BPSO and BRKGA for Broadcast Scheduling Problem

Shuai Xiaoying[1] and Yin Yuxia[2]

[1] College of Information Engineering, Taizhou University, Taizhou 225300, Jiangsu, China
[2] Library, Taizhou University, Taizhou 225300, Jiangsu, China
xyshuai@163.com

Abstract. Broadcasting in wireless networks is an essential information dissemination method. However, shared channel causes contention and collisions. TDMA (Time Division Multiple Access) is a widely used conflict-free scheduling scheme. In this study, a TDMA scheduling scheme based on BPSO (Binary Particle Swarm Optimization) and BRKGA (Biased Random-Key Genetic Algorithm) is proposed for BSP (Broadcast Scheduling Problem) which is a NP-complete problem. First, the initial solutions are generated by greedy algorithm; then, a better population is generated by BPSO; finally, the scheme uses BRKGA to get a solution closer to the optimization. The simulation results show that the proposed algorithm exhibits better performance in terms of lower frame length, iteration and higher channel utilization.

Keywords: BSP, TDMA, BPSO, BRKGA.

1 Introduction

An Ad hoc such as IoV (Internet of Vehicles), WSN (Wireless Sensor Network) is formed by a group of wireless nodes deployed within a certain area [1]. These nodes communicate directly with 1-hop neighbours via a shared wireless channel. Each node periodically sends collected data such as traffic information, environmental monitoring, etc. to the sink node. Due to resource constraints, the source nodes that are far from the target transmit information to the target via multi-hop nodes [2]. In a multi-hop Ad hoc network, each node not only needs to send its own traffic but also store and forward traffic from neighbour nodes [3]. Thus, the transmissions of each node in the network will increase. Due to share wireless medium, collisions caused by simultaneous transmissions of 1-hop or 2-hop neighbours. Therefore, it is very key to design an efficient medium access schedule scheme in a multi-hop Ad hoc network.

Contention-based access protocol such as CSMA (Carrier Sense Multiple Access) or scheduled-based access protocol such as TDMA (Time Division Multiple Access) are commonly used in WSN [4]. TDMA is simple, content-free, and more suitable for scenarios that require high rates. In a TDMA network, time is divided to slots and grouped into frames, as shown in Fig.1. The problem for TDMA is to minimize slots of a frame where each node is activated at least once time slot and maximize channel utilization. The problem is called broadcast scheduling problem (BSP) and is a NP-complete problem. Many studies have been carried out to TDMA in WSN [5][6].

Heuristic algorithm such as GA (Genetic Algorithm), Vertex Colouring and others have been applied to solve BSP [7].

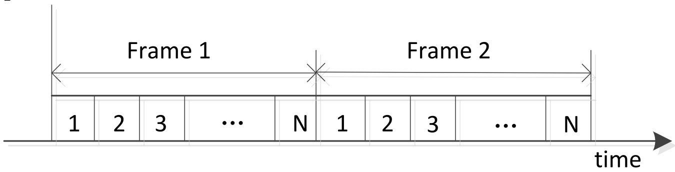

Fig. 1. TDMA Frame

The main works of this paper are as follows:

1) The greedy algorithm is used to initialize the TDMA scheduling solutions, which improves the search efficiency of PSO (Particle Swarm Optimization) and GA.

2) The BPSO is used to generate a good TDMA scheduling close to the optimal solution.

3) The broadcast scheduling problem is solved by using BPSO and BRKGA hybrid algorithm.

