Journal of Advances in Computer Research
Quarterly ISSN: 2008-6148
Sari Branch, Islamic Azad University, Sari, I.R.Iran
(Vol. 3, No. 4, November 2012), Pages: 77-87
www.jacr.iausari.ac.ir

Energy Efficient Routing in Mobile Ad Hoc Networks by Using Honey Bee Mating Optimization

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Received: 2012/09/06; Accepted: 2012/10/24

Abstract

Mobile Ad hoc networks (MANETs) are composed of mobile stations communicating through wireless links, without any fixed backbone support. In these networks, limited power energy supply, and frequent topology changes caused by node mobility, makes their routing a challenging problem. TORA is one of the routing protocols that successfully copes with the nodes' mobility side effects, but it doesn't take into the nodes' energy level. To solve this problem, this paper employs Honey Bee Mating Optimization (HBMO) principles to present a new routing protocol, called HBMO-TORA algorithm. Simulation results show that HBMO-TORA outperforms TORA in terms of packet delivery ratio, network life time, system life time and end-to-end delay.

Keywords: *MANET, TORA, HBMO, Energy-aware, Routing*

1. Introduction

Due to the rapid progress of wireless and mobile communications, mobile ad hoc networks (MANETs) have become very popular in the last few years. A mobile ad hoc network is defined as a collection of mobile and wireless devices that cooperatively forms a temporary and self-organizing network and doesn't need any underlying infrastructure or centralized administration. Indeed, communication between mobile nodes inside the network is wireless and all mobile devices behave as an endpoint or as a router, forwarding messages to nodes within radio range, according to the network needs [1][2]. MANETs are very flexible and suitable for several types of applications. Some important applications of MANETs are military applications, disaster recovery, exploration, law enforcement, sensor networks and multimedia applications [3]. In design of ad hoc networks a critical issue is the effective routing of packets to destinations [4-6]. These challenges have been successfully dealt with by nature, which, as a result of millions of years of evolution, have yielded many biological systems and processes with intrinsic appealing characteristics such as adaptively to varying environmental conditions, inherent resiliency to failures and damages, successful and collaborative operation on the basis of a limited set of rules and with global intelligence which is larger than superposition of individuals, self-organization, survivability, and resolvability [5][6].

In recent years, many routing protocols have been proposed for MANETs [3][6-12]. These protocols can be classified into three different groups: proactive, reactive and hybrid [13]. In proactive routing protocols such as DSDV [8] and OLSR [12], the routes to all the destination (or parts of the network) are determined at the start up, and maintained by using a periodic route update process. In reactive protocols such as AODV [7], DSR [9] and TORA [10], routes are determined when they are required by the source using a route discovery process. Hybrid routing protocols combines the basic properties of the first two classes of protocols into one.

MANETs routing protocols generally suffer from two important issues: frequent topology changes and limited battery capacity of nodes. In recent years, many efforts have been done to design energy-aware routing protocols e.g. OLSR-EA [14], EMRP [15], EAGER [16], DEAR [17], E-TORA [18] and BA-TORA [6].

TORA is one of basic routing protocols of MANETs that offers good stability in facing with high mobility of nodes. In order to add energy-awareness to this routing protocol, this paper borrows some principles of HBMO algorithm [22] and designs energy aware TORA based routing protocol. HBMO is a bio-inspired algorithm that is based on honey bee mating process in the nature. It is a typical swarm based approach to optimization, in which the optimization algorithm is inspired by the mating process of honey bees.

The reminder of this paper has been organized as follows. Section 2 describes motivation of this research. In section 3 we review the TORA routing protocol. Section 4 describes HBMO optimization and in section 5 we will describe our routing protocol. Section 6 explains the experimental framework and discusses the results obtained from the simulation and finally a conclusion is given in section 7.

1. Motivation

MANET has dynamic topology inside which mobile nodes move in different directions, on the other hand in this networks each mobile nodes have limited resources such as battery, processing power and on-board memory. This dynamic topology and limited power resources affect MANET's performance remarkably and reduce its life time and throughput. Routing protocols in MANET is a place that has good potential for upgrade the network performance. At the time TORA is a highly dynamic mobile networking environment. Although TORA can typically provide multiple routes for any source/destination pair, but it always select a route with minimum length. This causes the shorter routes to have a heavy load and hence their energy depletes earlier than others. The result is a decreased network life time and consequently a reduced network throughput. Since the honey-bee mating optimization (HBMO) is a very good optimization algorithm, which acts successfully in nonlinear, continuous constrained problems, this paper uses this algorithm for enhancing TORA routing protocol in mobile ad hoc networks.

