communication technology at those frequencies has many advantages [1]. Available publications only explored some particular aspects for the MIMO communication above 10 GHz, for example the references of [4–8]. The most those publications concern terrestrial MIMO systems or indoor environment, where the multipaths induced by terrain and the objects around the receiver are present. Though earth-station receiving diversity is exploited for mitigating the fading caused by tropospheric scattering effect on Ka band satellite signal in [9], the MIMO communication is not straightforward on satellite communication. Fortunately, attention has been paid to the application of the MIMO technology above 10 GHz in satellite communication system in recent years in [2] and [10–12] which just specifically analyze the effect of rain-induced attenuation on the channel characteristics.

This paper focuses on the capacity performance of 2×2 satellite-earth link at 30 GHz in rain environment. the equivalent model of STBC, VBLAST schemes for analyzing their channel capacity are given. The channel capacity performances of SISO, 2×2 STBC and 2×2 VBLAST schemes in 20 mm/h rain environment are simulated and discussed based on an assumed 2×2 satellite-earth link at 30 GHz in circular polarization as an example. The equivalent model given in this paper is valid for the single-polarization MIMO satellite-earth link at other bands above 10 GHz.

2. THE EQUIVALENT MODEL FOR MIMO SYSTEM CAPACITY

For a MIMO system with variance is m_T transmitting antennas and m_R receiving antennas, the relationship between the transmitted signal vector $\mathbf{x}(t)$ and the received signal vector $\mathbf{y}(t)$ can be given as

$$\mathbf{y}(t) = \mathbf{H}\mathbf{x}(t) + \mathbf{n}(t) \tag{1}$$

In (1), $\mathbf{H}$ expresses channel matrix, whose element $h_{i,j}(i = 1, 2, \ldots, m_R;\ j = 1, 2, \ldots, m_T)$ represents the random channel parameter from the jth transmitting antenna to the ith receiving antenna. In fact, a complete model for $h_{i,j}$ should include all the propagation and scattering effects except for noise and all filters, such as attenuation, multipath fading and receiver filter etc.. The propagation and scattering impacts are considered in this paper. For convenience, $h_{i,j}$ is also written as $h_{i,j} = h_{1\_i,j} h_{2\_i,j}$. Where, $h_{1\_i,j}$ represents path loss, which is a constant for a given specific link and specific propagation environment parameters. $h_{1\_i,j}$ mainly determines the average energy of received signals. $h_{2\_i,j}$ is a complex random variable, which indicates the randomly fading coefficient induced by random multipath propagation or the combination of the incoherent scattering in the troposphere. the incoherent scattering effect is similar to the multipath effect on mobile communications but their physical nature is not the same.

If the channel is unknown to the transmitter, then the vector $\mathbf{x}(t)$ is statistically independent, This implies that the signals are independent and the power is equally divided among the transmit antennas. The capacity in such a case is presented as

$$C = \log_2 \det\left(\mathrm{I}_{m_R} + E_s/m_T N_0 \mathbf{H}\mathbf{H}^{\mathrm{H}}\right) \tag{2}$$

where, E_s is the total energy of a transmitted symbol in J, N_0 is noise power spectrum density in J, the superscript H denotes Hermitian Transpose operation. If $m_T = m_R = 1$, (2) simplified as

$$C = \log_2 \left(1 + E_s/N_0 \left|H\right|^2\right) \tag{3}$$

For 2×2 STBC scheme using Maximal Ration Combing, the equivalent model of capacity can be given as

$$C = \log_2 \left[1 + E_s'/N_0 \left(\left|h_{2\_1,1}\right|^2 + \left|h_{2\_1,2}\right|^2 + \left|h_{2\_2,1}\right|^2 + \left|h_{2\_2,2}\right|^2\right)\right] \tag{4}$$

