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Ant colony-based energy control routing protocol for mobile ad hoc networks under different node mobility models

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Abstract

The energy of nodes is limited in mobile ad hoc networks(MANETs). In order to extend the network lifetime, how to select the best route is a critical issue for routing protocols in MANETs. In this work, we propose the ant colony-based energy control routing (ACECR) protocol to find an optimal route by using the positive feedback character of ant colony optimization (ACO). In our ACECR protocol, the routing choice depends on not only the number of hops between nodes and the node energy, but also the average and the minimum energy of the routes. The performance of our ACECR routing protocols is evaluated in different mobility models. In addition, we do extensive simulations to study the movement characteristics of different mobility models and their effect on routing protocols. Simulation results show that ACECR has a better performance in balanced energy consumption and a longer network lifetime compared with existing protocols.

Keywords: Mobile ad hoc network, Routing protocols, Ant colony optimization, Energy, Mobility model

1 Introduction

A MANET is self-organizing and of a dynamic topology, which enables wireless communication among mobile devices without relying on a fixed infrastructure. Due to limited resources such as power, bandwidth, processing capability, and storage space at the nodes as well as mobility, it is important to reduce routing overheads in MANETs, while ensuring a high rate of packet delivery. Since the battery of nodes is limited, the energy of nodes and the life time of network is a critical problem in MANETs.

Ant Colony optimization (ACO) [1] is a computational model of swarm intelligence which provides efficient solutions to some optimization problems. In ACO routing algorithms, multiple ants created by a node traverse the network to search paths between two nodes. If the ant finds a path, it lays down pheromone on the path. The amount of pheromone depends on the quality of the path such as its number of hops, delay, and energy of nodes on the path. A data packet is transmitted on a link with probability based on the amount of pheromone. ACO routing algorithm exhibits interesting properties for MANETs, as it works in a fully distributed way and provides multi-path routing.

Many routing protocols [2–10] have been studies in networks, routing algorithms for MANETs based on ACO have been proposed in [2–8]. AntHocNet [2] is a hybrid multi-path algorithm with the principle of ACO-based routing in MANETs. It uses forward ant (Fant) to find routes and backward ant (BANT) to build routes from the source node to the destination. In recent years, the power problem in MANETs has been receiving significant attention in mobile nodes. Power management schemes have two objectives [4], which are to minimize the total power consumption in the network and to minimize the power consumption per node. The first method targets to extend the overall network lifetime and the latter aims to extend individual node's lifetime. The overall power consumption reduction can be achieved by two different approaches. An ant-based on-demand energy route (AOER) protocol is proposed for mesh networks [5]. Compared to other ant-based route protocols, AOER needs less memory storages and lower processing capabilities, because the structures of ants can be simplified by the specific inverse pheromone table. An energy-aware ant-based

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routing(EAAR) protocol is proposed in [6]. It takes into account various factors such as the power consumed in transmitting a packet and the residual battery capacity of a node, so that they can increase the battery life of the nodes by reducing the repetitive use of a subset of nodes. The minimum battery energy remaining from the weakest node and the hop-count of the route are used as the metrics for path discovery. An ant-based energy-efficient routing protocol (AEERP) is proposed in MANETs [7], where the route choice is dependent on not only the number of hops between nodes, but also the energy consumed in transmitting packets and the residual energy of nodes. AEERP can balance the energy consumption of nodes in the network and extends the network lifetime.

Generally, a mobility model is designed to describe the movement pattern of nodes in MANETS [11], and to specify their locations, velocities, and accelerations over time. The mobility model is one of the most important factors in evaluating the performance of a routing protocol in a MANET. In this work, we evaluate the effect of existing mobility models on ant colony-based energy control routing protocols through simulations. The rest of this paper is organized as follows. In section 2, we propose ant colony-based energy control routing protocol ACECR. In section 3, we give some simulation results. Section 4 concludes the paper.

2 Ant colony-based energy control routing protocol

The efficient foraging behavior of naturally occurring small-sized and energy-constrained ants is studied in the theory of ACO [1]. ACO uses the concept of artificial ants, which is analogous to the natural ants that behave as packets in MANETs. In ACO-based routing algorithms, pheromone content is used to choose the best paths out of a given network. It can be used to forward data stochastically. Data for the same destination can be spread over multiple paths with more data transmitted on higher quality paths, which results in load balancing. ACO-based routing algorithms perform better in many ways due to their proactive and iterative behavior. These kinds of algorithms also reduce variability and errors in networks by choosing a trusted path which have behaved well for quite some time.

