A NOVEL ROUTING PROTOCOL USING MOBILE AGENTS AND REACTIVE ROUTE DISCOVERY FOR AD HOC WIRELESS NETWOKRS

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ABSTRACT

This paper proposes a novel routing scheme for mobile ad hoc networks (MANETs), which combines the on-demand routing capability of Ad Hoc On-Demand Distance Vector (AODV) routing protocol with a distributed topology discovery mechanism using ant like mobile agents. AODV requires the actual communication to be delayed until the route is determined (found). This may not be suitable for real time data and multimedia communication applications. Ant-AODV provides high connectivity, reducing the amount of route discoveries before starting new connections. This eliminates the delay before starting actual communication for most new connections making Ant-AODV routing protocol ideal for real time communication in highly dynamic networks such as MANETs. Simulation results show that the Ant-AODV hybrid technique proposed in this paper is able to achieve reduced end-to-end delay as compared to conventional ant-based and AODV routing protocols. In addition, Ant-AODV also provides high connectivity.

Keywords – MANET, routing protocols, mobile wireless ad hoc networks, ant-based routing protocol, mobile agents.

1. INTRODUCTION

The conventional routing protocols for mobile wireless ad hoc networks suffer from certain inherent shortcomings. The proactive routing schemes continuously update the routing tables of mobile nodes consuming large portion of the scarce network capacity for exchanging huge chunks of routing table data. This reduces the available capacity of the network for actual data communication. The on-demand routing protocols on the other hand launch route discovery and require the actual communication to be delayed until the route is determined (found). This may not be suitable for real time data and multimedia communication applications.

Ant-like mobile agents can be used for efficient routing in a network and discover the topology, to provide high connectivity at the nodes. However, the ant-based algorithms in wireless ad hoc networks have certain drawbacks. In that the nodes depend solely on the ant agents to provide them routes to various destinations in the network. This may not perform well when the network topology is very dynamic and the route lifetime is small. In ant-based routing mobile nodes have to wait to start a communication, till the ants provide them with routes. In some situations it may also happen that the nodes carrying ants suddenly get disconnected with the rest of the network. This may be due to their movement away from all other nodes in the network or they might go into sleep mode or simply turned off. In such situations, the amount of ants left for routing are reduced in the network which leads to ineffective routing.

This paper tries to overcome these shortcomings of ant routing and AODV [1] by combining them to develop a hybrid routing scheme. The Ant-AODV hybrid routing protocol is able to reduce the end-to-end delay and route discovery latency by providing high connectivity as compared to AODV and ant-based routing schemes. The hybrid scheme also does not overload the available network capacity with control messages like the proactive protocols.

2. DESCRIPTION OF ANT-BASED AND AODV ROUTING PROTOCOLS

2.1 Rationale behind using ant-like agents

The idea that ant-like agents or mobile software agents can be used for network control in telecommunications was introduced in mid 1990s [2, 3]. The ant-based algorithm used for routing in telecommunication networks has since then undergone many changes [4, 5]. The inspiration to use ant like routing scheme comes from the fact that social insects are able to solve complex problems in a distributed way, without any central control, on the basis of only local information that they have. Social insects also exhibit other features like responding to internal perturbations and external challenges and the failure of one or several individuals doesn't jeopardize a colony's functioning as a whole.

A two-bridge experiment demonstrates the distributed problem solving and self-organizing ability of social insects [6, 7]. When a food source is separated from an insect nest by two bridges X and Y, where X being longer than Y, then the shorter bridge Y is selected by the colony (if X is sufficiently longer than Y). This is attributed to the trail-laying and trail following characteristic of ants in which ants lay a chemical substance known as pheromone trace. This attracts the other ants. The ants returning first to the nest would have laid the pheromone twice on the shorter path hence influencing outgoing ants to take the shorter route instead of the longer one. Even if the long bridge is presented first, the shorter one will still be selected subsequently as the pheromone trace on the longer branch would evaporate and it would be difficult to maintain a stable pheromone trail on a longer path (than on a shorter one). Given these properties, it does not seem unreasonable to try transferring the current knowledge about how insect societies function into the context of engineering.