2. TORA Routing Protocol

TORA [10] is a source-initiated on demand routing protocol, which uses a link reversal algorithm and provides loop-free multi-path routes to a destination node. TORA is proposed to operate in a highly dynamic mobile networking environment. The protocol performs three basic functions: (a) route creation (b) route maintenance (c) route erasure. Also TORA has three different packets for establishing a path: the query (QRY) packet for creating a route, update (UPD) packet for creating and maintaining routes and clear (CLR) packet for erasing a route.

In creating routes phase, create all routes between source and destination nodes. This phase requires use of the QRY packets and UPD packets. In maintaining routes phase, repair routes that occurred with a link failure. Maintaining routes is only performed for nodes that their height is non-NULL. In erasing routes phase, erase routes that become multipart. By using these three phases, TORA discover and modify routes between source and destination nodes and also clear invalid routes.

Each of the nodes has a height feature in the network. A link is established between the nodes based on the height. Height of each node has five fields as follow: time to break the link (t), the originator id (oid), Reflection indication bit (r), frequency sequence (d) and the nodes id (i). The first three parameters are called the reference level and last two are offset for the respective reference level. Frequency sequence (d) is node distance until destination node. The establishment of the route from source to destination is based on the DAG mechanism thus ensuring that all the routes are loop free. Packets move from the source node having the highest height to the destination node with the lowest height.

A node that needs a route to a destination sends a query packet with its route-required flag. It starts with a query packet followed by an update packet then followed by a clear packet. This operation is performed by each node to send various parameters between the source and destination node. A query packet has a node id of the intended destination. When a query packet reaches a node with information about the destination node, a response known as an update packet is sent on the reverse path. The update packet sets the height value of the neighboring nodes to the node sending the update. It also contains a destination field that shows the intended destination. Links built in TORA are referred to as heights, and the flow is from high to low. At the beginning, the height of all the nodes is set to NULL i.e. (-,-,-,-,i) and that of the destination is set to (0,0,0,0,dest). In creating route phase these parameters adjusted by UPD packet. After routes created, TORA chose a route with lowest height and sent data packets via this route. Figure 1 shows the routes creating process in TORA routing protocol. When routes created, each node has the height structure. Also each node has an array that keeps information of neighbors. In this way, in each node we have information of situation about node and neighbors of node.

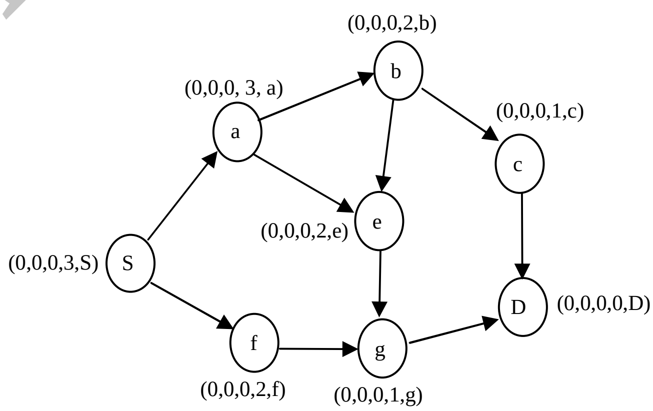

Figure 1. Routes creating process in TORA.

3. Honey Bee Mating Optimization (HBMO)

The honey bee mating process has been considered as a typical swarm based approach to optimization, in which the search algorithm is inspired by the process of real honey bee mating. A honey bee colony typically consists of a single egg-laying long-lived queen, anywhere from zero to several thousand drones (depending on the season) and usually 10,000 to 60,000 workers [19]. Queens are specialized in egg laying [20]. A colony may contain one queen or more during its life-cycle, which are named monogynous and/or polygynous colonies, respectively. Only the queen bee is fed royal jelly, which is a milky-white colored, jelly-like substance. Nurse bees secrete this nourishing food from their glands, and feed it to their queen. The diet of royal jelly makes the queen bee bigger than any other bee in the hive. A queen bee may live up to 5 or 6 years, whereas worker bees and drones never live more than 6 months. There are usually several hundred drones that live with the queen and worker bees. Mother Nature has given the drone's just one task, which is to provide the queen with some sperm. After the mating process, the drones die.

