Research Article

Performance Analysis and Comparison of Full Chip and Half Chip Rate DC and NC Code Acquisition in MIMO DSCDMA over Uncorrelated Rayleigh Wireless Channel

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This paper presents the performance analysis and comparison of full chip and half chip rate of noncoherent (NC) and differentially coherent (DC) code acquisition scheme in (multiple input-multiple output) MIMO assisted by direct sequence spread spectrum (DS-CDMA) wireless system when communicated over uncorrelated Rayleigh channel. Four schemes are investigated, namely, SISO with full chip rate, SISO with Half chip rate, MIMO with full chip rate, and MIMO with half chip rate by varying the code acquisition technique. The simulation is done in RF signal processing Lab using matlab tool box, and the performance metrics are considered, namely, Bit Error Rate (BER) and mean acquisition time (MAT). The simulation results indicate that DC performance is superior than NC in both full chip and half chip rate and also shown that half chip performance is better than full chip in both DC and NC code acquisition methods.

1. Introduction

MIMO technique is employed with spread spectrum to increase capacity and improve the overall performance in the MIMO scheme. In these systems, multiple antennas are used at both ends of the wireless link. This method allows cellular systems to provide users with high data rate services through reliable communication link. It has the ability to combat the fading phenomena in wireless links. Recent research in this method has shown an increase in system diversity and bandwidth efficiency [1]. This technique offers higher capacity to wireless systems, and the capacity increases linearly with the number of antennas. A basic MIMO channel model is depicted in Figure 1 with M transmitter and N receiver antennas. In each use of the MIMO channel, a vector $a = (a_1, a_2 \dots a_M)^T$ of complex numbers is sent and a vector $r = (r_1, r_2 \dots r_N)^T$ of complex numbers is received. We assume an input-output relationship of the form

$$r = Ha + V, \quad (1)$$

where H is an $N \times M$ matrix representing the scattering effects of the channel called as channel matrix, and $V = (v_1, v_2, v_N)^T$ is the noise vector. Throughout this paper, H is assumed as a random matrix with independent complex Gaussian elements $\{h_{ij}\}$ with mean 0, and unit variance is denoted as $h_{ij} \sim CN(0, 1)$. Also V is assumed as a complex Gaussian random vector with elements $v_i \sim CN(0, N_0)$, and H and V are independent of each other and of the data vector a .

2. DS-CDMA Modulation

A spread spectrum multiple access technique is one which spreads the bandwidth of the data uniformly for the same transmitted power. Spreading code is a pseudo-random (PN) code which has a narrow pulse codes. In CDMA scheme [2], a locally generated code runs at a much higher rate than the data to be transmitted. In this method, the modulated waveform is spread second time in such a way to produce an expanded wideband signal whose bandwidth is greater

FIGURE 1: MIMO Model.

FIGURE 2: Amplitude spectrum before and after spreading.

than the available bandwidth. This signal does not interfere with other signals. such an expansion is achieved using second modulation. Many potential advantages are achieved over conventional systems such as improved interference rejection, high resolution ranging, secured communication and increased capacity, and a better spectral efficiency. The Figure 2 shows the amplitude spectrum before and after spreading.

In DS-SS [3], the spread signal is obtained by multiplying the information signal directly with a wideband PN signal. The information rate is $R = 1/T_b$ bits per sec, where T_b is one bit interval. The PN signal rate is $1/T_c$ "chips" per sec where T_c is one chip duration [4]. One bit interval occupies (N)chips, that is,

$$N = \frac{T_b}{T_c}. \quad (2)$$

There are many issues in the conventional DS-CDMA [2] systems which are as given below

- (i) If all users transmit almost with identical power then beyond certain point increase of power of every user will not reduce the bit error rate [5].
- (ii) If the user transmits with widely different power, then the conventional receiver allows the signal from the powerful user by suppressing the weaker user signal.
- (iii) The detection of desired signal is limited by inherent suppression capacity of the system.

