저궤도 위성통신을 위한 칩레벨 DS/CDMA 시스템의 성능 평가에 관한 연구

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The Performance of Chip Level Detection for DS/CDMA Operating in LEO Satellite Channel

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Abstract

We present in this paper the ture union bound of the performance of chip level detection for coded DS/CDMA system operating in Rician fading channels such as LEO satellite mobile radio where the maximum doppler frequency is very high. The main objective of this paper is to calculate the exact true union bound of BER performance of different quadrature detectors and to find a optimun spreading factor as a function of fade rate. The rationale of using multiple chip detection is to reduce the effective fade rate or variation. We considered chip level differential detection, chip level maximum likelihood sequence estimation, noncoherent detection and coherent detection with perfect channel state information as a reference.

I. INTRODUCTION

In the past few years, many countries and organizations have started development programs for the third generation satellite communication using LEO/MEO (low/medium earth orbit) satellites to provide wide area personal communications services. The typical examples of LEO satellite systems are the Iridium, Odyssey and Globalstar [1][2]. Because of the small value of free-space propagation loss caused by low altitude and low frequencies, the LEO/MEO, combined with modern signal processing techniques, will permit reliable communication at reasonably low transmitted power level and with low propagation delay. However, due to the relative fast motion (in the order of thousands of Km/hour) of the LEO/MEO satellites with respect to the earth, the communication like is non-stationary and exhibits very fast fading.

We examine in this paper the subjectof chip level

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detection in coded DS/CDMA operating in very fast fading Rician channel. The maximum Doppler frequency is assumed to be few percent the chip rate. In this paper, we will present the True Union Bound (TUB) on the BER of coded DS/CDMA system using chip level detection with different code rate, spreading factor and detector type. The rationale of using chip level processing is to handle fast fade rate in the order of a few percent the chip rate. The detection techniques we consider here are chip-level differential detection, chip-level noncoherent detection, chip-level maximum likelihood detection and coherent detection with perfect channel state information (CSI). The TUB technique we use in this paper was taken from [3] and it provides the tightest upperbound of BER.

Ⅱ. SYSTEM MODEL

The block diagram of our system is shown in fig.1. The input data rate is $1/T_b$ and each data bit is convolutional coded with rate $1/2M$, then mapped into $2M$ channel symbols. Each encoded symbol is further spreaded N times by the CDMA tranceiver, yielding a total bandwidth expansion factor of $G=2NM$. For convenience we assume the encoded bits of the rate $1/2M$ encoder are obtained by repeating the output of an optimal rate $1/2$ code M times. The output of the convolutional encoder are mapped into BPSK symbols. After interleaving, interleaved symbols $x'(k)$ further mapped into a N-chip $\mathbf{y}(k)=(y(k,1),y(k,2),\dots,y(k,n))$, $y(k,n)\in\{+1,-1\}$ pattern. This chip pattern is then multiplied by a long PN code, $(\dots,c(1),c(2),\dots)$, $c(m)\in\{+1,-1\}$, forming the transmitted chip pattern given by

$$\mathbf{S}=(\dots,\mathbf{s}(-1),\mathbf{s}(0),\mathbf{s}(1),\dots)' \quad \text{......} (1)$$

where $\mathbf{s}(k)=(s(k,1),s(k,2),\dots,s(k,N))$, and $s(k,n)=x'(k)^n c(kN+n)$.

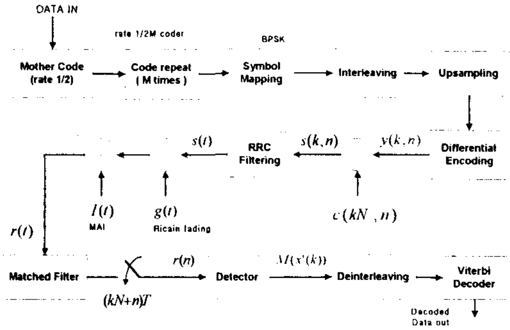

Fig 1. System block diagram

The total bandwidth expansion factor is thus $G=2NM$ and the chip duration is $T_c=T_b/G$. In this paper, we fixed the value of G at 256 while N can vary from 1 to 128 in power of 2. The transmitted signal, in complex baseband notation, is given by

$$s(t)=\sum_{k=-\infty}^{\infty}\left(\sum_{n=1}^{N}s(k,n)p(t-(kN+n)T_c)\right) \quad \text{......} (2)$$

with a roll-off factor of ρ and a normalized energy of unity.

