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PERFORMANCE ENHANCEMENT OF MC-DS/CDMA SYSTEM USING CHAOTIC SPREADING SEQUENCE

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ABSTRACT

A novel chaotic spreading sequences for multi-carrier direct sequence code division multiple access (MC-DS/CDMA) system is proposed. With this spreading sequence in the MC-DS/CDMA system, the effect of multiple access interference can be mitigated by choosing the spreading sequences with appropriate cross-correlation properties. The performance of the system is assayed in the multiuser environment by means of simulation. The simulation result shows that the proposed chaotic code spreading approach achieves a significant improvement in the system utility of about nine percent and it is useful in combating multiple access interference (MAI). The studies reveal that the proposed system significantly outperforms the Walsh Hadamard code spreading in MC-DS/CDMA system.

Key Words: *MC-DS/CDMA; Chaotic code; Spreading sequence; MAI*

1. INTRODUCTION

The enormous growth of wireless services during the last decade gives rise to the need for a bandwidth efficient modulation technique that can reliable transmit high data rates [1]. As Multi carrier technique combine good bandwidth efficiency with an immunity to channel dispersion, these technique have received considerable attention. To able to support multiple users, the multicarrier transmission technique can be combined with a CDMA scheme. Due to the wide bandwidth requirement for the wireless communication system the combination of MC-DS/CDMA with spreading in both time and frequency domain (TF domain) has recently attracted a lot of interest in wireless communication and provides an efficient approach to reduce the chip rate and the spreading code length [2,3,4,5,6].

It is well known that one of the major challenges in MC-DS-CDMA is its stringent power control requirements which limit its performance. Newly, an alternative approach to the power control problem in wireless systems based on an economic model has been offered. In this model, service preferences for each user are represented by a utility function. As the name implies, the utility function quantifies the level of satisfaction a user gets from using the system resources. Game theoretic methods are applied to study power control under this new model. Game theory is a powerful tool in modeling interactions between self-interested users and predicting their choice of strategies. Each player in the game maximizes some function of utility in a distributed fashion. [7,8]. The game settles at Nash equilibrium if one exits. Since users act selfishly, the equilibrium point is not necessarily the best operating point from a social point of view [9,10]. Pricing the system resources appears to be a powerful tool for achieving a more socially desirable result. A non-cooperative power control game with pricing (NPGP) in MC-DS/CDMA has been investigated in [7,8] and the existence of Nash equilibrium and corresponding sub-carrier allocation has also been addressed.

A classical set of spreading sequences used in DS-CDMA systems are the binary sequences generated by linear feedback shift register (LFSR)schemes, as discussed in [11]. Generation of fairly good set of Gold, Kasami and Walsh hadamard sequences require a large set dimension and period, which are generally limited by the LFSR polynomial degree [10,12,13,14]. Other limiting factors are that they are relatively smaller in number and limited privacy. This puts forth the need for optimal codes, which is the prime motiveof this work. These spreading sequences should possess minimal cross-correlation values to reduce the multiple access interference (MAI) as well as a very good auto correlation values for synchronization and multipath performance [10].

The utility improvement is achieved when more users are active, since the performance degradation due to the MAI becomes more obvious with large system capacity. The ability of the receiver to detect the desired signal in the presence of interference relies to a great extent on the correlation properties of the spreading codes (sequences). As the number of interferers or their power increases, MAI becomes substantial and can seriously degrade the bit error rate performance of the system, as a whole.

This work aims at employing the non-cooperative power control game with pricing (NPGP) with chaotic sequences such that the MAI is effectively reduced in a MC DS/CDMA environment comparing with Walsh spreading sequences. Interference parameter is one form of optimization criterion that is necessary to minimize MAI. Therefore, a successful implementation of MC- DS/CDMA systems strongly demands for spreading sequences that are capable of injecting minimal interference. The dependence of spread sequences on CDMA system performance is exhaustively discussed in [6].

The rest of the paper is organized as follows: Section 2 illustrates the MC-DS/CDMA system model. Section 3 deals about the discussion of chaotic codes, its comparison with the conventional codes. Section 4 introduces a pricing strategy to improve the power efficiency and the overall system utility. Section 5 presents the simulation results to demonstrate the performance improvement resulting from this approach and finally the conclusion is given in Section 6.

