Generation of Spreading Codes with Minimum Correlation using Sorting Genetic Algorithm-II

Shibashis Pradhan, Deepak Kumar Barik, M Vamshi Krishna, Sujatarani Raut

***Abstract:** In a code division multiple access (CDMA) system, multiple access interference (MAI) and Inter-symbol interference (ISI) appears if generated spreading codes are not maintained orthogonally and the communication channel is taken as multi-path communication channel. When generated spreading codes are multi-path spread and then channel delay occurs, it shows that ortho-gonality of the spreading codes is not maintained. The effect of MAI can be mitigated by maintaining low cross-correlation values as much as low between the large numbers of spreading codes. The code division multiple technique spreading codes must maintain absolutely impulsive autocorrelation at origin and very low cross correlation other than origin to avoid false synchronisation. i.e autocorrelation must be maximum at origin and cross correlation must be minimum at non origin point. In this paper, we propose multi-objective Genetic Algorithm approach –Genetic Algorithm-II (NSGA-II) to reduce the out-of-phase average mean-square aperiodic autocorrelation and average mean-square aperiodic cross-correlation value of randomly initialized binary spreading code set.*

***Index Terms:** Inter symbol interference (ISI), multiple access interference (MAI), code division multiple access (CDMA), Non-dominated Sorting Genetic Algorithm-II (NSGA-II)*

I. INTRODUCTION

The advantage of Code Division Multiple Access (CDMA) is universal frequency reuse [1] which makes it preferred in Wireless Communication system. In CDMA mobile communication system, the performance is predominantly based on the feature of the unique spreading codes. . These codes spread the original signal to a huge bandwidth which provides unique identity to different channels starting from base station to mobile station.

The performance of a CDMA wireless communication system also depends on Multiple Access Interference (MAI). Multiple Access Interference starts due to cross-correlation among the spreading codes assigned to different users. MAI terms cannot be made zero as it is not possible to generate spreading codes that have zero cross-correlation with all shifts of other spreading codes. It is desired to reduce MAI by reducing the magnitude of cross correlation.

Inter Symbol Interference (ISI) is another limiting factor in CDMA system which is a function of autocorrelation values of the used spreading codes. For the sake of minimize ISI effect, auto-correlation function (ACF) of the spreading code must be impulsive in nature at origin and minimum elsewhere.

Hence MAI and ISI limit the performance of CDMA system when the spreading codes are not orthogonal and depend on the correlation properties of the employed spreading sequences [2]. In this paper we develop an optimized binary spreading code family by maintaining desired auto and cross correlation properties. The optimized code family is developed using a fast and elitist non-dominated sorting based multiobjective Genetic Algorithm known as Non-dominated Sorting Genetic Algorithm II (NSGA-II). **Minimum Auto-correlation and Cross-correlation Spreading Codes**

A. Minimum auto-correlation Spreading Codes

For a spreading code of length *N*, the dispreading operation can be modelled for multi-path environment in matrix notation in the form [2]

$$\begin{bmatrix} X(1) & X(2) & \cdots & X(N) \\ & X(1) & \cdots & X(N-1) \\ & & \ddots & \\ & & & X(1) \end{bmatrix} \begin{bmatrix} X(1) \\ X(2) \\ \vdots \\ X(N) \end{bmatrix} \qquad (1)$$

The first row multiplication is an auto-correlation with zero shifts representing dispreading of signal from the desired path. The results of other rows multiplications in (1) are the autocorrelations with nonzero shifts, considered as the ISI terms. The multiplication result of (1) is desired is to be

$$\begin{bmatrix} X(1) & X(2) & \cdots & X(N) \\ & X(1) & \cdots & X(N-1) \\ & & \ddots & \\ & & & X(1) \end{bmatrix} \begin{bmatrix} X(1) \\ X(2) \\ \vdots \\ X(N) \end{bmatrix} = \begin{bmatrix} Maximum \\ 0 \\ \vdots \\ 0 \end{bmatrix} \qquad (2)$$

If spreading codes are non orthogonal and autocorrelation properties is not maintained impulsive peak, Then result obtained is impossible for the set of equations in (2). The set of desired restrictions in (2), are changed and desire to reach the optimal code which satisfies the following restrictions

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$$\begin{bmatrix} X(1) & X(2) & \dots & X(N) \\ & X(1) & \dots & X(N-1) \\ & & \ddots & \\ & & & X(1) \end{bmatrix} \begin{bmatrix} X(1) \\ X(2) \\ \vdots \\ X(N) \end{bmatrix} = \begin{bmatrix} 1 \\ min \\ \vdots \\ min \end{bmatrix} \quad (3)$$

The first row multiplication result in (3) is normalized and the autocorrelation value of all shifts other than origin is minimized.

