Variable step closed-loop power control with space diversity for low elevation angle High Altitude Platforms communication channel

Langkah variabel kontrol daya tertutup dengan keragaman ruang untuk sudut elevasi rendah pada kanal komunikasi High Altitude Platforms

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INFORMASI ARTIKEL

ABSTRAK

Kajian ini mengusulkan suatu algoritma kontrol daya langkah variabel loop tertutup dikombinasikan dengan keragaman ruang untuk meningkatkan kinerja komunikasi High Altitude Platforms(HAPs) pada sudut elevasi rendah menggunakan Code Division Multiple Access (CDMA). Kami berkontribusi untuk mengembangkan model kanal HAPs yang berasal dari pengukuran eksperimental sebelumnya. Dari percobaan tersebut, kami menemukan karakteristik kanal HAPs yang dapat dimodelkan sebagai distribusi Ricean karena kehadiran jalur tanpa penghalang. Eksperimen menunjukkan bahwa perbedaan sudut elevasi menghasilkan perbedaan nilai factor K. Nilai ini kemudian digunakan dalam Signal to Interference Ratio (SIR) berbasiskan evaluasi kontrol daya loop tertutup. Algoritma langkah variabel disimulasikan dibawah sudut elevasi yang berbeda dengan kecepatan yang berbeda dari pengguna vobile. Kinerja tersebut disajikan dalam hal sudut elevasi pengguna, kecepatan pengguna, ukuran langkah dan ketertiban ruang keanekaragaman. Kami menemukan bahwa kinerja langkah variabel kontrol daya loop tertutup kurang efektif pada sudut elevasi rendah. Namun simulasi kami menunjukkan bahwa ruang keragaman mampu meningkatkan kinerja kontrol daya loop tertutup untuk kanal HAPs di sudut elevasi rendah.

ABSTRACT

This paper proposes a variable step closed-loop power control algorithm combined with space diversity to improve the performance of High Altitude Platforms (HAPs) communication at low elevation angles using Code Division Multiple Access (CDMA). In this contribution, we first develop HAPs channel model that is derived from our previous experimental measurement. From that experiment, we found HAPs channel characteristic can be modeled as a Ricean distribution because the presence of line of sight path. Different elevation angle, resulting different *K* factor value. This value is then used in Signal to Interference Ratio (SIR) based closed-loop power control evaluation. The variable step algorithm is simulated under various elevation angles with different speed of mobile user. The performance is presented in terms of user elevation angle, user speed, step size and space diversity order. We found that the performance of variable step closed-loop power control less effective at low elevation angles. However, our simulation shows that space diversity is able to improve the performance of closed-loop power control for HAPs channel at low elevation angles.

1. Introduction

In recent year, high altitude platforms (HAPs) have been proposed as a new wireless system carrying equipment for some purposes. Those are for cellular 3G, 4G, and 5G broadband wireless technology (El-Jabu & Steele, 2001; Hidayat & Iskandar, 2015; Iskandar & Shimamoto, 2005, 2006, Karapantazis &

Pavlidou, 2005a, 2005b; Pereira & Heckler, 2015; Waluyo & Iskandar, 2015), weather and climate observation (Ilcev & Sibiya, 2015), and emergency system (Kosmerl & Vilhar, 2014). HAPs is being located around 20 km above the ground. It is the best place in the stratospheric layer in which the wind velocity is relatively calm and slow. As for cellular communication, HAPs is designed to use multi spot beam antennas serve as a base transceiver stations (BTS). Those BTS are located on-board the platform. So this is the new concept of cellular communication because it is different from that of conventional cellular using traditional terrestrial tower distributed on the ground. This unique geometry of cellular communication using HAPs is attracting much attention to us to observe its performance both capacity and quality of the system.

