A Route Discovery of Dynamic Wireless Network Using Particle Swarm Optimization

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Abstract —Route discovery in the routing process is of concern when network topology tends to change. This change can be caused by the movement of the node itself and the non-active node. This study aimed to propose a route selection technique using fixed particle swarm optimization (fixed-PSO). This algorithm was modeled in a purpose function, i.e. the minimum distance from the origin to the destination node. To demonstrate the performance of this mechanism, two scenarios used in the simulation. The first scenario used a 25-node in usual state topology where all the nodes in the network were connected and the second scenario used the same number of nodes representing abnormal conditions by disabling some nodes in the network. The simulation results showed that in general, the minimum distance of route selection of both scenarios was obtained in the first scenario (normal condition). More relay nodes were needed when the conditions were not normal. Similarly, when the node transmission coverage was shortened, more relay nodes were required to reach the destination. The fixed-PSO technique can be applied to active mobile network topologies while nodes join or leave the group unexpectedly.

***Index Terms*—**dynamic, wireless network, route discovery, particle swarm optimization

I. Introduction

A network can be illustrated in the form of a connected or disconnected graph. The main characteristic of the network is the frequency of nodes joining or leaving the group hence the network topology is always changing. The connectivity between them can be connected or disconnected because of the movement of each node approaching or away from its group [1], [2]. The process of route discovery until the delivery of a message packet from a node to other which members in the network becomes the main priority of the role of a routing protocol. In wireless networks, the challenge of route discovery mechanisms becomes more complicated due to the ever-changing topology. Some previous studies offer route discovery solutions with hybrid methods of the existing routing protocols and optimizations. The combination of these methods aims to determine the shortest path with minimum time required. Some performance metrics are used such as packet delivery time, an end to end delay, and throughput [3]. Figure 1 illustrates a dynamic wireless network in which a source node sends a message packet to the destination node through the relay nodes included in a range of the transmission.

Similarly, route discovery performance of location-aided routing 1 (LAR-1) combined with probabilistic algorithms showed that the resulting hybrid algorithm reduced the number of retransmissions compared to LAR-1 [4]. The same result was shown by the Breadth Fixed Gossip (BFG) mechanism, capable of reducing retransmission and transmission failure to be smaller compared to the performance of depth-first search and Gossip [5]. Meanwhile, a proposed Dichotomic Route Request (DRREQ) algorithm aimed to reduce the number of Route Request Packet (RREQ) messages and to affect the energy consumption in various scenarios [6].

Various objectives are to be achieved in the implementation of PSOs in wireless sensor networks like getting the best position of sensor nodes for better connectivity [7]. Optimization of energy savings is also highlighted in the sensor network due to the exchange of data on various applications among sensors. A clustering mechanism is offered to address the problem with the K-means clustering algorithm and the PSO [8], [9], as well as [10] to investigate the PSO algorithm combined with the distance effect routing algorithm for mobility (DREAM) and simple forwarding over trajectory SIFT) on the vehicular ad hoc network (VANET). This PSO implementation aimed to localize the network for navigation decisions to reduce congestion and delay, as well as [11] to offer solution to address vehicle routing problems with PSO hybrid and Genetic Algorithm (GA). For route recovery, a proposal is offered using a PSO on a Mobile Ad hoc NETwork (MANET) in which this algorithm can predict lifetime links and nodes by taking into account mobility and energy drain rate [12]. There is a study that develop PSOs with chaos search to solve allocation problems in container terminal systems where chaos search as a local search method is to be spared from non-optimal solution and chaos theory as one of the optimization solutions [13], [14].

The number of studies on PSO development are significant from 2010 to 2014 since it is a simple approach, easy to implement on multi-objective issues in various applications, more computationally efficient,

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robust algorithms based on the movement and intelligence of a group of living things, a form of social interaction, and overcomes various irregular and complex problems such as noisy and change by time [15]-[19].

