Performance Enhancement of Spread Spectrum LEO Satellite communication System Using Constant Modulus Antenna Array

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ABSTRACT

The structure of MMSE receiver front-ended by CMA(Constant Modulus Array) array working in CDMA forward link which is applicable to LEO spread spectrum satellite communication system is proposed. By using the despreaded pilot signal of forward link as a reference signal, the CMA array can capture multi-path signals securely even in severely faded LEO satellite channel. The remaining MAI (Multiple Access Interference) is cancelled by the cascaded MMSE receiver. Besides theoretical development, through relevant computer simulation, it is proved that the proposed system shows much better BER performance than any other possible candidate systems. As a spatio-temporal receiver mounted on a mobile vehicle, the proposed system also reduces implemental cost and complexity by adopting the simplest algorithm for its spatial and temporal domain processing.

Key Words : Lew Earth Orbit(LEO), MMSE receiver, CMA Array, Spread Spectrum communication

I. Introduction

As one of low earth orbit(LEO) satellite system Globalstar focus on the satellite phone and low-speed data communication system. After the first satellite was launched in February 1998, the last of 52 satellites-48 satellites and four in-orbit spare had launched in 2000. Unlike the first generation satellite, the second generation Globalstar constellation consisting of 24 satellites completed in February 2013.[1] This second generation Globalstar is expected to provide satellite voice and data service until at least 2025. By using L ,S band this LEO satellite system is somehow relieved from line of sight(LOS) condition for communication but exposed to fading condition such as Lician and Rayleigh according to the environment besides severe Doppler shift of the frequency. To expand the communication services beyond speech and low speed data it should secure communication quality in severely faded channel environment. The channel environment of the Globastar system is similar, even if not same, to the CDMA mobile communication system, some of the techniques used in CDMA mobile communication can be exploited.

A lot of research efforts is focused on the improvement of BER performance of received signal in muti-path fading CDMA mobile communication by canceling MAI spatially as well as temporally.[2][3] One of the typical approach in spatial domain is the selective beamforming technique using adaptive array antenna.[4] As a temporal domain approach, MMSE (Minimum Mean Square Error) receiver is widely studied as a possible candidate to improve BER performance significantly in multi-path fading environment.[5][6] The spatio-temporal system, adaptive array antenna followed by some temporal CCI canceler, is also proposed to achieve synergetic effect in BER performance in CDMA mobile communication.

Modeling Using optimum code that is constantly updated to the variance of signal condition, MMSE receiver shows better performance than the conventional matched filter receiver in a multi-path fading channel. However MMSE receiver requires the signal processor which computes statistics of received signal fast enough to catch up the variation of signal in fast fading channel.

Recently, demand for mobile data communication, such as mobile internet service and mobile computing, is increasing rapidly. To accommodate such kinds of new services, it is required to improve BER performance and channel capacity particularly in the forward link because these services have outbound congested traffic. Most of the research works on spatial and temporal system to improve signal quality and channel capacity are targeting the multiuser detection system, ie system for the base

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접수일자 : 2017년 5월 18일, 수정완료일자 : 2017년 6월 24일, 최종게재확정일자 : 2017년 6월 26일

station. Except channelized beamforming technique which can perform uplink and down link beamforming[4] simultaneously, those systems are able to improve signal quality and channel capacity of reverse link only. The channel, encountered by the mobile terminal mounted on a vehicle cruising metropolitan area, can be modeled as a fast fading Rayleigh distributed muti-path channel. The forward link signal passing through this kind of harsh environment barely reconstructed successfully without adequate compensation of channel distortion. However the compensation technique usable on the mobil terminal is quite limited by the cost and complexity allowable.

Resultantly the simplest adaptive algorithm, such as LMS algorithm is well suited for the mobile terminal. However in a multi-path fast fading channel, the LMS algorithm has some difficulty of adaptation because of its convergence speed. The LMS algorithm likely lose its tractability whenever excessive deep fading occur, so CMA array is adopted as a front-end system to keep received envelope relatively constant. Besides the function of stabilizing adaptive process of MMSE receiver cascaded, the CMA array antenna has its own function of canceling harmful multi-path signal so as to improve BER performance.