Like in CDMA cellular terrestrial communication, co-channel interference is one factor that produces a great contribution to the channel quality impairment. In this case, power control is known as a robust scheme to combat channel degradation caused by co-channel interference. However, power control performance to combat co-channel interference is completely influenced by multipath fading. Users who are located at the edge of HAPs coverage will experience multipath fading. These users, in fact, have a low elevation angle in looking at the platform. User elevation angle refers to an angle between the horizontal line at user position and the line joining the user and the platform. In such situations, there will be a worse condition of the users when both co-channel interference and also multipath fading are occurring (Foo, Lim, Tafazolli, & Barclay, 2000; Jong-Min Park, Bon-Jun Ku, Yang-Su Kim, & Do-Seob Ahn, 2002; Jong-Min Park et al., 2002).

In our previous work, we have shown the performance of closed-loop power control in cellular HAPs CDMA system with emphasizing on variable step parameter of closed-loop power control (Kurniawan, 2003). However, for the user in the cell edge closed-loop power control with variable step does not perform better due to severe of the multipath fading. Even though the use of power control algorithm with variable step size of 1 dB, the performance is still not increased. In this work we propose to use a combination of closed-loop power control and antenna space diversity together to overcome the severe condition of the user located on the cell edge that in fact they are located in a very low elevation angle in looking at the HAPs.

Therefore, in this contribution we propose a combination method of variable step closed-loop power control and space diversity to mitigate co-channel interference in multipath fading situation perceived by the users located at low elevation angle. Multipath fading in HAPs communications contributes a great impact on the channel performance especially for a user position at the low elevation angle and is moving fast. For example, at low elevation angle, fading depth could be more than 30 dB particularly for users with the speed above 40 km/h. On the other hand, at high elevation angle, i.e. higher than 600, not only fading depth is not significant but also Doppler shift is almost negligible. Therefore we are concerning in designing variable step closed-loop power control combined with the space diversity to improve HAPs CDMA channel performance at the low elevation angle, i.e. below 400. It is well known that HAPs channel will follow Ricean distribution since the presence of LOS signal. To limit the scope of this work we will focus our research on SIR based closed-loop power control using variable step algorithm with space diversity under experimentally measured HAPs channel. The rest of the paper is organized as follows. Section II reviews the CDMA signal model and HAPs channel. Section III describes the variable step power control and diversity concept. Section IV presents the simulation procedure and model. Section V shows the simulation results and discussion and finally we draw the conclusions in section 6.

2. CDMA Concept and HAPS Channel Model

In term of HAPs is used for cellular communication, one alternative of the network architecture can be modelled as in Fig. 1. Multi platform are deployed to cover wide service area. Spot beam antenna is required to be installed onboard to create cell like coverage of the BTS of the conventional cellular system. Backhaul must be provided to extend the service to another network such as PSTN or existing cellular terrestrial network. The communication range between the HAPs and the user on the ground depends on the

