Performance Analysis of MIMO STBC in A High Altitude Platforms Communications Channel

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***Abstract*–MIMO system recently emerged as a solution for the provision of wireless communications to improve capacity and decrease bit error rate. One of MIMO variant, which is used in this paper, is Space Time Block Code (STBC). STBC allows diversity gain using combination of spatial and time dimension without changing its bandwidth requirements. This paper presents an implementation of MIMO STBC 2x1 and 2x2 on HAPS channel with the assumption that the channel state condition is known at the receiver (perfect CSIR). HAPS channel characteristic is known to follow Ricean distribution in which it depends on its K factor. In case of HAPs, K factor also depends on its elevation angle. Using computer simulation, this paper analyzes HAPs channel performance using MIMO STBC 2x1 and 2x2 on the various of elevation angles. It is shown that MIMO STBC 2x1 and 2x2 are able to increase performance of HAPs channel including HAPs channel at low elevation angle. However from our simulation capacity improvement of MIMO STBC is obtained insignificant, therefore we propose MIMO spatial multiplexing, which is another variant of MIMO to obtain more capacity.**

Keywords*– *HAPs; MIMO; STBC; Ricean channel; K factor; Spatial Multiplexing.

I. INTRODUCTION

High Altitude Platforms (HAPs) is an object floating on a stratospheric layer bringing wireless communication equipment at approximately 17-22 km above the ground. HAPs is able to exploit much the advantages and at the same time overcome the drawback of the traditional systems in terms of propagation delay and path loss suffered by satellite system or a huge number of base station required by the terrestrial system.

In our previous research [1], HAPs channel characteristic which is experimentally measured in semi-urban environment, deteriorates at low elevation angle. In other word the performance of HAPs communication needs improvement for the users who are located at the edge coverage. Measurement result shows that for low elevation angle, i.e. lower than 40^0, fading depth is observed to be approximately 25 dB or more. Such huge fading depth, of course, will limit HAPs service coverage to elevation angle only higher than 40^0 or about 50 km in diameter of service coverage. To overcome such problems MIMO STBC is proposed in this work. MIMO STBC which allow diversity gain is expected to improve bad channel condition especially for low elevation angles.

MIMO is simply defined as an use of more than one antenna at transmitter and/or receiver. There are two kinds of MIMO called Spatial Multiplexing (SM) and Space Time Block Code (STBC). On this paper, we use MIMO STBC with 2 antennas transmitter with combination of 1 and 2 antennas at receiver. HAPS is then used as transmitter and both antennas is placed onboard the platform as depicted in Fig 1. The previous research [3] have shown that MIMO can be implemented on single HAPs with specific spacing between them depend on its frequency. For 2.4 GHz, both antennas must be separated about 12 meters. Simulation is then runned by MATLAB R2008a. The variables that are used in the simulation is elevation angle from 10 – 90 degree which represent the K factor and operating frequency at 1.2 and 2.4 GHz.

The remaining part of this paper is outlined as follows. Section 2 presents channel model and propagation characteristic in a HAPs system. Section 3 reviews in detail a concept of MIMO STBC. Simulation model is explained in Section 4. Section 5 shows simulation result, and finally, concluding remark is drawn in Section 6.

II. HAPS CHANNEL MODEL AND PROPAGATION CHARACTERISTIC

Generally, there are some propagation phenomena that can happen on HAPS channels as follow: Free space path loss, multipath fading, rain attenuation, gas absorption, and scintillation [2]. Most of them are frequency dependence. Rain attenuation, gas absorption, and scintillation are significant only on a high operating frequency, i.e. above 10 GHz. While this paper used freq 1.2 and 2.4 GHz, all of them will be ignored on the formulation and simulation.

