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Adaptive Multi User Detection for FD-MC-CDMA in Presence of CFO

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Abstract

The main targets of multi-carrier direct sequence code division multiple access (MC-DS-CDMA) mobile communication systems are to overcome the multi-path fading influences as well as the near-far effect and to increase its capacity. Different types of optimal and suboptimal multi-user detection schemes have been proposed and analyzed in literature. Unfortunately, most of them share the drawback of requiring an efficient practical solution. Genetic algorithm provides a more robust and efficient approach for solving complex real world problem such as multi user detection, but genetic algorithms are not computationally efficient. Computational complexity and performance of the genetic algorithms depends on number of generations and/or the population size, schemes involving genetic algorithms would compromise in computational complexity or performance. In this paper we propose adaptive population sizing genetic algorithm based multi user detection algorithm and compare its performance with existing multi user detection algorithms in various channels. Simulation results confirmed that the proposed adaptive genetic algorithm assisted multi user detection algorithm performs better compared to the existing multi user detection algorithms.

Index Terms: Frequency division-Multicarrier CDMA (FD- MC-CDMA), Multiuser detection, Carrier Frequency Offset (CFO), Fuzzy logic based Adaptive genetic algorithm.

1. Introduction

Code-Division Multiple Access (CDMA) is one of several methods of multiplexing that has taken a significant role in cellular and personal communications. Multicarrier CDMA (MC-CDMA) provides good probability-of-error performance in frequency selective fading channels. Specifically, high diversity gains are achieved by allowing transmitters to send information on N multiple carriers simultaneously and using receivers that separate the signal into carrier components to exploit frequency diversity. However, MC-CDMA experiences performance degradation due to MAI (multi access interference) caused by up to $N-1$ active users sharing the same N carriers. Typically, the performance of the MC-CDMA system is limited by the

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presence of MAI. Due to multiple-access interference (MAI), this single-user detection strategy creates a problem, called the near–far problem: the performance drops when the power of the transmitting users is dissimilar. Thus, Multi user Detection is required for cancellation of MAI to increase the performance of the MC-CDMA system. FD-MC-CDMA (Frequency Division Multicarrier CDMA) proposed in [1] simultaneously exploits frequency diversity and minimize MAI.

Various multi-user detectors (MUD) have been developed and analyzed for this proposed MC-CDMA systems [2, 3, 4, 6, 7, 8, 9]. Multi user detectors may be optimal or sub-optimal. The computational complexity of the optimal ML (maximum likelihood) MUD (multi-user detector) proposed in [20, 21] increases exponentially with the number of user and the length of the bit sequence, thus making it infeasible for implementing in practical systems.

To reduce complexity in implementation, two different suboptimal methods for MUD emerged, and they had been proved to have much lower complexity than the optimum multi-user detector. They are interference cancellation (IC) and adaptive filtering. In [12] Successive interference cancellation methods for multicarrier DS/CDMA are proposed. In [13, 14, 15, 16] various optimal and suboptimal methods for MUD are described. In [17, 18] performance of MUD methods in rapidly fading channels is given. In [19] computationally efficient adaptive MMSE receiver for synchronous MC-CDMA communication systems is proposed. The minimum mean square error (MMSE) multi-user detection is described in [20, 21, 22, 23, 24], while an interference cancellation based MUD has been proposed in [25, 26, 27, 28]. The IC techniques can be broadly broken into serial and parallel schemes for canceling MAI. Unfortunately, when in heavy system load, the multistage conventional PIC (CPIC) detector suffers performance degradation due to a poor cancellation, which is brought about by the relatively high error rate of bit decisions in the preceding stage [28].

Evolutionary computation has inspired new resources for optimization problem solving, such as the optimal design of code division multiple access (CDMA) and fuzzy system. In contrast to traditional computation systems which may be good at accurate and exact computation but have brittle operations, evolutionary computation provides a more robust and efficient approach for solving complex real world problem. Many evolutionary algorithms, such as Genetic algorithm (GA) [5, 9, 10, 11, 22, 23, 25, 26], ant colony optimization (ACO) [27], simulated annealing (SA) [28]. This paper is organized as follows in *section 2* introduces FD-MC-CDMA model and ML estimation of Multi User Detector. In *section 3* Adaptive Genetic Algorithm based ML estimation of MUD is presented. In *section 4* simulation results using Fuzzy logic and in *section 5* comparison of proposed MUD algorithm with existing MUD algorithms in various channels is given. In *section 6* papers is concluded.