Drones are the fathers of the colony. They are haploid and act to amplify their mothers' genome without altering their genetic composition, except through mutation. Therefore, drones are considered as agents that propagate one of their mother's gametes and function to enable females to act genetically as males. Workers are specialized in brood care and sometimes lay eggs. Broods arise either from fertilized or unfertilized eggs. The former represent potential queens or workers, whereas the latter represent prospective drones.

In the marriage process, the queen(s) mate during their mating flights far from the nest. A mating flight starts with a dance performed by the queen who then starts a mating flight during which the drones follow the queen and mate with her in the air. In each mating, sperm reaches the spermatheca and accumulates there to form the genetic pool of the colony. Each time a queen lays fertilized eggs, she randomly retrieves a mixture of the sperm accumulated in the spermatheca to fertilize the egg.

The queen is pursued by a large swarm of drones (drone comets), when copulation occurs. Insemination ends with the eventual death of the drone, and the queen receiving the ''mating sign''. The queen mates multiple times but the drone, inevitably, only once. These features make bee mating the most spectacular mating among insects.

The mating flight may be considered as a set of transitions in a state-space (the environment) where the queen moves between the different states in some speed and mates with the drone encountered at each state probabilistically. At the start of the flight, the queen is initialized with some energy content and returns to her nest when the energy is within some threshold from zero to full spermatheca.

The queens play the most important role in the mating process in nature as well as in the HBMO algorithm. Each queen is characterized with a genotype, speed, energy, and a spermatheca with defined capacity. The spermatheca is the repository for the drone's sperm after the mating process with the queen. Thus, for a queen's defined spermatheca size, speed and energy are initialized before each mating flight, with random realization in the range of (0.5, 1).

In the algorithm, a drone is represented by a genotype and a genotype marker. Because all drones are naturally haploid, a genotype marker may be employed to randomly mark half of the genes, leaving the other half unmarked. In this case, only the unmarked genes are those that form a sperm to be randomly used in the mating process [21].

Workers that are used to improve the brood's genotype may represent a set of different heuristics. The rate of improvement in the brood's genotype, as a result of a heuristic application to that brood, defines the heuristic fitness value.

Since the drones are assumed to be haploid, after a successful mating, the drone's sperm is stored in queen's spermatheca. Later in breeding process, a brood is constructed by copying some of the drone's genes into the brood genotype and completing the rest of the genes from the queen's genome. The fitness of the resulting genotype is determined by evaluating the value of the objective function of the brood genotype and/or its normalized value. It is important to note that a brood has only one genotype.

Thus, an HBMO algorithm may be constructed with the following five main stages [22]:

1. The algorithm starts with mating flight, where a queen (best solution) selects drones probabilistically to form the spermatheca (list of drones). A drone is then selected from the list randomly for the creation of broods.
2. Creation of new broods (trial solutions) by crossovering the drone's genotypes with the queens.
3. Use of workers (heuristics) to conduct local search on broods (trial solutions).
4. Adaptation of worker's fitness, based on the amount of improvement achieved on broods.
5. Replacement of weaker queens by fitter broods.

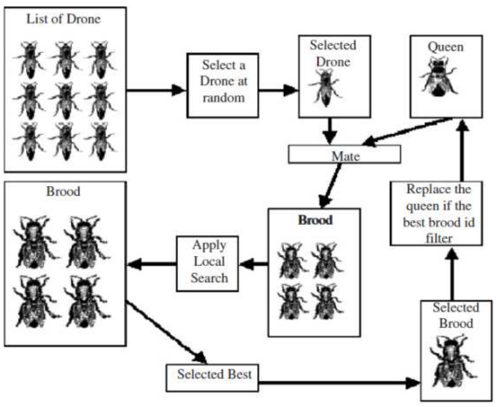

Figure 2. The HBMO process [22].

4. HBMO-TORA Routing Protocol

Although TORA can typically provide multiple routes for any source/destination pair, but it always selects a route with fewer hops. Obviously this puts the shorter routes under a heavy load and hence their energy depletes earlier than others. The result is a decreased network life time and consequently a reduced network throughput. To solve this problem we develop a nature inspired TORA-based energy aware routing protocol that considers jointly routes length and routes' energy level in the route selection process. For this purpose, any node in the route from source to the destination, redefines the routing process as an optimization problem and solves it by using HBMO algorithm. The goal is to select one of the shorter routes that have higher energy level. As a result, load is distributed between various routes and energy of different nodes depletes with similar rates; with hence the network life time increases.

