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Performance Comparison and Evaluation of Efficient Routing Protocols for MANETs: Ant Inspired Adaptive Routing

S. Nagalakshmi[1], Dr. Rakesh Poonia[2]

Research Scholar, Dr Ambedkar Institute of Technology[1]

Asst. Prof. Dept. of Computer Application, Govt. Engg. College, Bikaner[2]

Abstract: Mobile nodes in a network often create link changes that demand reconstruction of the already identified routes. A routing algorithm is consistently challenged with route discovery and successive route maintenance. The Ant Colony Optimization (ACO) is a probabilistic technique designed for solving computational problems and which can also be adopted to find optimal paths in wireless ad hoc networks. Many researchers have take inspiration from the foraging behavior of the ants, its optimal route finding capability and the fact that it lays down a chemical substance called pheromone along the path of their movement which has a limited time before it evaporates. In this paper we bring out the characteristics and analyze the performance of a proposed Ant Colony Optimization (ACO) based ad hoc routing protocol and compare it with well-known ad hoc routing protocols. The performance and comparison is made through evaluating network parameters like average end to end delay, packet delivery ratio and throughput, residual energy of a network and is simulated by Network Simulator 2 (NS2).

Keywords: Ant Colony Optimization, Routing, MANETs, Mobile Ad Hoc Networks, packet delivery fraction, average end-to-end delay, routing overhead.

1. INTRODUCTION

Mobile ad hoc networks (MANETs) are wireless mobile, infrastructure less networks that are formed spontaneously. MANETs have found use in crisis management services like military operations and disaster rescue programs, in fields like satellite communication and Personal Area Networks. In recent times MANETs have also been employed in Internet of Things, Body Area Networks, 5G devices [1-5] etc. A lot of attention of researchers has been drawn to performance characteristics and issues of MANETs such as security in a network, reliability of a network, Quality of Service (QoS), inter-networking, power consumption and multicasting.[6].

The conventional protocols have adopted Dijkstra's and Bellman-Ford algorithms in routing and which have yielded good routing solutions. The random movement of mobile nodes in MANETs provides a challenge in routing and thereby making the network performance to largely depend upon the performance of the routing protocols [7-10]. Furthermore, compared with traditional networks, MANETs suffer from resource constraints in energy, computational capacities and bandwidth. In some scenarios, the routing maintenance overhead may consume so much resource that it seriously compromises long-term efficiency. In order to maximize the network lifetime and achieve an optimum route connection, the initial energy present in the node needs to be taken into consideration. To reducing energy consumption and increase the efficiency of a mobile ad-hoc network are a few important requirements in mobile networking [11]. Routing challenges in MANETs have many solution approaches of which nature inspired solution space is a popular area of research. Biological systems have the ability to self-organize which inspires us to apply their principles to mobile ad hoc networks, like recently evolutionary and swarm intelligent routing protocols have been developed like Genetic Algorithms [12], Particle Swarm Optimization [13], Bird-flight algorithm [14] , Bee Colony Optimization [15] and Ant Colony Optimization (ACO) [16].

2. CLASSIFICATION OF ROUTING PROTOCOLS FOR MANETS

The protocols used in routing in MANETs have been categorized into three classes which are table driven or proactive, demand driven or reactive and hybrid. In proactive routing protocols, the routes to all the destination (or parts of the network) are determined during the start and these routes are maintained by the use of a periodic route update process.

In reactive protocols, routes are determined as and when they are required by any source node using a route discovery process. Hybrid routing protocols however combine the characteristics of both the proactive and reactive protocols into one in addition to its own characteristics. Each of these classes of routing protocols may employ flat or hierarchical routing structure strategies.