2. FD-MC-CDMA System model

In a traditional MC-CDMA system, at the transmitter the *k*th user's transmission can be given as

$$S^{(k)}(t) = b^{(k)}c^{(k)}(t) \tag{1}$$

Where $b^{(k)}$ is k's user information symbol and $c^{(k)}(t)$ is k's user spreading code, which in MC-CDMA refers to

$$C^{(k)}(t) = \sum_{i=1}^{N} \beta_i^{(k)} e^{j2\pi i\Delta f t} g(t) \tag{2}$$

Where, N is the total number of narrowband carriers in the MC-CDMA, $\beta_i^{(k)}$ is the i th value in user k's spreading sequence, $i\Delta f$ is the frequency position of the i^{th} carrier component, T_s is symbol duration, to ensure carrier orthogonality. $g(t)$ is a rectangular waveform of unity height which time limits the code to one symbol duration T_s. Fading channels in spread spectrum wireless systems demonstrate an M-fold frequency which can be given by

$$BW = M.(\Delta f)c \tag{3}$$

Where BW is the bandwidth of the MC-CDMA transmission and $(\Delta f)c$ is the coherence bandwidth of the frequency selective fading channel. As proposed in [1] to build a multiple access system exploiting the available M folds diversity while minimizing MAI at the same time, rather than allowing all users to share all the N carriers, small sets of M users sharing sets of M carriers via MC-CDMA are given

Assuming $N/M \in I$, assuming $M = 2^m$

$$\beta_i^{(k)} = \begin{cases} \pm 1,..i \in I_1^{(k)}, I_2^{(k)},...I_m^{(k)} \\ 0, otherwise \end{cases} \tag{4}$$

where $I_1^{(k)} = [(k-1)/M]+1, I_2^{(k)} = [(k-1)/M]+N/M+1,.. I_m^{(k)} = [(k-1)/M]+(m-1)N/M+1$

$\lfloor x \rfloor$ represents the closest integer less than or equal to x. A total of $N/M = 2^{n-m}$ *sets of* $M = 2^m$ carriers are used concurrently to maintain the total capacity of the system. Different sets of M carriers are frequency division multiplexed such that the M users residing on one set do not interfere with the M users on another set.

The received signal at the receiver can be given as

$$r(t) = \sum_{k=1}^{K} b^{(k)} \operatorname{Re} \times [\sum_{i=1}^{N} \alpha_i \beta_i^{(k)} e^{j(2\pi f_{cc} t + 2\pi i \Delta f t + \varphi_i)}] g(t) + \eta(t) \tag{5}$$

where K is the total number of users occupying the system, α_i is the gain, φ_i is the phase offset in the i^{th} carrier due to the channel fade, and $\eta(t)$ represents additive white Gaussian noise. The received signal is first decomposed into its M information-bearing carriers and dispread by user 1's spreading code. Eq(5) can also be given as

$$r(t) = \sum_{i=-\infty}^{\infty} \sum_{k=1}^{k} \sqrt{\frac{2E_{bk}}{M}} c_{k,m}(t - iT_b) \gamma_{k,m} b_k^{(i)} e^{(j\omega_m t + \varphi_{k,m})}$$

The i^{th} carrier generates the decision variable which is given as

$$r_i^{(1)} = \alpha_i b^{(1)} + \alpha_i \sum_{k \in U_{1k} \neq 1} b^{(k)} \beta_i^{(k)} \beta_i^{(1)} \tag{6}$$

$$i \in I_1^1, I_2^1, ... I_M^1$$

where $U1$ is the set of up to M active users in user 1's carrier set, and $\eta(i)$ is a Gaussian random variable with mean zero and variance $\sigma_n^2 = N_0/2$. An optimal combining strategy is used to combine all M carriers in user 1's set to best exploit frequency diversity and minimize MAI.

3. Multiuser Detection Using Genetic Algorithm

Genetic Algorithm (GA) is a famous probabilistic search technique based on the principles of biological evolution. Similar to biological organism which evolves to adapt to its environment, Genetic Algorithm follows a path of analysis from which a design evolves, one that is optimal for the environmental restrictions placed upon it. Genetic Algorithm uses probabilistic transition rules to select someone to reproduce or to die so as to guide their search toward regions of the search space with likely improvement. Thus, Genetic Algorithm is a powerful and globally stochastic search and optimization technique and is widely used in optimization problems.