For 2×2 VBLAST scheme using Maximal Ration Combing, the equivalent model of capacity can be given as

$$C = \log_2 \left[1 + E_s'/N_0 \left(\left|h_{2\_1,1}\right|^2 + \left|h_{2\_2,1}\right|^2\right)\right] + \log_2 \left[1 + \frac{E_s'}{N_0} \left(\left|h_{2\_2,1}\right|^2 + \left|h_{2\_2,2}\right|^2\right)\right] \tag{5}$$

E_s' in (4) and (5) signifies the symbol energy from the transmitting antenna j to the receiving antenna i after taking path loss into account, is presented as

$$E_{s\_i,j}' = E_s/m_T h_{1\_i,j}^2 \tag{6}$$

N_0 can be given by

$$N_0 = 1.38 \times 10^{-23} T_{sys}/2 \tag{7}$$

where

$$T_{sys} = T_{clear} + T_m \left(1 - 10^{-\frac{L_{atm}}{10}}\right) \tag{8}$$

In (8), T_{clear} is a given constant, L_{atm} signifies all atmosphere-induced attenuation.

The fading coefficient in rain can be given as

$$h_{2\,rain\_i,j} = \alpha_{i,j} \cdot \exp\left[-j(\varphi_{0\_i,j} + \varphi_{f\_i,j})\right] \tag{9}$$

where, $\alpha_{i,j}$ and $\phi_{f\_i,j}$ are the random number respectively following

$$p(\alpha) = 2K\alpha \exp[-K(\alpha^2 + 1)] I_0(2K\alpha) \tag{10}$$
$$p(\varphi_f) = 1/2\pi \tag{11}$$

And, φ_0 can be calculated by $\varphi_0 = L_{eff} \cdot 57.296 \times 10^3 \frac{2\pi}{k^2} \int_{D_{\min}}^{D_{\max}} \mathrm{Im}(S(0)) N(D) dD$ [1].

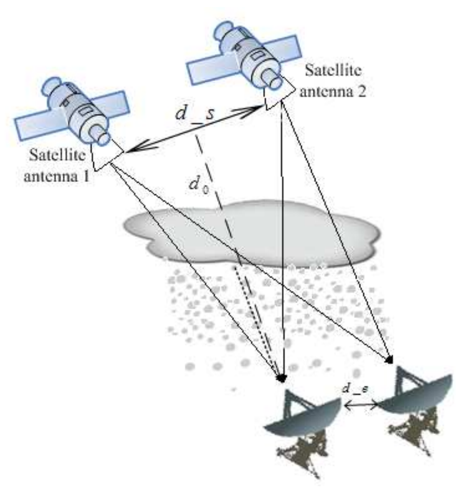

Figure 1: The sketch of the assumed satellite-earth MIMO communication link.

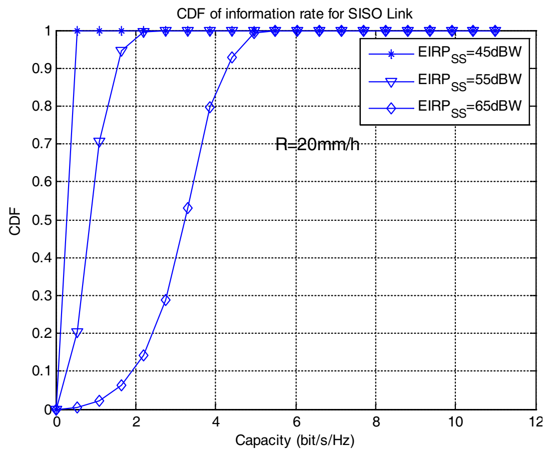

Figure 2: CDF of capacity for SISO link in rain.

