

# Maximal Simultaneous Users Code Set Selection in FO-CDMA using Genetic Algorithm

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**Abstract**—In this paper we propose a solution to find the maximal simultaneous users code set by genetic algorithm. By this methodology, the code set can be exactly selected which is error free. Besides, the computing time for this methodology is much faster than the heuristic solution as the prime number  $P$  is larger than 5.

## I. INTRODUCTION

Techniques of fiber-optic code division multiple access (FO-CDMA) has been proposed by various authors recently [1][2]. Many classes of binary signature sequence have been studied and the prime code was identified as a suitable candidate for FO-CDMA. Moreover, synchronous code division multiple access (S/CDMA) and the modified prime code have been investigated in [3] to improve the capacity. Many papers [3][4] analyze the performance of S/CDMA in terms of the error probability without finding the exact maximal simultaneous users code set. This paper is the first time to propose the efficiently algorithm to find the simultaneous users capacity code set. If we use the heuristic solution to find the maximal simultaneous users, we need to spend a lot of time. Genetic algorithm (GA) has recently been used as robust stochastic searching algorithms for various optimization problems, such as multiprocessor scheduling [6], topology design and bandwidth allocation [7] and channel allocation [8]. Therefore, we use GA to find the maximal simultaneous users code set for the prime code and make sure these codes are error free.

The rest of the paper is organized into six sections. The short description of the modified prime code in S/CDMA will be in Section II. In Section III, we introduce the fundamentals of GA and the maximal simultaneous users code set selection of modified prime code in section IV. We analyze the computing time needed by GA and heuristic solution in section V. Finally, some results will be in Section VI and the conclusion is given in Section VII.

## II. MODIFIED PRIME CODE IN FO-S/CDMA

In FO-CDMA, each data bit 1 is encoded in to a waveform  $s(n)$ , consisting of a code sequence of  $N$  chips, which represent the destination address of that bit. Data bits 0 are not encoded. The receiver correlate its own address  $f(n)$  with the received signal  $s(n)$ . The receiver output  $r(n)$  is

$$r(n) = \sum_{k=1}^N s(k)f(k-n) \quad (1)$$

If the signal has arrived at the correct destination, then  $s(n) = f(n)$ , and (1) represents an auto-correlation function; otherwise  $s(n) \neq f(n)$ , and (1) represents a cross-correlation function. At each receiver, it is necessary to maximize the auto-correlation and minimize the cross-correlation function to optimize the performance.

Many classes of binary signature sequence have been studied. The prime code and modified prime code [3] were identified as a suitable candidate for CDMA and S/CDMA, respectively. In modified prime codes, the number of subscriber is equal to  $P^2$ , where  $P$  is a prime number; and the length of the sequence is also equal to  $P^2$ . The code set of the modified prime sequence for  $P=3$  is in Table I.

## III. FUNDAMENTALS OF GENETIC ALGORITHM

Genetic algorithm, first specified by John Holland [5] in the early seventies, is becoming an important tool in machine learning and function optimization. Unlike other optimal methods that follows only one search path at one time, the GA searches through several paths simultaneously and the convergence rate is faster. This algorithm initially generates a set of random solutions known as *population*. Each individual solution in the population is called a *chromosome*. Each chromosome represents a feasible solution by a

sequence of binary or real numbers known as *genes*. Through an evolution process, a new *generation* of chromosomes replaces the current population. The new population consists of the new generated chromosomes known as *offspring* which are generated by three genetic operators *reproduction*, *crossover* and *mutation*. Reproduction operation forms a new population by selecting chromosomes from the old population according to its *fitness value*. The fitness value indicates the quality of the chromosome which is evaluated by the *fitness function*. Chromosomes with higher fitness value would have a higher chance of surviving to the new generation. The crossover operation merges two parent chromosomes and forms two new chromosomes. Mutation modified one or more genes of the selected chromosomes. After the three genetic operations, a new population will be generated to the next generation. This evolutionary process continues until either a limited number of generations reaches or no more better chromosomes will be generated.

#### IV. MAXIMAL SIMULTANEOUS USERS CODE SET SELECTION USING GA

In this section, we use GA to select the maximal simultaneous users and the least interference code set of the prime code. Our algorithm is shown in *Fig. 1*.

