Intensified Particle Swarm Optimization For The Minimum Order Frequency Assignment Problem

Osman M. S. A., EL Sherbieny, M. M., Abd AL Hamed. R. Z., Emam A. M.

Abstract: The Minimum Order Frequency Assignment Problem (MO-FAP) is one of the main four schemes of the frequency assignment problem. The MO-FAP is a process of resource management of using the limited available spectrum in communication systems efficiently. The main objective is to minimize the total number of different used frequencies in the spectrum while satisfying the increasing capacity of customers, and quality of the service. In this paper a modified PSO is called Intensified Particle Swarm Optimization (IPSO). The proposed modified PSO is used for solving MO-FAP, while tackling the original PSO of being trapped in local minimum in the search space. The execution of the IPSO incurred using LabView programming. The effectiveness and robustness of the proposed algorithm have been demonstrated on a well-known benchmark problems and comparing the results with a number of previously related works.

Index Terms: Communication Systems; Frequency Assignment problem; Particle swarm optimization; Robustness; Spectrum.

1. INTRODUCTION

Frequency assignment is the most important in the design of communication systems for increasing the capacity, quality, and fidelity of service.This achievedby assigning the required number of frequencies to each node region providean efficient frequency spectrum utilization provided, and interference effects are eliminated. The FAP is strongly NP-hard, that arisen since 1960s by Metzger 1970 [6]. The FAP has two main properties: the limited availability of frequencies allocated to communication network connections, and interference levels between them [4]. Formally the communication system network is described with distinct set N of cells (nodes), where N={n_1,n_2, n_3…n_i}. Each cell (node) in the network serves a certain geographic area. Some pairs of cells are defined in set E presenting a predefined forbidding conditions in case of assigning certain frequencies, where E ⊂N. The Spectrum Bandwidth B of the communication system has a limited band of frequencies. This band is divided into sub bands named domains$B$= {D_1, D_2…...}, where Di ⊂B. Each communication network cell (node) has to assign its own frequencies from certain predefined domain, and they may assign to the same domain. FAP has many schemes found in [1], and various applications for further details in [7]. Allof them have twomaintypes of constraints.

- *Osman M.S.A Professor of Operations Research, Vice President of El Asher University, Egypt.*
- *EL Sherbieny, M. M. Professor of Operations Research, Head of Operations Research Department, Institute of Statistical Studies and Operations Research, Cairo University, Egypt.*
- *Abd AL Hamed. R. Z. Professor of Operations Research, Institute of Statistical Studies and Operations Research, Cairo University, Egypt.*
- *Emam A. M. M.Sc. of Operations Research, Institute of StatisticalStudies and Operations Research, Cairo University, Egypt.*

The first is the multiplicity constraints, that represents the demand number of frequencies needed for each cell from its own predefined domain in order to achieve the maximum service with high quality in certain geographical area.

The multiplicity constraints can be stated as

$$\sum_{f \in Dn_i} x_{fn_i} = m(n_\text{i}) \quad \forall\, n_\text{i} \in N \quad (1)$$

For every cell ni and the available frequency f where, fєD_{ni}we define

$$x_{fn_i} = \begin{cases} 1 & \text{if frequency } f \in Dn_i \text{ is assigned to vertex } n_i \in N \\ 0 & otherwise \end{cases}$$

where,
m (n_i): The number of frequencies required to cell ni,
D_{ni}: The domain of cell n_i, D_{ni}⊂B.

The second type of constraints is the Interference/Packing constraints. There are several types of interference that effect on the nature of the FAP for more details in [7]. This type of constraints introduces the relationship between any two paired of cells that may have interference between each other in case of assigning certain frequencies to them. The interference for every paired cell incurred if the distance between the centers of cells in case of certain assigned frequencies less than certain predefined distance, or when the interference level value exceeds the maximum predefined threshold. The interference constraints can be defined as following:

$$x_{fn_i} + x_{gn_j} \leq 1 \;\; \forall n_i n_j \in E,\; f \in Dn_i,\; g \in Dn_j,\; i \neq j: \quad (2)$$
$$|f - g| \geq R_{n_i n_j}$$

where,
$|f - g|$: Actual allowable distance between centers of node noden_i and $n_j$in case of assigning frequencies f and g respectively, so no interference incurred,
$R_{n_i n_j}$: Minimum allowable distance between centers of node n_i and n_j in case of assigning frequencies f and g respectively, so no interference incurred, The use of the spectrum efficientlybecomes one of the most important aspects for evaluating new communication systems design