3. System Model

A finite length tapped with delay line channel model generates the L Rayleigh-faded multipath signals, each is

FIGURE 3: DC and NC modules used in the receiver design.

arriving with a time delay τ_l having a tap spacing of one chip duration and half chip duration considered. It is also assumed that the Rayleigh fading is sufficiently slow for the faded envelope to remain constant over τ_D chip intervals. The Neyman-Pearson criterion is adopted [6, 7], which leads to a Constant False-Alarm Rate (CFAR). The received signal of the MIMO over the multipath Rayleigh-fading channel can be expressed mathematically as in (4).

The DC and the NC receiver module used in code acquisition scheme using transmit/receive antennas is as shown in Figure 3, and the timing hypothesis test is carried out for binary spreading. The NC module generates its decision variable by accumulating $P \cdot R$ number of independently faded signals observed over a given time interval. In the DC scheme, instead of squaring the summed energy as suggested by the procedures outlined, the channel's output samples accumulated over a full spreading code period is multiplied by the conjugate of the N -chip-delayed samples, where N is represented by

$$N = \frac{\tau_D}{T_c}, \quad (3)$$

$$r(t) = \sum_{l=1}^L \sum_{m=1}^P \sum_{n=1}^R \left[\alpha_{(l,m,n)} \sqrt{\frac{E_c}{PT_c}} C(t + dT_c + \eta) \cdot w_m(t + dT_c + \eta) e^{(2\pi f t + \phi_{(l,m,n)})} + I_{k(l,m,n)}(t) \right], \quad (4)$$

where P = number of transmit antennas, R = number of receive antenna, $\alpha_{(l,m,n)}$ = complex-valued envelope of the $(l,m,n)^{\text{th}}$ signal path obeying a Rayleigh magnitude distribution and a uniform phase distribution, E_c = pilot signal energy per PN code chip, $C(t)$ = common PN sequence having a cell-specific code-phase offset is the code phase offset with respect to the phase of the local code, T_c = one chip duration, $w_m(t)$ = specific Walsh code assigned to the m th transmit antenna, f = carrier frequency, ϕ = carrier phase of a specific user's modulator.

where $k = k^{\text{th}}$ chip's sampling instant, $S_{k(l,m,n)} = a$ deterministic value, which depends on whether a signal is present or absent. Furthermore, the definition of $W_{1,k(l,m,n)}$, $W_{2,k(l,m,n)}$, $W_{3,k(l,m,n)}$, and $W_{4,k(l,m,n)}$ which are mutually independent Gaussian random variables having zero means and unit variances.

Equation (4) can be given in a simplified form as

$$Z_{k(l)}^{\text{DC}} = X_{k(l)} - Y_{k(l)}, \quad (5)$$

FIGURE 4: (a, b) BER characteristics of SISO full chip and half chip rate, respectively.

where,

$$X_{k(l)} = \sum_{m=1}^P \sum_{n=1}^R \left[\left(\sqrt{\frac{4E_c}{NI_0P}} \cdot S_{k(l,m,n)} + W_{1,k(l,m,n)} \right)^2 + W_{3,k(l,m,n)}^2 \right],$$

$$Y_{k(l)} = \sum_{m=1}^P \sum_{n=1}^R \left[W_{2,k(l,m,n)}^2 + W_{4,k(l,m,n)}^2 \right]. \quad (6)$$

Then the final decision variable is obtained as

$$Z_{k(l)}^{\text{DC}} = X_{k(l)} - Y_{k(l)} = \sum_{m=1}^P \sum_{n=1}^R X_{k(l,m,n)} - \sum_{m=1}^P \sum_{n=1}^R Y_{k(l,m,n)}. \quad (7)$$