2.1 Data structures of ants

In this section, we propose an ant colony-based energy control routing protocol ACECR. In ACECR, when a source node wants to send a data packet to its destination, it checks its pheromone table and finds the next relay node in the path. If the pheromone table does not have next node to the destination node, the source node will start a path discovery process. The source node sends out a request packet, which is called Fant (forward ant). When a node receives Fant, it will update the node list and record the node which Fant has passed. Each node in networks forwards the Fant packet until it reaches the destination. When Fant arrives the destination node, it will create a new packet which is called Bant (backward ant). The destination will send the Bant back to the source node along the reverse route. Structures of Fant and Bant are shown in Tables 1 and 2, where SID stands for the source ID, DID is the destination ID, Seq is the sequence number of the forward ant (backward ant), HOP is the number of hops from the source node to the current node for Fant or the number of hops from the destination node to the current node for Bant, the path is the listed of node IDs of routing path, E_{min} is the minimum residual energy of nodes in the path, E_{sum} is the summation of residual energy of nodes in the path, and TTL is the living time of the ant.

To maintain the amount of pheromone on a link, each node has a pheromone table that stores the amount of pheromone on each incident link. The pheromone table, as shown in Table 3, is a two-dimensional array, in which the row and the column denote neighboring nodes and destination nodes, respectively. A value ϕ_{nd} in the pheromone table of node u is the amount of pheromone on a link (u, n) in paths to destination d. Thus, the amount ϕ_{nd} of pheromone represents how good the link (u, n) is to transmit a data packet to the destination d. The notations used in this paper are shown in Table 4.

2.2 Route discovery process

To establish a path from a source s to a destination d, source s creates a Fant and broadcasts it to all neighbors of s. The aim of Fant is to search a path from source s to destination d, by traversing the network and establishes the pheromone track to the source node. Node i forwards a Fant according to Procedure sendFant(i), if node i has routing information available for d, the node i will forward it to next node j with probability $P_i(j) = \frac{(\phi_{jd})^\beta}{\sum_{s \in N_i} (\phi_{sd})^\beta}$, where N_i is the neighbor node set of node i, and β is a constant parameter. If i has no pheromone for the destination d (i.e., $\forall j \in N_i, \phi_{jd} = 0$), Fant is broadcasted to all neighbors of node i.

```
 /* Node i sends a Fant*/
Procedure sendFant(i)
1. if i is not a destination, then
2.   if there is an entry for
destination d in pheromone table, then
3.     it selects a next node j with
probability Pi(j)
```

Table 1 Structure of Fant

SID	DID	Seq	HOP	Path	TTL

Table 2 Structure of Bant

SID	DID	Seq	HOP	Path	E_{min}	E_{sum}

```
      and it sends Fant to node j
     else
4.    Broadcast Fant;
     endif
   else
5.   sendBant(i)
   endif
endProcedure
```

During the route request phase, when a node receives a Fant, the operations are done according to Procedure recvFant. It first checks whether the Fant is in the received S_{Fant} set of node i. If the Fant is in S_{Fant}, it denotes that the Fant has arrived at node i, it does not do anything; If the Fant is not in S_{Fant}, it adds its node ID to Fant.Path, then it checks the DID to determine whether the entry is its own ID. If a node is the destination, it will create a Bant to the source node along the discovered path and initialize some parameters such as $E_{min} = E_{sum} = 0$ and $HOP = 0$. If the node is not the destination, it forwards Fant according to sendFant procedure continually.

```
 /* Node i receives a Fant*/
Procedure recvFant(i)
1. if Fant.ID is in S_Fant(i), then return
endif
2. it adds node i to Fant.Path and
Fant.ID to S_Fant(i)
3. If i is the destination d, then
4.    node i creates a Bant,
Bant.E_sum(i) = 0,
5.    Bant.E_min(i) = 0, Bant.HOP = 0,
Bant.Path=Reverse(Fant.Path)
   else
6.     sendFant(i)
    endif
endProcedure
```

