

Research Article

The Characteristics of Metaheuristic Method in Selection of Path Pairs on Multicriteria Ad Hoc Networks

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This research analyzes the metaheuristic methods, that is, ant colony optimization (ACO), genetic algorithm (GA), and particle swarm optimization (PSO), in the selection of path pairs on multicriteria ad hoc network. Multicriteria used are signal-to-noise ratio (SNR), load variance, and power consumption. Analysis of the simulation result is done as follows: first, in terms of computing time, the ACO method takes the most time compared with GA and PSO methods. Second, in terms of multicriteria performance, i.e., the performance of SNR, load variance, and power consumption, the GA method shows the same value in each repetition. It is different from ACO and PSO that show varying values. Finally, the selection of the path pairs by the GA method indicates the pairs of the path that are always the same as by the ACO and PSO methods indicate those that vary.

1. Introduction

A metaheuristic method helps in solving the optimization problem. Problems in optimization can be found in many daily life aspects. The kinds of the metaheuristic method are various which are ant colony optimization (ACO), genetic algorithm (GA), and particle swarm optimization (PSO).

The application of ACO is done in the traveling salesman problem by renewing and with the strategy of adaptive pheromone adjustment that is modified [1]. The problem-solving is done in job-shop scheduling with a method that tries to reduce the delay of appointment of process operation through the elitist ant system (EAS) [2] and in vehicle traffic system to guide vehicles so that it can reduce congestion [3]. Furthermore, it is applied to the conical tank system to optimize the parameter in controlling design [4], in a sensor network for node selection that requires smaller energy, reducing packet loss rate [5].

The GA method is applied to measure bandwidth available from cache hit rates with bandwidth as the function of cache hit rates [6] and in an ad hoc network with multiple criteria problem resulted in path pairs that create cooperative communication [7].

Next, the field-effect transistor element (FET) is determined with a modified PSO method. The problem solved is multiple objective optimization problems with Pareto-optimal solution [8]. PSO is applied for instructional optimization problem design that is emphasized in the form and the size of the problem [9]. The application of PSO is to optimize the route of vehicles and salesmen's trip [10]. PSO is applied to plural optimization problems by making it adaptable for inertial weight and acceleration coefficients that change with iteration.

Not only using one metaheuristic method, furthermore, the merging of two metaheuristic methods is also done to solve the optimization problem. The merging of ACO and GA is used to find the solution to the identification problem on fed-batch of *E. coli* MC4110 [11]. Next, the comparison between GA and PSO methods is done. The comparison between GA and PSO methods is done to find out the feature and the effectiveness in the simulation. It is also used to choose path pair in an ad hoc network with multiple criteria with rank sum weights [12].

The results of the review of these studies have not yet used the three metaheuristic methods. In this research, the three metaheuristic methods are applied in the selection of pairs of

tracks on an ad hoc network with multiple criteria. The main contribution of this research is to know the characteristics of ACO, GA, and PSO methods that are analyzed from computing time and performance of multicriteria, such as SNR, load variance, and power consumption. The characteristics of these three metaheuristic methods become very important to acknowledge when choosing an algorithm in finishing one optimization problem.

Section 2 of this paper explains an ad hoc network and scalarization of multicriteria. Section 3 explains the metaheuristic method. Computing time and multicriteria performance or SNR, load variance, and power consumption are summarized in the simulation result in Section 4. In Sections 5 and 6, there are discussion and conclusion consecutively.

2. Ad Hoc Networks and Scalarization

A node communicates with another node and is dynamic and has no infrastructure is a characteristic of an ad hoc network. In the formed communication, the node can act as a source or as a relay or destination. The nodes use broadcast routing and amplify and forward (AF) relays, where the node as the source sends information to each node that has the potential as a relay has, so the information reaches the destination [13]. Broadcast routing is chosen because the data sent could be received by all nodes that are next to each other at the same time, so it will save transmission time.

