Using Particle Swarm Optimization for Enhancing the Hierarchical Cell Relay Routing Protocol

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Abstract—In mobile ad hoc networks (MANETs), the maximum transmission radius is generally used for transmission. The advantage is that each mobile node can communicate with more mobile nodes within the transmission range and packets can reach the destination rapidly in fewer hops. However using the maximum transmission radius will induce high power consumption. We proposed the Hierarchical Cell Relay (HCR) scheme earlier, which is a hierarchical topology routing protocol for the MANETs. In order to enhance the performance of HCR, in this paper we use the Particle Swarm Optimization (PSO) algorithm to find a suitable transmission radius for each node. The nodes do not use maximum transmission radius in order to prolong the network lifetime. In addition to comparing the enhanced HCR with the original HCR, we also compare it to another hierarchical topology routing protocol—Adaptive Cell Relay (ACR). The comparison results show that using PSO in HCR can reduce energy consumption without sacrificing the packet transmission delay.

Index Terms—particle swarm optimization (PSO), HCR scheme, mobile ad hoc networks (MANETs), energy consumption.

I. INTRODUCTION

In mobile ad hoc networks (MANETs), the topology of routing protocols can be divided into two categories, flat and hierarchical. Generally, flat topology routing protocols are worse in regard to scalability [3] [8]. This means that network performance will descend rapidly as the network area or nodes increase. Relatively, hierarchical topology routing protocols reduce the size of routing tables, so they have better scalability [2] [4] [11] [16]. In addition, it has been proven that routing protocols using geographic location information on MANETs are useful for scalability and routing strategy [1] [6] [8]. The Hierarchical Cell Relay (HCR) [12] is a hierarchical topology routing protocol which utilizes the Global Positioning System (GPS) to locate the mobile node position. In HCR, the entire network region is divided into multiple regular triangles of equal size, called cells. The side length of cell is equal to the node transmission radius, as illustrated in Fig. 1. The main idea of HCR is to relay the route discovery packets or data packets in selected cells which is determined by the direction from source node to the destination. By restricting packet forwarding in certain cells, HCR can avoid the considerable overhead resulting from complete flooding.

In a general routing strategy, every node uses the maximum

radius to transmit packets. The advantage is that more nodes will be in its transmission range and packets use fewer hops to arrive destination. The disadvantage is that large transmission radiiuses consume more energy. On the other hand, while a shorter transmission radius can reduce the energy consumption, the hop counts of routing path will increase, making the packet delay time longer.

Particle Swarm Optimization (PSO), introduced by Kennedy and Eberhart [7] in 1995, was inspired by the paradigm of birds flocking. It is a population-based and self-adaptive search optimization technique. In PSO, particle represents a candidate solution, and the entire candidate solution set is called a swarm. Each particle first tries to return to its own previous best position and also attempts to move to the best position of all particles. The whole action of the swarm is rapid concentrating on probable regions of search space. This evolutionary computing method is useful in searching for the solution space for problems requiring definite optimization targets [5] [9].

To enhance the performance of HCR, we aim to find an appropriate transmission radius to reduce energy consumption and not to increase the packet transmission time. PSO has been used to determine optimum solutions in various domains, including networking [10] [17], and obtained rather good results. In this paper we utilize PSO to find the transmission radius so as to strike the optimum balance between energy consumption and transmission delay in HCR.
The rest of this paper is organized as follows. Section II introduces a number of related works. Section III applies the PSO on the determination of optimum transmission radius in HCR. Section IV demonstrates the simulation results. Finally, section V concludes the paper.

II. RELATED WORK

Many researches indicated that geographic location information can improve the performance of routing in MANETs. Typical routing protocols such as Distance Routing Effect Algorithm for Mobility (DREAM) [1], Location-Aided Routing (LAR) [8], and Greedy Perimeter Stateless Routing (GPSR) [6] are based on the location information.

Combining hierarchical topology with geographic location information, the Multiclass (MC) routing protocol [15] has been applied in heterogeneous MANETs. A routing area in MC is divided into equally sized square cells, and nodes in the network are classified into two types: backbone node (B-node) and general node (G-node). B-node has a wider transmission range (power), higher data rate and processing capability, and is more reliable and robust than G-node. The primary principle is that most routing traffic within an MC routing goes through B-nodes which connect to each other in different cells. However, in realistic MANETs, most nodes have the identical abilities, so the MC routing will lack B-nodes to structure the network.

The Adaptive Cell Relay (ACR) routing protocol [14] is another routing protocol combining hierarchical topology with geographic location information. ACR has two routing strategies: one is the Cell Relay (CR) routing strategy applied in dense networks, and the other is the Large Cell (LC) routing strategy applied in sparse networks. ACR can adjust the routing strategy as global node density changes. Both MC and ACR can send routing packets to neighboring cells only. Since the diagonal is the half of transmission radius, their actual transmission range is smaller than the maximum transmission range. In addition, these two routing protocols take only the maximum transmission range into consideration to transmit packets, so they will consume more energy.