Through computer simulation, it is proved that the proposed MMSE receiver with CMA array show better performance than any other system such as conventional matched filter receiver, rake receiver and CMA array only system. Furthermore the proposed system has advantage in its cost and complexity as a receiver working on mobile terminal because it uses only the simplest algorithm for its spatial and temporal domain adaptive processing.

Ⅱ. Channel and System Model

The transmitting signal model in the CDMA forward link with pilot channel can be expressed as

$$s(t) = \sum_{k=0}^{K} \sum_{i} \sqrt{P_k}\, b_k(t) c_k(t) \tag{1}$$

where $b_k(t), c_k(t)$ mean data symbol, spreading code with its Walsh function and K is the total number of user. The signal, k=0, means pilot in the forward link. In multi-path Rayleigh fading channel, the received signal consists of several multipath components with different amplitude, delay and arrival angle. The impulse response function representing channel characteristics can be expressed as follows

$$h(t) = \sum_{l=1}^{L} \alpha_l \exp(j\phi_l) \exp(j\theta_l) \delta(t - \tau_l) \tag{2}$$

In the equation $\alpha_l, \phi_l, \theta_l$ and γ_l are representing amplitude, phase, arrival angle and time delay of lth path respectively and L means the maximum number of multi-path signal. The satellite mobile channel is assumed in the condition of Rayleigh fading, so α_l has Rayleigh distribution. The received signal distorted by this channel transfer function, can be represented as

$$r(t) = \sum_{l=1}^{L} \alpha_l \exp(j\phi_l) \exp(j\theta_l) s(t - \tau_l) + n(t) \tag{3}$$

where $n(t)$ is the AWGN within the channel.

The proposed system model of Constant Modulus Array(CMA) antenna array cascaded with MMSE receiver in the CDMA forward link is shown in figure 1.

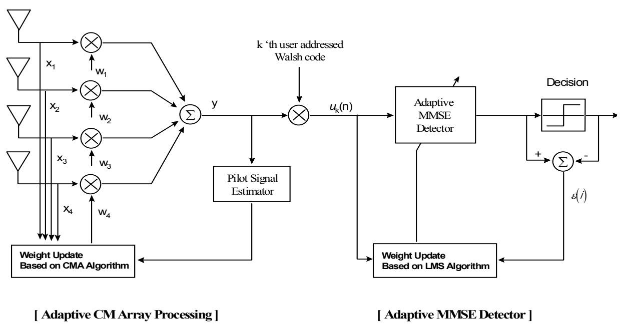

Figure 1. The System Model

The increasing mobile internet service and mobile computing are demanding much more channel bandwidth capacity in forward link than the reverse link. To accommodate this kind of requirement of newly emerging mobile service by expanding channel capacity in forward link, the MMSE receiver with CMA antenna array system is proposed as figure1.

Adaptive array antenna system in forward link has some difficulties in technical as well as economical point of view to be implemented successfully. Basically this array antenna is to be installed on the mobile terminal so that the cost and size of the system should be reasonably low and small. The suggested system may meet this requirement by using the simplest adaptive algorithm and the minimum number of array elements. Nevertheless this system has cost increasing factor compared to conventional omni-directional antenna system.

Ⅲ. MMSE Receiver with CMA Array Antenna

It is well known that MMSE receiver has advantage in its cancellation effects of multiple access interference compared to the conventional matched filter receiver in CDMA mobile system. Since this advantage is directly related with BER performance and channel capacity of CDMA system, MMSE receiver is being seriously considered as a possible candidate system to improve conventional matched filter receiver. However MMSE receiver has to update optimum code of receiver against to the time-varying multi-path fading mobile channel and Multiple Access Interference(MAI), it needs relatively fast signal processor to compute the optimum receiver code based on signal statistics. This kind of computation power and related cost may not be a barrier for the MMSE muti-user detector on base station as long as this system can improve BER performance of receiver remarkably. But the MMSE receiver on a mobile terminal is in a different situation. Inherently receiver system on a mobile terminal is to be limited in its cost and complexity. So code update algorithm itself should be simple enough for the signal processor with moderate speed can handle. That is the reason why simple LMS like algorithm is considered first. It is noticed through computer simulation that sometimes normal LMS algorithm is not fast enough to catch up the signal correctly in Rayleigh fading multi-path channel environment. To solve this convergence problem of LMS algorithm by diminishing the fluctuation of received envelope due to multi-path fading, array antenna of constant modulus algorithm(CMA) is positioned just before the MMSE receiver. The cancellation of harmful multi-path signal on spatial domain as well as MAI cancellation on channel level can be achieved simultaneously with this proposed system

