Mobile Agents based Routing Protocol for Mobile Ad Hoc Networks

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Abstract-- **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 is proposed in this paper. The proposed hybrid protocol reduces route discovery latency and the end-to-end delay by providing high connectivity without requiring much of the scarce network capacity. On the one side the proactive routing protocols in MANETs like Destination Sequenced Distance Vector (DSDV) require to know, the topology of the entire network. Hence they are not suitable for highly dynamic networks such as MANETs, since the topology update information needs to be propagated frequently throughout the network. These frequent broadcasts limit the available network capacity for actual data communication. On the other hand, on-demand, reactive routing schemes like AODV and Dynamic Source Routing (DSR), require the actual transmission of the data to be delayed until the route is discovered. Due to this long delay a pure reactive routing protocol may not be applicable for real-time data and multimedia communication. Through extensive simulations in this paper it is proved that the proposed Ant-AODV hybrid routing technique, is able to achieve reduced end-to-end delay compared to conventional ant-based and AODV routing protocols.**

I. INTRODUCTION

Current routing protocols for mobile ad hoc networks (MANETs) suffer from certain inherent shortcomings. On the one side the proactive routing schemes like Destination Sequenced Distance Vector (DSDV) [1] 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 like Ad Hoc On-Demand Distance Vector and Dynamic Source routing [2,3] on the other hand launch route discovery, and require the actual communication to be delayed until the route is determined. This may not be suitable for real-time data and multimedia communication applications. Mobile agents similar to ants [4,5,6,7] 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 pure 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.

The current paper tries to overcome these shortcomings of ant-based routing and AODV 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.

II. BACKGROUND DESCRIPTION OF AODV AND ANT-BASED ROUTING PROTOCOLS

A. *AODV Routing Protocol*

If a node using AODV [2] 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 loop free. Each node maintains its own sequence number, and a broadcast ID. The sequence number is incremented whenever there is a change in the neighborhood of a node and 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 simply discarded.

When 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. Periodic HELLO broadcasts are used in AODV 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.

B. Ant-based routing

Routing algorithms for MANET which employ ants have been previously explored by [4,5,6]. Ants in network routing applications are simple agents embodying intelligence and moving around in the network from one node to the other and updating the routing tables of the nodes they visit with what they have learned in their traversal so far [4,5,6,]. 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 for updating the routing table at that node with the best routes 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 for finding routes. The ant-based routing algorithm implemented in this paper does not consider any communication among the ants. Each ant works independently. The population size of the ants is another important parameter, which affects the routing overhead.

Ants that take the "no return rule" [4] while selecting the next hop at a node have been implemented in this paper. In the conventional ant algorithms the next hop is selected randomly. 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 frequently 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.

III. ANT-AODV HYBRID ROUTING PROTOCOL

Ant-AODV technique, forms a hybrid of both ant-based routing and AODV routing protocols to overcome some of their inherent drawbacks. The hybrid technique enhances the node connectivity and decreases the end-to-end delay and route discovery latency. Route establishment in conventional ant-based routing techniques 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 real-time communication applications.

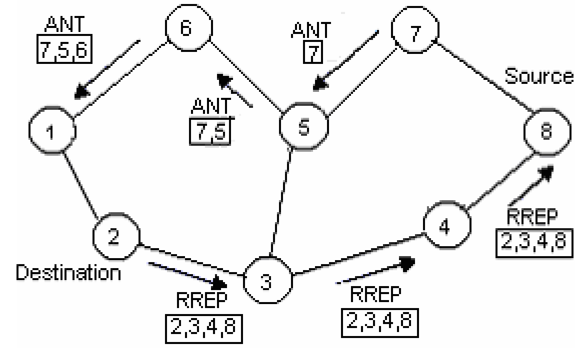

Fig. 1. Propagation of route reply and traversal of ant packet in Ant-AODV routing protocol.

In Ant-AODV ant agents work independently and provide routes to the nodes as shown in fig. 1. The nodes also have capability of launching on-demand route discovery (fig. 1) 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. Ant-AODV uses route error messages (RERR) to inform upstream nodes of a local link failure similar to AODV. Routing table in Ant-AODV is common to both ants and AODV. Frequent HELLO broadcasts are used to maintain a 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 agents.

IV. SIMULATION MODEL

Extensive simulations were carried out to compare the Ant-AODV hybrid routing protocol proposed in this paper with the conventional ant-based and AODV routing protocols. Network Simulator (NS-2) [7] 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 a multi-hop wireless ad hoc network 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.

A. *Ant history size and ant population*

Several combinations of ant population and history sizes were used in the simulations to arrive at the values that gave the best performance. These values of ant population and history size were then 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.

B. *Mobility*

A network of 50 mobile nodes migrating within an area of 1500m X 300m with a speed of 0 - 10m/s was simulated. 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 [8]. 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. After pausing for pause time seconds the mobile node again selects a new destination and proceeds at a speed distributed uniformly between 0 and a maximum speed.

