A GA-SSO Based Intelligent Channel Assignment Approach for MR-MC Wireless Sensors Networks

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Abstract. In this paper, based on the simplified swarm optimization (SSO) algorithm and genetic algorithm (GA), a novel GA-SSO hybrid optimization algorithm is proposed to solve the NP-hard channel assignment problem of multi-radio multi-channel (MR-MC) wireless sensors networks (WSN) which is promising for data intensive application. The aim of channel assignment is to minimize total network interference so as to maximize network throughput. In the GA-SSO based channel assignment, an improved channel merging method is proposed to satisfy the interface constraint condition. Matlab based simulation results show that the proposed GA-SSO features better global search capacity and can reduce the total network interference more effectively, compared to the SSO and DPSO-CA algorithms.

Keywords: GA-SSO · Wireless sensors network · Multi-radio multi-channel · Channel merging

1 Introduction

In recent years, wireless sensors networks (WSNs) are broadly adopted in data-intensive applications, such as structural health monitoring, earthquake monitoring, volcano monitoring and so on [1]. These applications usually need to transfer massive data through the WSN. For these kinds of applications, how to maximize throughput of the WSN is a critical issue that deserves to be solved.

Conventional WSNs are based on single-radio single-channel and work in contention-based mode, which is hard to meet the requirement of massive data transmission in data-intensive applications. This problem can be well solved by the multi-radio multi-channel architecture. However, there only exist few researches about the MR-MC WSNs [2–6]. Gao et al. [2] proposed a data gathering method for WSN, which was composed of multi-radio sink node and double-radio relay nodes, which can effectively improve the WSN performance. Ji et al. [3] proposed a multi-path scheduling algorithm for snapshot data collection in single-radio multi-channel WSN and a continuous data collection method for dual-radio multi-channel WSN, which improved the network capacity. Li et al. [4] studied a jointly cross-level method used in

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dual-radio multi-channel WSN, which is composed of routing, scheduling and channel assignment. Athota et al. [5] proposed two kinds of channel assignment algorithms for MR-MC wireless mesh networks, which can minimize network aggregate interference and assure connectivity.

In this paper, we propose a multi-radio multi-channel assignment method in WSN based on GA-SSO algorithm, which mainly combines the simplified swarm optimization algorithm (SSO) [7] with genetic algorithm (GA). The aim of this research is to minimize the total interference and maximize the throughput of MR-MC WSNs for data intensive applications.

2 Problem Formulation

In this section, firstly the network and interference model is described. And then, the MR-MC channel assignment problem in WSNs is discussed in detail.

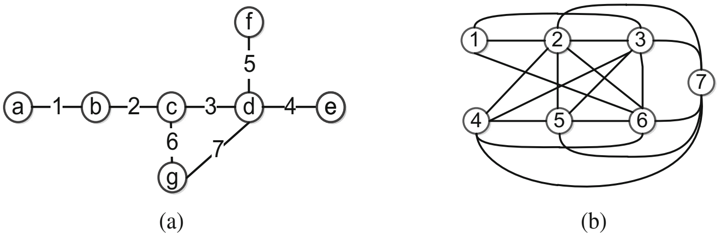


Fig. 1. A MR-MC network with 7 nodes and 7 links. (a) The communication graph consisting of 7 nodes and 7 links. (b) The conflict graph corresponding to (a).

2.1 Network Model

The studied WSN model consists of a set of wireless sensor nodes with fixed position in a plane, and every node is configured with a set of radios. We assume that all radios work in half-duplex mode, the antenna is omni-directional, and the transmission distance is L. The WSN topology can be modeled as an undirected graph $G = (V, E)$, where V represents the set of wireless sensor nodes and E the set of communication links. If node i and node j are in the communication range of each other, a link is defined between node i and node j, denoted as (i, j). Figure 1(a) shows an MR-MC network topology, which has seven node $\mathrm{a, b, c, d, e, f, g}$ and seven communication links $\mathrm{l_{ab}}$, $\mathrm{l_{bc}}$, $\mathrm{l_{cd}}$, $\mathrm{l_{de}}$, $\mathrm{l_{df}}$, $\mathrm{l_{cg}}$, $\mathrm{l_{dg}}$, which are numbered as 1, 2, 3, 4, 5, 6, 7 respectively.