2 Related Research

Jun Long et al. proposed a green TDMA protocol to lengthen lifetime for WSN [8]. Yeo proposed two-phase TDMA (TP-TDMA) based on sequential vertex colour (SVC) [9]. The TP-TDMA can achieve the lower time delay by minimize the number of a frame and maximize the total number of active nodes per frame. To improve throughput, a two-phase combinatorial TDMA was proposed by Clayton W. Commander [10]. In the first phase, the scheme based on vertex colour was applied to discover a shortest feasible frame time. In order to maximize throughput, the randomized heuristic improvement method was adopted in the second stage. The N-TDMA dynamically allocates time slots for ad hoc. Zhang Xizheng [11] adopted modified SVC to minimize TDMA frame length. To improve throughput for WSN, a HNN (Hopfield Neural Network) was used in [11]. A TDMA scheme based on SVC and matrix operation was proposed in [12]. Two centralized heuristic algorithms have been proposed for WSN to reduce running time [13].

Particle swarm optimization (PSO) is a stochastic optimization technique based on population. PSO incorporates swarming behaviours observed in flocks of birds, schools of fish, or swarms of bees [14]. PSO is applied to solve optimal problems. PSO simulates the process of bird and fish predation in nature. Using the information sharing of individuals in the group, the movement of the whole group can generate an evolution process from disorder to order in the solving space, so as to obtain the optimal solution of the problem [15]. There is a population of random solutions. Each potential solution, called particles, fly through the problem space by following the current optimum particles. Flying in the search space, each particle has a velocity which is dynamically adjusted according to the experiences of its own and its colleagues, this makes the swarm have an intelligent ability of flying towards the optimal position [16]. The speed update of each particle mainly depends on the speed of the previous time, the difference between the current position and the historical optimal position of the particle, and the difference between the current position and the historical optimal position of the particle swarm. The update formula of the d-th dimension velocity of particle i is as equation (1).

$$v_{id}^{t+1} = wv_{id}^{t} + c_1 r_1 (pbest_{id} - x_{id}^{t}) + c_2 r_2 (gbest_{id} - x_{id}^{t}) \quad (1)$$

The equation of particle i update position is as equation (2) .

$$x_{id}^{t+1} = x_{id}^{t} + v_{id}^{t} \quad (2)$$

Where, w is the inertia weight, c_1 and c_2 are the acceleration coefficients, and r_1 and r_2 are two random real numbers on the [0,1] interval respectively.

To minimize the total time slot and save energy, a multi-objective hybrid TDMA algorithm (HPSO) is designed [17]. HPSO embeds simulated annealing (SA) into particle swarm optimization to improve slot allocation in WSN. A particle swarm optimization algorithm is proposed for TDMA to allot slots in WSN [18]. Hong Yu et al. designed a conflict free scheduling strategy using binary particle swarm optimization (BPSO) for broadcast scheduling problem [19].

Some GAs (genetic algorithm) are used to optimize TDMA and solve BSP in Ad hoc networks [20-22]. Traditional genetic algorithms perform poorly for larger networks. Been proposed the RKGA (random-key genetic algorithms) based on genetic algorithms and random keywords to solve combination optimization problems [23]. BRKGA is a heuristic algorithm proposed based on RKGA, as shown in Fig. 2 [24]. BRKGA was originally applied for permutation optimization problems [25] and is now widely designed to solve scheduling problems [26].