In case of HAPs channel, Ricean fading is a general case of fading channel model that there are two components of signal arrive at the receiver. First component arrive at receiver

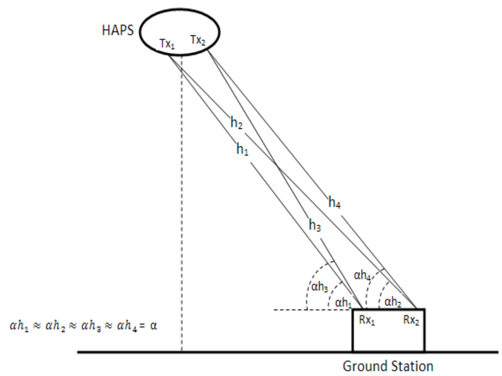

Fig. 1 MIMO STBC model in HAPs channel.

through line of sight (LOS) path and the second component come from multipath scattered signal. In HAPs communication channel, it is possible to have both components because HAPs is highly positioned above the ground. Therefore, the channel characteristic in HAPs system can be represented by Ricean distribution which is expressed as follow,

$$x(t) = \sqrt{\frac{K\Omega}{K+1}}\, e^{j(2\pi f_D \cos(\theta) t + \Phi} + \sqrt{\frac{K}{K+1}} h(t) \qquad (1)$$

where K is a Ricean factor, θ and Φ are elevation angle, f_D is Doppler frequency from receiver movement with velocity (v), and $h(t)$ is a scattered component that can be expressed as,

$$r_h(\tau) := E[h(t)\, h^*(t+\tau)] = \int_{-\pi}^{\pi} p_h(\theta)\, e^{j2\pi f_D \cos(\theta)\tau}\, d\theta \qquad (2)$$

If $E[h^2(t)]$ is estimated to be one, then scattered signal power on the formula above become σ^2. On the other hand, LOS signal power which is significant in HAPs channel, is denoted by A^2, and K is defined as $A^2/2\sigma^2$. So, the total received power is represented by

$$E[x^2(t)] = A^2 + 2\sigma^2 \qquad (3)$$

$E|x^2(t)|$ is local mean received power. Therefore it is to be said that Ricean signal is an addition of LOS and NLOS component with a weighting factor of K. Then, the formula above can be written as follow

$$H = \sqrt{\frac{K}{K+1}}.H_d + \sqrt{\frac{1}{K+1}}.H_s \qquad (4)$$

where H_d is LOS component, and H_s is NLOS component.

III. MIMO SPACE TIME BLOCK CODE

Now we simple analyze a multiple input multiple output (MIMO) technique which is defined as the use of more than one antenna at transmitter and/or receiver as shown in Fig. 2. As already mentioned, there are two kinds of MIMO called Spatial Multiplexing (SM) and Space Time Block Code (STBC). In this paper, we evaluate the use of MIMO STBC 2x2 which in HAPs channel it can be proposed to improve the user performance located at the edge of coverage. We use the transmission scheme of orthogonal STBC which is firstly introduced by Alamouti [4]. At time t, antenna T_{x0} sends signal s_0 and T_{x1} sends signal s_1, then at time t+T, T_{x0} sends signal $-s_1$* and T_{x1} sends signal signal s_0*. Fig 3 shows a system configuration using MIMO STBC 2x2. Both of the signal then transmitted by two independent Rician channel h_0 and h_1. Channel is assumed same at time t+T and time t.

$$h_o(t) = h_o(t+T) = h_o = \alpha_o\, e^{j\theta_o} \qquad (5)$$

$$h_1(t) = h_1(t+T) = h_1 = \alpha_1\, e^{j\theta_1} \qquad (6)$$

Received signal is a multiplication of transmitted signal with channel and addition with AWGN noise.

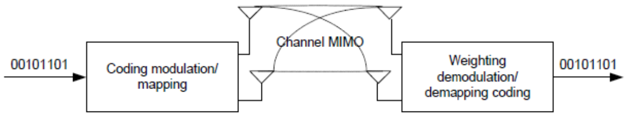

Fig. 2 Basic concept of MIMO.