Therefore the PSO approach becomes an alternative to dynamic wireless networking solutions. In this study, modeling the route discovery becomes the focus of the investigation as the first step offering a comprehensive proposal in the delivery mechanism of the message packet from the source node to the desired destination node.

II. Discovery of Dynamic Wireless Network Route

A. Route Discovery Issues

Route discovery is one of the processes in routing. This process plays an essential role in the delivery of the package that is the demand process to get the best route from several availability of options to the destination [20], [21].

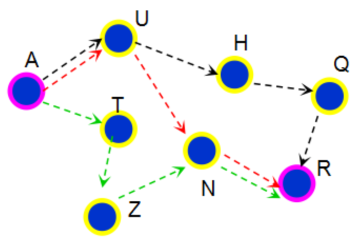

Fig. 1. Route discovery in a network from A to R.

Fig. 1 shows some alternative routes for sending packets from A to R. With the implementation of PSO. It is possible to optimize which route is best by considering some predefined parameters. Problems become complex when network size increases, different transmission coverage for each node, and ever-changing network topology.

B. Dynamic Network

A network can be represented as a form of a graph connected directly or indirectly among nodes. In general, network classification is divided into dynamic, static, synchronous, and asynchronous. From the dynamic network characteristics, a node can join and move out of its group because this movement can cause links between nodes connected or disconnected [1]. In wireless networks, several factors that can cause links between nodes to get disconnected are as follows:

- The transmission coverage of a node cannot reach the nearest neighboring node [22].
- Each node that adjacent/near with a source node still within the transmission range of other node is off, it cannot be used as a relay node.
- Environmental conditions around the node are either sender, receiver or a bad relay, so the signal transmission power is not acceptable.

For the implementation of route discovery model with PSO, it is necessary to add a fixed radius model, a dynamic wireless network realistic model [5], [22], [23]. The route discovery model is the best solution and output model expected. This model is divided into two sub-models (Fig. 2). The optimization model is used to find out the best solution by using PSO and fixed radius model as well as a simulation model and its evaluation. Dynamic node characteristics are determined by three parameters: node's state, node transmission coverage (tx range), and the node's rate. These parameters are used in the simulation and computing fitness to evaluate each route discovery. This study only discusses the optimization model.

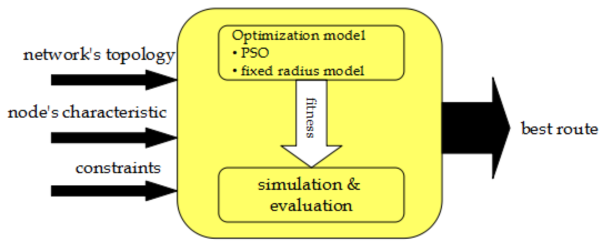

Fig. 2. A framework of route discovery with PSO.

III. Particle Swarm Optimization

The term *particle* here represents the node in the network in which all the particles move in the M dimension to find the global optimality while the term *swarm* is a group, a herd represents a network. In each iteration, the position of each particle is updated based on the three factors: [13]

- On its way (its movement and direction)
- best previous position (based on experience)
- the best previous position of all particles (based on communication with their neighbors)

The search space in dimension M and a swarm has k particles. The position of the i-th particles in dimension M expressed as $X_i = (x_{i1}, x_{i2}, \ldots x_{iM})$ $(i = 1, 2, \ldots, k)$ and its speed is expressed as $V_i = (v_{i1}, v_{i2}, \ldots v_{iM})$ $(i = 1, 2, \ldots, k)$. In each iteration, the speed of each particle is updated according to their best position and the best position known to all particles using the following rules:

$$v_i^{t+1} = \omega . v_i^t + c_1 . rand_1() . (p_i^t - x_i^t) + c_2 . rand_2() . (p_g^t - x_i^t) \quad (1)$$