2.2 Ant-based routing protocol

Ant-based routing algorithm for MANETs have been previously explored by [8,9,10]. Ants in network routing applications are simple agents embodying intelligence and moving around in the network from one node to the other, updating the routing tables of the nodes that they visit with what they have learned in their traversal so far (fig. 1). 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. The higher the history size the larger the overhead, hence a careful decision on the history size of the ants has to be made. All the nodes in the network rely on the ants for providing them the routing information, as they themselves do not run any program (protocol) for finding routes. The ant-based routing algorithm implemented in this paper does not consider any kind of communication among the ants and each ant works independently. The population size of the ants is another important parameter, which affects the routing overhead.

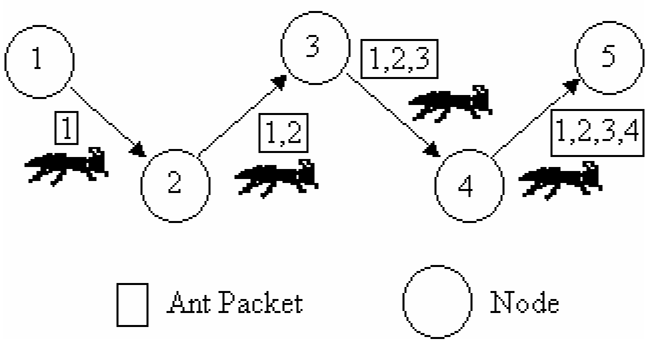

Figure1. Figure shows an ant traversing the network and providing routing information to nodes.

This paper implements ants that take the "no return rule" [9] while selecting the next hop at a node. In the conventional ant algorithms the next hop is selected randomly. This is because, if the next hop selected is the same as the previous node (from where the ant came to the current node) then this route would not be optimal. Data packets sent on such routes would just be visiting a node and going back to the previous node in order to reach the destination.

Every node frequent broadcasts HELLO messages to its neighbors so that every node can maintain a neighbor list, which is used for selecting the next hop by the ants.

2.2 AODV Routing Protocol

In AODV [1], if a node desires to send a message to a destination node for which it does not have a valid route to, it initiates a route discovery to locate the destination node. The source node broadcasts a route request (RREQ) packet to all its neighbors, which then forward the request to their neighbors and so on until either the destination or an intermediate node with a "fresh enough" route to the destination listed in the RREQ is located. AODV makes use of sequence numbers to ensure that the routes are kept loop free. Each node maintains its own sequence number, and also a broadcast ID. The sequence number is incremented whenever there is a change in the neighborhood of a node. The broadcast ID is incremented for every route discovery the node initiates. Along with its own sequence number and the broadcast ID, the source node also includes the most recent sequence number it has for the destination node. Intermediate nodes may reply to the RREQ if they have a route to the destination with a destination sequence number equal to or more than the one listed in the RREQ. If additional copies of the same RREQ are later received, these packets are discarded. Once the RREQ reaches the destination or an intermediate node (having fresh enough route to the destination), it responds by sending a route reply (RREP) packet to the source.

AODV uses periodic HELLO broadcasts by the nodes in the network to inform each mobile node of other nodes in its neighborhood. These broadcasts are used to maintain local connectivity. If a node along the route moves, its upstream neighbor notices the move and propagates a link failure notification/route error message (RERR) to each of its active upstream neighbors to inform of the removal of that part of the route.

3. ANT-AODV HYBRID ROUTING PROTOCOL FOR MOBILE AD HOC NETWORKS

To overcome some of the inherent drawbacks of ant-based routing and AODV routing protocols the proposed Ant-AODV technique forms a hybrid of both. The hybrid technique enhances the node connectivity and decreases the end-to-end delay and route discovery latency. In conventional ant-based routing techniques route establishment is dependant on the ants visiting the node and providing it with routes. If a node wishes to send data packets to a destination for which it does not have a fresh enough route, it will have to keep the data packets in its send buffer till an ant arrives and provides it with a route to that destination. Also, in ant routing algorithms implemented so far there is no local connectivity maintenance as in AODV. Hence when a route breaks the source still keeps on sending data packets unaware of the link breakage. This leads to a large number of data packets being dropped. AODV on the other hand takes too much time for connection establishment due to the delay in 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. This long delay in AODV before the actual connection is established may not be applicable in a real time communication application.