Accordingly, the decision variable $X_{k(l,m,n)}$ of each path obeys a noncentral chi-square PDF with two degrees of freedom, where as $Y_{k(l,m,n)}$ is centrally chi-square distributed with two degrees of freedom. The individual PDFs are given by as follows

$$f_{X_{k(l,m,n)}}(z | H_x) = \frac{1}{2} e^{-(z+\lambda_x)/2} \cdot I_0(\sqrt{z \cdot \lambda_x}), \quad (8)$$

$$f_{Y_{k(l,m,n)}}(z | H_x) = \frac{1}{2} e^{-z/2},$$

respectively, where $z \geq 0$, $x = 0$ or 1 , $I_0(\cdot)$ is the zeroth order modified Bessel function of the first kind. Let us now express the PDF of the desired user's signal at the output of the acquisition scheme conditioned on the presence of the desired signal in $f_{X_{k(l,m,n)}}(z | H_x)$, when communicating over an uncorrelated Rayleigh channel. In this scenario, E_c is multiplied by the square of the Rayleigh distributed fading

amplitude, β , which has a chi-square distribution with two degrees of freedom: $f(\beta) = e^{-\beta/\sigma^2}/\sigma^2$, where σ^2 is the variance of the constituent Gaussian distribution. Then the average pilot signal energy E_c per PN code chip can be expressed as $\bar{E}_c = \beta E_c = \sigma^2 E_c$.

The probability of correct detection for the l th path according to $x = 1$ is expressed as

$$P_{D(l)}^{\text{DC}} = \int_{\theta}^{\infty} f_{Z_{k(l)}^{\text{DC}}}(z | H_1) dz, \quad \theta \neq 0, \quad (9)$$

where θ = threshold value.

$P_{D(l)}^{\text{DC}}$ = the probability of correct detection for the l th path. Finally, the false alarm probability in the context of an H_0 hypothesis is expressed as

$$P_F^{\text{DC}} = \int_{\theta}^{\infty} f_{Z_{k(l)}^{\text{DC}}}(z | H_0) dz, \quad \theta \neq 0, \quad (10)$$

where P_F^{DC} = the false alarm probability.

For comparison, the NC counterpart of the previously described DC scheme is characterized here, where the final decision variable of the l th path is given by

$$Z_{k(l)}^{\text{DC}} = \sum_{m=1}^P \sum_{n=1}^R \left\| \frac{1}{\sqrt{2}} \left(\sqrt{\frac{4E_c}{NI_0P}} \cdot S_{k(l,m,n)} + I_{k(l,m,n)} \right) \right\|^2, \quad (11)$$

where $\|\cdot\|$ represents the Euclidian norm of the complex-valued argument and the factor of $1/\sqrt{2}$ is employed to normalize the noise variance. The NC decision variable $Z_{K(l)}^{\text{NC}}$ has exactly the same statistical behavior as $X_{k(l)}$ described above. Thus its derivation follows the same procedures that of $f_{X_{k(l)}}(z | H_x)$ outlined. $S_{k(l,m,n)}$ becomes deterministic while $I_{k(l,m,n)}$ is the complex-valued additive white Gaussian

FIGURE 5: shows the BER characteristics for MIMO full chip using BPSK modulation.

noise having zero means and variances of $\sigma^2 = 2$ for both their real and imaginary parts.

The probability of correct detection corresponding to $x = 1$ for the l th path is obtained as

$$P_{D(l)}^{\text{NC}} = e^{-\theta/\mu_1} \cdot \sum_{k=0}^{P \cdot R - 1} \frac{(\theta/\mu_0)^k}{k'}, \quad (12)$$

where k = False locking penalty factor, θ = threshold value

In explicit MAT analysis, formulas are provided as single-antenna-aided serial search-based code acquisition system. There is no distinction between a single-antenna-aided scheme and a multiple-antenna-assisted one in terms of analyzing their MAT performance, except for deriving their correct detection and the false alarm probability based upon using transmit/receive antennas. It is assumed that in each chip duration T_c , α number of timing hypotheses are tested, which are spaced by T_c/α . Hence, the total uncertainty

FIGURE 6: BER characteristics of MIMO receiver simulation half chip using BPSK modulation.