with symbol ω is called inertia weight, c_1 and c_2 is a constant called the cognitive belief coefficient, usually worth 2. While the function of $rand_1()$ and $rand_2()$ can generate a random number between 0 and 1. x_i^t is the position of the i-th particles on the iteration t. p_i^t is the best local position when the i-th particle has reached iteration t and p_g^t is the global best position of all the particles that reach the iteration t. The position of each particle is updated by adding velocity vectors:

$$x_i^{t+1} = x_i^t - v_i^{t+1} \quad (2)$$

In order to be spared of improper particle positions, the initial and updated positions must fit within the search space limit [X^{min}, X^{max}]. Each particle position located above the search space can be adjusted to:

$$x_{ij} = \begin{cases} X^{\min} & if \quad x_{ij} < X^{\min} \\ X^{\max} & if \quad x_{ij} > X^{\max} \end{cases} \tag{3}$$

The particle velocity in the current position should also be limited to prevent the particle from exiting the search space. So speed should be limited to [-V^{max}, V^{max}] which is defined as $V^{\max} = k \bullet X^{\max} (0 < k \le 1)$. Each particle velocity above space [-V^{max}, V^{max}] can be customized with:

$$v_{ij} = \begin{cases} -V^{\max} & if \quad v_{ij} < -V^{\max} \\ V^{\max} & if \quad v_{ij} > V^{\max} \end{cases} \tag{4}$$

IV. Fixed-PSO

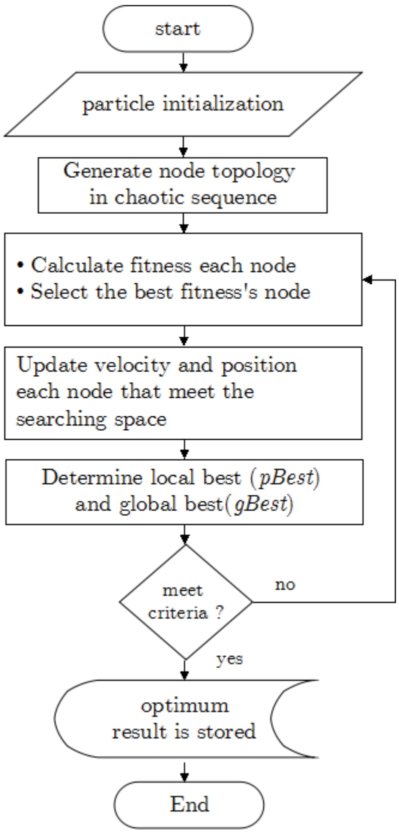

Fig. 3. Flowchart of fixed-PSO.

The proposed route discovery mechanism is a combination of fixed radius and PSO (Fixed-PSO) models on the network. The fixed radius model is a model of each node that has the same transmission coverage, limiting the message delivery capability to its neighbor. The Fixed-PSO can be explained in the form of the following flowchart. Fig. 3 shows the Fixed-PSO flowchart and the explanations are as follows:

Step 1: Initialization, including the initial position of the node $\left(p_i^1\right)$, swarm size k, X^{min}, X^{max}, V^{max}, initial speed 0, transmission coverage (Tx *range*).

Step 2: Displays the starting position of all nodes.

Step 3: Calculate the fitness of each node and choose the best fitness as p_g^1.

Step 4: Update the position of each node according to equation (3) and according to the search space of equation (5).

Step 5: Evaluate updated nodes to get the best locale (p_{best}) and global (g_{best}).

Step 6: End the simulation when the criteria are met. If not, then repeat step 4.

A. *Swarm Size*

In determining swarm size, time efficiency needs to be considered in computing and get its local optimum. The processing time required for small swarm sizes is little but can be trapped on a local optimum. While large swarm sizes are rarely trapped in local optimum and longer processing times [24]. Twenty-five nodes are used in this study. Although the size of swarms is small, PSO enables them to avoid local optimum too early.