2. TIME AND FREQUENCY DOMAIN MC-DS/CDMA SYSTEM DESCRIPTION

The transmitter schematic of the MC -DS/CDMA scheme using both T-domain and F-domain, i.e. TF-domain spreading [13] is shown in Fig.1 in the context of the k^{th} user. At the transmitter side, the binary data stream $b_k(t)$ is first direct-sequence (DS) spread using the T-domain signature sequence $a_k(t)$. Applying T-domain spreading, the T-domain DS spread signal is divided into M parallel branches, where each branch-signal is multiplied by a corresponding chip value of the F-domain spreading sequence $C_{k}= [C_k[1], C_k[2], C_k[3] \ldots C_k[M]]^T$ of length M . Following F-domain spreading, each of the M branch signals modulates a sub carrier frequency using binary phase shift keying (BPSK). Then, the M numbers of subcarrier-modulated substreams are added in order to form the transmitted signal. Hence, the transmitted signal of user k can be expressed as

$$S_k(t)=\sqrt{\frac{2P_K}{M}}\sum_{m=1}^{M} b_k(t)a_k(t)c_k[m]\cos(w_m t), k=1,2,3....K \quad (1)$$

where P represents the transmitted power of each user and $\{w_m\}$, m=1,….,.M represents the subcarrier frequency set. The binary data stream's $b_k(t)$ waveform consists of a sequence of mutually independent rectangular pulses P_{Tb} of duration T_b and of amplitude +1 or -1 with equal probability. The spreading sequence $a_k(t)$ denotes the T-domain spreading sequence waveform of the user. By assuming the T-domain spreading factor $N=T_b/T_C$, represents the number of chips per bit-duration. It is assumed that the subcarrier signals are orthogonal and the spectral main-lobes of the sub carrier signals are not overlapping with each other. The received signal may be expressed as

$$r(t)=\sum_{k=1}^{K}\sqrt{\frac{2P_K}{M}}\sum_{m=1}^{M} b_k(t)a_k(t-t_k)c_k[m]g_{m,k}\times\cos(w_m t+\phi_{m,k})+n(t) \quad (2)$$

where n(t) represents the AWGN having zero mean and double-sided power spectral density of $N_0/2$. As shown in Fig.2 and Eq.(1), each TF-domain spread MC DS-CDMA signal is identified with the aid of two spreading sequences, one applied in the context of the T-domain.

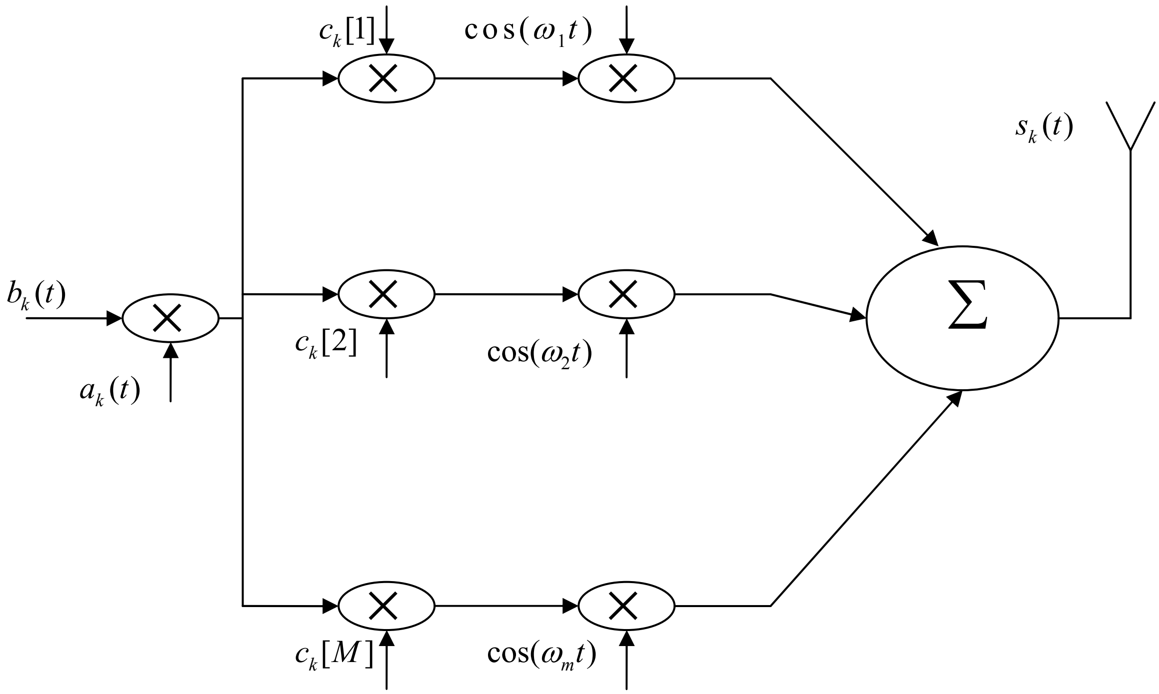

Fig 1: Transmitter model of MC DS-CDMA using both time domain and frequency-domain spreading.