Nodes on the ad hoc network in communication tend to look for other nodes that are closer to the relay node so that it will form a multihop path, irrespective of 2 hops, 3 hops, 4 hops. The multihop path can search for path pairs that form multihop path pairs. The combination of path pairs that can occur can be in the form of a pair of path consisting of 1 hop with 2 hops, 2 hops with 2 hops, 2 hops with 3 hops, 3 hops with 3 hops, or others. In this research, the maximum number of hops considered for a path is limited to 3. The combination of the path pairs that occur for the 3 hops with 3 hops is $|R(3, 3)| = (N - 2)(N - 3)P_2^{(N-2)-2}$ [12].

Selection of nodes in an ad hoc network to form a path can be done based on the criteria used. In this study, various multicriteria, namely, SNR, load variance, and power consumption, are used. Mathematical equations, path pairs, and optimal path pairs of each criterion used have been determined [12].

Every criterion is arranged to make a scalar form by giving weight on every criterion [14]. The function that minimizes is given a negative mark, while the function that maximizes is given a positive mark. In this research, to obtain fairness of every object problem, weight is given and normalized with the root mean square (RMS). This normalization is used to give a sense of fairness in every criterion.

The scalarization form from the three criteria is as follows [7]:

$$\max F = \frac{w_1 \gamma_R}{\sqrt{E(\gamma_R^2)}} - \frac{w_2 V_R}{\sqrt{E(V_R^2)}} - \frac{w_3 P_{t,R}}{\sqrt{E(P_{t,R}^2)}}, \quad (1)$$

where F states the fitness function; γ_R , V_R , and $P_{t,R}$ state criteria function of consecutively SNR, load variance, and

power consumption; and w_1 , w_2 , and w_3 state the weight to 1, 2, and 3, respectively. In this research, weight is determined by RS weight. RS weight can be determined with the following equation [15]:

$$w_i = \frac{2(m+1-i)}{m(m+1)}, \quad (2)$$

where i states the index of criteria and m states many criteria with $0 \leq w_i \leq 1$ and $\sum_i w_i = 1$. For $m = 3$, the weights that are resulted are $w_1 = 0.500$, $w_2 = 0.333$, and $w_3 = 0.167$.

3. Metaheuristic Methods

Broadly speaking, the optimization problem can be solved by using the exact method and approach method. The word metaheuristic derived from the word meta and heuristic. Meta means a high-level methodology, while heuristics means art in finding new strategies for solving a problem. Metaheuristic is an approach method based on a heuristic method that does not rely on the type of the problem. The metaheuristic method can be distinguished into two which are metaheuristic with single-solution based (local search) and metaheuristic based on population (random search). The examples of a metaheuristic method based on population are ACO, GA, and PSO. This research uses three metaheuristic methods, which are ACO, GA, and PSO.

3.1. Ant Colony Optimization. Ant colony optimization (ACO) is inspired by the behavior of colony of ants. Communication between ants or ants with their environments is based on the use of chemical compound produced by ants. The chemical compound is called pheromone. The ACO algorithm is as follows [16].

The ACO algorithm starts from parameter initialization and pheromone networks. This is done repeatedly iteratively on the cycle so that the path of the first ant is formed and then the path of the ant is made continuously according to local search. Finally, the pheromone network is updated (Algorithm 1).

3.2. Genetic Algorithm. The genetic algorithm (GA) is a random and nonlinear search method based on the principles of natural selection. This method is found by John Holland in around 1960. The proofs of GA start from the coding or parameters coding. Next, the chromosomal generation is done. A chromosomal generation is a group of genetics. The steps of GA are shown in Algorithm 2 [17, 18].

3.3. Particle Swarm Optimization. Dr. Eberhart and Dr. Kennedy developed the PSO algorithm in 1995. PSO inspired the behavior of a flock of birds or school of fish. The PSO algorithm is developed in the form of population-based stochastic optimization.

In PSO, the optimal solution is obtained if the algorithm has reached convergence. If the algorithm has reached convergence, it is influenced by the position and the velocity of the particles. The process of all algorithms can be seen in the PSO algorithm [19, 20] (Algorithm 3).

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Procedure: ACO metaheuristic
Set parameter and initialize pheromone trails
While (termination condition not met) do
    Construct ant solutions
    Apply local search
    Update pheromones
end
end

```

ALGORITHM 1: Algorithm of ACO.

```

Initialize population
Repeat
    Repeat
        Crossover
        Mutation
        Phenotype mapping
        Fitness computation
    Until population complete
    Selection of parental population
Until termination condition

```

ALGORITHM 2: Algorithm of GA.