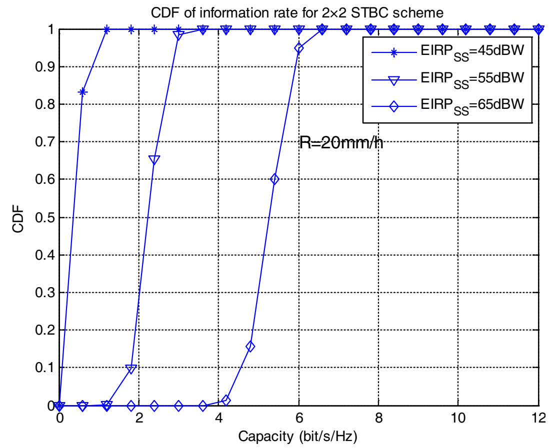

Figure 3: CDF of capacity for 2×2 STBC scheme in rian.

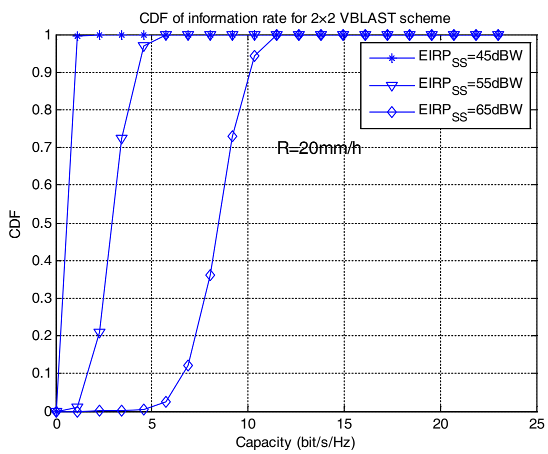

Figure 4: CDF of capacity for 2×2 VBLAST scheme in rain.

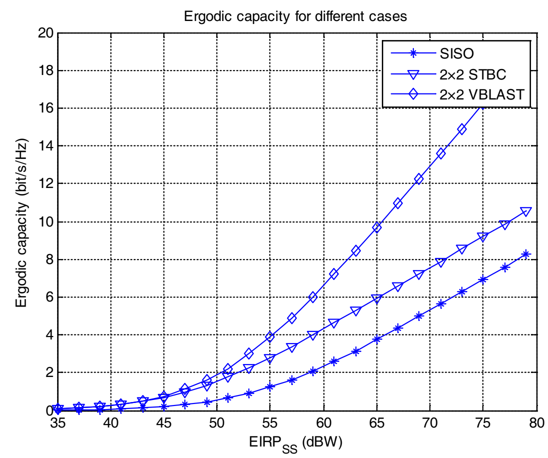

Figure 5: Ergodic capacity for SISO, 2×2 STBC and 2×2 VBLAST schemes in rain.

Table 1: The parameters of the link illustrated in Figure 1.

The parameters of earth station			Satellite Parameters	
The parameters of earth station		108.95°E; 34.26°N	Location of the subsatellite point	100°E 0°
Receiving frequency		30.0 GHz	Transmitting frequency	30.0 GHz
T_{clear_i}		95.09 K	Orbit altitude	15000 km
Antenna parameter I	type	Parabolic	IPB_o	3.83 dB
	aperture	1 m		
	gain	48 dB		
	Half-power beamwidth	0.7°		
	Elevation angle	40.7°		
Antenna parameter II	type	reflector	Polarization state	Circular polarization
	aperture	27 m		
	gain	76 dB		
	Half-power beamwidth	0.3°		
	Elevation angle	40.7°		

In (10), K in rain environment is estimated by (13) [1]

$$K = \exp(-\gamma \cdot L_{\mathit{eff}})/2\pi \int_{D_{\min}}^{D_{\max}} \int_{0}^{\theta_A} \sin\Theta N(D) g(\gamma \cdot L_{\mathit{eff}}, \Theta) |f(\Theta, D)|^2 / \gamma \mathrm{d}\Theta \mathrm{d}D \tag{12}$$

And, the model for calculating atmosphere-induced attenuation can find in [1].