##### A. Definition

In this paper, we use the binary string as a chromosome to represent the code selection. Each string is consisted of  $P^2$  bits. '1' and '0' represents the corresponding code to be selected or not, respectively. Taking  $P=3$  as example, a solution may be as 010001010 to represent the used codes as  $\{C_{01}, C_{12}, C_{21}\}$ .

##### B. Initialization

Initialization of the GA, we need to randomly generate an initial population and the number of chromosomes in the population is *population size*. In each chromosome, we randomly select one code from each group. Therefore, every chromosome uses the number of  $P$  codes in the initial state.

##### C. Evaluate the Fitness Value

In our algorithm, the fitness function is 130.

defined as

$$S \times (N^2 + (P - V)) + (1 - S) \times P \quad (2)$$

where the parameter  $S$  is equal to 1 or 0 determined by whether these codes can be used simultaneously or not.  $N$  is the total number of selected codes in this chromosome.  $V$  is the interference between these codes in this chromosome and  $P$  is the prime number. That is, the solution for selected code set can be used simultaneously, with the fitness value to be  $N^2 + (P - V)$ . Otherwise, its fitness value is  $P$ .

In order to provide the codes are error free, we utilize the worse case design rule. In the code set, only one user transmits '0' and all the other users transmit '1'. Then we verify the only corresponding receiver must decode the signal to be '0' and each user should be chosen alternately to be the only user which transmit '0'. If all codes in this code set satisfied the decision rule, the code set can be used simultaneously. Moreover, the interference  $V$  is the average cross-correlation value in these codes.

##### D. Reproduction

We use the roulette wheel parent selection to implement the reproduction where each chromosome in the population occupies a slot size proportional to its fitness value. And then we generate a random number to determine which chromosome will be selected to the new population. Because chromosomes with higher fitness value will have large slots, they have larger opportunity to be selected. To improve the performance, we make a slight modification by always passing the best chromosome from current population to the new population.

##### E. Crossover

We use the uniform crossover in the algorithm. First, we randomly generate a  $P^2$  bits mask array which composes of '1' and '0'. Secondly, we randomly select two chromosomes from the new population after reproduction and cross with the *crossover probability*. If the crossover is performed, the two chromosomes must exchange their bit information under the

condition that the bit in the mask array is '1', as shown in Fig.2.

#### F. Mutation

Each chromosome in the new population mutates with the *mutation probability*. If the mutation is performed, we randomly inverse one bit in this chromosome such as shown in Fig 3.

### V. ANALYSIS

We utilize the GA to obtain the maximal simultaneous users instead of the heuristic solution. Their corresponding computing time can be expressed by (3) for GA and (4) for the heuristic solution, respectively.

$$(POP \times DT + GT) \times Gen \quad (3)$$

$$\sum_{K=P}^{P_{max}} C_K^{P2} \times DT \quad (4)$$

where *POP* is the population size, *DT* is the computing time for determining simultaneous codes, *GT* is the computing time for the genetic operations per generation, *Gen* is the maximal generations of the algorithm, and  $P_{max}$  is maximal simultaneous users.

The *DT* is about 60ns and the *GT* is about 1ms in the case of  $P=5$  by the PC based on Pentium-Pro 200. In the Fig.4, we have shown the computing time by these two solutions versus *P* as  $POP=20$  and  $Gen=4000$ . When *P* is smaller, the heuristic solution may be better than GA. As the number of *P* increases, the difference between these two solutions increases dramatically. Although with the increase of *P*, the *DT* and *GT* will increase slightly, the difference is still very large.

### VI. RESULTS

In this paper, we use the following parameters in the algorithm:

- population size = 20
- crossover probability = 0.8
- mutation probability = 0.15
- maximum number of iteration = 4000

In the Fig.5, we display the results using GA to find the maximal simultaneous users versus prime number. Besides, we also compare the analysis results from [4] in the same figure. These two lines indicate the simultaneous users with optical hard-limiter for both coded and uncoded ( $BER \leq 10^{-9}$ ). Taking  $P=7$  as example, the simultaneous users in [4] is about 7 (uncoded) and

9 (coded), but the number is 18 by GA. Moreover, we have shown the exactly maximal simultaneous code set as  $P=3,5,7$  in TableII.

In the Fig.6, we have shown the maximal simultaneous users of chromosomes in each generation. The convergence rate is slower as the number of *P* increases. From the results in the Fig.6, the  $P=11$  and 23 converge at 150 and 2500 generations, respectively. However, as  $P=31$  the algorithm converges more than 4000 generations.