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2.1 Ad Hoc on Demand Distance Vector Routing Protocol (AODV) [17] [18]

AODV is a reactive routing protocol which is based on the proactive DSDV protocol in terms of using the destination sequence numbers (Perkins et. al.) for ensuring loop freedom and on the reactive DSR protocol in terms of on demand route discovery techniques. AODV has been designed to improve scalability and performance of routing protocols. AODV creates loop free, on demand single path routes, offering low overheads in terms of processing and memory. AODV adapts very quickly to the constantly changing network conditions in MANETs. AODV uses hop-by-hop routing vis–à–vis DSR uses source routing. Every node knows every other node nearby, the costs associated to reach each of them and there are minimum number of system-wide broadcasts in AODV. AODV allows mobile nodes to obtain routes quickly for new destinations, and it doesn't maintain routes to nodes that are not a part of the in active communication. Route discovery process is initiated only when a source node has to send data to a destination node and also the routes are maintained only as long as they are required. As MANETs have a dynamic set up if any of the links in the network break, the affected nodes are informed so as to make the routes using the lost link not valid. AODV makes no provisions for security. [18].

2.1.1 Working Principle of AODV

The requirement for a node to send information to a destination node makes it to check the entries in its route table for current existent routes to the destination node. If a route is available then the requesting node is required to select the one with the greatest sequence number after which the data packets are forwarded through the appropriate hops in that route to reach the destination. If a route isn't available then a route discovery process is initiated which involves Route Request (RREQ), Route Reply (RREP) and Route Error (RERR) type messaging through UDP.

RREQ- The source node which needs to establish a communication to a destination node initiates the process of route discovery by sending a Route Request (RREQ) message. This RREQ message from the source node is propagated to the neighboring nodes which in turn forward it to their neighbors and so on. Every RREQ message consists of information like a unique identifier, the source address from which the request originated, address of the destination, a generated current sequence number, the destination's last sequence number, a hop count storing the number of hops from the source to the node which has currently received the request etc. A route is said to be found if the RREQ reaches the destination itself or reaches an intermediate node which has a relatively new route to the destination. The freshness of the identified route is determined through the sequence numbers. The source node sets a time within which it expects and waits for a reply. Intermediate nodes upon receiving a RREQ message store the reverse route entry from it to the node from which the RREQ originated, in its route table. This helps in forwarding the Route Reply (RREP) back to the source node. Reverse route entries have a lifetime associated with it and the reverse route information has to be used within that specific lifetime, otherwise the route information is deleted. For every RREQ which may be lost during transmission, the corresponding source node is allowed to start the route discovery mechanism again. For every re initiation of an RREQ, the RREQ is broadcast with an incremented unique identifier and retransmissions of requests for communication occur even when there is no reply too [19]. If the route that was requested for is found, a RREP is unicast back to where the RREQ had originated.

RREP- As the RREP is routed back along the reverse path which has been set up by the intermediary nodes, a forward path entry is set up to the destination in the routing tables of the intermediary nodes. As a route has been established from source to the destination data transmission can begin.

RERR- In AODV the routes discovered are managed in routing tables. The route between a source and destination nodes is maintained only as long it is needed by the source node. Nodes keep track of the links of the next hops for active communication nodes. In case a break occurs due to any of the active routes going out of the network, a RERR message is broadcast notifying about the loss of the link to their predecessor nodes which process continues until the source node is reached. Upon getting the RERR the source node either stops sending the data or requests for a new route discovery mechanism by issuing a new RREQ message.
When destinations cannot be reached because of broken links or a node becomes deactivated, the route is invalidated with action taken using the sequence number and marking that route table entry state as invalid. Also it is possible that the source node itself moves during an active session, then the source node reinitiates route discovery mechanism to establish a new route to destination. In AODV the nodes in the network use broadcasting of periodic HELLO messages to inform about its presence in its neighborhood. Through this HELLO message broadcasting local connectivity is maintained. In case a node which is taking part in an active route moves, its upstream neighbor notices the move and informs this movement by propagating a link failure notification or a RERR message. This causes the removal of that part of the route in the routing table entry from the active upstream neighbors.

Advantages and Limitations of AODV

1. Establishment of on-demand routes with little delay.
2. Efficient handling of link breakages in active routes.
3. Identification of the latest routes to the destination through Destination sequence numbers.
4. Setting up of connection takes less time.
5. Intermediate route inconsistencies may arise if old sequence numbers are used.