1. CMA Array Antenna

Constant modulus algorithm was introduced firstly as a blind equalizer algorithm. The same algorithm can be used for array antenna to make the envelope of received signal constant in multi-path fading channel.[7] The merit of this algorithm is simplicity. In the CMA array system of this paper, despreaded pilot signal in the forward link is utilized as a reference signal of adaptive algorithm. One of the advantage of using pilot signal as a reference is that it can provide relatively secure reference signal compared to the traffic signal because it has much higher transmit power than the traffic signal. Around 15% to 20% of transmitted power of base station is allocated to the pilot signal in IS-95. The other advantage of no delay in adaptation is coming from the fact that data symbol of the pilot signal is always known since the pilot carrier is modulated with known data symbol.

To make reference signal even more secure, actual reference signal is generated after despreading the received pilot signal by walsh code 0 as can be seen in figure 1. With this scheme, the proposed system can capture the desired multi-path signals even in sevely distorted mobile channel.

If the total number of array antenna is assumed M then the sample of the received signal at the array antenna and antenna weights can be represented in vector notation like

$$\mathbf{X}(n) = [x_1(n)\ x_2(n) \cdots x_M(n)]^T \tag{4}$$

$$\mathbf{W}(n) = [w_1(n)\ w_2(n) \cdots w_M(n)]^T \tag{5}$$

From this received sample the cost function of CMA array for pilot signal can be generated as

$$J(n) = E\left[\left(\left| y_p(n) \right|^2 - R \right)^2 \right] \tag{6}$$

where y_p means the pilot signal component of array output signal $y(n)$ and R is the desired constant envelope level of pilot signal. The weight vector is updated using stochastic gradient algorithm which is almost same as LMS algorithm

$$\begin{aligned}\mathbf{W}(n+1) &= \mathbf{W}(n) - \mu \cdot \nabla J(n) \\ &= \mathbf{W}(n) - \mu \cdot e(n) \cdot \mathbf{X}^*(n)\end{aligned} \tag{7}$$

where $X^*(n)$ is conjugate of received signal and $e(n)$ is the error signal represented as follows

$$e(n) = \left\lfloor R - \left| y_p(n) \right|^2 \right\rfloor y^*{}_p(n) \tag{8}$$

The received signal vector of L path and K user after compensating the channel phase distortion ϕ_l can be expressed as

$$\mathbf{X}(t) = \sum_{l=1}^{L} \sum_{k=1}^{K} \mathbf{a}(\theta_l) \alpha_l \sqrt{P_k} b_k(t-\tau_l) c_k(t-\tau_l) + n(t) \tag{9}$$

where b_k, c_k are representing symbol and chip signal and $a(\theta_l)$ is the array antenna direction vector of lth path which has different angle of arrival θ_l. The CMA array output that is the summation of input signals multiplied by the relevant weights can be expressed as

$$y(n) = \mathbf{W}^H(n)\mathbf{X}(n) \tag{10}$$

where H means transpose conjugate of the vector.

Resultantly the weight vector calculated by CMA algorithm steers beam pattern to the certain direction to make the array output keep constant envelope

2. MMSE Receiver

By getting optimum receiver code in terms of MAI, the MMSE receiver has better performance than conventional matched filter receiver. However the MMSE receiver code should be constantly updated according to time varying signal condition of the receiver, it needs signal processor and algorithm fast enough to catch the variance of the received signals in multi-path environment. As it has been mentioned, the processor and algorithm for mobile terminal in CDMA forward link are limited in its cost and complexity. So the LMS algorithm is selected as a code update algorithm even though there is fast algorithm such as RLS like algorithm.

The LMS algorithm is very simple to be implemented by processor with moderate speed, however it has a critical disadvantage of slowness as an adaptive algorithm in fast time-varying multi-path mobile channel. Throughout computer simulation, it has been noticed that the LMS algorithm sometimes is a little bit behind to the time variance of the signal particularly in Rayleigh fading multi-path mobile channel. This is largely due to the fluctuation of received envelope level that varies too fast and too broad.