When a Fant reaches the destination d, node d creates a Bant as shown in Table 2. The task of the Bant is to return to the source node s along the path that was followed by the Fant and establishes the pheromone track to the destination node. Each node forwards Bant according to procedure sendBant. When a Bant arrives at the node i from its neighbor j, it updates corresponding parameters for path discovered by the Bant according to Procedure recvBant as follows:

$$HOP = HOP + 1, \quad E_{min} = min\{E_{min}, E_{cur(i)}\},$$
$$E_{sum} = E_{sum} + E_{cur(i)},$$
$$E_{avg} = \frac{E_{sum}}{(HOP+1)}, \qquad \phi_{id} = \frac{E_{avg} * E_{min}}{HOP+1}. \quad (1)$$

The pheromone of a node is the maximum pheromone of all paths at this node. When a Bant arrives at a node, it updates all parameters, the node forwards Bant to the next node in the path. When a Bant arrives at the source node, multi-paths have been built and the path discovery process is finished.

```
 /* Node i sends a Bant*/
Procedure sendBant(i)
1. If i is not the source, then
2.   it selects a next node j in
Bant.Path
3.   it sends Bant to j
   endif
endProcedure
 /* Node i receives a Bant from node j*/
Procedure recvBant(i)
1. update parameters of Bant
  Bant.HOP=Bant.HOP + 1,
  Bant.E_min = min{Bant.E_min, E_cur(i)},
Bant.E_sum=Bant.E_sum + E_cur(i),
  E_avg = Bant.E_sum / Bant.HOP,  Bant.phi_id = E_avg*Bant.E_min / Bant.HOP,
2. phi_jd = max{Bant.phi_jd, phi_jd}
3. If v is not the source, then
4.   sendBant(i)
   else
5.   start data transmission
   endif
endProcedure
```

Table 3 Structure of pheromone table at node u

	Destination nodes					
Neighbor	d_1	d_2	$\cdots$	d_i	$\cdots$	d_n
n_1	$\phi_{n_1 d_1}$	$\phi_{n_1 d_2}$	$\cdots$	$\phi_{n_1 d_i}$	$\cdots$	$\phi_{n_1 d_n}$
n_2	$\phi_{n_2 d_1}$	$\phi_{n_2 d_2}$	$\cdots$	$\phi_{n_2 d_i}$	$\cdots$	$\phi_{n_2 d_n}$
$\cdots$	$\cdots$	$\cdots$	$\cdots$	$\cdots$	$\cdots$	$\cdots$
n_k	$\phi_{n_k d_1}$	$\phi_{n_k d_2}$	$\cdots$	$\phi_{n_k d_i}$	$\cdots$	$\phi_{n_k d_n}$

Table 4 Notations used in this paper

Symbol	Comments
Fant	Forward ant
Bant	Backward ant
ϕ	Pheromone of nodes
E_{avg}	The average energy of a path
E_{sum}	The total energy of a path
E_{min}	The minimum energy of a path
$E_{max}(i)$	The maximum energy of node i
$E_{cur}(i)$	The residual energy of node i
$N(i)$	The neighbor node set of node i
HOP	Hop count of a path
$S_{Fant}(i)$	Set of received Fants of node i

2.3 Data transmission and route maintenance

When routes are discovered, the data packets can be sent through one of them. When a node i receives a data packet for a destination d, node i sends the data packet to a neighbor j, which is selected with probability $P_i(j)$. If i has no pheromone for the destination d in its pheromone table, i sends the data packet to a neighbor j, which is selected randomly. If node i has no neighbor, the data packet is discarded. In order to maintain the path and keep alive, the ACECR should update pheromone value dynamically. The traversal of each data packet increases the pheromone value of each link by $\phi_{id} = \phi_{id} * (1 + \Delta_{id})$, where $\Delta_{id} = (E_{cur}(i))^{\beta}$ and β is a constant, generally we set $\beta = 0.1$. To adapt dynamic network change in the ACO routing algorithm, each node evaporates a amount of pheromone at regular time intervals as $\phi_{id} = \phi_{id} * (1 - \theta_{id})$, $\theta_{id} \in (0, 1)$ is evaporation rate.

In order to explain the proposed ACECR protocol, an example network topology is shown in Fig. 1. There are 11 nodes in the network, each node has its energy. We assume that node 1 is the source and node 10 is the destination. When source 1 broadcasts a Fant packet to find the route paths, there are many return ants from destination 10, when Bants arrive at source 1, many paths are discovered with pheromone to the path listed at node 1 in Table 5. According to Table 5, a route table and route selection probability can be obtained by using RecvBant Procedure and probability calculation formula as shown in Table 6. The multiple paths can be used to forward a data packet according to selected probability.