B. *Fitness Function*

The fitness function of dynamic network route discovery is influenced by the followings:

1) The shortest distance is needed because it can impact the time and power efficiency of the node. The longer the route taken will take longer to send the information to the destination. While the other effect is that the energy of the node to remain active is greater to be wasted.

2) Many relay nodes are used to reach the destination. The more nodes needed, the greater the delay for information transmission. Therefore, a small number of relay nodes makes sending messages faster. Based on these two things, the fitness function is as follows:

$$\min f(x_i) = \sum_{i=1}^{j} D(x_{ij}) + d\left(x_j\right) \tag{5}$$

where $f(x_i)$ is the fitness function of particle *i*. $D(x_{ij})$ declares the distance between nodes *i* to *j* using the Euclidean formula, meanwhile $d(x_j)$ declares the distance of the last node to the destination node *j*.

C. *Inertia Weight*

Inertia weight is one of the parameters that influence the induced movement of group members. Inertial weight values range from 0 and 1. Refer to the empirical studies that have been performed, the value 0.9 has the smallest error value [24].

V. Simulation and Results

The simulation of dynamic network route discovery by applying PSO method and PSO chaos is done in 2 scenarios. First, randomly generating 25 nodes in an area of 60×60 (in km²) where all nodes have connectivity with other nodes. Each node moves randomly arranged in 24 states (assuming the node changes its position 24 times in equal time over a 24 hour period) and moves as far as 18 km so that each node is moving at a speed of 5 m/s (see Table I). The first network topology scenario is shown in Fig. 4 where all nodes are connected and can reach all neighbor's nodes. In the second scenario, nodes are generated like the first scenario, the direct-connected between a source and destination nodes is active, while the relay nodes are active and inactive, expressed in an on-off matrix (Fig. 5).

TABLE I: SIMULATION PARAMETER

Parameter	Value
Number of nodes	25
Area	50×50 km^2
Origin node	1
Node speed	1-5 m/s
Number of states	24
Transmission coverage	15 km

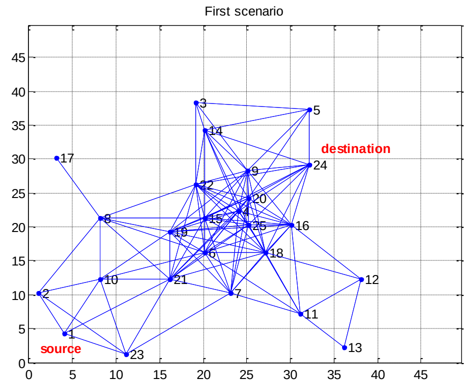

Fig. 4. A scenario of PSO network topology

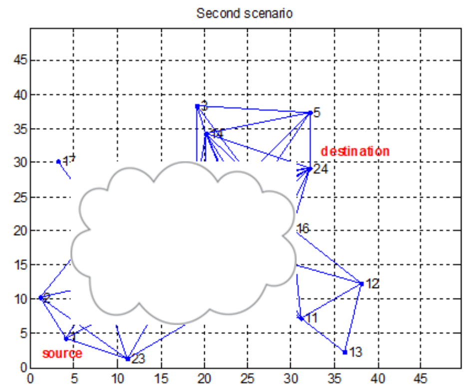

Fig. 5. A scenario of fixed-PSO network topology

Simulations were performed to evaluate the purpose function (equation 6) of each method, i.e. PSO and fixed-PSO. The simulation result using the PSO method are shown in Table II - VI.

