The Efficient Ant Routing Protocol for MANET

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ABSTRACT

In recent years, mobile computing and wireless networks have witnessed a tremendous rise in popularity and technological advancement. The basic routing problem in MANET deals with methods to transport a packet across a network from source node to destination node. Due to the dynamic nature of MANET, it is difficult to design effective routing algorithms. In this paper, we introduce a novel meta-heuristic on-demand routing protocol Ant-E, using the Blocking Expanding Ring Search (Blocking-ERS) to control the overhead and local retransmission to improve the reliability in term of packet delivery ratio (PDR). This method enhances the efficiency of MANET routing protocol. Ant-E is inspired by the ant-colony optimization (ACO) used to solve complex optimization problems and utilizes a collection of mobile agents as “ants” to perform optimal routing activities. Exhaustive simulations are carried out and it is observed that, Ant-E performs better than other two on demand routing protocols like AODV and DSR.

Keywords: ACO; Ant-E; Routing Protocol; MANET;

1. INTRODUCTION

Ant Colony algorithm tends to provide properties such as adaptivity and robustness, which are essential to deal with the challenges of Mobile Ad hoc Network (MANET). MANET is a communication network of a set of mobile nodes, placed together in an ad hoc manner, without any fixed infrastructure that communicate with one another via wireless links. All nodes have routing capabilities and forward data packets for other nodes in multi-hop fashion. Nodes can enter or leave the network at any time, and may be mobile, so that the network topology continuously changes during deployment. The need for exchange of digital information outside the typical wired office or unarranged environment is growing such as a class of students may need to interact during a lecture; business associates serendipitously meeting in an airport may wish to share files; or disaster recovery personnel may need to coordinate relief information after a hurricane or flood. Each of the devices used by these information producers and consumers can be considered a node in a MANET.

The challenges arise from the dynamic and unplanned nature of ad hoc network are inherent unreliability of wireless communication, the limited resources available in terms of bandwidth, processing power, limited battery power etc., in large scale network. Due to its dynamic nature, a primary challenge of MANET is the design of effective routing algorithm that can adapt its behavior to frequent and rapid changes in the ad hoc network.

Generally three different types of routing protocols are available for MANET; they are proactive, reactive and hybrid routing protocol. In proactive routing protocol all nodes are active and each node discovers route to other nodes in the network before the actual communication request. This leads to less time delay of route discovery during communication request. However, the overhead cost is too high in this case. DSDV [1] is an example of proactive routing protocol. In other hand, reactive routing protocol is on demand basis. All nodes are in sleep mode. The nodes become active as and when they need to communicate with others. Therefore, it produces less overhead but requires more route set up time during communication. AODV is an example of on-demand routing protocol. Hybrid routing protocol combines the advantages of both reactive and proactive routing protocols. ZRP is an example of hybrid routing protocol.

Ant Colony Optimization (ACO)[2][3] is an example of Swarm Intelligence that can be applied to a wide range of different optimization problems, often giving better results. This is based on the study of ant colony behavior. In nature, ants collectively solve problems by cooperative efforts. Each individual ant performs a simple activity that has a random component. However, collectively ants manage to perform several complicated tasks with a high degree of consistency and adaptivity.

ACO protocol for routing in ad hoc network substantially differs from traditional routing protocols. These protocols gather routing information through the repetitive sampling of possible paths between source and destination nodes using artificial ant packets.

Pheromone tables mimics the role of pheromone in nature, with artificial ants being forwarded along them in a hop-by-hop basis using stochastic forwarding decisions and data packets are forwarded stochastically using similar tables, resulting in automatic data load balancing also. ACO routing protocols exhibit some of the properties which are important for MANET routing, such as adaptivity, optimality, robustness, etc., are mainly due to the continuous exploration of the network by stochastically forwarded probing packets known as ants.

Ants are biologically blind and thus the communications between ants are indirect in which they sense and follow a chemical substance called pheromone. Pheromone attracts other ants and therefore ants tend to follow trails that have higher pheromone concentrations as more ants use that route and lay down more pheromone. As a result of this autocatalytic effect, the shortest path will emerge rapidly because a shorter path will have a higher pheromone concentration. After a while, the situation will converge where all other ants would follow only the trail which exudes the strongest scent indicating the best-possible route from the colony's nest (i.e. source) to the food source (i.e. destination end) [4].