Table1. Basic Simulation Parameters used by GA Assisted MUD

Parameters	Value
Modulation Scheme	BPSK
Spreading Code	WALSH
No. of Subcarriers	16
Processing gain	32
GA selection method	Fitness based
GA crossover	Uniform crossover
GA Mutation probability	0.1
GA Crossover probability	1
Elitism	yes

To accomplish this we propose a Maximum Likelihood Multiuser Detector Using Genetic algorithm to enhance the performance of detector compared with existing Maximum Likelihood Multiuser Detectors. Equation (5) can be given as

$$r_m(t) = \sum_{i=-\infty}^{\infty} \sum_{k=1}^{k} \sqrt{\frac{2E_{bk}}{M}} c_{k,m}(t - iT_b) \gamma_{k,m} b_k^{(i)} e^{(j\omega_m t + \varphi_{k,m})} \tag{7}$$

where ***k*** is the number of users supported and *n(t)* is the Gaussian noise process with a variance of $N_0/2$. Where the amplitude $\gamma_{k,m}$ is a Rayleigh distributed random variable. while the phase $\phi_{k,m}$ is uniformly distributed between $(0,2\pi)$. E_{bk} is the kth user's signal energy per bit. $c_{k,m}$ Is signature waveform used for spreading the hits to N chips in the time-domain. T_c is the chip duration. *N* is the number of chips per hit associated with each subcarrier and $T_b/T_c = N$. *T*he total processing gain is *NM.* It is more convenient to express the associated signals in matrix and vector format, when the sum of the transmitted signals of all users can be expressed as

$$r_m(t) = C_m W_m A b + n \tag{8}$$

Where

$$C_m = [C_{1,m}(t), C_{2,m}(t), ...C_{1,r}(t), ...C_{k-1,m}(t), C_{k,m}(t)]$$

$$W_1 = diag[\gamma_{1,m}e^{j\varphi 1,m}, \gamma_{2,m}e^{j\varphi 2,m}, ..., \gamma_{r,m}e^{j\varphi r,m}, ..., \gamma_{k,m}e^{j\varphi k,m}]$$

$$A = diag[\sqrt{\frac{2E_{b1}}{M}}, ...\sqrt{\frac{2E_{bk}}{M}}]$$

$$b = [b_1.....b_k]^T \quad \text{and} \quad n = [n_1....n_k]^T$$

The optimum multiuser detector of the mth subcarrier will maximize the following objective function

$$\Omega_m(b) = 2R_e[b^T AW^*{}_m Z_m] - b^T AW_m R_m W^*{}_m Ab \tag{9}$$

Where * indicates complex conjugate of a matrix. The objective function to he maximized for optimum multiuser detection in MC-CDMA system can be given as

$$\Omega(b) = \sum_{m=1}^{M} \Omega_m(b) = \{2\,\mathrm{Re}[b^T AW_m^* Z_m] - b^T AW_m R_m W_m^* Ab\} \tag{10}$$

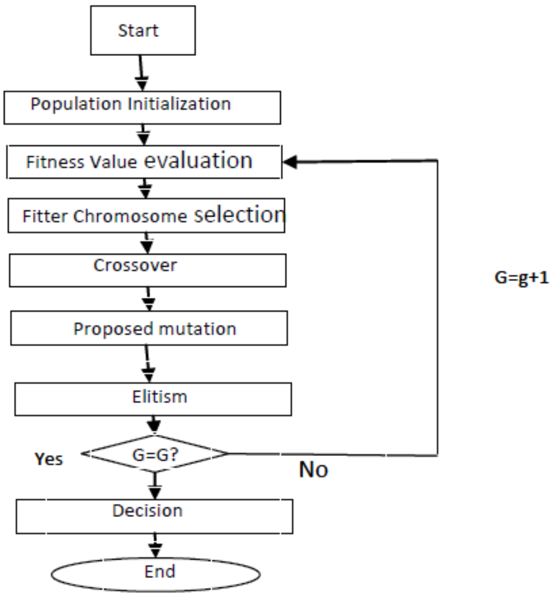

Fig.1. Flow chart of the proposed Genetic Algorithm assisted Multiuser detection scheme

The steps involved in implementing Multiuser detection using genetic algorithm is described below.