[4]. This paper aims to introduce an intensified particle swarm optimization (IPSO) for solving the MO-FAP. The paper is organized as follows: in section 2, the model formulation and related works are introduced, while a brief introduction for the PSO in section 3. This is followed by the proposed algorithm in section 4. Test functions and conditions are shown in section 5. Section 6 exposed the experimental results. Finally, conclusion is reported in section 7.

2. Model Formulation and Related Works

FAP has variousformulationsthat relies on bandwidth, interference kinds and levels, optimization criterion. The operators in communication systems applications suffer from the charge value of the usage of each single frequency separately which is licensed by the government. The optimization criterion in this paper concerned with one of the most important models of the FAP, named minimum order – frequency assignment problem (MO-FAP). In MO-FAP model the consistence of the solution for the problem exists by satisfying the constraints (1, 2). As mentioned previously that the communication providers paid for the spectrum used in communication system to the governor, so the main objective in MO-FAP is to minimize the total number of different frequencies used (y_f) in the system network. The provider can exploit the unused frequencies for other applications.

Where,

$$y_f = \begin{cases} 1 & if\ frequency\ f \ \in\ B \text{ used} \\ 0 & otherwise \end{cases}$$

The MO-FAP model is formulated as follows:

$$min \sum_{f \in B} y_f \qquad (3)$$

S. to $\quad x_{fn_i} \leq y_f \forall n_i \in N,\ f \in Dn_i \qquad (4)$

$$\sum_{f \epsilon Dn_i} x_{fn_i} = m(n_i) \quad \forall\ n_i\ \in\ N \qquad (5)$$

$$x_{fn_i} + x_{gn_j} \leq 1 \quad \forall n_i n_j \in E,\ f \in Dn_i,\ g \in Dn_j,\ i \neq j:\ \left| f - g \right| \geq R_{n_i n_j} \qquad (6)$$

$$x_{fn_i} \in \{0,1\} \forall n_i \in N, f \in Dn_i \qquad (7)$$

$$y_f \in \{0,1\} \qquad \forall\ f \in B \qquad (8)$$

$$m(n_i) \in \mathbb{Z}_+\ \forall\ n_i \in N \qquad (9)$$

The MO-FAP have been tackled in many military applications such as in [14], while in[13], [16] the MO-FAPapplied to cellular mobile and communication systems. Furthermore, the TV and broadcasting has been introduced in [10], [12], [15] Many meta-heuristics have been proposed to solve the MO-FAP including genetic algorithm (GA) [8], evolutionary search (ES) [2], ant colony optimization (ACO) [5], simulated annealing (SA) [3] and tabu search(TS) [9], [11].

3. Particle Swarm Optimization

Particle swarm optimization (PSO) algorithm provided by Kennedy and Elberhart[18], as an inspiration of social stochastic behavior of bird flocking. PSO is a population - based technique in which individuals called particles fly around to explore a multidimensional search space of a given problem to maximize/ minimize the objective function. PSO algorithm works simultaneously maintaining several candidate solutions. Each particle considered as a candidate solution, where they move in the search space with a velocity according to their own experience, and the experience of the neighborhood particle. Assume that the search space is S-dimensional, then the j^{-th} particle of the swarm can be represented by a S-dimensional vector, $X_j = (x_{i1}, x_{i2}, \ldots, x_{iS})$. The velocity (position change) of this particle, can be represented by another D-dimensional vector $Vj = (v_{j1}, v_{j2}, \ldots, v_{jS})$. The best previously visited position of the j-th particle is denoted as $P_j = (p_{j1}, p_{j2}, \ldots, p_{jS})$. Defining g as the index of the best particle in the swarm (i.e., the g^{-th} particle is the best), and let the superscripts denote the iteration number, then the swarm is manipulated according to the following two equations [26]:

$$v_{jd}^{t+1} = wv_{jd}^{t} + c_1 r_1^t \left(p_{jd}^t - x_{jd}^t\right) + c_2 r_2^t \left(p_{gd}^t - x_{jd}^t\right), \qquad (10)$$

$$x_{jd}^{t+1} = x_{jd}^{t} + v_{jd}^{t+1}. \qquad (11)$$

Where, $d = 1, 2, \ldots, S$ and, S is the number of variables; $j = 1, 2, \ldots, k$, and k is the size of the swarm; c is a positive constant, called acceleration constant; r_1, r_2 are random numbers, uniformly distributed in [0, 1]; and $t = 1, 2, \ldots,$ determines the iteration number.