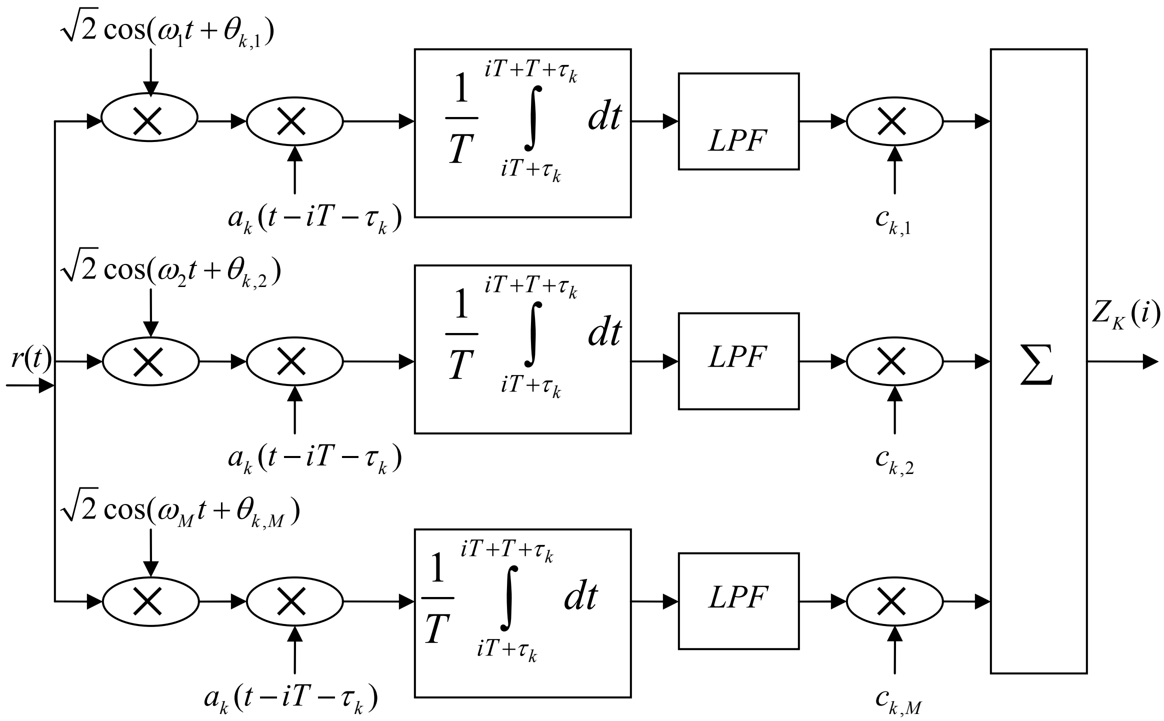

Fig 2: Receiver model of MC DS-CDMA using both time-domain and frequency domain spreading

3. PROPOSED CHAOTIC CODES

Chaos based communication systems qualify as broadband systems in which the natural spectrum of the information signal is spread over a very large bandwidth. This class of systems is called spread spectrum communication systems since they make use of a much higher bandwidth than that of the data bandwidth to transmit the information. Nowadays, pseudo-noise sequences such as Gold sequences and Walsh hadamard sequences are by far the most popular spreading sequences have good correlation properties, limited security and it can be reconstructed by linear regression attack for their short linear complexity [12]. A chaotic sequence generator can visit an infinite number of states in a deterministic manner and therefore produce a sequence which never repeats itself [14].

described by its discrete chaotic map can generate a very large number of distinct chaotic sequences, each sequence being uniquely specified by its initial value. This dependency on the initial state and the non-linear characteristic of the discrete map make the DS-CDMA system highly secure. A chaotic map is a dynamic discrete-time continuous-value equation that describes the relation between the present and next value of chaotic system. Let X_{n+1} and X_n be successive iterations of the output X and M is the forward transformation mapping function. The general form of multidimensional chaotic map is $X_{n+1} = M(X_n, X_{n-1} \ldots X_{n-m})$.
A simple logistic map is given in Eq.(3)

$$X_{n+1} = \mu X_n (1-X_n), 0 < X_n < 1, \text{and } 1 \le \mu \le 4 \quad (3)$$

where μ is the bifurcation parameter and the system exhibits a great variety of dynamics depending on the value of μ , ($3.6 \le \mu \le 4$).