After passing through a Rician fading channel, received signal is filtered by a matched filter and the filtered signal is sampled at the chip rate. Assuming that the fading is constant at the chip duration, then the sequence of filtered signal is given by

$$\mathbf{R}=(\dots,\mathbf{r}(-1),\mathbf{r}(0),\mathbf{r}(1),\dots)' \quad \text{......} (3)$$

where $\mathbf{r}(k)=(r(k,1),r(k,2),\dots,r(k,N))'$, and $r(k,n)=u(kN+n)s(k,n)+e(kN+n)$. $e(m)$ is a zero mean complex Gaussian random variable representing multiple access interference (MAI) with unity variance and $u(m)$ is a non zero mean complex Gaussian random variable representing Racian fading. Note that, in this paper, our definition of bit signal-to-interference ratio (SIR) is

$$\frac{E_b}{I_0}=G\frac{\left(A^2/2+\sigma_g{}^2\right)}{I_0} \quad \text{......} (4)$$

where, I_0 is the power spectral density of the MAI, $A^2/2$ and σ_g^2 is the signal power of specular component and variance of diffused component $u(m)$ respectively. Finally, the $e(m)$'s are statistically independent and identically distributed (iid) while the autocovariance of the $u(m)$'s is $\phi_u(m)=\sigma_g^2 J_0(2\pi m f_d T_c)/I_0$ where J_0 is the zero-order Bessel function and f_d is the maximum Doppler frequency.

Ⅲ. THE CHIP LEVEL DETECTORS

We will present in this section four different detection algorithms. These detectors are (1) chip-level differenctial detection, (2) chip-level non-coherent detection, (3) chip-level MLSE detection and (4) an ideal coherent detection. It will be shown that in each case, the metric generates soft decision decoding metrics which can be descrived in quadratic forms.

A. Chip-level Differential Detection

The chip level differential detector operates as follows. The received samples $\{r(k,n)\}$ are first multiplied by the chip pattern $\{c(kN+n)\}$to remove the dependency on the differentially detected and those differentially detected samples belonging to the same convolutionally coded symbols will be added together to form the soft decision metrics.

Specifically, the decoding metric for $x'(k)$ is

$$M(x'(k))=-\frac{x'(k)}{2}\tilde{\mathrm{r}}(k)^{+}\tilde{\mathrm{c}}(k)\mathrm{M}_1\tilde{\mathrm{c}}(k)\tilde{\mathrm{r}}(k) \quad \cdots\cdots (5)$$

where, M_1 is a matrix whose (i,j)-th element is

$$m_1(i,j)=\begin{cases}-1 & |i-j|=1 \\ 0 & \text{otherwise}\end{cases} \quad \cdots\cdots (6)$$

and

$$\begin{aligned}\tilde{\mathrm{r}}(k)&=[r(k-1,N),\mathrm{r}(k)]' \\ &=\tilde{\mathrm{c}}(k)\tilde{\mathrm{y}}(k)\tilde{\mathrm{u}}(k)+\tilde{\mathrm{e}}(k)\end{aligned} \quad \cdots\cdots (7)$$

with $\tilde{c}(k)=diag(1,c(k,1),c(k,2),\ldots,c(k,N))$ a diagonal matrix of signature chip pattern, $\tilde{y}(k)=diag(1,y(k,1),y(k,2),\ldots,y(k,N))$, $y(k,n)=x'(k)^n$, is a differentially encoded data matrix, $\tilde{u}(k)=(u(kN),u(KN+1),\ldots,u(kN+N))^t$ is a vector of complex fading gains, $\tilde{e}(k)=(e(kN),e(kN+1),\ldots,e(kN+N))^t$ and is a noise vector.

The soft decision branch metrics in the above equation will be de-interleaved before passed to the Viterbi decoder. The rationale for using chip level

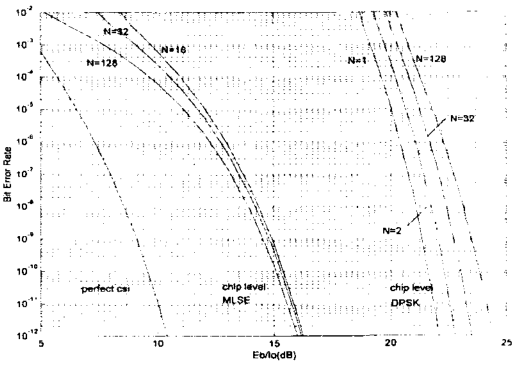

Fig 2. Performance of 16 state code with chip level differential detection and chip level MLSE detection. The fade tate is f_dT_c=0.01. Rician factor K = 5dB.