platform altitude, signal arrival elevation angle and the earth's dimensions. The service area covered from the platform is then heavily dependent on the minimum elevation angle definition.
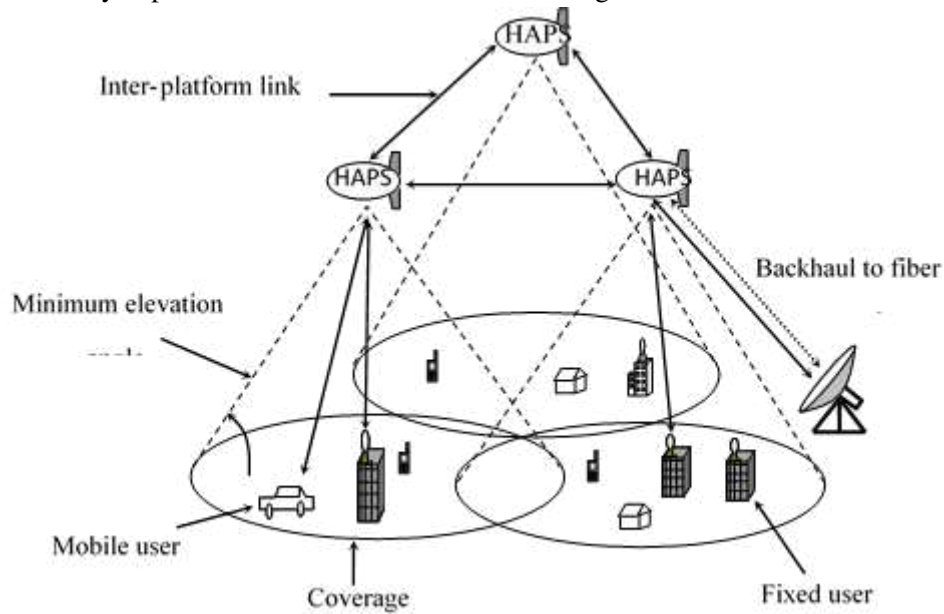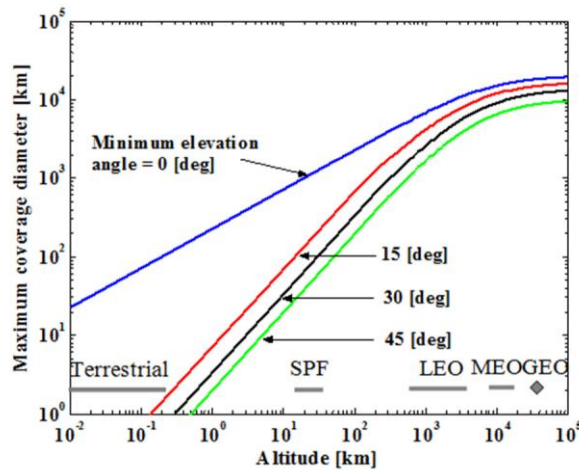

Fig. 1 HAPs geometry.

Fig.2 Coverage diameter for altitude from 10 m up to 100,000 km. Note logarithmic scale on both axes.

Fig. 2 shows the maximum diameter of the LOS coverage area for station altitudes from 10 m up to GEO satellites altitude as a function of minimum elevation angle. The diagram was created exploiting the approximation that microwaves propagate along almost straight lines, like the visible light. It can then be said that the higher is the antenna located on the station, the greater is the station range, but there is a limit. The maximum diameter of the coverage area is somewhat less than the earth's diameter.

There are two type of CDMA system. One is direct sequence CDMA (DS-CDMA). The other is frequency hopping CDMA (FH-CDMA). In a DS-CDMA system the spread spectrum waveform is characterized by the Number of chips per symbol *M*, the chip waveforms and the types of spreading sequence of length *M*. Consider a CDMA system with quadrature phase shift keying (QPSK) modulation as can be seen in Fig. 3 (Kosmerl & Vilhar, 2014). The nth transmitted symbol of the kth user $b_k(n) = b_k{}^I(n) + jb_k{}^Q(n)$ is spread by the kth user's spreading sequence $c_k(m) = c_k{}^I(m) + jc_k{}^Q(m), m \in \{1,2,...,M\}$. Note that $j = \sqrt{-1}$.
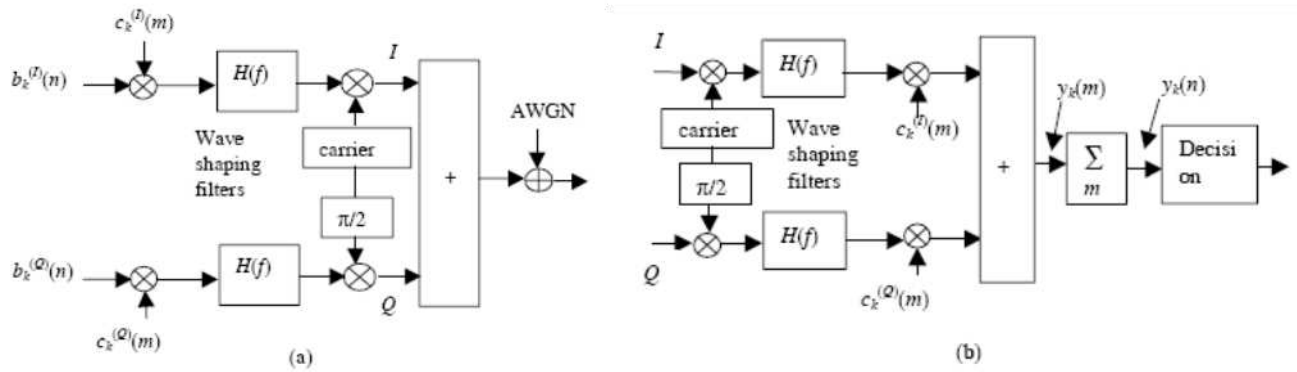
Fig. 3 CDMA with QPSK modulation : (a) modulator (b) demodulator (Kurniawan, 2003).