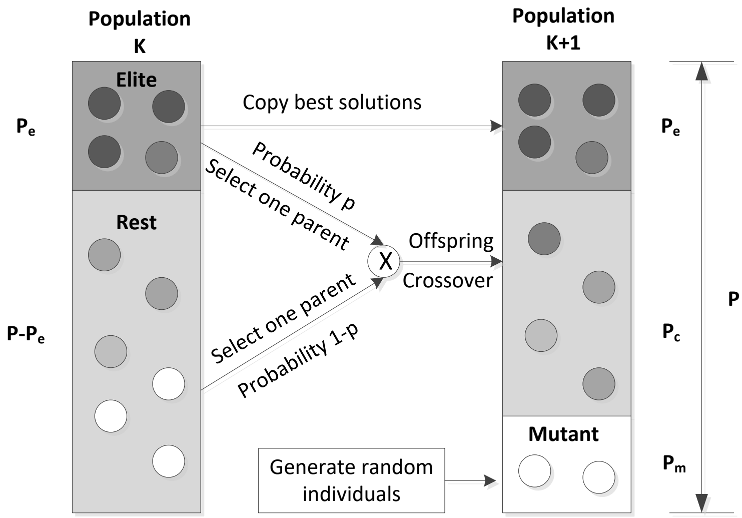

Fig. 2. evolutionary process of the BRKGA

3 Model

In Fig. 3, an undirected graph G represents an Ad hoc network. Let V represent the set of nodes and E be the set of edges, so G = (V, E). As in Fig. 3, G has 15 nodes and 29 edges. Where V={1,2,⋯,15}, E= {(1,2),(1,3),⋯,(14,15)}. Node 1 and node 2 are within the communication range of each other, they are 1-hop neighbours connected by a line. The distance between node i and node j is denoted as L_{ij}, and the distance between adjacent nodes is set to 1, such as $L_{12} = 1$.

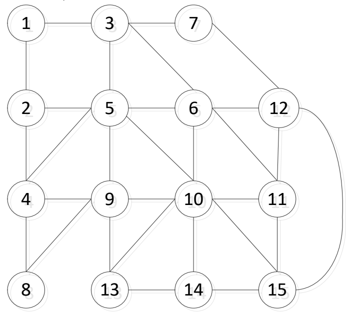

Fig. 3. An Ad hoc with 15 nodes

The connectivity matrix C_{N*N} as follow:

$$C_{ij} = \begin{cases} 1 & \text{if } L_{ij} == 1 \\ 0 & \text{otherwise} \end{cases} \tag{3}$$

Where, $1 \leqslant i, j \leqslant N$, $N = |V|$.

If $C_{ix} = C_{xj} = 1$ and $C_{ij} = 0$, then nodes i and j are called 2-hop neighbours, set $L_{ij} = 2$. Node 5 is a 2-hop neighbours of node 1, $L_{15} = 2$. Equation (4) defines the 2-hop neighbour relationship matrix.

$$D_{ij} = \begin{cases} 1 & \text{if } L_{ij} == 2 \\ 0 & \text{otherwise} \end{cases} \tag{4}$$

In a wireless Ad hoc network, if more than one nodes with distance less than or equal two send simultaneously, it will interfere with the correct reception of data. The interference matrix I_{N*N} as follow:

$$I_{ij} = C_{ij} \vee D_{ij} = \begin{cases} 1 & \text{if } L_{ij} \leq 2 \\ 0 & \text{otherwise} \end{cases} \tag{5}$$

Thus, let M represents the time slots in each frame. Use $T : M \times N \mapsto \{0,1\}$ to denote a slot schedule. The following is the elements of T.

$$T_{mj} = \begin{cases} 1 & \text{if node } j \text{ use the mth slot} \\ 0 & \text{otherwise} \end{cases} \tag{6}$$

So, an optimum TDMA scheduling problem in an Ad hoc network is famulated as follow:

Minimize M

$$\text{Maximize} \sum_{m=1}^{M} \sum_{j=1}^{N} T_{mj} \tag{7}$$

$$s.t.\ \sum_{m=1}^{M} T_{mj} \geq 1 \qquad m = 1, 2, \cdots, M \tag{8}$$

$$\sum_{m=1}^{M} \sum_{j=1}^{N} \sum_{k=1, k \neq j}^{N} T_{mj} d_{jk} T_{mk} = 0 \tag{9}$$

Equation (8) reflects each node should occupy at least one slot. Equation (9) can avoid collisions, implies that neighbours within the range of 2-hop must send in different slots.

4 TDMA Scheduling Scheme

4.1 Optimization Framework

The broadcast scheduling problem in Ad hoc networks is an NP problem. TDMA scheduling can be represented by a matrix, that is, a particle (individual). The i-th row and j-th column of the matrix are 1, indicating that time slot i is allocated to node j, otherwise it is 0. Two stochastic optimization algorithms, PSO and GA, are applied to TDMA scheduling in Ad hoc networks, the optimization framework as Fig. 4.