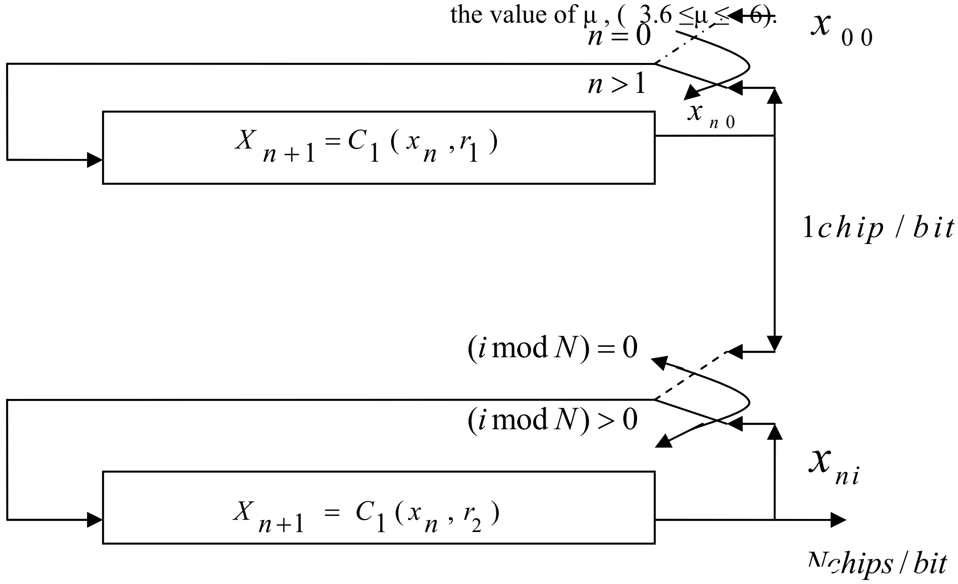

Fig. 3 Generation of chaotic sequences

The designer gets the flexibility in choosing the spreading gain as the sequences can be truncated to any length. Many authors have shown that chaotic spreading sequences can be used as an inexpensive alternative to the LFSR. However, the search for the best set of codes contributing reduced MAI is still one of the severe requirements of future MC-DS/CDMA systems**.** Generation of good set of sequences demands for large set dimension, period and limited privacy. To overcome these limitations, new chaotic spreading codes, is being used in this work. Instead of using other spreading codes in MC DS-CDMA, this chaotic code has produced good result in utility and reducing MAI. A single system

Using logistic map the chaotic spreading sequences for the DS/SS/BPSK system is generated. After assigning different initial condition to each user, the chaotic map is started with the initial condition of the intended receiver and iterated repeatedly to generate multiple codes. It is assumed that the transmitter and the intended receiver have agreed upon a starting point, x_{00} and two chaotic maps, $C_1(x, r_1)$ and $C_2(x, r_2)$ with their corresponding bifurcation parameters, r_1 and r_2. The chaotic maps and their bifurcation parameters may or may not be the same and their uniqueness among the different pairs of transmitters and receivers is not necessary. In Fig.3, x_{00} initiates a chaotic sequences $X_0 = \{x_{n0}: n = 0, 1, 2,\}$ through the chaotic map $C_1(x, r_1)$. The elements of this sequence are then used to generate the sequences $S_n = \{x_{ni}: i = 0, 1, 2...\}$, n = 0, 1, 2... through the chaotic map $C_2(x, r_2)$. The sequences S_n, so obtained are the spreading sequences to be used for each data bit. Note that the spreading sequence changes from one bit to another. The receiver regenerates the sequence S_n is exactly the same manner as the transmitter does. Every receiver will be assigned distinct x_{00}, $C_1(x, r_1)$, $C_2(x, r_2)$, r_1 and/or r_2, and therefore, the resulting spreading sequences for each receiver in a multiple-access communication system will be completely independent and uncorrelated.