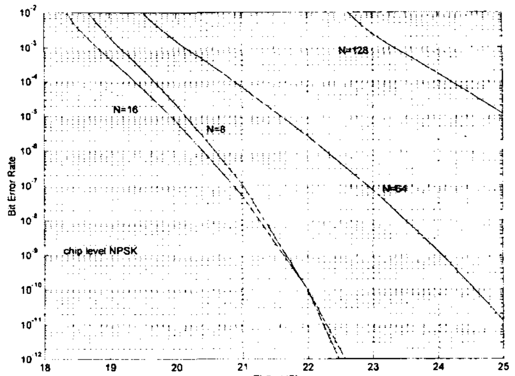

Fig. 3 Performance of 16 state code with chip level NPSK. The fade rate is f_dT_c=0.01. Rician factor K = 5dB.

differential detection is that it apears to be more robust against fast fading when compared to symbol level differential detection. For a maximum Doppler frequency f_d, a symbol level differential detector sees an effective fade rate of $f_d T_s$ which is times that seen by its chip level counterpart. From past experience [7], the lower the effective fade rate, the smaller is the bit error rate.

B. Noncoherent Detection

As mentioned earlier, all the chip-level differential encoding process does to the interleaved symbol $x'(k)$ is to mapped it to an all +1 chip pattern or a pattern of alternating 1 and +1, depending on whether $x'(k)$ is +1 or 1. These two patterns are orthogonal and consequently non-coherent detection can be used. Specifically, the decoding metric of a noncoherent detector is

$$M(x'(k)) = \begin{cases} -\mathrm{r}(k)^{+}\mathrm{c}(k)\mathrm{M}_2\mathrm{c}(k)\mathrm{r}(k), & x'(k)=1 \\ -\mathrm{r}(k)^{+}\mathrm{c}(k)\mathrm{M}_3\mathrm{c}(k)\mathrm{r}(k) & x'(k)=-1 \end{cases} \quad \cdots\cdots\cdots\cdots (8)$$

where, M_2 is an all-one matrix, M_3 is a matrix whose (i,j)-th element is $m_3(k,j)=(-1)^{i+j}$ $c(k)=diag(c(k,1), c(k,2),...,c(k,N))$ is a diagonal matrix of chip pattern, $r(k)$ and was defined in (3).

C. Chip level Maximum Likelihood Sequence Estimator

The chip level differential detector in (5) and the noncoherent detector in (8) represent two simple ways to process the received information. However, it is not optional from the bit-error-rate (BER) point of view. Recall the vector $\tilde{r}(k)$ in (7) is Gaussian conditioned on the matrices $\tilde{c}(k)$ and $\tilde{y}(k)$. Its covariance matrix is given by

$$\tilde{\Phi}_{rr} = \tilde{c}(k)\,\tilde{y}(k)\left(\tilde{\Phi}_{uu} + I\right)\tilde{y}(k)\,\tilde{c}(k) \quad \cdots\cdots\cdots\cdots (9)$$

where $\tilde{\Phi}_{uu}$ and I are respectively the covariance matrices of $\tilde{u}(k)$ and $\tilde{e}(k)$. Since $x'(k) \in \{\pm 1\}$, this implies $\tilde{y}(k)$ is either an identity matrix, or the diagonal matrix

$$\tilde{d} = diag\ (1,-1,1,\ldots,-1,1) \quad \cdots\cdots\cdots\cdots (10)$$

of alternating +1 and 1. Given that $\tilde{r}$ is conditionally Gaussian and that the determinant of $\tilde{\Phi}_{rr}$ is independent of $\tilde{c}(k)$ and $\tilde{y}(k)$, this means the optimal soft decision metric for $x'(k)$ is

$$M(x'(k)) = \begin{cases} \tilde{\mathbf{r}}(k)^{+}\tilde{\mathbf{c}}(k)\mathbf{M}_4\tilde{\mathbf{c}}(k)\tilde{\mathbf{r}}(k), & x'(k)=1 \\ \tilde{\mathbf{r}}(k)^{+}\tilde{\mathbf{c}}(k)\tilde{\mathbf{d}}\mathbf{M}_4\tilde{\mathbf{c}}(k)\tilde{\mathbf{r}}(k) & x'(k)=-1 \end{cases} \quad \cdots\cdots (11)$$

where $M_4 = (\tilde{\Phi}_{uu} + I)^{-1}$.

D. Ideal Coherent Detection

By an ideal coherent detector, we mean the fading gain vector

$$\mathbf{u}(k) = (u(kN+1), u(kN+2), \ldots, u(kN+N))' \quad \cdots (12)$$

is known to the receiver. Consequently, the decoding metrics for $x'(k)=1$ and $x'(k)=-1$ are respectively

$$M(x'(k)) = \begin{cases} -(\mathbf{r}(k)^{+}\mathbf{c}(k)\mathbf{u}(k) + \mathbf{u}(k)\mathbf{c}(k)\mathbf{r}(k) \\ -(\mathbf{r}(k)^{+}\mathbf{c}(k)\mathbf{d}\mathbf{u}(k) + \mathbf{u}(k)\mathbf{d}\mathbf{c}(k)\mathbf{r}(k) \end{cases} \quad \cdots\cdots (13)$$

where **d**=diag(-1,1,...,-1,1) is a diagonal matrix containing an alternating pattern of 1 and +1. Although it is impossible to implement an ideal coherent detector, its performance is still of theoretic interest since it establishes a point of reference for the other detectors.