In order to HBMO-based formulation of the routing problem, we need to answer two important questions: (1) how mapping is done from HBMO parameters to the network elements? (2) how the objective function is defined?

To address the first question, consider following mapping from HBMO to MANET:

Queen: Any node of MANET that has a packet to forward and hence runs the routing algorithm is considered as queen bee of the colony.

Drone: Neighbor nodes of sending node (queen node) in the MANET are considered as drone bees of the colony. By this mapping queen node selects one of drone nodes based on its fitness function.

Broods: When one drone nodes is selected to forward the data packet, all the neighbor nodes of this selected node are considered as brood bees of the colony.

To address the second question keep in mind our design goals. Hence, a fitness function considers jointly routes length and route's energy level. Fitness function of drone node i is defined based on its energy and its distance to the destination node as shown in equation (1).

$$fitness_i = \frac{energy_i}{\max\_energy} \times \frac{\max\_distance}{distance_i} \quad (1)$$

Where $energy_i$ refers to energy level of drone node *i*, *max_energy* is the highest energy level among all dron nodes, $distance_i$ is the number of hops from neighbor node *i* to the destination, *max_distance* is the maximum *distance* among the neighbor nodes. In this way, when a queen node wants to select a drone node, it uses above fitness function and selects a drone node with highest fitness.

Hence, HBMO-TORA acts as follows in a node that has a packet to be sent to the destination:

1. Queen node (source node) calculates fitness of all drone nodes (neighbors node) using equation (1) and selects the node with highest fitness value to mate with it (to forward packet to it).
2. By mating queen node with the selected drone node, brood nodes are created. In other words, the neighbors of selected drone node are considered as brood nodes.
3. Data packet is forwarded to the selected drone node. Then this node is considered as queen node and brood nodes are considered as drone nodes.
4. Stages 1-3 are repeated until data packet arrives to the destination node.

5. Simulation Results

Now, we examine the proposed protocol through its implementation in ns-2 [23] environment. This implementation is run by making some modifications over TORA module of ns-2 simulator. We change UPD packet and add a field to carry energy of nodes. As mentioned above energy of adjacent nodes are used in the route creation phase.

This analysis is based on the following simulation setup:

- Network space: 1000m × 1000m
- Number of nodes: Different in various scenarios, but always only 10 nodes are sending packets.
- Simulation time: 500 second
- Traffic model: CBR
- Primary energy of each node: 40 j
- Packet size: 512 bytes
- Mobility model: Random Way Point
- Medium access protocol: IEEE 802.11
- Maximum speed of mobile nodes: 20 m/s

In order to analysis HBMO-TORA's performance we use three different scenarios. In these scenarios HBMO-TORA and TORA are evaluated for wide ranges of "number of nodes", "nodes' pause time" and "traffic rate". In each scenario we compare the proposed algorithm with TORA in terms of four basic performance metrics, namely, packet delivery ratio, network life time, system life time and end-to-end delay which are defined as follow.

1. Packet Delivery Ratio: it is the ratio of number of packets received at the destination nodes to the number of packets sent from the source nodes [24].
2. Network Life Time: it is the time when a node finished its own battery for the first time [25].
3. System Life Time: it is the time when 20% of nodes finish their own battery [25].
4. End-to-End Delay: it is the average time for data packets to travel from the source node to the destination node [24]. To find out the end-to-end delay the difference of packet sent and received time is stored and then dividing the total time difference over the total number of packet received gave the average end-to-end delay for the received packets.

Scenario 1: Performance metrics versus number of nodes

In this scenario HBMO-TORA and TORA are simulated under different numbers of nodes. To this end we fix nodes' pause time at 10 seconds, nodes' sending rate at 10 packets per second and repeat the network simulation for different numbers of nodes i.e. 10, 20, 30, 40 and 50 nodes. Simulation results are shown in Figures 3-6.

From these figures we can find that with increasing number of nodes, performance of network in all cases decrease. Figure 3 shows how the packet delivery ratio of these protocols decreases as the number of nodes increases. But we observe that the packet delivery ratio of HBMO-TORA is higher than TORA algorithm. Fig. 4 shows that the end-to-end delay of HBMO-TORA is lower than TORA. On the other hand Figures 5-6 show that the network life time and system life time of HBMO-TORA are higher than of TORA. This improved performance of HBMO-TORA has roots in this fact that HBMO-TORA includes nodes' energy level in the route selection process.