B. Minimum Magnitude Cross-correlation Spreading Codes

To investigate the dependency between MAI and cross-correlation as stated in [3] consider a known code "***x***" and unknown code "***s***". For a spreading code of length N, the cross-correlation between the codes as in [7, 8] as $\sum_{i=1}^{N} Xi\ Yi$.

Assuming the known code "***x***" is propagated over a multi-path channel, the received signals of this code will be$[X(1)\ X(2)\ \dots\ X(N)]^T$, , ..., .$[0\ 0\ \cdots\ X1]^T$

The cross-correlation of the received codes with "***s***" is [3]

$$\begin{bmatrix} X(1) & X(2) & \dots & X(N) \\ 0 & X(1) & \cdots & X(N-1) \\ \vdots & & \ddots & \\ 0 & 0 & \cdots & X(1) \end{bmatrix} \cdot \begin{bmatrix} Y(1) \\ Y(2) \\ \vdots \\ Y(N) \end{bmatrix} \quad (4)$$

The multiplication in first row represents dispreading the signal in the direct path, gives cross-correlation at zero time shift. The multiplication of other rows in (4) gives cross-correlation with non-zero time shifts considered as multiple access interference terms. For cross-correlation between the codes the result of (4) is desired to be

$$\begin{bmatrix} X(1) & X(2) & \dots & X(N) \\ 0 & X(1) & \cdots & X(N-1) \\ \vdots & & \ddots & \\ 0 & 0 & \cdots & X(1) \end{bmatrix} \cdot \begin{bmatrix} Y(1) \\ Y(2) \\ \vdots \\ Y(N) \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \\ \vdots \\ 0 \end{bmatrix} \quad (5)$$

The result obtained is impossible for the set of equations in (5) (rather than the trivial solution). The set of desired restrictions in (5), are changed and desire to reach the optimal code which satisfies the following restrictions

$$\begin{bmatrix} X(1) & X(2) & \dots & X(N) \\ 0 & X(1) & \cdots & X(N-1) \\ \vdots & & \ddots & \\ 0 & 0 & \cdots & X(1) \end{bmatrix} \cdot \begin{bmatrix} Y(1) \\ Y(2) \\ \vdots \\ Y(N) \end{bmatrix} = \begin{bmatrix} \min(1) \\ \min(2) \\ \vdots \\ \min(N) \end{bmatrix} \quad (6)$$

C. Establishment of relationship between R_{AC} and R_{CC}

Therefore, it has been found that the cross-correlation (CC) properties of a set of spreading codes come at the expense of auto correlation (AC) properties and vice versa. Hence, a trade-off between auto and cross correlation properties needs to be established [3, 4].

Consider a spreading sequence of length N and K number of codes in the code set.

A pair of sequences

$$Ux = [\,Ux(0), Ux(1), \dots \dots \dots \dots \dots \dots, Ux(N-1)]$$

And

$$Uy = [\,Uy(0), Uy(1), \dots \dots \dots \dots \dots \dots, Uy(N = 1)]$$

, the aperiodic correlation function between Ux and Uy is defined as:

$$Cxy\,(l) = \begin{cases} \sum_{v=0}^{N-1-l} Ux(v)Uy(v+1) & for\ 0 \le l \le N-1 \\ \sum_{v=0}^{N-1+l} Ux(v-l)Uy(v) & for\ 1-N \le l \le 0 \\ 0 & elsewhere \end{cases} \quad (7)$$

The focus is shift from periodic to non periodic correlation measures in concern of performance of wireless communication system.

Thus, in this paper our focused on optimizing average mean-square aperiodic autocorrelation and average mean square aperiodic cross correlation features of spreading code set.