It is important that the receiver knows the user spreading sequence. The number of chips per symbol *M* is called processing gain or spreading factor of a DS-CDMA system (Chung-Ju Chang, Jeh-Ho Lee, & Fang-Ching Ren, 1996; Iskandar, Kurniawan, & Ernawan, 2010). After carrier demodulation and filtering in a QPSK - CDMA, the received baseband signal is de-spread by the conjugate of the kth user spreading sequence c_k^* and integrated over one symbol period to obtain decision variable $y_k(n)$. The SIR of kth user for a slow fading channel can be expressed as.

$$\gamma_k(n) = \frac{|A_k \beta_k(n)|^2}{\frac{1}{M}\sum_{j \neq k}|A_j \beta_j(n)|^2 + \sigma_k(n)^2}. \qquad (1)$$

Where A_k is the received signal of the kth user, $\beta_k(n)$ is the fading channel coefficient, and $\sigma_k(n)^2$ is the noise power. Unlike terrestrial systems, in HAPs communication channel there are two components of the signal arriving at the receiver. The first component arrives at receiver through the line of sight (LOS) path and second component come from the multipath scattered signal. In case of no LOS component, the channel characteristic is represented by Rayleigh distribution. In HAPs communication channel it is possible to have both components because HAPs is highly positioned above ground. Therefore, the channel characteristic of HAPs system can be presented by Ricean distribution with probability density function of the signal envelope is expressed as,

$$P(S) = \frac{S}{\sigma^2}exp\left[\frac{S^2 + A^2}{2\sigma^2}\right] Io\left(\frac{SA}{\sigma^2}\right), S \geq 0, \qquad (2)$$

Where S denotes the envelope of the received signal, a2 is the variance or average power of the multipathcomponents, A represents the amplitude of the LOS path or dominant signal and IO( ) is the zeroth order modified Bessel function of the first kind. We have experimentally investigated the parameter of Ricean channel in the case of HAPs in term of K factor as a function of elevation angle from 100 to 900 in a step of 100. It was shown that the K factor would have to vary from 1.4 to 16.8 dB in the frequency 2.4 GHz. K factor is representing the ratio between LOS power and multipath scattered power. We can express K factor as follow,

$$K = \frac{A}{2\sigma^2} \qquad (3)$$

This experimentally measured of Ricean fading characteristic is used to evaluate the performance of variable step closed-loop power control over HAPs channel for various elevation angles. The fading rate

and depth are simulated based on the value of K factor, so that the performance of variable step closed-loop power control for each elevation angle can be evaluated.

3. Power Control and Diversity

In cellular CDMA systems, to ensure that the received signals at the base station are equal for all users we employ a power control algorithm. The main idea of power control is to make sure that all received signals at the base station will have an equal power level since at uplink channel the users will transmit the signal from different locations and distances within the cell. In cellular HAPs CDMA system, base stations are implemented by using multi spot beam antenna on board the platform with the size of antenna element approximately 3 m to 4 m. Therefore, all base stations are almost co-located at the same location when they are seen by the users on the ground. This configuration is different from cellular CDMA terrestrial base station concept where they are located at different spatial location.