Ant-AODV utilizes ants working independently and providing routes to the nodes as shown in fig. 2. The nodes also have capability of launching on-demand route discovery to find routes to destinations for which they do not have a fresh enough route entry. The use of ants with AODV increases the node connectivity (the number of destinations for which a node has un-expired routes), which in turn reduces the amount of route discoveries. Even if a node launches a RREQ (for a destination it does not have a fresh enough route), the probability of its receiving replies quickly (as compared to AODV) from nearby nodes is high due to the increased connectivity of all the nodes resulting in reduced route discovery latency. Lastly, as ant agents update the routes continuously, a source node can switch from a longer (and stale) route to a newer and shorter route provided by the ants. This leads to a considerable decrease in the average end-to-end delay as compared to both AODV and ant-based routing.

Local connectivity in Ant-AODV is maintained in a fashion similar to AODV using route error messages (RERR). The routing table in Ant-AODV routing scheme is common to both ants and AODV. Frequent HELLO broadcasts are used to maintain the neighbor table. This table is used to select a randomly chosen next hop (avoiding the previously visited node) from the list of neighbors by the ant.

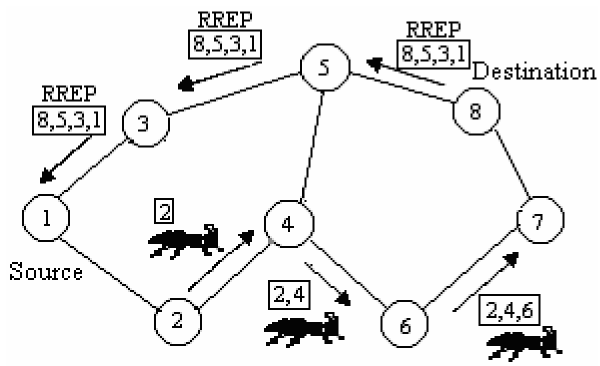

Fig. 2. Propagation of route reply and traversal of ant in Ant-AODV routing protocol.

4. SIMULATION MODEL

The Ant-AODV hybrid routing protocol proposed in this paper is compared with the conventional ant-based and AODV routing protocols. Network Simulator (NS-2) [11] is used to simulate these protocols. NS-2 is a discrete event simulator. The latest version of NS-2 (ns-2.1b8a) which can model and simulate multi-hop wireless ad hoc networks was used for the simulations. The physical layer for the simulation uses two-ray ground reflection as the radio propagation model. The link layer is implemented using IEEE 802.11 Distributed Coordination Function (DCF), Media Access Control Protocol (MAC). It uses "RTS/CTS/Data/ACK" pattern for unicast packets and "data" for broadcast packets. Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA) is used to transmit these packets.

All protocols simulated maintain a send buffer of 64 data packets, containing the data packets waiting for a route. Packets sent by routing layer are queued at the interface queue till MAC layer can transmit them, which has a maximum size of 50 data packets. The interface queue gives priority to routing packets in being served. The transmission range for each of the mobile nodes is set to 250m and the channel capacity is 2Mbps. Simulations were run for 600 simulated seconds. The routing table used for all the three protocols are similar. 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.

4.1 Mobility model

The simulation models a network of 50 mobile nodes migrating within an area of 1500m X 300m with a speed of 0 - 10m/s. A rectangular space was chosen in order to force the use of longer routes between nodes than would be there in a square space with the same amount of nodes [12]. The mobility model uses the *random waypoint* model in the rectangular field. The simulations were run multiple times for 6 different pause times: 0, 30, 60, 120, 300 and 600 seconds. Pause time is the dormant time during which the node does not move after reaching a destination. After pausing for pause time seconds it again selects a new destination and proceeds at a speed distributed uniformly between 0 and certain maximum speed.