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6. Control Overheads are higher because for every RREQ multiple RERR packets may be sent.
7. More Bandwidth is consumed due to periodic beaconing.

3. ANT COLONY OPTIMIZATION (ACO)

It is a probabilistic technique which may be used for solving computational problems in MANETs. ACO was introduced by Marco Dorigo in the year 1992 and was originally called the Ant System. ACO studies artificial systems which are inspired by the behavior of real ant colonies and the ACO algorithms can be used to solve discrete optimization problems. The foraging behavior of real ant colonies is modeled in ACO algorithms and the optimal path is determined by generating artificial ants. In nature the real ants search for food in their environment, the artificial ants in the system modeled too search the solution space for optimal routes. The nature of ants is to move away from their nest to wander randomly in search of food. They lay along a trail of chemical substance known as pheromone as they move which the other ants have the ability to detect and follow. The strength of the pheromone deposit directs the artificial ants toward the best paths and has the ability to evaporate with time and avoiding the convergence to a locally optimal solution. The system which is probabilistically determined allows the movement of ants such that the ants explore new paths and can also re-explore the paths that have been visited earlier. The basic idea of the Ant Colony Algorithm is to simulate the behavior of ants within the artificial ants and use them to find an optimal solution in routing in MANETs. There have been classes of algorithms which have been inspired on the behavior of foraging ants.
The ACO algorithm's basic principle is to obtain information about the routes through repeated sampling, ants which are nothing but some control packets are sent for this purpose [20][21]. Ants are created and released by the source node to test check and acquire information for computing parameters like end-to end delay, no. of hops etc. to the destination that it wants to send data to. Ants upon acquiring information about a route update the intermediary nodes whilst going back to the source node. Ants constantly sample complete paths from one source node to the destination node [22].

Individual tables for each destination contain vector entries called the pheromone variables, one for each known neighbor node. These pheromone entries at each node indicate the goodness of the path, and hence specify how good it is to take this route via the node to the destination. The pheromone variables are frequently updated according to path quality values as calculated by the ants. Every node has a list of frequently used, available paths along with its estimated measure of quality. This is a result of the repeated and concurrent generation of path-sampling ants. Random hops are taken in a probabilistic manner, based on higher pheromone values. This collective learning behavior is achieved through the individual ants. Every artificial ant is a complex entity, which is autonomous, and updates the pheromone entries thereby participating in stigmergic communication in the network.[mine]

3.1 Background

Ants are creatures of limited intelligence, with limited eyesight and aren't capable of achieving complex tasks on their own. However in nature they manage amazing feats such as building nests, have a strong defense mechanism, capable of forming bridges, cooperatively carry large items and most importantly they collaborate in an organized manner to find food. A French entomologist named as Pierre-Paul Grasse investigated into the social behavior of insects and found that the ants are capable of reacting to what he referred to as "significant stimuli", which has signals that can activate reaction in similar genetic species. He observed that the effects of these reactions can act as new significant stimuli for the other insects in the colony. Grasse coined the term Stigmergy.

Stigmergy is a form of self organization which creates complex explicit structures that have an associated behavior without any particular type of direct communication.[Wikipedia] The ants can smell pheromone and whilst choosing their way, in general they choose the paths marked by stronger pheromone concentrations. As more and more ants follow the trail, the trail becomes increasingly more attractive. The binary bridge experiment was done to investigate pheromone trail laying and the behavior of ants done by Goss et.al., 1989 and Bonabeau et. al, 1997 . Here in, the nest of a colony of ants and a food source were separated by a diamond-shaped double bridge. Ants were then left free to move between the nest and the food source. The strength of ants which choose one or the other of the two branches was observed over time. As a result of this experiment it was the shortest path between the two available paths that was chosen and there by choosing the natural optimization path in observed that after few minutes' ants tend to converge on a same path. The branches of the bridges with different length had the majority of ants follow the shortest path due to pheromone concentration in the food-path experiment shown in fig 5 [23][24].