The biological ant's problem solving paradigm can be used to solve routing problems in a MANET, by modeling an ant colony as a society of mobile agents. The ant's' inherent ability to find the shortest path from their nest to a food source becomes the key motivation to apply ACO in ad hoc network routing. Based on the local information, it deposits a substantial amount of pheromones on the trail. This information implicitly ranks the path it has traversed. A route with higher pheromone concentration indicates a route of better quality. Therefore traffic can be directed to travel along better routes to reach the destination end. The collection of mobile agents in MANET is inherently scalable and resource efficient and thus can be applied to larger areas. It relies upon pheromone traces that become the routing guide. The ant-based solutions for wireless ad hoc routing are more appealing because they easily fit into the dynamic nature of MANET. It provides adaptivity, flexibility, robustness and even efficiency which are prime requisites in such environment.

We investigate the issue of adaptive routing in MANET, using ideas of ACO mechanisms along with other techniques of Artificial Intelligence (AI) to get a powerful protocol for the MANET. The Ant-E routing protocol combines ideas from ACO routing with techniques from dynamic programming, local retransmission and Blocking-ERS. Through a series of simulation tests, we show that for a wide range of different environments and performance metrics, Ant-E performs better than AODV, DSR.

The rest of the paper is organized as; section 2 discusses related works of on-demand and ant based routing protocols. Section 3 describes the background and analysis of proposed routing protocol. New proposed routing protocol is discussed in section 4. Simulation environment is discussed in section 5 followed by performance evaluation parameters in section 6. Section 7 discusses results of routing protocol followed by conclusions in section 8.

2. RELATED WORK

In Dynamic Source Routing (DSR**)** [5] [6] data packets contain complete route information in terms of route learning capability and can learn more routing information from the traffic and thus generates fewer route discoveries. DSR is able to obtain multiple routes through multiple route replies and many routes can be generated by a single route discovery as well. In DSR, the destination node generates route replies (RREPs) after received route requests (RREQs). Route information in DSR is maintained by the source. Source routes are carried in data packets and likely to cause significant overhead in larger networks where routes are longer. Route cache can also help to cut the overhead burden, where as packet header size grows with route length due to source routing.

AODV [7] [8] is reactive destination based routing protocol in which, table driven routing framework and destination sequence numbers have been used. It uses traditional routing tables with one entry per destination. AODV does not maintain any routing information nor take part in the routing table exchanges. It does not get into loops during route discovery process. It provides unicast, multicast and broadcast capabilities to all nodes and disseminates information about link breakage to its neighboring nodes, which is used to minimize the broadcast of control packets. A key feature of AODV is the use of sequence numbers. Sequence numbers determine the newness or freshness of routing information and to prevent routing loops. It does not support multi-paths form source to destination. Each data packet only needs to know the address of the next hop node to reach its requested destination. When an active link is broken, AODV has to initiate a new route discovery process which would incur additional delay and network flooding.

AntNet [9] is a meta-heuristic ant based routing protocol in which, two types of routing agents have been used like forward ants and backward ants. At regular intervals, forward ants are launched towards randomly selected destination. The backward ant is generated after the forward ant reach at the destination point and to utilize useful information gathered by the forward ants. The backward ants inherit route information from the forward ant and use it to update the pheromone values in the node's routing tables as it travels back on the same path of the forward ant. The amount of pheromones deposit is dependent on the trip time of the forward ants. AntNet is very slow in terms of end-to-end delay which is a main disadvantage.

ARA [10] is routing protocol based on AntNet and has similar operations in terms of route discovery. But in ARA, routes are maintained primarily by data packets as they flow through the network. The path to the destination is reinforced by increasing the pheromone value in the routing table as data packets travel along instead of using periodic ants like AntNet,. This brings higher benefit as flooding of periodic ants is being reduced. Established paths do not maintain their initial pheromone concentration forever. The pheromone concentration value will be reduced from time to time. ARA implements a pheromone decay mechanism where its value in the routing table decreases over time. This is to have faster convergence of pheromones on the network edges. In case of a route failure, an attempt is made to send the packet over an alternate route; otherwise, it is returned to the previous hop expecting that there exists an alternate route in the network. As data packets increase the pheromone of a routing path and at the same time, pheromones of other alternate routes evaporate, making the whole data traffic network will quickly converge to a particular route. New routes are never discovered in ARA until a route error message notifies the source to initiate a new route discovery action. ARA has no updating mechanism to adapt the changes in a dynamic network such as MANET.

In [11], the authors compare the performance of AntNet with Dijkstra's shortest path algorithm. AntNet performs better than shortest path routing. It performs well for random graphs and lattice topologies. The performance of AntNet routing degrades as network size or link density is increased. It is robust to changes in the topology of network and convergence to a good solution. It performs better than shortest path routing.