4.2 Traffic model

20 Continuous Bit Rate (CBR) connections (traffic flows) were used for the simulations. CBR traffic sources were chosen, as the aim was to test the routing protocols. Source nodes and destination nodes were chosen at random with uniform probabilities. Connections were started at times uniformly distributed from 0 and 180 seconds. The sending rate used was 4 packets per second with a packet size of 64 bytes. Each data point in the comparison results represents an average of multiple runs with identical traffic models but with different movement scenarios. Same movement and traffic scenarios were used for all the three protocols.

4.3 Ant history size and ant population

After experimenting with many combinations of ant population and history sizes, the values that gave the best performance were chosen so as to keep a balance between control overhead and efficient routing. For simulating ant-based routing protocol the number of ants was kept equal to the number of nodes (which was 50) with a history size of 15. For Ant-AODV, 10 ants with a history size of 12 were used.

5. RESUTS

5.1 Average end-to-end delay

This includes buffering delay during route discovery, queuing delay at interface queue, retransmission delays and propagation and transfer times. The average end-to-end delay for AODV and Ant-AODV hybrid protocol is very less (fig. 4). But in case of Ant routing technique (fig. 3) the average end-to-end delay is high. The high end-to-end delay in ant-based routing is attributed to the lack of on-demand route discovery capability of the nodes in ant routing. Due to this the packets to be sent by a node keep waiting in the send buffer till the ants visit that node and provide it with routes. Comparing Ant-AODV and AODV it can be observed that the end-to-end delay (fig. 4) is considerably reduced in Ant-AODV as compared to AODV. From fig. 4 it is evident that at high mobility rates (small pause time) the end-to-end delay of Ant-AODV is very less compared to AODV, making the hybrid routing protocol perform well even at high mobility.

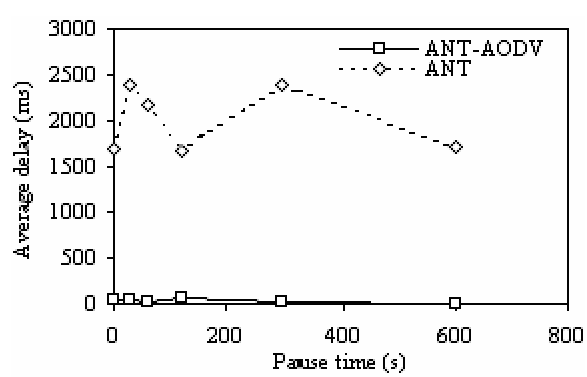

Fig. 3. Average end-to-end delay of routing data packets in ant-based and Ant-AODV routing protocols.

In Ant-AODV, ants help in maintaining high connectivity hence the packets need not wait in the send buffer till the routes are discovered. Even if the source node does not have a ready route to the destination, due to the increased connectivity at all the nodes the probability of its receiving replies quickly from nearby nodes is high resulting in reduced route discovery latency. Lastly, the dynamic nature in which routes are kept updated by the ants leads to the source node switching from a longer (and stale) route to newer and shorter ones hence reducing end-to-end delay for active routes.

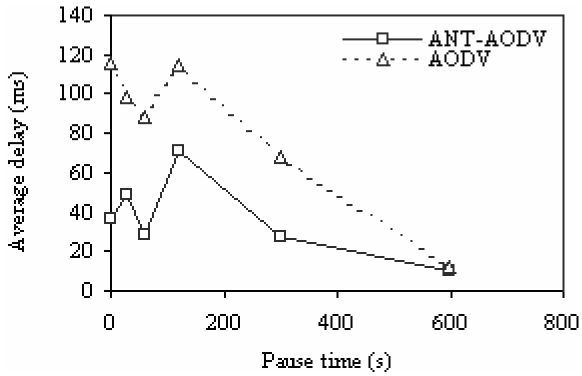

Fig. 4. Average end-to-end delay provided by AODV and Ant-AODV routing protocols.