4. The Proposed Intensified PSO (IPSO)

The original PSO has several advantages exposed in its robustness, consistent record of accomplishments locating near optima solutions. Recently variety alterations have been provided to enhance the performance of the regular PSO, such as El_Sherbiny [19], [20], [21], and Yi Jiang and Qingling Yue [22]. This section introduces an Intensified PSO (IPSO) algorithm that tackle the cons of the original PSO representing in its random initial search state, fast convergence rate due to that the velocity update depends only on wv_{id}^{n}.This result incurred when a particle in the search space approaches the global best solution so its velocity approaches zero, implying that eventually all particles will stop searching.This consequentlyconverge to points in between their previous best positions and the global best positions discovered by all particles so far. That may have trapped in local minima as a result. The pseudocode of the main steps for the proposed IPSO algorithm for solving the MO-FAP is presented as follows:

1. Set number of generations g.
2. Set number of population size j, that represents the particle index P_j in the swarm.
3. Randomly select the candidates' domain index for network nodes for each particle in the swarm P_j.
4. Check the constraints violation for feasibility evaluation.
5. Evaluate the solution of the nodes candidates index for each particle in the swarm.

5.1. Applying the reading counterpart frequencies.
5.2. Objective function evaluation for each particle.

6. Determine the global best P_{gd} in the swarm, and the local best P_{id} for each particle.
7. Applying the swarm manipulation according to equations 10, and 11.
8. Check the candidates index domain violation for each node for all particles.

8.1. If any of candidate's index violated apply to equation 12, and go to step 9.

8.2. If not go to step 9.

9. Repeat from 4 to 8 till reaching the stopping criteria.

In this section an illustrated example of IPSO for MO-FAP is exposed while, the execution, and the pseudocode of each step are demonstrated in the following subsections. The proposed example of communication network system *N* consists of three cells n_i, i=1,2,3 for simplicity. The required number of frequencies (multiplicity constraints) $m(n_1) = m(n_3) = 3$ while, $m(n_2) = 2$. number of particles Pt in the swarm is 4, where t= 1,2,3,4 is the index of the particle in the swarm. The network has two domains each one consists of a defined set of five frequencies D_1= {20, 35, 45, 55, 70}, D_2 = {20, 40, 55, 66, 75}, where the required number of frequencies for each node ni must be assigned from a specified domain D_{ni} Suppose that n_1, n_2 ϵD_1= {20, 35, 45, 55, 70}, and n_3 ϵD_2 = {20, 40, 55, 66, 75}. The objective for this problem is to minimize the total number of different used frequencies y_f in equation 3, while satisfying the multiplicity constraints i.e. $\sum m\,(n_i) = 8$, and interference constraints in equations 5, 6 respectively. Figure 1 shows the general flow chart of the proposed algorithm (IPSO).