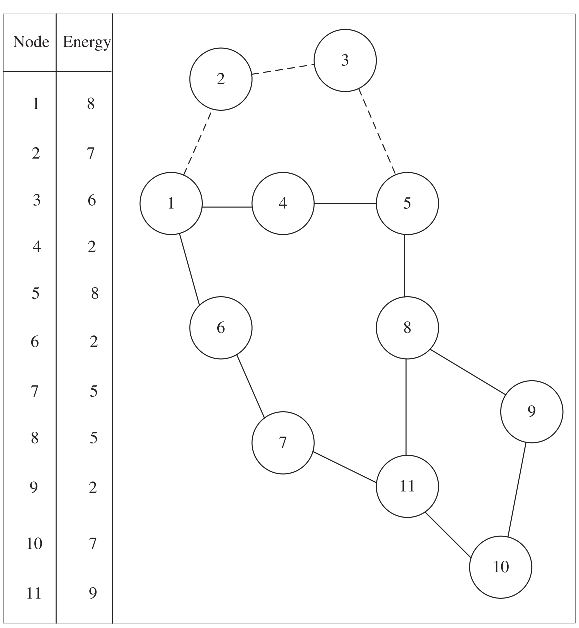

Fig. 1 Network topology and energy distribution

Table 5 Discovered paths from 1 to 10 with pheromone at node 1

Paths	Pheromone
1-2-3-5-8-9-10	14.3
1-2-3-5-8-11-10	14.7
1-6-7-11-10	15.5
1-4-5-8-9-10	2.1
1-4-5-8-11-10	2.6

3 Simulation and performance evaluation for different mobility models

In this section, we compare the performance of our proposed protocol ACECR to other two protocols AOMDA [3] and EAAR [6]. AOMDA protocol extends the single path AODV protocol to compute multiple paths, which always offers a superior overall routing performance than ADOV in a variety of mobility and traffic conditions. EAAR is an ACO-based energy-aware routing protocol, which not only incorporates the effect of power consumption in routing a packet, but also exploits the multi-path transmission properties of ant swarms and use min-max energy to calculate pheromone value; hence, it increases the battery life of a node. Mobility is a natural characteristic of ad hoc networks, it is imperative to use a mobility model that accurately represents the mobile nodes that will eventually utilize the given protocol. The choice of a mobility model can have a significant effect on the performance of an ad hoc network routing protocol. Many mobility models have been reviewed in [11], the mobility models are designed to describe movement pattern of mobile nodes including their locations, velocities and accelerations over time [12]. A mobility prediction-based routing protocol is proposed for DTNs in [13], which will be future research direction for ant conlony-based routing in MANETs. To the best of our knowledge, there is no research on ACO-based energy control routing protocols for different mobility models in ad hoc networks .

In this paper, we do not propose a new mobility model, our target is to measure the influence of the different mobility models to ant colony-based energy control protocols. We discuss following three different mobility models for three ant colony-based energy control protocols in ad hoc networks:

Table 6 Routing table and selection probability at node 1

Destination	Next hop	Pheromone	Probability
10	2	41.7	0.69
10	6	15.5	0.26
10	4	2.6	0.95

(1) Random walk mobility model (Randwalk): each node moves from its existing location to a new location by randomly choosing an arbitrary direction and speed from a specified range [11].
(2) Random waypoint mobility model (Randway): this model is equivalent to the random walk model except that the modification in speed and direction is done after predefined pause time [11].
(3) Reference point group mobility (RPGM): this mobility model represents the random motion of a group of nodes as well as the random motion of each individual node within the group [14]. Group movements are based upon the path traveled by the logical center for the group.

3.1 Performance evaluation of routing protocols

NS-2 simulator is used to evaluate the performance of different protocols. There are 100 nodes in a network, which move over a square $1000m * 1000m$ flat space. For RPGM model, we divided all nodes into four groups, there are 25 nodes in each group. Node's MAC layer uses IEEE-802.11 DCF media access control protocol, the radio transmission range and the interference range of nodes are all set to be 200 meter. Each node has a total energy of $100J$. Mobile nodes are assumed to move randomly according to the random walk, random waypoint, and RPGM mobility models . The speeds of nodes are set to be 1.5, 5, 10, 15, and 20 per second, each node starts moving from a randomly selected initial position to a target position, which is also selected randomly in the simulation. Each packet size is 512-bytes, 10 constant-bit-rate (CBR) flows are generated randomly at a rate of 10 packets per second for 1000 s to test the performance of protocols.