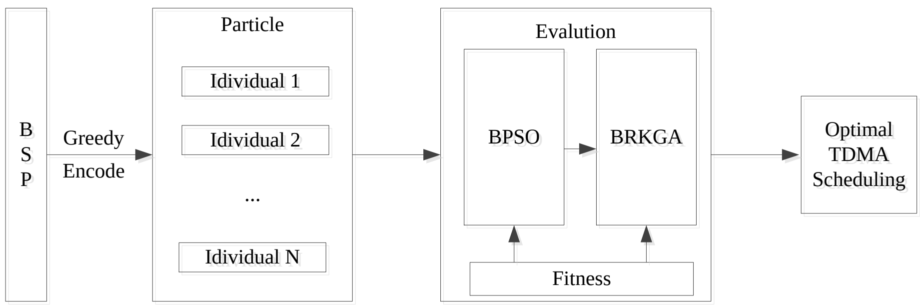

Fig. 4. Optimization Framework

Firstly, randomly generate a group of valid but non-optimal individuals (particles). Each initial individual is generated by the greedy method. Every individual is a feasible TDMA scheduling, which helps to improve the search efficiency. Then, binary particle swarm optimization and biased random-key genetic algorithms are applied to optimize slot scheduling. Finally, output the best scheduling (individual) of the problem.

4.2 Initialization

A new particle(individual) is generated by random permutation of nodes. In Fig. 5, a node permutation is randomly generated, , and store the random permutation nodes to node list V , such as V= {3, 1, 2, 4, 5}. First, set all elements of matrix T_{N*N} (N=5) to

0. Next, the first slot is assigned to the first node V[1] of V, set the T_{13} to 1. Next, assign a slot to V[2]. We attempt to assign time slot 1 to node V[2]. If there is no conflict, we assign it. Otherwise, we assign a new time slot (slot 2) to node V[2]. We repeat the above process to allocate a time slot for node V [3], and so on. A new TDMA scheduling T_{M*N} is created, as show in Fig. 6.

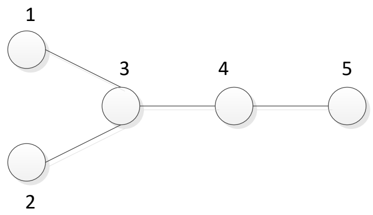

Fig. 5. An Ad hoc with 5 nodes

nodes

slots	1	2	3	4	5
1	1	0	0	0	1
2	0	1	0	0	0
3	0	0	1	0	0
4	0	0	0	1	0
5	0	0	0	0	0

N=5, M=4

Fig. 6. A TDMA scheduling

4.3 Fitness evaluation

When selecting the solutions to generate the next generation, it is necessary to apply an appropriate value function to compute fitness. The aim of TDMA scheduling is to minimize the frame length and maximize the channel utilization. So, the fitness is judged by the frame length M and the channel utilization p. The fitness calculation for each chromosome is shown in equation (10). Fig. 6 is a TDMA scheduling of the network in Fig. 5, and the fitness is 3.75.

$$fitness(x) = M - p \tag{10}$$

$$p = \frac{1}{MN}\sum_{m=1}^{M}\sum_{j=1}^{N} T_{mj} \tag{11}$$

4.4 BPSO

PSO is mainly used to optimize continuous value problems. To optimize discrete space constraint problems, DPSO (Discrete Particle Swarm Optimization) is proposed. BPSO is based on the DPSO and specifies that the position vector is composed of 0 and 1. BPSO adopts the probability mapping method, and uses the sigmoid function to map the speed to the [0, 1] interval as the probability that the position is 1. The sigmoid function as equation (12), the particle position update equation is as equation (13):

$$s(v_{id}^{k}) = \frac{1}{1 + e^{-v_{id}^{k}}} \tag{12}$$

$$x_{id}^{k} = \begin{cases} 1 \; if \; random() \le s(v_{id}^{k}) \\ 0 \qquad otherwise \end{cases} \tag{13}$$