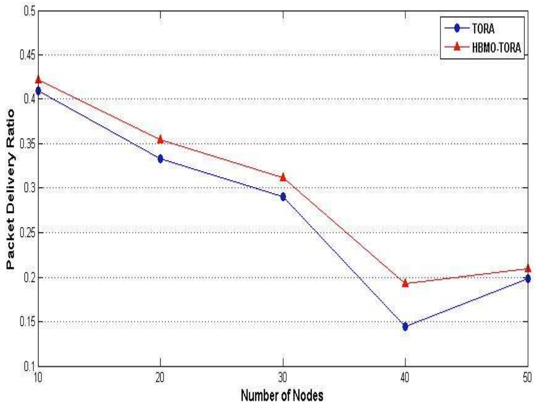

Figure 3. Packet delivery ratio versus number of nodes

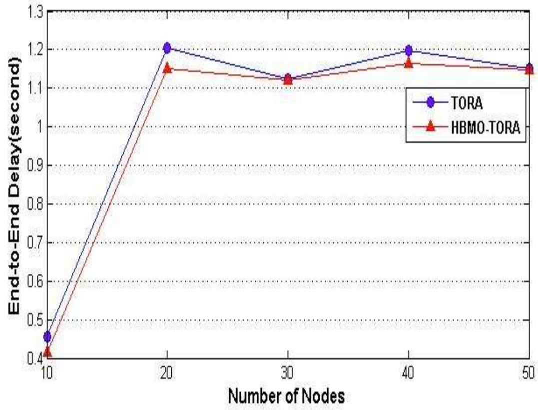

Figure 4. End-to-end delay versus number of nodes

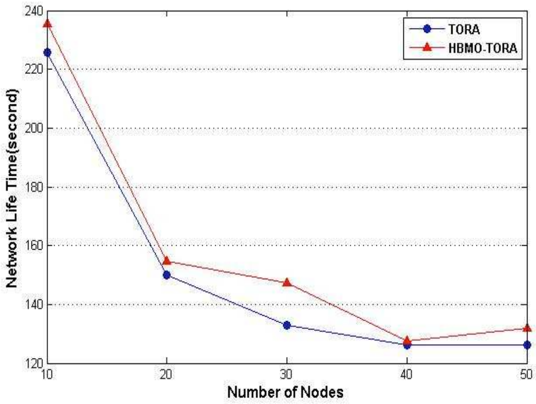

Figure 5. Network life time versus number of nodes

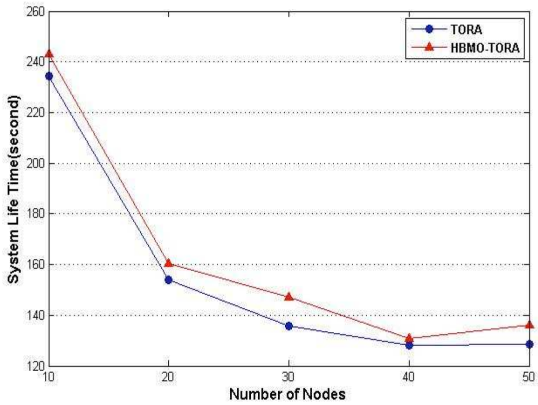

Figure 6. System life time versus number of nodes

Scenario 2: Performance metrics versus pause time

In this scenario HBMO-TORA and TORA are simulated under different pause times. To this end we fix nodes' count at 25, nodes' sending rate at 10 packets per second and repeat the network simulation for different pause times i.e. 0, 10, 20, 30 and 40 seconds. Simulation results are shown in Figures 7-10.

Figure 7 shows that the packet delivery ratio of HBMO-TORA is higher than TORA algorithm. Figure 8 shows how the end-to-end delay of these protocols changes as the nodes' pause time changes. On the other hand Figures 9-10 show that the network life time and system life time of HBMO-TORA are higher than of TORA routing protocol. We can find the reason of this improved performance in this fact that HBMO-TORA selects a route that not only has shorter length but also has an acceptable energy level. This leads to balanced distribution of the network traffic among different routes that causes in turn to an increased network life time.