In our simulation experiment, the following metrics are used for our performance study:

3.1.1 Data packet delivery ratio

The percentage of the number of data packets correctly delivered to the number of data packets sent by source nodes.

Figure 2 shows the packet delivery ratio of AOMDV, EAAR, and ACECR protocols at different speeds in different mobility models, where the packet delivery ratio for three routing protocols decreases when the speeds of nodes increase. We observe that the packet delivery ratio for ACECR and EAAR protocols is better than AOMDV protocol, because ACECR and EAAR protocols are energy control routing protocols, they can balance the energy use of the network, and reduce the link break caused by dead nodes. Since both average energy and the minimum energy of a path is considered in ACECR, it can select a path with more residual energy on global view, EAAR only considers the residual energy of nodes instead of paths, the packet delivery ratio for ACECR protocols is higher than that for AOMDV protocol.

3.1.2 Average end-to-end delay

The average time between transmission of data packets at sources and successful reception at receivers.

Figure 3 shows the average end-to-end delay of data packets from source nodes to their destination nodes for AOMDV, EAAR and ACECR in different mobility models, the end-to-end delays decrease with increase of node mobile speeds, because the increase of node mobile speeds will make network topology change, which will

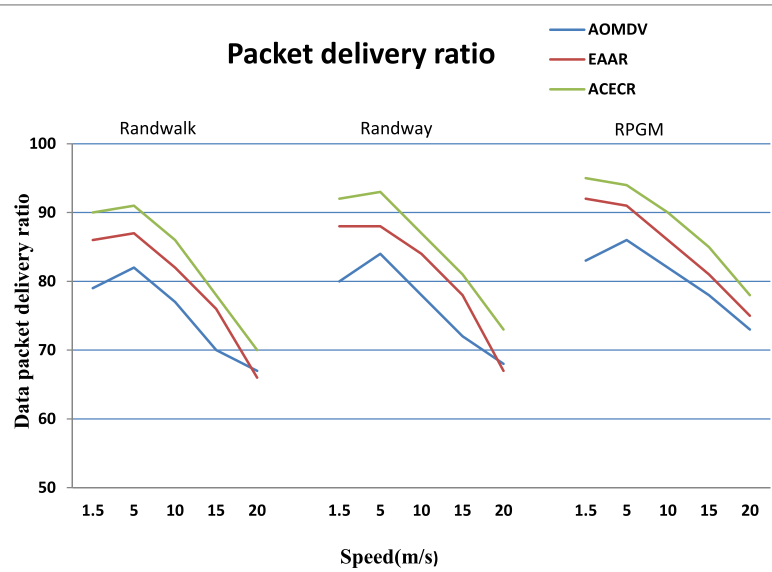

Fig. 2 Packet delivery ratio for AOMDV, EAAR, and ACECR protocols in different mobility models

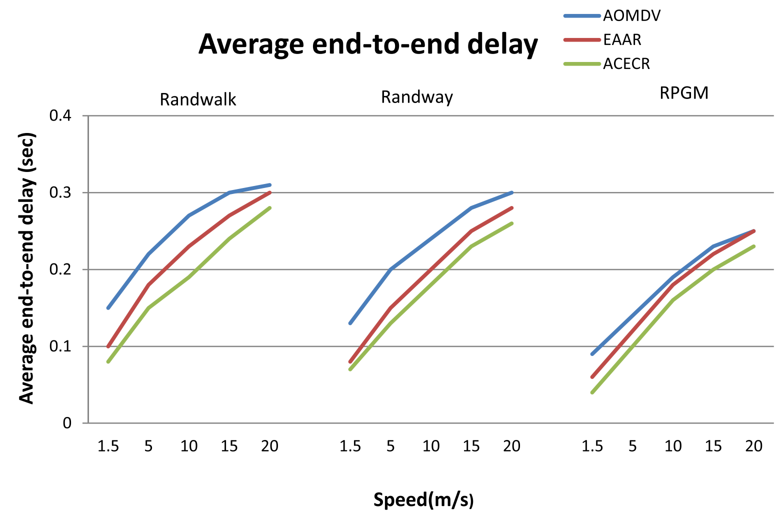

Fig. 3 Average end-to-end delay for AOMDV, EAAR, and ACECR protocols in different mobility models