To simplify the problem, the available channels are assumed to be completely orthogonal. The set of available channels is denoted by $\mathrm{K} = \{1, 2, \ldots, k_{\max}\}$. $\mathrm{R_i}$ represents the number of radios, and $\mathrm{K_i}$ represents the set of available channels for corresponding node i.

2.2 Interference Model

In this paper, the protocol model is adopted. In this model, two links interfere with each other if their physical distance is less than the interference distance. When two interfering links transfer data in a same channel at the same time, communication conflict will happen, leading to transmission failure. A conflict graph $G_c = (V_c, E_c)$ can represent the interference model, and a set of vertices V_c correspond to the communication links in the graph G, as shown in Eq. (1).

$$V_c = \{l_{ij} | (i,j) \text{ is communication link}, l_{ij} \in E\} \tag{1}$$

In the conflict graph G_c, V_c is the set of the links in the communication graph; A conflict edge (l_{ab}, l_{cd}) in E_c denotes that links (a, b) and (c, d) interfere with each other if they work simultaneously in the same channel. In this paper, interference distance is configured to be identical with the communication distance L. Figure 1(b) is the corresponding conflict graph of Fig. 1(a).

2.3 Multi-radio Multi-channel Assignment Problem

Assuming that every node in the WSN is configured with a certain number of radios, we need to assign different channel to every link in WSN, and ensure that the number of node's operating channels is less than or equal to the node's radio number. Our goal is to minimize the total interference number so as to improve the whole network capacity, so we define the sum of the interfering links' number as the total interference number.

Provided that the WSN consists of N sensor nodes, the problem is to find the optimal function: $f : V_c \rightarrow K$ which can minimize the overall network interference $I(f)$ and satisfy the interface constraint, which are defined as below:

$$\text{Interface Constraint: } \forall i \in N, |\{k | f(e) = k, e \in E(i)\}| \leq Ri \tag{2}$$

$$\text{Network Interference: } I(f) = \sum_{e \in V_c} \textit{interference number of } e \tag{3}$$

2.4 Channel Merging

In the optimization process of the network interference, the interface constraint is very likely to be violated. In order to handle the violation, the following 'channel merging' procedure is applied. The channel merging procedure proposed by [9] will introduce new channel for relevant nodes, which might further violate the constraint. To solve the issue, an improved channel merging operation is proposed. As shown in Fig. 2, Fig. 2 (a) is the network before merging operation, and Fig. 2(b) is after it.

(a)Before (b)After

Fig. 2. The communication graphs of node i in the network before and after merging operation

The details of channel merging operation are described as follows:

```
Algorithm 1：Channel Merging
Input   : Channel Assignment Scheme X,Xe,N,Ri
Output  : Channel Assignment Scheme after Merging Xm
1 Change X to Xv, which stands for the Channel Assignment Scheme
  corresponding to node;
2 Find node i(i∈N),which has max channel number,the number is m.
3  If m<=Ri
4    Xm=X;
5    Return;
6  Endif
7  While (m>Ri)
8    Find the two channel number c1 and c2,which correspond to mim
     number edges incident on node I;
9    Channel merging.Change the edges with channel c1 to c2,the edge
     incident on node i,and do the same operation to the edges connected
     to the changed edges aforementioned ,then Xi;
10   Do step from 1 to 6 for Xi
11 Endwhile
12 Xm=Xi.
```