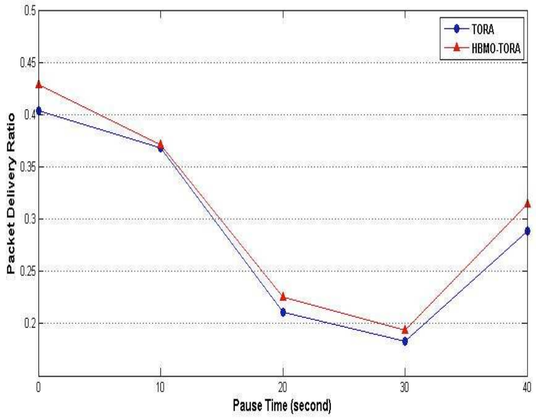

Figure 7. Packet delivery ratio versus pause time

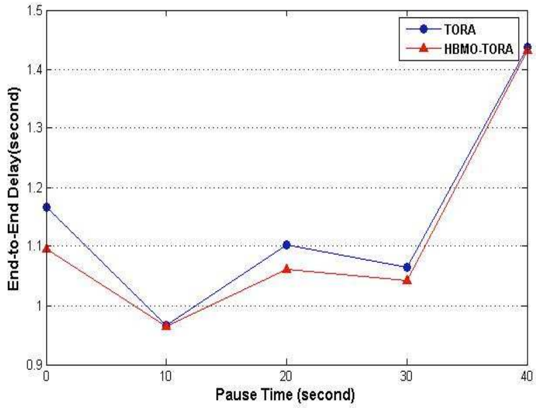

Figure 8. End-to-end delay versus pause time

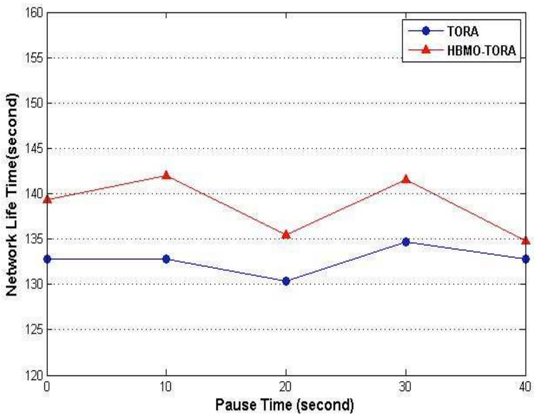

Figure 9. Network life time versus pause time

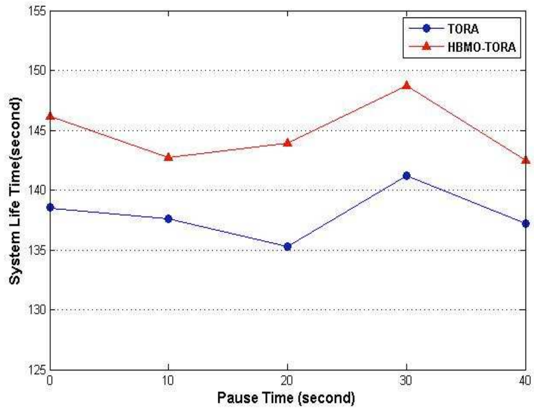

Figure 10. System life time versus pause time

Scenario 3: Performance metrics versus traffic rate

In this scenario we study the proposed routing protocol under different amount of the network load. For this purpose we consider 3 different levels of traffic rates for each node i.e. Low (5 packets per second), Medium (10 packets per second), High (15packets per second) and analyze behavior of TORA and HBMO-TORA under each one of these traffic intensity. Figures 11-14 show the simulation results.

Same as previous scenarios, in this scenario HBMO-TORA outperforms TORA in terms of packet delivery rate, end-to-end delay, network life time and system life time.

From these simulations we conclude that HBMO-TORA has better performance in compared with TORA. Better performance of HBMO-TORA is due to this fact that it uses those routes that have higher level of energy and shorter length. This leads to balanced consumption of energy in various routes and nodes; hence HBMO-TORA experiences less route breakages and achieves better performance.