cause data buffer and route rediscovery. The average end-to-end delay for ACECR and EAAR protocols is less than AOMDV protocol, because ACECR and EAAR protocols are energy control routing protocols, and ant colony-based energy control routing protocol is multi-path routing protocols, they can balance the energy use of the network, and reduce the route rediscovery.

3.1.3 Routing load ratio

The percentage of the number of control packets sent and forwarded by all nodes to the number of all packets (control and data packets) propagated by nodes.

The communication overhead has profound impact on the performance of routing protocols, it represents the total size of exchanging packets in the network. The control packets increase the communication overhead and reduce the throughput of the network. Figure 4 shows that routing overhead of ACECR and EAAR protocols is higher than AOMDV protocol, since ACECR and EAAR protocols are multi-path routing protocols, they use pheromone updating to maintain the route selection.

3.2 Energy consumption evaluation of nodes

Figure 5 shows the dead node ratio for AOMDV, EAAR, and ACECR protocols at different simulation times when nodes are moving at 15-m/s speed. In Fig. 5, the longer the simulation time is, the more there is dead nodes in the network, the ratio of dead nodes of ACECR and EAAR protocols is less than that of AOMDV protocol, since both average energy and minimum energy of a path is considered in ACECR, it can select a path with more residual energy on global view, EAAR only considers the residual

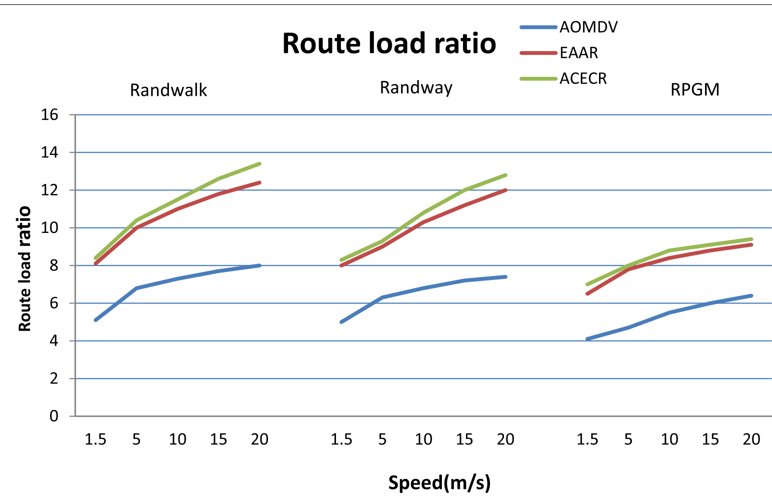

Fig. 4 Route load for AOMDV, EAAR, and ACECR protocols in different mobility models

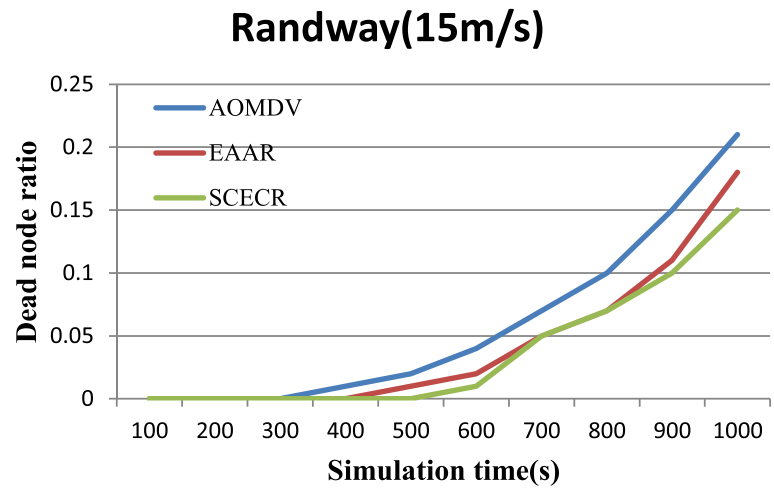

Fig. 5 The node dead ratio for AOMDV,EAAR, and ACECR protocol at different times

energy of nodes instead of paths, AOMDV does not deal with energy balancing problem.