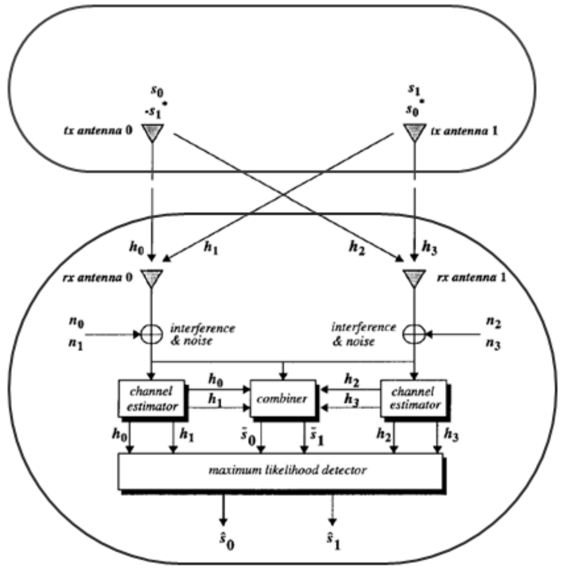

Fig. 3 MISO STBC 2x1 [4].

$$r_o = h_o s_o + h_1 s_1 + n_0 \qquad (7)$$

$$r_1 = -h_o s_o^* + h_1 s_o^* + n_1 \qquad (8)$$

$$r_{21} = h_2 s_o + h_3 s_1 + n_2 \qquad (9)$$

$$r_3 = h_2 s_1^* + h_3 s_o^* + n_3 \qquad (10)$$

Finally, to get signal s_0 and s_1, front end combiner uses channel information from channel estimator.

$$s_o = h_o^* r_o + h_1 r_1^* \qquad (11)$$

$$\tilde{s}_o = h_o^* r_o - h_1 r_1^* \qquad (12)$$

Block combiner then makes a new signal from combination of these 4 channel and 4 received signal as follows

$$\tilde{s}_0 = h_0^* r_0 + h_1 r_1^* + h_2^* r_2 + h_3 r_3^* \qquad (13)$$

$$\tilde{s}_1 = h_1^* r_0 - h_0 r_1^* + h_3^* r_2 - h_2 r_3^* \qquad (14)$$

IV. SIMULATION MODEL

The simulation model is presented in Fig 4. First, we generate random data to make a symbol stream input that consist of approximately 1000 bit. Then the data is BPSK modulated and then its output is inserted to STBC encoding block. The process that happen in this block is almost same as explained before. Bit stream is separated into two parts and for the next time slot, Alamouti [4] conjugate data is sent on each antenna.

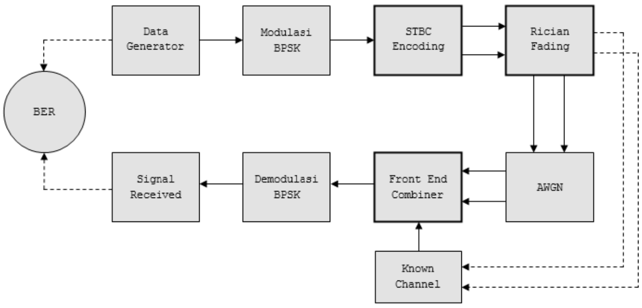

Fig. 4 MIMO STBC on HAPS channel simulation model.

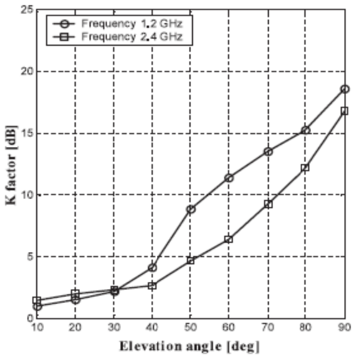

Fig. 5 K Factor and HAPS elevation angles [1].

TABLE I. SIMULATION PARAMETERS.

Frequency	1.2 GHz dan 2.4 GHz
Amount of bits	100000
Eb/No	STBC 2x1 = 0; 2; 4; 6; 8; 10; 12; 14; 16; 18; 20 STBC 2x2 = 0; 2; 4; 6; 8; 10; 12
Modulation	BPSK
Frame length	100
Number of packet	1000
Antenna Tx	2
Antenna Rx	STBC 2x1 = 1 SBTC 2x2 = 2
K Factor	Freq1.2 GHz = 0.9; 1.5; 2.2; 4.1; 8.9; 11.4; 13.5; 15.2; 18.6. Freq 2.4 GHz = 0.9; 1.5; 2.2; 4.1; 8.9; 11.4; 13.5; 15.2; 18.6.