3 GA-SSO Algorithm

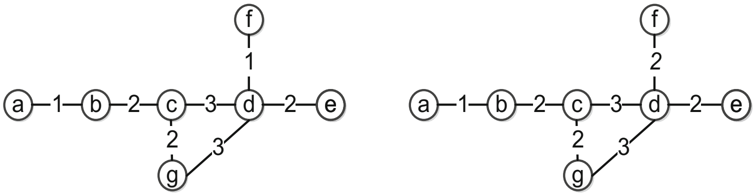
In this paper, based on GA and SSO optimization algorithms, a novel hybrid algorithm GA-SSO is proposed to solve the channel assignment problem for MR-MC WSNs. The GA-SSO's process is detailed described as follows.

3.1 Encoding

Assume that the number of communication links in the WSN is L, and the links are numbered by $\{1, 2, \ldots, L\}$. The particles of the GA-SSO algorithm represent a channel assignment scheme. The particle i'position at current time step t is represented by $X_i^t = (x_{i1}^t, x_{i2}^t, \ldots, x_{iL}^t)$, where x_{ik}^t denotes the channel assignment for node k at time t. The best position of the particles which is achieved so far is represented by $Pbest_i^t = (p_{i1}^t, p_{i2}^t, \ldots, p_{iL}^t)$. The global best position in the population is represented by $Gbest^t = (g_1^t, g_2^t, \ldots, g_L^t)$.

3.2 Population Initialization

In the initialization of the GA-SSO algorithm, channel merging operation is performed after assigning a random position value to each particle in order to satisfy the interface constraint. The particle's position initialization process for the topology in Fig. 1(a) can be shown in Fig. 3, in which each node owns two radios and there are three available orthogonal channels.



(a) Particle initialization position (b) Position value after channel merging

Fig. 3. Particle initialization process

3.3 Particle Position Update

The GA-SSO algorithm mainly consists of two parts: one is that Pbest and Gbest have effects on particle position by generic crossover operation, and the other is that particles change position by generic mutation operation. The basic iterative formula of GA-SSO algorithm is presented as follows:

$$X_i^t = \begin{cases} X_i^{t-1}, \textit{if } r \in [0, C_w), \\ \text{Cross}(X_i^{t-1}, \text{Pbest}_i^{t-1}), \textit{if } r \in [C_w, C_p), \\ \text{Cross}(X_i^{t-1}, \text{Gbest}^{t-1}), \textit{if } r \in [C_p, C_g), \\ \text{Mutate}(X_i^{t-1}), \textit{if } r \in [C_g, 1). \end{cases} \quad (4)$$

where $\mathrm{i} = 1, 2, \ldots, \mathrm{m}$, m is the swarm population. X_i^t is the current time position value of the i - th particle, and X_i^{t+1} is the next time position value; Pbest_i^t is the i - th particle's personal best position until current time; Gbest^t is the global best position in the current whole population;C_w, C_p and C_g are three predetermined positive constants with $0 < C_w < C_p < C_g \leq 1$, C_w is the probability to remain the same, C_p is the crossover factor with Pbest, C_g is the crossover factor with Gbest; r is a random number with $0 < r < 1$. The position update strategy of the GA-SSO can be summarized as follows: in each iteration of position update, the particles choose one of the four operations according to the value of r. The four operations include: (1) remaining the same, (2) crossover with Pbest, (3) crossover with Gbest, and (4) mutation.

3.4 Fitness Function

The main objective of our algorithm is to minimize the total network interference so as to maximize network throughput. Therefore, the total network interference number is used as the GA-SSO algorithm's fitness value. Fitness Function can be represented as $I(f)$, as shown in Eq. 3.