5.2 Packet delivery fraction and Goodput

Packet delivery fraction is the ratio of number of data packets sent to the number of data packets received and goodput is total number of useful packets received at all destination nodes. Packet delivery fraction is very high for AODV and Ant-AODV (fig. 6) as compared to ant-based routing as shown in (fig. 5).

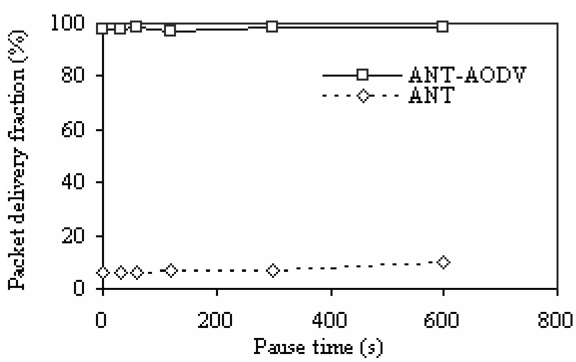

Fig. 5. Packet delivery fraction of ant-based and Ant-AODV routing protocols.

Goodput also is very high for Ant-AODV and AODV compared to ant-based routing (fig. 7,8). The reason for high packet delivery fraction and goodput in Ant-AODV and AODV is that they make use of link failure detection and route error messages. Whereas in case of ant-based routing there is no such feature and so the source nodes keep on sending packets unaware of the link failures. This leads to a large amount of data packets being dropped which reduces the packet delivery fraction and the goodput.

Also seen in the graphs for packet delivery fraction (fig. 5,6) and goodput (fig. 7,8) is that as the pause time increases the goodput and packet delivery ratio increase due to less link failures at low mobility rates (high pause time).

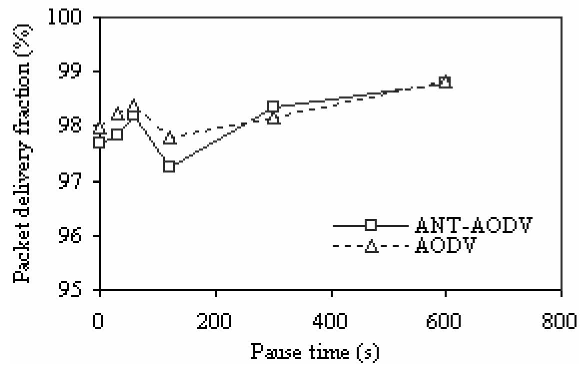

Fig. 6. Packet delivery fraction of AODV and Ant-AODV routing protocols.

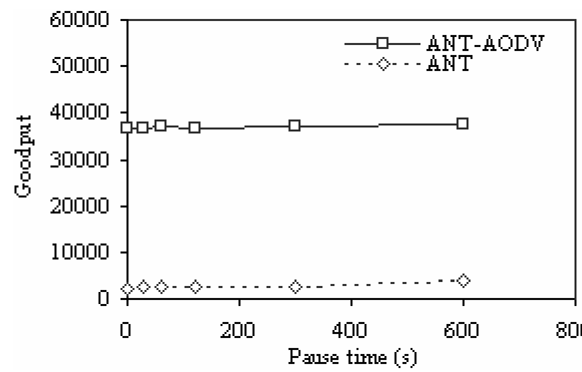

Fig. 7. Goodput of ant-based and Ant-AODV routing protocols.

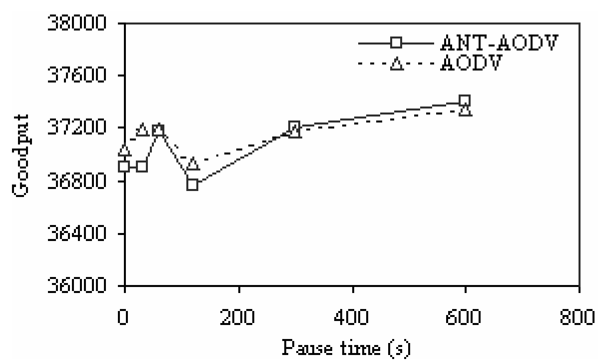

Fig. 8. Goodput of AODV and Ant-AODV routing protocols.