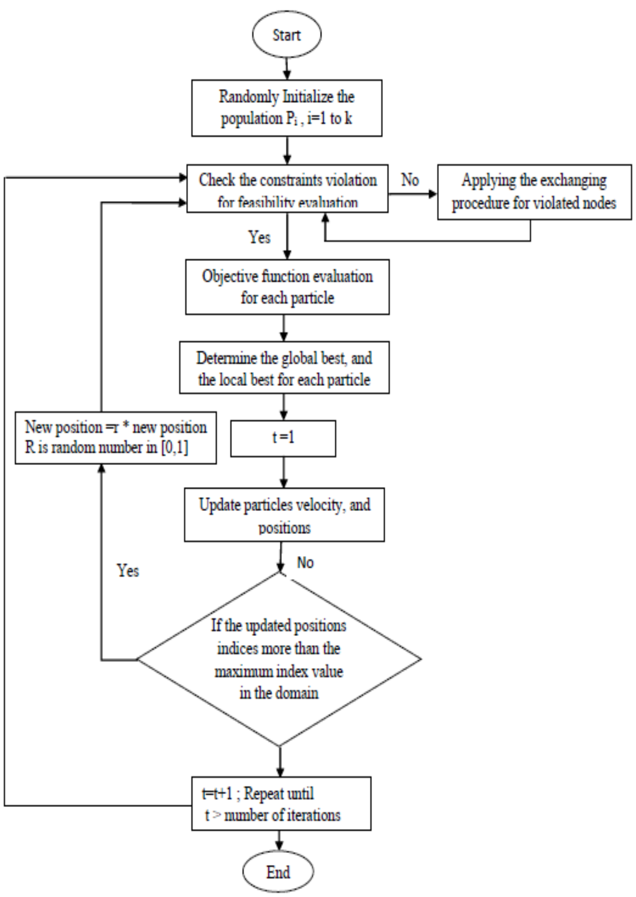

***FIG.1**. GENERAL FLOWCHART OF THE PROPOSED IPSO ALGORITHM*

4.1. Algorithm structure and Initialization

The implementation of the IPSO for tackling the MO-FAP has different criteria than other problems that have been tackled by original PSO. The IPSO has been adapted to satisfy the FAP nature using integer numbers that represents the indices of the candidate frequency in the predefined domain *D* for each cell ni in the network *N*, as mentioned previously each domain has five frequencies, so the indices take integer numbers from 1 to 5. Suppose that the interference constraints between the three cells are $|n_1 - n_2| \geq 3$, $|n_2 - n_3| \geq 5$. The structure of each particle shown in figure 2.

n_1 $n_2 n_3$

2	1	4	1	5	2	5	3

***FIGURE 2.** AN EXAMPLE OF PROPOSED IPSO INDICES STRUCTURE*

The population is initialized randomly for each node by selecting the candidate indices of the required number of frequencies from the assigned domain. The structure length delivered by each particle in IPSO is $X = \sum m(n_i)$, and divided into labeled slots *Q*=1,…*X* each group of slots represents the required number of frequencies for ni order sequence, where the each integer number inside each slot shown above represents the index of the selected frequency in the specified domain, for example the first number 2 means that the first selected frequency for n_1 is with index 2 from in the domain D_1 refer to frequency 35. This process is repeated for all particles in the swarm. The counterpart frequencies of the candidate's indices illustrated in figure 2 are shown in figure 3.

$n_1 n_2 n_3$

35	20	55	45	70	40	75	55

FIGURE 3. SELECTED INDICES FREQUENCIES

The following step is to check the constraints violation for feasibility evaluation. The feasibility evaluation incurred by marking the candidates index that result in violation of the constraints first. In figure 2 it found that the first slot with index 1 for node 2, and slot with index 5 for node 3 not satisfying the interference constraints, then the process of exchanging for the candidates' indices incurred for any node that has interference violated constraint. Each particle in the swarm has a string that contains the candidates' indices for all the nodes in the network that satisfying both of the multiplicity, and the packing constraints. Figure 4 shows the results of the initialization after the marking, exchanging, and evaluation process applied.

$n_1 n_2 n_3$

2	1	4	3	5	2	4	3

(A)

$n_1 n_2 n_3$

35	20	55	45	70	40	75	55

(B)

FIGURE 4. *IPSO INITIALIZATION RESULTS (A) CANDIDATES FOR ALL NODES (B) COUNTERPART FREQUENCIES*

Pseudocode of the Algorithm structure and Initialization is presented as follows:
1.Define particle population P_j, j=1,…k , with swarm size k=3.
2.Set j=1
3.Generate the structure of Pj$\forall\ n_i \in N$.
3.1. select randomly the index of $m(ni)$ $\forall\ n_i \in N$.
3.2. For every Q $\forall\ n_i$ in Pj Check constraint violation

$$\sum_{f \epsilon Dn_i} x_{fn_i} = m(n_i) \quad \forall\ n_i \in N$$

$x_{fn_i} + x_{gn_h} \leq 1 \quad \forall n_i n_h \in$ E, f $\in \mathrm{D}n_i$, g $\in \mathrm{D}n_h$, i ≠ h:
$|$f - g$| \geq R_{n_i n_h}$

Check if any of Q indices constraint violated go to step 3.5 Else go to step 4.
3.3. Mark violated Q in sequence till Q=X for Pj
3.4. Remove the marked Q's indices in step 3.3 and replace with new index.
3.5. Repeat 3.2.
4. Return Pj.
5. j=j+1.
6. Repeat step 3 to step 4 until j=k.