Step 1. Start with encoding

To start Genetic Algorithm, the trial data vector $\hat{b}$ must first be encoded into binary string form. The encoded binary string is regarded as a chromosome in Genetic Algorithm and its elements are regarded as genes. Thus, the MUD can be treated as a multi-objective optimization solution that finds the most likely combination of the binary bits. Without loss of generality, BPSK modulation has already been employed in the transmission model. Thus, the chromosome encoding procedure is unnecessary. The number of genes in a chromosome, which is the number of bits in a trial data vector for BPSK, is the number of users. If the transmission signals are modulated by QPSK, namely two bits per symbol, the chromosome must have two bit genes. In general, the number of bits in a symbol is equal to the number of bits in a gene.

Step 2. Population initialization

After encoding, an initial population consisting of *P* members, called individuals, is created. In our proposed Genetic Algorithm, each individual or chromosome in the population is represented by a vector including *K* bits. In the vector, each bit is a trial data belonging to one of the *K* users. The p^{th} individual which is the estimated value of $b = [b1, b2, ..., b_k]^T$ in Eq. (1) is defined as

$$\hat{b}_p^{(g)} = [\hat{b}_{1,p}^{(g)}, \hat{b}_{2,p}^{(g)}, ..., \hat{b}_{3,p}^{(g)}]^T, \quad p = 1,2,3,4,...P \tag{11}$$

where superscript g (g=1, 2, …, G) denotes the g^{th} generation and $\hat{b}_{k,p}^{(g)}$ denotes the k^{th} (k=1, 2, …, K) gene of the p^{th} individual at the g^{th} generation. After initialization of the population of *P* individuals the optimization process starts, in which the initial generation g is 1.

Step 3. Fitness evaluation

In the procedure of this fitness evaluation, Genetic Algorithm exploits an objective function (OF) to evaluate the fitness of each individual in the population, which represents how closely each individual matches the optimum individual. The optimum individual can maximize the objective function value. We will now discuss how to find the objective function. The solution of optimum detection is the most likely trial data vector $\hat{b}_{opt}$ is to choose the specific K-user bit combination b, which maximizes the metric of Eq (10).

$$\text{Hence } \hat{b}_{opt} = \arg\{\overset{\max}{b}[\Omega(b)]\} \tag{12}$$

Step 4. Selection

To evolve the population, some excellent individuals will be chosen to constitute a next population for reproduction. The fitter individuals with better genes are more likely to be selected to produce the descendant individuals. So, the rule of selection is based on their fitness or objective function values. The selection probability of the p^{th} individual is given by

$$P_P = \frac{\Omega(b_P{}^{(g)}) - \hat{\Omega}_W{}^{(g)} + 1}{\sum_{P-1}^{P} (\Omega(b_P{}^{(g)}) - \hat{\Omega}_W^{(g)} + 1)} \tag{13}$$

where $\Omega(b_P^{(g)})$ the objective is function value of the p^{th} individual at the g^{th} generation and $\Omega_W^{(g)}$ is the worst objective function value at the g^{th} generation.

Step 5. Crossover

Crossover is the operation by which the selected individuals exchange their genes to produce pairs of descendants. The crossover operation randomly chooses one cutting point or many cutting points and exchanges the binary strings of individuals before or after the cutting points. For example, after a cut in the first bit in each of the two strings 0011 and 1010, these two strings are crossed over to produce a new pair of descendants 0010 and 1011. Since the offspring inherit the merits of their parents, they are expected to be superior to their parents.

Step 6. Mutation

Mutation is the proposed complementary error function to increase the diversity of the population, this mutation operation randomly changes some of the crossover result genes. Without mutation, the GA's search falls into local optima. Thus, the mutation operation is crucial to the success of Genetic Algorithm. A mutation probability $p_m^{(i,j)}$ which is relative to a signal-to-noise ratio (SNR) from *i* to *j* is defined. It can be calculated with the help of a complementary error function which can be given by.

$$erfc(x) = \frac{2}{\sqrt{\pi}} \int_{x}^{\infty} e^{-t^2} dt, x \geq 0 \tag{14}$$

Step 7. Elitism

An elitism operation is used to avoid losing excellent individuals which have higher fitness or greater OF values from one generation to another. The operation copies a small part of the best parent individuals, and replaces the worst offspring.