The next process is to send the data via MIMO antenna through Ricean HAPs channel with its characteristic has been experimentally investigated in our previous work as depicted in Fig. 5. K factor as a Ricean parameter for HAPs channel has been measured and we found that its value directly governed by an elevation angle of the user that look to the HAPs [1]. Additionally, *K* factor has frequency dependency in which the higher the frequency the smaller the value of K factor. Output data from STBC encoder block in frequency domain are then multiply by this Ricean fading parameter and also added by Additive White Gaussian Noise at receiver. After that, front end combiner block processes the received data stream using channel information that in this work we assume perfect channel estimation. The extracted data from this block is then demodulated into received bit stream. This received bit stream finally compared by first bit stream sent before to get the Bit Error Rate (BER) at specific signal to

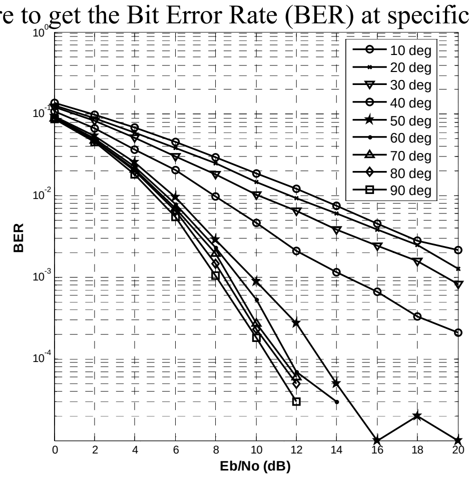

Fig. 6 Performance of SISO 1x1 (freq 1.2 GHz; elevation 0-90^0).

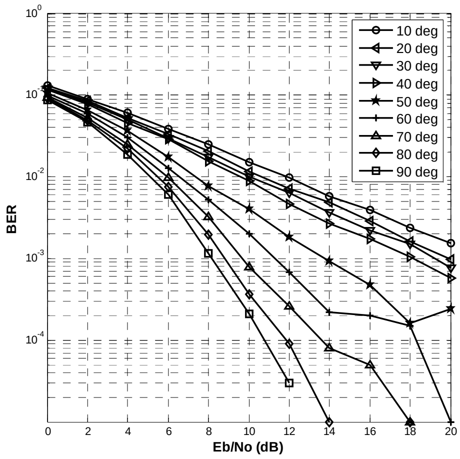

Fig. 7 Performance of SISO 1x1 (freq 2.4 GHz; elevation 0-90^0).

noise ratio (SNR) value. Table I shows parameters that is used in the simulation. We use total 100,000 bits which is separate into 1000 packet data, each of them consist of 100 bit (frame length).

V. SIMULATION RESULTS

For the comparison of all methods, SISO 1x1 HAPS system is simulated first. The result is shown in Figs. 6 and 7 for each operating frequency, 1.2 and 2.4 GHz respectively. As mentioned before, in the model, simulation is run on various elevation angles which represent K factor of Ricean channel. K Factor value is taken from previous experiment and measurement in Hokaido, Japan [1]. Based on the result, there is a gap between elevation angle 40 – 50 deg shows the profile area of K factor measurement which has a quite strong fading at low elevation angle (0 – 40 deg).

Then, the configuration is changed by adding one more antenna at transmitter creating MISO 2x1 HAPS system. Using STBC Alamouti encoding-decoding technique proposed in [3], the simulation result is shown in Fig. 8. Simulation shows that MISO can increase HAPS channel performance not only for low elevation but also for all of ground station positions. MISO is able to achieve better performance of about 1-11 dB for required BER 10^{-3} variously at 10-90 deg.

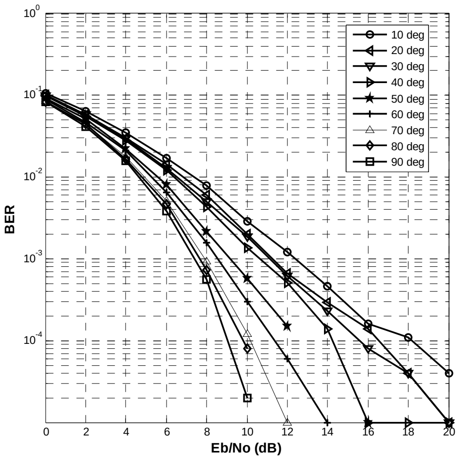

Fig. 8 Performance of MISO STBC 2x1 (freq 2.4 GHz; elevation 0-90^0).