5.3 Routing overhead

Routing (or control) overhead is the total number of routing packets transmitted by the routing protocol. Normalized routing load is the number of routing packets transmitted per data packet received at the destination.

The total routing overhead in case of ant-based routing is independent of the traffic. Even if there is no communication the ants would still be traversing the network and update the routing tables. However in case of AODV, the overhead is dependent on the traffic and if there is no communication then there will be no control messages generated in the network. In Ant-AODV the overhead has two components. It has the ants traversing in the network, and the route discovery and route reply messages being generated in case the nodes do not have routes provided to them by ants for some destinations.

From the comparison results (fig. 9,10) it is seen that the normalized overhead is too high in case of ant-based routing scheme. The reason for this is that the actual data packets delivered are too less and hence the ratio of control overhead to data packets delivered becomes too high.

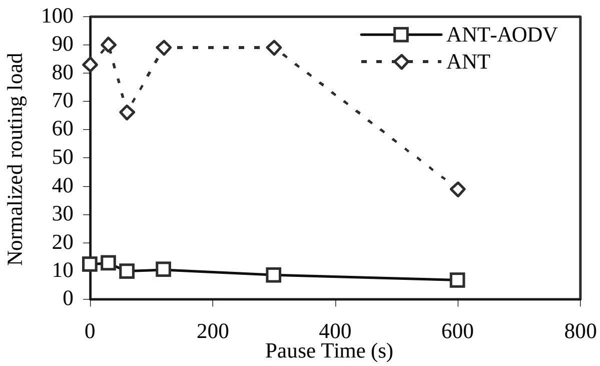

Fig. 9. Comparison of normalized routing overhead in ant-based and Ant-AODV routing protocols.

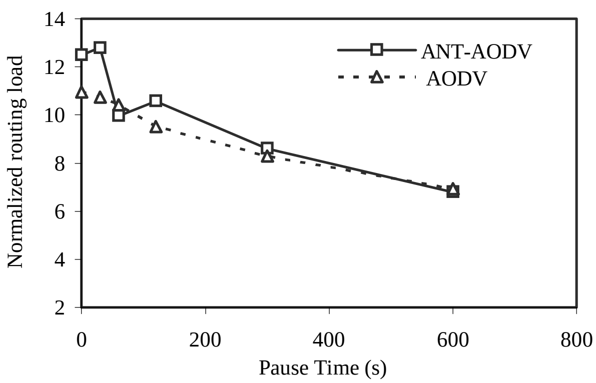

Fig. 10. Comparison of normalized routing overhead for AODV and Ant-AODV routing protocols.

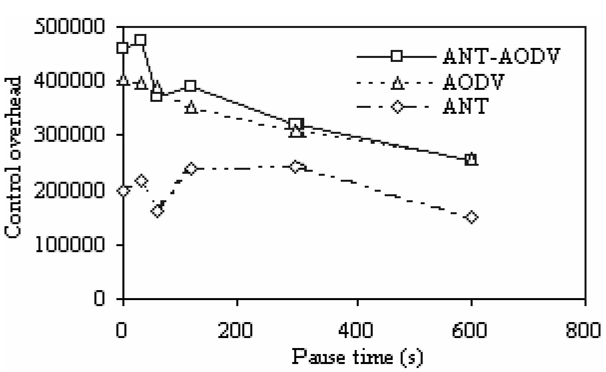

Fig. 11. Control overhead of AODV, ant-based and Ant-AODV routing protocols.

In case of AODV (fig. 10) the normalized overhead is the least. The normalized and total overhead (fig. 9,10), are slightly greater in Ant- AODV as compared to AODV because of the continuous movement of ants in the network. The total overhead (fig. 11) is slightly greater in Ant-AODV as compared to AODV because of the continuous movement of ants in the network. The total overhead is however least in case of ant-based routing as compared to AODV and Ant-AODV routing protocols. The continuous drop in normalized routing overhead as shown in fig. 9,10 and 11 for all the three protocols is attributed to the increased packet delivery fraction and goodput at higher pause times (normalized load is the ratio of total control packets generated to actual data packets received).