C. *Traffic*

The simulations carried out consisted of 20 Continuous Bit Rate (CBR) sources. 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. 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 simulated.

V. SIMULATION RESULTS

A. *Average end-to-end delay*

The average end-to-end delay 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 (fig. 2) is very less. 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.

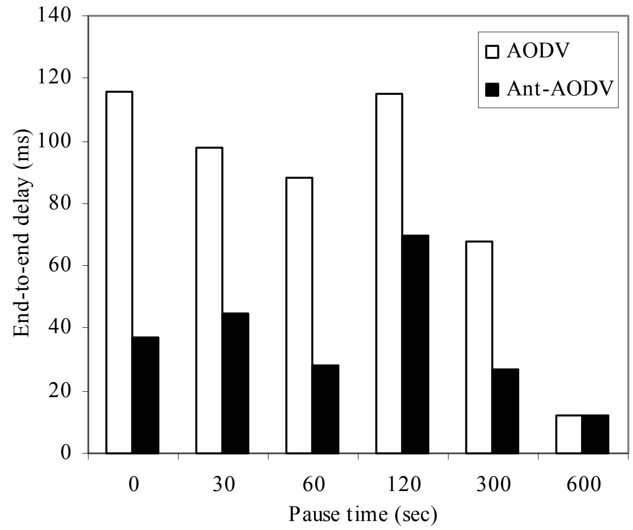

Fig. 2. Average end-to-end delay provided by AODV and Ant-AODV routing protocols.

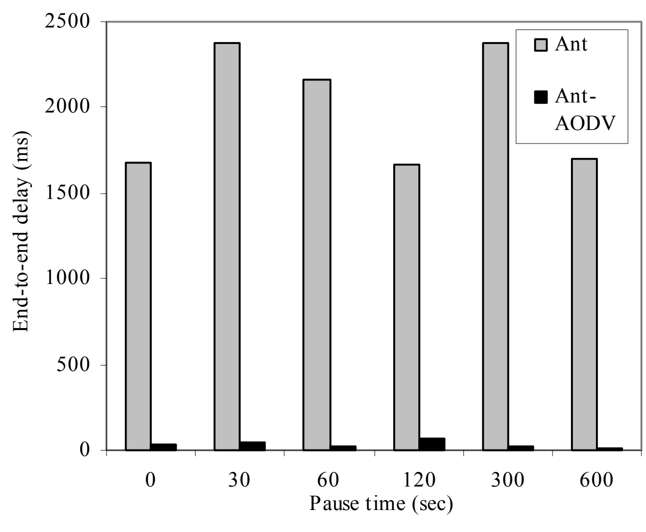

Fig. 3. Average end-to-end delay provided by Ant-based and Ant-AODV routing protocols.

Comparing Ant-AODV and AODV it can be observed that the end-to-end delay (fig. 2) is considerably reduced in Ant-AODV as compared to AODV. Ants help in maintaining high connectivity in Ant-AODV, 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.

B. Goodput and Packet delivery fraction

Goodput is the total number of useful packets received at all the destination nodes and packet delivery fraction is the ratio of number of data packets sent to the number of data packets received. Packet delivery fraction is very high for AODV and Ant-AODV (fig. 4) as compared to ant-based routing. Goodput is also higher for Ant-AODV and AODV as compared to ant-based routing (fig. 5).

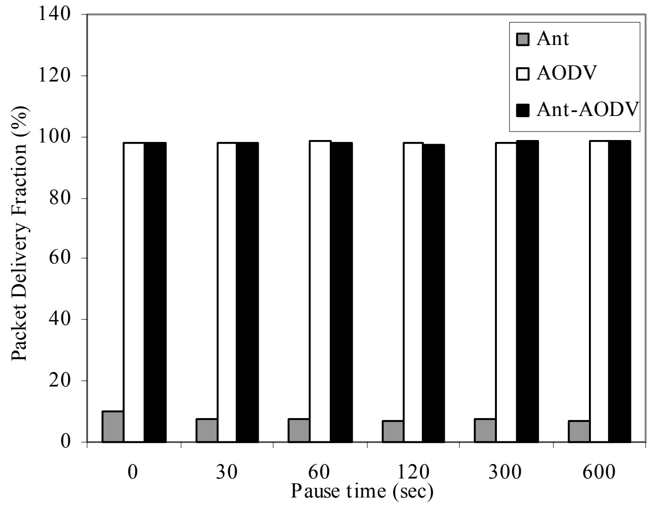

Fig. 4. Packet delivery fraction provided by Ant-based, AODV and Ant-AODV hybrid routing protocols.