The front-end CMA array relieves this phenomenon by enforcing the envelop of the received signal constant as possible as it can by preventing deep fading due to adverse multi-path component.

After despreading kth user Walsh code the signal can be expressed as

$$u_k(n) = y(n)c_k(n) \tag{11}$$

The estimated symbol of MMSE receiver with N taps, which is the same number as process gain ,sampling one sample data per each chip, can be expressed in vector form

$$z_k = \hat{b}_k = \mathbf{W}_{MMSE}^H \mathbf{U} \tag{12}$$

where

$$U = [u(1)u(2)\cdots u(N)]^T \tag{13}$$

The MMSE weight vector in steady state can be expressed as

$$\mathbf{W}_{MMSE} = \mathbf{R}_{uu}^{-1}\mathbf{p}_{ud} \tag{14}$$

where covariance matrix of user siganl vector U and correlation vector of U and desired signal d are represented as R_{uu} and p_{ud} like following equations,

$$\mathbf{R}_{uu} = E[\mathbf{U}\mathbf{U}^H] \tag{15}$$

$$\mathbf{p}_{ud} = E[\mathbf{U}d] \tag{16}$$

The LMS algorithm used in this paper is

$$\mathbf{W}_{MMSE}(i+1) = \mathbf{W}_{MMSE}(i) - \mu\varepsilon^*(i)\mathbf{U}(i) \tag{17}$$

where

$$\varepsilon(i) = \mathbf{W}_{MMSE}^H \mathbf{U} - \hat{b}_k(i) \tag{18}$$

Ⅳ. Simulation and Discussion

The performance of the proposed MMSE receiver with CMA array in multi-path Rayleigh channel of CDMA forward link is checked through computer simulation. To compare the performance of several receiver system in forward link, conventional matched filter receiver, matched filter with rake receiver, matched filter with CMA array and MMSE receiver with CMA array are modeled and simulated in a same multi-path mobile channel environment. The parameters used in performance comparison are constellation figure, mean square error of received signal and BER performance of the receiver systems.

The specification of receiver system used in simulation can be summarized as follows. The multi-path mobile channel is modeled by 4 ray of independent and Rayleigh faded signal. The maximum delay due to multi-path is assumed greater than one chip period. For the convenience of simulation, receiver system is assumed as BPSK modulated CDMA with its process gain 16. The antenna are assumed linearly deployed 4 element array.

Figure 2 and 3 shows the variation of envelope of received signal. As can be seen, the fluctuation of envelope of signal is smoothed by CMA array.

Figure 4,5,6,7 shows the constellation of received BPSK modulated signal. Figure 4 is the constellation of received signal with conventional matched filter receiver. The 4 ray multi-path signals are modeled so widely dispersed in time that the conventional matched filter receiver with single omni antenna hardly shows desirable performance. Figure 5 shows the constellation of received signal of rake receiver. There is little improvement compared to figure 4, but still unsatisfactory. Figure 6 show the signal constellation of matched filter receiver with CMA array antenna. As can be seen, there is conspicuous improvement compared to figure 4 and 5. Figure 7 show the received signal constellation of the proposed system-CMA array followed by MMSE receiver.

Finally BER performance of the several different receiver are shown in figure 8. As can be seen from the result of simulation, the MMSE receiver with CMA antenna array shows the best performance compared to the other type of receiver.

V. Conclusion

Through computer simulation, it is certified that the proposed MMSE receiver with CMA array in the forward link of CDMA mobile system shows best performance compared to the other system. Considering implementation aspect, the proposed system adopts the simplest adaptive algorithm for the antenna array as well as MMSE receiver. Besides spatial filtering capability of canceling the harmful interference, the frond-end CMA array provides relatively constant envelope of received signal so as to make LMS algorithm of MMSE receiver always stable.

CMA array and MMSE receiver have its inherent function of performance enhancement because of its spatial filtering and MAI cancellation capability. When these two systems are combined as a CDMA receiver, the synergy effect in the BER performance can be expected as seen in the computer simulation.

Recently, the demand of mobile internet services and mobile computing are increasing rapidly. For this kins of services, traffic on the forward link is much higher than that of reverse link. The proposed MMSE receiver front-ended by CMA array may well be suited this kind of application whatever the configuration of base station may be.