3. SIMULATION AND DISCUSSION

An assumed link parameters are listed in Table 1, and link configuration is illustrated in Figure 1. The simulation results in 20 mm/h rain environment are given in the figures of Figure 2–Figure 5.

Note that the performance of a MIMO is critically de d_s d_e pendent on the availability of an independent and identically distributed channel fading matrix. It is well known that channel correlation will downgrade the performance of a MIMO system. Therefore, it is assumed that and are great enough to ensure the fading matrix being independent and identically distributed.

It is obvious that channel capacity can be improved by adopting MIMO technology in satellite communication system. It is natural that VBLAST scheme is the best scheme to improve channel capacity, however it is at the cost of bit error rate. STBC should be the ideal scheme because of its potential merit of both capacity and bit error rate. We will give more comprehensive and deeper investigation in future.

ACKNOWLEDGMENT

This work has been supported by “the National Natural Science Foundation of China (61001065)” and “the Fundamental Research Funds for the Central Universities”. And, thank all teachers and students, who do many contributions for measuring.

REFERENCES

1. Gong, S. H., “Study on some problems for radio wave propagating and scattering through troposphere,” Ph.D. Dissertation, Dept. Science, Xidian Univ., 2008.
2. Arapoglou, P. D., K. Liolis, M. Bertinelli, A. Panagopoulos, P. Cottis, and R. D. Gaudenzi, “MIMO over satellite, a review,” *IEEE Communications Surveys & Tutorials First Quarter,* Vol. 13, No. 1, 27–51, May 2011.
3. Paulraj, A. J., D. A. Gore, R. U. Nabar, and H. Bolcskei, “An overview of MIMO communications — A key to gigabit wireless,” *Proc. IEEE,* Vol. 92, No. 2, 198–218, Nov. 2004.
4. Huang, K. C. and Z. C. Wang, “Millimeter wave MIMO,” *Millimeter Wave Communication Systems*, Vol. 29, 133–159, Wiley-IEEE, CA, 2011.
5. Pi, Z. Y. and F. Khan, “A millimeter-wave massive MIMO system for next generation mobile broadband,” *Signals, Systems and Computers*, 693–698, ASILOMAR, Pacific Grove, CA, 2012.
6. Suzuki, S., T. Nakagawa, H. Furuta, and T. Ikeda, “Evaluation of millimeter-wave MIMO-OFDM transmission performance in a TV studio,” *APMC Asia-Pacific*, 843–846, Yokohama, Japan, 2006.
7. Madhow, U., “Multi gigabit millimeter wave communication: System concepts and challenges,” *Proc. Information Theory and Applications Workshop*, 193–196, San Diego, CA, 2008.
8. Moraitis, N. and P. Constantinou, “Indoor channel capacity evaluation utilizing ULA and URA antennas in the millimeter wave band,” *The 18th Annual IEEE International Symposium on PIMRC*, 1–5, Athens, Greece, 2007.
9. Enserink, S. W., “Analysis and mitigation of troposphere effects on Ka band satellite signals and estimation of ergodic capacity and outage probability for terrestrial links,” Ph.D. Dissertation, Dept. Electrical Engineering, University of California-Los Angeles, 2012.
10. Oh, C. I., S. H. Choi, D. I. Chang, and D. G. Oh, “Analysis of the rain fading channel and the system applying MIMO,” *ISCIT 2006*, 507–510, Bangkok, Thailand, 2006.
11. Schwarz, R. T., A. Knopp, and B. Lankl, “The channel capacity of MIMO satellite links in a fading environment: A probabilistic analysis,” *IWSSC*, 78–82, Tuscany, Italy, 2009.
12. Liolis, K. P., A. D. Panagopoulos, and P. G. Cottis, “Multi-satellite MIMO communications at Ku-band and above: Investigations on spatial multiplexing for capacity improvement and selection diversity for interference mitigation,” *EURASIP Journal on Wireless Communications and Networking*, Vol. 2007, 1–11, Jul. 2007.