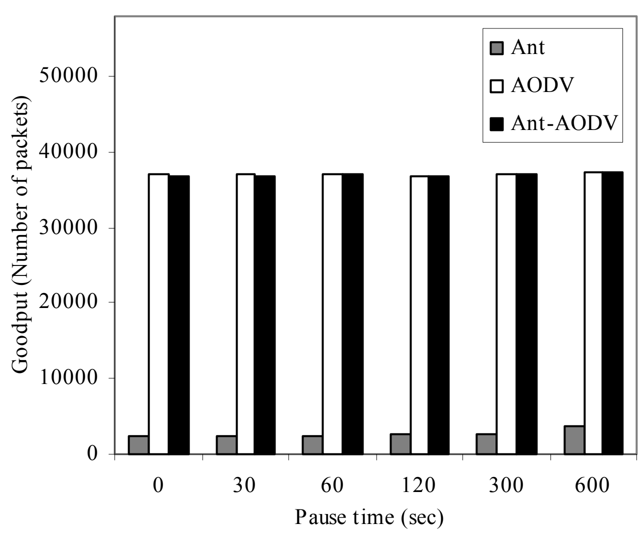

Fig. 5. Goodput of Ant-based, AODV and Ant-AODV routing protocols.

High packet delivery fraction and goodput in Ant-AODV and AODV is because 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. 4) and goodput (fig. 5) 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).

C. Normalized Routing overhead

Normalized routing overhead is the number of routing packets transmitted per data packet received at the destination. The 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 the ants for some destinations. From the comparison results (fig. 6) 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. In case of AODV (fig. 6) the normalized overhead is the least. The normalized overhead (fig. 6), is slightly greater in Ant-AODV as compared to AODV because of the continuous movement of ants in the network. The continuous gradual drop in normalized routing overhead (fig. 6) 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).

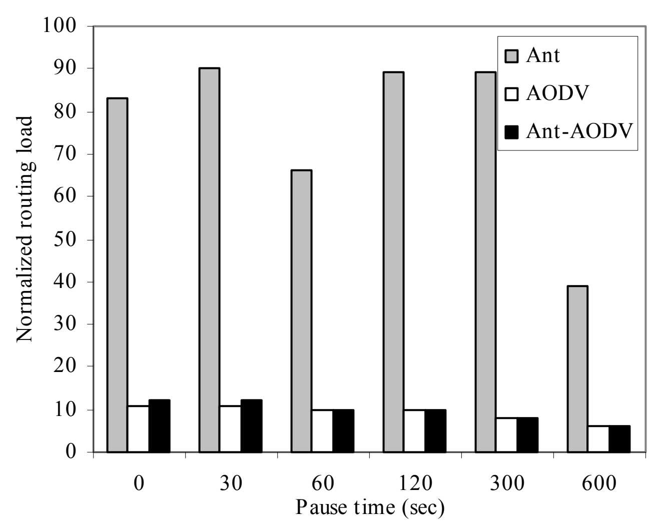

Fig. 6. Normalized routing overhead of Ant-based, AODV and Ant-AODV routing protocols.

D. *Connectivity*

Connectivity is the average number of nodes in the network for which a node has un-expired routes. In case of Ant-AODV and ant-based routing protocols (fig. 7), ant 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. Connectivity in Ant-AODV and ant-based routing schemes is more than double the connectivity in AODV (fig. 7). Higher connectivity leads to lesser route discoveries and reduced end-to-end delay.

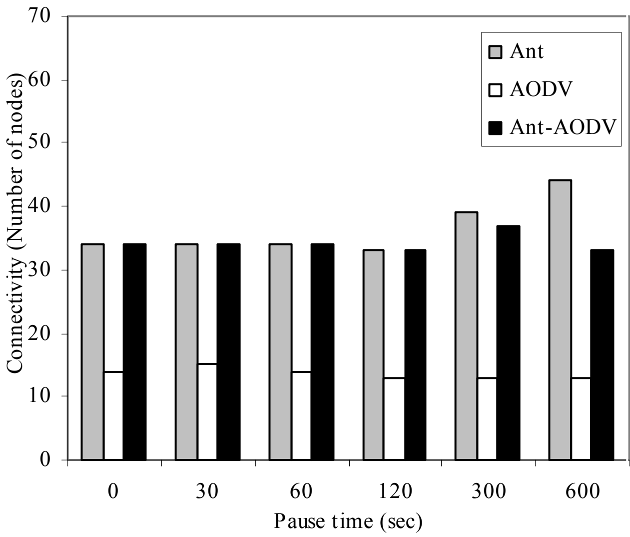

Fig. 7. Average connectivity provided by Ant-based, AODV and Ant-AODV routing protocols.

VI. Discussion

A. *Ant Visit Period*

During the simulations an important characteristic of ant agents for routing in MANETs was observed. 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.

B. *Performance of Ant-AODV*

It is evident from the simulation results 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.

VII. 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 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 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 capacity. However this does not adversely affect the packet delivery fraction or the goodput. 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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