Figure 6 shows the dead node ratio for ACECR protocols under in Randway, Randwalk, and RPGM mobility models at different simulation times when nodes are moving at 15-m/s speed. In Fig. 6, the more stable is the network topology , the less is the dead node ratio. If network topology is unstable, it will rediscover the routing paths and will consume more energy of nodes.

Figure 7 shows the relation between dead node ratio and node moving speed for ACECR protocols under Randway models. In Fig. 7, the higher is the speed of nodes, the more is the dead node ratio, this is because the increase of node moving speed will make network topology is unstable, it will rediscover the routing paths and will consume more energy of nodes.

4 Conclusions

In this paper, we propose an ant colony-based energy control routing protocol ACECR and evaluate the affect of different mobility models to the performance of ant colony-based energy control routing protocols in MANETs. In ACECR, the routing protocol will find the better route which has more energy than other routes through the analysis of average energy and the minimum energy of paths. Simulation results show that ACECR has a better performance than existing routing protocols, such as AOMDV and EAAR, in the number of dead nodes and the packet loss rate, which means that ACECR can extend the network lifetime. In addition, we test the performance of AOMDV, EAAR and ACECR for different mobility models in MANETs. Simulations investigate the movement characteristics of different mobility models and the

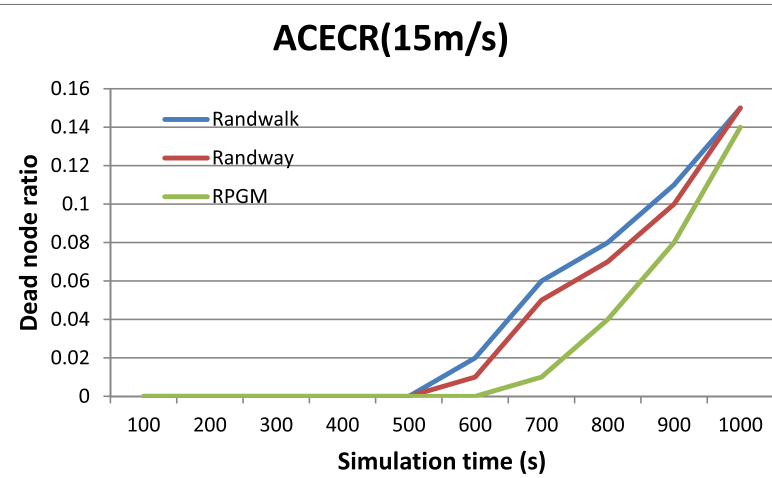

Fig. 6 The node dead ratio for ACECR protocol in different mobility models

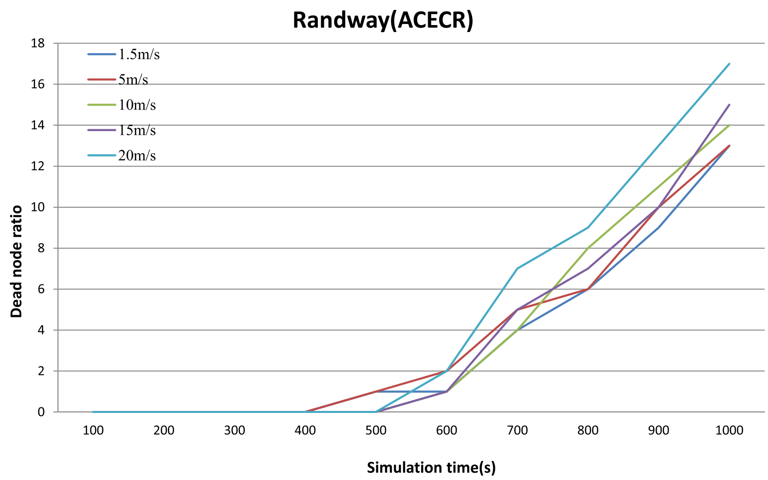

Fig. 7 The node dead ratio nodes for ACECR protocol at different speeds

effect on routing protocols. Simulation results show that ACECR has a better performance than the other two protocols in balanced energy consumption and extended network lifetime.

Competing interests
The authors declare that they have no competing interests.

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