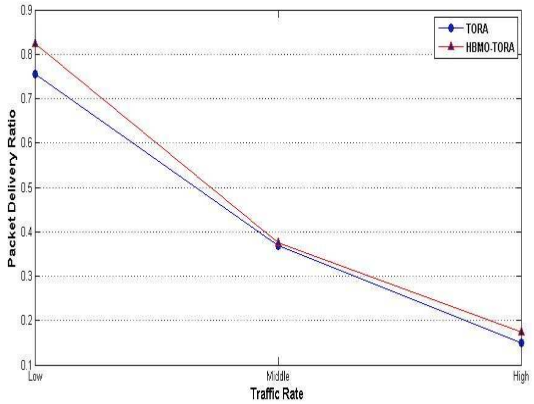

Figure 11. Packet delivery ratio versus traffic rate

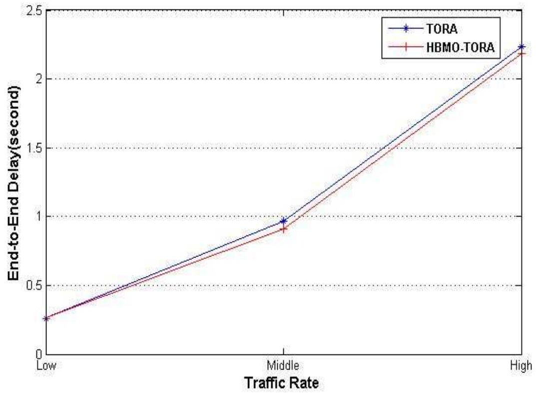

Figure 12. End-to-end delay versus traffic rate

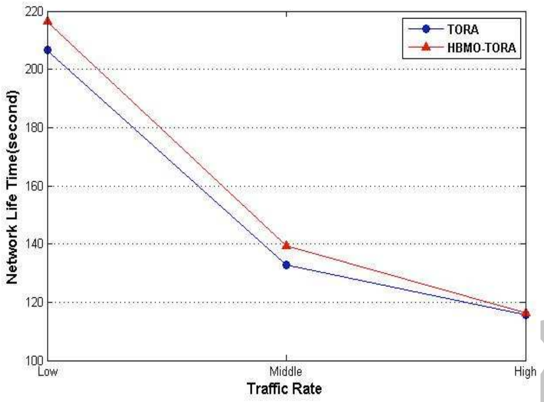

Figure 13. Network life time versus traffic rate

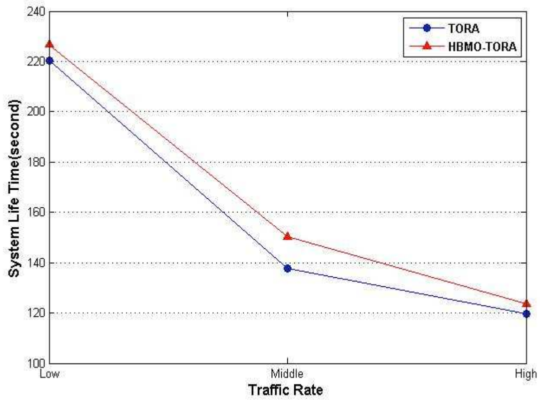

Figure 14. System life time versus traffic rate

6. Conclusion

In this paper we designed HBMO-TORA, an improved version of TORA routing protocol. This improvement achieved using the honey bee mating optimization principles. The HBMO-TORA chooses routes by jointly considering of routes energy level and length uniformly. This causes the load to be distributed uniformly among routes and leads to long life time of the network. Obviously when the network life time increases more packets can be sent over it and hence the performance of the network will be increased. The simulation results indicated that the packet delivery ratio, network life time, system life time and end-to-end delay in HBMO-TORA are better than TORA routing protocol.

8. References

[1] R. Ramanathan and J. Redi, "A Brief Overview of Ad Hoc Networks: Challenges and Directions", IEEE Communications Magazine, 2012, pp. 98-102.

[2] W. Kiess and M. Mauve,"A survey on real-world implementations of mobile ad-hoc networks", Ad Hoc Networks, 2007, pp. 408-413.

[3] B. Safarzadeh,Sh. Jamali and H. Alimohammadi, "A High Performance Scalable QoS Routing Protocol for Mobile Ad Hoc Networks", IJCTA, 2011, pp. 332-339.