Now, the out-of-phase average mean-square aperiodic AC measure for K sequences $U1, U2, \dots \dots \dots \dots \dots . . UK$ corresponds to

$$R_{AC} = \frac{1}{KN^2} \sum_{x=1}^{K} \sum_{l=1-N, l\neq 0}^{N-1} |Cxx(l)|^2 \quad (8)$$

To compare between codes of different lengths, the R_{AC} has been normalized to code length N. It basically measures the energy in the side lobes of the auto correlation other than origin or other than zero shift.

In the same way, the average mean-square aperiodic cross correlation (CC) can be measured for a code set consisting of K codes is given by

$$Rcc = \frac{1}{K(K-1)} \frac{1}{N^2} \sum_{x=1}^{K} \sum_{y=1, y\neq x}^{K} \sum_{l=1-N}^{N-1} |Cxy(l)|^2 \quad (9)$$

The relation connecting R_{AC} and R_{CC} is given by a theorem which states that for any set of K codes of length N satisfying $Cxx(0) = N$ for all x's in the code set,

$$R_{AC} + Rcc(K-1) > (K-1) \quad [5, 6]$$

The spreading codes with minimized R_{AC} and Rcc is the requirement. But, both the requirements are contradictory and cannot be achieved at the same time. By following the above theorem a proper trading has to be made between R_{AC} and Rcc. Therefore, the extreme values of R_{AC} and Rcc for the design of CDMA spreading codes is desirable to avoid.

Finally,

For a fixed population size (N) which contains N number of code sets and each code set containing fixed (K) number of codes of constant code length (l) spreading code set is obtained which is optimal with respect to out-of-phase average mean-square aperiodic auto-correlation R_{AC} and average mean-square aperiodic cross-correlation (R_{CC}) value of that code set.

The optimization problem is formulated as below:

$$\begin{cases} \min RAC \\ \min Rcc \end{cases} \quad (10)$$

The problem is two dimensional as it includes two non-linear continuous cost functions R_{AC} and R_{CC}.

II. NON-DOMINATED SORTING GENETIC ALGORITHM-II (NSGA-II)

The NSGA-II algorithm was effective but has been generally criticized for its $O(MN^3)$ computational complexity (where M and N are the number of objectives and population size respectively), lack of elitism and the need for specifying a sharing parameter σ_{share}.

NSGA-II a modified version was developed which is a better sorting algorithm with computational complexity $O(MN^2)$. The algorithm incorporates elitism and no sharing parameter is needed. Here, a selection operator is used that creates a mating pool by combining the parent and offspring populations and selecting the best (with respect to fitness and spread) N solutions. In most of the problems, the NSGA-II shows its efficiency to find much improved spread of solutions and superior convergence near the true Pareto-optimal front. The complete description of NSGA-II is mentioned in [9].

The step by step procedure for NSGA-II algorithm as in [9] is given below:

- Combine the Parent population P_t and Child population Q_t of size N *i.e.* $R_t = P_t \cup Q_t$, now R_t is the combined population and of size 2N.
- Sort R_t according to non-domination. After sorting we will obtain all non-dominated fronts of R_t *i.e.* F = fast-non-dominated-sort (R_t), here, F_i denotes the i^{th} front.
- Initialize P_{t+1} = and i = 1, following is carried out until the parent population is filled *i.e.* $|P_{t+1}| + |F_i| \leq = N$
  - ✓ Calculate the crowding distance value of each solution the front F_i
  - ✓ Add all the solutions of the i^{th} non-dominated front in the parent population of next generation *i.e.* $P_{t+1} = P_{t+1} \cup F_i$
  - ✓ Now increment the front count by 1 and then check the next front for inclusion *i.e.* i = i + 1.
- If any front is not totally included in the next generation parent population for filling up the population size of exactly N then we sort the solutions of that front using the crowded comparison operator in descending order and choose the best solution needed to fill the next generation parent population slots *i.e.* Sort (F_i, $\geq_n$), here sorting is in descending order using $\geq_n$ operator *i.e.* after crowded comparison sorting only the first (N-) solutions of *Fi* are selected to fill the parent population.
- After that selection, crossover and mutation operations are performed on to produce the child population the next generation *i.e.* Q_{t+1}.
- Increment the generation counter *i.e.* t = t+1 and the whole above process repeats for t = t+1 and it continues.