Ⅳ. NUMERICAL ANALYSIS

The soft decision branch metrics generated by a detector will be de-interleaved and passed to the Viterbi decoder. The decoder selects the codeword that minimizes the sum of the branch metrics. The erformance of the detectors were evaluated through the TUB analysis. In particular, if we let the transmitted codeword and the detector's selection be X=(...,x(0),x(1),...)$'$ and $\hat{X}=(\ldots, \hat{x}(0), \hat{x}(1), \ldots)'$ respectively, then the TUB on the BER is given by

$$P_b \le \sum_{\mathbf{X}} P(\mathbf{X}) \sum_{\hat{\mathbf{X}} \ne \mathbf{X}} P(\mathbf{X} \to \hat{\mathbf{X}}) n(\mathbf{X} \to \hat{\mathbf{X}}) \quad \cdots\cdots (14)$$

where $P(X)$ is the probability that was transmitted, $P(X \to \hat{X})$ is the so-call pairwise error probability and $n(X \to \hat{X})$ is the number of bit errors in an error event. The TUB technique uses all pairwise error events and exact expression them using elementary characteristic functions. The elementary characteris functions are obtained as following. The quadratic form of the difference metric can be expressed by

$$\mathbf{Q} = \mathbf{R}^t \mathbf{F} \mathbf{R} \quad \cdots\cdots (15)$$

where R is a column vector of non-zero mean correlated complex Gaussian random variables. Using linear transform, T , independent Gaussian random variables vector N is obtained according to

$$\mathbf{R} = \mathbf{T}\mathbf{N} \quad \cdots\cdots (16)$$

Substituting (16) into (15) gives

$$\mathbf{Q} = \mathbf{N}^t(\mathbf{T}^t\mathbf{F}\mathbf{T})\mathbf{N} \quad \cdots\cdots (17)$$

If the matrix T^tFT is diagnal the characteristic function of branch metric difference Q is given by

$$\Phi_D(s) = \frac{\exp(-s\langle R'\rangle F(I+2s\phi_{RR})^{-1}\langle R\rangle)}{det(I+2s\phi_{RR}} \quad \cdots\cdots (18)$$

where, s is the Laplace domain variavle, I is the identity matrix, <R> and $\varnothing_{RR}$ are the mean and auto-covariance matrix and det(*) represents the determinent of a matrix [10]. Note that

$$\det(\mathbf{I} + 2s\phi_{\mathbf{RR}}) = \prod_{k=1} (1 + 2\lambda_k s) \quad \cdots\cdots (19)$$

where λ_k is the I-th eigenvalue of the matrix $\Phi_{RR}F$. $\Phi_D(s)$ is used to calculate the TUB of BER, thus it gives the tightest bound possible. In our analysis, we used the optimal rate 1/2, 16 state convolutional code as the mother code.

V. RESULTS AND DISCUSSION

Fig. 2 shows the performance of chip level differential detection and chip level MLSE detection at $f_dT_c = 0.01$. As the results of differential detection indicate, the BER increase as N decrease. The main reason for considering chip-level differenctial detection is that it provides a lower effective fade rate compare to symbol level differential detection. At the low fade rate, these chip level receivers do not necessaraly perform better than their symbol level counter part using samples over two symbol intervals. However, they are quite robust in the sense that a reasonable level of energy efficiency can be maintained even when the fade rate is increased to a few percent the chip rate. This is in contrast to symbol level detectors for DS/CDMA whose performances usually degrade drastically when the fade rate increase. As for the MLSE detector, it was found that the BER decrease with increasing N, a behavior opposite to that in differential detection. Also shown is the performance curve when perfect channel state information (CSI) is available at the receiver as a reference. The performance of the non-coherent detector at $f_dT_c = 0.01$ is shown in Fig. 3. Note that there exists an optimal spreading factor. According to the figure the optimal spreading factor is 16 in conjunction with rate 1/16 code. As for the potential applications of these receiver techniques, a good possibility is in LEO satellite systems providing personal communication systems.

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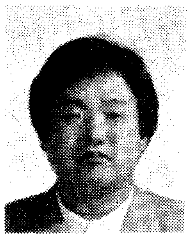

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