3.5 Algorithm Pseudocode

The algorithm pseudocode is shown as follows. Assume that each node has the same number of radios. The termination condition in algorithm is “iteration times”.

```
Algorithm 2：GA-SSO
Input: G,K={1,2,...,kmax},N,Ri,sizepop,maxgen,Cw,Cp,Cg,iteration times
Output: The channel assignment result Ki for each i∈Vc
Convert G to Gc=(Vc,Ec);
Initialize the GA-SSO’s parameters;
Initialize population;
Calculate fitness function;
While(termination)
   Generate a random number r∈（0,1）
    If (r < Cw) Keep position；
    Elseif  (r <Cp)  Crossover operation with Pbest;
    Elseif  (r <Cg)  Crossover operation with Gbest;
    Else  mutate operation ;
    Endif
 Update Pbest,Gbest,the current position X;
Endwhile.
```

4 Experimental Results

In this section, the performance of the designed GA-SSO algorithms is verified by Matlab based simulation. In order to evaluate the GA-SSO algorithm and channel merging approach proposed in paper, it is compared with the SSO [7] and DPSO-CA [8]. The simulation experiments perform in finite random networks, which have variable number of radios and channels. In a square meters area 1000 m × 1000 m, we consider that the networks have 25 nodes deployed randomly. It is supposed that the range of transmission and interference are all 250 m, and the WSN nodes havethe same number of radios.

The metric Interference Percentage is used to evaluate our algorithms’ performance, which is defined by Eq. 5 as follows.

$$\mathrm{Interf}(f) = I(f)/(L \bullet (L-1)) \tag{5}$$

where f is a feasible assignment solution, $I(f)$ is the interference value in network, and L is total interference links in G_c. This metric refers to the thought of normalization method.

Figure 4 shows the simulation results in a network (consisting of 25 nodes), where every node has 12 available channels and radios’ number varying from 2 to 12. With the increasing number of radios, the interference percentage reduces. From Fig. 4, it can be observed that when the radio number is less than 5, the interference percentage can be obviously reduced by increasing the number of radios. Overall speaking, the performance of the proposed GA-SSO is better than the other two algorithms.

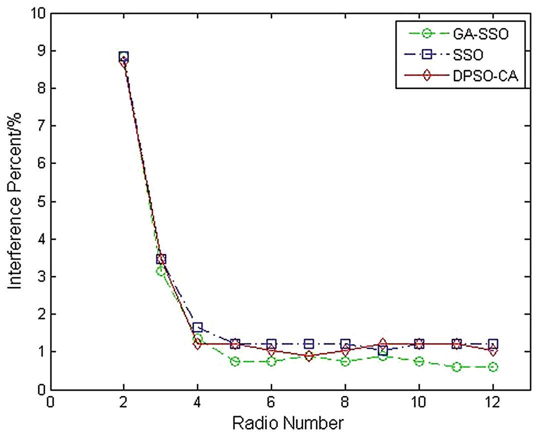


Fig. 4. Interference percentage in WSN with 25 nodes (12 available channels)

Table 1 shows the experimental results in the network (25 nodes) with channel number as 3 and radio number as 5. The running speed of GA-SSO is superior to SSO, but slightly inferior to DPSO-CA. The iteration process of GA-SSO can inherit the last iteration, which can reduce the time from channel merging. But the inheritance property of SSO is worse than GA-SSO's. Moreover, the GA-SSO can effectively solve the premature convergence problem and improve the global convergence performance, which benefits from generic algorithm's property.

Overall, GA-SSO algorithm can obtain better result among the three algorithms.

Table 1. Comparision results (3 channels and 5 radios)

Parameter	SSO	DPSO-CA	GA-SSO
Iteration time per round/s	0.278	0.184	0.192
Interference percentage/%	6.42	5.75	5.55

5 Conclusion

In this paper, a novel hybrid optimization algorithm named GA-SSO is proposed to solve the NP-hard channel assignment problem for data-intensive MR-MC WSN. Moreover, an improved channel merging method is proposed to satisfy interface constraint condition. Compared with SSO and DPSO-CA algorithm through Matlab simulation, the proposed GA-SSO has a better global search and thus can improve the network capacity. In future, the authors will consider how to apply this algorithm to real MR-MC WSNs.

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