Information exchange with neighboring nodes is facilitated by helping ants of "modified AntNet"[12], which is extension of AntNet. Helping ants are used to improve the routing in terms of speed of convergence. The author demonstrates a method by which mean delay and overhead can be reduced without a higher loss rate or jitter. The modified AntNet performs better under the different conditions of network.

Reactive routing protocols in MANETs such as DSR and AODV are often supported by an Expanding Ring Search [13]. The basic route discovery structure of Blocking-ERS is extension of ERS which is used to control the time delay and energy consumption.

In this paper, we used and implemented the Blocking-ERS [13] concept to improve the performance of proposed routing protocol in terms of NRL, end-to-end delay and packet delivery ratio. As a result it reduced energy consumption at each node of network. Further, the local retransmission mechanism is an extension of transmission [14] that has been implemented to improve the efficiency of proposed routing protocol. AODV and DSR protocol are used for comparison with proposed Ant-E. The important evaluation parameters like Packet Delivery Ratio (PDR), end-to-end delay and Normalized Routing Load (NRL) have been considered. This proposed Ant-E protocol performs better than other two on-demand routing protocols (i.e., AODV and DSR) for MANET.

3. BACKGROUND OF PROPOSED ROUTING PROTCOL

The scalability problem can arise in large network if the destination node is close to source node. The request message that pass through each node in the network, can be extremely wasteful; especially if the destination node is relatively close to route request originator source node. Using the expanding ring search (ERS) method [15], the request message is flooded in the form of ring search, first in a smaller scale neighborhood with small time to live (TTL) value and it is incremented till destination is found. If the originating source node does not receive a reply within certain period of time, it rebroadcasts the request message with higher TTL value. This will be continuing till the route is discovered. The search is controlled by the maximum hop count field. If TTL values in the route request have reached a certain threshold, and still no request reply has been received, then destination node is assumed to be unreachable. However it consumes large routing overhead and it may end in the loop which leads to reduce the PDR. So the performance of routing protocol in form of efficiency and scalability decreases.

To improve the scalability and efficiency of routing protocol Blocking-ERS [13] can be used which is the extension of ERS. Blocking-ERS does not resume its route search procedure from the originating source node when a rebroadcast is required. The rebroadcast can be generated by any appropriate intermediate node instead of originating source node. The rebroadcast can be performed on behalf of the originating source node act as relay node. This technique is used to scale up the performance of proposed routing protocol. It also controls the end-to-end delay and network routing load of routing protocol.

Local retransmission technique is used to retransmit the data packet after receiving negative acknowledgement (NACK) from the receiver node. In this technique the failure or unsuccessful data packet is retransmitted from local intermediate node instead of originating source node.

The proposed routing protocol Ant-E is based on meta-heuristic swarm intelligence whose working principle is inspired by social insect behavior and on-demand feature of AODV. Further it uses the Blocking-ERS, local retransmission to make the Ant-E scalable, effective, efficient and reliable.

The study of ant's behavior in [2][3] the exhibits the capability of finding the shortest path from the ant's nest to the food source. This intrinsic mechanism can also be deployed in mobile ad hoc network to find the optimal path for routing. For Ant-E, each route in the node's routing table is assigned a pheromone value that represents the quality of the route. It depicts the cost and goodness of choosing a particular path to reach a destination. As an ant reaches a node, the initial pheromone value is calculated based on the information collected by the ant, which is maintained in the node's routing table.

At the beginning, it directs data packets to travel on the best optimal route based on the amount of pheromone at each outgoing links. Ant-E uses the table-based approach to find the route which is similar with AODV. Each routing table entry contains only the next hop and the distance to the destination. The distance metric is indicated by the amount of pheromone laid by the ants in order that the chosen next hop leads to the shortest or optimal path.

As more ants travel along a path, each ant deposits pheromone chemicals causing the cumulative strength of pheromone scent along that path to increase. In Ant-E, data packets would also travel over a route which owns the highest pheromone value in conjunction with the objective of fully utilizing the optimal route. Once the ants have established the pheromone tracks for the source and destination, subsequent data packets are used to maintain the path.

Pheromones direct data packets to travel on the best optimal route based on its value at each outgoing links. Forward ant is searching for the beginning of a pheromone trail to the destination which leads faster route discovery. If the data packet transmitted over a node to destination node, that node increases the pheromone value by

$$P_{new} = P_{id} + \Phi P_{id} \text{ .... (1)}$$

Where, P_{new} is the new updated value, by P_{id} which is the previous pheromone value before reinforcement and Φ is a scaling factor.