4. PRICING STRATEGY TO INCREASE ENTIRE SYSTEM UTILITY

In the NPG, each terminal aims to maximize its own utility by adjusting its own power, but it ignores the cost (or harm) it imposes on other terminals by the interference it generates. The self-optimizing behaviour of an individual terminal is said to create an *externality* when it degrades the quality for every other terminal in the system. Among the many ways to deal with externalities, *pricing* (or taxation) has been used as an effective tool both by economists and researchers in the field of computer networks. Typically, pricing is motivated by two different objectives: 1) it generates revenue for the system and 2) it encourages players to use system resources more efficiently. Pricing does not refer to monetary incentives, but rather refers to a control signal to motivate users to adopt a *social* behavior. An efficient pricing mechanism makes decentralized decisions compatible with overall system efficiency by encouraging efficient sharing of resources rather than the aggressive competition of the purely non cooperative game. A pricing policy is called incentive compatible if pricing enforces a Nash equilibrium that improves social welfare. A social welfare is defined as the sum of utilities. In order to improve the equilibrium utilities of NPG in the Pareto sense, the usage-based pricing schemes has been introduced in [12].Through pricing, system performance can be increased by implicitly inducing cooperation and the noncooperative nature of the resulting power control solution had been maintained. An efficient pricing scheme should be tailored for the problem at hand. Within the context of a resource allocation problem for a wireless system, the resource being shared is the radio environment and the resource usage is determined by terminal's transmit power. Although the Nash equilibrium provides a self-optimizing power control solution for individual user, it is not necessarily the best operating point for the whole system. That is, there exist the other power solutions to make the utilities of all the users greater than those at the Nash equilibrium. In order to make efficient use of system resource, NPGP is introduced to force each user to efficiently share rather than aggressively approaches the system resource.

The utility function of user *k* for the MC-DS/CDMA is defined as the ratio of the total throughput over the total transmits power among all sub-carrier is given in Eq. (4)

$$u_k^M = \frac{L}{D} R_k \frac{f(\gamma_k)}{\sum_{m=1}^{M} P_{k,m}} \quad (4)$$

where *L* and *D* are the number of information bits and the number of bits in a packet, respectively, R_k is the transmission rate for user *k*, P_k is the transmit power of user *k,* and $f(\gamma_k)$ ε [0,1] is the efficiency function for the transmission of user *k* and monotonously increasing with γ_k. The utility function by means of pricing is reorganized in Eq. (5).

$$u_k^{MP}(t_j) = u_k^M(t_j) + g_k(t_j)\, p_k^{\lambda}(t_j) \quad (5)$$

where

$\mathbf{u_k^{MP}}$ is utility function with pricing

$\mathbf{u_k^{M}}$ is traditional utility function

$\mathbf{g_k}$ is set of updated instances for all the users

$\boldsymbol{P_k^{\lambda}}$ is transmitted power

In NPGP each terminal maximizes its net utility given by the difference between the utility function and pricing function. The class of pricing functions studied is linear in transmit power, where the pricing function is simply the product of a pricing factor and the transmit power. Such a pricing function allows easy implementation to the power control algorithm is realized by the base station announcing the pricing factor to all the users, which is followed by each terminal choosing the transmit power from its strategy space that maximizes its net utility

5. Numerical Results

For comparison of chaotic and Walsh spreading code, it is assumed that the number of information bits per frame L =64, while the total number of bits per frame D = 80; the transmission rate for each user R_K is assumed to be 10^5 *bits/s;* the total transmit power is limited by P_{max} = 6 W and P_{min} = 0.1 W.

The total utility for fifty users is compared in Fig.4 for Walsh Hadamard and chaotic code. From this figure, it is observed that, by employing Walsh code of length 64 bits yielded around 9×10^6 utility where as chaotic code yielded 10×10^6. This shows eight percent ballpark amelioration in the total utility has been achieved by the use of chaotic code. NPGP sets up certain cooperation among terminals via the pricing strategy, and each terminal tries to increase its own utility and reduces the interference to other users as well. Although Nash equilibriums are the best operating points to increase the traditional utility function μ^M_k, each player in NPG cares about its own utility, and may generate significant interference to other users. Therefore, considerable improvement is achieved by NPGP with chaotic sequence when many users are active, circumventing MAI