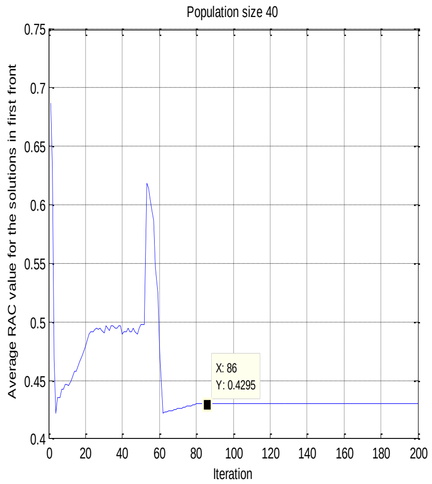
III. SIMULATION RESULTS AND ANALYSIS

In this section, the simulation results are presented for the design of optimized binary spreading codes using Non-dominated Sorting Genetic Algorithm (NSGA-II). The algorithm has been developed using MATLAB 7.1 [10] and the simulation results for different population size and code length have been presented.

4.1 Convergence behaviour of NSGA-II for the design of Binary Spreading codes

4.1.1 Convergence behaviour for different population sizes

This study has been carried out for the code length (L) = 8; number of codes in a code set (K) = 8; number of iteration (I) = 200. The convergence rate of NSGA-II has been presented in Figure. 1 for different population sizes, considering the average value of RAC as the averaged cost function. It is found that for population size of 40, the NSGA-II optimization technique takes approximately 86 iterations to converge. But when the population size is increased to a value of 60, the required number of iteration reduces to a value of 60 (approx.). On further increase of the population size (80), the number of iteration is further reduced to a value of 40.



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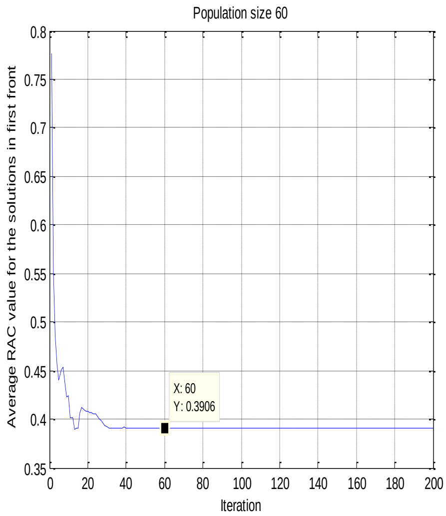

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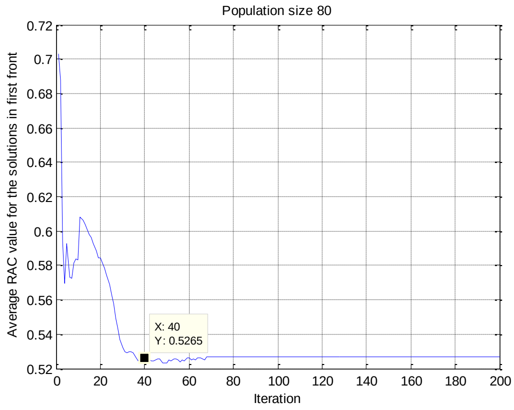
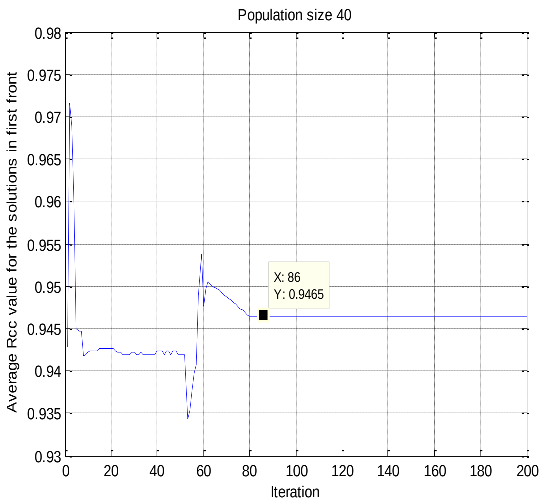


(c)

Fig: 1 Convergence rate of NSGA-II (cost function R_{AC})

The above results shown in Fig.1resembles that as the population size increases, the number of desired solutions in the population also increases, which improvises the convergence rate. Hence by proper selection of population size, the NSGA-II optimization technique can be made more efficient for this specific design problem.