Particle i (TDMA scheduling) is a M * N matrix, denoted x_i. The position of the particle, x_{irc}, represents the element in row r and column c of the TDMA scheduling i. The probability that the position x_{irc} of generation k+1 particle i is 1 is as follows:

$$p(x_{irc}^{k+1}) = \frac{\frac{1 \times x_{irc}^{k}}{fitness(x_i^k)} + c_1 r_1 \frac{1 \times x_{irc}^{pbest}}{fitness(pbest_i)} + c_2 r_2 \frac{1 \times x_{irc}^{gbest}}{fitness(gbest)}}{\frac{1}{fitness(x_i^k)} + c_1 r_1 \frac{1}{fitness(pbest_i)} + c_2 r_2 \frac{1}{fitness(gbest)}} \tag{14}$$

Map probability p to [v_{min}, v_{max}], and update speed v_{irc} as follows:

$$v_{irc}^{k+1} = p(x_{irc}^{k+1})(v_{\max} - v_{\min}) + v_{\min} \tag{15}$$

Then use sigmoid to calculate s, and use the formula to get x_{irc}.

4.5 BRKGA

All solutions of generation *k* are sorted by their fitness value. All solutions are classified into elite group and rest group., as shown in Fig. 2. The P_e best individuals in the best group of generation *k* are stored directly to the next generation. The worst P_m solutions of the rest group of generation *k* are replaced by the mutants. The remaining $P_c = P - P_e - P_m$ offspring are generated through muting. Randomly select one chromosome from each of the elite group and the rest group of the generation *k* as parents, and mate to generate a new individual.

4.6 Algorithm

1) Initialization

Initialize the parameters of BPSO, such as: N, P, K, w, c_1, r_1,c_2, r_2 etc; initialize the parameters of BRGGA, including p_e, p_c, p_m etc.

```
Generate a random permutation sequence of nodes, V.
for i=1 to N  //assign slot j to node i (the ith node in the V)
   j=1
   while (slot j cannot be assigned to node i )
       j++;
   endwhile
endfor
set M= the length of TDMA frame
```

2) BPSO

for k=1 to K
    for i=1 to P
        Evaluate fitness of X_i;
        Update pbesti;
    Endfor
    Update gbest
    Apply equation (14) to get $p(x_{irc}^{k+1})$
    Update v_{irc}^{k+1} by the equation (15)
    Apply equation (12) to get $s(v_{irc}^{k+1})$
    Generate the swarm by the equation (13)
Endfor
Output particles for BRKGA
3) BRKGA
While (stopping condition not met) do
    Sort P by fitness
    Get elite individuals to next generation P^+
    Crossover P_c individuals to P^+
    Mutate P_m individuals to P^+
    $P \leftarrow P^+$
Endwhile
4) output the TDMA frame