Generally there are three types of power control: open-loop power control, closed-loop power control and outer loop power control. For our HAPs CDMA system, we consider to use SIR-based power control rather than strength-based power control. The reason is because SIR-based algorithm refers to the communication quality or system performance not to signal level only (Kurniawan, 2003). To overcome the near far effect and shadowing problems, we employ open loop power control, while closed-loop power control is able to overcome the multipath fading problems experienced in HAPs channel. SIR for each user, y_{est} is estimated at the base station for the ith time slot.Then the estimated SIR $y_{est}(i)$ is compared with the target SIR y_t to produce the error signal $e(i)$. The error signal then quantized using a binary representation, therefore it can be transmitted via the downlink channel to the mobile station.

There are two methods of quantizing the error signal $e(i)$. First method is called a fixed-step power control and the second method is called variable-step power control. In fixed step, the error signal is quantized into one PCC bit, whereas in variable-step is quantized into multiple PCC bits. Fixed-step power control can be realized using DM (Delta Modulation) while variable-step power control quantization can be implemented using PCM (Pulse Code Modulation) mode q realization that can be expressed as,

$$e(i-D)_q = \begin{cases} q & idx \leq -q + 1/2 \\ q-1 & -q+1/2 \leq idx \leq -q+3/2 \\ \ \vdots & \vdots \\ 0 & -1/2 \leq idx \leq 1/2 \\ \ \vdots & \vdots \\ -(q-1) & q+3/2 < idx < q+1/2 \\ -(q) & idx \geq q+1/2 \end{cases} , \qquad (4)$$

Where $e(i-D)_q = y_{est} - y_t$. In (4) idx or index is defined as $e(i-D)_q/\Delta p$, where Δp is the step size, and D is the feedback delay expressed in T_p. The y_{est} can be defined as the estimated SIR and y_t as the target SIR, respectively. Technically, variable-step with PCM mode $q = 1$ can be considered as fixed-step power control. Note that q represents the number of PCC bits in each power control interval. In HAPs, a cell or spot beam on the ground can be realized by a spot beam antenna array which is referred as a base station as in terrestrial system but located in the same location at the bottom of HAPs. This condition is prone to interference between spot beams, therefore we must carefully designed the spot beam antenna which having a side lobe gain smaller than the main lobe gain. International Telecommunication Union (ITU)

has given the recommendation for the HAPs antenna gain pattern as expressed in (5). $G(\phi)$ is the antenna gain in dBi of the spotbeam with boresight angle ϕ.

$$G(\phi) = \begin{cases} 34.8 - 3(\phi/1.57)^2 & for\ 0^0 \le \phi \le 4.53^0 \\ 9.8 & for\ 4.53^0 \le \phi \le 5.87^0 \\ 55.95 - 60log(\phi) & for\ 5.87^0 \le \phi \le 37^0 \\ -38.2 & for\ 37^0 \le \phi \le 90^0 \end{cases} \quad (5)$$

In case of the spot beam antenna radiation pattern is not perfectly designed, guard frequency among spot beams must be allocated to minimize the interference level, hence more bandwidth is required. For this condition, fixed-step power control is the most convenient choice since this algorithm is capable to minimize the signaling bandwidth and very simple. However, this algorithm cannot directly compensate the fading factor, unlike variable- step power control which is able to compensate the fading factor directly using multiple PCC bits during one power control interval. Thus, variable-step power control can be expected to have a better performance than the fixed-step power control. On the other hand, variable-step power control based on SIR-based estimation has its own limitation. At low elevation angles the power control performance degrades significantly for medium speed user, i.e. above 40 km/h, especially at low elevation angles i.e. below 500. This is due that at higher speed, the fading will changes dramatically and power control cannot follow the channel variations and also at low elevation angles the multipath signal distribution is higher than the LOS signal, hence the communication channel is worse. Therefore, we use another approach using a space diversity technique with SDC (Selective Diversity Combining) algorithm. This approach applied at worst channel condition, i.e. user with speed above 40 km/h at low elevation angles (100 – 300). At this condition, the fading will change rapidly and the power control itself cannot compensate the fading condition. The performance improvement that can be offered from SDC can be expressed as,