### VII. CONCLUSION

In this paper, we propose a genetic algorithm (GA) to find the maximal simultaneous users in FO-CDMA. By GA, we can obtain more simultaneous users code set than the other papers [3][4] and we can guarantee these codes to be error free. In our analysis, the computing time for GA is much faster than the heuristic solution. Moreover, we can exactly obtain the exact code set and the convergence rate about *P*.

### ACKNOWLEDGMENT

This work was support by the National Science Council, Taiwan, R.O.C., under Contract NSC-88-2215-E-032-003

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Table I Modified Prime Code Sequence for P = 3

Group	Code Sequences
0	$C_{0,0}=100\ 100\ 100$
	$C_{0,1}=001\ 001\ 001$
	$C_{0,2}=010\ 010\ 010$
1	$C_{1,0}=100\ 010\ 001$
	$C_{1,1}=010\ 001\ 100$
	$C_{1,2}=001\ 100\ 010$
2	$C_{2,0}=100\ 001\ 010$
	$C_{2,1}=001\ 010\ 100$
	$C_{2,2}=010\ 100\ 001$

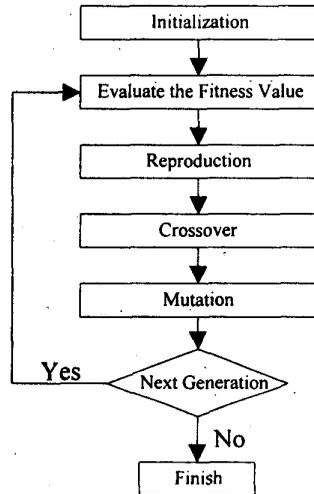


Figure 1. Genetic Algorithm

Before Crossover      After Crossover  
 String1: 110000100      010000100  
 Mask: 101101101      101101101  
 String2: 010000110      110000110

Figure 2. Crossover

Before Mutation      After Mutation  
 String1: 110000100      110001100

Figure 3. Mutation

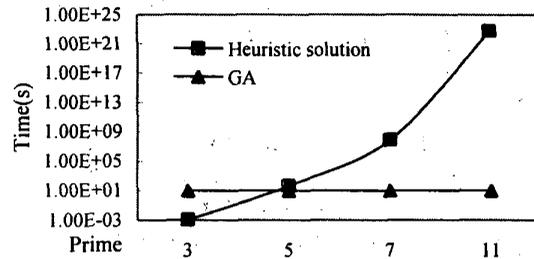


Figure 4. The comparison of two solutions' needed time

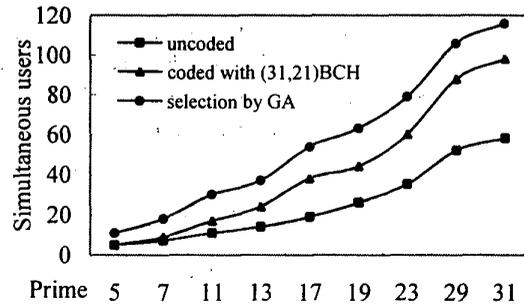


Figure 5. The comparison of simultaneous users versus prime number with hard-limiter for different cases

Table II Maximal simultaneous users code set

P	Uncoded	Coded	GA	Code set selected by GA
3	—	—	5	$C_{00}, C_{01}, C_{10}, C_{20}, C_{22}$
5	5	5	11	$C_{01}, C_{02}, C_{12}, C_{13}, C_{20}, C_{22}, C_{24}, C_{30}, C_{32}, C_{40}, C_{41}$
7	7	9	18	$C_{00}, C_{02}, C_{06}, C_{11}, C_{15}, C_{20}, C_{26}, C_{30}, C_{32}, C_{33}, C_{40}, C_{42}, C_{51}, C_{52}, C_{56}, C_{63}, C_{65}, C_{66}$

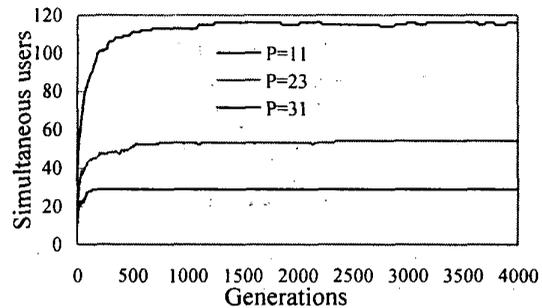


Figure 6. Simultaneous users obtained by GA at different generation