5 Simulation

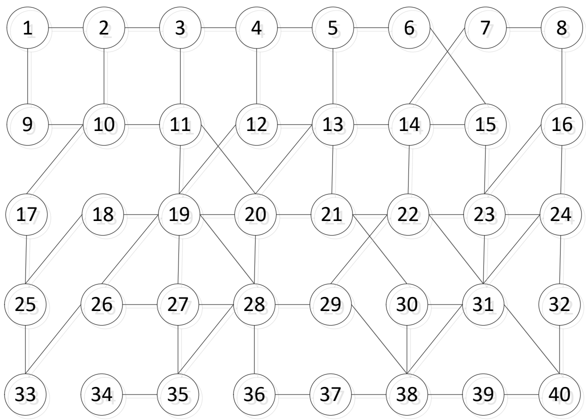

Fig. 7. An Ad hoc with 40 nodes

Simulator has been created by C++ program to run on Windows 11 and Intel Core™ i7. Two network topologies were used, i.e. 15-node network as in Fig. 3 and 40-node network as in Fig. 7. We compared the BPSO+BRKGA TDMA algorithm with other algorithms in terms of capacity, frame length, utilization and convergence by simulations. Figures 8, 9, and 10 show the TDAM frame time, capacity, and utilization of different algorithms in networks with 15 and 40 nodes, respectively. The frame length of BPSO and BPSO+BRKGA on both networks is 8. The simulation results demonstrate that the BPSO+BRKGA TDMA has shorter frame time than TP-TDMA, N-TDMA and BRKGA-TDMA algorithms. The channel utilization of BPSO+BRKGA algorithm is not lower than algorithms TP-TDMA, N-TDMA and BPSO-TDMA in both networks, as in Fig.10.