$$\frac{\bar{\gamma}}{\Gamma} = \sum_{k=1}^{L} \frac{1}{k} \quad , \quad (6)$$

4. Simulation Model

Due to a unique geometry in HAPs uplink channel, the interferences will be originated from all users at it's serving beam and also users from adjacent beams (Ilcev & Sibiya, 2015; Jong-Min Park et al., 2002; Kosmerl & Vilhar, 2014). Every user will give a different interference effect based on its position to the interfered user which determined by the boresight angle as can be seen in Fig. 4. We must note that the interfering users considered in this work are following the antenna pattern as expressed in (5). We assume only uplink channel with seven spot beams (cells) served by HAPs for low elevation angle i.e. 100, 200, and 300. The number of users in each spot beam is 10 users, so there are 70 users within the coverage area. User position is normally distributed inside the coverage. The frequency of 2.4 GHz is used so that we can use the HAPs channel characteristic with K-factor value obtained from experiment to evaluate the performance of variable step power control and space diversity at low elevation angles. The HAPs channel fading is generated using modified Jakes method to include the LOS component so that we can obtain Ricean fading distribution as suggested in HAPs communication channel. We assume for CDMA system in HAPs communication employing QPSK modulation so that one symbol can carry 2 information bit. Received signal at the base station from all users can be expressed as,

$$r(t) = \sum_{k=1}^{K} G(\phi_j)\left(\beta_k(t)\sqrt{2P_k} b_k c_k s_k(t) + \sigma_k n(t)\right), \quad (7)$$

Where $2P_k$ is the transmitted power and (b_k) is the data symbol, (c_k) spreading sequence and (s_k) is the chip waveform of kth user, respectively. $,B_k(t)$ is the fading channel coefficient, $G(\phi\ )$ is normalized

antenna gain and n(t) denotes the additive white Gaussian noise (AWGN) with deviation of the AWGN experienced by the kth user. Note that in HAPs communications, interference will come from all users at its serving cell and users from adjacent cell. Every user will give a different interference effect based on its position in the center of interfering beam which determined by the boresight angle (ϕ_i) as described in Fig.5. We can expressed the SIR with considering the boresight angle gain as,

$$\gamma_k(n) = \frac{G(\phi_k)|A_k\beta_k(n)|^2}{\frac{1}{M}\sum_{j\neq k} G(\phi_j)\left(|A_j\beta_j(n)|^2 + \sigma_k^2(n)\right)}, \quad (8)$$

Where M is the processing gain. The greater detail of simulation parameters in this work is described in Table I. where k is the number of path, Γ is the average branch SIR and y is the mean SIR.

To improve the performance in the edge coverage, we employ the diversity of two antenna at the base station of HAPs. Following an SIR-based estimation as it was used for single base station antenna, we then compute SIR from each received signal through different antenna as depicted in Fig. 5. After computing SIR for each branch, the combining algorithm is used to calculate the highest SIR and the weighting factor is apply to each branch which is expressed as,

$$w_l = \begin{cases} 1 & \gamma_l = \gamma_{l,max} = max_l(\gamma_l) \\ 0 & otherwise \end{cases}. \quad (9)$$

The output of diversity combiner can be expressed as,
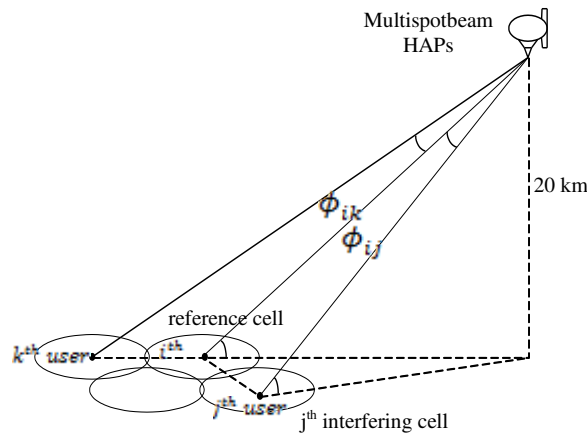
$$y(t) = \sum_{l=1}^{L} w_l x_l(t), \quad (10)$$