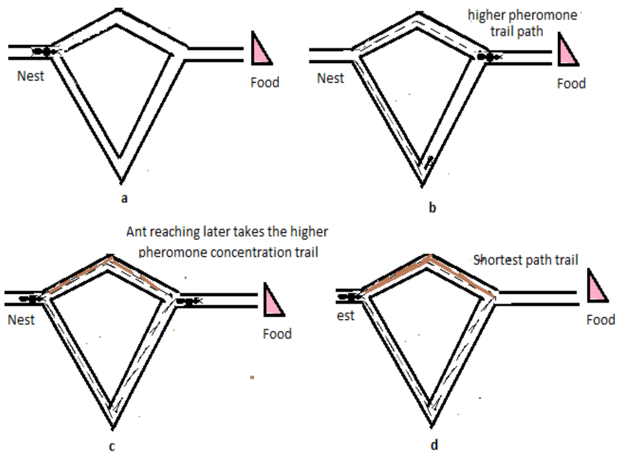

Fig 1: Binary bridge experiment with different path lengths

International Journal of Advanced Research in Computer and Communication Engineering
ISO 3297:2007 Certified
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The goal for the artificial ants is to solve more complicated problems than the simple bridge. The artificial ants not only model real ant behavior but also exploit elements of ant stigmergic activities to create a heuristic for difficult problems. The artificial ants need to be flexible towards the changing environment. The real ants lay pheromone on the trip to and from the food source. There is an evaporation of pheromone to prevent one locally optimal solution. However there are problems of the real ant systems like, when deciding complicated paths and ants can become trapped in loops, sometimes shortest path may no longer be the favored path. These have to be addressed by the artificial ants in the algorithms which are inspired by the real ants.

Network routing issues may be addressed using ACO in MANETs. Network characteristics like traffic load and network topology may vary stochastically and in a time varying nature also the distributed nature of network routing in MANETs is well matched to the multiple agent collaborative nature of ACO algorithms [25]. The network of nodes can be represented as a graph in which the vertices correspond to set of nodes which act as routers and the links represent the connections amongst the nodes. To identify efficient routes minimum cost path routes between nodes in a MANET can be done by taking into considering ant algorithms.

3.2 Routing in Ant Systems

The most important part of any network is control routing that strongly affects the overall network performance. Routing deals with issues like maximizing network performance by defining optimal paths and controls the flow of data traffic. In a routing system decision making can be seen to be distributed. (Jha et al., 2011). Every node forwards the data packets in accordance to the contents of the routing table. A variety of different classes of specific routing can be defined according to the different characteristics of processing, transmission components, traffic pattern and type of performance (Baluja & Davies 1998).

The following is the set of ACO characteristics as used in routing (Baluja & Davies 1998).

• It provides traffic-adaptive and multipath routing.
• Uses both proactive and reactive forms for information computation.
• Make use of stochastic components
• Does not allow local estimates to have effect on larger scale.
• The paths set up are load balanced rather than purely shortest paths.

These characteristics are identified as a result from the application of ACO's design guidelines along with the use of controlled random experiments . The ants are generated in a controlled manner to actively gather information about the characteristics of a set of paths connecting source-destination nodes. (Baluja &Davies 1998).

3. 3 Ant-based routing protocol

There are many Ant-based routing algorithms designed for MANETs [8mar,9mar,10mar]. In these routing algorithms the ants are simple agents into which intelligence has been built and they move around in the network from one node to the other. Fig 1 shows that as the ants move around across nodes they update the routing tables of the current node it is in with the information that it has learnt along the traversal. Routing ants keep a history of the nodes previously visited by them. When an ant arrives at a node, it uses the information in its history to update the routing table at that node with the best routes that it has for the other nodes in the network. A careful decision on the history size of each of the ants has to be made so as to not increase the network overheads. In ant based routing algorithms all the nodes in the network depend on the ants rather than any specific protocol implemented for providing them the routing information.