By adding one more antenna in receiver, the configuration is now change to MIMO STBC 2x2. In Fig. 9, simulation shows that this model can make significant improvement better than the previous SISO or MISO 2x1. It has 4-17 dB improvement compared to SISO and 3-6 dB compared to MISO 2x1 at BER value 10^{-3} for all elevation angles.

By comparing all simulation results we have, it also shown that when the elevation angle is decreased (ground station is getting farther from HAPS), the impact of implementation MISO and MIMO STBC is bigger than in a high elevation angle. It can be understand because of MIMO STBC configuration is generally good for fading handling, while fading is depending on transmitter-receiver position. In a low elevation angle, fading is more severe because the path from transmitter to receiver is covered by building, trees, or another obstacle makes a NLOS signal.

While comparing MISO STBC 2x1 and MIMO STBC 2x2 on HAPS channel based on its elevation angle. At high elevation angle values, the performance of MISO STBC 2x1 is much worse than MIMO STBC 2x2, although it always still better than SISO 1x1. But at low elevation angles, the improvement is as significant as MIMO STBC 2x2.

In general, we found performances of MISO 2x1 and MIMO STBC 2x2 on HAPs channel are superior against SISO 1x1. From this results, we can also analyze the performance improvement from coverage area point of view. As mentioned before, elevation angles are so important variable in HAPS system. It can, not only represent the condition of Ricean channel, but also the coverage area itself. Fig. 10 shows the radius of coverage area of HAPs can be increased significantly from 7.28 km (SISO) to 16.78 km (MISO STBC 2x1) and 113.4 km (MIMO STBC 2x2).

Now, for the capacity analysis, we only use 3 elevation angles to make a simply understanding result (10, 40, and 90 deg). Simulation shows that MIMO STBC and MIMO Spatial Multiplexing (SM) have quite similar curve for frequency 2.4 GHz and 1.2 GHz, so that we show only result for 2.4 GHz as in Fig. 11 for MIMO STBC and Fig. 12 for MIMO SM. We can see that elevation angles have significant impact on the curve on outage capacity, but for the ergodic they have no big influences. It means that for MIMO STBC and MIMO SM, when we analyze the average HAPs channel capacity in a

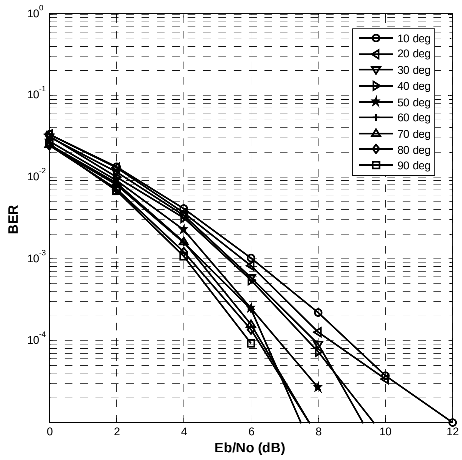

Fig. 9 Performance of MIMO STBC 2x2 (freq 2.4 GHz; elevation 0-90^0).

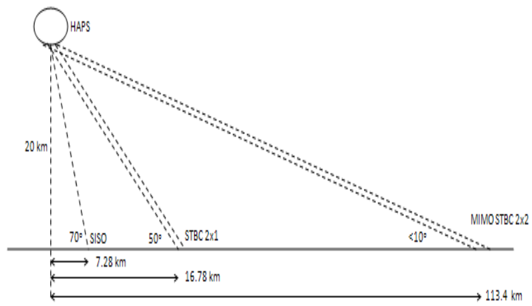

Fig. 10 HAPS radius coverage improvement by implementing MIMO STBC 2x2 and STBC 2x1.

quite long measurement time (ergodic), the elevation angles variables can be ignored, but not for outage capacity analysis.