All pheromone values in the routing table decreases over time. It shows the utilization rate of a route in the network. When the pheromone entry reaches a minimum threshold, it is considered a stale route and will be discarded from the routing table. The evaporation function is defined as:

$$P_{new} = P_{id} - \delta P_{id} \text{ .... (2)}$$

Where, δ is the evaporation scaling factor. This helps the ant to find out the maximum probability of an ant to choose the path at time $t+1$.

Alternate routes disappear after some time due to evaporation and thus lead to network saturation. It is important to ensure that the network does not go to saturation mode where data packets only transmitted over a particular path. To make the algorithm fully adaptive to changes and routing to remain optimal, the proposed routing protocol Ant-E uses another type of ant 'update ants' to update and refresh the network in which it explore and quickly reinforce newly discovered paths in the network. It replaces the existing pheromone value with the newly computed value based on the current network condition; thus quickly reinforcing newly discovered paths and ensuring that previously discovered paths do not get saturated.

Multiple routes are important for a highly dynamic network such as MANET. So Ants in Ant-E establish multiple routes to same destination. Due to rapid changes in network topology in ad hoc network, routes may suffer frequent break down. Having access to many alternate routes saves the time to initiate another route discovery flood, thus reducing delay and overhead. By having multiple paths, the algorithm needs to select the best route for data delivery. The key focus is to determine the optimal path that data packets should traverse. This is accomplished by adopting the ant's pheromone metaphor.

Ant-E is a purely on-demand routing scheme. It sends update ants only to existing active destinations. If there is no communication then there will be no ant generated in the network.

4. PROPOSED ROUTING PROTOCOL

In this section we discuss the adaptation of the ant colony optimization meta-heuristic for MANET and describe the Ant-Efficient (Ant-E).

The packets used in the network can be divided into two classes like data packets and control packets. Data packets represent the information that the end-users exchange with each other. In ant-routing, data packets use the information stored at routing tables for travelling from the source to the destination node. Ant-E contains a special routing table, in which each destination is associated to all interfaces and each interface has a certain probability.

Control packets like forward ant (FANT) and a backward ant (BANT) are used to update the routing tables and distribute information about the traffic load in the network. Apart from the above control packets, the neighbor control packets are used to maintain a list of available nodes to which packets can be forwarded. The HELLO messages are broadcasted periodically from each node to all its neighbors. It is necessary to check if the ant has arrived or not, as the destination address will change at every visited node. Birth time of an ant is the time when the ant has been generated. Arrival time at the final destination is used to calculate the trip time.

In the route discovery phase new routes are created by FANT and BANT. A FANT is an agent which establishes the pheromone track to the source node. It gathers information about the state of network. In contrast, a BANT establishes the pheromone track to the destination node. BANTs use the collected information to adapt the routing tables on their path. The FANT is a small packet with a unique sequence number. Nodes are able to distinguish duplicate packets on the basis of the sequence number and the source address of the FANT. It creates a set of routing agents called FANT to search for the destination host. The source node would initiate a route discovery mechanism when a path to destination needs to be established. The source node would disseminate FANT to all its one-hop neighbors. While the destination is still not found, the neighbor would keep forwarding the FANTs to their own neighbors and so on. This process continues until a route to the destination is found using Blocking-ERS; otherwise it sends a reply message to the source node. To prevent cycles, each node stores recently forwarded route request in a buffer.

A node which receives a FANT for the first time creates a record in its routing table which consists of destination address, next hop, and pheromone value. The node interprets the source address of the FANT as destination address of

BANT, the address of the previous node as the next hop, and computes the pheromone value depending on the number of hops the FANT needs to reach the node. Then the node relays the FANT to its neighbors. Duplicate FANTs are identified through the unique sequence number and destroyed by the intermediate nodes. When the FANT reaches the destination node, the destination node extracts the information of the FANT and destroys it. Subsequently, it creates a BANT and sends it to the source node. When the sender receives the BANT from the destination node, the path is established and data packets can be sent. Ant-E ensures that routing paths are free from loops, and does not require extra overhead of sequence number to prevent loops. Nodes can recognize duplicate receipt of data packets, based on the source address and the sequence number.