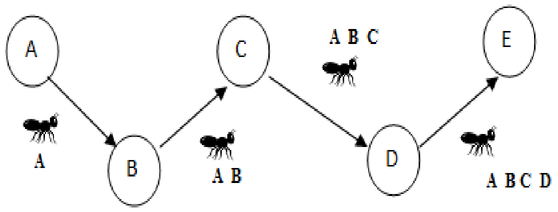

Fig 2: Ant passing the information it gathers about the nodes it visits

4. ANT-AODV HYBRID ROUTING PROTOCOL [26]

Ant AODV is a routing protocol proposed by Marwaha et.al, for MANETs. It is a hybrid protocol in which the reactive routing capability is just like in AODV but this has been combined with the proactive technique of an ant-based mechanism. The ant based system uses a distributed topology and the discovery mechanism uses ant-like mobile agents known as uniform ants. This ant-based routing algorithm does not implement any communication amongst the ants and each of the ants work independently. The population size of the ants is an important factor affecting the routing overhead and has to be chosen judiciously. The ants take the "no return rule" [9mar] while selecting the next hop at a node. It is ensured that the next hop selected at the current node is not the same as the previous node from where the ant came as this route would not be optimal. Ant-AODV's artificial pheromone model works on the basis of the number of hops and it works to continuously discover network topology and thereby creating new routes. This increases the probability of finding routes more quickly thereby reducing the end-to-end delay and the network latency [27]. The Ant-AODV hybrid routing protocol is suitable for real-time data and multimedia communications.

Route establishment in conventional ant-based routing techniques is based on the ants entering the node with information about providing the source with routes. If a node wishes to send data packets to a destination and it doesn't have a fresh enough route to it, then the data

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ISO 3297:2007 Certified
Vol. 5, Issue 9, September 2016

packets are stored in its send buffer till an ant arriving to it brings with it a route to that destination. In conventional ant algorithms when a route breaks the source would still keep on sending data packets without knowing about the link breakage which leads to dropping of a large number of data packets. This is so because they have not implemented local maintenance issues. In case of the AODV protocol on the other hand more time is taken for connection establishment due to the route discovery process whereas in ant- based routing if a node has a route to a destination it just starts sending the data packets without any delay.

In Ant-AODV ant agents work independently and provide routes to the nodes as shown in Fig. 2. The ants randomly traverse the network and keep track of the last n visited nodes. The source nodes have the ability to launch on-demand route discovery to establish a connection to the destination if there is no fresh enough route entry in its routing table. The use of ants in AODV gives increased node connectivity which means there are increased number of valid routes to various destinations in nodes, which results in reduced route discoveries. If a node sends a RREQ as there is no fresh route the chances of it receiving replies is more faster in comparison to AODV. This is because of the increased connectivity. Lastly, as ant agents update the routes continuously, a source node can switch from a longer older routes to a newer shorter routes provided by the ants. Ant-AODV shows reduced end-to-end delay in comparison to both AODV and ant-based routing protocols. Ant-AODV uses route error messages to inform all the upstream nodes in case of a local link failure which is similar to what happens in AODV. Routing table in Ant-AODV is common to both ants and AODV.

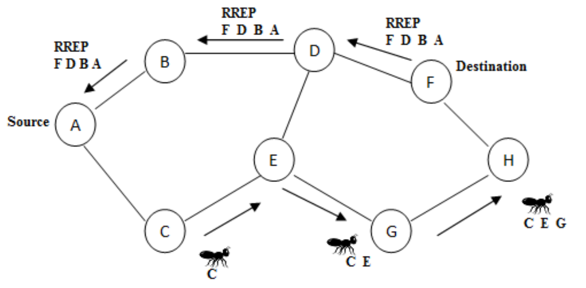

Fig 3 : Traversal of ants and propagation of route reply from destination to source

5. EANT-AODV HYBRID ROUTING PROTOCOL

Energy management is one of the key issues in an ad hoc network. Several researchers have proposed many algorithms for better energy management. Some of them through approaches using techniques like Particle Swarm Optimization, Ant Colony Optimization, and Firefly Algorithm etc. Erdös and Rényi proposed a ER random graph model based on classic graph theory and statistical physics [28]. Watts and Strogatz, established the WS small-world network model [29] for complex networks . Barabási and Albert build the BA model, which reveals the scale-free characteristic of complex networks In [30].