In the similar way as stated above the convergence rate of NSGA-II for different population sizes, considering the cost function R_{AC} is given in Fig.2



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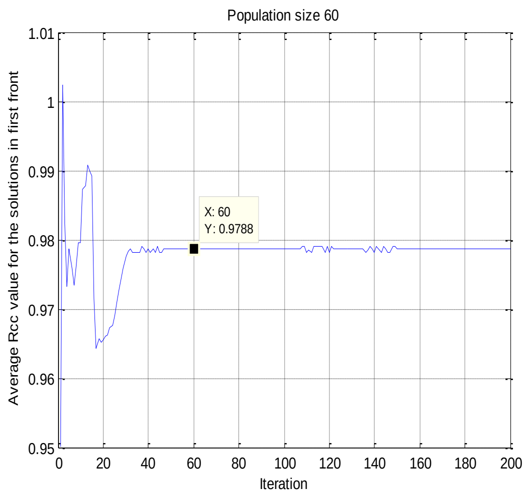

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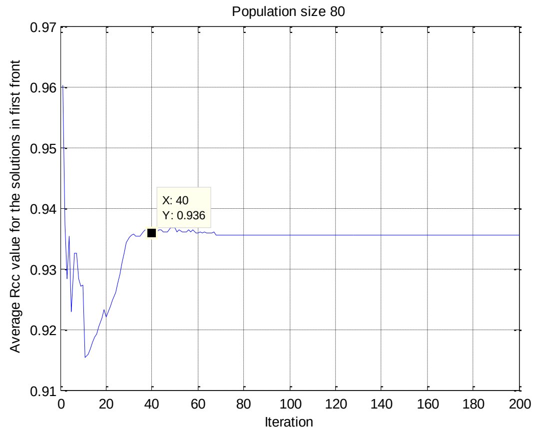

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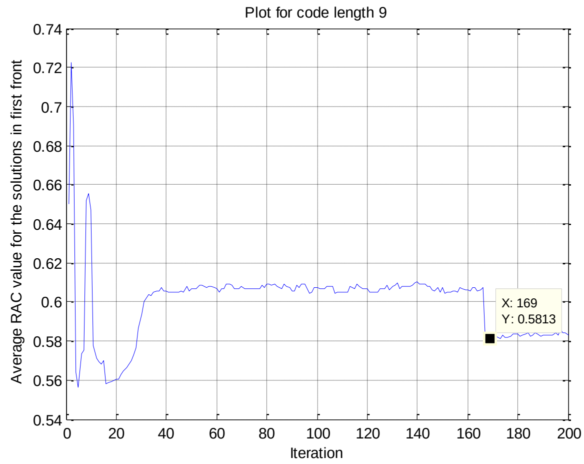
Fig: 2 Convergence rate of NSGA-II (cost function R_{CC})

4.1.2 Convergence rate for different code lengths

The convergence rate of NSGA-II for different code lengths, considering the average R_{AC} as the averaged cost function is shown in Figure: 3 for a fixed population size of 60.



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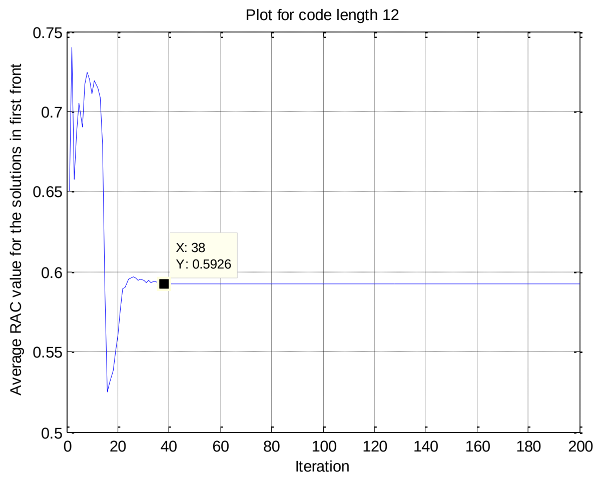

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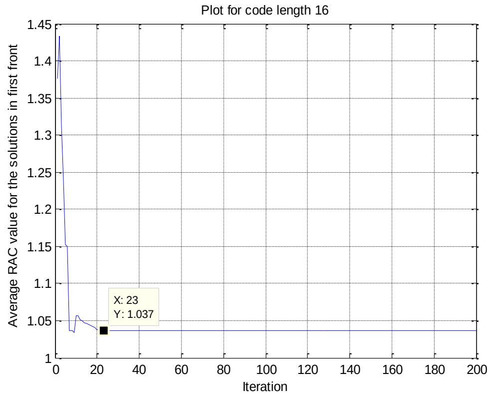