TABLE II: PSO SIMULATION RESULTS

Dest. node	Number of a relay node	Distance (km)
2	0	6.50191 - 7.79377
3	2	27.0938 - 41.1408
	3	44.3861 - 47.898
4	1	26.2733 - 27.2619
	2	27.5296 - 28.6704
5	2	43.4943 - 44.2365
	3	43.7605 - 45.8586
6	1	20.0791 - 21.4901
7	1	20.7609 - 28.2158
8	1	17.2686 - 23.2352
9	2	32.4292 - 33.8001
10	0	8.6378 - 9.70528
11	2	30.2409 - 38.0152
12	2	35.8238 - 39.6303
	3	41.0352 - 46.7739
13	2	34.0319 - 41.9608
	3	37.3017 - 45.683
14	2	36.7992 - 36.9765
	3	39.8888 - 40.2173
15	1	24.0585 - 24.349
	2	24.2129 - 25.5579
16	2	31.1269 - 36.9044
17	2	27.0938 - 30.3554
18	1	26.1269 - 29.1201
	2	31.3114 - 32.304
19	1	19.8704 - 21.807
20	1	28.6201 - 29.5099
	2	29.4645 - 32.0585
21	0	14.4222 - 14.4949
22	1	28.7344 - 28.8369
	2	27.4515 - 29.1027
23	0	4.61697 - 14.4806
24	2	36.9956 - 38.0666
	3	38.1088 - 43.518
25	1	26.4638 - 27.3399
	2	28.4236 - 33.8747

The simulation results show that the greater the speed of nodes in a network, the distance traveled to reach the destination node can be shorter or farther. This is due to the movement of neighboring/relay nodes able to approach or get away from the destination node.

Some points of concern from Table II are as follows:

- A node can reach destination nodes up to 14.5 km.
- The more the number of relay nodes, the farther the distance between the origin node to the destination.
- To reach the destination node, the maximum relay nodes needed are only 3 nodes.

Referring to Table III, a route from node 1 to 24 can be explained here. There are several route options to node 24. With fewer relay nodes, the distance traveled is shorter. In accordance with equation 6, the sum of the distances between the node to a destination node is chosen with the smallest value (route 1). Simulation is also done on the transmission range (Tx range) <15. It turns out that the required relay node is more than the Tx range = 15.

TABLE III: ROUTE OPTIONS OF NODE

Route	Node	Distance (km)	Total of distance (km)
1	1 – 21	14.4222	37.8585
	21 – 4	12.8062	
	4 – 24	10.6301	
2	1 – 21	14.4222	38.0667
	21 – 20	15.0423	
	20 – 24	8.60233	
3	1 – 10	8.9443	41.6645
	10 – 6	12.6491	
	6 – 9	13.0000	
	9 – 24	7.0711	
4	1 – 10	8.9443	42.8296
	10 – 19	10.6301	
	19 – 16	14.0357	
	16 – 24	9.21954	

While in the second scenario, the0 chaos state on a network is assumed that the condition of relay or neighbors' nodes is off. If one of the neighbors' nodes is off, the network will become chaotic, so it must be set from the beginning of each change of state. If there are 24 conditions and moving, it is possible for each condition to go through a different route. As a result of this condition, the route to destination becomes broken, and information cannot be transmitted. For example, the origin of node 1 and destination is node 24, and there are several routes selected when node 21 is off.

Meanwhile, in Table IV, there are results of several node route options when node 21 is off.

TABLE IV: ROUTE OPTION (NODE 21 IS OFF)

Route	Node	Distance (km)	Total of distance (km)
1	1 − 10	8.9443	41.6645
	10 −6	12.6491	
	6 −9	13.0000	
	9 − 24	7.0711	
2	1 − 23	7.61577	44.0419
	23 − 7	15.0000	
	7 − 16	12.2066	
	16 − 24	9.2195	
3	1 − 2	6.7082	45.1713
	2 − 8	13.0384	
	8 − 22	12.083	
	22 − 24	13.3417	
4	1 − 10	8.9443	38.4723
	10 − 19	10.6301	
	19 − 20	10.2956	
	20 − 24	8.60233	
5	1 − 10	8.9443	42.82964
	10 − 19	10.6301	
	19 − 16	14.0357	
	16 − 24	9.21954	

TABLE V: ROUTE OPTIONS (NODE 21 AND 10 ARE OFF)