Routing in ad hoc networks has some unique characteristics. With limited power supply being one of the issues of an ad hoc network, an ad hoc routing protocol designed must meet the challenges of battery constraints. Energy of nodes is important and depends upon the battery which has limited power supply. If we want to increase the network life time i.e. the duration of time when the first node of the network runs out of energy then we must have an energy efficient protocol. The energy-balanced routing method is based on a forward-aware factor. Link weight and forward energy density contribute to the forward aware factor to decide the next hop. A spontaneous reconstruction mechanism for local topology is designed additionally. A forward aware factor is calculated based on the nodes locality and remaining energy. Forward transmission area (FTA) defines the forward energy density which constitutes forward aware factor with link weight. This proposed communication protocol sense of balance the energy consumption and increases the network life time. Here in this routing method the original energy of the node is drained means node dies, however energy of the sink node can be added [31]. In this routing method, each time the node finishes the transmission, the strength of the next hop node is checked. [31]. This algorithm determines multiple routes from the source node to the destination node using the route discovery algorithm and then selects the best route which has the maximum forward factor. Forward Aware Factor = No. of hops from Source to Destination nodes + Total route distance + Total energy consumed over the route Energy consumption for transferring the control packets is the sum of energy consumed over all the links. The energy consumed for every link is Ec = 2 * Energy used to transmit control packets + Energy required for amplification * d^{δ} where d is the distance between the nodes and δ is the attenuation factor.

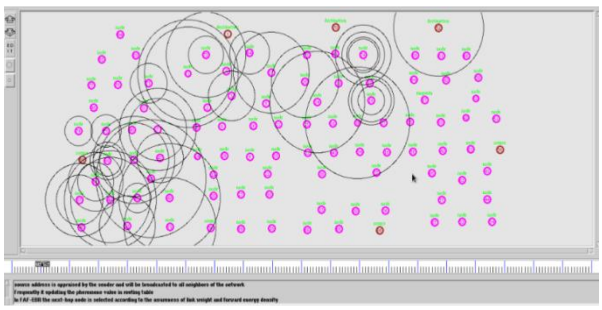

Fig 4: Simulation of EAnt-AODV for 100 Nodes

6. EXPERIMENTAL RESULTS :

6.1 Performance Metrics

The metrics to evaluate the performance of ad-hoc routing protocols are:

Packet Delivery Fraction: It is defined as the ratio of number of packets received by the destination over all the generated packets by the source. Every network aspires to acheive a higher Packet delivery fraction.

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Average end-to-end Delay: It is the average delay time incurred when data packets are sent from the source to the destination which includes delay due to buffering, route discovery, transmission time, queuing time etc.

Throughput: It is the average rate of successful packets delivered per unit time.

Routing Overhead: is the number of routing packets generated for the data packets received. Nodes often change their location within network; some stale routes are generated in the routing table which leads to unnecessary routing overhead.

6.2 Evaluation scenario with varying network size

Simulation Results

In this section, the proposed method has been simulated in NS2.35 and the simulation results are presented.

Parameter	Value
1. Network Simulator	Ns2.35
2. Channel	Wireless Channel
3. Propagation Model	Two Ray Ground
4. Queue	Drop Tail
5. Antenna	Omni-Directional
6. Routing Protocol	AODV, Ant-AODV, EAnt-AODV
7. Energy Model	Radio Energy Model
8. Initial Energy	1000J
9. Application	FTP
10. Transport	TCP
11. Area Size	800 X 800
12. Packet Size	512
13. Queue Length	50