```

Random initialization of the whole swarm
Repeat
    Evaluate fitness
    For all particles
        Update velocities
        Move to the new position
        Selection best position
        Update velocities and position
    EndFor
Until stopping criteria

```

ALGORITHM 3: Algorithm of PSO.

4. Simulation Results

4.1. Model Configuration. We reviewed an ad hoc wireless network under the outside building condition. The model that is shown in this paper is one of the simulation results that are done for 500 times. Configuration, for example, that was reviewed can be seen in Figure 1. Under the outside building condition, every node is in outdoor with the area of 40 m × 40 m. In that configuration, there are 32 nodes with the random position. Node 1 acts as the source, node 32 acts as a destination, and other nodes act as relays.

Simulation using the parameters that match the WLAN conditions in an ad hoc network is obtained through Matlab version 8.1.0.604 (R2013a) that was done in a computer with the specification of Intel Core i5-3230 M processor at 2.60 GHz CPU and 4 GHz RAM. These parameters can be seen in Table 1.

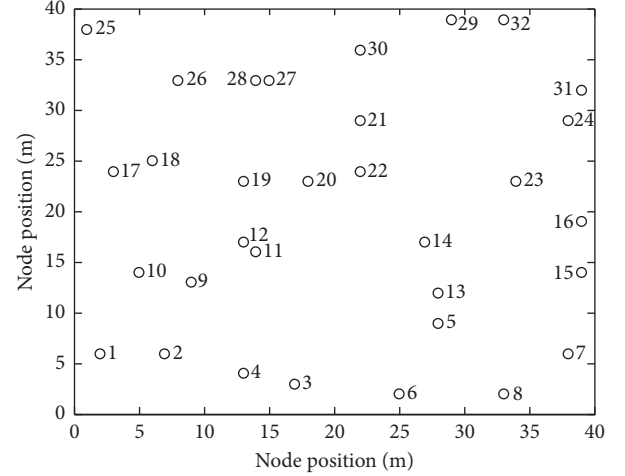


FIGURE 1: Outdoor model configuration.

TABLE 1: Parameter of simulation.

Parameter	Value
Outdoor path loss exponent, α_0	4
Standard deviation of shadowing, φ	8 dB
Wall transmission coefficient, Γ	0.3
Power transmit, P_t	1 W
Transmit antenna gain, G_t	2 dB
Receive antenna gain, G_r	2 dB
Frequency, f	2.5 GHz
Bandwidth, W	20 MHz
Noise, N_0	-101 dBm
Samples, S	1000
Iteration, I_t	100
Replications, R_{ep}	100
ACO parameter α_{ACO}	3
ACO parameter β_{ACO}	1
GA parameter, crossover rate	20%
PSO parameter ρ_{max}	0.9
PSO parameter ρ_{min}	0.4

4.2. Computation Time. The simulation result is based on computing time. The ACO method needs 172.35 minutes with the average time of 103.41 seconds. Other than that, the result of the path pair selection shows that the path pairs chosen vary.

The GA method takes the computing time of 48.53 minutes with the average time of 29.12 seconds. Other than that, the result of path pairs selection shows that the path pairs chosen do not vary.

Meanwhile, The PSO method takes the computing time of 43.82 minutes with the average time of 26.29 seconds. Other than that, the result of path pairs selection shows that the path pairs chosen vary. The computing time with three metaheuristic methods can be seen in Table 2.

4.3. Multicriteria Performance

4.3.1. SNR. In the SNR performance, the ACO method produces a minimum SNR value of 43.11 dB, a maximum SNR value of 45.48 dB, and an average SNR value of 43.75 dB.

TABLE 2: Computation time.

Metaheuristic	Time total (minutes)	Time average (seconds)	Path pairs selection
ACO	172.35	103.41	Variation
GA	48.53	29.12	Same
PSO	43.82	26.29	Variation