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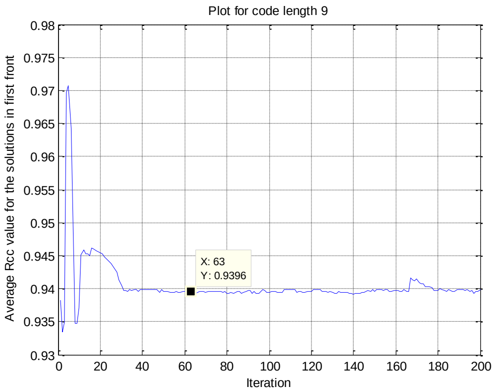
Fig: 4 Convergence rate of NSGA-II (cost function R_{AC})

Now for the same population size of 60, the convergence rate of NSGA-II considering the average R_{CC} as the averaged cost function is shown in Figure: 4.



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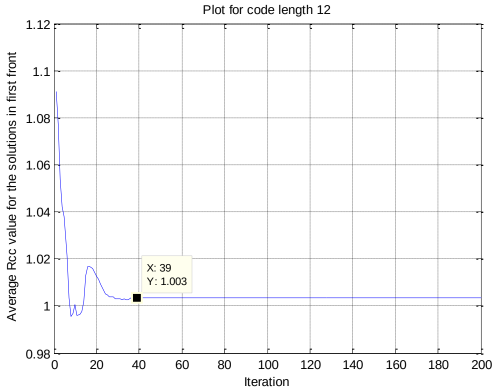

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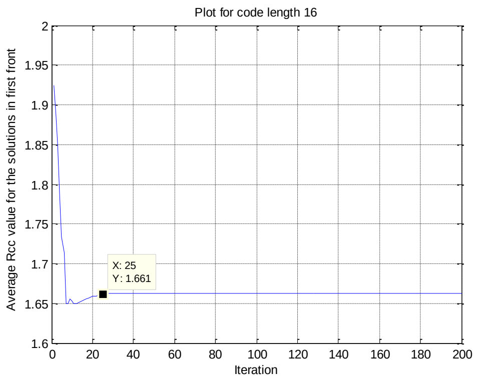

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Fig: 4 Convergence rate of NSGA-II (cost function R_{CC})

The convergence speed for both the cost functions RAC and RCC, the NSGA-II behaves similarly.

IV. PERFORMANCE OF THE PROPOSED CODE BASED ON CORRELATION PROPERTY

The correlation property of the proposed binary spreading codes has studied for K = L = 16 codes, where K is the number of codes in a code set and L is the code length. The number of iteration and populations size has been kept at a value of 200 and 60 respectively. The results corresponding to correlation property of the proposed code along with other existing codes have been summarized in Table. 1.

Table: 1 Comparison of NSGA-II based codes with other orthogonal codes

Code Set	R_{AC}	R_{CC}
NSGA based code set	1.037	1.661
	1.138	1.665
	1.257	1.775
	1.123	1.762
	1.045	1.602
	1.136	1.707
Walsh code set	4.0625	0.7292
Orthogonal code set	0.9063	0.9396
Orthogonal small set kasami code set	0.8730	0.8836

It is marked from the Table.1 that the NSGA-II based approach not only provides codes with “good” correlation property but also gives a wide range of intermediary values of RAC and RCC. Since these intermediate solutions are the optimized required solutions, more the number, better the result. The comparative study amongst the various codes shows that although our proposed code outperforms the Walsh code to a great extent, it lags behind the other two codes as far as correlation property is concerned.

V. CONCLUSION

In this paper we propose fast and superior multi-objective Genetic Algorithm approach – Non-dominated Sorting Genetic Algorithm-II (NSGA-II) to generate spreading codes with minimum magnitude of auto-correlation and cross-correlation. The average magnitude cost functions R_{AC} and R_{CC} , maintain minimum auto-correlation and cross-correlation values that mitigate the effect of ISI and MAI respectively. In comparison with the average magnitude cross-correlation value, with that of Walsh code set, there appears a visible development in the proposed code.

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