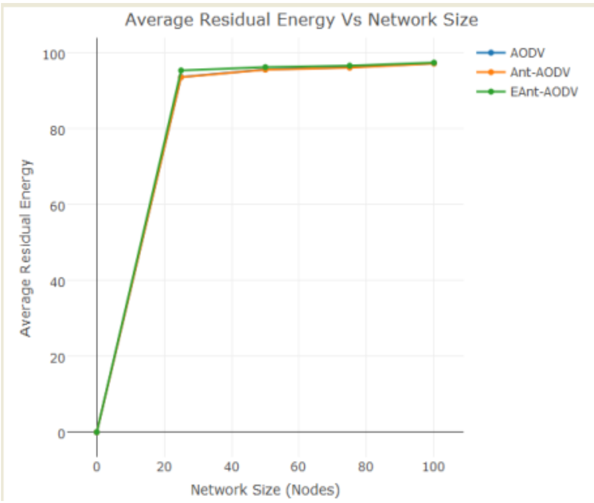
Table1: Simulation Parameters

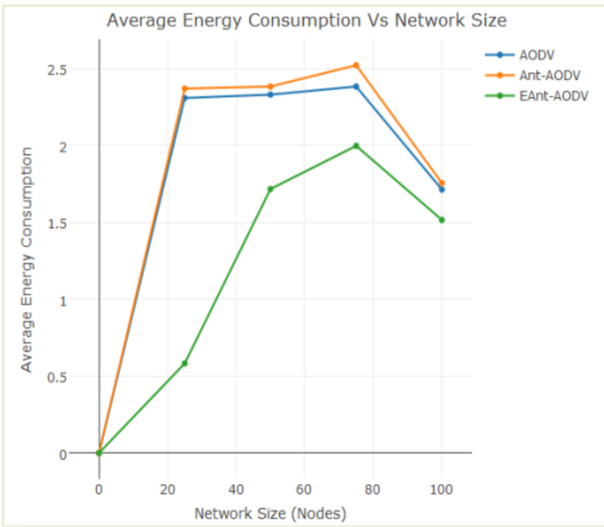
Every route entry in the routing table has a destination node address, number of hops to reach that destination, the next hop to route the packets, the sequence number of the destination and the time to live for that route.

physical layer	Radio propagation model :two ray ground reflection
link layer	IEEE 802.11 Distributed Coordination Function (DCF) Media Access Control Protocol (MAC) "RTS/CTS/Data/ACK" pattern for unicast packets and "data" for broadcast packets. Transmission of Data Packets : Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA).
Send Buffer Size	64
Interface queue between Routing and MAC layer	50
Transmission range for each mobile node	250m
Channel capacity	2Mbps
Area of simulation	1500m X 300m
Speed	0 - 10m/s
Mobility Model	Random waypoint model
Traffic	CBR Source nodes and destination nodes were chosen at random with uniform probabilities.

Same movement and traffic scenarios were used for all the three protocols simulated.

The population size of the ants is an important factor affecting the routing overhead and has to be chosen judiciously and a balance has to be maintained between control overhead and improving the efficiency of routing. For Ant-AODV, 10 ants with a history size of 12 were used.





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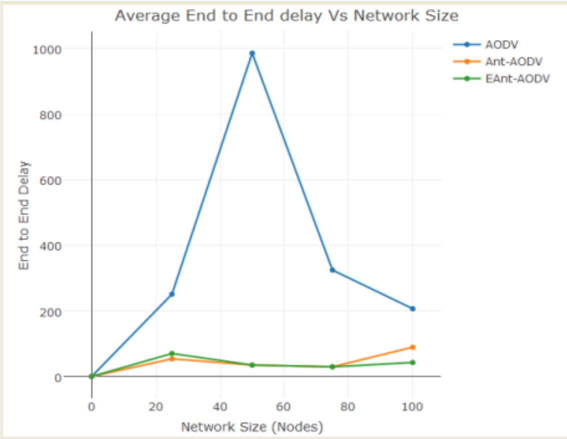