5.4 Connectivity

Connectivity is the average number of nodes in the network for which a node has un-expired routes.

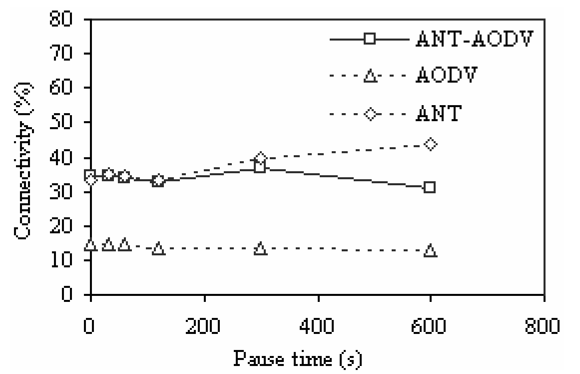

Fig. 12. Average connectivity provided by AODV and Ant-AODV routing protocols.

In case of Ant-AODV and ant-based routing protocols (fig. 12), agents continuously traverse the network and update the routing table entries. Due to this, a node has fresh enough (or un-expired) routes to a large number of nodes in the network at any given point of time. The connectivity in Ant-AODV and ant-based routing schemes is more than double the connectivity in AODV (fig. 12). Higher connectivity leads to lesser route discoveries and reduced end-to-end delay.

6. DISCUSSION

An important characteristic of ant agents for routing in MANETs was observed during the simulations. After a certain period (nearly 100 simulation seconds), the ant activity (ant hopping from one node to the other and updating routes) would almost subside. This could be due to various reasons such as (i) the ant packets could be lost in wireless transmission, (ii) the next node which was to receive the ant packet moves out of the wireless range of the sending node, or (iii) the ant bearing node goes out of wireless range of every node in the network and there is no next hop node available for the ant. In such situations the number of ants actually available for routing purpose decreases. To overcome this decrease in number of ants available for routing, a “minimum ant visit period” was set. If no ant visited a node within this period the node would generate a new ant and transmit it to one of its neighbors selected randomly. This way the ant activity would never subside and the network would not become devoid of ants. The simulations carried out used a minimum ant visit period of 5 seconds.

From the simulation results it is clear that by combining ant like mobile agents with the on-demand route discovery mechanism of AODV, the Ant-AODV hybrid routing protocol would give reduced end-to-end delay and route discovery latency with high connectivity. Such low end-to-end delay cannot be achieved from either of the two base protocols (ant-based and AODV) because of their inherent shortcomings.

TABLE I
PERFORMANCE COMPARISON OF ROUTING PROTOCOLS

Performance parameters	Ant-based routing	AODV	Ant-AODV
End-to-end delay	Highest	Low	Lowest
Connectivity	High	Low	High
Packet delivery fraction	Least	Highest	High
Application in network management	Yes	No	Yes
Link failure notification	No	Yes	Yes
Use of sequence numbers	Yes (Included in this paper)	Yes	Yes
Routing overhead	Low	High	High

7. CONCLUSION AND FUTURE WORK

This paper tries to overcome the shortcomings of on-demand routing protocols like AODV and ant-based routing by combining them to enhance their capabilities and alleviate their weaknesses. Ant-AODV hybrid protocol is 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. This makes Ant-AODV hybrid routing protocol 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 distributed network control and management get automatically laid.

The reduction in end-to-end delay and higher connectivity are achieved at the cost of extra processing of the ant messages and the slightly higher overhead occupying some network capacity. This however does not adversely affect the packet delivery fraction or the goodput.

The future work will involve adding inter agent communication and intelligence to the ant agents. This coupled with the ants providing information such as node affinity and power levels etc. to the nodes would help in taking intelligent routing decisions.

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