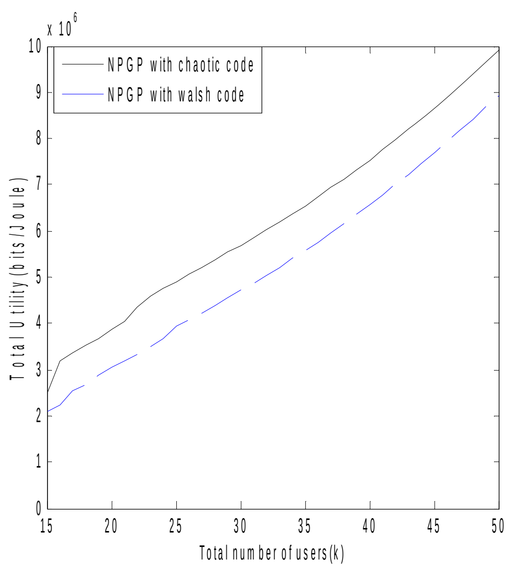

Fig.4. Total utility vs total number of users K

The total utility for chaotic and Walsh code is compared in figs.5 and 6 by varying the noise power from 10^{-6} to 10^{-2} . From this figure, it is observed that, when noise power is around 10^{-3} the utility start to drastically decrease due to increase in noise power. But there is a remarkable improvement in utility factor by using chaotic code when the noise power levels increases. Hence chaotic code outperforms by 9% when compared Walsh hadmard code in term of utility factor. Thus, the chaotic code is an excellent candidate for mitigating MAI, which in turn contribute for the amelioration of the system capacity. Furthermore, when the noise power at the receiver side increases, the SNR (γ_k) and the efficiency function $f(\gamma_k)$ decreases. Thus, fewer utility is obtained with increase in σ^2_N. When the noise power is limited to 10^{-4} , the utility factor is appreciable. On the other hand, when noise power increases, the efficiency function $f(\gamma_k)$ decreases significantly. When $\sigma^2_N > 10^{-3}$, total utility drops more drastically for conventional NPGP, than proposed NPGP with chaotic sequences. This is due to the fact that the terminals in the modified NPGP carefully manage the transmit power to increase individual utility and combat MAI as well, since modified NPGP can tolerate higher noise power than conventional NPGP.

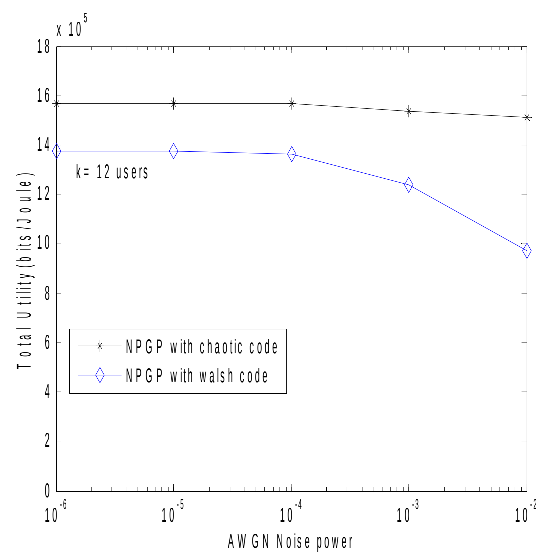

Fig.5. Total utility vs AWGN noise power

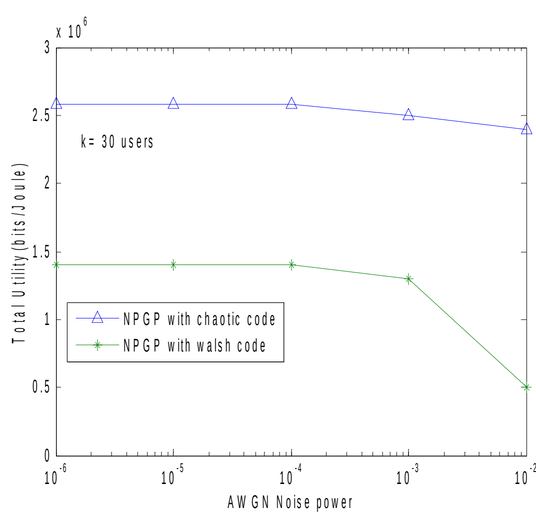

Fig.6. Total utility vs AWGN noise power

6. Conclusion

The proposed NPGP algorithm with chaotic spreading codes performs effectively by reducing the MAI in MC DS-CDMA system. The application of chaotic codes performs better in the system than the classical codes in terms of exterminating MAI. Care has been taken to drastically minimize the interference factor in MC DS-CDMA systems through the spreading of chaotic codes. When the system is occupied by large number of users, it is observed that by initializing chaotic spreading code, the utility performance is improved compared to the traditional NPGP.

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