4.2 Solution Evaluation Algorithm and Manipulation

AS mentioned above each particle in the swarm deliver solution represented as a string that contains candidates' indices, where the solution evaluation executed into two steps. The first is the transformation procedure that incurred by reading the counterparts frequencies of the selected indices. Applying the value of the objective function for each particle is assigned as its fitness is the second step. Pseudocode of IPSO solution evaluation for initialization is illustrated as follows:

1.For P_j, j =1 to k, where K is the swarm size
1.1.Read counterpart frequency for Q =1 to X, $X = \sum m(n_i)$
2.2.Calculate $Y_f \forall P_j$ in the swarm, where Y_f number of different used frequencies.
2. Get min of $Y_f \forall\ P_j$
3. Set p_{gd} of Y_f is the global best.

For simplicity from figure 3 we can found that the total number of different frequencies used Y_f = 7 frequencies, and that number is a valuable compared to the total number of frequencies in D_1, and D_2, and there may be better solution that minimize the objective function Y_f. The algorithm manipulation executed through applying equations 10, and 11. This is incurred after determining the global best of all the particles Pgd, and the local best of each particle Pid depending on the fitness for each particle in the swarm. The introduced algorithm IPSO has a guarantee of exploiting the search space to achieve a high degree of exploration, and diversity. This process incurred with two sub process the first is that the particles updating positions in IPSO not executed unless checking if the frequency index of the candidate solution within the maximum frequency index in the predefined domain if each cell. In case of the violation of the frequency index value of the highest index in the assigned domain the particle updating position for each cell will obtained according to the following equation

$$x_{jd}^{t+1} = r * (x_{jd}^{t} + v_{jd}^{t+1}) \qquad (12)$$

Where, r is a random number, uniformly distributed in [0, 1]
The second is achieved after updating the particles positions and before selecting the global best in the swarm.
Pseudocode of the Algorithm Manipulation is presented as follows:
Set t=1 , where t is the iter. #
Set u, and v integer numbers, calculate EI = floor (0.75*t)
Update iteration weight w= (u-v)/EL
Set j=1
For Q=1 to X update velocity
4.2.Calculate particle new position x_{jd}^{t+1}
4.3. if x_{jd}^{t+1} =Int [x_{jd}^{t+1}]
Set x_{jd}^{t+1} =x_{jd}^{t+1}
Else x_{jd}^{t+1} = floor (x_{jd}^{t+1})
4.4. if Q value in$x_{jd}^{t+1}$of n_i > index value of D_{ni}
Generate r=[0,1]
Set x_{jd}^{t+1} = r * x_{jd}^{t+1}
Else x_{jd}^{t+1} = x_{jd}^{t+1}
Repeat step 4.3 to step 4.4
Repeat step 3.2. to step 4 as shown in pseudocode of the Algorithm structure and Initialization
7. j=j+1
8.Repeat step 4.1. to step 6 till j = k.
9. repeat step 1 and step 2 as shown above in pseudo code of IPSO solution evaluation
10. Get the global, and local best
If new p_{jd}< old $p_{jd}\forall P_j$, j=1 to k
  Set p_{jd} = new p_{jd}
   If p_{jd}<p_{gd}
  Set p_{gd} = p_{jd}
   If new p_{gd} = old p_{gd}
  Set p_{gd} = newp_{gd}
11.Return Yf
12.t=t+1
13.Repeat step 2 to step 12 until t = defined value

The equation (12) guarantee more exploitation of the particles for enhancing the exploration of the search space. Steps from 4.1. through 4.4., in addition to step 10 in IPSO algorithm assure that the convergence rate during the execution of velocity updating will not depends only on wv_{id}^{n}, that result in enhancing the diversity in search space, will not have trapped in local minima.