In the SNR performance generated, the GA method produces the same SNR value or the value does not change during the computation time of 45.48 dB. So in Figure 2, there is a vertical straight line at the SNR value of 45.48 dB. However, in the SNR performance generated, the PSO method produces a minimum SNR value of 43.60 dB, a maximum SNR value of 45.48 dB, and an average SNR value of 44.49 dB. The cumulative distribution function of SNR performances is produced with the three metaheuristic methods which can be seen in Figure 2.

4.3.2. Load Variance. In the load variance performance, the ACO method produces the minimum of load variance value which is 44.76 Mbps², the maximum value of load variance of 61.42 Mbps², and the average value of 51.74 Mbps².

In the load variance performance produced, the GA method produces the same load variance value or does not change which is 49.76 Mbps² during computing time. So, in Figure 3, there is a vertical straight line at the load variance value of 49.76 Mbps².

However, in load variance performance produced, the PSO method produces the minimum value of load variance which is 44.76 Mbps², the maximum value of 61.42 Mbps², and the average value of 51.92 Mbps². The cumulative distribution function (CDF) is produced by the load variance performances with the three metaheuristic methods that can be seen in Figure 3.

4.3.3. Power Consumption. In the performance of power consumption, the ACO method produces a power consumption of 4 W as much as 57 and 5 W as much as 43. This means that, in choosing path pairs, choosing 2 hops and 3 hops pairs and 3 hops and 3 hops. One of the results from 100 repetitions is the path pair (1-22-32) with (1-9-27-32) for the power consumption of 4 W and path pairs (1-10-20-32) with (1-4-22-32) for the power consumption of 5 W.

With the GA method, power consumption needed is always 5 W from 100 repetitions. So that the power consumption of 4 W does not exist. This means that, in choosing path pairs, 3 hops and 3 hops is chosen. The results of 100 repetitions are path pair (1-9-30-32) with (1-3-22-32) and (1-3-22-32) with (1-9-30-32). These path pairs are chosen alternately.

While with the PSO method, the power consumption of 4 W as much as 5 and 5 W as much as 95. This means that in choosing path pairs, more choose a 3 hops pairs with 3 hops compared to the 2 hops and 3 hops. One result of 100 repetitions is the path pair (1-9-30-32) with (1-22-32) for 4 W power consumption and path pair (1-2-20-32) with (1-9-27-32) for 5 W power consumption.

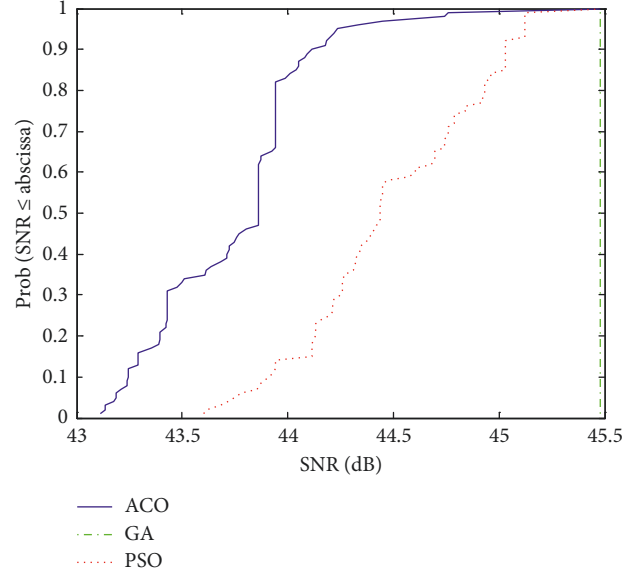


FIGURE 2: CDF of SNR.

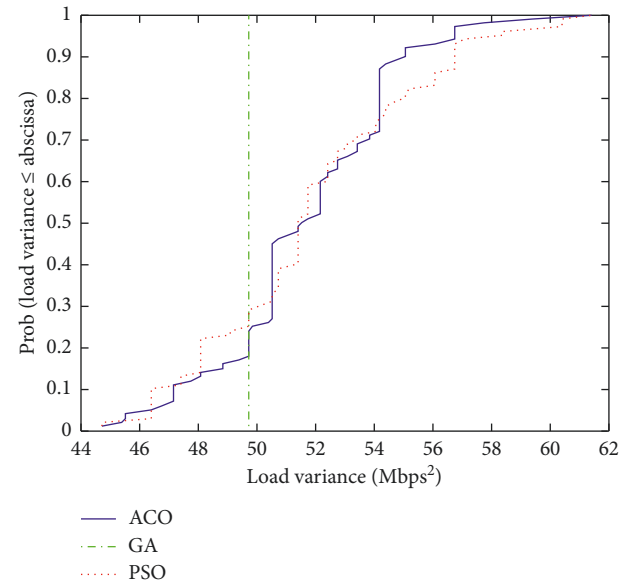


FIGURE 3: CDF of load variance.

The power consumption performance with the three metaheuristic methods produced probability distribution function (PDF) value that can be seen in Figure 4.

5. Discussion

The characteristics of the three metaheuristic methods analyzed from the computing time are that the ACO method takes the most time compared to GA and PSO methods. For GA and PSO methods, GA computing time takes longer than PSO. This can be explained by the algorithm. The ACO method takes the longest computing time because of the pheromones that always look for the closest route. It is shown on pheromone trails in the algorithm. For GA and PSO methods, even they both raise population randomly,