In route maintenance phase, the routes need to be monitored and strengthened during the communication. Once the FANT and BANT have established the pheromone tracks for the source and destination nodes, subsequent data packets are used to maintain the path. But established paths do not keep their initial pheromone values forever. When a node relays a data packet toward the destination node, it increases the pheromone value of the entry as per equation 1, to strengthen the route to the destinations by the data packets. The evaporation process of the pheromone values is performed according to equation 2.

The route failures handling is also an important concern, which is mainly due to node mobility in MANET. Ant-E recognizes a route failure through a missing acknowledgement. If a node gets a route error (RERR) message for a certain link, it deactivates this link by setting the pheromone value to 0. Then the node searches for an alternative link in its routing table. It sends the packet via this alternate path, if there exist one; otherwise the node informs its neighbors, to relay the packet. If the packet does not reach the destination, the source has to initiate a new route discovery phase.

Further using the local retransmission technique the failure or unsuccessful data packet is retransmitted from intermediate node instead of originating source node. The data packet retransmits only after receiving negative acknowledgement (NACK) from the receiver node. This leads to improve the PDR with minimum end-to-end delay.

The proposed routing protocol is simulated using NS-2[16] under different mobility and network size environment. The extensive simulation carried out reveal that the performance of Ant-E which is an on-demand ant based routing protocol is better than AODV and DSR in all respect.

5. SIMULATION ENVIRONMENT

Network simulator NS-2[16] is used under Linux platform to evaluate the performance of our proposed routing protocol. We have used the programming language C++ to code the main routines of the routing agent, and OTCL to modify the parameters during simulations. The nodes mobility speed is varied as per table-1 and according to the random waypoint mobility model. The simulation time is set as 900 seconds. The mobility model describes the movement pattern of mobile nodes and each node is responsible for computing its own position and velocity. Nodes move around as per defined mobility model. Constant Bit Rate (CBT) is used to transfer data packets. The simulations have been carried using the parameters mentioned in table-1.

TABLE 1. Parameter values of Ant-E, DSR and AODV for simulation

S.No	Parameters	Values
1	Area size	700x700 m
2	Transmission range	250 m.
3	Number of Nodes	50 Nos.
4	Simulation time	900 secs.
5	Nodes Mobility	1,5,10,15,20 m/s
6	Pause times	10 sec.
7	Data rate	1 Kbps
8	No. of experiments	5 times.

6. PERFORMANCE EVALUATION PAPRAMETERS

The following metrics are often chosen to compare the performance of various routing protocols:

i. Normalized Routing Load (NRL)

It is the sum of all transmissions of routing packets per total delivery packets. For packets transmitted over multiple hops, each transmission over one hop is counted as one transmission.

ii. End-to-End delay

This includes all possible delays caused by buffering during route discovery latency, queuing at the interfaces, queuing transmission delays at MAC, and propagation and transfer times of data packets. This is the average overall delay for a packet to traverse from a source node to a destination node.

So, Average-End-to-End-Delay of routing protocol is calculated as:

$$Avg.End-to-end-Delay = \frac{\sum e}{P}$$

Where

$$e = T_d - T_s$$

and

T_d = Time when packet received at destination.

T_s=Time when packet created by source.

P =Total Packet

iii. Packet delivery ratio (PDR)

It is the percentage of ratio between the number of packets sent by sources and the number of received packets at the sinks or destination.

$$PDR = \frac{\sum_i \text{No. of received packet at sink}_i}{\sum_i \text{No. packets sent by source}_i} * 100$$

This performance evaluation parameter measures effectiveness, reliability and efficiency of a protocol.

In this paper exhaustive simulation experiments are carried out with different mobility rates for comparison among Ant-E, DSR and AODV.

7. RESULTS

In this paper, local retransmission is used to improve the PDR of Ant-E. Improved PDR denotes the efficiency, reliability and effectiveness of proposed routing protocol. Retransmission made from neighboring nodes of source node to destination instead of original source node. Thus, the total overhead is reduced to some extent. Though it is expected to produce high overhead and take more end-to-end delay for the proposed routing protocol; it is reduced by Blocking-ERS, controlled flooding and resuming its route discovery process from where it left in the previous round following a failure to discover a route to the destination node.

PDR is an indication of reliability, efficiency, and effectiveness of routing protocol. From Figure 1, the PDR of Ant-E is more than other two on-demand routing protocol (i.e. AODV, DSR) due to local retransmission of Ant-E. It shows improved reliability, effectiveness and efficiency of Ant-E in comparison to DSR and AODV.