[4] M. Abolhasan, T. Wysocki and E. Dutkiewicz, “A review of routing protocols for mobile ad hoc networks”, Ad Hoc Networks 2, 2004, pp. 1-22.
[5] F. Dressler and O.B. Akan, “A survey on bio-inspired networking”, Computer Networks, 2010, pp. 1-20.
[6] Sh. Jamali, S. Jahanbakhsh, “BA-TORA: a Multipath Routing Protocol for MANETs by Inspiration from Bee and Ant Colonies”, Electrical Review, 2011, pp. 183-187.
[7] C. E. Perkins and E. M. Royer, “Ad Hoc On-demand Distance Vector Routing,” In Proceedings of the 2nd IEEE Workshop on Mobile Computing Systems and Applications, 1999, pp. 90-100.
[8] C. E. Perkins and P. Bhagwat, ” Highly dynamic Destination-Sequenced Distance-Vector routing (DSDV) for mobile computers”, In Proceedings of the SIGCOMM ’94 Conference on Communications Architectures, Protocols and Applications, 1994, pp. 234–244.
[9] D. B. Johnson and D. A. Maltz, “Dynamic Source Routing in Ad-Hoc Ad hoc Networks", Mobile Computing, 1996, pp. 153-181.
[10] V.D. Park and M.S. Corson, “A Highly Adaptive Distributed Routing Algorithm for Mobile Wireless Networks”, INFOCOM, 1997, pp. 97-106.
[11] Sh. Jamali, B. Safarzadeh and H. Alimohammadi, “ SQR-AODV: A stable QoS-aware reliable on-demand distance vector routing protocol for mobile ad hoc networks”, Scientific Research and Essays, 2011, pp. 3015-3026.
[12] T. Clausen and P. Jacquet “Optimized Link State Routing Protocol (OLSR).” RFC 3626, IETF Network Working Group, October 2003.
[13] M. Tarique, K. E. Tepe, S. Adibic and Sh. Erfani, “Survey of multipath routing protocols for mobile ad hoc networks”, Journal of Network and Computer Applications 32, 2009, pp. 1125–1143.
[14] Zh. Guo, Sh. Malakooti, Sh. Sheikh, C. Al-Najjar, M. Lehman and B. Malakooti, “Energy aware proactive optimized link state routing in mobile ad-hoc networks”, Applied Mathematical Modelling, 2011, pp. 4715–4729.
[15] M. Li, L. Zhang, V. O. K. Li, X. Shan and Y. Ren, “An Energy-Aware Multipath Routing Protocol for Mobile Ad Hoc Networks”, ACM Sigcomm Asia’05, 2005, pp. 1-6.
[16] Q. Zhao, L. Tong and D. Counsil, “Energy-Aware Adaptive Routing for Large-Scale Ad Hoc Networks: Protocol and Performance Analysis”, IEEE TRANSACTIONS ON MOBILE COMPUTING, 2007, pp. 1048-1056.
[17] A. Avudainayagam, W. Lou, and Y. Fang. "DEAR: A Device and Energy Aware Routing protocol for Heterogeneous Ad Hoc Networks". Proceedings in Academic press Journals of Parallel and Distributed Computing, 2003, pp. 228-236.
[18] F.Yu, Y.Li, F.Fang and Q.Chen, “ A New TORA-based Energy Aware Routing Protocol in Mobile Ad Hoc Networks”, 2007.
[19] R.F.A. Moritz and E.E. Southwick, “Bees as Super organisms”, Springer, 1992.
[20] H.H. Laidlaw, R.E. Page, Mating designs, in: T.E. Rinderer (Ed.), Bee Genetics and Breeding, Academic Press Inc., New York, NY, 1986, pp. 323–341.
[21] H.A. Abbass, “Marriage in honey-bee optimization (MBO): a haplometrosis polygynous swarming approach”, The Congress on Evolutionary Computation, 2001, pp. 207–214.
[22] A. Afshara, O. Bozorg Haddada,_, M.A. Marin˜ ob,c, B.J. Adamsd, “Honey-bee mating optimization (HBMO) algorithm for optimal reservoir operation”, Journal of the Franklin Institute, 2007, pp. 452–462.
[23] NS-2, “The Network Simulator”, http://www.isi.edu/nsnam/ns/.
[24] B. Maqbool, M.A.Peer and M.K.Quadri, “Towards the Benchmarking of Routing Protocols for Adhoc Wireless Networks”, 2011, pp. 28-35.
[25] S. Jahanbakhsh Gudakahriz, Sh. Jamali and E. Zeinali, “NISR: A Nature Inspired Scalable Routing Protocol for Mobile Ad Hoc Networks”, IJCSET, 2011, pp. 180-184.