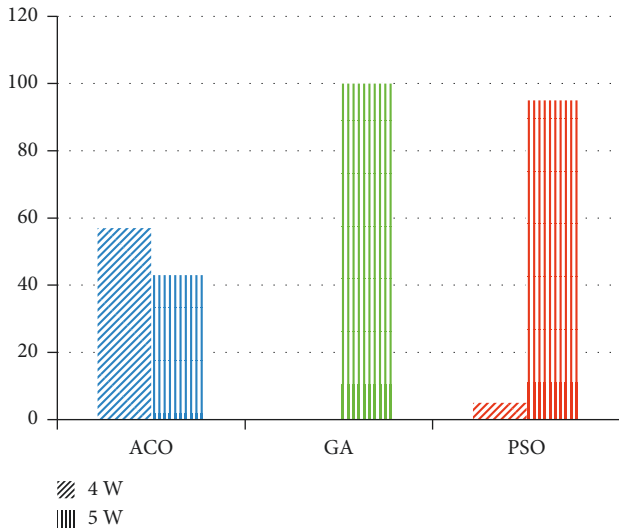


FIGURE 4: PDF of power consumption.

but there is a crossover and mutation in GA, and thus, the computing time takes longer than PSO.

The characteristics of the three metaheuristic modes are reviewed from multicriteria used which are SNR, load variance, and power consumption. The performances of SNR, load variance, and power consumption with the GA method shows the same value on every repetition that produces the result in choosing path pairs always the same or does not change, which is always 3 hops with 3 hops. Using ACO and PSO methods shows variative values, so the path pair selection also varies, which are 2 hops with 3 hops and 3 hops with 3 hops. This is because with the GA method, the unwanted paths will be selected and mutated. It is indicated by crossover and mutation in the algorithm.

The numbers of path pairs from ACO and PSO methods are varied. There are two 2 hops with 3 hops paths, and with the ACO method, it is 57 more than the PSO method with 5. In contrast, the 3 hops and 3 hops path pairs with the ACO method is 43 less than the PSO method with 95. This happens because the ACO method always looks for the closest route where the algorithm showed by pheromone trails.

In terms of performance, the GA method produces a stable performance compared to the ACO and PSO methods. This is indicated by the value of the SNR, load variance, power consumption, and the number of path pairs always the same for each repetition. Besides the stable performance, the GA method produces better performance. This can be seen in the SNR performance which results in the largest SNR value compared to the ACO and PSO methods.

6. Conclusions

This research is about the characteristics of ACO, GA and, PSO methods for selecting path pairs on the ad hoc multicriteria network. The results that analyzed are based on computing time and performance of multicriteria which are SNR, load variance, and power consumption. From the result of the simulation analysis, it can be concluded that

first, from computing time, the ACO method takes the longest time compared to GA and PSO methods. It can be explained by the algorithm. The ACO method takes the most computing time because the pheromones always look for the closest route. Second, from the multicriteria performance, i.e., the performance of SNR, load variance, and power consumption, using the GA method shows the same value on every repetition and using the ACO and PSO methods shows the values that vary because there are crossover and mutation on the GA method. Finally, choosing path pairs with the GA method shows the same path pairs, while the results of ACO and PSO methods are variative path pairs.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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