5. Test Functions and Conditions

This section provides the results of IPSO algorithm for the MO-FAP using CALMA project data sets (available on the FAP website). Ten well known benchmarking for MO-FAP, where five for CELAR, and five for GRAPH used in [23], and [24], were selected to test the performance of the proposed algorithm. Table 1 summarize the CELAR, and GRAPH networks construction of the MO-FAP instances.

TABLE. 1 *SHOWS CELAR AND GRAPH NETWORK CONSTRUCTION*

Instance	Interference Constraints	No. of Nodes	No.of Pre-assigned frequencies	Optimal Solution
CELAR01	5548	916	0	16
CELAR02	1236	200	0	14
CELAR03	2760	400	0	14
CELAR04	3967	680	280	46
CELAR11	4103	680	0	22
GRAPH01	1134	200	0	18
GRAPH02	2245	400	0	14
GRAPH08	3757	680	0	18
GRAPH09	5246	916	0	18
GRAPH14	4638	916	0	8

The parameters of IPSO are set as follows: the cognitive, and social values are set C_1 = C_2 = 0.5, where the inertia value w changed from 1.4 to 0.2 according to the following formula w =(x-y)/ every iter. Where, x=1.4, y=0.2, and every iter= floor (0.75* iteration number). Number of particles in the swarm N = 50, while the number of iterations is 500 on average.

6. IPSO Results versus other related works

The performance of IPSO algorithm and other algorithms based onTabu Search TS in [17, 27, and 28], genetic algorithm GA introduced in [25], simulated annealing SA shown in [27], and finally algorithm based on ES presented in [26]. The instance name, optimum solution, and the best obtained solution are summarized in table 2. The optimal solution shown in bold, while a dash "-"means the results could not obtain.

TABLE 2. *IPSO PERFORMANCE AGAINST OTHER RELATED WORKS*

Instance	Optimal Solution	GA [25]	IPSO	SA [27]	TS [17]	TS [27]	TS [28]	ES [26]
CELAR01	**16**	20	**16**	**16**	**16**	**16**	18	-
CELAR02	**14**	**14**	**14**	**14**	**14**	**14**	**14**	**14**
CELAR03	**14**	16	**14**	**14**	**14**	**14**	**14**	**14**
CELAR04	**46**	**46**	**46**	**46**	**46**	**46**	**46**	-
CELAR11	**22**	32	**22**	24	38	**22**	24	-
GRAPH01	**18**	20	**18**	-	**18**	**18**	**18**	**18**
GRAPH02	**14**	16	**14**	-	**14**	**14**	16	14
GRAPH08	**18**	-	**18**	-	**18**	20	24	-
GRAPH09	**18**	28	**18**	-	**18**	22	22	-
GRAPH14	**8**	14	**8**	-	**8**	10	12	-

The results of IPSO shown in table 2 expose the high performance of the algorithm for obtaining the optimum solution for all bench marks. Moreover, the IPSO algorithm, and the TS [27] which achieved the optimal solution for CELAR11. Also the IPSO beat on the SA algorithm [27] in all GRAPH instances, GA algorithm [25] on GRAPH08, and ES algorithm [26] for CELAR04, CELAR11, GRAPH08, GRAPH09, and GRAPH14.

7. Conclusion

This paper introduced an improved algorithm named IPSO for solving MO-FAP. The introduced algorithm has been coded with LabView programming, and applied on well-known ten MO-FAP benchmark problems. The performance of the exposed algorithm is outstanding when compared with other algorithms in the literature. The proposed algorithm enhanced the efficiency of the regular PSO representing in its random initial search state, which overcome by a guided initial solution from the regular PSO algorithm. The FAP has a special nature so, the introduced IPSO algorithm has an improvement for updating the particles positions using a random number thatuniformly distributed, so the convergence rate not depending only on the inertia weight, and hence the algorithm has more chance for exploring the search space without trapping in local minima. However, the algorithm execution is performed using a uniform distribution. Other distributions need to betested and their effect on the resulting solution needs to be verified. Applying the algorithm to the other different models of FAP for minimizing the interference, and the span for in the communication network need more investigation.

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