Raza et al. researched the use of PSO to enhance CGSR in a wireless sensor network [10]. Each particle represents the location of each sensor in a cluster and calculates total energy loss as its fitness value. After a number of iterations, all sensors move to their final locations in the setup phase and the sensor which has the global best value will act as the cluster head. Whenever the fitness value of the global best value goes below any of the local best values, the swapping of service will take place.

Jin et al. proposed PCPSO, an improved PSO, for optimizing multiple constrained Quality of Service (QoS) attributes on a multicast routing [17]. In this research, the network is modeled as a weighted graph, and each particle in the swarm represents a multicast tree. PCPSO uses four QoS attributes (delay, delay jitter, packet loss rate and cost) to construct the fitness function. Each particle in PCPSO is updated by a computed probability, which makes converging to the optimum solution faster than the original PSO. Although PSO is applied to each domain, we did not find any research using PSO to find the optimum transmission radius in MANETs.

By raising energy efficiency, Feng et al. [13] tried to find the optimum transmission radius in a rectangular wireless area. There was only one static sink in the corner in that environment. Nodes which were near the sink used a small transmission radius to reduce congestion and energy consumption, and nodes which were farther from the sink used large transmission radius for transmitting farther. It is not similar to our study because we do not consider only one static destination node and we use a uniform transmission radius on all nodes.

III. USING PSO TO FIND OPTIMUM TRANSMISSION RADIUS

In the study, we utilize PSO to look for the most feasible transmission radius for all nodes, and construct the HCR into cell structure based on the transmission radius. We use energy consumption and time delay to evaluate the efficiency of HCR. The scheme is detailed as below.

1) Issue formalization:
PSO defines N particles in a swarm. Each particle is located at D-dimensional coordinates which indicates a D-parameter solution of the problem within the D-dimensional solution space. In our study, the position of particle represents the radius of transmission. We apply the transmission radius given by particle on HCR, and all nodes use the fixed transmission radius until each simulation finish. We use these particles to find the optimum transmission radius to make that HCR has minimum power consumption and end-to-end delay. Since the transmission radius of nodes is the unique parameter that we want to solve, the solution space for our problem is one-dimensional.

2) Particle swarm initialization:
The swarm size N is set to 20 in this study. Particles in swarm are located at random positions in first iteration. In our study, the range of each particle’s position is between 0 and 250 which represents the transmission radius in meter. Each particle has a corresponding velocity \( V \) which is responsible to update the position of particle and initialized to 0.

3) Fitness function design:
Fitness function is used to determine the fitness of the candidate solution (particle). In the study, we use total energy consumption and total delay time to establish the fitness function for determining the fitness of transmission radius represented by particle. Suppose that there are \( m \) nodes and \( k \) data packets in a network environment and the following notations are used.

\[ a) \quad n_i : \text{the } i\text{-th node.} \]
\[ b) \quad \text{pkt}_i : \text{the } i\text{-th packet.} \]
\[ c) \quad E_{\text{initial}}(n_i) : \text{the initial energy of node } n_i. \]
\[ d) \quad E_{\text{init_total}} : \text{the total energy of nodes before simulation.} \]
\[ e) \quad E_{\text{remain}}(n_i) : \text{the remaining energy of node } n_i. \]
\[ f) \quad E_{\text{consum}} : \text{the total energy consumed by all nodes during simulation.} \]
\[ g) \quad T_{\text{arr}}(\text{pkt}_i) : \text{the arrival time of packet } \text{pkt}_i. \]
\[ h) \quad T_{\text{dep}}(\text{pkt}_i) : \text{the departure time of packet } \text{pkt}_i. \]
i) \( D_{\text{total}} \): the sum of end-to-end delay for each packet.

Then, total energy and delay function is

\[
E_{\text{init, total}} = \sum_{i=1}^{m} E_{\text{initial}}(n_i)
\]

(1)

\[
E_{\text{consum}} = \sum_{i=1}^{m} [E_{\text{initial}}(n_i) - E_{\text{remain}}(n_i)]
\]

(2)

\[
D_{\text{total}} = \sum_{i=1}^{k} [T_{\text{arr}}(p_{kt_i}) - T_{\text{dep}}(p_{kt_i})]
\]

(3)

and the fitness function is

\[a(E_{\text{consum}} / E_{\text{init, total}}) + b(D_{\text{total}} / \text{simulation time})\]

(4)

Eq. (1) calculates the total energy of all nodes before simulation. Eq. (2) calculates the total energy consumption by all nodes. Eq. (3) calculates the total end-to-end delay by adding each packet delay. In the fitness function of equation (4), \( a \) and \( b \) are weight constants and \( \text{simulation time} \) is the total time of simulation. By assuming the energy consumption and end-to-end delay are of equal weight, we set both \( a \) and \( b \) to 0.5.

4) Optimum value calculation:

Particle calculates the fitness value of its position by fitness function, and uses the fitness value to determine whether the position is optimum. Thus, we apply the transmission radius given by particle’s position on HCR to calculate total energy consumption and total end-to-end delay in equations (2) and (3). After simulation completed, we substitute total energy consumption and end-to-end delay into the fitness function (equation (4)), and then we can get the fitness value of each particle’s current position. In our study, the particle in better position will have a smaller fitness value, so the particle located in the optimum position will have the minimum fitness value.