When both curves of MIMO STBC and MIMO SM are combined together with the HAPs SISO at same elevation angle, the result is shown in Fig. 13. As we mentioned before, MIMO STBC and MIMO SM have a quite similar shape of curve, but when they are put together on one graph, its clearly shown that MIMO SM have a slope sharper than STBC. It means that MIMO SM is much more better in increasing capacity than STBC. Then SISO curve is used as a comparison (red line). We can see the line of SISO is very close together with the STBC. It means STBC is not a good method for improving HAPS channel capacity. Note that to comparing between its 3 configurations (SISO, MIMO STBC, and MIMO SM) we only use the ergodic capacity which is equivalent with Shannon capacity in SISO model.

MIMO STBC is different with MIMO SM. When MIMO SM separated two symbol stream to each antenna, STBC doesn't. As mentioned before, STBC uses Alamouti encoding which separate data in two part for each antenna Tx, then makes a "duplicate" behind them that will be sent on next time slot (t + T). For this we can understand why MIMO SM can improve HAPS channel capacity extremely better than MIMO STBC.

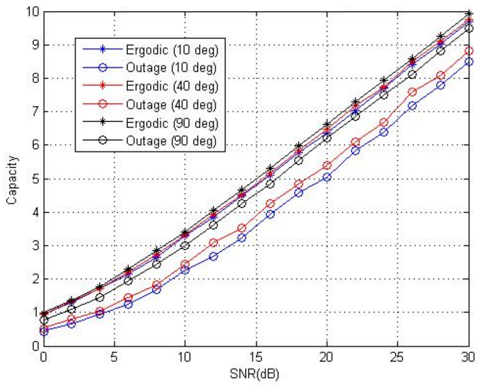

Fig. 11 Capacity of MIMO STBC 2x2 on HAPS channel (2.4 GHz).

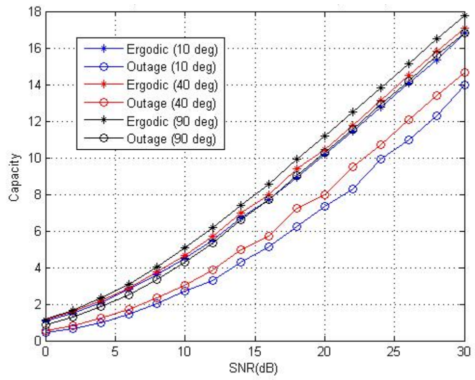

Fig. 12 Capacity of MIMO SM 2x2 on HAPS channel (2.4 GHz).

VI. CONCLUSIONS

Performance analysis of MIMO STBC on HAPS Channel has been proposed in this paper. Simulation result shows that STBC 2x1 can improve BER performance from HAPS SISO 1x1 configuration (1-11 dB on BER 10^{-3}), while MIMO STBC 2x2 even can improve more significant from SISO 4-17 dB on the same BER value for all elevation angles. By adding more antennas in receiver or transmitter may can improve a better performances. For high elevation angles (50-90 deg), the use of MIMO STBC 2x2 is much more significant than STBC 2x1. All of this improvement can also increase the radius of HAPS coverage. From 7.28 km (SISO) to 16.78 km (MISO STBC 2x1) and 113.4 km (MIMO STBC 2x2).

MIMO STBC can really improve the BER performance of HAPS system, but not the capacity. Simulation results shows that MIMO STBC have no improvement comparing to HAPS SISO configuration. To increase it, we can use another MIMO variant called Spatial Multiplexing.

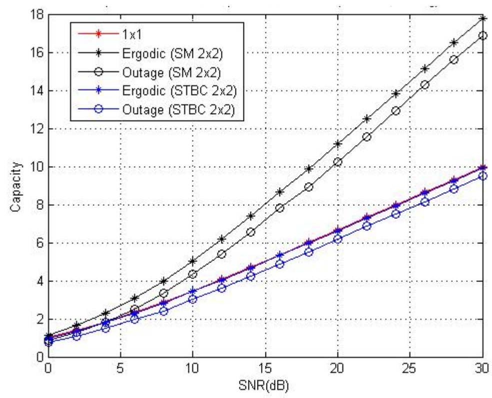

Fig 13. Capacity of SISO, MIMO SM, and MIMO STBC 2x2 on HAPS channel (freq. 2.4 GHz; elevation 90^0).

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