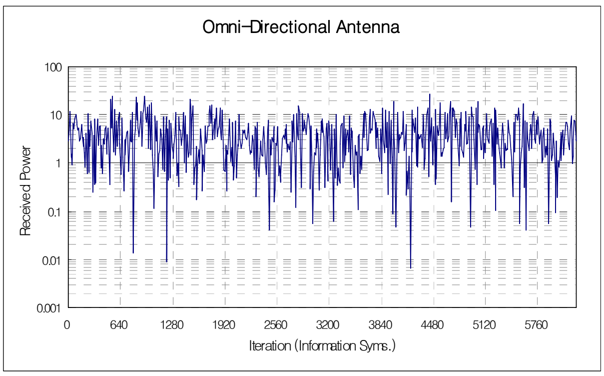

Figure 2. The Received Power with Omni-Directional Antenna

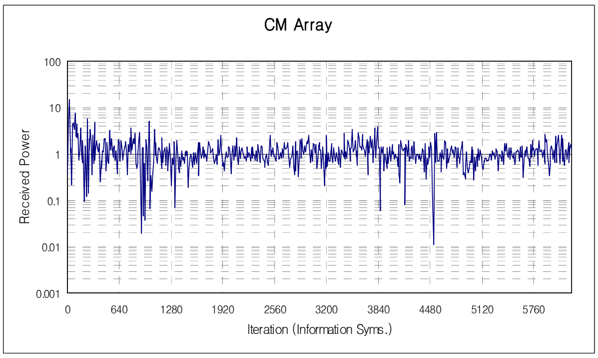

Figure 3. The Received Power with CMA Array

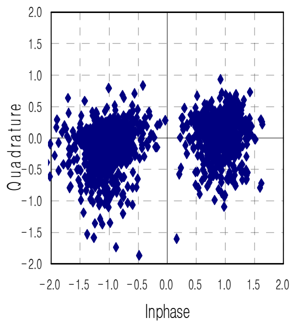

Figure 4 .Conventional matched filter receiver

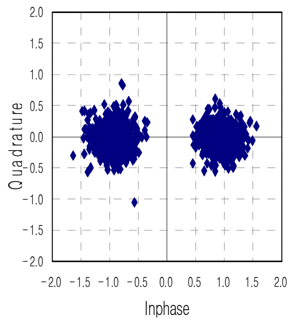

Figure 5. Rake Receiver

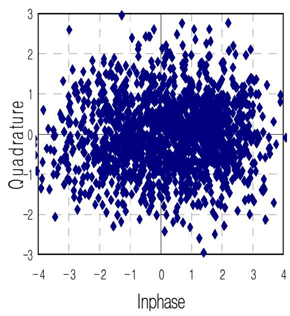

Figure 6. CMA Array only

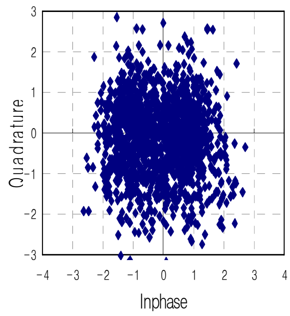

Figure 7. CMA+MMSE

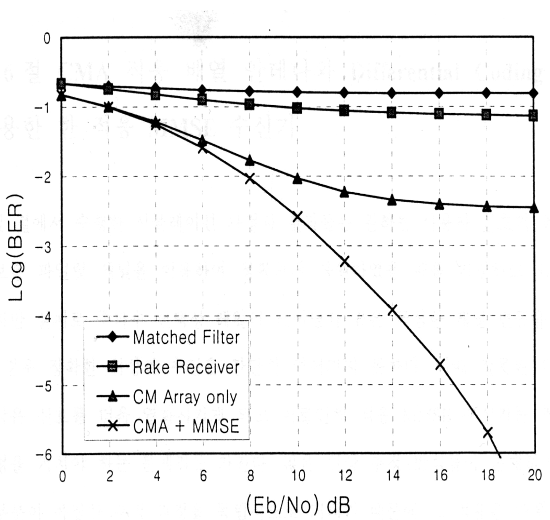

Figure 8. BER Performance of Different Receivers

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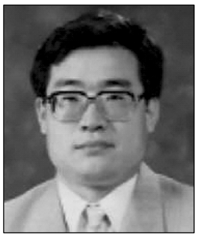

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