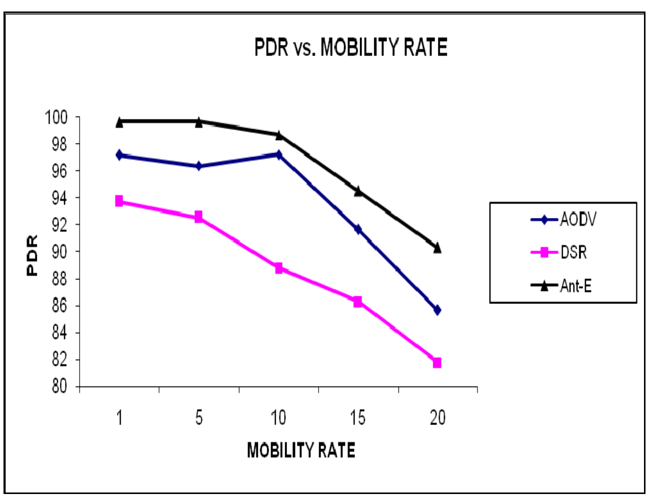

Figure 1: PDR vs. Mobility Rate

The NRL of Ant-E is controlled through Blocking-ERS and also through controlled flooding. From figure 2, it is observed that the NRL of proposed routing Ant-E protocol is better than AODV and DSR for different mobility rates.

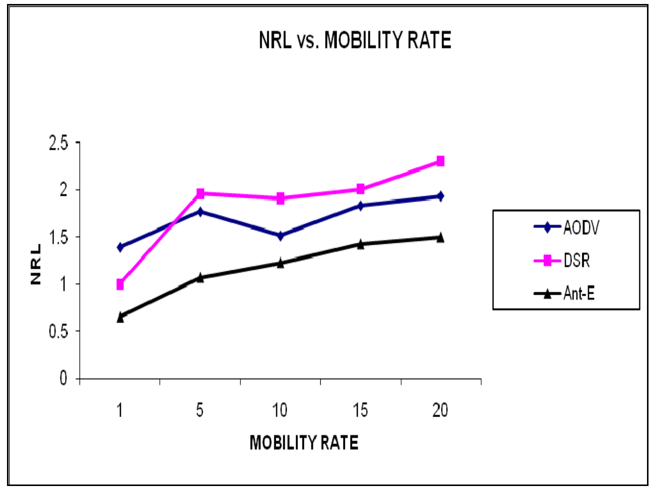

Figure 2: NRL vs. Mobility Rate

In real time application, end-to-end delay is one of the important parameter to measure performance of routing protocol. Now, from Figure 3; it can be concluded that, end-to-end delay for Ant-E is less than AODV and DSR for all mobility rates.

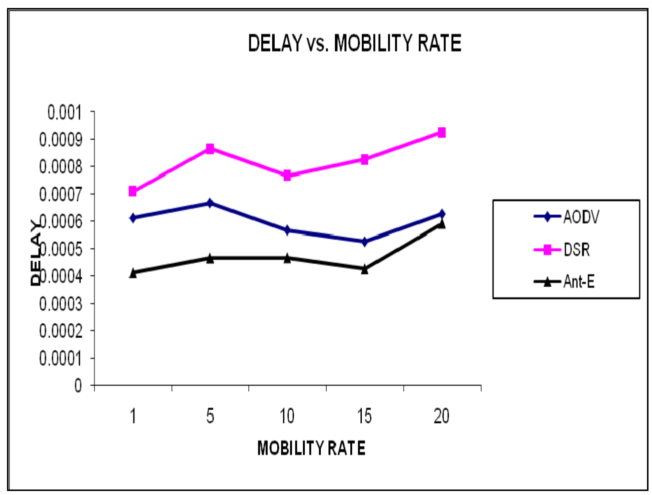

Figure 3: Delay vs. Mobility Rate

From the above results, it is observed that, the performance of Ant-E is better than AODV and DSR for all possible combination of mobility rates. This shows that the proposed routing protocol Ant-E outperforms both on demand routing protocols AODV and DSR.

8. CONCLUSION

In this paper, a new routing protocol for MANET environment is proposed based on Ant Colony Optimization principle coupled with other intelligent techniques. The proposed Ant-E algorithm improves the efficiency, robustness and reliability. The efficiency of proposed routing protocol Ant-E is shown to better than other two on demand routing protocols AODV and DSR. The proposed Ant-E routing protocol uses blocking ERS and local retransmission along with principles of ant colony to reduce the end-to-end delay and NRL. It enables optimal path routing and fast route discovery with better PDR and Delay.

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