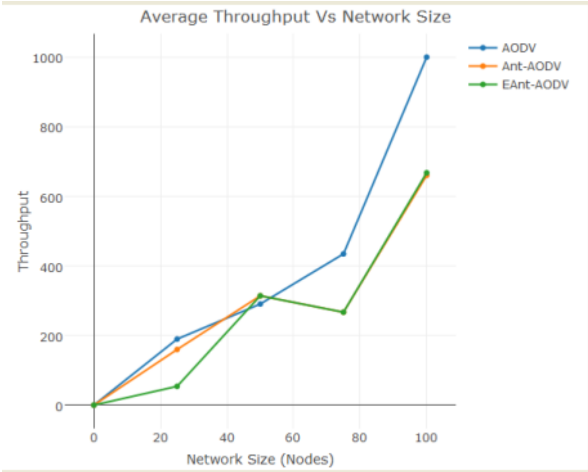

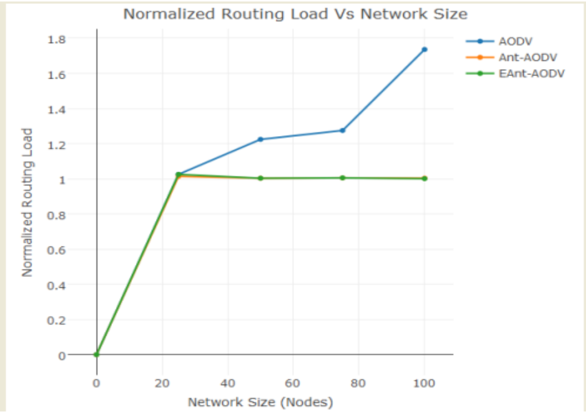

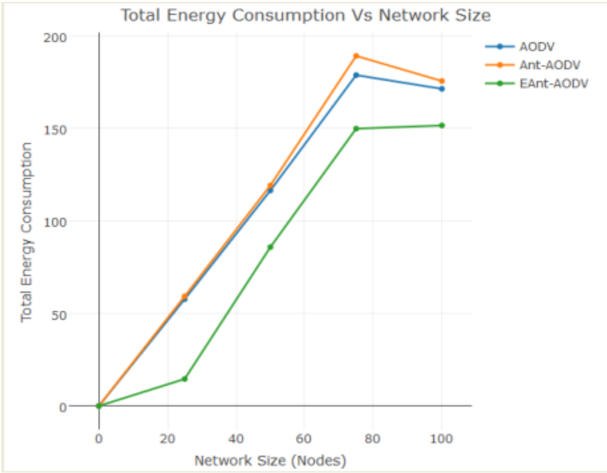

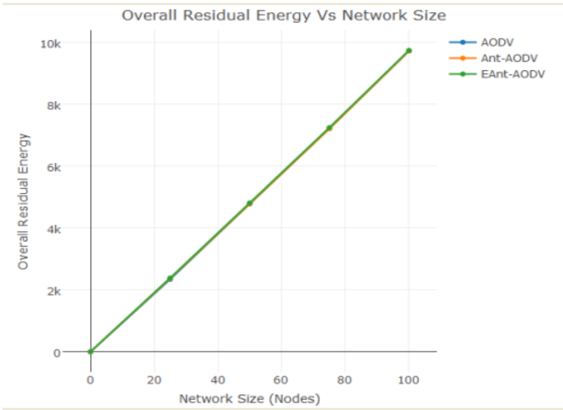

Scenario 1: No. of Nodes : 25 to 100

7. CONCLUSION

The shortcomings of on-demand routing protocols like AODV and ant-based routing have been tried to overcome in this paper by combining both of them to enhance their capabilities and alleviate their weaknesses. Ant-AODV and Enhanced Ant-AODV hybrid routing protocols are able to provide reduced end-to-end delay and high connectivity as compared to AODV. As a result of increased connectivity the number of route discoveries is reduced and also the route discovery latency.

The Energy consumption in the hybrid routing protocol is much lower. The average End to End Delay is considerably lower compared to AODV and the normalized routing load is lower in the hybrid routing protocol. The average energy consumption is much lower in the hybrid routing protocols. This makes the hybrid routing protocols suitable for real-time data and multimedia communication. As a direct result of providing topology information to the nodes (using ants), the foundations for designing a distributed network control and management get automatically laid. Higher connectivity and reduced end-to-end delay are achieved at the cost of extra processing of the ant messages and the slightly higher overhead occupying some network

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capacity. However this does not adversely affect the packet delivery fraction or the good put. The future work would be to explore the use of back up or multiple routes provided to the nodes by ants in their frequent and continuous visits to the node.

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