4. Fuzzy Logic Based Adaptive Population Sizing Genetic Algorithm

Genetic Algorithm is convergent, but the degree of convergence depends on the number of generations *G* and/or the population size *P* [37]. As given in [34], if *P* and/or *G* are sufficiently large, our proposed Genetic Algorithm based Multi User Detection approaches the optimum maximum likelihood detection results. However, increasing *P* increases the computational complexity of the Multi User Detection system. Fixed population sizing genetic algorithm assisted schemes either compromise in computational complexity or performance. In this paper we propose fuzzy logic based adaptive population sizing genetic algorithm assisted MUD algorithm in order to achieve optimum performance with acceptable computational complexity. Figure.1 shows BER performance of GA assisted MUD for generations 10, 20 and 30. It is shown clearly that the BER performance improves with increase of number of generations. In figure 2 computational complexity of GA assisted MUD for generations 10, 20 and 30 is shown. It can be observed clearly that computational complexity increases with number of generations.

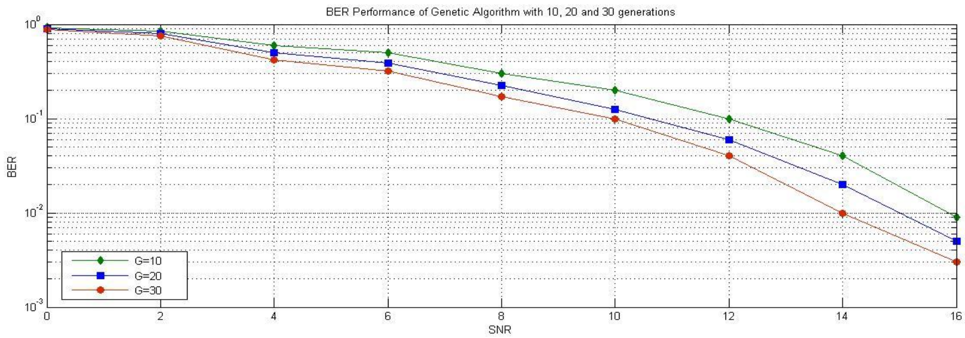

Fig.2. BER performance of GA assisted MUD for 10,20 and 30 generations

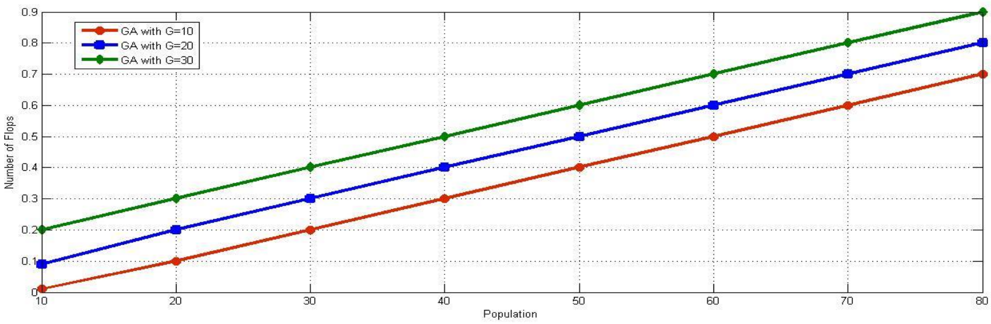

Fig .3 BER Computational complexity of GA assisted MUD for 10, 20 and 30 generations

In conventional GA assisted multi user detectors number of generations is fixed, so GA assisted multi user detectors should compromise in performance or computational complexity. In this paper we proposed adaptive population/Generation sizing genetic algorithm assisted MUD scheme where adaptive population/Generation size is adjusted based on SNR. In the proposed scheme at the receiver non data aided SNR detector proposed in [9] is utilized to estimate SNR in block fading channel. Based on present SNR and present size of population/generation a fuzzy controller is used to estimate the size of population/generations to be employed as shown in fig. 3. In fig 4, membership functions of output estimate of size of population/generations is shown and in Fig.5 membership functions of input size of present population/ generations. In the proposed scheme fuzzy controller is used to estimate the size of population/generations adaptively based on present SNR in block fading channel.