region is increased by a factor of α [8], while the analysis of the MAT performance of NC receiver Z_{tot} decision variable is generated by the NC module and is compared with threshold value θ_1 . The search method involves two serial searches, namely search mode and validation mode and hence called as Double Dwell Serial Search method. When the desired user tentative code phase is obtained in the search mode of double dual serial search, the verification mode is activated which may use DC/NC modules in order to conform that the correct code phase is same as in search mode. DC

scheme is excluded in the search mode since it requires further processing carried out with DC module and thus the complexity is minimized, by not employing DC scheme to verification mode. Let Z_1 and Z_2 be the two decision variables of search and verification modes respectively and θ_1 and θ_2 be acquisition threshold of search and verification mode respectively. Z_1 is compared to θ_1 , and if it exceeds the threshold, Z_2 generated by either DC or NC module is compared to θ_2 . If successful code acquisition is declared, then the code tracking loop is enabled. Otherwise, the

FIGURE 7: Comparison between MIMO full chip (Figures 7(a)–7(d)) and half chip configuration (Figures 7(e)–7(h)).

acquisition system reverts back to the search stage, until the correct code and its phase are found.

4. Simulation Results and Discussions

The simulation was carried out at RF signal processing lab. Initially single-input single-output (SISO) system was considered employing DC and NC schemes using BPSK modulation scheme with full chip rate, and half chip rate, respectively. It is evident that DC code acquisition system performs better in terms of BER characteristics when compared to NC systems. This is as shown in Figures 4(a) and 4(b).

The Figures 5(a), 5(b), 5(c), and 5(d) shows the MIMO receiver simulation for 4, 8, 16, and 32 path employing DC and NC code acquisition for full chip rate using BPSK modulation method. In Figures 5(c) and 5(d), it is seen that BER is nil and also is DC is a better option than NC. Further it is also evident that BER decreases as transmission path increases hence improving the capacity.

Similarly Figures 6(a), 6(b), 6(c), and 6(d) depict the MIMO receiver simulation for 4, 8, 16, and 32 path employing DC and NC code acquisition for half chip rate using BPSK modulation method. In the Figures 6(a) and 6(d), BER is reduced much comparing to full chip. This shows that DC is better suited when compared to NC code acquisition method. Also it is observed that in half chip

performance characteristics the BER decreases with increase in the number of transmission path.

For the benefit of visualization and the comparison effects, the four sets of figures are shown again in Figure 7, Which brings out the difference between MIMO full chip (Figures 7(a)–7(d)) and half chip configuration (Figures 7(e)–7(h)).

Figure 8 shows the variation of the mean acquisition time (MAT) with respect to the SINR (E_c/n_0) ratio. From the figures, it is clear that the MAT decreases with increase of SINR ratio. This is one of the favorable results of this system. The mean acquisition time of DC is less than NC code acquisition. From the result, it is observed that as SINR ratio is increased, the mean acquisition time is reduced considerably for both DC and NC code acquisition methods. Also For 32 paths, the MAT of DC code acquisition is very less or zero. The MAT for DC code acquisition is decreasing as the number of transmission path increases. Hence DC is again a better option than NC.

5. Conclusion

This paper is a successful implementation of full chip and half chip rate with DC and NC schemes. It is evident that MIMO technique is employed with spread spectrum to increase capacity and improves performance in the MIMO scheme. This paper highlights the effects of two performance metrics for MIMO-DSCDMA over uncorrelated Rayleigh

FIGURE 8: Mean acquisition time versus SINR characteristics—MIMO.

wireless channel, namely, BER characteristics and MAT performance characteristics using Matlab toolbox. The simulation results are compared for four MIMO systems for both DC and NC code acquisition schemes. The observations from the simulation results are as follows:

- (i) As the number of paths increases, the BER is decreased for both DC code acquisition and NC code acquisition for both the half and full chip rate schemes.

- (ii) DC performance is better than NC in both half chip and full chip for both SISO and MIMO.
- (iii) Half chip method is best suited in terms of BER when compared to full chip for both DC and NC schemes.
- (iv) As the number of paths increases the BER is decreased for both half chip and full chip.
- (v) The mean acquisition time of DC is less than NC code acquisition.

- (vi) As SINR ratio is increased, the mean acquisition time is reduced considerably for both DC and NC code acquisition methods.
- (vii) For 32 paths, the MAT of DC code acquisition is very less or zero stating that the mean acquisition time is reduced as the number of path increases.

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