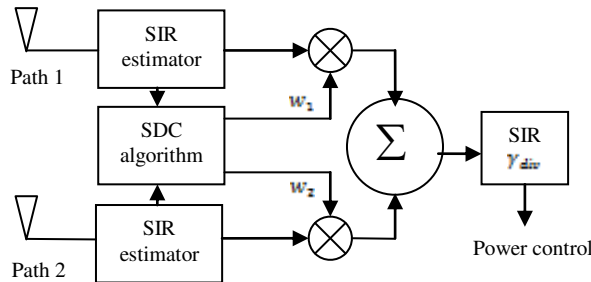Fig.4 HAPs uplink channel interference geometry.

Fig.5 Space diversity model.

Table 1. Simulation Parameters

Parameters	Notation and Value
Platform height	$h = 20$ km
Frequency	$f = 2.4$ GHz
Users	$N = 10$ / cell
Vehicles speed	$V_{mobile} = 40$ and 80 kmph
Modulation	QPSK
Symbol Rate	$R_S = 60$ ksps
Symbol Duration	$T = 16.7\,\mu$s
Number of Symbol	$B = 40$ symbol/time slot
Chip Rate	$R_C = 3.84$ Mcps
Power Control Rate	$fp = 1.5$ Kbps
Processing Gain	$M = 64$
Step Size	$\Delta_p = 1$ and 2 dB
Mode q	$q = 1$ (fixed) and 4 (variable)
Diversity order	$L = 2$ path
Elevation angle	$10^0, 20^0,$ and 30^0
K-factor	$1.4, 2,$ and 2.3 dB

Where $x_l(t)$ is the input signal from each diversity branch. The weight vector $w = [w_1, w_2, ., w_L]^T$ depends on the combining algorithm employed. For SDC, w_l can be expressed as in (9).

5. Result and Discussion

Performance of variable-step power control for low elevation angle with space diversity using SDC algorithm is evaluated in this section in term of bit error rate (BER) as a function of E_b/I_o. We use an average value of diversity technique in our simulation. The parameter of evaluation includes user elevation angle *(8)*, user speed and also diversity with two branches.

In Fig. 6 we evaluate variable step power control mode $q = 1$ (fixed step) and mode $q = 4$ (variable step) at low elevation angle of 10^0 for user with 40 km/h speed combined with space diversity order of two with SDC algorithm for simplicity at the implementation. In this simulation, we would like to observe the effect of space diversity into the variation of the variable step mode (q) in very low elevation angle that is 10^0. We found that the performance of the power control at 10^0 elevation angle improves for both mode $q=1$ and $q=4$ when space diversity is employed. In Fig. 7 and Fig. 8 we try different speed of user those are 40 km/h and 80 km/h respectively. Both simulations are carried out for the users located at an elevation angle below 40^0 to observe the power control performance improvement. We can see that the space diversity technique clearly improves the variable step power control performances at low elevation angles for both different speeds of users.

This simulation condition is able to represent the Rayleigh fading channel condition because of multipath and Doppler shift. The space diversity techniques combined with variable step power control have shown the performance improvement so that multipath fading can be overcome. It means that the multipath fading can be reduced using space diversity technique so that the power control can track the channel variation faster and work effectively. However, we must note that for a HAPs communication channel this technique can be applied effectively at low elevation angles only, i.e. below 50^0, this is because at low elevation angles the multipath signals are giving more significant contribution than the LOS signal so that the channel quality is not very good and the power control are having difficulty in maintaining the performances. On the contrary, at high elevation angles the LOS signal is giving more significant contribution than the multipath signals, hence the channel