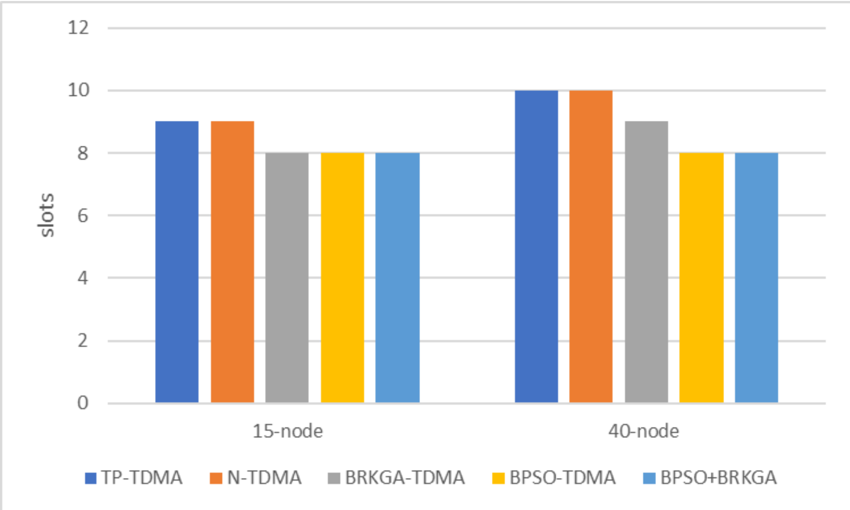

Fig. 8. Comparison of TDMA frame length

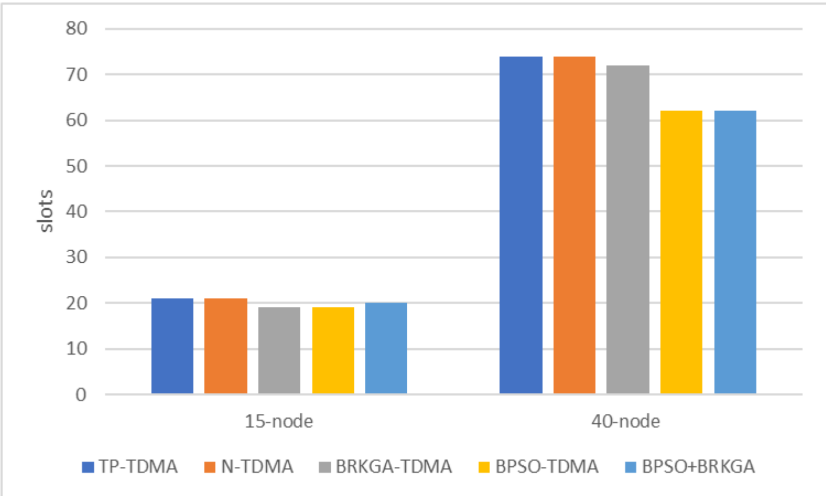

Fig. 9. Comparison of TDMA capacity

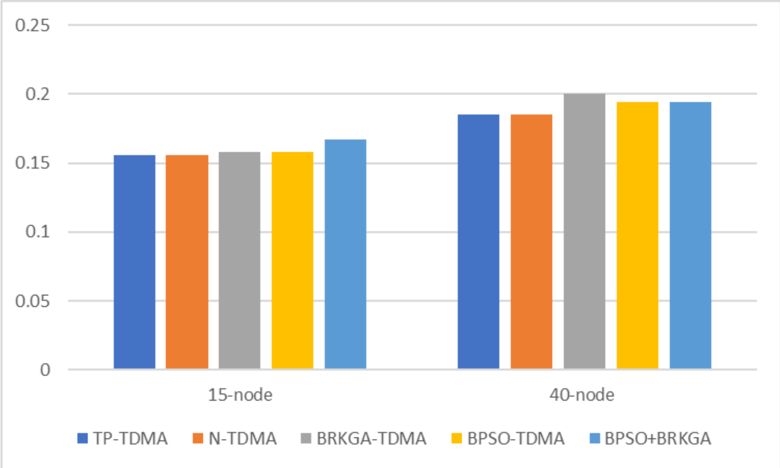

Fig. 10. Comparison of TDMA channel utilization

The convergence speed of BPSO is slow in the later stage, and the number of iterations exceeds 500. The convergence speed of BRKGA is fast, but it is easy to obtain the local optimum. Fig. 11 shows BPSO+BRKGA not only converges quickly but also has better solution.

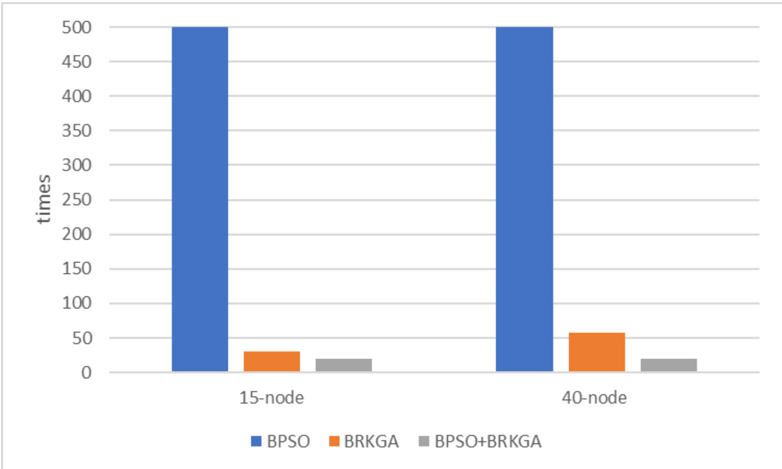

Fig. 11. Comparison of TDMA iterations

6 Conclusion

To optimize contend-free slot scheduling in Ad hoc, a TDMA scheme based on BPSO and BRKGA is proposed. Firstly, apply random permutation and greedy method to generate a set of valid but non-optimal individuals. Next, BPSO is used to generate a good TDMA scheduling close to the optimal solution. Next, the individuals are classified into one elite group with the best fitness and one rest group. Then, the population evolves until the end condition is met. At each iteration, individuals are sorted by fitness. Next, all of the elite group are stored to next generation. In addition, P_m mutant offspring are created in the same method as the initial solution. Next, the remaining P_c offspring are generated through crossover. We compared the BPSO+BRKGA TDMA scheme with TP-TDMA, N-TDMA, BPSO-TDMA and BRKGA-TDMA in terms of frame time, capacity, utilization and converge. The simulation results demonstrate that the BPSO+BRKGA TDMA has shorter frame time, iterations and higher utilization than other algorithms in the 15-node network and 40-node network. The dynamic characteristics of Ad hoc, such as mobility, have not been taken into account. In the future, we will discuss how to optimize TDMA in real MANET.

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