After obtaining the fitness value, we determine local optimum values and the global optimum value by the following steps.

a) Local optimum value:

Local optimum is the minimum fitness value of each particle. Whenever a particle gets a new fitness value, the particle compares that value with the local optimum. If the new fitness value is less than the local optimum, the local optimum will be replaced by this new value, and PSO denotes the \( i \)-th particle position as \( P_{\text{best}, i} \). The fitness value calculated in the first iteration will be set as the local optimum.

b) Global optimum value:

After all particles find their local optimums, PSO will use the smallest one as the global optimum. After the next iteration, if the global optimum in this iteration is less than the global optimum in the previous iteration, the global optimum will be replaced by the new global optimum, and PSO will mark the position of that particle as \( G_{\text{best}} \). Otherwise, the global optimum will remain unchanged.

5) Particle updating:

After determining the optimum values, PSO will update the velocity, and then update the particle position by the velocity. The new position of the particle will be closer to the position of the global optimum, and finally the optimum transmission radius for HCR is found. In PSO, both the position of particle and the velocity are indicated by vectors. Let \( P_i \) be the position vector of \( i \)-th particle and \( V_i \) be the velocity vector corresponding to \( P_i \). The updating method is as below:

\[ V_i \leftarrow \omega \cdot V_i + c_1 \cdot r_1 \cdot [P_{\text{best}, i} - P_i] + c_2 \cdot r_2 \cdot [G_{\text{best}} - P_i] \]

(5)

\[ P_i \leftarrow P_i + V_i \]

(6)

In equation (5), \( \omega \) is the inertia weight for the velocity; \( c_1 \) and \( c_2 \) are weight constant. In this paper, we concentrate on whether the optimum transmission radius can be found by PSO, so we set the parameter the same as in original PSO; namely both \( c_1 \) and \( c_2 \) are equal to 2 and \( \omega \) is equal to 1. \( r_1 \) and \( r_2 \) are random values between 0 and 1 which keep particles from falling into the local optimum space. The change of velocity will be affected not only by the local optimum but also by the global optimum of each particle and the last velocity. After getting the new velocity, the particle changes to the new position by using equation (6).

6) Iteration and termination:

After particles updating their position, we obtain new transmission radiuses. By applying these radiuses on HCR, we calculate new energy consumptions and end-to-end delays and finally get new fitness values. Local optimums and the global optimum will be determined again. This procedure forms an iteration. The iterations will continue until the assigned iteration time is reached or the iteration termination conditions are satisfied. In our study, we set the number of iteration to 10 and the termination condition is that the difference between the last global optimum and the current global optimum is less than 1. Finally, the fitness value of the global optimum is the best transmission radius in meter.

IV. SIMULATION

In this section, we evaluate the proposed scheme by using network simulator NS-2. Before using PSO to find optimum transmission radius of HCR, we observe the performance by using some different transmission radius in environment 1 as shown in Table I. Fig. 2 shows that energy consumption gets larger when transmission radius and flow amount increases. Fig. 3 shows that end-to-end delay gets larger when the transmission radius decreases; this is because short transmission radius leads to more hop count. However, the end-to-end delay also increases when the transmission radius gets larger; this is because large transmission radius leads to more interference between nodes.
Next we compare our protocol with ACR. ACR is a routing protocol strategy which also includes a hierarchical structure and cell relaying scheme similar to HCR. We use HCR-PSO to denote our protocol. Tables I and III list two simulation environments; each using four flow amounts: 5, 10, 15 and 20 flows. Environment 1 and environment 2 are of equal density, but environment 2 has more nodes and wider area than environment 1. We calculate the optimum transmission radius by using PSO in each environment. The results are shown in Tables II and IV.

In simulation environment 1 (see Fig. 4) we find that HCR-PSO consumes less energy than HCR. This is because HCR-PSO uses a shorter transmission radius instead of the maximum transmission radius to reduce energy consumption. Due to using maximum transmission radius in ACR and HCR, their energy consumptions are higher than HCR-PSO.

The delay time of HCR-PSO and HCR are only slightly different (see fig. 5). This confirms that HCR-PSO has the capability of finding best transmission radius for save energy, without sacrificing the average end-to-end delay.

To confirm that HCR-PSO can also perform well in environments which have a larger network area and more nodes, we take simulation in environment 2, and do the same comparisons as in environment 1.

When the network area gets larger and nodes increase, the hop count of each path will also increase, and routes will break.
more often. This can infer that there has an optimum transmission radius in such environments which can save more energy and reduce the end-to-end delay. The simulation results using environment 2 are shown in Fig. 6 and Fig. 7 which verify that HCR-PSO can conserve energy consumption and not sacrifice the end-to-end delay.

V. CONCLUSION

In this paper, we use PSO to find the optimum transmission radius in HCR. It does not sacrifice the end-to-end delay but can save energy consumption. Compared to using maximum transmission radius in HCR and ACR, HCR-PSO consumes less energy not only in small-scale environment but also in large-scale environment. This confirms that using PSO can find the optimum transmission radius to conserve total energy consumption.

REFERENCES