quality are better and the fading depth is shallower. This impact, allowing power control to track the fading channel variations easily and diversity techniques would be less effective.
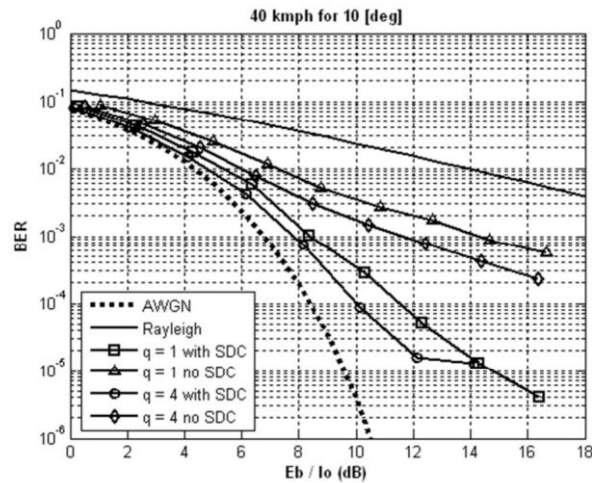

Fig. 6 Variable step power control performance on low elevation angle for user Vuser = 40 km/h with space diversity and combining algorithm.
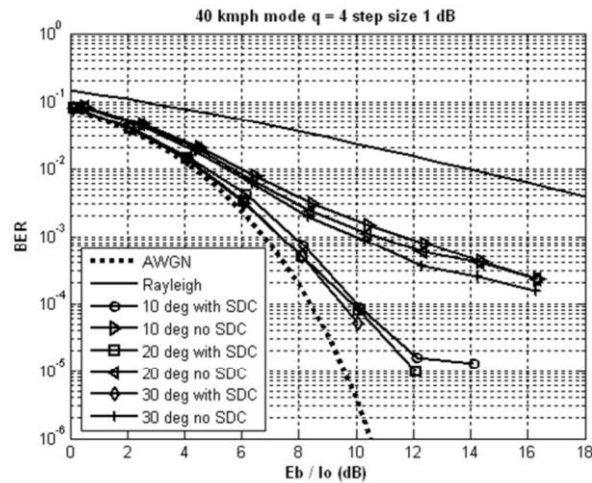

Fig. 7 Variable step mode $q = 4$ with diversity for user $V_{user} = 40$ km/h at low elevation angles.
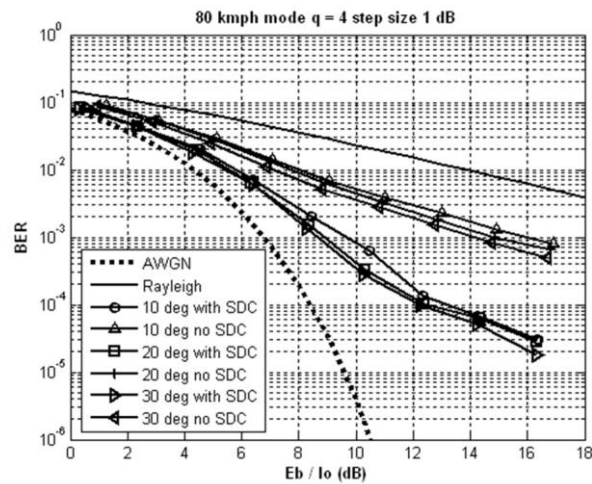

Fig. 8 Variable step mode $q = 4$ with diversity for user $V_{user} = 80$ km/h at low elevation angles.

6.   Conclusions

We have evaluated variable step closed-loop power control in wireless HAPs CDMA channel. This algorithm performs well only at medium or high elevation angle. However, at low elevation angle this scheme performs less effective so that we combine with space diversity to improve its performance. With the use of space diversity using SDC algorithm, it is shown by computer simulation that variable step closed-loop power control algorithm has a significant performance improvement at low elevation angles. Therefore, users with low elevation angles who are suffering from fading can be overcome by combining closed-loop power control and space diversity.

Acknowledgements

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