Fig .4. Fuzzy Controller Input and Output Variables

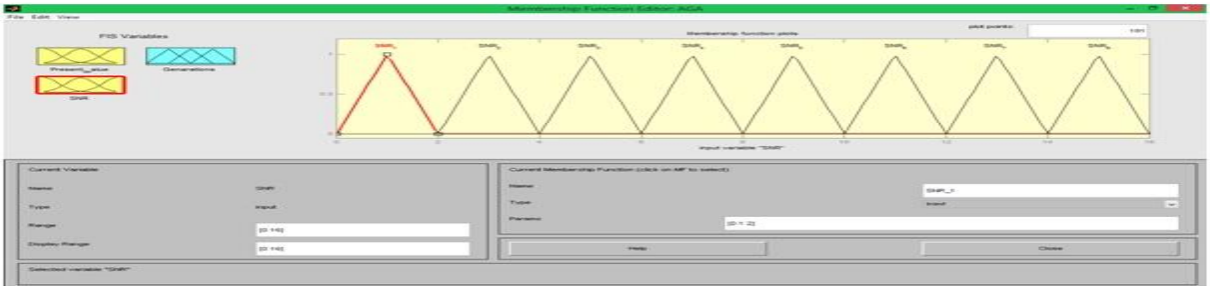

Fig 5. Membership functions of input estimated SNR

5. Simulation Results

The proposed AGA assisted MUD scheme is simulated in MATLAB and its performance is compared with existing MUD schemes in Rayleigh fading channel. The parameters used in simulation are listed in table 1. The following Fig 6, and Fig7 s hows the comparison of proposed AGA assisted MUD with existing schemes like GA assisted MUD with 10, 20 and 30 generations respectively in PIC and SIC in Rayleigh fading channel. Simulation results confirmed that the proposed AGA assisted MUD scheme performs better compared to existed MUD schemes in AWGN and Rayleigh fading channels. Further complexity of proposed AGA assisted MUD is compared with GA assisted MUD with 10, 20 and 30 generations. Complexity of the proposed AGA assisted MUD scheme varies adaptively with SNR of the channel. Keeping in mind good performance and acceptable computational complexity, proposed AGA assisted MUD scheme proved better compared to existing MUD schemes.

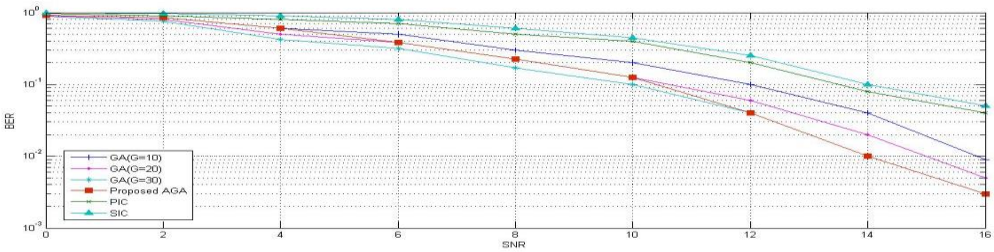

Fig 6. Comparison of BER performance of proposed AGA assisted MUD with existing schemes

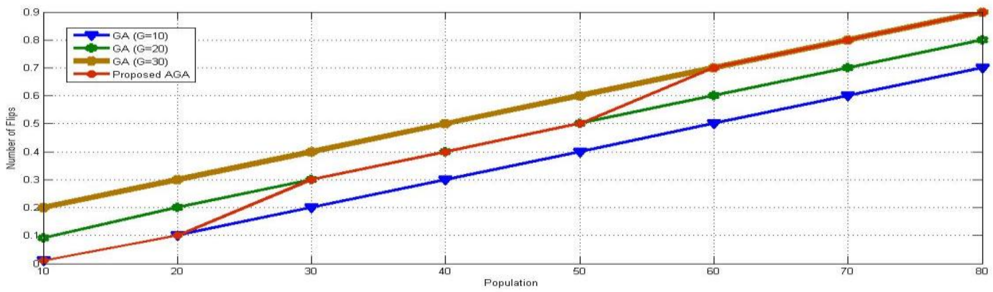

Fig 7. Comparison of computational complexity of proposed AGA with Assisted MUD with existing schemes

6. Conclusion

In conventional GA assisted multi user detectors size of population/number of generations is fixed, so GA assisted multi user detectors should compromise in performance or computational complexity. In this paper we proposed AGA assisted MUD scheme for FC-MC-CDMA system where the size of population/number of generations is changed adaptively. The proposed scheme is simulated in MATALAB and its performance and computational complexity is compared with existing MUD schemes in Rayleigh fading channel. Simulation results confirmed that the proposed AGA assisted MUD scheme outperformed existing MUD schemes.

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