Route	Node	Distance (km)	Total of distance (km)
1	1 − 23	7.61577	44.0419
	23 − 7	15.0000	
	7 − 16	12.2066	
	16 − 24	9.2195	
2	1 − 2	6.7082	45.1713
	2 − 8	13.0384	
	8 − 22	12.083	
	22 − 24	13.3417	
3	1 − 23	7.6115	59.5282
	23 − 2	13.4536	
	2 − 8	13.0384	
	8 − 22	12.0830	
	22 − 24	13.3417	
4	1 − 23	7.61577	45.3605
	23 − 7	15.0000	
	7 − 20	14.1421	
	20 − 24	8.60233	
5	1 − 23	7.61577	48.4398
	23 − 7	15.0000	
	7 − 15	11.4018	
	15 − 24	14.4222	

From many alternative nodes, the shortest distance is selected. When compared to Table III, further distances are taken to achieve the goal. Route 4 becomes an option when node 21 is off. When 2 nodes (21 and 10) are off, the alternate route becomes as listed in Table V. The simulation results when 3 nodes are disabled (off) as listed in Table VI.

TABLE VI: ROUTE OPTIONS (NODE 21,10, AND 23 ARE OFF)

Route	Node	Distance (km)	Total of distance (km)
1	1 − 2	6.7082	45.1713
	2 − 8	13.0384	
	8 − 22	12.083	
	22 − 24	13.3417	
2	1 − 2	6.7082	46.42222
	2 − 8	13.0384	
	8 − 15	12.000	
	15 − 24	14.4222	
3	1 − 2	6.7082	52.8177
	2 − 8	13.0384	
	8 − 6	13.0000	
	6 − 9	13.0000	
	9 − 24	7.0711	
4	1 − 2	6.7082	46.89074
	2 − 8	13.0384	
	8 − 19	8.24621	
	19 − 20	10.2956	
	20 − 24	8.60233	
5	1 − 2	6.7082	48.45001
	2 − 8	13.0384	
	8 − 19	8.24621	
	19 − 25	9.0554	
	25 − 24	11.4018	

From the simulation results when some nodes are off, it can be concluded as follows:

- The relay nodes needed to reach the destination can be more or equal before it is off but the distance traveled is further.
- Similarly, when the scope of transmission is minimized, the route reaches the destination longer because the required relay nodes are getting more.
- When the scope of transmission is minimized, more relay nodes are required to reach the destination.

When compared to both scenarios and implementation methods, the condition of the network topology is different. The second scenario is more complex so that the simulation results produce different things. By deactivating one of the nodes (node 21), the selected route to node 24 becomes longer. The conditions are getting worse due to deactivating other nodes so that the route selected is longer. The application of the two mechanisms is different but it can be used as an alternative. Both of these mechanisms can be used, but the CPSO fix becomes the main alternative for more extreme/abnormal conditions.

VI. CONCLUSIONS

Dynamic networks are networks that are always changing because node movement or state is disconnected or off. This is possible because nodes can get closer or move away from the group. Or for the purpose of resource efficiency, a node needs to be in an off state. The fixed-PSO approach allows route discovery in a dynamic network but it is somewhat normally different from PSO standard technique because, in this technique, the nodes are allowed to move as they wish and not update their position.

Route selection becomes significant in the transmission of message packets in wireless networks. The simulation that has been done to reach the destination node is an origin node when its transmission coverage can reach the destination node, and it will directly send the message. However, if outside the scope of transmission, it requires relay nodes (intermediaries). The number of relay nodes depends on topology conditions, speed, and state of each node in the network. As a result, the higher the speed, the more unstable the route, changing every situation, so the number of relay nodes can be less or more than before. Fixed-PSO can be applied, choosing the shortest route to reach the destination. It can be lowered from the shortest distance variable to obtain time variable, other than that. It also takes into account variable cost for fuel or energy efficiency during the node moves.

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